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SEISMIC MAPPING, SALT DEFORMATION, AND HYDROCARBON POTENTIAL OF THE CENTRAL WESTERN OFFICER BASIN WESTERN AUSTRALIA

by A. P. Simeonova and R. P. Iasky

Geological Survey of Western Australia

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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Cover photograph:
Sand dunes of the Gibson Desert in the northwestern part of the study area, with the GSWA Lancer 1 drill rig in the background. Photo courtesy of P. Haines

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Seismic mapping, salt deformation, and hydrocarbon potential of the central western Officer Basin, Western Australia

by

A. P. Simeonova and R. P. Iasky

Abstract

The Officer Basin is an inland frontier area that covers about 300 000 km^2 in Western Australia and 225 000 km^2 in South Australia. The stratigraphic succession of the western Officer Basin ranges in age from Neoproterozoic to Cambrian, and contains clastic, evaporite, carbonate, and glacigene sedimentary rocks deposited in three supersequences. This Report focuses on the central western Officer Basin, where approximately 6500 km of 2D seismic data were reprocessed by Japan National Oil Company and the Geological Survey of Western Australia in 1996 and 2002 respectively. This is the first integrated seismic interpretation and mapping study of the entire central western Officer Basin. Five seismic horizons have been mapped; these were selected for their lateral continuity, structural significance, and relevance to hydrocarbon prospectivity.

Seismic interpretation and mapping, integrated with available well data, show that halotectonics was the major deformation mechanism in the western Officer Basin and produced both regional and local structures. Salt mobilization was most extensive in the north-northeastern portion of the basin, resulting in considerable thickness variations of the Browne Formation, piercement through and erosion of the younger section, and a variety of salt-related features. Compressional processes, associated with deformation in the adjacent Paterson Orogen, are probably the key mechanisms initiating the salt mobilization. In northeastern areas, where the sedimentary succession has greater depositional thickness, the overburden might have triggered the salt movement, which was further enhanced by tectonism. Each of the deformation events recorded in the basin and Paterson Orogen probably contributed to multiple salt movements, with peaks during the Areyonga Movement and Petermann Orogeny.

No hydrocarbon fields or significant accumulations have been discovered to date in the Western Australian part of the Officer Basin, where only 13 wells have been drilled by petroleum exploration companies. Most of these were spudded as stratigraphic wells, and therefore not considered as exploration tests. Oil and gas shows have been recorded in a total of 12 petroleum exploration and stratigraphic wells and mineral drillholes, indicating generation and migration of hydrocarbons through the study area.

Thin, but organic-rich source intervals are present in the Browne, Hussar, Kanpa, and Steptoe Formations, with measured thermal maturity corresponding to the oil window. Maturity modelling suggests that there was potential for major oil-generation phases during the latest Neoproterozoic, Cambrian, and Permian–Triassic, which is considered favourable with regard to trap formation. However, multiple episodes of salt mobilization might have affected trap integrity. Traps that formed at later stages of the basin's evolution may retain hydrocarbons generated during the Permian–Triassic, or oil and gas that remigrated from breached older pools. Structural, stratigraphic, and combined plays have been identified in the western Officer Basin, and are largely a result of the extensive salt tectonics. Prospective geometries include drape folds with a potential for multiple pay zones, thrust-related anticlinal features, combined traps at diapir flanks, and enhanced porosity traps. Stratigraphic plays have never been tested, but their potential could be significant in the slightly deformed Western Platform Zone, where they could be present at relatively shallow depths.

KEYWORDS: seismic interpretation, salt deformation, halotectonics, petroleum potential, source rock, maturity, plays, traps, Officer Basin.

Introduction

In Western Australia the Neoproterozoic western Officer Basin covers about 300 000 km^2 between the Pilbara and Yilgarn Cratons and the Capricorn Orogen to the west and northwest, and the Musgrave Complex, Canning Basin, and Paterson Orogen to the north and northeast (Fig. 1). To the south it extends beneath the Cainozoic Eucla Basin. The Officer Basin succession unconformably overlies Mesoproterozoic or older sedimentary, metamorphic, and igneous rocks, and underlies the Palaeozoic Gunbarrel Basin (Hocking, 1994). Deposition spanned the period from the Neoproterozoic to the early Palaeozoic, and included clastic rocks, evaporites, and carbonate rocks. Surface outcrop is limited, and does not allow a complete investigation of basin stratigraphy or the temporal and spatial interrelations between the lithostratigraphic units. Seismic data and well control are essential in unravelling the geological evolution of the basin and evaluating its hydrocarbon potential.

This Report focuses on the area with seismic coverage in the central western Officer Basin (Fig. 2), where the Geological Survey of Western Australia (GSWA) reprocessed about 4268 km of early 1980s 2D conventional reflection seismic data in 2002. This was combined with 2165 km of seismic data reprocessed by Japan National Oil Company in 1996. The original vintages were acquired by Shell Company of Australia (Shell) in 1980–82 (4628 km), News Corporation in 1983–84 (1132 km), and Swan Resources Ltd in 1981 (106 km).

This is the first integrated interpretation and mapping study of the entire area covered by seismic data. Five seismic horizons have been mapped; these were selected for their lateral continuity, structural significance, and relevance to hydrocarbon prospectivity. A detailed analysis of potential petroleum systems and post mortems of some of the petroleum exploration wells are also provided, and were coupled with the seismic interpretation results to determine prospective trends for future exploration in the western Officer Basin.

History of investigation

Several explorers traversed the Officer Basin between 1873 and 1905, but it was not until 1916 that Talbot and Clarke, and later Forman in 1931, carried out geological investigations of the area between the Warburton Range and Yilgarn Craton (Talbot and Clarke, 1917, 1918; Forman, 1933).

Petroleum exploration in the western Officer Basin began in the early 1950s when Frome Broken Hill and Australasian Oil Exploration investigated the Phanerozoic succession (Fitzpatrick, 1966). In the late 1950s and early 1960s the Bureau of Mineral Resources (BMR, now Geoscience Australia) carried out reconnaissance geological mapping in the Gibson Desert and conducted regional aeromagnetic, gravity, and seismic surveys (Appendix 1). The geophysical surveys showed the western Officer Basin to be an asymmetric ‘half-graben’ with a thick sedimentary succession that thickens towards the Musgrave Complex at the basin’s northeastern boundary (Jackson, 1966; Fitzpatrick, 1966).

In 1961, GSWA investigated the hydrogeology of the Warburton Range area in an attempt to identify new water supplies (Sofoulis, 1961). At the same time, a consortium led by Hunt Oil explored for petroleum mainly in the central part of the basin, and between 1961 and 1966 carried out airborne and ground magnetic surveys, a gravity survey, and several seismic surveys totalling over 1000 km (Appendix 1). The exploration program led to the drilling of five stratigraphic wells (Appendix 2), two of which (Browne 1 and 2) reported minor oil and gas shows (Jackson, 1966). In the mid 1960s an Alliance Petroleum – Union Oil consortium carried out geological reconnaissance and an airborne magnetic survey in the Gibson Desert.

In 1967, GSWA began mapping the western Officer Basin, and in 1970 was joined by BMR to accelerate the mapping program, which was completed by the end of 1973. The surface mapping revealed only limited stratigraphic information due to the extensive Cainozoic cover. This invoked BMR to carry out a stratigraphic drilling program consisting of 18 shallow stratigraphic drillholes (Jackson et al., 1975) and acquire seismic and gravity data (Harrison and Zadoronyj, 1978). The acquisition of seismic data and more-detailed gravity data was complementary to the BMR regional aeromagnetic (3000 m line spacing) and gravity (11 km spacing) coverage of the area, which began in 1971. The results of all this work were published in a joint BMR–GSWA Bulletin (Jackson and van de Graaff, 1981).

The new information on the western Officer Basin provided the incentive for Shell to start exploring for oil and gas in the central western Officer Basin in 1980. The company was awarded a concession of 46 198 km^2 (EP 178, 179, and 180), and acquired 4682 line-km of 2D seismic data and drilled three exploration wells — Yowalga 3, Kanpa 1A, and Lungkarta 1 (Appendix 2). Of those, only Kanpa 1A reported hydrocarbon shows. Almost at the same time, a consortium consisting of News Corporation, Eagle Corporation, and Swan Resources were exploring the Gibson area and acquired 1436 line-km of seismic data between 1981 and 1984. Following the initial survey in 1981, two stratigraphic wells (Hussar 1 and Dragoon 1) were drilled, and both reported hydrocarbons shows (Appendix 2). Even though Shell and News Corporation did not find hydrocarbon accumulations and relinquished their permits, their investigations (Townson, 1985) considerably improved the stratigraphic and structural knowledge of the western Officer Basin.

Mineral exploration in the western Officer Basin began in the late 1970s to early 1980s when BHP Co Ltd (BHP), Kennecott Exploration (Australia) Ltd, and Western Mining Corporation Pty Ltd drilled shallow drillholes while exploring for copper, uranium, and base metals on the southern and southwestern margins of the basin (Perincek, 1998). Between 1978 and 1987, PNC Exploration (Australia) Pty Ltd drilled a few shallow drillholes in the Gibson and Warri Ridge area while exploring for uranium. Throughout the 1980s,

Figure 1. Location map of the western Officer Basin showing seismic coverage, petroleum exploration and stratigraphic wells, and selected mineral exploration drillholes

BHP and CRA Exploration Pty Ltd (CRAE) carried out aeromagnetic surveys (referred to in Perincek, 1998) over parts of the basin while exploring for diamonds and base metals. Some magnetic anomalies were followed up with shallow drilling, but no discoveries were made.

After Shell and News Corporation relinquished their permits in the 1980s, there was no petroleum exploration in the western Officer Basin for a period of about 10 years. Then in the mid-1990s, Japan National Oil Corporation (JNOC) undertook another phase of exploration in the central western Officer Basin. The company carried out a high-resolution airborne magnetic survey (500 m line spacing) and reprocessed 2165 line-km of the seismic data acquired by Shell in 1980–82. Japan National Oil Corporation concluded that most of the area has limited potential for significant petroleum accumulation, as the source rocks intersected to date are lean and most of the generative potential had been exhausted during the Neoproterozoic – Early Cambrian. This implies long preservation for any potential trapped hydrocarbons. However, they did consider the Northern Depression (see **Structural interpretation**) as attractive and mapped several anticlinal structures there. However, they did

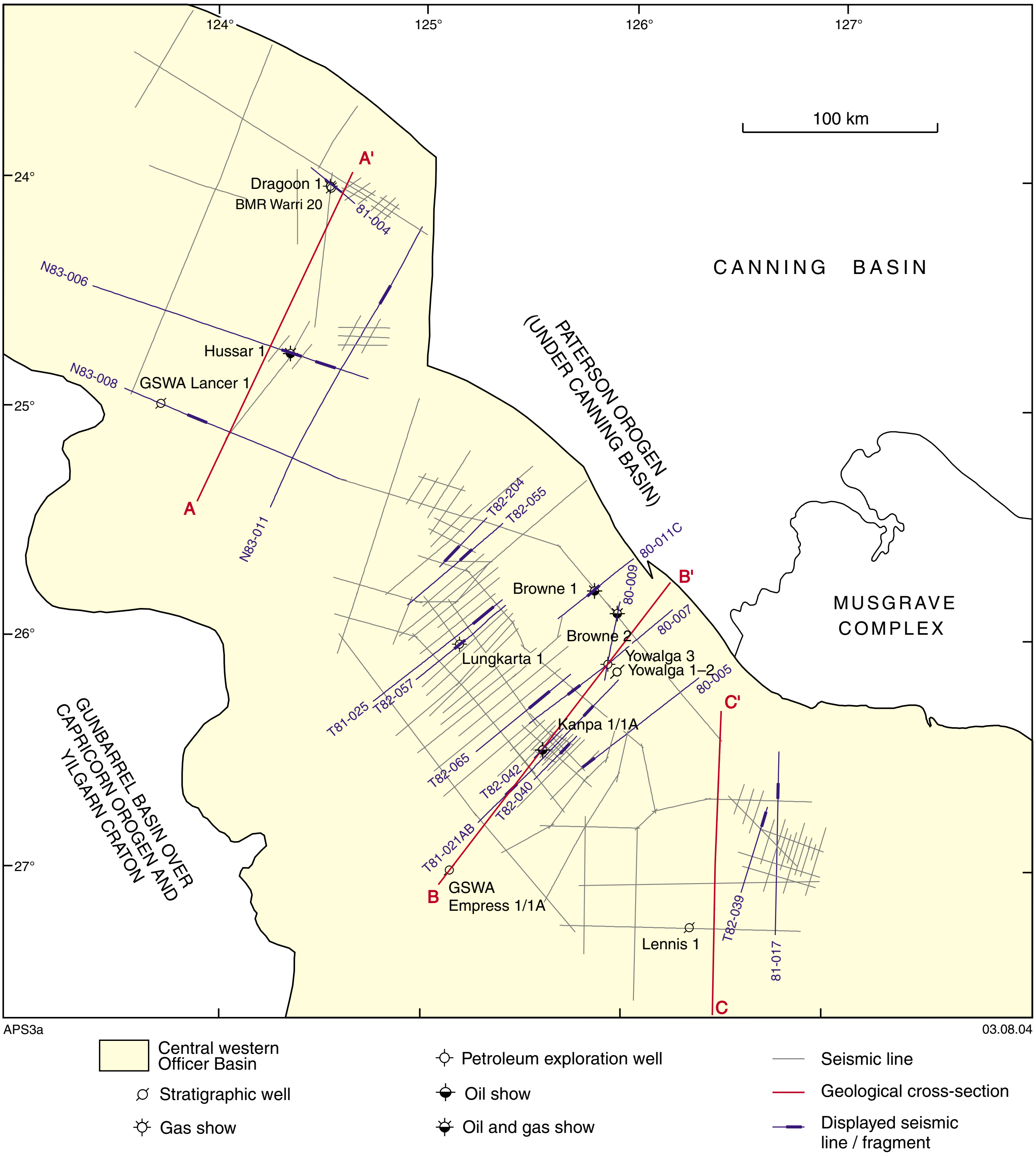


Figure 2. The study area in the central western Officer Basin, showing seismic coverage, petroleum exploration and stratigraphic wells, and regional geological cross sections

not drill any of these structures (Japan National Oil Corporation, 1997).

In an attempt to revive petroleum exploration, GSWA began reviewing and reinterpreting the geology of the western Officer Basin in 1994. Perincek (1998) compiled a detailed review of the work done in the basin and surrounding areas to that time. In the same year, Durrant and Associates (1998) were commissioned to map the Gibson and Lennis areas using existing seismic data. These interpretations were incorporated in further detailed studies and analyses of the petroleum potential of the Yowalga, Lennis, and Gibson areas (Apak and Moors, 2000a, 2001; Moors and Apak, 2002). The areas in those studies broadly coincide with regions of the same name that were previously defined as sub-basins (Townson, 1985; Iasky, 1990). Around the same time, Stevens and Carlsen (1998) reviewed the geology of the 'Savory Sub-basin'. This was previously considered a separate basin, the Savory Basin, but was reinterpreted to be a part of the Officer Basin (Perincek, 1996, 1998) and is now referred to as the northwestern Officer Basin (Bagas et al., 1999; Grey et al., in prep.). These studies by GSWA, combined with oil and bitumen shows in mineral hole OD23, encouraged Amadeus Petroleum NL to take up a petroleum tenement (EP 380) and drill three exploration wells (Boondawari 1, Mundadjini 1, and Acubra 1) on surface anticlines to assess the petroleum potential of the area. Weak oil shows were recorded in two of these wells — Mundadjini 1 and Boodnawari 1.

To improve the understanding of petroleum systems and stratigraphy of the western Officer Basin, GSWA drilled four deep, continuously cored stratigraphic wells (Appendix 2). GSWA Trainor 1 was drilled in the Savory area in 1995 (Stevens and Adamides, 1998), GSWA Empress 1/1A on the western margin of the basin in 1997 (Stevens and Apak, 1999), GSWA Vines 1 in the Waigen area in 1999 (Apak et al., 2002b), and GSWA Lancer 1 in the southern Gibson area in 2003 (Haines et al., 2004). In addition, in 2002, GSWA contracted WesternGeco Pty Ltd to reprocess 4268 line-km of the Shell (1980–82) and News Corporation (1983–84) seismic data. This consisted of 1433 line-km from field tapes and 2835 line-km from post-stack data (Simeonova, 2003). The new reprocessed data, together with the data reprocessed by JNOC in 1996, has improved subsurface visualization and facilitated the structural mapping of the western Officer Basin.

Stratigraphy

The stratigraphic succession of the western Officer Basin ranges in age from Neoproterozoic to Cambrian, and contains clastic, evaporite, carbonate, and glacigene sedimentary rocks deposited in Supersequences 1, 3, and 4 (Walter et al., 1995; Fig. 3). Regional unconformities defining the supersequence boundaries are associated with major tectonic events in the basin, including the Areyonga Movement and the Petermann and Delamerian Orogenies (Apak and Moors, 2000a; Apak et al., 2002a). The Officer Basin succession is underlain by Archaean, Palaeoproterozoic, and Mesoproterozoic sedimentary, metamorphic, and igneous rocks and is unconformably overlain by the Table Hill Volcanics or sedimentary rocks at the base of the Gunbarrel Basin (Hocking, 1994).

The following is a review of the stratigraphy of the central western Officer Basin (Fig. 3), which encompasses the parts with seismic coverage of the previously referred to Gibson, Yowalga, and Lennis areas (Apak and Moors, 2000a, 2001; Moors and Apak, 2002). Grey et al. (in prep.) documented the stratigraphy of the entire Officer Basin in Western Australia in detail, and made regional correlations with other Neoproterozoic basins in Australia.

Buldya Group (Supersequence 1 — SS1)

The Buldya Group (Grey et al., in prep.) includes the Townsend Quartzite, the Lefroy, Browne, Hussar, Kanpa, Steptoe, and Ilma* Formations, and the Mason Conglomerate*.

Townsend Quartzite

The Townsend Quartzite is the basal unit of the Buldya Group, and consists of medium- to coarse-grained, in part pebbly, sandstone with intense silica cementation. The unit was deposited in fluvial to nearshore-marine environments, and outcrops at the north-northeastern margin of the basin, along the boundary with the Musgrave Complex. The Townsend Quartzite has not been unequivocally recognized elsewhere in the western Officer Basin. A possible exception is a unit at the bottom of Kanpa 1A (Shell Company of Australia Ltd, 1983); however, Grey et al. (in prep.) interpret this interval to be an older Mesoproterozoic unit. Although there is no evidence that the Townsend Quartzite is present in the main part of the basin, it is absent in GSWA Empress 1A (Stevens and Apak, 1999) and GSWA Lancer 1 (Haines et al., 2004), suggesting that it is probably not present on the western margin of the Officer Basin.

Although the Townsend Quartzite cannot be distinguished on seismic sections, the seismic data indicate that the base of the Neoproterozoic succession unconformably overlies Mesoproterozoic and older units. The upper boundary of the Townsend Quartzite, known only from limited outcrops, is conformable with the Lefroy Formation (Jackson and van de Graaff, 1981). The age of the Townsend Quartzite is poorly defined, and is loosely constrained between 1080 and 800 Ma. Its most probable age is about 830 Ma, based on broad regional correlations and age determinations (Grey et al., in prep.).

Lefroy Formation

The Lefroy Formation consists of well-bedded shales and micaceous siltstone, with minor intervals of medium- to thick-bedded quartz sandstone, which indicate deposition in a low-energy, sub-wavebase, marine-shelf environment (Grey et al., in prep.). The formation has only been clearly identified on the southern margin of the Musgrave Complex, where it conformably overlies the Townsend Quartzite. There are disputed interpretations of the Lefroy Formation in GSWA Empress 1 (Stevens and Apak, 1999) and WMC NJD 1 (Hocking, 2003). Grey et al. (in prep.) interpret the units in these wells to be part of the Mesoproterozoic succession and Hussar Formation, respectively.

In outcrop along the boundary with the Musgrave Complex, the Lefroy Formation is overlain unconformably by the Lupton Formation (Supersequence 3 or 4). Elsewhere in the basin, the unit may be present in the subsurface, but the poor seismic resolution and lack of well control do not allow it to be differentiated from the rest of the lower Buldya Group.

* The Ilma Formation and Mason Conglomerate are known only in the southern part of the western Officer Basin, along the boundary with the Eucla Basin, but are not discussed in this Report as there is no seismic coverage in the area.

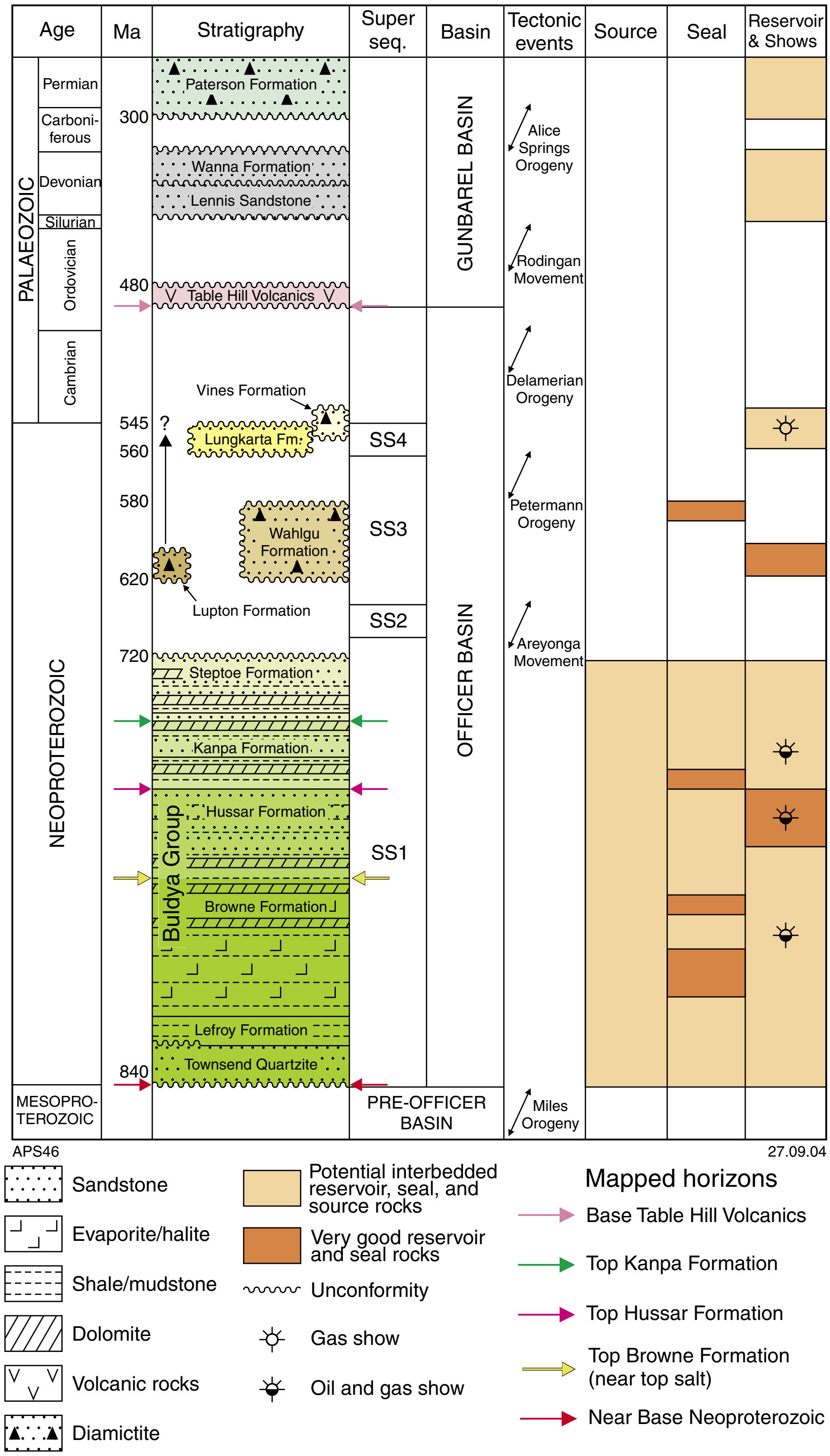


Figure 3. Generalized stratigraphy of the central western Officer Basin

An age of between about 825 and 800 Ma for the Lefroy Formation is inferred from its relative stratigraphic position and the age of palynomorphs in the correlative Alinya Formation in the eastern Officer Basin (Grey et al., in prep.).

Browne Formation

The Browne Formation is an evaporitic sequence of dolomite or dolomitic limestone, halite, anhydrite, gypsum, siltstone, shale, and sandstone. It was deposited in oxidizing, restricted, shallow-marine, peritidal to intertidal or lagoonal, and sabkha environments.

The Browne Formation shows considerable thickness variations as a result of extensive salt movement (see **Structural interpretation**). Primary depositional thickness increases towards the Paterson Orogen along the northeastern margin of the basin, and gradually decreases to the southwest, where the formation is not significantly deformed by halotectonics. The formation is 275 m thick in GSWA Empress 1A, and 277 m think in GSWA Lancer 1. Its thickness increases to 1156 m in Kanpa 1A, with evidence of only minor thickening due to salt displacement. In Yowalga 3, 2308 m of the formation was intersected before the well was terminated. However, seismic interpretation shows that Yowalga 3 was drilled on a salt pillow structure, which explains the considerably increased thickness at this location.

GSWA Lancer 1 intersected 96 m of well-sorted, medium-grained sandstone with very large scale cross-bedding in the uppermost Browne Formation. This lithology has not been observed elsewhere in the Browne Formation and is defined as the Lancer Member (Haines et al., 2004). The unit is interpreted to have been deposited in eolian dune and inter-dune environments (Haines et al., 2004).

The Browne Formation is conformably, and locally disconformably, overlain by the Hussar Formation except where the salt has pierced through the younger section. Where this has occurred, the unit is unconformably overlain by younger Neoproterozoic or Phanerozoic rocks. For example, in Browne 1 and 2, the Permian Paterson Formation rests directly on the Browne Formation.

The Browne Formation is inferred to be older than 800 Ma through correlations to other basins based on stromatolite and acritarchs biostratigraphy (Grey et al., in prep.)

Hussar Formation

The Hussar Formation is composed predominantly of sandstone interbedded with mudstone, dolomite, minor evaporite, and local conglomerate intercalations, accumulated in upward-coarsening, progradational cycles. Depositional environments range from shelf, shoreline, and tidal flat, to transitional and possibly fluvial–deltaic.

Six petroleum exploration and stratigraphic wells (Yowalga 3, Kanpa 1A, Hussar 1, Lungkarta 1, GSWA Empress 1A, and GSWA Lancer 1) intersected the Hussar Formation. Seismic data indicate that the Hussar Formation is present throughout the central western Officer Basin, with a thickness ranging from about 900 m (Yowalga 3) in the northeast, to 387 m (GSWA Empress 1A) near the southwestern margin. The thickness of the formation is relatively uniform throughout the study area, only decreasing gradually towards its southwestern margin.

The Hussar Formation conformably and locally disconformably (Grey et al., in prep.) overlies the Browne Formation, and is conformably overlain by the Kanpa Formation. Based on lithostratigraphic, biostratigraphic, and isotope-chemostratigraphic grounds, the Hussar Formation has been correlated with the lower Burra Group of the Adelaide Rift Complex, which contains a volcanic unit dated at 777 ± 7 Ma (Grey et al., in prep.).

Kanpa Formation

The Kanpa Formation is a sequence of interbedded stromatolitic dolomite, mudstone, shale, siltstone, and sandstone, with some evaporites and chert, deposited in shallow-marine to tidal-flat settings, with carbonate accumulating under oxidizing to slightly reducing conditions (Apak and Moors, 2000a). The lower Kanpa Formation is predominantly composed of mudstone overlain by mixed rock types, and the upper Kanpa Formation consists of a mudstone overlain by a predominantly dolomitic sequence.

Within the Kanpa Formation, GSWA Lancer 1 encountered 49 m of basalt flows between 527 and 576 m*, which were defined as Keene Basalt (Haines et al., 2004). Based on broad regional correlations, these volcanic rocks may be related to the Mundine Well Dyke Swarm, which is dated at 755 ± 3 Ma (Grey et al., in prep.).

Seismic data indicate that the Kanpa Formation is present throughout study area, with its distribution being similar to that of the underlying Hussar Formation. Within parts of the study area, the Kanpa Formation is partly or completely eroded due to salt movement and piercing. The unit outcrops in several locations on the western and southwestern margins of the basin and at the southern margin of the Musgrave Complex (Grey et al., in prep.). Seven petroleum exploration and stratigraphic wells (Yowalga 2, Yowalga 3, Kanpa 1A, Hussar 1, Lungkarta 1, GSWA Empress 1A, and GSWA Lancer 1) and one mineral drillhole (WMC NJD 1) have intersected the Kanpa Formation, with Kanpa 1A having the thickest intersection of 476 m.

The Kanpa Formation conformably overlies the Hussar Formation and is conformably overlain by the Steptoe Formation (Townson, 1985; Phillips et al., 1985; Apak and Moors, 2000a,b), except in areas where the latter has been eroded. In these areas the Kanpa Formation is unconformably overlain by younger Neoproterozoic rocks. The maximum age of the top of the Kanpa Formation is constrained to 725 ± 11 Ma, based on SHRIMP U–Pb dating of detrital zircons from GSWA Empress 1A (Stevens and Apak, 1999; Grey et al., in prep.).

* All depths from drill floor (DF), unless otherwise specified.

Steptoe Formation

The Steptoe Formation was deposited conformably over the Kanpa Formation in a similar shallow-marine to coastal environment, with evaporitic conditions and intermittent emergence. The lithologies consist of sandstone, dolomite, siltstone, and shale. The lower Steptoe Formation is composed of claystone, sandstone, mudstone, unconsolidated sand, and stromatolitic dolomite, whereas the upper section consists of a basal massive shale unit, overlain by sandstone interbedded with shale and anhydritic dolomite (Grey et al., in prep.).

Seismic data indicate that the Steptoe Formation is widespread throughout the study area, but is partly or fully eroded locally due to halotectonics. The formation was identified in Kanpa 1A (Shell Company of Australia Ltd, 1983) and GSWA Empress 1A (Apak and Moors, 2000a), and possibly in WMC NJD 1 (Hocking, 2003).

The Steptoe Formation is unconformably overlain by the Wahlgu Formation, Lungkarta Formation, or Table Hill Volcanics. There is no direct evidence for the age of the unit, but it is younger than the Kanpa Formation, which top is dated at 725 ± 11 Ma.

Wahlgu Formation (Supersequence 3 — SS3)

The Wahlgu Formation is a clastic sequence composed of diamictite, sandstone, mudstone, and conglomerate, that accumulated in shallow-marine, glaciomarine, and possibly eolian environments. A predominantly shallow-marine depositional environment is indicated by large volumes of glacially derived clastic material deposited rapidly by debris flow and turbidity currents (Eyles and Eyles, 1998).

The Wahlgu Formation is widespread throughout the northwestern part of the central western Officer Basin (formerly known as the Gibson area), and seismic data indicate it is present in the rest of the central western Officer Basin, but the resolution of the data is inadequate to confidently differentiate the unit from the overlying Lungkarta Formation. The Wahlgu Formation has been intersected in Hussar 1, GSWA Empress 1A, and GSWA Lancer 1.

The Wahlgu Formation unconformably overlies the Steptoe or Kanpa Formations. Typically, the Lungkarta Formation disconformably overlies the Wahlgu Formation. However, in GSWA Empress 1A the formation is disconformably overlain by a sandstone unit, which may correspond to either the younger Lungkarta Formation or a sandstone within the Boondawari Formation (Grey et al., in prep.), which is known from outcrops in the northwest Officer Basin (Savory region).

The only indirect evidence for the age of the Wahlgu Formation is a SHRIMP U–Pb detrital zircon age of 791 ± 18 Ma from GSWA Empress 1A (Nelson, 1999), which provides a maximum age of deposition. However, the formation is tentatively correlated on lithostratigraphic grounds with the Marinoan glacial succession of other Australian Neoproterozoic basins, which is dated at 580–620 Ma (Grey et al., in prep.).

Lungkarta Formation (Supersequence 4 — SS4)

The Lungkarta Formation is predominantly sandstone with siltstone, claystone, mudstone, and minor gypsum. The lower part of the formation was deposited under eolian and playa-lake environments (Haines et al., 2004), whereas the upper section accumulated in fluvial or high-energy nearshore-marine environments (Grey et al., in prep.).

The Lungkarta Formation has been intersected in GSWA Lancer 1, Hussar 1, Kanpa 1A, and Lungkarta 1. It has also been reported in the shallow bores BMR Westwood 1 and 2 and 90 RCHE 003 (Perincek, 1998; Grey et al., in prep.). Seismic data indicate that the formation is widespread throughout the western Officer Basin, but insufficient data resolution and limited well control do not allow for accurate differentiation from the underlying Wahlgu Formation.

The Lungkarta Formation unconformably overlies the Wahlgu Formation or Buldya Group. It is unconformably overlain by the Table Hill Volcanics in most areas, and by the Permian Paterson Formation in the northwestern part of the basin. From its stratigraphic position, the Lungkarta Formation is constrained to a latest Neoproterozoic or possibly Cambrian age (Grey et al., in prep.).

Vines Formation (Supersequence 4 — SS4)

The Vines Formation consists of sandstone, diamictite, siltstone, shale, mudstone, and conglomerate, with evidence of turbiditic to submarine mass-flow deposition in a deep-basinal environment (Apak et al., 2002b; Stevens et al., 2002).

To date the formation has only been recognized in GSWA Vines 1, which was drilled just south of the Musgrave Complex. The formation may be restricted to the Waigen area, but could extend to the eastern Officer Basin (Grey et al., in prep.).

Post-Officer Basin succession (Gunbarrel Basin)

The Neoproterozoic to earliest Cambrian Officer Basin succession (Supersequence 4) is overlain by the Table Hill Volcanics, which marks the base of the overlying Phanerozoic Gunbarrel Basin (Hocking, 1994). Various radiometric ages for the Table Hill Volcanics have been determined, ranging from latest Neoproterozoic (575 ± 40 Ma; Compston, 1974) from samples in Yowalga 2, to Early Ordovician (484 ± 4 Ma; Amdel Ltd, 1999) from samples in GSWA Empress 1. The unit is overlain by the ?Devonian Lennis Sandstone and overlying clastic rocks of the Wanna Formation. In places where the Table Hill Volcanics were either eroded or not deposited, the latest Carboniferous – Permian Paterson Formation unconformably overlies the Officer Basin succession. The Paterson Formation is widespread in the region and is unconformably overlain by the Cretaceous Samuel Formation, which consists of sandstones and finer grained clastic rocks. A thin layer of Cainozoic sedimentary rocks was deposited over large portions of the western Officer Basin.

Seismic interpretation and mapping

Seismic dataset

The seismic dataset used for this interpretation consists of 4268 km of 2D data reprocessed by GSWA (contractor WesternGeco) in 2002, and 2165 km reprocessed by Japan National Oil Corporation in 1996. The original vintages were acquired by Shell in 1980–82 (4628 km), News Corporation in 1983–84 (1132 km), and Swan Resources in 1981 (106 km).

The dataset (Figs 1 and 2; Plate 1) is made up of a low-density regional grid with an average line spacing of between 20 and 45 km, and a small number of semi-detailed grids (5–10 km line spacing) and detailed grids (2.5–5 km line spacing).

Data quality

Data quality is highly variable, ranging from poor to very good. Most of the Shell data acquired in 1980 are poor to only fair quality, mainly because of less than optimum acquisition parameters. The change from Cord to Thumper energy source significantly improved data resolution of the late 1981–82 vintages, with very good quality data in some of the lines from the detailed grids.

Both the 1996 and 2002 reprocessing achieved improved seismic imaging, which is mostly attributed to the application of Tau-P refraction and Kirchhoff DMO. The latter appeared to be very efficient in areas of the Officer Basin where the salt deformation is associated with steeply dipping positive features (Simeonova, 2003). Details on acquisition and reprocessing parameters and techniques can be found in Japan National Oil Corporation (1997) and Simeonova (2003).

Despite the improved acquisition parameters and modern processing techniques, there was little improvement of data quality in some areas. This is attributed to near-surface geology, structural complexity, and abrupt lithological changes. In the north-northeastern areas, for example, data quality is poor due to extensive salt deformation. In the southern and southwestern portion of the study area, the resolution of the seismic data is better because of the significant decrease in structural deformation. In these areas, seismic events are easier to pick, but the sparse seismic coverage, although reasonable for regional interpretations, does not allow for detailed mapping.

Misties and shifts

The seismic lines used in the interpretation are from four different sources, including: lines reprocessed by JNOC in 1996; lines reprocessed by WesternGeco in 2002 from field tapes; lines reprocessed by WesternGeco in 2002 from stacked data; and three detailed lines scanned into SEGY data format from hardcopies.

Although lines within each dataset tie at intersection points with other lines of the same dataset, there are considerable misties with intersecting lines from different datasets. The misties between datasets typically range from 10 to 50 msec (occasionally up to 100 msec) due to the different static corrections applied by different processing contractors. The problem is further complicated by the fact that, in some cases, the size of the vertical misties between lines is not constant, but rather varies with increasing travel time. Therefore, seismic lines were interpreted without applying bulk shifts, and the interpreted regional horizon maps are only accurate to about 30 msec for most of the study area. In the eastern part of the study area, where seismic lines acquired in 1980–82 intersect lines acquired in 1983, the maps are only accurate to about 50 msec.

Well control

In the central western Officer Basin there is limited well control, with only five wells that are useful for tying the seismic data to the Neoproterozoic succession: Yowalga 3, Kanpa 1A, Lungkarta 1, Hussar 1, and GSWA Lancer 1 (Table 1). Browne 1, Browne 2, and Dragoon 1 were drilled in salt walls and are of limited use, and Lennis 1 was terminated in the Table Hill Volcanics and cannot be used to tie Neoproterozoic sequences. Although GSWA Empress 1A fully penetrated the Officer Basin succession, it is situated about 25 km from the nearest seismic line (Figs 1 and 2; Plate 1).

The distance between well ties ranges from about 50 km between Yowalga 3 and Kanpa 1A, to 163 km between Lungkarta 1 and Hussar 1, and about 185 km between Lungkarta 1 and GSWA Lancer 1. Only Yowalga 3 and Browne 1 and 2 were drilled relatively close to each other (distance 20–35 km), but these are seismically isolated by large zones of poor-quality data due to structural complexity associated with salt diapirism. Frequent jump correlations over considerable distances were required along and between lines. In order to reduce the degree of uncertainty caused by jump correlations, stratigraphic correlations based on log signature and lithological descriptions, as well as all available velocity surveys, were used to facilitate seismic interpretation.

Mapped seismic horizons

Five seismic horizons have been interpreted throughout the study area. These were selected for their lateral continuity, structural significance, and relevance to hydrocarbon prospectivity. The interpreted horizons are the near base Neoproterozoic, top Browne Formation (near top salt), top Hussar Formation, top Kanpa Formation, and base Table

Table 1. Formation tops in wells used to calibrate the seismic interpretation

	Well								
Formation	*Browne 1*	*Browne 2*	*Dragoon 1*	*Hussar 1*	*Kanpa 1A*	*GSWA Lancer 1*	*Lennis 1*	*Lungkarta 1*	*Yawalga 3*
Paterson Fm	84	94.5	26	43	40	?17	140	88	106
Lennis Sandstone	–	–	–	–	440	–	187	364	555
Table Hill Volcanics	–	–	–	–	547	–	612	540	763
Lungkarta Fm	–	–	–	101	658	?169	–	704	–
Wahlgu Fm	–	–	–	560	?	344	nr	–	–
Steptoe Fm	–	–	–	–	829	–	nr	–	–
Kanpa Fm	–	–	–	892	1 341	466.5	nr	809	880
Hussar Fm	–	–	–	1 294	1 817	707.5	nr	1 196	991
Browne Fm (near top salt)	133	262	407	1 965	2 515	1 202	nr	nr	1 888
?Mesoproterozoic	nr	nr	nr	nr	3 671	1 479	nr	nr	nr
TD	**386.7**	**292.6**	**2 000**	**2 040**	**3 803**	**1 051.3**	**614.5**	**1 770**	**4 196.5**

NOTES: nr: not reached
TD: total depth
Fm: Formation
–: absent

Hill Volcanics. Two-way time (TWT) structure maps were constructed for all horizons and TWT thickness maps for the Browne, Hussar, and Kanpa Formations.

Despite the insufficient data coverage, limited well control, poor seismic resolution in some areas, and frequent jump correlations, the confidence in this interpretation is moderate to good. Although the accuracy of the seismic mapping and the resulting structural–stratigraphic framework are regional scale, this interpretation and accompanying petroleum-system analysis provide valuable insights into prospective trends for future exploration of the western Officer Basin.

Near base Neoproterozoic

This basal event is picked confidently in the west-southwestern parts of the study area, where it is present at shallow depths (less than 1500 msec) and is expressed as a moderate- to high-amplitude, low-frequency event. To the north-northeast in the salt-deformed areas, this marker is often indistinct or absent. In these instances, the horizon was mapped with a low level of confidence. Furthermore, the low confidence is compounded by poor well control, with only Kanpa 1A, GSWA Lancer 1, and GSWA Empress 1A possibly reaching the base Neoproterozoic and only two of these wells drilled on seismic lines.

The TWT structure map of the base Neoproterozoic horizon (Plate 2; Fig. 4) indicates deepening to the north and northeast. Within the study area, faults at this level exhibit minor throws and often normal movement. The latter indicates there was an extensional regime before the deposition of the Officer Basin Neoproterozoic succession.

Top Browne Formation (near top salt)

The top Browne Formation (near top salt) horizon is the most variable, and indicates complex deformation. The Browne Formation is an evaporitic sequence comprising halite, dolomite, anhydrite, sandstone, siltstone, and shale, which results in a package of often persistent subparallel reflectors within the expected reflection-free salt interval.

In the southern and southwestern portion of the study area, which is characterized by minor or no salt movement, a relatively high amplitude continuous reflector is associated with the top of the Browne Formation. However, in the north and northeast, geometries of reflections become more complex and less distinct due to the salt activation and associated features. In these areas of intense salt mobilization, the high-amplitude reflectors abruptly change in character to semi-chaotic and chaotic. In some places these features are well imaged (Fig. 5a) and horizons can be accurately traced across the feature, but in other areas, intense structuring has resulted in chaotic and disrupted imaging and continuous reflectors can not be traced (Fig. 5b).

The TWT structure map of the top Browne Formation (near top salt) horizon (Plate 3; Fig. 6) shows regional deepening to the north-northeast, with maximum depths in the east-northeastern part of the study area. However, the primary depositional features of the formation were modified by halotectonics, and the horizon shows significant structuring, particularly in the northeastern areas. The TWT thickness map of the Browne Formation (Plate 4; Fig. 7) indicates considerable thickness variations, which is mostly a result of the salt movement. The greatest thicknesses are observed in the north-northeastern areas, and these correspond to salt walls and diapirs.

Top Hussar Formation

The top Hussar Formation seismic marker has been followed with a reasonable degree of confidence throughout the central western Officer Basin. In the north-northeastern areas, it is picked at the top of a package of parallel, moderate- to high-amplitude reflectors associated with seismically more transparent layers. In the south-southwest region, the Hussar and Kanpa Formations, and possibly the Steptoe Formation, show very similar seismic signatures (Fig. 8). Although they can be mapped over large distances, it is difficult to differentiate between these units. The Hussar Formation has a higher sand content than the overlying Kanpa Formation, and therefore the top Hussar Formation reflector can often be identified at the top of a lower-amplitude seismic package. In the region of intense salt mobilization, the top Hussar Formation seismic marker loses continuity, and the reflections abruptly terminate against salt walls and diapirs. In most cases, jumped correlation was made on both flanks of the salt features in order to restore the correct position of this seismic marker.

The TWT structure map of the top Hussar Formation horizon (Plate 5; Fig. 9) indicates deepening to the north-northeast, towards the Paterson Orogen. This tendency had been later modified by halotectonic uplift. The salt caused drape folding and partial erosion of the Hussar Formation, and in some cases the salt has pierced through most of the section and the unit has been completely eroded. The TWT thickness map of the Hussar Formation (Plate 6; Fig. 10) indicates generally uniform depositional thickness for the Hussar Formation over most of the study area. However, there is a gradual regional thickening to north-northeast.

Top Kanpa Formation

The top Kanpa Formation is similar to the seismic marker of the Hussar Formation, and is characterized by a variable seismic signature. In many areas, particularly with intense salt mobilization, the Kanpa Formation has been partly to completely eroded. In these areas, the strong reflector that represents the unconformity surface is used to map the top of the Kanpa Formation. In the south-southwestern areas, where the Hussar, Kanpa, and Steptoe Formations form a relatively uniform package of subparallel reflectors intercalating with low-amplitude ones, the pick is less confident and the seismic horizon may include parts of the Steptoe Formation.

The TWT structure map of the top Kanpa Formation horizon (Plate 7; Fig. 11) indicates that, like the top Hussar Formation reflector, the top Kanpa Formation reflector

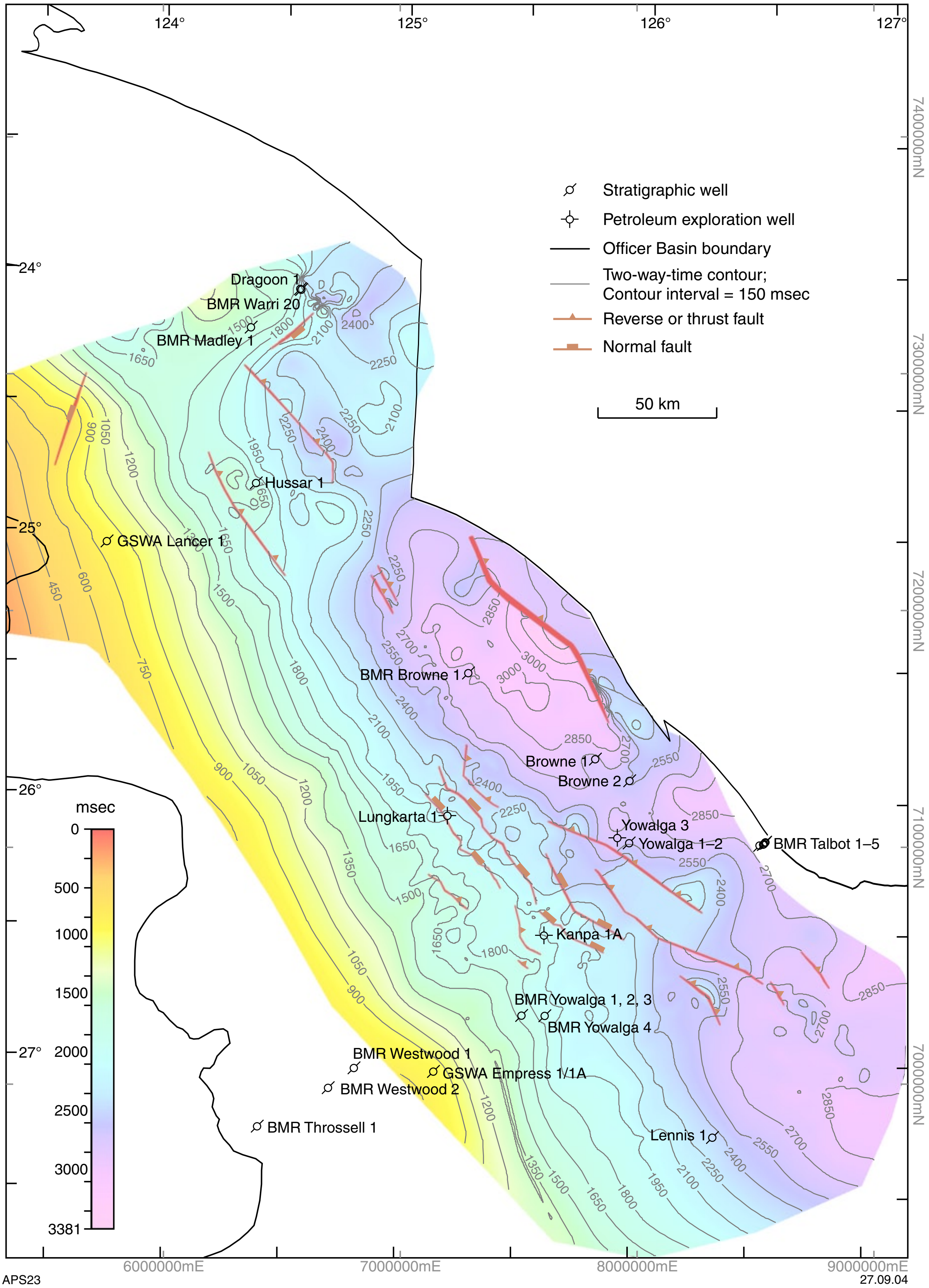


Figure 4. TWT structure map of the near base Neoproterozoic horizon

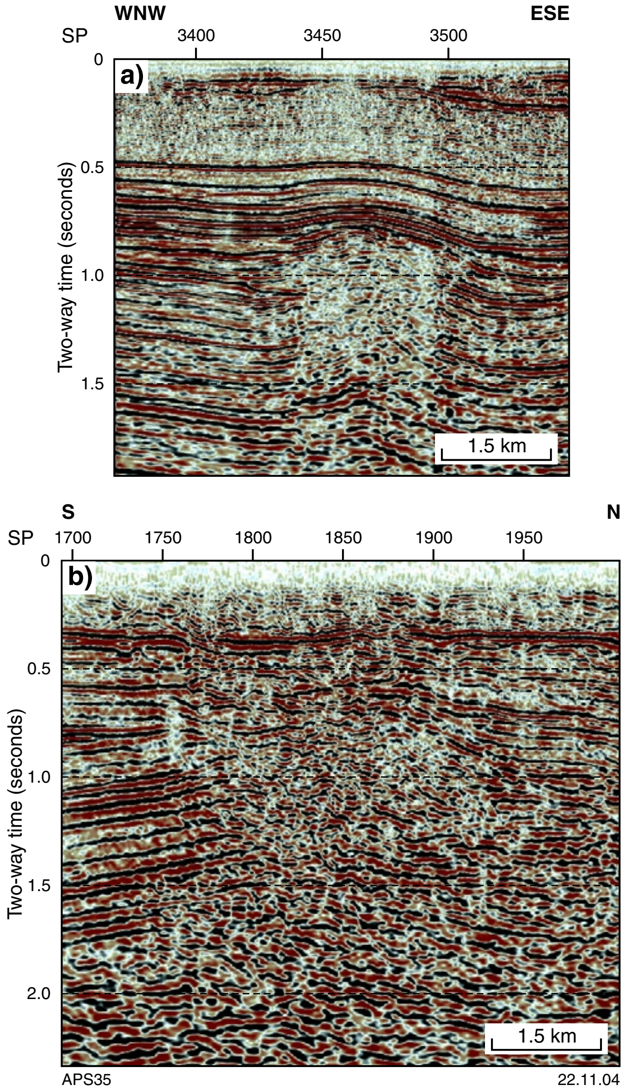


Figure 5. a) Seismic line N83-006, showing a well-imaged salt feature in the Browne Formation, piercing through the overlying strata; b) seismic line 81-017, showing a poorly imaged salt feature in the Browne Formation

is present throughout the study area, except where the formation was uplifted by halokinetic processes, which led to partial or complete erosion along salt walls and on the hangingwalls of thrusts. As with the top Hussar Formation, the Kanpa Formation gradually thickens to the north-northeast (Plate 8; Fig. 12).

Base Table Hill Volcanics

The Table Hill Volcanics are widespread throughout the western Officer Basin and have a very prominent high amplitude seismic signature that is easy to trace across the entire area with the highest level of confidence. This is partly due to the contrast in acoustic properties between sedimentary and volcanic rocks, and also to the structural simplicity of the horizon. Only minor deteriorations in the seismic reflections are observed, mainly above some salt structures. The seismic reflection representing the base Table Hill Volcanics was picked at the first continuous zero crossover of the wavelet, and may appear slightly above the true base, but the difference does not exceed 15 msec.

The TWT structure map of the base Table Hill Volcanics horizon (Plate 9; Fig. 13) indicates that this is a shallow horizon with very little structuring. Most of the regional faults observed in the lower horizons do not cut through the Table Hill Volcanics, but occasionally produce small-relief drag rollovers. The Browne salt wall is the only diapiric structure that pierced through the Table Hill Volcanics (Figs 13 and 14). In the remainder of the area, the salt movement either did not affect this horizon, or only produced small-scale drape folds, which may or may not be associated with minor normal faulting and collapse. Normal faulting within Table Hill Volcanics is common, although some reverse faults are also present, but throws are less than 30 msec and are not taken into consideration in the regional mapping.

The mapping indicates that the Table Hill Volcanics is absent only in the most northwestern portion of the study area. In the east-northeastern regions, the reflector shallows gradually, in contrast to the underlying seismic horizons. This implies that a significant amount of sediment accumulated in this area after the deposition of the Buldya Group, but before the extrusion of the Table Hill Volcanics.

Structural interpretation

All of the mapped horizons below the Table Hill Volcanics deepen to the north-northeast towards the Paterson Orogen. The base Neoproterozoic horizon (the base of the Officer Basin succession) is interpreted at between 600 and 900 msec in the southwestern areas, and between 2800 and 3000 msec (about 5500–6000 m subseismic datum) near the Paterson Orogen (Plate 2; Figs 4 and 14). The well data indicate a shallow southwestern margin, with the base Neoproterozoic at a possible 377 m in WMC NJD1, 1478 m in GSWA Lancer 1, and 1521 m in GSWA Empress 1A. In the central part of the basin, Kanpa 1A possibly intersected the base Neoproterozoic at a considerably greater depth (3671 m). Although the original depositional features have been modified by later halokinetic deformation, TWT structure maps of the Browne, Hussar, and Kanpa Formations show the same trend of structural deepening to the north-northeast. Furthermore, even though halotectonics and marginal thrusts of the Paterson Orogen led to significant erosion of the Steptoe, Kanpa, Hussar, and, in places, Browne Formations, their depositional thicknesses also increase to the north-northeast (Plates 4, 6, and 8; Figs 7, 10, and 12).

The dominant structures observed on the seismic maps trend in a northwesterly direction, parallel to structural trends in the Paterson Orogen (Plates 3, 5, and 7; Figs 6, 9, and 11), and are consistent with trends observed in potential-field data (Figs 15 and 16). The most common faults in the western Officer Basin are thin-skinned thrusts lubricated by salt, and reverse faults typically developed

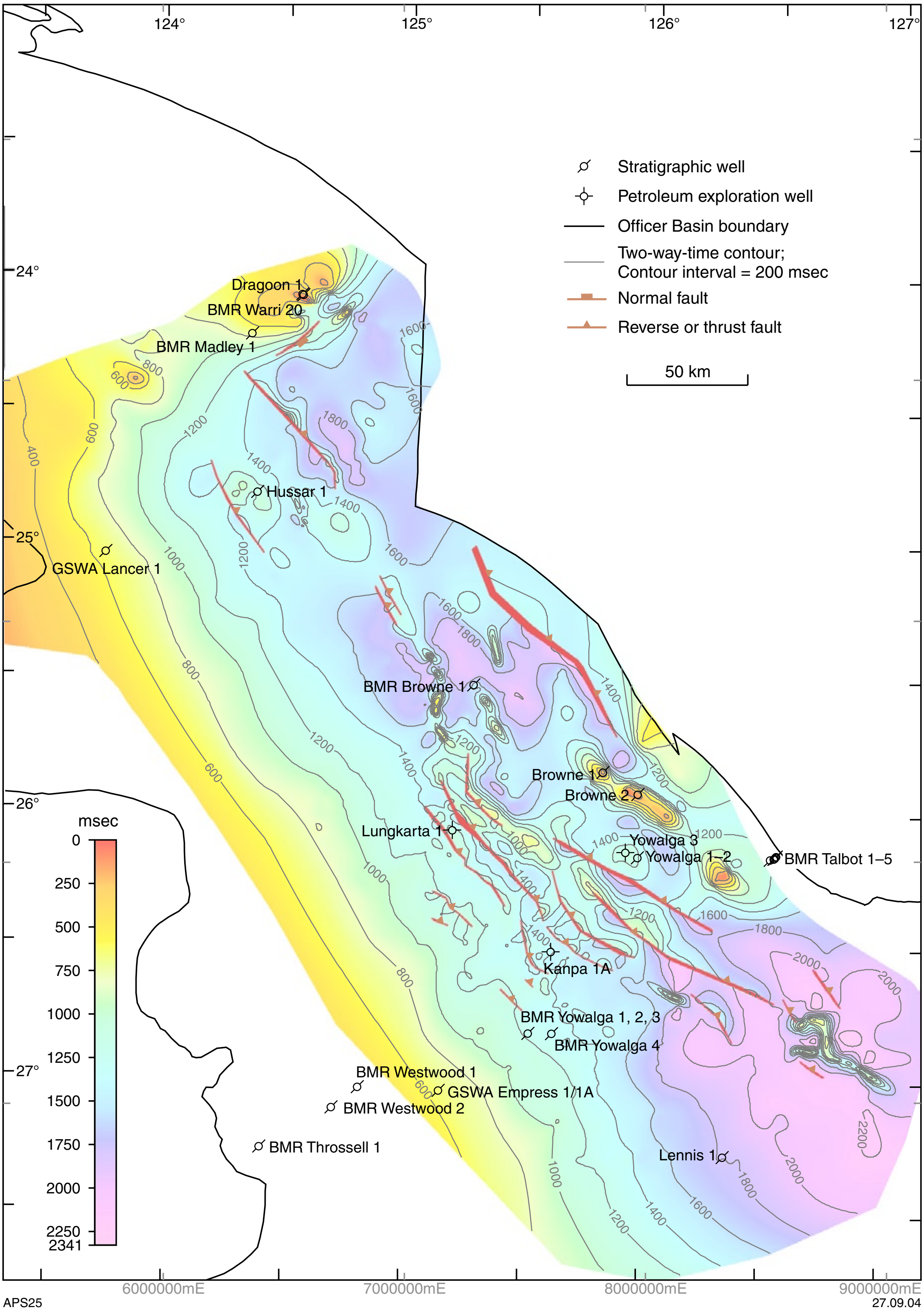


Figure 6. TWT structure map of the top Browne Formation (near top salt) horizon

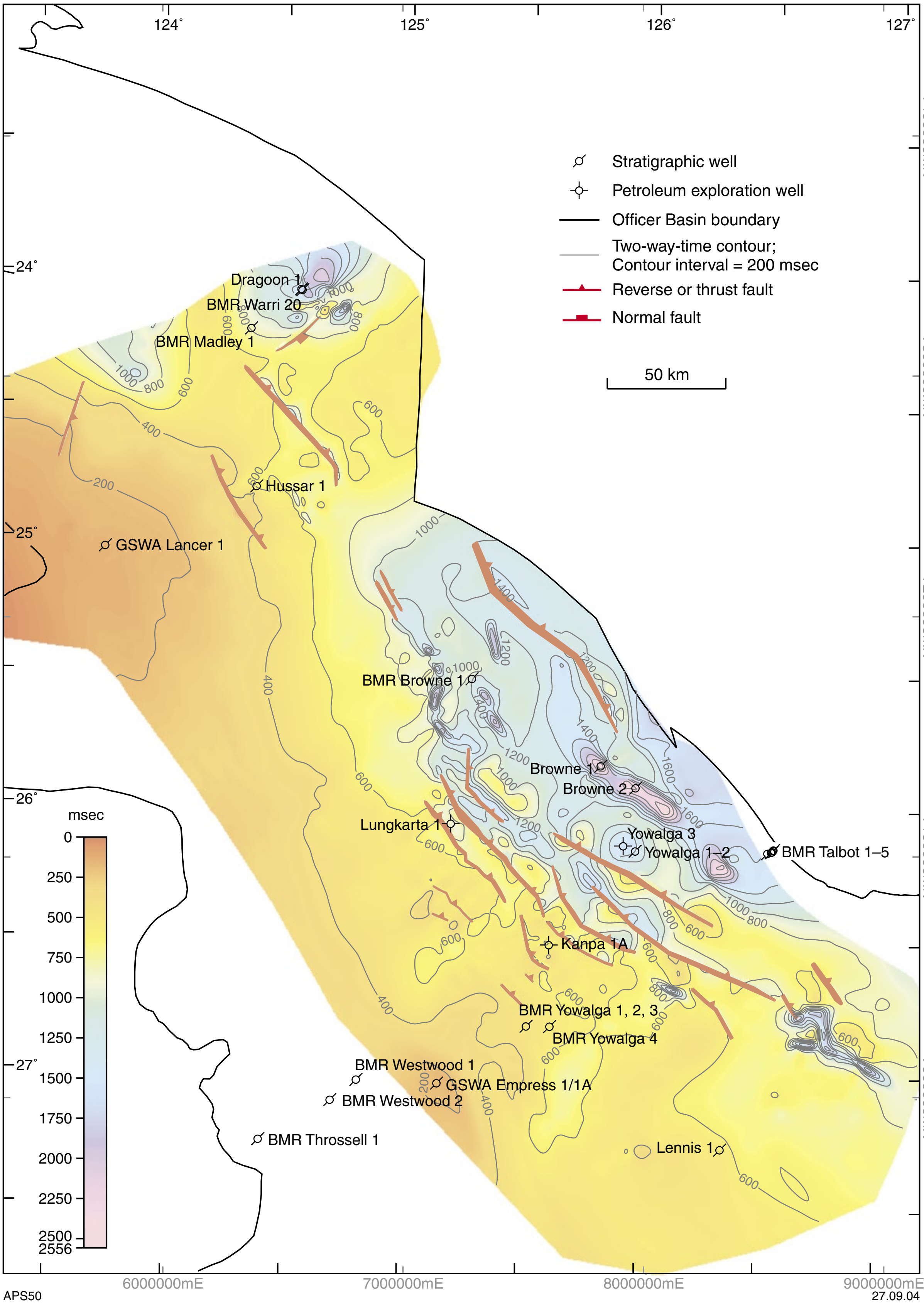


Figure 7. TWT thickness map of the Browne Formation

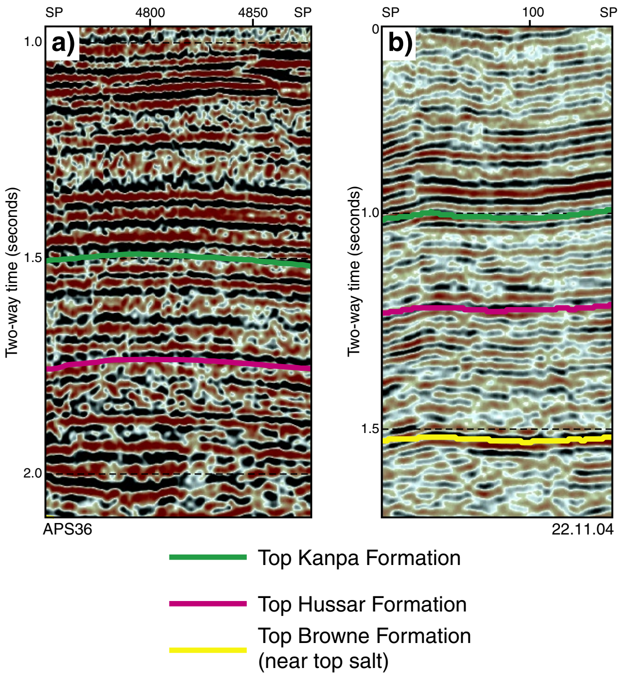


Figure 8. Similarity in seismic signature of the Hussar and Kanpa Formations in south and southwestern areas of the basin: a) seismic line T82-139; b) seismic line 80-005

along structurally weak zones in the pre-Neoproterozoic section.

The seismic interpretation clearly indicates that the present-day structural–stratigraphic framework of the western Officer Basin is dominated by salt tectonics and associated features. Salt mobilization was most active in the north and northeastern portions of the study area, which resulted in considerable thickness variations of the Browne Formation (Figs 7 and 14; Plate 4), erosion in the overlying section, and a variety of salt-related features. Many of the salt structures that formed during earlier phases were modified by further halokinetic uplift, leading to intense piercement into overlying strata. Some salt walls extend more than 100 km laterally (Figs 6, 9, 11, and 13; Plates 3, 5, 7, and 9), and vertical piercement ranges from tens of metres to more than 1500 m (Fig. 14). Most of the mapped salt walls and diapirs correlate well with negative gravity anomalies (Fig. 15). There appears to be a very good match between the seismically mapped Browne salt wall — a west-northwesterly trending feature that has pierced through the entire Neoproterozoic and early Palaeozoic sequence — and a gravity low with the same trend, although the anomaly could be partly caused by the increased depositional thickness in this area. The Woolnough and Madley diapirs also correlate well with a gravity low in the north-northwestern part of the study area. However, in places the relationship between negative gravity anomalies and halotectonics is less obvious, probably due to variations in the density contrast between the salt, the rest of the Neoproterozoic succession, and the underlying Mesoproterozoic rocks. This is particularly so in the western areas, where a thick Mesoproterozoic section is interpreted to lie beneath the Officer Basin succession.

Several structural zones can be differentiated using the seismic interpretation of the central western Officer Basin, based mostly on the intensity of the salt movement and the style of the halotectonic features. Japan National Oil Corporation (1997) recognized four zones within their Special Prospecting Authority area in the Officer Basin — Salt-ruptured Zone, Thrusted Zone, Western Platform, and Northern Depression (Fig. 17a) — but gave only brief regional descriptions of these structural divisions. Apak and Moors (2000a) and Apak et al. (2002a) adopted this subdivision and attempted to explain the origin and probable timing of the salt movement, but did not extend the zones outside the area studied by JNOC. Carlsen et al. (2003) reinterpreted selected seismic lines and proposed a structural subdivision that further developed the terminology of the previous authors, distinguishing five structural zones: Marginal Overthrusted, Salt-ruptured, Thrusted, Western Platform, and Minibasins Zones (Fig. 17b). Using the terminology proposed by the previous authors, but with the advantage of the newly reprocessed seismic data, the current interpretation refines the structural subdivision of the central western Officer Basin and extends it over all areas with seismic coverage. Only four zones are identified: Marginal Overthrusted, Salt-ruptured, Thrusted, and Western Platform Zones (Fig. 18). Details of the characteristic structure within each of these zones are described below.

The Marginal Overthrusted Zone is located in the north-northeastern part of the study area, where Neoproterozoic sedimentary rocks of the Officer Basin succession are thrusted by movements of the adjacent Paterson Orogen. The zone is observed only on the northeastern ends of regional lines 80-007, 80-011C, and possibly 80-013.

The Salt-ruptured Zone is located to the southwest of the Marginal Overthrusted Zone, and is characterized by salt piercement through the overlying section, causing a variety of halotectonic features. The diapirism is most extensive in the northern and northeastern parts of the study area, where the Woolnough and Madley diapirs are exposed (Fig. 18) and the Browne salt wall has pierced through the entire Neoproterozoic section and is overlain by the Permian Paterson Formation (Table 1 — Browne 1 and 2; Fig. 14 — section B–B'). To the south of the Browne salt wall, another salt feature is mapped parallel to it (Figs 6 and 7; Plates 3 and 4). This salt wall is less pronounced and has resulted in drape folding in the supra-salt strata, with complete erosion of the Kanpa Formation and partial erosion of the Hussar Formation. In the central and southwestern areas of the Salt-ruptured Zone, halotectonics produced drape folds, in some instances accompanied by different levels of erosion in the overlying section (Fig. 14). Various types of salt-related structures in the Salt-ruptured Zone are shown on Figure 19.

The Thrusted Zone lies to the southwest of the Salt-ruptured Zone and is characterized by thin-skinned thrusts and reverse faults lubricated by the salt in the Browne

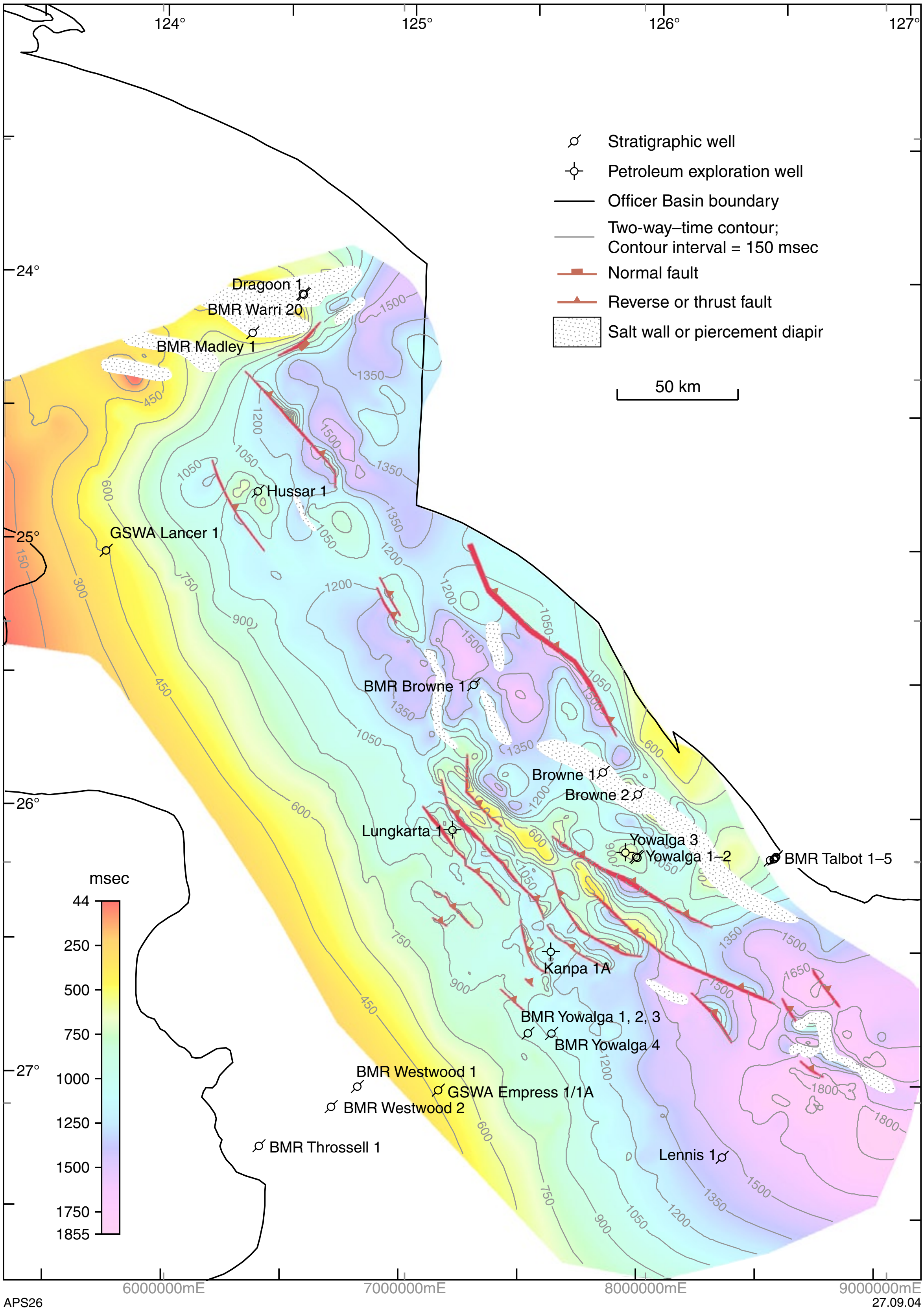


Figure 9. TWT structure map of the top Hussar Formation horizon

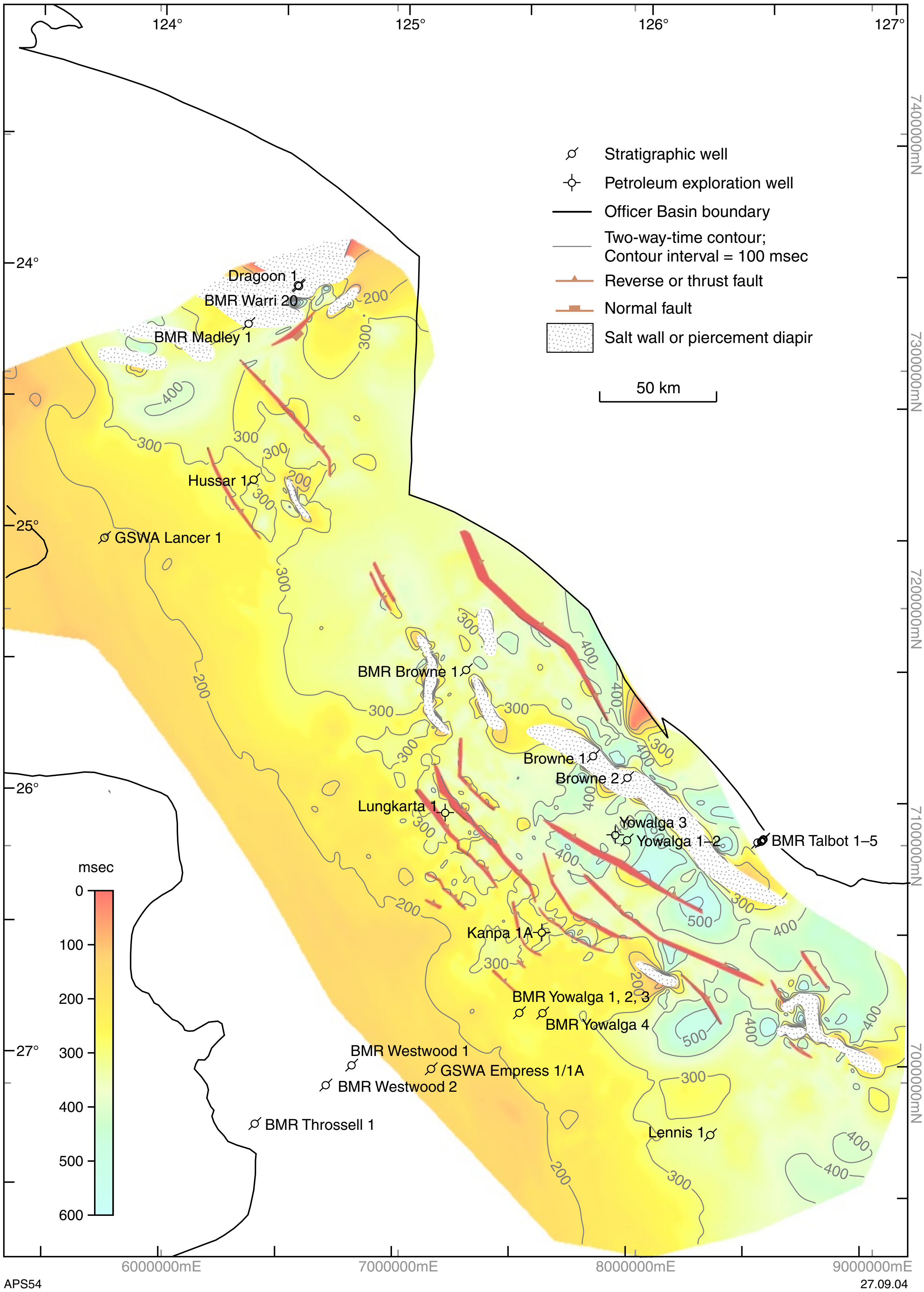


Figure 10. TWT thickness map of the Hussar Formation

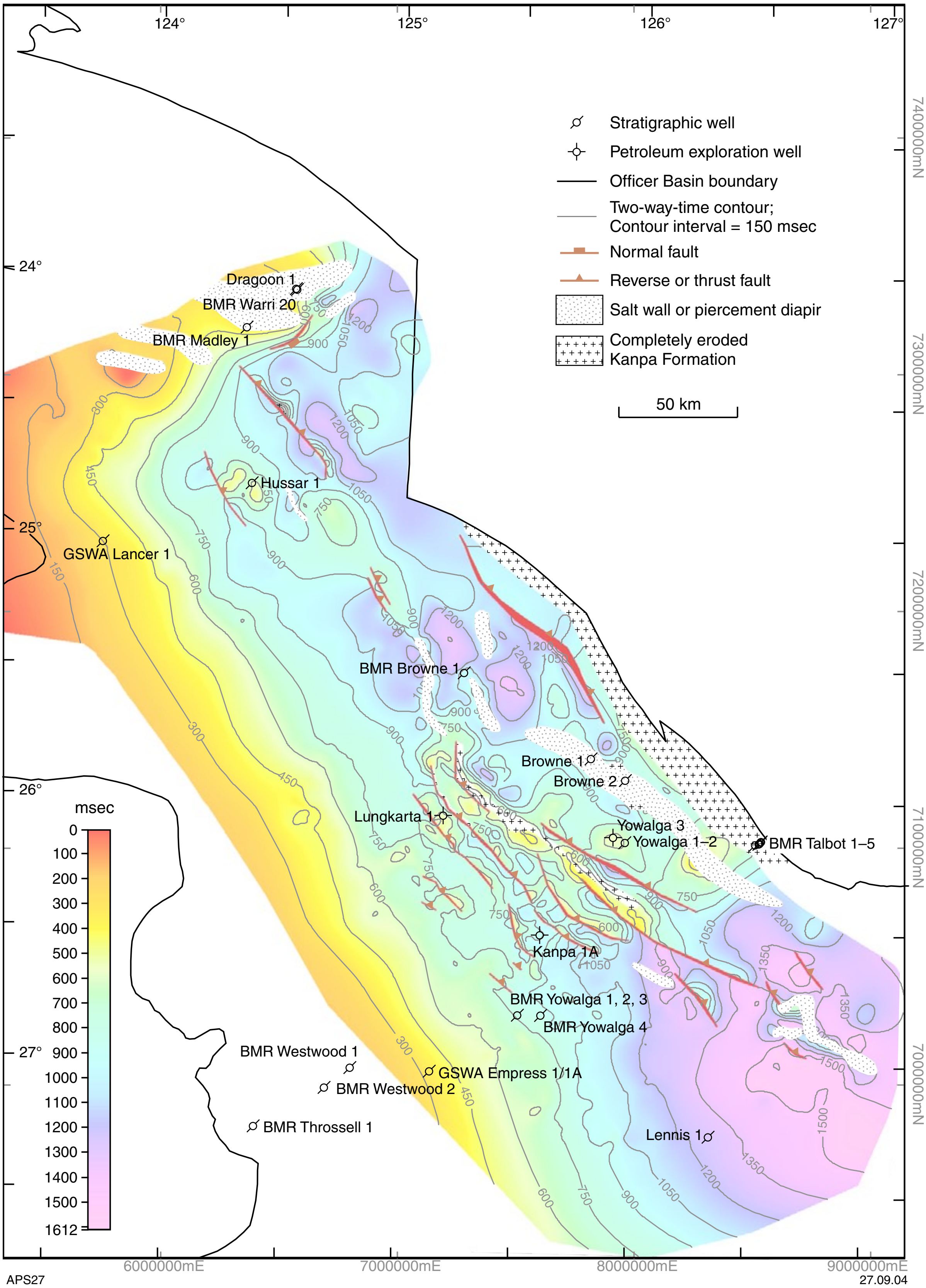


Figure 11. TWT structure map of the top Kanpa Formation horizon

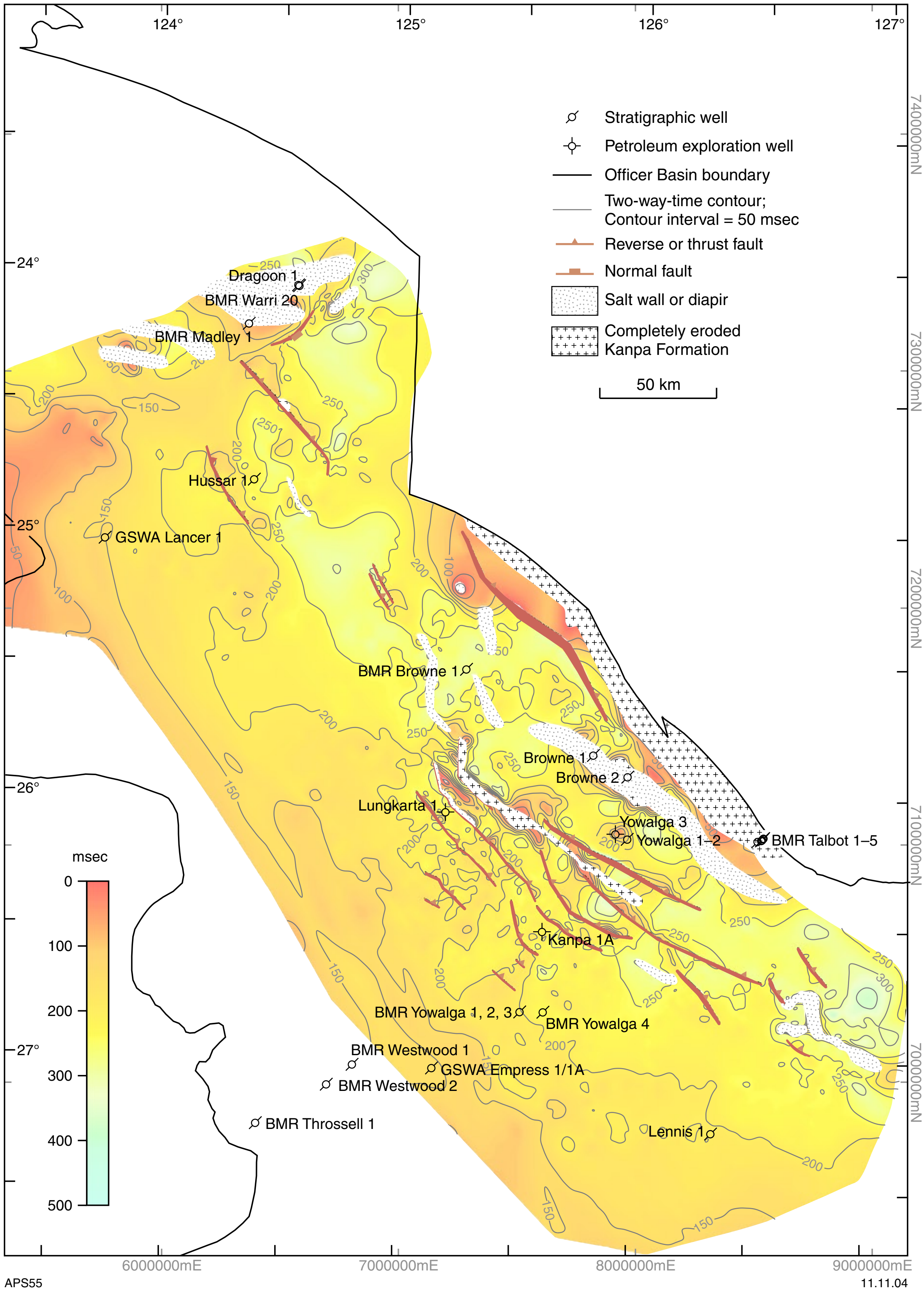


Figure 12. TWT thickness map of the Kanpa Formation

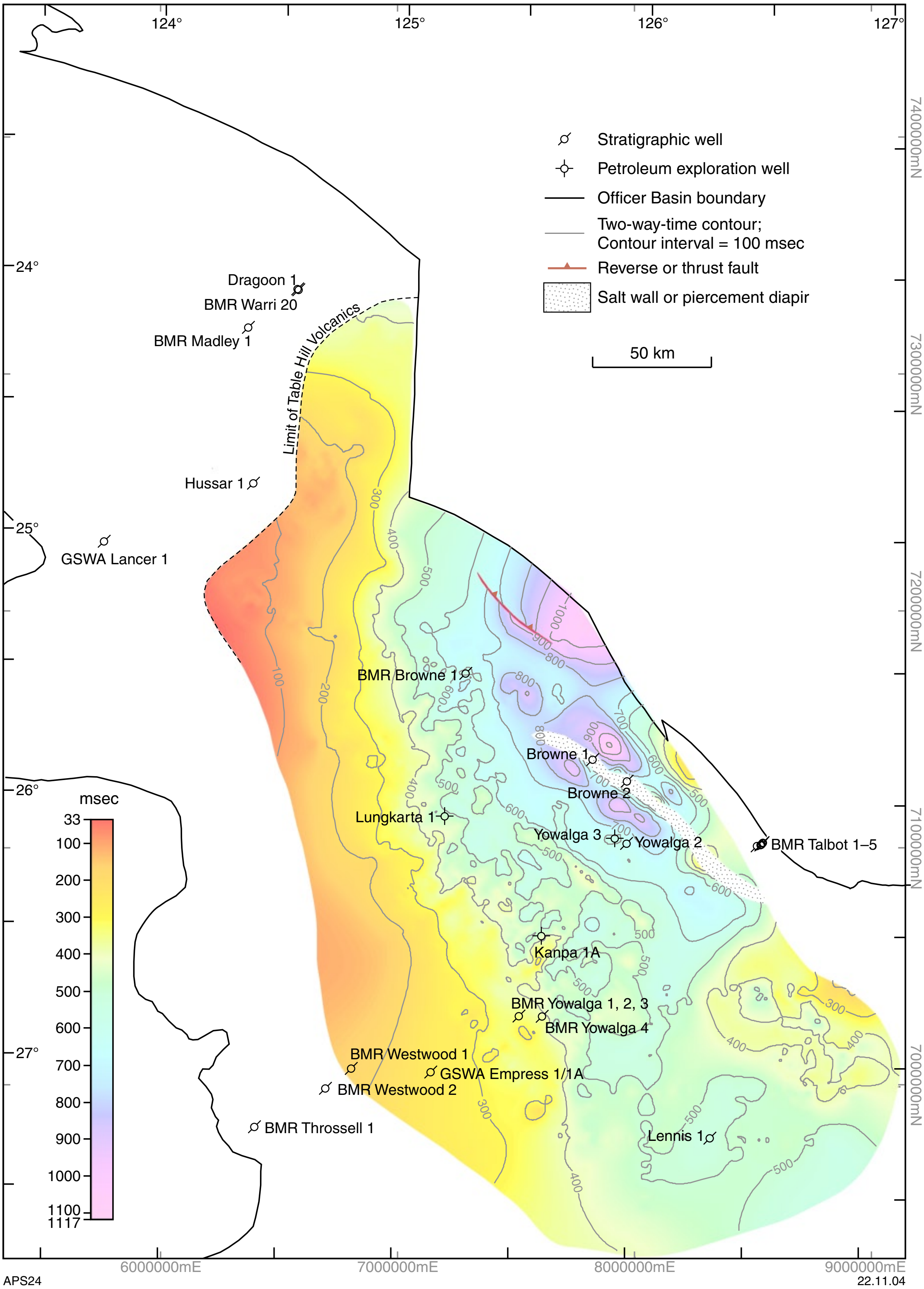


Figure 13. TWT structure map of the base Table Hill Volcanics horizon

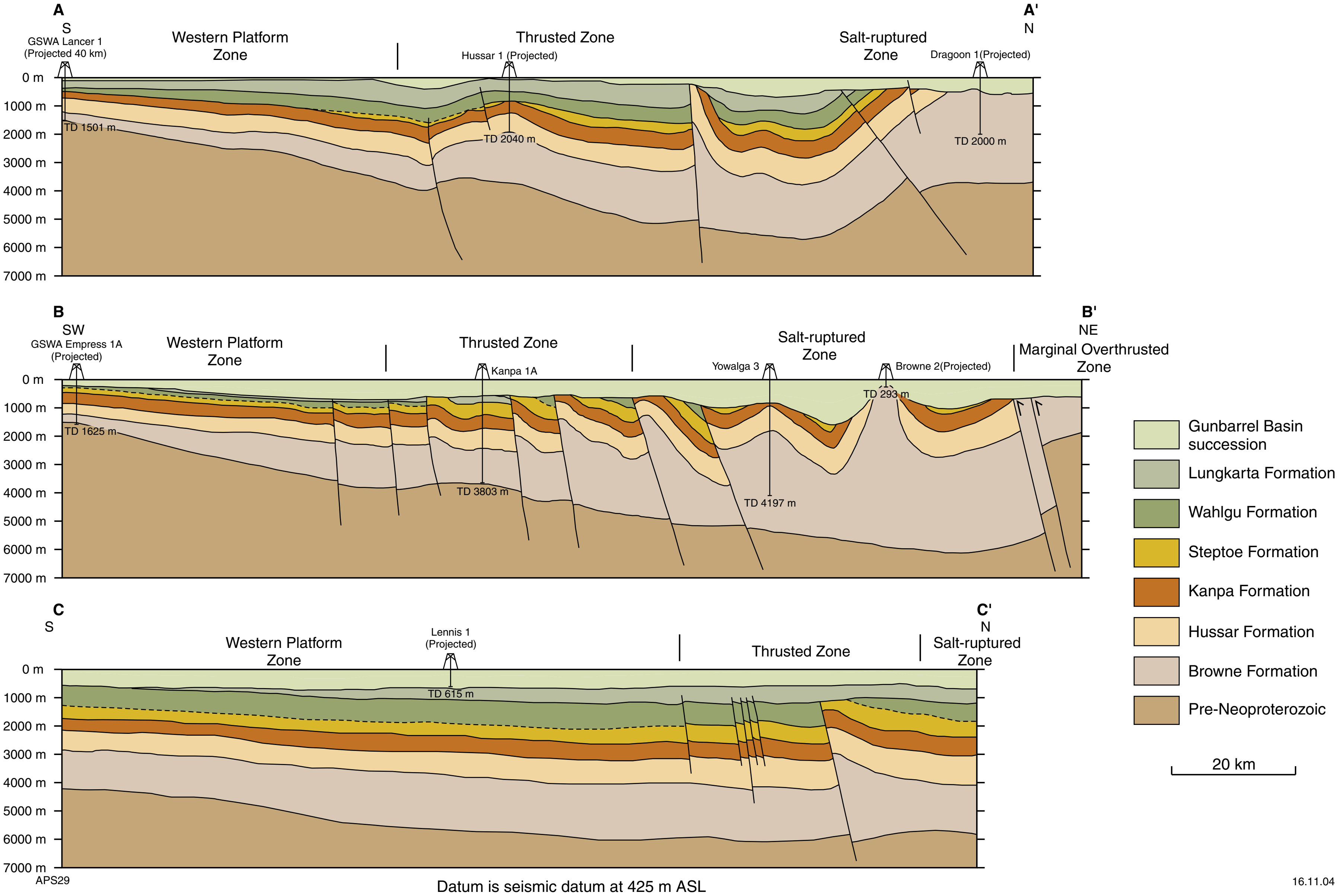


Figure 14. Regional geological cross sections across the central western Officer Basin, based on seismic and well data. See Figure 2 for locations

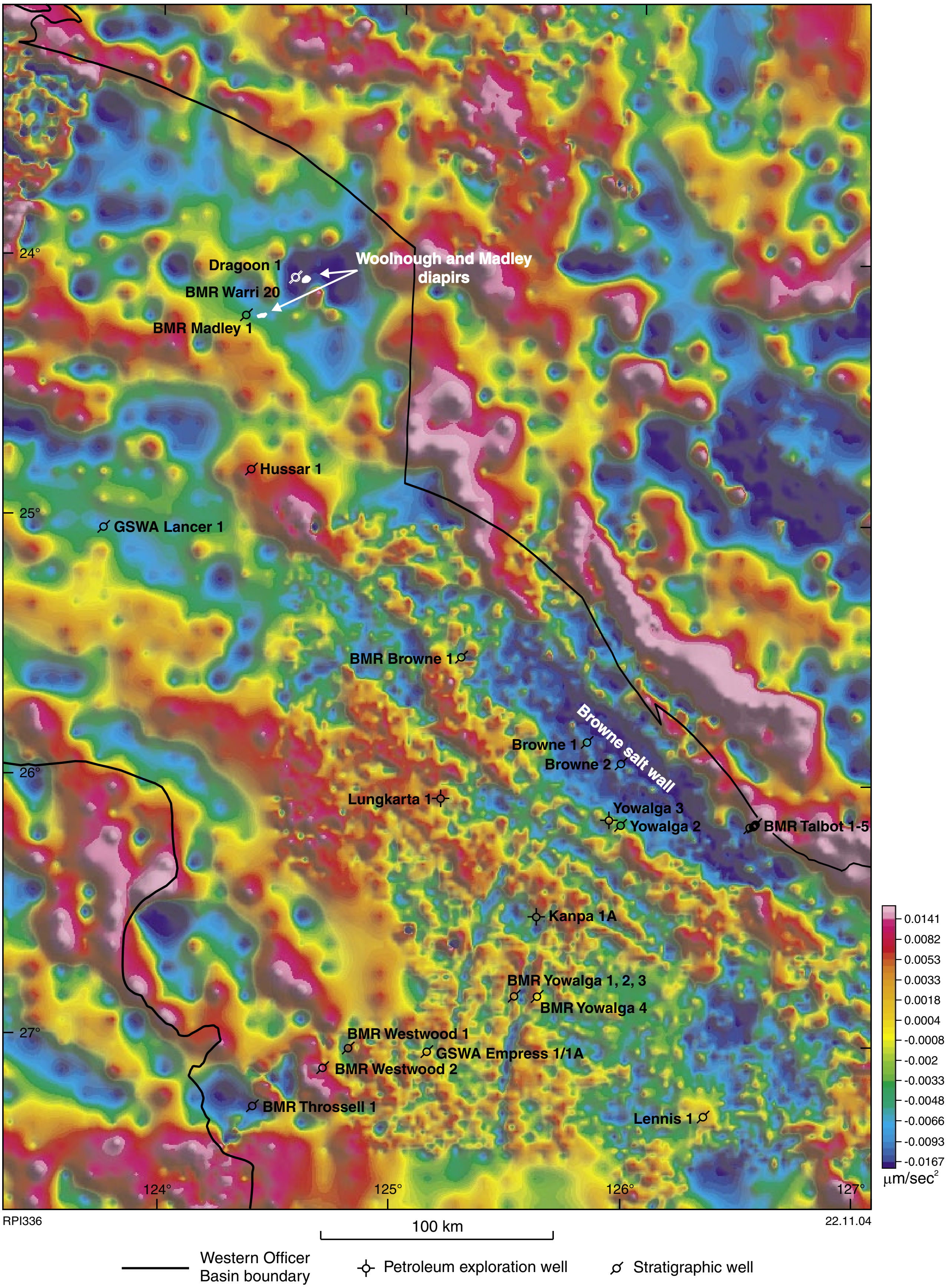


Figure 15. Image of the first vertical derivative of Bouguer gravity

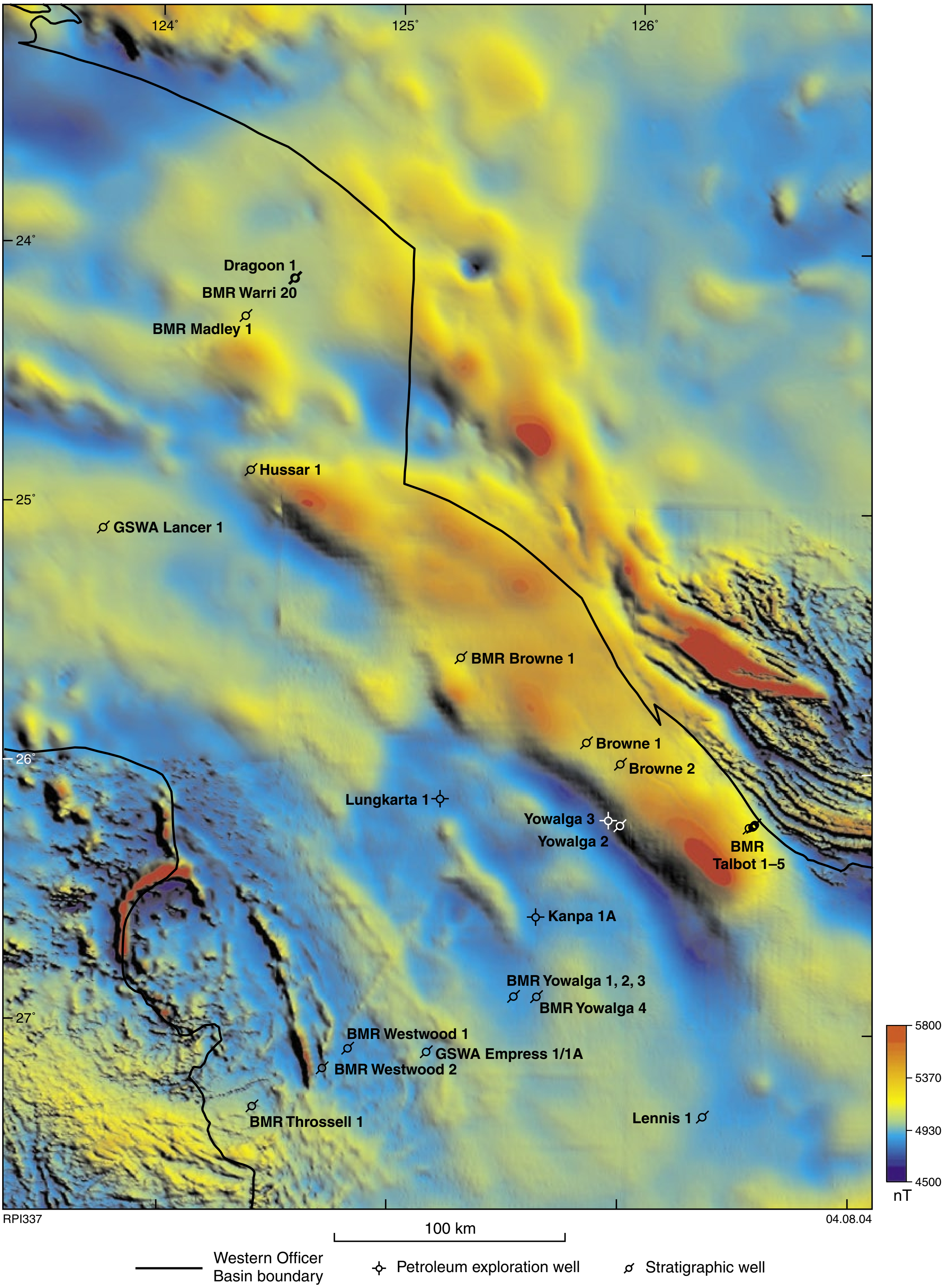


Figure 16. Image of total magnetic intensity

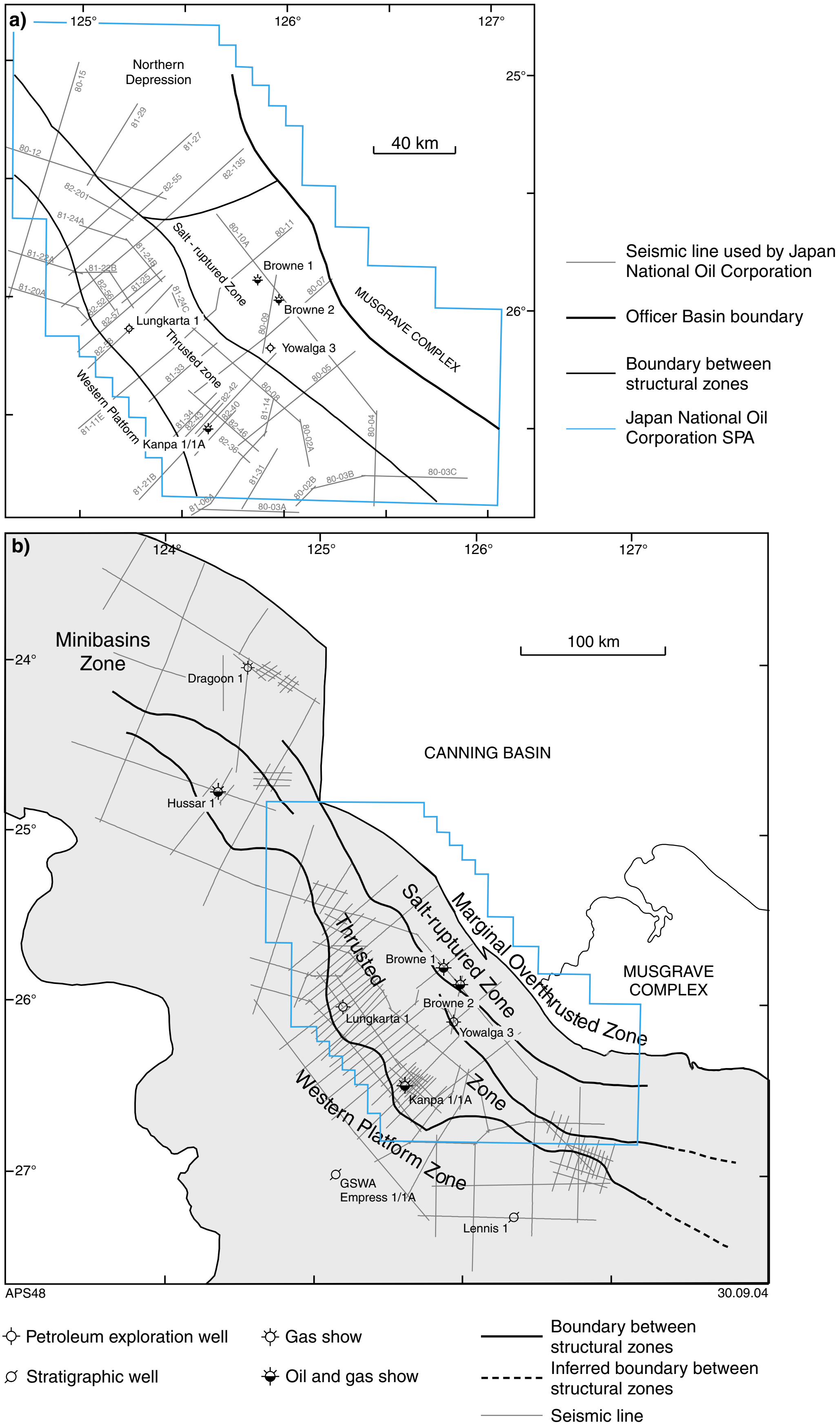
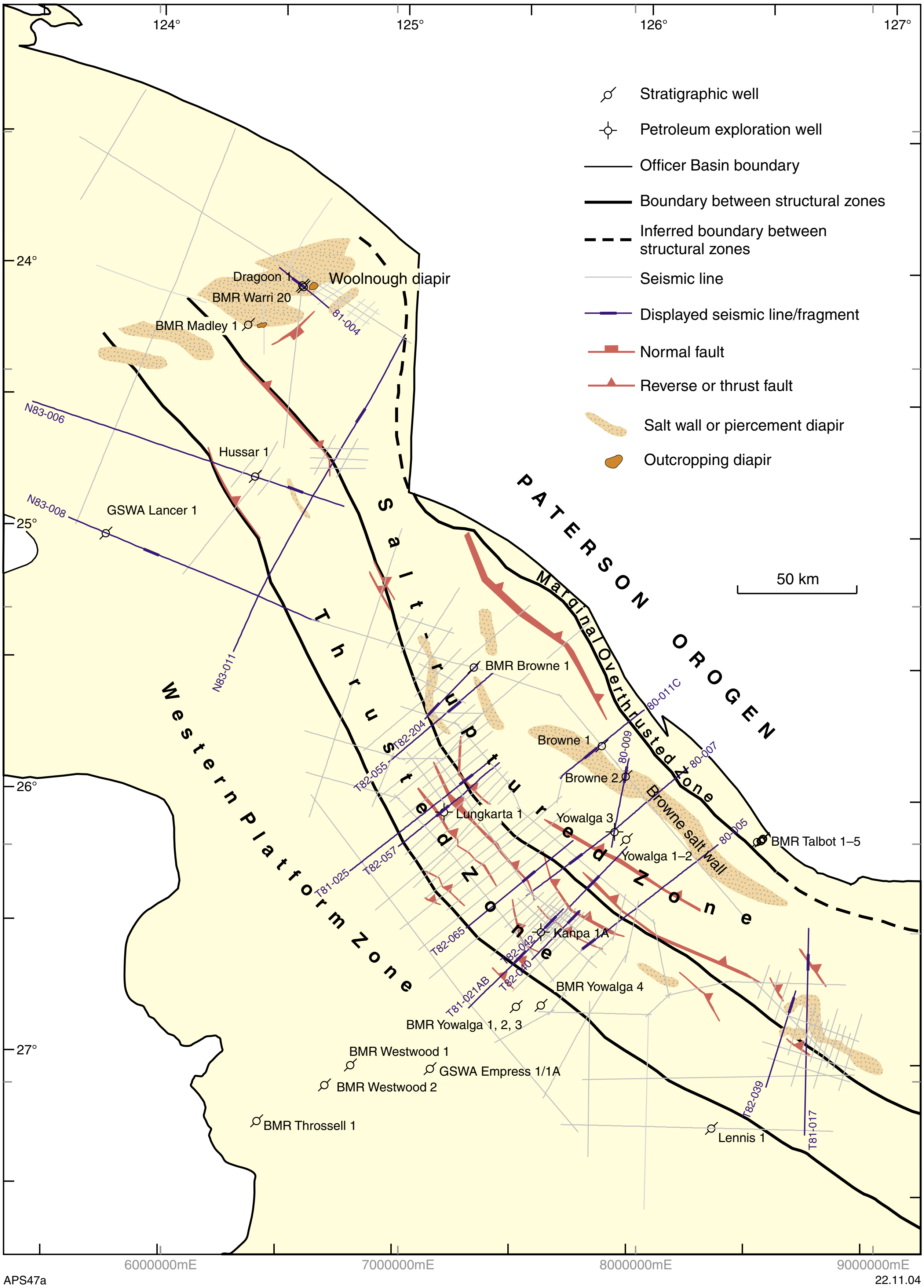


Figure 17. Previous structural subdivisions in the western Officer Basin: a) structural subdivision proposed by Japan National Oil Company (1997); b) structural subdivision proposed by Carlsen et al. (2003)



Figue 18. Structural subdivision proposed in this study

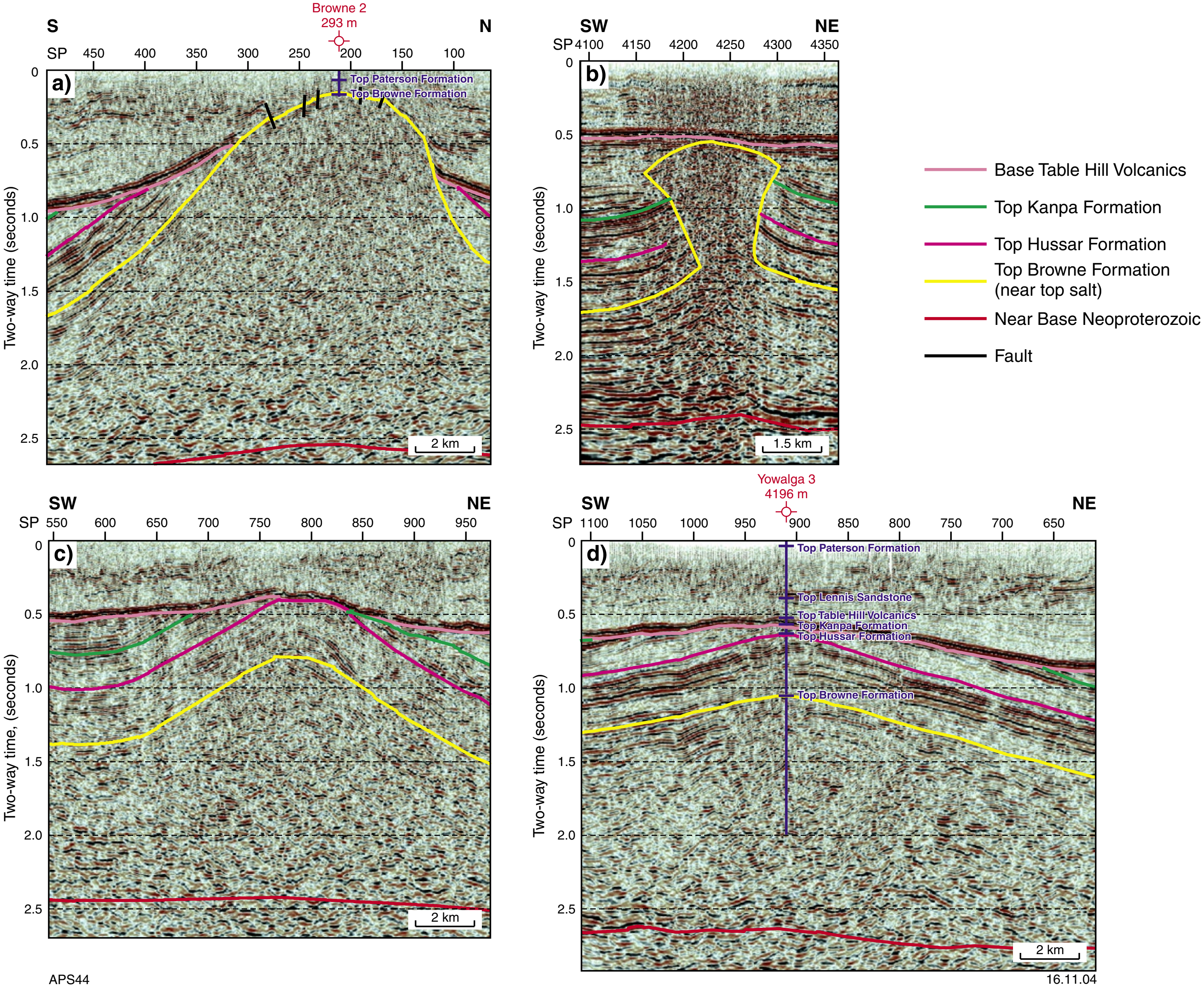


Figure 19. Salt structures in the Salt-ruptured Zone

Formation. These thrusts produced rollovers and salt-cored anticlinal features with drape folding in the overlying section. Minor diapirs and salt pillows are also present. In many areas, the thrusts developed in pre-existing zones of weakness in the Mesoproterozoic section. Some of the salt-associated faults exhibit normal movement at the near base Neoproterozoic horizon (Plate 2; Fig. 4), indicating that in some areas salt was initially mobilized in structurally weak zones that were later inverted. The seismic data indicate that salt movement and over-thrusting were most intense in the northeastern part of the zone, and in some places this caused complete erosion of the Kanpa Formation on the hangingwall (Plate 7; Figs 11 and 14). To the south-southwest, thrusts are characterized by minor throws, and the salt features decrease in amplitude towards the margin; in the most distal parts of the zone, reverse faults are observed without any evidence of salt emplacement (Figs 14 and 20).

The Western Platform Zone is the farthest from the Paterson Orogen. It is a relatively stable area that is minimally affected or not affected by halokinetic deformation. No significant salt features have been identified on seismic data, and only minor local reverse faults are observed.

The Northern Depression (Fig. 17a) defined by Japan National Oil Corporation (1997) has not been identified in this study, and is interpreted as a part of the Salt-ruptured Zone where some of the primary depositional features of the Neoproterozoic succession have probably been preserved.

The observations and further interpretation herein do not support the existence of a Minibasins Zone (Fig. 17b), or at least not in the sense defined by Carlsen et al. (2003). In the area where the zone was defined, the seismic data are sparse and the poor reflections do not clearly show any onlapping onto the salt diapirs, which is typical of salt-withdrawal basins (minibasins). However, salt-withdrawal basins are expected to be developed along salt walls and diapirs in the Salt-ruptured Zone, but the sparsity and low resolution of the data, coupled with structural complexity, do not allow these to be accurately mapped.

Consistent with the structural trend, most of the salt walls and thrusts are west-northesterly trending, parallel to the Paterson Orogen, and exhibit features indicative of a contractional stress regime. Compression, associated with deformation in the adjacent Paterson Orogen, is probably the key mechanism for initiating the salt mobilization (Simeonova and Apak, 2003). However, in the northeastern areas with a thicker primary sedimentary section, the sedimentary overburden might have triggered the salt movement, which was further enhanced by tectonism in the adjacent orogen. Timing of salt mobilization is difficult to quantify due to the sparsity of Neoproterozoic biostratigraphic data, limited well ties, and variable seismic data quality. However, each of the deformation events recorded in the basin and the Paterson Orogen probably contributed to multiple salt movements, with peaks during the Areyonga Movement and Petermann Orogeny.

Petroleum-system analysis

Well post-mortems

No hydrocarbon fields or significant accumulations have been discovered to date in the Western Australian part of the Officer Basin. However, hydrocarbon shows have been recorded in 12 wells and drillholes in the form of gas, live oil, bitumen, oil fluorescence, and oil stains (Table 2). In the western Officer Basin, only 13 wells have been drilled by petroleum companies (Appendix 2), the majority of which were spudded as stratigraphic wells and cannot be considered valid exploration tests. The following is a summary of the objectives and results for some of the wells drilled into the Neoproterozoic succession of the western Officer Basin.

Yowalga 3

Yowalga 3 was drilled by Shell in 1980 at shot point (SP) 85 on seismic line 32A (acquired by Hunt Oil in 1965). This was the first deep well drilled in the basin, with a total depth (TD) of 4197 m. It was drilled on a salt pillow structure — the Yowalga structure (Fig. 21) — to investigate the Neoproterozoic sequence and predicted subsalt clastic units. Other objectives of the well were to obtain information on source, seal, and reservoir rocks to assess the hydrocarbon potential of the area, and to provide well control for future seismic surveys.

The well intersected the top of the Neoproterozoic sequence at 880 m in what is currently interpreted as lower Kanpa Formation (Perincek, 1998), and drilled through a 100-m thick interval of argillaceous siltstone, shale, and dolomite (dolomitic limestone) followed by a sandstone-dominated sequence currently thought to be the Hussar Formation. The Browne Formation was intersected at 1888 m and drilled to a TD of 4197 m. Below 2169 m the unit was highly deformed, with west-northwesterly striking dips ranging between 20 and 80°. Shell Company of Australia Ltd (1981) suggested that the salt-dominated sequence had been affected by reverse faults induced by up-thrusting of the Musgrave Complex. However, this study shows that the well is located on a salt pillow in the Salt-ruptured Zone. Therefore, in our opinion these deformations are most likely a product of halotectonics in a compressional regime, with the measured dips associated with salt-deformed beds.

Yowalga 3 intersected very good reservoir rocks in the supra-salt sequence. Log porosities of up to 23% were calculated for sandstones between 1000–1400 m, in what is now interpreted as the Hussar Formation. In the Browne Formation, intersected clastic rocks are very fine grained with low porosity–permeability characteristics. Core analyses indicate that evaporite minerals typically infill fractures and vugs where present in carbonate rock, but log porosities of 7–15% were calculated for a carbonate section between 2048 and 2196 m. A drill-steam test was performed over the interval 2057–2062 m to confirm a resistivity-log anomaly, but it recovered only water. The well was terminated in the Browne Formation, and thus failed to test the existence of a potential subsalt reservoir.

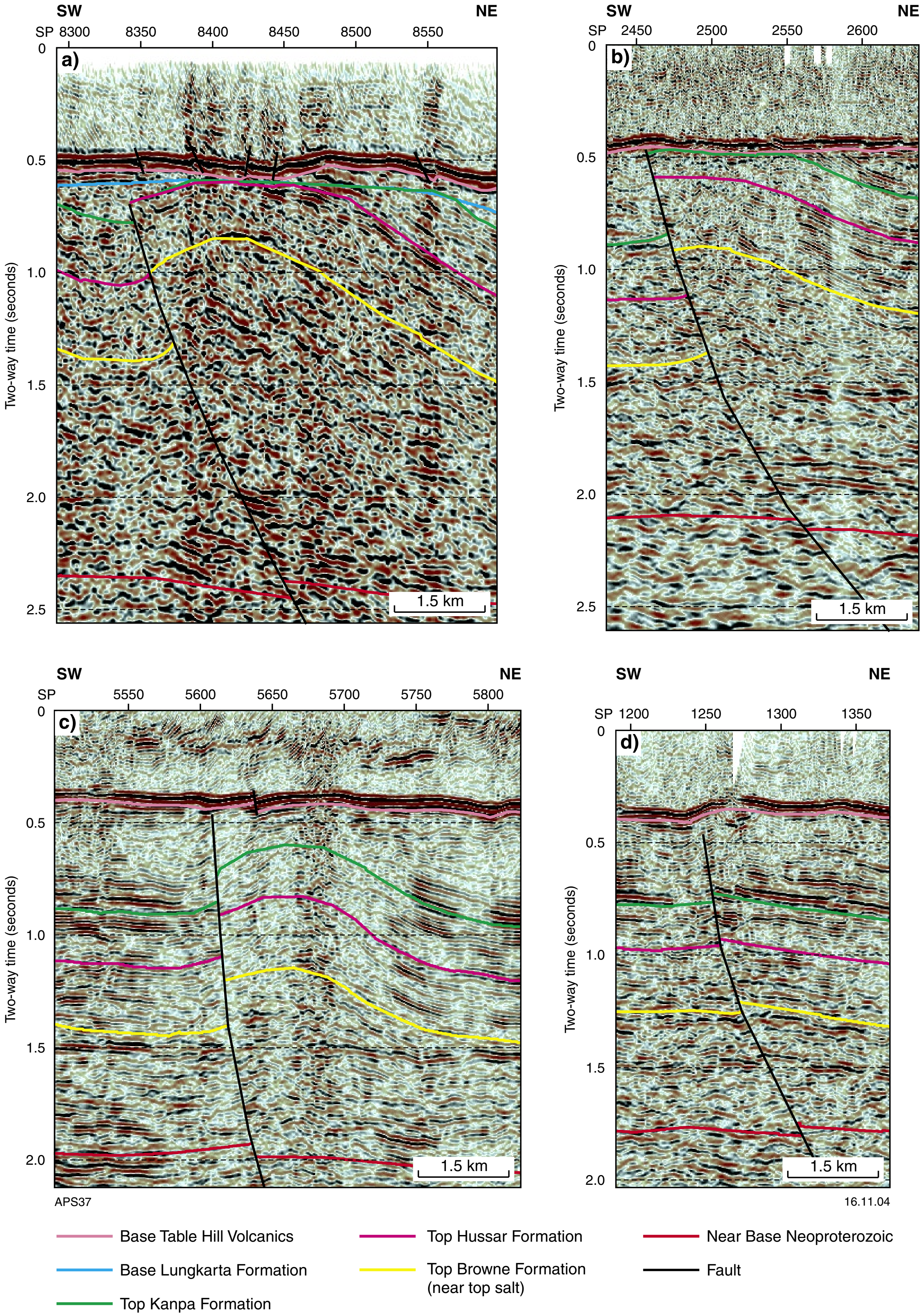


Figure 20. Salt structures in the Thrusted Zone

Table 2. Hydrocarbon shows recorded in the western Officer Basin

Well name	*Year*	*Well type*	*Operator*	*Hydrocarbon shows*	*Formation*	*Reference*
Browne 1	1965	Stratigraphic test	Hunt Oil	Gas-cut mud and good fluorescent cuts in well cuttings	Browne Fm	Jackson (1966)
Browne 2	1965	Stratigraphic test	Hunt Oil	Gas-cut mud and good fluorescent cuts in well cuttings	Browne Fm	Jackson (966)
NJD 1	1981	Mineral drillhole	Western Mining Corp.	Extensive bitumen-filled veins and bleeding oil	Hussar Fm ?Mesoproterozoic	Western Mining Corp. Ltd (1981) Hocking (2003)
Dragoon 1	1982	Stratigraphic test	Eagle Corp. et al.	Mud-gas show, methane to pentane	Browne Fm	Karajas and Taylor (1983b)
Hussar 1	1982	Stratigraphic test	Eagle Corp. et al.	Gas show and bitumen	Kanpa Fm Hussar Fm	Karajas and Taylor (1983a)
Kanpa 1A	1983	Petroleum exploration	Shell Company of Australia Ltd	Fluorescence and brown oil stains	Steptoe Fm	Shell Company of Australia (1983)
LDDH 1	1993	Mineral drillhole	Normandy Exploration Ltd	Bitumen in fractures	Tarcunyah Group[(a)]	Stevens and Carlsen (1998) Busbridge (1993)
OD23	1996	Mineral drillhole	Jubille Gold Mines NL	Bitumen and live oil in vugs and fractures	Scorpion Group (Mesoproterozoic age)	Cooke (1997) Stevens and Carlsen (1998)
Boondawari 1	1997	Petroleum exploration	Amadeus Petroleum	Fluorescence, confirmed by geochemical analysis	Spearhole Fm[(b)]	Warris (1998b)
Mundadjini 1	1997	Petroleum exploration	Amadeus Petroleum	Fluorescence, confirmed by geochemical analysis	Spearhole Fm[(b)]	Warris (1998a)
GSWA Vines 1	1999	Stratigraphic test	GSWA	Gas peaks equivalent to 10% methane in air	Vines Fm	Apak et al. (2002b)
GSWA Lancer 1	2003	Stratigraphic test	GSWA	Traces of bitumen and oil	Hussar and Kanpa Fms	Haines et al. (2004)

NOTES: (a) Unit distributed in the northwestern Officer Basin; equivalent to Buldya Group in the study area
(b) Unit distributed ind the northwestern Officer Basin; equivalent to the Townsend Quartzite in the study area

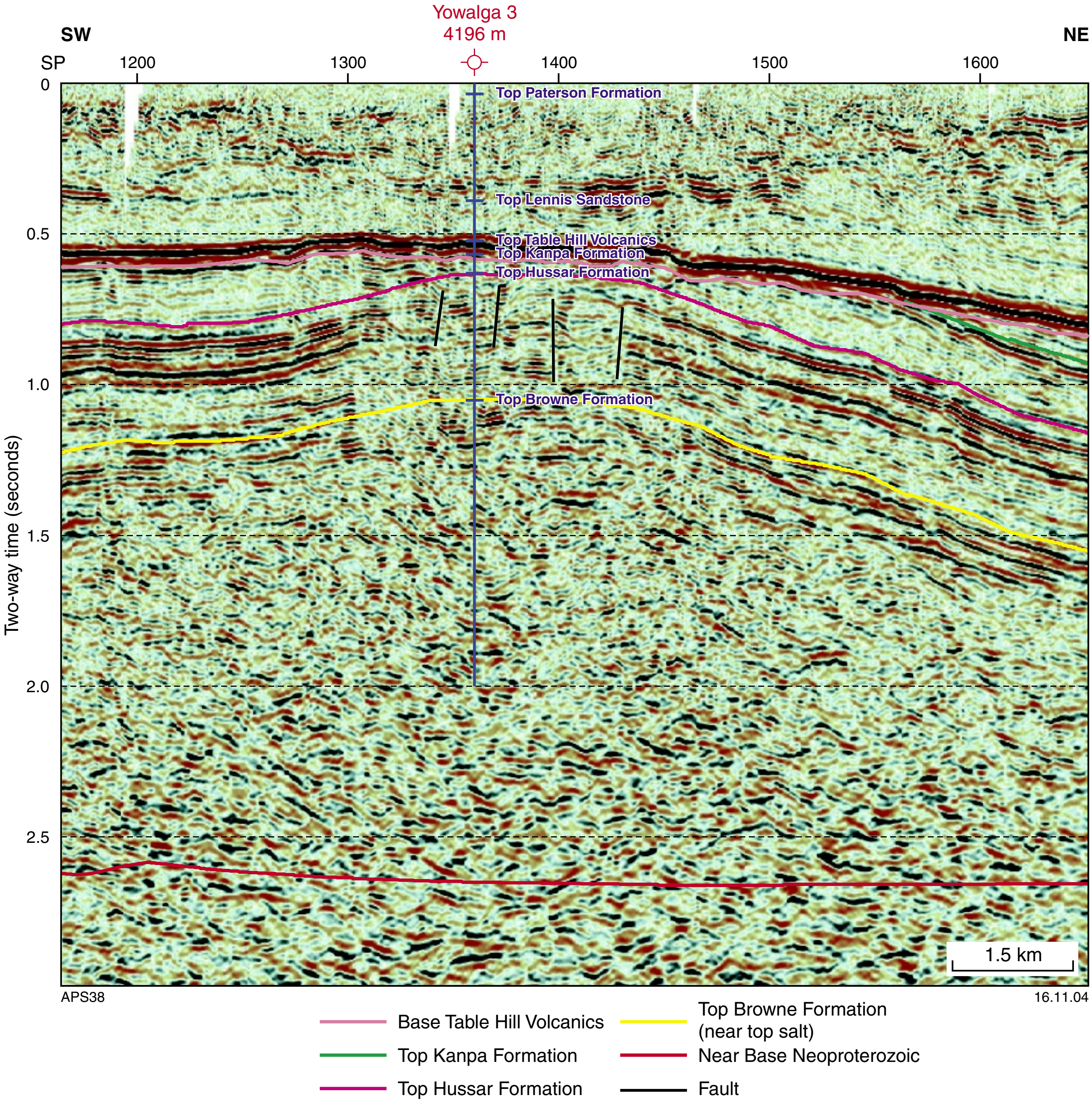


Figure 21. Seismic line 80-007, showing the location of Yowalga 3. See Figure 18 for location

Test-tube pyrolysis performed on sidewall samples and cuttings indicated potential source rocks from various depths between 945 and 3259 m. Further geochemical analyses were carried out on five sidewall samples (interval 3037–3259 m) and core samples (interval 3227.6 – 3286.6 m). The Western Australian Institute of Technology (WAIT) analyses indicated moderate to good petroleum source rocks in two samples from 3249.7 – 3259 m, and poor to moderate petroleum source potential in one sample at 3235 m (Shell Company of Australia Ltd, 1981, appendix 1). The analyses suggest that these samples are within the oil window and did not reach the gas window, which was estimated to start at an approximate depth of 3300 m. Parallel analyses of the same sidewall samples and additional core samples were carried out in-house by Shell (Shell Company of Australia Ltd, 1981), and it was suggested that the rocks are mostly post-mature for oil. However, marginal generative potential for gas was suggested for the sample at 3194.2 m, and only one sample was considered to have possibly generated some oil (Shell Company of Australia Ltd, 1981).

Subsequent geochemical analyses and maturity modelling (Ghori, 2000, 2002) show similar results to those obtained by WAIT (Shell Company of Australia Ltd, 1981, appendix 1), indicating that only the lowermost section (below 3300 m) is late mature to overmature for oil generation.

The major reservoir–seal pair found in Yowalga 3 (sandstone of the Hussar Formation and mudstone of the Kanpa Formation) was breached by crestal faults, and therefore the well is not considered a valid test. However, the complete absence of hydrocarbons may be a result of non-migration into the structures. The well may be in a migration shadow, with lateral migration hindered by the vicinity of west-northwesterly trending salt walls and/or faults lubricated with salt along their planes. Although the well did not penetrate a hydrocarbon-saturated reservoir, the existence of potential mature, rather than overmature, source rocks encouraged further exploration in the basin.

Kanpa 1A

Kanpa 1A petroleum exploration well was drilled by Shell in 1983 to a TD of 3803 m. The well is located on seismic line T82-042 at SP 4245 (Fig. 22a). Its primary objectives were to assess the source, reservoir, and seal potential of the lower Neoproterozoic succession, which had not been penetrated previously by Yowalga 3, and to investigate for possible hydrocarbon entrapment and migration at that level. The well was drilled at a TWT dip closure (Fig. 22b), as no unambiguous depth closure of considerable size was defined at the Browne Formation level (Shell Company of Australia Ltd, 1983). Kanpa 1A was located in an area of good-quality seismic data and provided regional calibration for seismo-stratigraphic interpretation and correlation in the basin.

Kanpa 1A was the first well to fully penetrate the Neoproterozoic evaporitic sequence. It reached TD in a unit originally interpreted as the Townsend Quartzite (Shell Company of Australia Ltd, 1983). Grey et al. (in prep.) suggested a possible Mesoproterozoic age for this lowermost part of the section. The drilling of Kanpa 1A failed to achieve its primary objective, as no sandstone or carbonate beds of good reservoir quality were found in the Browne Formation and underlying units. However, it encountered very good sandstone reservoirs and associated seals in the supra-salt sequence in the Steptoe (average porosity 20%) and Hussar (porosity over 15%) Formations.

Geochemical analyses of cuttings and sidewall samples indicated that rocks with moderate to good source potential were intersected between 3407 and 3412.2 m. Further analysis has shown that these samples are mature for oil generation (Shell Company of Australia Ltd, 1983; Ghori, 1998b; 2002).

Brown oil stains and fluorescence were recorded in sandstones of the Steptoe Formation between 1139 and 1183 m. Maximum intensity of the show is recorded at 1141.5 m, below a tight dolomite. The well was located downdip of an anticlinal closure at the Steptoe Formation level (Fig. 22c), and is not considered a valid exploration test. The oil shows indicate a migration pathway through the sequence.

Lungkarta 1

Lungkarta 1 was drilled by Shell in 1984 to a TD of 1770 m, and is located at SP 5120 on seismic line T82-057 (Fig. 23a). The primary objectives were stacked sandstone reservoirs in the Kanpa and Hussar Formations, sealed by intraformational shales and trapped in a northwest-elongated, dip-closed anticline (Fig. 23b). The structure was well defined seismically with no evidence of crestal faults.

The stratigraphic section intersected by Lungkarta 1 was close to that predicted from the seismic data, with the exception of the Steptoe Formation, which was completely eroded. No faults or fractures were intersected at the crest of the structure, making the well a valid test. The presence of reservoir–seal couplets in the supra-salt section was confirmed. Sandstones of good reservoir quality were intersected in the Kanpa Formation (average porosity of 14%, with a maximum of 24%) and Hussar Formation (average porosity of 12.5%, with a maximum of 17.2 %). Thin carbonate beds in the Kanpa Formation with log porosities of up to 14.9% were also observed. No source rocks were detected from geochemical analyses carried out on samples from 1001.5 to 1720 m (Shell Company of Australia Ltd, 1985).

The operator attributed the absence of hydrocarbons to a lack of significant source rocks (Shell Company of Australia Ltd, 1985). This had been the highest pre-drill risk. Later maturity modelling (Ghori, 2000, 2002) indicated that there may be mature source rocks at the Browne Formation level in the Lungkarta area, but the presence of source rocks with good generative potential are yet to be confirmed. In addition, the complete absence of oil and gas may be a result of the lack of migration into the structure — the trap is located between two regional faults (Fig. 23a,b), which might have caused a migration shadow.

Hussar 1

Hussar 1 was drilled to a TD of 2040 m in 1982 by a consortium consisting of Eagle Corporation, News Corporation, and Swan Resources. It was drilled as stratigraphic test to obtain information on the stratigraphy and hydrocarbon potential of the Neoproterozoic rocks in the northwestern Officer Basin. The well was located about 800 m east of the only seismic line (81-002) in the area at that time. Seismic data from the later 1983–84 surveys confirm that Hussar 1 was not drilled on the crest of the anticlinal structure, but rather on its western flank (Fig. 24).

Hussar 1 intersected the top of Neoproterozoic succession, interpreted as Lungkarta Formation by Grey et al. (in prep.), at 101 m and drilled through the Wahlgu, Kanpa, and Hussar Formations before reaching TD in massive halite within the Browne Formation.

The well penetrated very good reservoir rocks in the Hussar Formation. The wireline log evaluation indicates that, within the interval 1294–1550 m, there are 100–130 m of sandstones with porosities ranging from 12% to 20.8%. The seal is provided by the claystone-dominated sequence at the base of the Kanpa Formation (1125–1294 m). No significant source rocks were encountered, but the depositional model implies that potential source rocks may have developed in an adjacent, deeper-water depositional environment (Karajas and Taylor, 1983a; Moors and Apak, 2002). The maturity measurements indicate that, at present, most of the Neoproterozoic

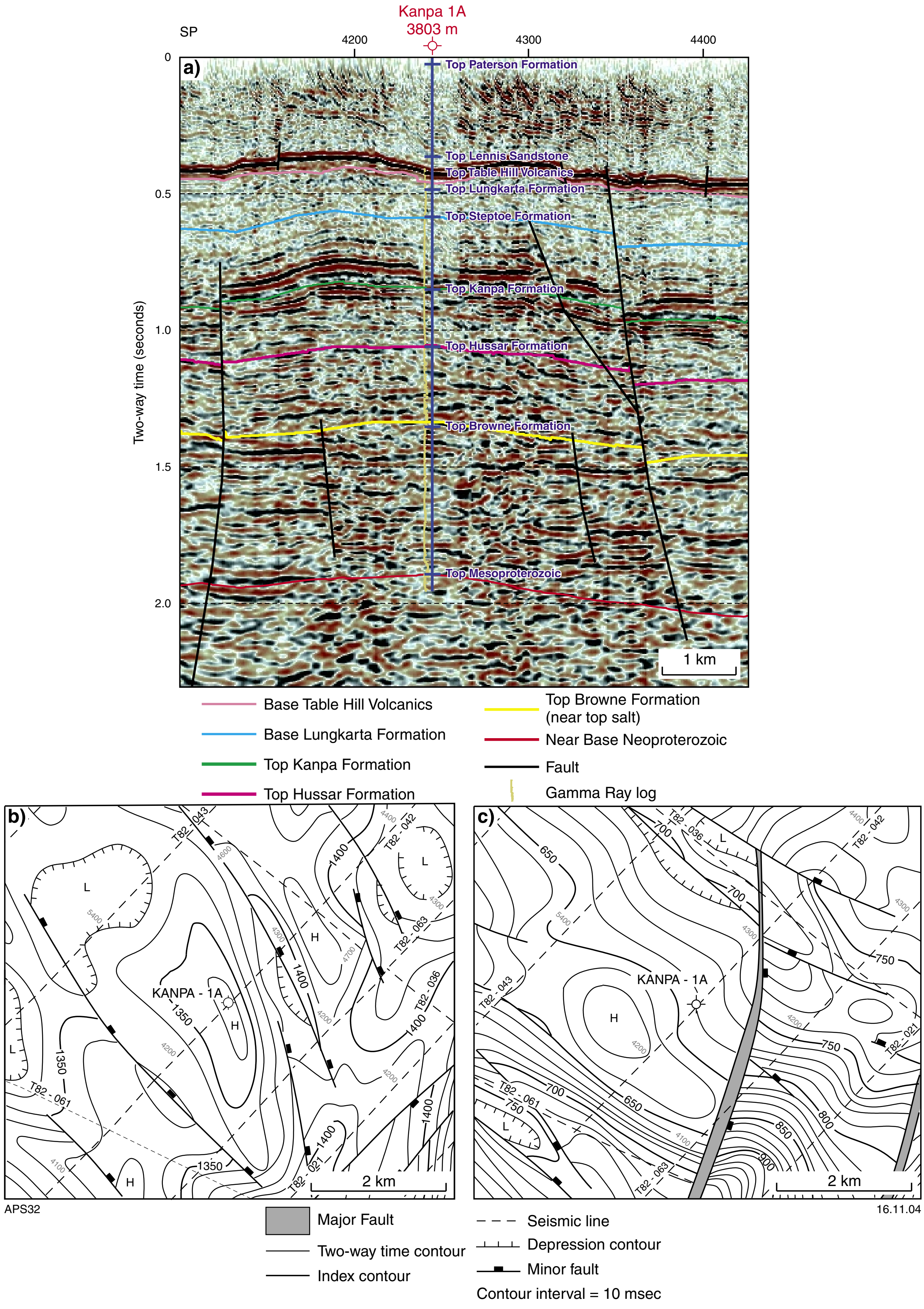


Figure 22. a) Seismic line T82-042, showing the location of Kanpa 1A on a TWT dip closure (see Figure 18 for location); b) TWT structure map of base upper mobile salt (intra-Browne reflector), after Shell Company of Australia (1983); c) TWT structure map of base Steptoe Formation, after Shell Company of Australia (1983)

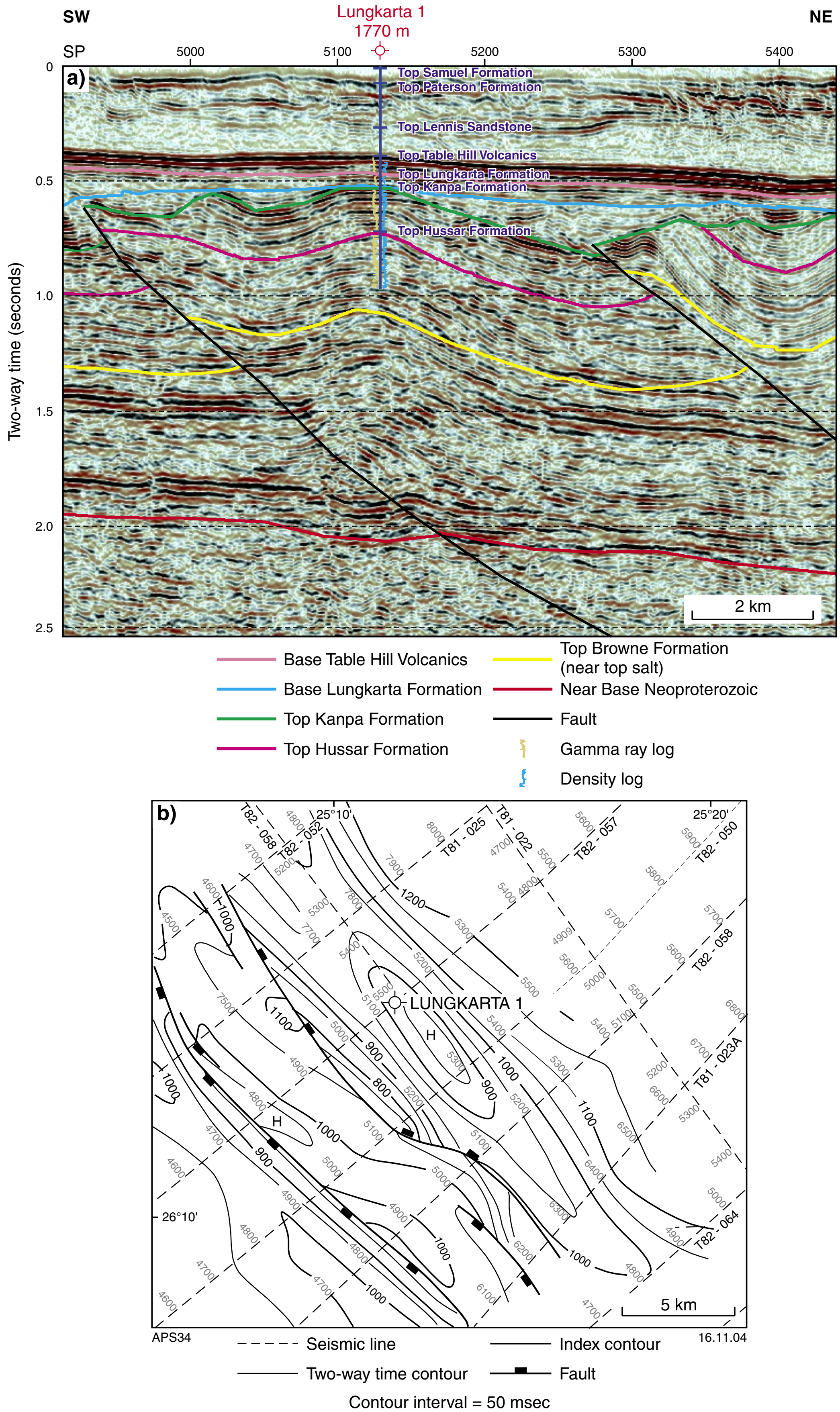


Figure 23. a) Seismic line T82-057, showing the location of Lungkarta 1 on a dip-closed anticline (see Figure 18 for location); b) TWT structure map of an intra-Hussar Formation reflector, after Shell Company of Australia (1985)

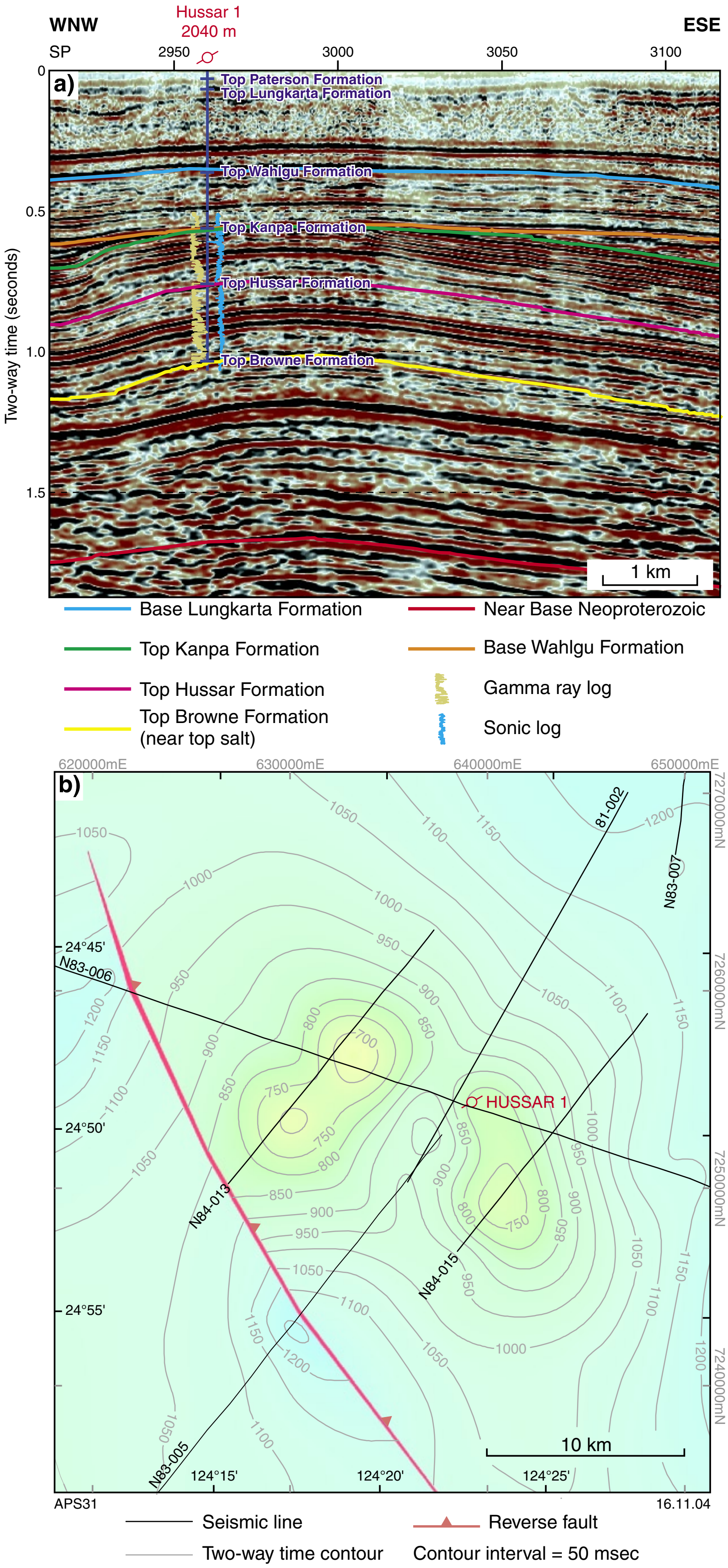


Figure 24. a) Seismic line N83-006, showing the location of Hussar 1 on the flank of a large anticlinal structrure (see Figure 18 for location); b) TWT structure map of top Hussar Formation reflector, showing that the well was drilled off-structure

section is within the oil window. Karajas and Taylor (1983a, appendix 14) suggested that maturity was probably reached during the Devonian–Carboniferous, which is favourable timing for charging already existing structural and stratigraphic traps.

Significant gas shows and bitumen were encountered in Hussar 1. Mud-gas chromatograph readings greater than 1000 ppm were recorded over the intervals 1140–1158 m and 1200–1222 m. After an airlift drilling attempt at 1908 m, gases from methane to butane were recorded as follows: 53 400 ppm methane, 2780 ppm ethane, 242 ppm propane, and 80 ppm butane (Karajas and Taylor, 1983a). Bitumens in shales were identified in the core sample from 1823.2 m and possibly in cuttings from the intervals 1410–1415 m, 1595–1600 m, and 1650–1655 m (Karajas and Taylor, 1983a, appendix 14). The recorded hydrocarbon shows are indicative of generation and possible migration pathways in the area. Log evaluation indicated that sandstones over the interval 1138–1195 m could possibly contain hydrocarbons (36–40% water saturation). Two drill-stem tests were performed at that depth, but both recovered only salt water.

Dipmeter measurements in Hussar 1 indicate that the crest of the anticlinal structure is southeast of the well location and that the well was drilled downdip on a structural closure. Although this makes it a possible valid test, the seismic data do not cover the southern end of the closure (Fig. 24b), and thus breaching can not be ruled out.

Dragoon 1

Dragoon 1 is a stratigraphic test drilled in 1982 by a consortium consisting of Eagle Corporation, News Corporation, and Swan Resources. The well reached TD at 2000 m, after drilling through about 1600 m of evaporites of the Browne Formation. The well was drilled on seismic line 81-004, close to Woolnough diapir (Fig. 25) in the northwestern Officer Basin. The objectives of the well

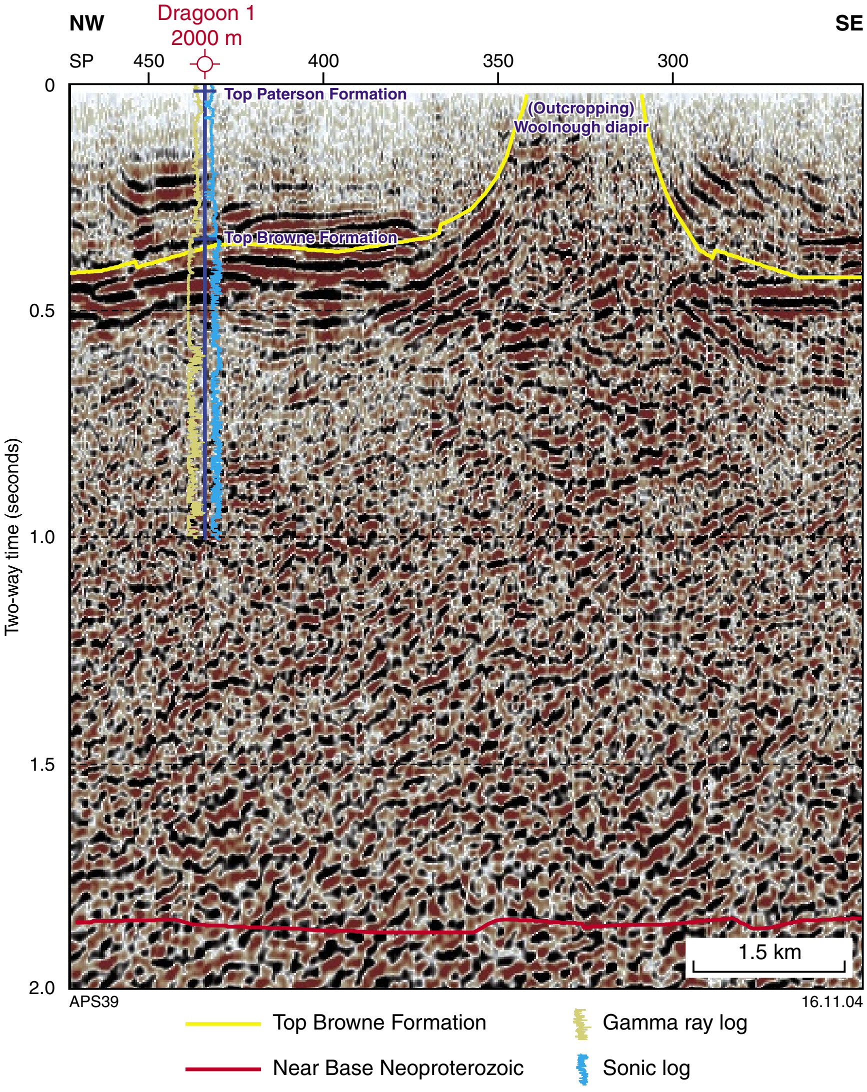


Figure 25. Seismic line 81-004, showing the location of Dragoon 1 and the Woolnough diapir. See Figure 18 for location

were to provide information on the Neoproterozoic and Phanerozoic successions, and to assess the potential for source, reservoir, and seal rocks.

Dragoon 1 penetrated siliciclastic rocks of Phanerozoic age before intersecting the top of the Browne Formation at 407 m, and then drilled through anhydrite, claystone, dolomite, and halite of this formation down to TD. The well intersected potential reservoir rocks with log-derived porosities of up to 27% at 330–339 m and 382–387 m within the lower Paterson Formation. Dolomites in the Browne Formation have low porosity due to infill of vugs and fractures by evaporite minerals, and only a single 10-m thick interval has some reservoir potential (log-derived porosity of about 10%; Karajas and Taylor, 1983b).

Geochemical analyses indicate poor source potential. Vitrinite reflectance equivalent indicates Neoproterozoic rocks are late mature to overmature for oil, and that the lower part of the Browne Formation is within the dry-gas generation zone (Karajas and Taylor, 1983b; Ghori, 1998b, 2002)

A mud-gas chromatograph gas show was encountered in the well with maximum methane values of 1%. Other hydrocarbon gases up to pentane were recorded over the interval 407–935 m in the Browne Formation.

Browne 1 and 2

Browne 1 and Browne 2 were stratigraphic tests drilled in 1965 by a joint venture between Hunt Oil Company and Placid Oil Company in the northeastern part of the western Officer Basin, which was regarded as a frontier basin. Browne 1 was located at SP 65 on seismic line 65-13C, and Browne 2 at SP 105 on seismic line 65-15G, both corresponding to gravity anomalies. Both wells drilled through a relatively thin Phanerozoic succession and intersected the top of the Browne Formation immediately below the Permian Paterson Formation — Browne 1 at 133 m (Fig. 26a), and Browne 2 at 262 m (Fig. 26b). Both wells were drilled on the Browne salt wall and did not intersect potential reservoir–seal couplets. However, both reported minor oil and gas shows in gas-cut mud and fluorescent cuts, which were confirmed by subsequent core analyses (Jackson, 1966). The shows were recorded from carbonate rocks with poor reservoir characteristics in the Browne Formation at 134–275 m in Browne 1, and 259–262 m in Browne 2 (Jackson, 1966). Browne 1 was resampled for potential source rocks, but no deposits with TOC greater than 1% were reported (Townson, 1985). There are no other data available for these two wells, but the hydrocarbon shows indicate potential generation and migration in the area.

Reservoirs

There are a number of potential reservoirs within the Neoproterozic succession in the western Officer Basin. These include intervals in the Browne, Hussar, Kanpa, Steptoe, and Wahlgu Formations. In the overlying Phanerozic sequences the Lennis Sandstone, Wanna Formation, and Paterson Formation have good reservoir characteristics (Fig. 3), but due to the lack of reliable seals, they are not considered potential targets. Only the reservoir characteristics of the Neoproterozoic formations are discussed here.

Browne Formation

Within the Browne Formation, reservoir quality is generally poor both in carbonate and siliciclastic rocks. Clastic rocks are very fine grained, and analyses of samples from GSWA Empress 1/1A and Yowalga 3 show that primary vugular and granular porosities within carbonate rocks are occluded by in-filling evaporite minerals. However, GSWA Lancer 1 intersected a 96-m thick sandstone unit at the top of the formation (Lancer Member) with core porosities greater than 20% (maximum 26%) and permeabilities over 1 Darcy, with a maximum of 9.980 Darcy (Haines et al., 2004). In GSWA Empress 1/1A, sandstones have permeabilities of up to 491 mD and 9.9% porosity. In contrast, dolomites show poor reservoir potential. A single measurement shows core porosities of up to 18% for dolomites at a depth of 1301 m (Stevens and Apak, 1999, appendix 10), but this was considered anomalous, and most likely a result of dissolution of halite while taking the plug (Apak and Moors, 2000a). In Yowalga 3, log porosities of 7–15% were calculated for oolitic, argillaceous dolomites (Shell Company of Australia Ltd, 1981).

Hussar Formation

Medium- to coarse-grained sandstones in the Hussar Formation show very good to excellent reservoir characteristics in most of the wells that intersected the formation.

In GSWA Empress 1/1A, core analyses indicated porosities greater than 15% and permeability greater than 100 mD, with a maximum of 2.69 Darcy (Stevens and Apak, 1999, appendix 10). Sandstones with excellent visual porosity (Fig. 27) were intersected in GSWA Lancer 1. Core measurements confirmed porosities greater than 20% and permeabilities of over 1 Darcy, with a maximum of 5.660 Darcy (Haines et al., 2004). Hussar 1 intersected about 100–130 m of reservoir rock with wireline-log-derived porosities of 12 – 20.8% over the interval 1294–1550 m.

The three wells drilled by Shell reported log-derived porosities as follows: up to 23% (average 15%) calculated for a 183-m thick, poorly cemented sandstone in Yowalga 3; up to 17.2% with an average of 12.5% for a 181-m thick sandstone unit in Lungkarta 1; and an average of 12.1% for a 151-m thick sandstone unit in Kanpa 1A, with a 34-m thick interval having porosities between 15% and 20%.

In all of these wells the best reservoir properties for the Hussar Formation are observed in the uppermost part of the unit, where the sandstone reservoir beds are sealed by the widespread, thick mudstone unit at the base of the Kanpa Formation.

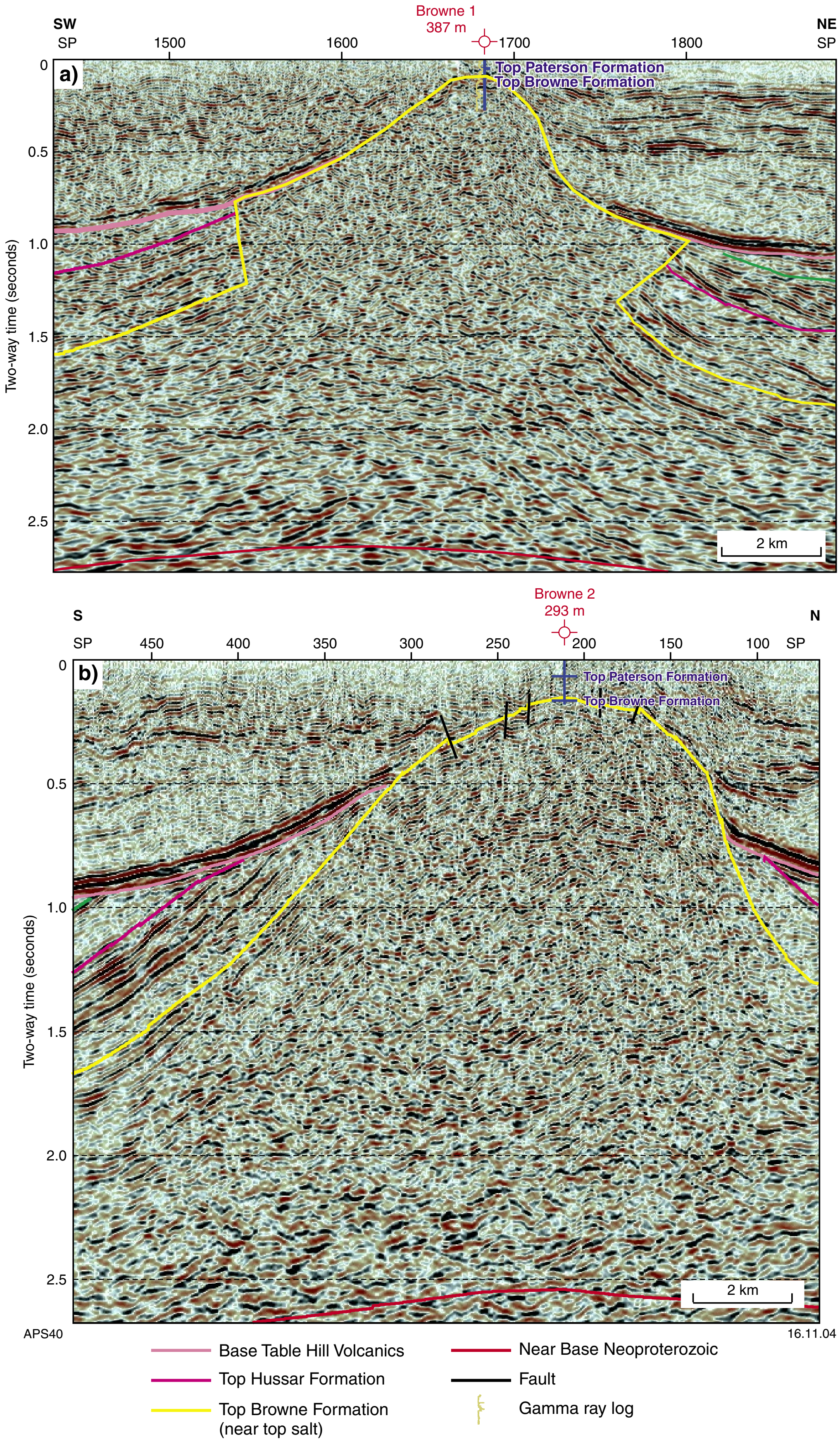


Figure 26. a) Seismic line 80-011C, showing the location of Browne 1; b) seismic line 80-009, showing the location of Browne 2. See Figure 18 for locations

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Figure 27. Photo of Hussar Formation sandstone with excellent visual porosity intersected in GSWA Lancer 1 (750 –765 m)

Kanpa Formation

The Kanpa Formation is characterized by a lower sand content compared to the underlying Hussar Formation, and sandstone beds typically do not exceed 30 m in thickness. However, Lungkarta 1 intersected 57 m of sandstone with an average log porosity of 14%, with a maximum of 23% (Shell Company of Australia Ltd, 1985). Although the sandstones in the Kanpa Formation are not regarded as a primary exploration target, together with the overlying Steptoe Formation reservoir lithologies and the underlying Hussar Formation sandstones, they can form a stacked reservoir.

Carbonate rocks are more widespread in the Kanpa Formation than in the overlying and underlying units, but dolomitization did not considerably improve porosity or permeability. In Lungkarta 1, a log porosity of 14.9% was calculated for a 6.5-m thick dolomite bed, but typically the values are less than 5% (Shell Company of Australia Ltd, 1985). However, GSWA Lancer 1 is interpreted to have intersected karstified carbonate rocks at the top of the formation (Haines et al., 2004), which indicate that where the formation has been partially eroded, karstification and enhanced porosity could develop.

Steptoe Formation

The Steptoe Formation contains siliciclastic and carbonate rocks with good to very good reservoir characteristics. The formation has been intersected and differentiated from the underlying Kanpa Formation only in Kanpa 1A, GSWA Empress 1/1A, and possibly WMC NJD 1. On seismic images, there is no prominent reflector associated with the boundary between these two lithostratigraphic units, and it is possible the interpreted Kanpa Formation includes parts of the Steptoe Formation.

Kanpa 1A intersected 128 m of sandstones of the Steptoe Formation with average log porosities in excess of 20%, (27.3% maximum). These were recorded at the uppermost levels of the formation, where there were also indications of oil throughout the interval 1139–1183 m (Shell Company of Australia Ltd, 1983). In GSWA Empress 1/1A, a single measured plug porosity of 23% and permeability of 30 mD was recorded for sandstone at a depth of 567 m, which was initially referred to as Kanpa Formation in the well completion report (Stevens and Apak, 1999; Apak and Moors, 2000a).

Log porosities in Kanpa 1A indicated that carbonate rocks of the Steptoe Formation have poor reservoir characteristics, with only a 1.1-m thick bed with average porosity of over 10%. However, GSWA Empress 1A intersected karstified carbonate rocks, about 21 m thick, below the unconformity between the Steptoe and Wahlgu Formations (Stevens and Apak, 1999; Apak and Moors, 2000a; Carlsen et al., 2003), representing a good example of a potential karstic reservoir.

Both sandstones and carbonate rocks in the Steptoe Formation are potential exploration targets, particularly in areas where they can be reached at shallow depths in the crests of drape anticlinal structures or in unconformity traps, but a reliable regional top seal may be a risk.

Wahlgu Formation

The siliciclastic, partially glacigene succession of the Wahlgu Formation is a potential reservoir. In GSWA Empress 1/1A, the formation (initially referred as Lupton Formation — Stevens and Apak, 1999) is about 200 m thick, and consists of mainly sandstone and diamictite with a number of mudstone beds about 5 m thick. Measured core-plug porosities range from 10.9 to 32%, with an average of 23.5%, and permeabilities range from 0.04 to 831 mD.

In GSWA Lancer 1, medium- to coarse-grained sandstones intersected within the upper Wahlgu Formation have porosities of 22–24% and permeabilities reaching 10 Darcy. A porous coarse-grained to pebbly sandstone from the interval 391–397 m in GSWA Lancer 1 is an artesian aquifer (Haines et al., 2004), suggesting that a reservoir–seal couplet at this level exists in this region.

Seals

The Officer Basin succession contains halite, fine-grained siliciclastic rocks, and tight carbonate rocks that are effective regional and local seals for both oil and gas. The widespread salt in the Browne Formation is an excellent top seal for possible subsalt plays. Various-scale halokinetic structures should form a reliable lateral seal for structural and combined salt-related traps.

Shale units deposited on flooding surfaces provide reliable intraformational seals for reservoirs in the Hussar, Kanpa, and Steptoe Formations. The thick mudstone and shale beds at the base of the Kanpa Formation reach a thickness greater than 100 m and form a reliable top seal for the major sandstone reservoir in the upper part of the Hussar Formation. This reservoir–seal couple is regionally developed, can be easily correlated between wells, and can be recognized on seismic images for over hundreds of kilometres across the basin.

Diamictites and mudstones of the Wahlgu Formation form intraformational seals for sandstone reservoirs within the formation. They could also seal potential accumulations within the Steptoe Formation or older units. A leak-off test carried out on the Wahlgu Formation in GSWA Lancer 1 indicated that diamictite is able to take 2.67 SG mud weight (Haines et al., 2004). However, diamictites are typically characterized by frequent facies changes and would only act as a local seal.

Source rocks, maturation, and petroleum generation

Most of the wells drilled in the western Officer Basin encountered thin Neoproterozoic source rocks with fair to good hydrocarbon-generating potential. With the exception of the lowermost sections in Yowalga 3, GSWA Empress 1A, and Dragoon 1, these rocks are not overmature. Lean but organically rich beds are developed in the Browne, Hussar, Kanpa, and Steptoe Formations (Ghori, 2000, 2002). Pyrolysis-gas chromatography and extract analysis show that the organic matter is mostly oil- and gas-generating type-II kerogen. The maximum TOC values of 6.64% were recorded in shales from mineral drillhole NJD 1 (Ghori, 1998b, 2002) belonging to either the Kanpa or Lefroy Formation (Hocking, 2003). Potential source rocks with good organic richness and hydrocarbon-generating potential were also intersected in GSWA Empress 1A, Kanpa 1A, Yowalga 3, Throssel 1, Browne 1 and 2, Hussar 1, and the mineral drillhole LDDH 1. Figure 28 summarizes the source-rock characteristics from nine wells in the basin. In the north-northeastern

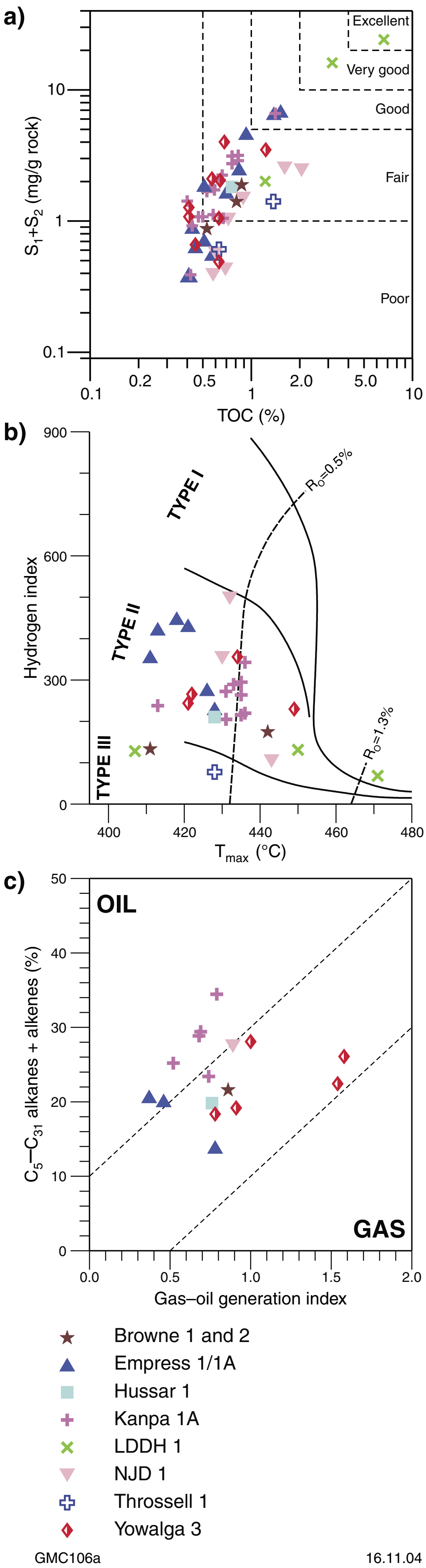


Figure 28. Source-rock characterization: a) petroleum-generating potential, as a function of organic richness versus potential yield, for samples interpreted as reliable; b) type of kerogen as a function of T_{max} versus hydrogen index, from Rock-Eval pyrolysis; c) type of kerogen as a function of oil proneness (C_5–C_{31} alkanes + alkenes) versus gas–oil generation index ((C_1–C_5)/C_{6+}) from pyrolysis-gas chromatography (after Ghori, 2002)

parts of the basin, where the seismic data indicate the Neoproterozoic section to be at its thickest, it is likely that the source intervals are also thicker, but as yet there are no wells deep enough to confirm this.

The maturation level of the Neoproterozoic source rocks in the central western Officer Basin ranges from immature to overmature (Fig. 29). Equivalent vitrinite reflectance and Rock-Eval pyrolysis suggest that a significant section is presently within the oil window (Ghori, 1998b, 2000, 2002). The analyses indicate that the most-mature Neoproterozoic rocks are in the Salt-ruptured Zone. This was the most subsided area during deposition, and contained the thickest primary sedimentary section. In the Thrusted Zone, the maturation levels vary from mature (Browne, Hussar, and lower Kanpa Formations) to immature (upper Kanpa and Steptoe Formations). Analyses from GSWA Lancer 1 and GSWA Empress 1A indicate that, along the Western Platform Zone, the Neoproterozoic source rocks are immature to mature. In this area, there is evidence of higher maturity levels in the underlying Mesoproterozoic section based on analyses from GSWA Trainor 1, GSWA Empress 1A, and drillhole WMC NJD 1 (Ghori, 1998b, 2002).

Fine-grained clastic rocks of Mesoproterozoic age are also potential source rocks. The seismic interpretation indicates that, in the Western Platform Zone, a thick sedimentary section of probable Mesoproterozoic age underlies the Neoproterozoic strata. Results obtained from GSWA Trainor 1 suggest that this section contains thicker and organically richer source beds than the Neoproterozoic strata (Ghori, 1998a). Initially, the 225-m thick, organically rich (TOC up to 3.65%) section intersected in this well was attributed to the Neoproterozoic (Stevens and Adamides, 1998), but was later reinterpreted as the Mesoproterozoic Quadrio Formation (Hocking et al., 2000). The section in GSWA Trainor 1 is presently overmature for hydrocarbon generation, but may have generated significant volumes in the past. Mineral drillhole OD23, located to the southwest of GSWA Trainor 1, encountered bitumen and live oil in dolomites of Mesoproterozoic age (Cooke, 1997; Stevens and Carlsen, 1998), suggesting a Mesoproterozoic or older source.

Basin modelling is poorly constrained due to the limited data and insufficiently detailed dating of the major tectonic and erosional events in the Neoproterozoic. However, the modelling does indicate that the major phases of oil generation in the Neoproterozoic succession occurred during the latest Neoproterozoic, Cambrian, and Permian–Triassic (Ghori, 1998b, 2000, 2002). These models demonstrate significant variations in timing and levels of maturation for the Browne, Hussar, Kanpa, and Steptoe Formations. These variations depend on the intensity of several tectonic events, of which the Areyonga Movement and the Petermann Orogeny had the greatest effect.

During the Neoproterozoic, parts of the Browne Formation were deeply buried, particularly in the Salt-ruptured Zone and northeastern Thrusted Zone, and thus reached optimum maturation levels in which most of its hydrocarbon-generative potential was exhausted. During the same period the Hussar, Kanpa, and Steptoe

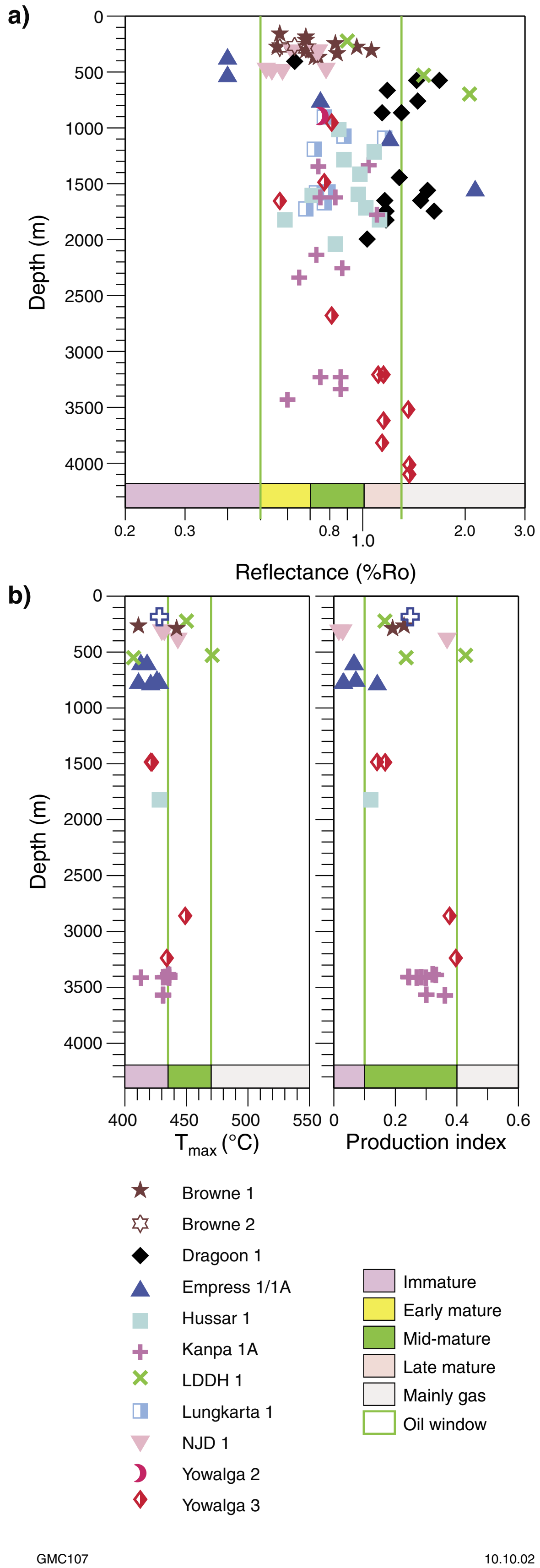


Figure 29. Measured maturity: a) as a function of equivalent vitrinite reflectance versus depth; b) as a function of the Rock-Eval parameters T_{max} and production index versus depth (from Ghori, 2002)

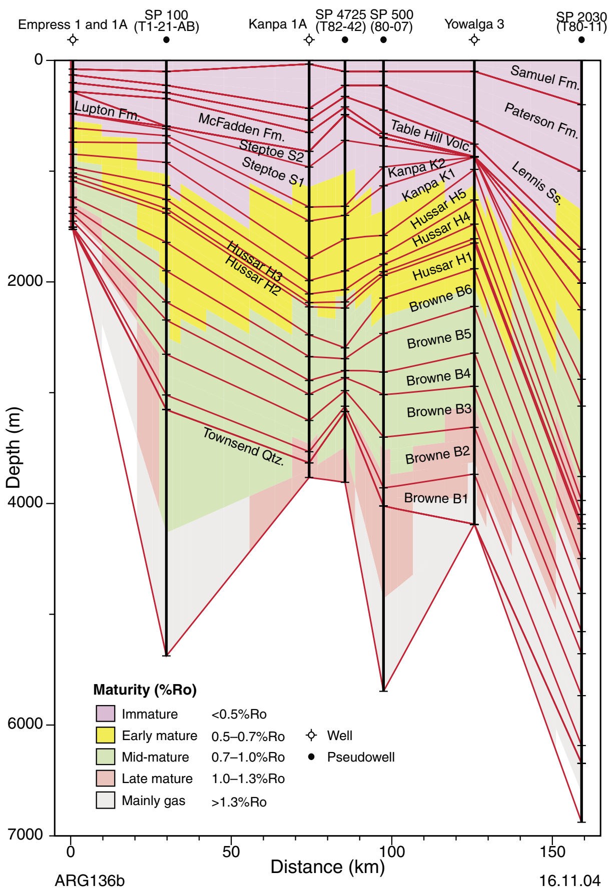


Figure 30. Present-day maturity cross section based on 2D basin modelling (from Ghori, 2002)

Formations were not deeply buried, and retained generative potential during later stages of subsidence. The maturation of these formations increased in the Cambrian and Permian–Triassic. A significantly thick (up to 2000 m in Yowalga 3) Neoproterozoic section is presently within the oil window (Fig. 30), although a major peak in the rate of oil generation occurred during the latest Neoproterozoic, and minor peaks occurred during the Cambrian and Permian–Triassic (Ghori, 2002; Carlsen et al., 2003).

Play types

In the western Officer Basin, structural, stratigraphic, and combined traps have been identified in the Neoproterozoic succession (Fig. 31). These are largely salt-related as a result of widespread halokinetic deformation. Most of the traps remain poorly tested or untested.

Structural plays

Drape folding in the supra-salt section is common in the Salt-ruptured Zone, and creates four-way dip closures above the salt diapirs and turtle structures. Such traps are most prospective where both the Hussar and Kanpa Formations are preserved at the crest of the structures, providing a reliable reservoir–seal couplet (Fig. 32a). The possibility of multiple pay exists in areas where reservoirs of the upper Kanpa Formation and Steptoe Formation are present and dip-closed in the structures. These are more likely to be developed in the Thrusted Zone and the southwestern portion of the Salt-ruptured Zone. Drape folding can provide four-way dip closures of significant size, but trap integrity may be breached by crestal faults.

Accentuated rollovers and drape closures over salt-core structures (Fig. 32b) are the major trapping mechanisms in the Thrusted Zone. Such traps are prospective particularly where reservoir facies, such as those in the Hussar and Steptoe Formations and possibly upper Kanpa Formation, are present, forming stacked reservoirs that may significantly improve the trap volume. The major risks associated with such traps include crestal tensional faults and leaking cross-fault seals, particularly for thrust faults with significant throw.

Overhangs and the upturn of sediments on flanks of diapirs and salt walls form prospective salt-abutment traps (Fig. 32c). Traps beneath overhangs are particularly prospective in the Salt-ruptured Zone, where Hussar Formation sandstone beds are sealed laterally by the salt wall, and the overhang provides the top seal (Fig. 32d). The limited seismic data do not allow detailed mapping of such traps, but they may be of considerable size, as salt walls (e.g. the Browne salt wall) extend laterally over tens of kilometres. These traps are typically observed in the Salt-ruptured Zone, and the timing of their formation is favourable with regard to hydrocarbon accumulations, as their final shape was possibly formed at a late stage of basin evolution (assuming multiple salt movements). Furthermore, these traps could be charged from hydrocarbons generated after the end-Neoproterozoic, or from secondary migration of breached pools.

Combined structural–stratigraphic plays

Traps related to enhanced porosity are possible above both diapirs and salt-nucleated rollovers, where leaching of soluble components such as halite and anhydrite in sandstone and carbonate rocks results in extensive secondary porosity, particularly at unconformity surfaces. As indicated in GSWA Empress 1A and GSWA Lancer 1, karst development in carbonate rocks within the Steptoe and Kanpa Formations is also possible. These reservoirs could be sealed by tight diamictite and mudstone of the unconformably overlying Wahlgu Formation, although there is the risk that this formation only acts as a seal locally. Enhanced porosity traps are also possible at the distal limb of rim synclines due to updip truncations away from the diapir (Fig. 33).

Updip pinch-out traps are expected to be present in the Western Platform Zone. Although the limited seismic coverage in the area is inadequate to map these features, they cannot be ruled out. It is possible that reservoir horizons of the Buldya Group pinch out against the western and southwestern flanks of the basin and are sealed above an unconformity by diamictite and mudstone within the Wahlgu Formation. There is a high risk for

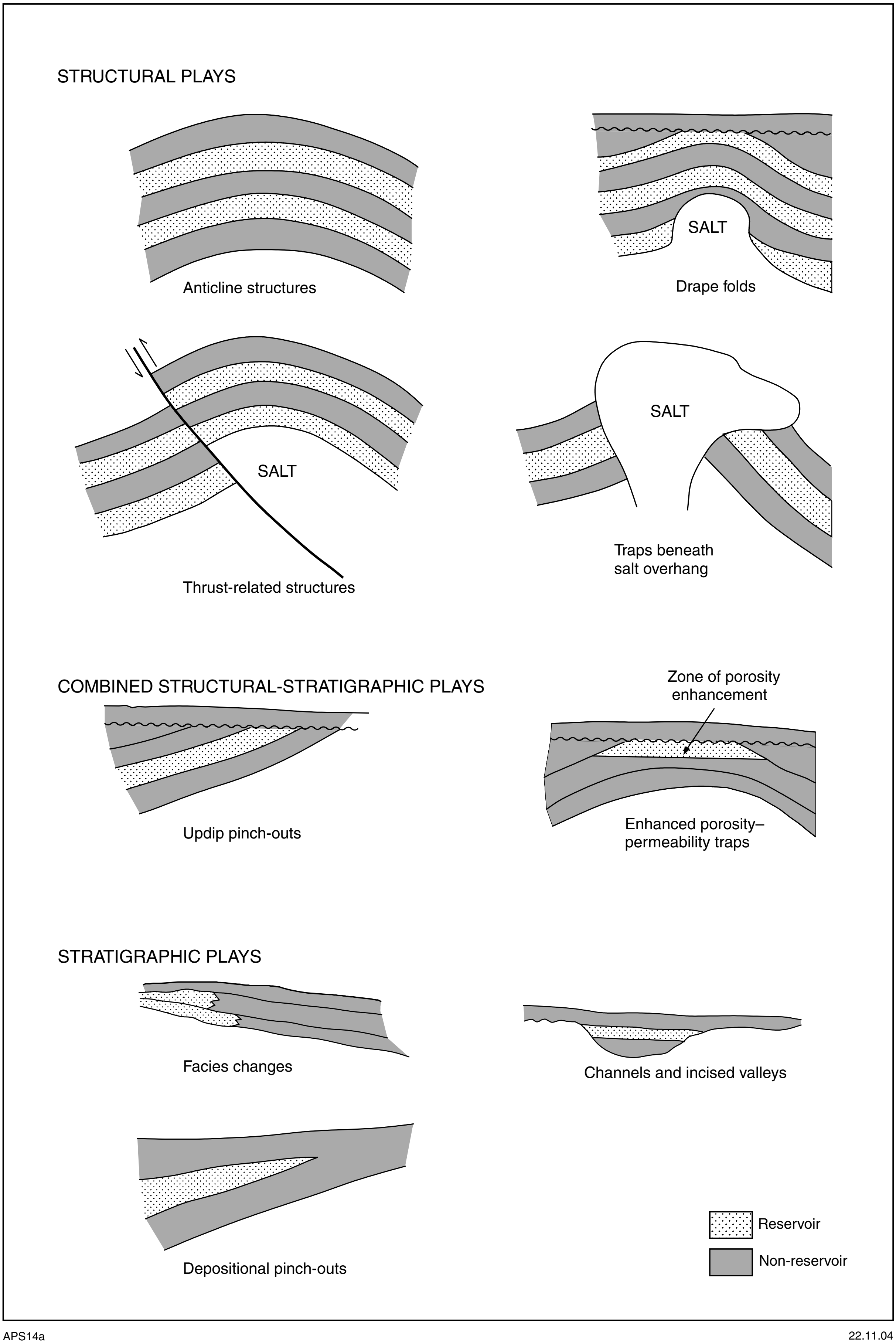


Figure 31. Play types in the central western Officer Basin

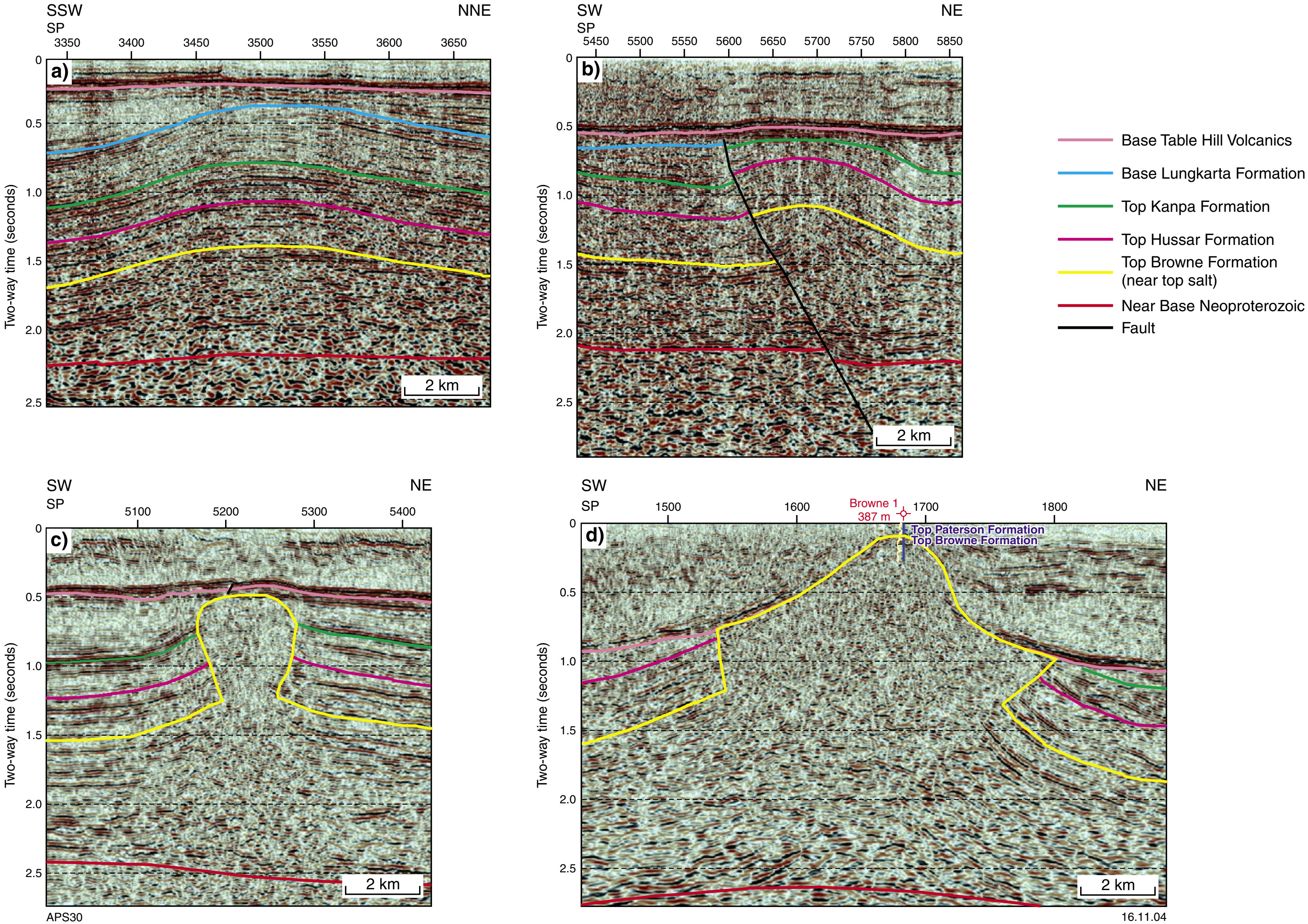


Figure 32. Structural traps in the central western Officer Basin: a) Seismic line N83-011, showing a drape anticlinal trap; b) seismic line T82-065, illustrating a salt-lubricated thrust and associated roll-over trap; c) seismic line T82-055, illustrating salt-abutment traps on the flanks of a diapir; d) seismic line 80-011C, illustrating a hydrocarbon trap beneath salt overhang. See Figure 18 for locations

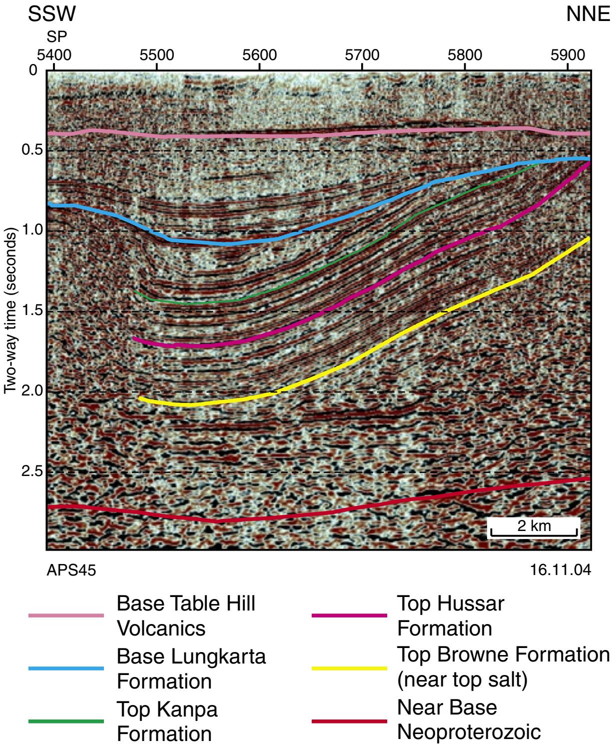


Figure 33. Seismic line T82-139, showing updip pinch-out at the distal flank of a rim syncline. See Figure 18 for location

trap integrity associated with this top seal due to common facies changes and the likelihood that it only forms seals locally.

Stratigraphic plays

Facies mapping is limited by insufficient seismic resolution and well control. Nevertheless, intraformational facies changes and associated plays are expected, particularly in the Western Platform Zone, close to the basin margin, where juxtaposition of reservoir and impermeable seal rocks over relatively short lateral distances is possible both in clastic and carbonate rocks. The early formation of such traps is favourable with respect to hydrocarbon charge, and the stable, almost structureless low-angled ramp geometry of the area facilitates the maintenance of trap integrity over extended periods.

Unconformities create the possibility for development of erosive channels, which are most prominent at the base of the Wahlgu Formation (Fig. 34). Some of the channels may be of considerable size, but there is a high risk associated with a reliable top seal. Lateral leaking and thief-bed development is also possible due to the frequent facies changes in the Wahlgu Formation.

Prospectivity

In the western Officer Basin only 13 wells have been drilled by petroleum exploration companies, most of which were programmed as stratigraphic wells and cannot be considered as valid exploration tests. The four deep stratigraphic tests drilled during the last decade by GSWA were drilled along the margins of the basin, and of these, only GSWA Lancer 1 is located on a seismic line. However, these stratigraphic wells were fully cored, and therefore significantly improved the geological knowledge of the basin and its petroleum potential. The reported hydrocarbon shows from nine wells and three mineral drillholes (Table 2) indicate generation and migration of oil and gas through the system.

Lack of source rocks was considered the greatest risk during earlier stages of petroleum exploration. Recent geochemical analyses (Ghori, 1998b, 2000, 2002) confirmed the existence of lean source intervals in the western Officer Basin, even though identification of thick, good-quality source rocks remains a major problem in the region. Thin, but organic-rich source beds have been found in the Browne, Hussar, Kanpa, and Steptoe Formations, suggesting that favourable conditions for accumulation of generative rocks existed during the basin's evolution. Thicker source intervals are possible in the thickest Neoproterozoic section in the north-northeastern areas, which have not yet been drilled. Maturity measurements indicate that most of the Neoproterozoic source rocks have not progressed far into the oil-generation phase, except for the lowermost succession in the Salt-ruptured Zone. Thus, mature source rocks are likely to be present in a large area of the basin, with a considerable part of the succession presently in the oil window. Maturity modelling (Ghori, 2000, 2002) suggests that there were major oil-generation phases during the latest Neoproterozoic, Cambrian, and Permian–Triassic. This timing is considered favourable with regard to trap formation, although the multiple salt-

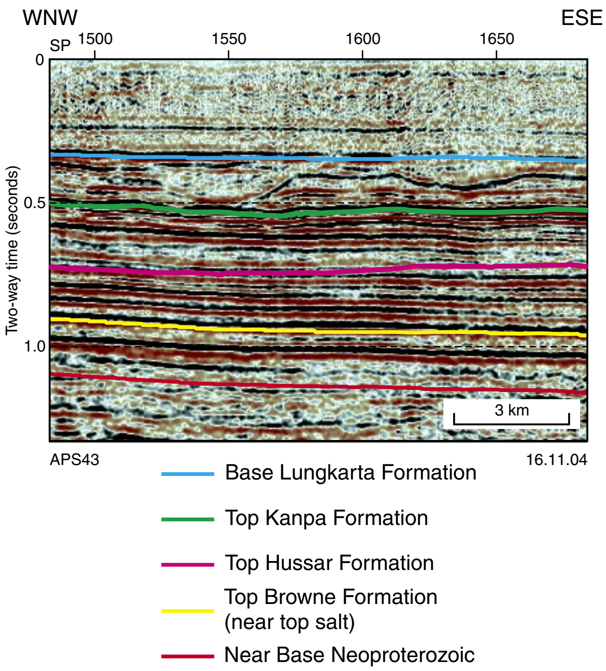


Figure 34. Seismic line N83-008, showing erosive channels in the Wahlgu Formation. See Figure 18 for location

mobilization events might have affected trap integrity, as in some instances salt continued to move after the extrusion of the Table Hill Volcanics. However, traps formed after the deposition of the Table Hill Volcanics may retain hydrocarbons generated during the Permian–Triassic, or oil and gas that remigrated from breached older pools. There is also the possibility that Mesoproterozoic fine-grained clastic rocks could be potential source rocks. The seismic interpretation indicates that there is a thick sedimentary succession of probable Mesoproterozoic age underlying the Neoproterozoic strata. GSWA Trainor 1 intersected organically rich (TOC up to 3.65%) source beds belonging to this succession (Ghori, 1998a).

Sandstones in the supra-salt sequences have very good to excellent reservoir characteristics, but carbonate rocks are mostly dolomitized without development of significant porosity and permeability. The sandstones in the Hussar Formation have the best reservoir parameters and are the lowest-risk exploration objective, as the formation is sealed over wide areas by the thick mudstone unit of the lower Kanpa Formation. Carbonate rocks may be a very high risk secondary target in areas of possible karstification, where the Kanpa or Steptoe Formations have been eroded and sealed above the unconformity by the Wahlgu Formation.

Structural, stratigraphic, and combined plays have been identified in the western Officer Basin, largely forming as a result of the intense salt tectonics. In the Salt-ruptured and Thrusted Zones, drape folds, turtle structures, and thrust-related rollovers could form interesting petroleum targets, with the possibility of multiple pay. However, these structures may be associated with the development of crestal faults, which could breach trap integrity.

In the Salt-ruptured Zone, structural traps beneath salt overhangs may have significant potential, as they could be of considerable size. The final architecture of these traps was probably created at the latest stage of the basin's evolution and may be charged with oil and gas generated after the Cambrian, or with remigrated hydrocarbons from older breached pools.

Traps related to enhanced porosity are possible above diapirs and in salt-nucleated drag rollovers, where leaching of soluble components and karstification can result in extensive secondary porosity, particularly at unconformity surfaces. Tight diamictite and mudstone in the Wahlgu Formation provide the top seal, but could be a risk due to frequent intraformational facies changes.

Stratigraphic plays have never been tested in the western Officer Basin. Although these plays are best considered as secondary exploration targets, they may be particularly prevalent in the Western Platform Zone. Within this zone, they could be reached at relatively shallow depths, and trap integrity is more likely to be preserved because the zone is not affected by halotectonics or significant structuring.

Neoproterozoic rocks are immature, or at best early mature, for hydrocarbon generation in the Western Platform Zone. However, as indicated by the results from GSWA Trainor 1, potential stratigraphic plays in the area could be sourced by the thick and organically rich Mesoproterozoic succession underlying the Neoproterozoic strata.

Conclusions

Seismic interpretation and mapping integrated with the available well data show that halotectonics was the major deformation mechanism in the central western Officer Basin, and produced both regional and local structures. The salt mobilization was greatest in the northern and northeastern portion of the study area, resulting in considerable thickness variations of the Browne Formation, piercement through and erosion of the younger section, and a variety of salt-related features. Most of the salt walls and salt-associated thrusts exhibit compressional features and are north-northwesterly trending, parallel to the structural trends observed in the Paterson Orogen. Compressional processes, associated with deformation in the adjacent orogen, are probably the key mechanisms initiating the salt mobilization. However, in the northeastern areas, with a primary thicker sedimentary succession, the overburden might have triggered the salt movement, which was further enhanced by tectonism in the adjacent orogen. Each of the post-Mesoproterozoic deformation events recorded in the basin and Paterson Orogen probably contributed to multiple salt movements, with peaks during the Areyonga Movement and Petermann Orogeny.

The structural subdivision of the central western Officer Basin has been refined into four zones, which have been mapped throughout the entire area: Marginal Overthrusted, Salt-ruptured, Thrusted, and Western Platform Zones. Analyses of the structures within each zone indicate that salt movement was greatest in the northern areas, where the Woolnough and Madley diapirs outcrop, and in the northeast, where the Browne salt wall pierced through the entire Neoproterozoic succession. To the south-southwest, salt structures are less prominent, salt-related thrusts have smaller throws, and in the Western Platform Zone, which is the farthest from the Paterson Orogen, only minor local faults are observed with no evidence of salt tectonics.

No hydrocarbon fields or significant accumulations have been discovered to date in the Western Australian part of the Officer Basin. However, hydrocarbon shows have been recorded in 12 wells and mineral drillholes, indicating generation and migration of oil and gas in the area. In the central western Officer Basin only 13 wells have been drilled by petroleum exploration companies, most of which were spudded as stratigraphic wells and cannot be considered as exploration tests. To date, Lungkarta 1 is the only well drilled that validly tested a structure (at the Hussar Formation level), but the well did not encounter any hydrocarbons. Hussar 1, although programmed as a stratigraphic well, could also possibly be considered a valid test at the Hussar Formation level — seismic mapping indicates the well was drilled downdip on a TWT closure, and encountered a significant gas show and bitumen, but the seismic coverage is insufficient to confidently map the southern extension of the closure.

Thin, but organic-rich source intervals are present in the Browne, Hussar, Kanpa, and Steptoe Formations, indicating that favourable conditions for the accumulation of generative rocks existed during the basin's evolution. Thicker source intervals may be present in the northeastern region, where the thickest Neoproterozoic section is expected, although the area has not yet been drilled. However, source rocks of significant thickness and good generative potential remain the highest risk for petroleum exploration and are yet to be identified in the western Officer Basin.

Maturity measurements indicate that most of the Neoproterozoic source rocks have not progressed far into the oil-generation phase, except for the lowermost succession in the Salt-ruptured Zone. Thus mature source rocks are likely to be present in a large area of the basin, and a considerable part of the succession is expected to be in the oil window. Maturity modelling suggests that there was a major oil-generation phase during the latest Neoproterozoic, and minor phases occurred during the Cambrian and Permian–Triassic, which is considered favourable with regard to trap formation. However, the preservation of potential pools charged at earlier stages is significantly risky because of multiple episodes of salt mobilization. Seismic data indicate that salt continued to move after the extrusion of the Table Hill Volcanics, particularly in the northern and northeastern areas. Traps formed at later stages of the basin's evolution may retain hydrocarbons generated during the Permian–Triassic, or oil and gas that remigrated from breached older pools.

The seismic interpretation revealed a thick sedimentary succession, of probable Mesoproterozoic age, underlying the Neoproterozoic strata. This succession contains organic-rich, fine-grained clastic rocks of significant thickness, which may have charged potential subsalt plays at the earliest stages of the basin's evolution. At later stages such source rocks may have charged stratigraphic and combined traps, particularly in the Western Platform Zone, where the area was not significantly affected by halotectonics or structuring, and preservation conditions are good.

A variety of structural, stratigraphic, and combined traps, largely associated with the salt deformation, have been identified in the western Officer Basin. Structural closures above salt diapirs, turtle structures, and rollovers are most prospective in the southwestern parts of the Salt-ruptured and Thrusted Zones. These are of particular interest in the areas where the permeable lithologies in the Hussar, Kanpa, and Steptoe Formations form stacked reservoirs. Although stratigraphic plays have never been tested in the western Officer Basin, their potential could be significant in the Western Platform Zone, where they are interpreted to be present at relatively shallow depths.

References

AMDEL LTD, 1999, Appendix 2: K–Ar dating of two basalts, *in* Empress 1 and 1A well completion report, Yowalga Sub-basin, Officer Basin, Western Australia *compiled by* M. K. STEVENS and S. N. APAK: Western Australia Geological Survey, Record 1999/4, p. 45.

APAK, S. N., GHORI, K. A. R., CARLSEN, G. M., and STEVENS, M. K., 2002a, Basin development with implications for petroleum styles of the Neoproterozoic Officer Basin, Western Australia, *in* The sedimentary basins of Western Australia 3 *edited by* M. KEEP and S. J. MOSS : Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth, WA, 2002, p. 913–927.

APAK, S. N., and MOORS, H. T., 2000a, Basin development and petroleum exploration potential of the Yowalga area, Officer Basin, Western Australia: Western Australia Geological Survey, Report 76, 61p.

APAK, S. N., and MOORS, H. T., 2000b, A sequence stratigraphic depositional model of Neoproterozoic strata, Yowalga area, Officer Basin, Western Australia: APPEA Journal, v. 40, p. 15–25.

APAK, S. N., and MOORS, H. T., 2001, Basin development and petroleum exploration potential of the Lennis area, Officer Basin, Western Australia: Western Australia Geological Survey, Report 77, 42p.

APAK, S. N., MOORS, H. T., and STEVENS, M. K., 2002b, GSWA Vines 1 well completion report, Waigen Area, Officer Basin, Western Australia: Western Australia Geological Survey, Record 2001/18, 32p.

BAGAS, L., GREY, K., HOCKING, R. M., and WILLIAMS, I. R., 1999, Neoproterozoic successions of the northwestern Officer Basin — a reappraisal: Western Australia Geological Survey, Annual Review 1998–99, p. 39–44.

BUSBRIDGE, M., 1993, Lake Disappointment, summary of lithological and analytical data for diamond drillhole (LDDH 1) (license 45/1064): Western Australia Geological Survey, Statutory mineral exploration report, Item M7567 (unpublished).

CARLSEN, G. M., SIMEONOVA, A. P., and APAK, S. N., 2003, Petroleum systems and exploration potential in the Officer Basin, Western Australia: APPEA Journal, v. 43 (1), p. 473–494.

COMPSTON, W., 1974, The Table Hill Volcanics of the Officer Basin — Precambrian or Paleozoic?: Geological Society of Australia, Journal, v. 21, p. 403–412.

COOKE, J., 1997, Naberru Project Annual Report 1996, E69/652–655, 1082, 1142, 1145–1147, 1161; 9 February 1996 – 8 February 1997, Combined Reporting Number: C320/1996. Technical Report No. 160: Western Australia Geological Survey, Statutory mineral exploration report, Item M 11469 A51195 (unpublished).

DURRANT AND ASSOCIATES, 1998, Officer Basin regional interpretation project, Lennis and Gibson Sub-Basins: Western Australia Geological Survey, Statutory petroleum exploration report, S31319 A4 (unpublished).

EYLES, N., and EYLES, C. H., 1998, Summary of late Proterozoic glaciogenic succession in Empress 1, Officer Basin: Western Australia Geological Survey, Statutory petroleum exploration report, S20424 A6 (unpublished).

FITZPATRICK, B., 1966, Officer Basin summary for Exoil Pty Ltd: Western Australia Geological Survey, Statutory petroleum exploration report, S24 A1 (unpublished).

FORMAN, F. G., 1933, Conclusions on a report on a reconnaissance survey of the country lying between Laverton and the Warburton Ranges: Western Australia Geological Survey, Annual Report 1932, p. 6–8.

GHORI, K.A. R., 1998a, Appendix 5 — Geochemistry, *in* GSWA Trainor 1 well completion report, Savory Sub-basin, Officer Basin, Western Australia, with notes on petroleum and mineral potential *by* M. K. STEVENS and S. N. ADAMIDES: Western Australia Geological Survey, Record 1996/12, 69p.

GHORI, K. A. R., 1998b, Petroleum source-rock potential and thermal history of the Officer Basin, Western Australia: Western Australia Geological Survey, Record 1998/3, 52p.

GHORI, K. A. R., 2000, Appendix 1 — Petroleum source-rock potential and maturation history of the Yowalga area, *in* Basin development and petroleum exploration potential of the Yowalga area, Officer Basin, Western Australia *by* S. N. APAK and H. T. MOORS: Western Australia Geological Survey, Report 76, 61p.

GHORI, K. A. R., 2002, Modelling the hydrocarbon generative history of the Officer Basin, Western Australia: PESA Journal, v. 29, p. 44–57.

GREY, K., HOCKING, R. M., STEVENS, M. K., BAGAS, L., CARLSEN, G. M., IRIMIES, F., PIRAJNO, F., HAINES, P. W., and APAK, S. N., in prep., Lithostratigraphic nomenclature of the Officer Basin and correlative parts of the Paterson Orogen, Western Australia: Western Australia Geological Survey, Report 93.

HAINES, P. W., MORY, A. J., STEVENS, M. K., and GHORI, K. A. R., 2004, GSWA Lancer 1 well completion report (basic data), Officer and Gunbarrel Basins, Western Australia: Western Australia Geological Survey, Record 2004/10, 39p.

HARRISON, P. L., and ZADORONYJ, I., 1978, Officer Basin, seismic, gravity, magnetic and radiometric survey, Western Australia 1972: Australia BMR, Report 191, BMR Microform MF69.

HOCKING, R. M., 1994, Subdivisions of Western Australian Neoproterozoic and Phanerozoic sedimentary basins: Western Australia Geological Survey, Record 1994/4, 83p.

HOCKING, R. M. (compiler), 2003, Drillhole WMC NJD 1, western Officer Basin, Western Australia: stratigraphy and petroleum geology: Western Australia Geological Survey, Record 2002/18, 26p.

HOCKING, R. M, GREY, K., BAGAS, L., and STEVENS, M. K., 2000, Mesoproterozoic stratigraphy in the Oldham Inlier, Little Sandy Desert, central Western Australia: Western Australia Geological Survey, Annual Review 1999–2000, p. 49–56.

IASKY, R. P., 1990, Officer Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 362–380.

JACKSON, M. J., van de GRAAFF, W. J. E., and BOEGLI, J. C., 1975, Shallow stratigraphic drilling in the Officer Basin, Western Australia, 1972: Australia BMR, Record 1975/49 (unpublished).

JACKSON, M. J., and van de GRAAFF, W. J. E., 1981, Geology of the Officer Basin, Western Australia: Australia BMR, Bulletin 206, 102p.

JACKSON, P. R., 1966, Geology and review of exploration, Officer Basin: Western Australia Geological Survey, Statutory petroleum exploration report, S26 A1 (unpublished).

JAPAN NATIONAL OIL CORPORATION, 1997, Geological and geophysical survey in the western Officer Basin, Western Australia — Integrated geological interpretation study: Western Australia Geological Survey, Statutory petroleum exploration report, S10276 (unpublished).

KARAJAS, J., and TAYLOR, D., 1983a, Hussar 1 well completion report: Western Australia Geological Survey, Statutory petroleum exploration report, S2242 A4 (unpublished).

KARAJAS, J., and TAYLOR, D., 1983b, Dragoon No. 1 well completion report: Western Australia Geological Survey, Statutory petroleum exploration report, S2185 A8 (unpublished).

MOORS, H. T., and APAK, S. N., 2002, Basin development and petroleum exploration potential of the Gibson area, Officer Basin, Western Australia: Western Australia Geological Survey, Report 80, 42p.

NELSON, D. R., 1999, Compilation of geochronology data, 1998: Western Australia Geological Survey, Record 1999/2, 222p.

PERINCEK, D., 1996, The age of Neoproterozoic–Palaeozoic sediments within the Officer Basin of the Centralian Super-Basin can be constrained by major sequence-bounding unconformities: APPEA Journal, v. 36 (1), p. 61–79.

PERINCEK, D., 1998, A compilation and review of data pertaining to the hydrocarbon prospectivity of the Officer Basin: Western Australia Geological Survey, Record 1997/6, 209p.

PHILLIPS, B. J., JAMES, A. W., and PHILIP, G. M., 1985, The geology and hydrocarbon potential of the northwestern Officer Basin: APEA Journal, v. 25 (1), p. 52–61.

SHELL COMPANY OF AUSTRALIA LTD, 1981, Yowalga 3 well completion report: Western Australia Geological Survey, Statutory petroleum exploration report, W1709 A5/V1,V2 (unpublished).

SHELL COMPANY OF AUSTRALIA LTD, 1983, Kanpa 1/1A well completion report: Western Australia Geological Survey, Statutory petroleum exploration report, S2281 V1/A2/V1,V2,V3 (unpublished).

SHELL COMPANY OF AUSTRALIA LTD, 1985, Lungkarta 1 and Lungkarta 1 Sidetrack 1 well completion report. Western Australia Geological Survey, Statutory petroleum exploration report, S2667 A4/V1,V2 (unpublished).

SIMEONOVA, A. P., 2003, Seismic data reprocessing, Officer Basin, Western Australia: Western Australia Geological Survey, Record 2003/13, 21p.

SIMEONOVA, A. P., and APAK, S. N., 2003, Salt deformation and associated traps, Officer Basin, Western Australia: AAPG International Conference and Exhibition, Barcelona, Spain, September 2003, Extended Abstracts Volume.

SOFOULIS, J., 1961, Geological reconnaissance of the Warburton Range area: Geological Survey Branch, W.A. Department of Mines, Report 1961, p. 16–20.

STEVENS, M. K., and ADAMIDES, S. N., 1998, GSWA Trainor 1 well completion report, Savory Sub-basin, Officer Basin, Western Australia, with notes on petroleum and mineral potential: Western Australia Geological Survey, Record 1996/12, 69p.

STEVENS, M. K., and APAK, S. N., 1999, GSWA Empress 1 and 1A well completion report, Yowalga Sub-basin, Officer Basin, Western Australia: Western Australia Geological Survey, Record 1999/4, 110p.

STEVENS, M. K., and CARLSEN, G. M., 1998, A review of data pertaining to the hydrocarbon prospectivity of the Savory Sub-basin, Officer Basin, Western Australia: Western Australia Geological Survey, Record 1998/5, 65p.

STEVENS, M. K., APAK, S. N., GREY, K., GHORI, K.A.R., and BLUNDELL, K., 2002, The Vines 1 stratigraphic drillhole, central Officer Basin, Western Australia, *in* The sedimentary basins of Western Australia 3 *edited by* M. KEEP and S. J. MOSS: Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth, W.A., 2002, p. 929–942.

TALBOT, H. W. B., and CLARKE, E. de C., 1917, A geological reconnaissance of the country between Laverton and the South Australian border (near south latitude 26°) including part of the Mount Margaret Goldfield: Western Australia Geological Survey, Bulletin 75.

TALBOT, H. W. B., and CLARKE, E. de C., 1918, The geological results of an expedition to the South Australian border and some comparisons between Central and Western Australian geology suggested thereby: Journal and Proceedings of the Royal Society of Western Australia, v. 3, p. 70–98.

TOWNSON, W. G., 1985, The subsurface geology of the western Officer Basin — results of Shell's 1980–1984 petroleum exploration campaign: APEA Journal, v. 25 (1), p. 34–51.

WALTER, M. R., VEEVERS, J. J., CALVER, C. R., and GREY, K., 1995, Neoproterozoic stratigraphy of the Centralian Superbasin, Australia: Precambrian Research, v. 73, p. 173–195.

WARRIS, B., 1998a, Mundadjini No 1 well completion report: Western Australia Geological Survey, Statutory petroleum exploration report, S20441 A1 (unpublished).

WARRIS, B., 1998b, Boondawari No 1 well completion report: Western Australia Geological Survey, Statutory petroleum exploration report, S20442 A1 (unpublished).

WESTERN MINING CORPORATION LTD, 1981, Terminal report on the Neale temporary reserves 8165H, 8166H, 8167H, 8168H, and 8169H for the period 27 February 1981 to 9 November 1981: Western Australia Geological Survey, Statutory mineral exploration report, Item M2752 (unpublished).

Appendix 1

Geophysical surveys acquired in the western Officer Basin

Survey name	*Type*	*Line prefix*	*Km*	*Date*	*Operator*	*Contractor*	*Reference*
Seismic							
Babbagoola S.S.	2DRefl	B63	55	Nov–Dec 1963	Hunt Oil	Seismograph Serv.	S120
Gibson S.S.	2DRefl	N83	544	Sep–Nov 1983	News	Petty-Ray	S2449
Gibson North S.S.	2DRefl	GN81	84	Jan–Feb 1981	Swan	Horizon	S1769
Gibson South S.S.	2DRefl	GS81	22	Jan 1981	Swan	Horizon	S1770
Giles–Carnegie S.S.	2DRefl	GC61	19	Sep–Oct 1961	BMR	BMR	S3018
Hancock S.S.	2DRefl	N84	144	Feb 1984	News	Petty-Ray Geophys.	S2527
Lennis North S.S.	2DRefl	LN66	270	Oct 1965 – Jan 1966	Hunt Oil	Ray Geophysics	S235
Mable Creek S.S.	2DRefl /Refr	MC62	224	May–Aug 1962	Exoil Oil	Namco	S24
Officer 1980 S.S.	2DRefl	O80	1 250	Oct–Dec 1980	Shell	Horizon	S1714
Officer 1981 S.S.	2DRefr	O81	1 636	Feb–Oct 1981	Shell	Horizon & Petty Ray	S1856
Officer 1982 (Phases 1 and 2) S.S.	2DRefl	T82	1 029	Jan–Dec 1982	Shell	Petty-Ray	S2148
Officer 1982 (Phases 3 and 4) S.S.	2DRefl	T82	526	Jan–Dec 1982	Shell	Petty-Ray	S2225
Officer 1982 (Phases 5 and 6) S.S.	2DRefl	T82	272	Jan–Dec 1982	Shell	Geosource	S2264
Officer 1983 Vibroseis Experimental S.S.	2DRefl	OV83	14	July 1983	Shell	GSI	S2390
Salt Pan S.S.	2DRefl	N84	125	Feb–Mar 1984	News	Petty-Ray	S2526
Traeger S.S.	2DRefl	N83	519	Sep–Nov 1983	News	Petty-Ray	S2448
Warburton S.S.	2DRefl/Refr	W64	273	Apr–Jul 1964	Hunt Oil	Geophysical	S161
Yowalga S.S.	2DRefl	Y66	495	Mar 1965 – Jan 1966	Hunt Oil	Ray Geophysics	S187
Gravity							
Breaden Gravity Survey	Gravity		14 964	Apr 1963 – Mar 1964	Hunt Oil	Bell Bros/Hel. Util.	S29
Cobb Gravity Survey	Gravity		na	May–Jun 1981	Balmoral	–	S1811
GSWA Savory Basin Gravity Survey	Gravity		13 600	Jun–Aug 1995	GSWA	Daishsat	S10312
GSWA Waigen Sub-Basin Gravity Survey	Gravity		2 730	Jun 1998	GSWA	Geoterrex	S10401
Lennis Gravity Survey	Gravity		na	Apr 1963 – Mar 1965	Hunt Oil	–	S160
Wanna Mason Gravity Survey	Gravity		na	May 1982	CRAE	Geoterrex	S2173
Magnetic							
Aeromagnetic Interpretation Officer Basin	Aeromag		10 585	May–Sep 1961	Hunt Oil	Adastra Hunting	S28
Gibson Desert Aeromagnetic Survey	Aeromag		32 421	May–Jul 1965	Union Oil	Aero Service	S260
Neale Junction Ground Magnetic Survey	Magnetic		565	Aug 1965	Hunt Oil	Hunt Oil	S233
Rawlinson Younge Ranges Aeromagnetic Survey	Aeromag		na	Oct 1960	BMR	–	S3017
SPA 1/1995-96	Aeromag		86 854	Dec 1995 – Jan 1996	JNOC	World Geoscience	S10276
Westwood Aeromagnetic Survey	Aeromag		15 000	Dec 1987	Lapp Res	Aerodata	S3236
Electron Spin Resonance							
EP 380 KDLS Mk21 Airborne Survey	ESR		33	Sep 1995	Amadeus	WA & NT Oil Search	S10371

NOTES:
Reference: GSWA statutory petroleum exploration report reference number
2DRefl: Two-dimensional seismic reflection survey
2DRefr: Two-dimensional seismic refraction survey
Amadeus: Amadeus Petroleum NL
Balmoral: Balmoral Resources Pty Ltd
JNOC: Japan National Oil Company
Lapp Res: Lapp Resources
News: News Corporation Pty Ltd
Shell: Shell Company of Australia
Swan: Swan Resources Pty Ltd
na: not available

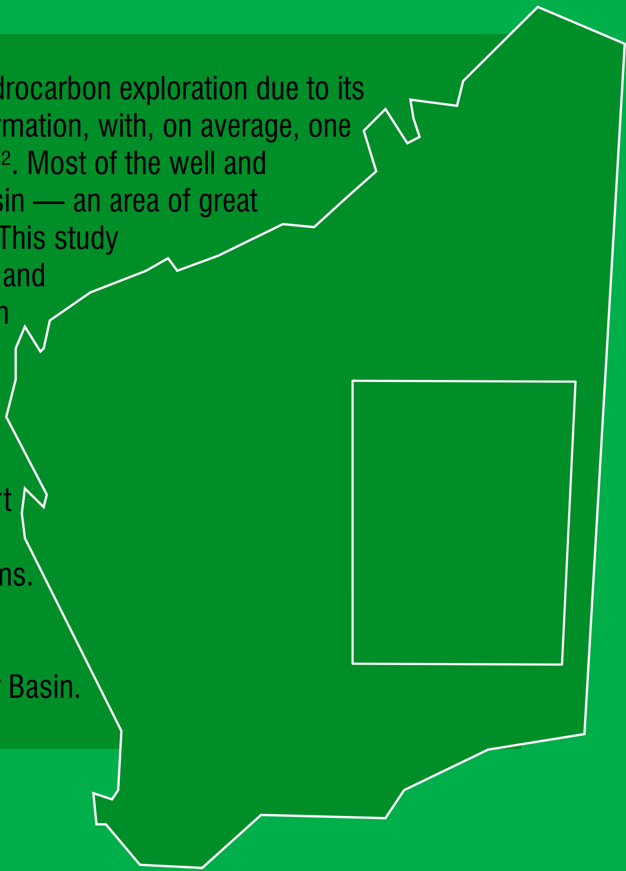
Appendix 2

Petroleum exploration and stratigraphic wells drilled in the western Officer Basin

Name	*Operator*	*Class*	*GDA94*		*Date*	*GL (m)*	*Rig Elev (m)*	*TD (m)*	*TD Formation*	*Well Status*	*Reference*
			Latitude	*Longitude*							
Akubra 1	Amadeus	NFW	23°29'20.39"S	121°22'41.58"E	Nov 1997	530	530	181	Dolorite	P&A no show	S 20444
BMR Browne 1	BMR	STR	25°31'59.04"S	125°16'34.89"E	Jan 1972	540	540	121.92	Paterson Fm	P&A no show	BMR Record 1975/49
BMR Madley 1	BMR	STR	24°13'35.05"S	124°20'54.84"E	Jan 1972	470	471.20	207.60	Browne Fm	P&A no show	BMR Record 1974/194
BMR Neale 1A–1B	BMR	STR	28°18'13.08"S	125°56'40.99"E	Jan 1972	328	328	205.75	Lennis Ss	P&A no show	BMR Record 1975/49
BMR Neale 2	BMR	STR	28°47'48.00"S	125°49'12.00"E	Jan 1972	270	270	74.80	Paterson Fm	P&A no show	BMR Record 1975/49
BMR Neale 3	BMR	STR	28°09'55.08"S	125°49'16.99"E	Jan 1972	335	335	38.10	Paterson Fm	P&A no show	BMR Record 1975/49
BMR Rason 1	BMR	STR	28°33'18.00"S	123°47'36.00"E	Jan 1972	475	475	68.50	Yilgarn Granite	P&A no show	BMR Record 1975/49
BMR Rason 2	BMR	STR	28°33'13.16"S	124°02'47.06"E	Jan 1972	465	465	146.59	Yilgarn Migmatite	P&A no show	BMR Record 1975/49
BMR Rason 3	BMR	STR	28°33'13.16"S	124°02'47.06"E	Jan 1972	485	485	74.70	Yilgarn Granite	P&A no show	BMR Record 1975/49
BMR Talbot 1	BMR	STR	26°09'06.89"S	126°32'35.01"E	Jan 1972	445	445	33.10	Townsend Qz	P&A no show	BMR Record 1975/49
BMR Talbot 2	BMR	STR	26°09'19.12"S	126°32'24.93"E	Jan 1972	445	445	13.70	Cainozoic	P&A no show	BMR Record 1975/49
BMR Talbot 3	BMR	STR	26°09'33.16"S	126°32'13.05"E	Jan 1972	445	445	77.40	Lefroy Fm	P&A no show	BMR Record 1975/49
BMR Talbot 4	BMR	STR	26°09'45.05"S	126°31'59.01"E	Jan 1972	445	445	69.60	Lefroy Fm	P&A no show	BMR Record 1975/49
BMR Talbot 5	BMR	STR	26°09'55.01"S	126°31'04.90"E	Jan 1972	445	445	95.10	Wahlgu Fm	P&A no show	BMR Record 1975/49
BMR Throssell 1	BMR	STR	27°16'19.11"S	124°24'34.99"E	Jan 1972	385	385	198.12	Lungkarta Fm	P&A no show	BMR Record 1975/49
BMR Wanna 1	BMR	STR	28°21'59.02"S	127°37'48.94"E	Jan 1972	400	400	154.53	Paterson Fm	P&A no show	BMR Record 1975/49
BMR Warri 20	BMR	STR	24°04'55.04"S	124°33'04.83"E	Sep–Oct 1972	520	521.20	265.48	Browne Fm	P&A no show	BMR Record 1974/194
BMR Westwood 1	BMR	STR	27°02'37.09"S	124°49'10.97"E	Jan 1972	450	450	85.34	Lungkarta Fm	P&A no show	BMR Record 1975/49
BMR Westwood 2	BMR	STR	27°07'15.09"S	124°42'40.97"E	Jan 1972	450	450	101.50	Lungkarta Fm	P&A no show	BMR Record 1975/49
BMR Yowalga 1,2,3	BMR	STR	26°50'04.00"S	125°37'33.00"E	Jan 1972	460	460	100	Paterson Fm	P&A no show	BMR Record 1975/49
BMR Yowalga 4	BMR	STR	26°49'58.89"S	125°37'37.82"E	Jan 1972	460	460	43	Paterson Fm	P&A no show	BMR Record 1975/49
Boondawari 1	Amadeus	NFW	23°31'05.57"S	121°31'18.84"E	Oct–Nov 1997	490	490	1 367	Neoproterozoic	P&A poor O show	S 20442
Browne 1	Hunt Oil	STR	25°51'10.03"S	125°49'02.89"E	Sep 1965	453	455.40	387	Browne Fm	P&A poor O&G show	S 234
Browne 2	Hunt Oil	STR	25°55'55.03"S	125°57'49.90"E	Oct 1965	484	485.60	292.60	Browne Fm	P&A poor O&G show	S 234
Dragoon 1	Eagle et al.	STR	24°04'44.48"S	124°33'02.91"E	Jul–Sep 1982	434	438	2 000	Browne Fm	P&A poor G show	S2185
GSWA Empress 1/1A	GSWA	STR	27°03'08.37"S	125°09'29.27"E	Jun–Aug 1997	461	461.40	1 624.60	Mesoproterozoic	P&A no show	GSWA Record 1999/4
GSWA Lancer 1	GSWA	STR	25°02'44.50"S	123°45'20.70"E	Oct–Nov 2003	450	450	1 501.30	?Mesoproterozoic	P&A poor O show	GSWA Record 2004/10
GSWA Trainor 1	GSWA	STR	24°31'36.80"S	122°44'23.20"E	Nov 1995	455	–	709	Mesoproterozoic	P&A	GSWA Record 1996/12
GSWA Vines 1	GSWA	STR	26°42'04.87"S	128°15'07.72"E	Jul–Sep 1999	472	452	2 017.50	Vines Fm	P&A fair G show	GSWA Record 2001/18
Hussar 1	Eagle	STR	24°49'09.41"S	124°22'38.77"E	Sep–Dec 1982	430	434	2 040	Browne Fm	P&A fair G show	S 2242
Kanpa 1A	Shell	NFW	26°31'36.72"S	125°36'56.58"E	Dec 1982 – Jun 1983	480	486.86	3 803	?Mesoproterozoic	P&A poor O show	S 2281
Lennis 1	Hunt Oil	STR	27°17'00.12"S	126°21'00.00"E	Sep–Oct 1965	415	417	615	Table Hill Volcanics	P&A no show	S 234
Lungkarta 1	Shell	NFW	26°04'38.38"S	125°11'50.86"E	Sep–Nov 1984	404	411	1 770	Hussar Fm	P&A no show	S 2667
Mundadjini 1	Amadeus	NFW	23°27'13.52"S	121°13'52.09"E	Oct 1997	500	500	599	Neoproterozoic	P&A poor O show	S 20441
Yowalga 1	Hunt Oil	STR	26°10'12.00"S	125°58'00.12"E	Sep 1965	474	475	613	Lennis Ss	P&A no show	S 234
Yowalga 2	Hunt Oil	STR	26°10'12.00"S	125°58'00.00"E	Mar 1966	472.49	476.55	989	Kanpa Fm	P&A no show	S 281
Yowalga 3	Shell	NFW	26°08'58.16"S	125°55'00.99"E	Aug 1980 – Jan 1981	475.55	482.65	4 196.50	Browne Fm	P&A no show	S 1709

NOTES:
NFW: new field wildcat or exploration well
STR: stratigraphic test
GL: ground level
Rig Elev: rig elevation
TD: total depth
TD Formation: formation reached at total depth
P&A: plugged and abandoned
O: Oil
G: Gas
Reference: GSWA statutory petroleum exploration report reference and published BMR and GSWA Records

The western Officer Basin is a frontier area for hydrocarbon exploration due to its vast size, remoteness, and limited geological information, with, on average, one petroleum exploration well drilled every 27000 km^2. Most of the well and seismic data are in the central western Officer Basin — an area of great sedimentary thickness and structural complexity. This study integrates, for the first time, all of the geophysical and geological data in the central western Officer Basin to produce subsurface structural and thickness maps of the most prospective horizons. The seismic interpretation indicates that halotectonics was the major deformation mechanism and formed a variety of hydrocarbon traps. This Report provides post-mortems of petroleum exploration wells and a thorough analysis of petroleum systems. These are coupled with the seismic interpretation results to identify prospective trends for potential hydrocarbon accumulations in the western Officer Basin.



SIMEONOVA, IASKY

Seismic mapping, salt deformation, and hydrocarbon potential of the central western Officer Basin, Western Australia

REPORT 98

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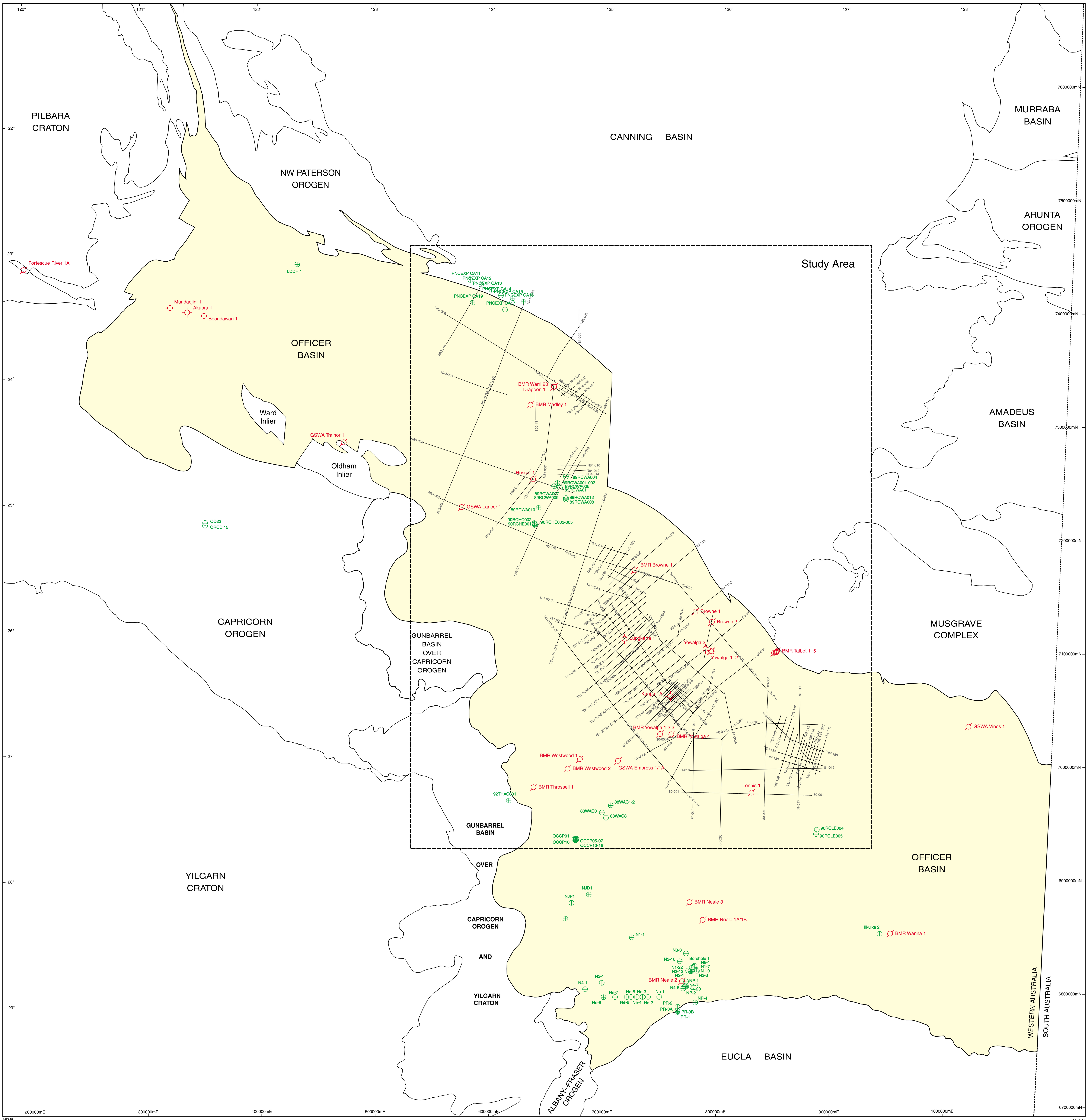

Stratigraphic well

Petroleum exploration well

Mineral Drillhole

Officer Basin boundary

T81-025 Seismic line

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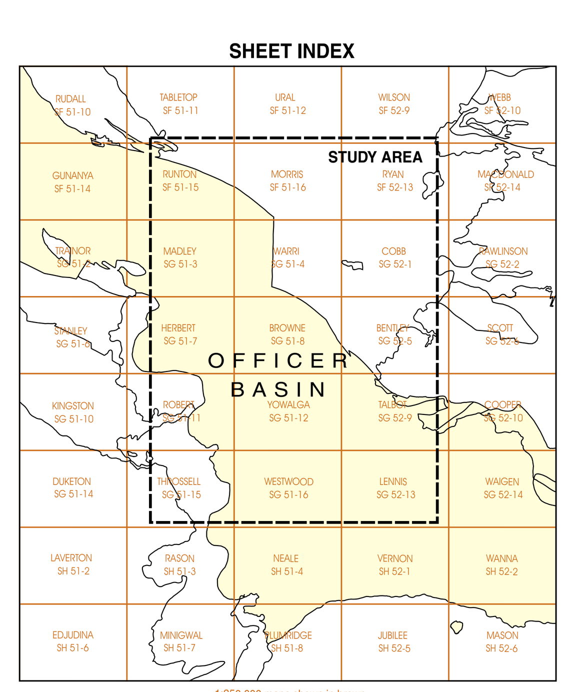

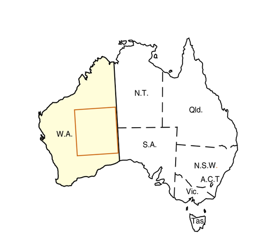

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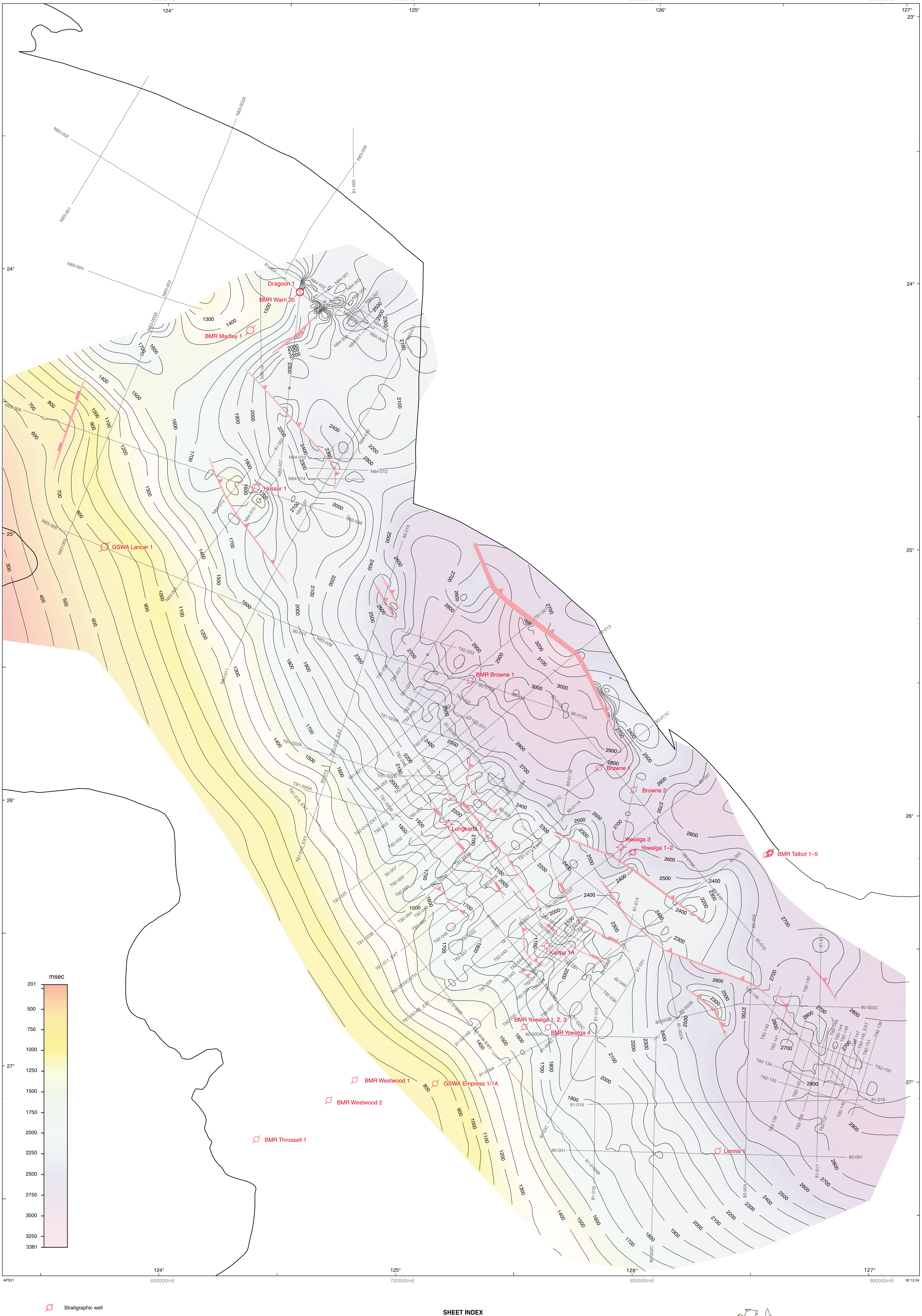
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
REPORT 98 PLATE 1

LOCATION MAP OF SEISMIC LINES, PETROLEUM EXPLORATION AND STRATIGRAPHIC WELLS, AND SELECTED MINERAL EXPLORATION DRILLHOLES, WESTERN OFFICER BASIN, WESTERN AUSTRALIA



Stratigraphic well

Petroleum exploration well

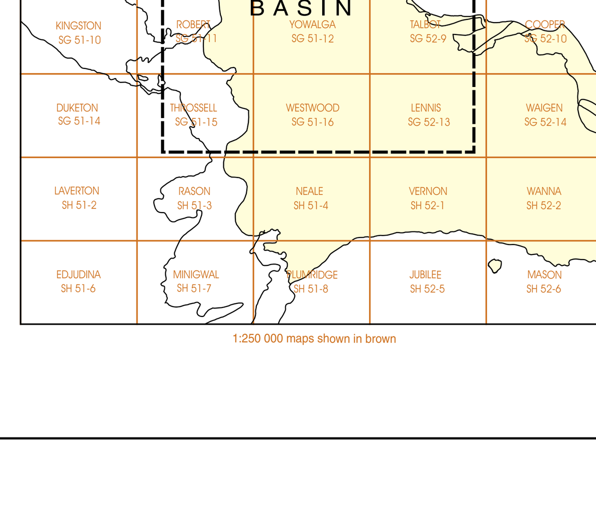
Officer Basin boundary

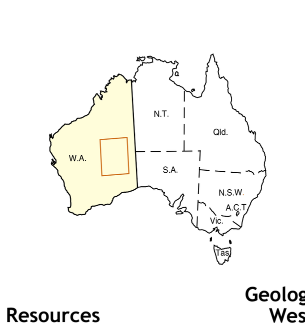
Two-way-time contour;
Contour interval = 50 msec

Normal fault

Reverse or thrust fault

T82-052 Seismic line





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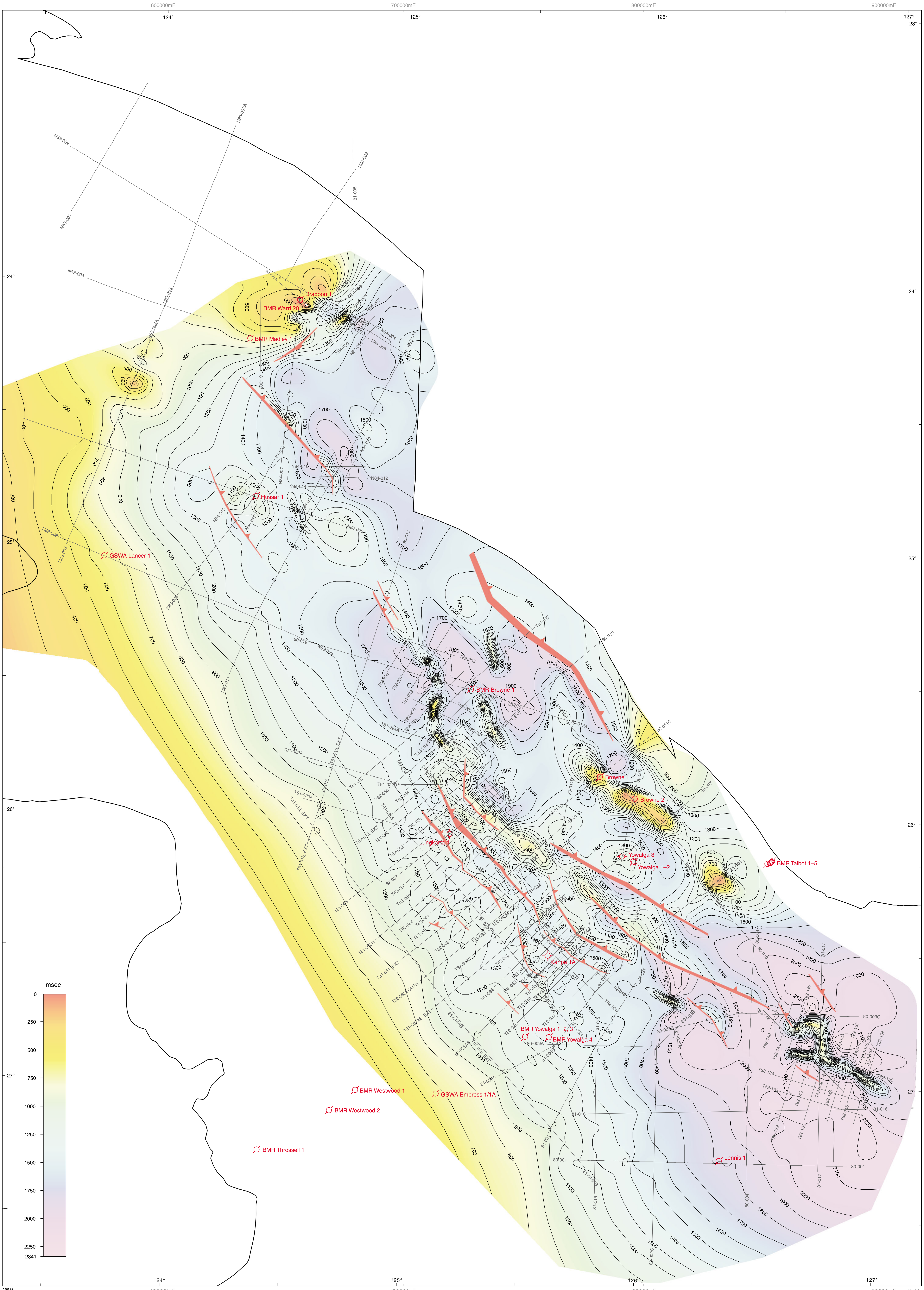
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
REPORT 98 PLATE 2

TWO-WAY TIME STRUCTURE MAP OF THE NEAR BASE NEOPROTEROZOIC HORIZON, CENTRAL WESTERN OFFICER BASIN, WESTERN AUSTRALIA



Stratigraphic well

Petroleum exploration well

Officer Basin boundary

Two-way- time contour;
Contour interval = 100 msec

Normal fault

Reverse or thrust fault

T82-052 Seismic line

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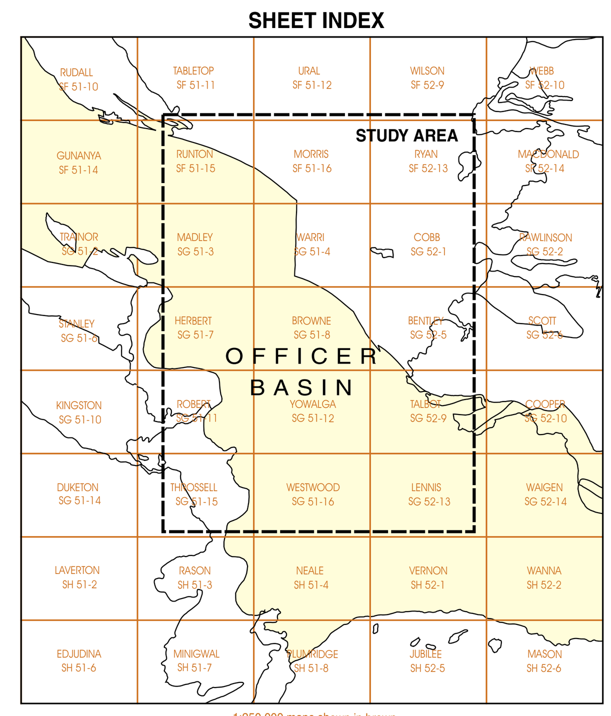

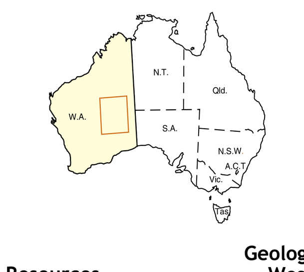

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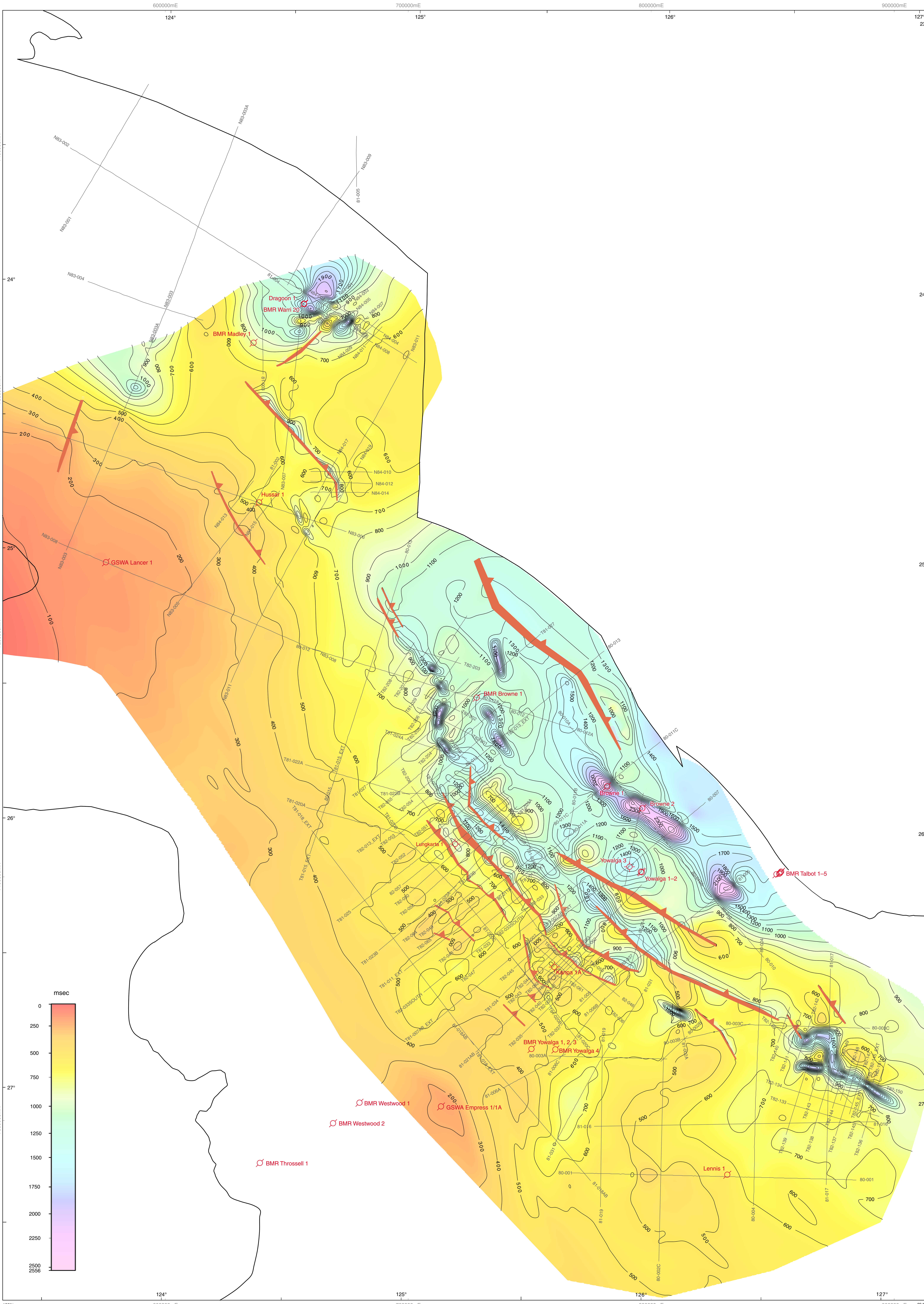
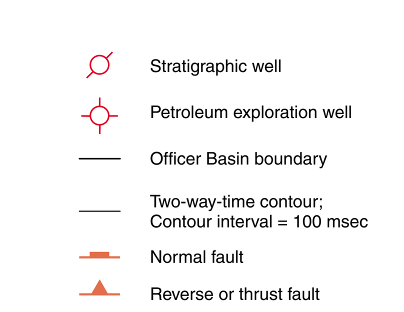
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
REPORT 98 PLATE 3

TWO-WAY TIME STRUCTURE MAP OF THE TOP BROWNE FORMATION (NEAR TOP SALT) HORIZON, CENTRAL WESTERN OFFICER BASIN, WESTERN AUSTRALIA





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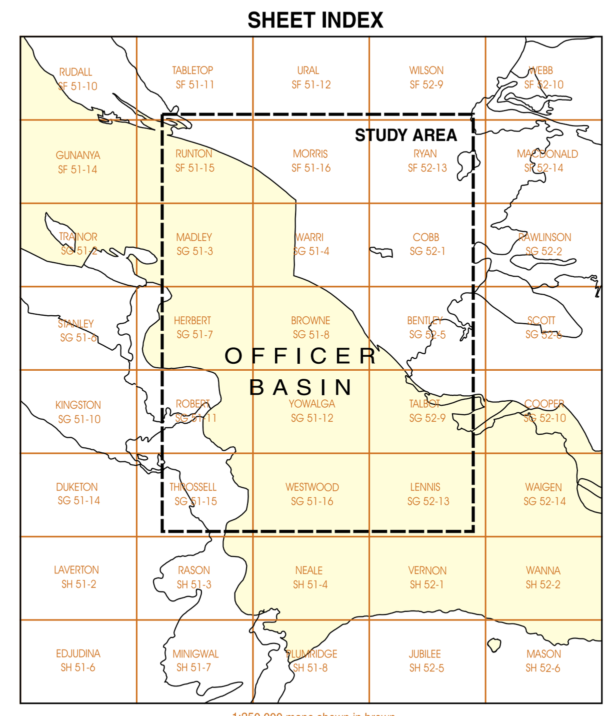

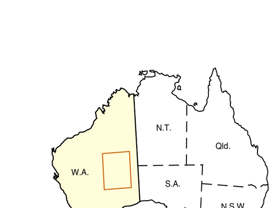

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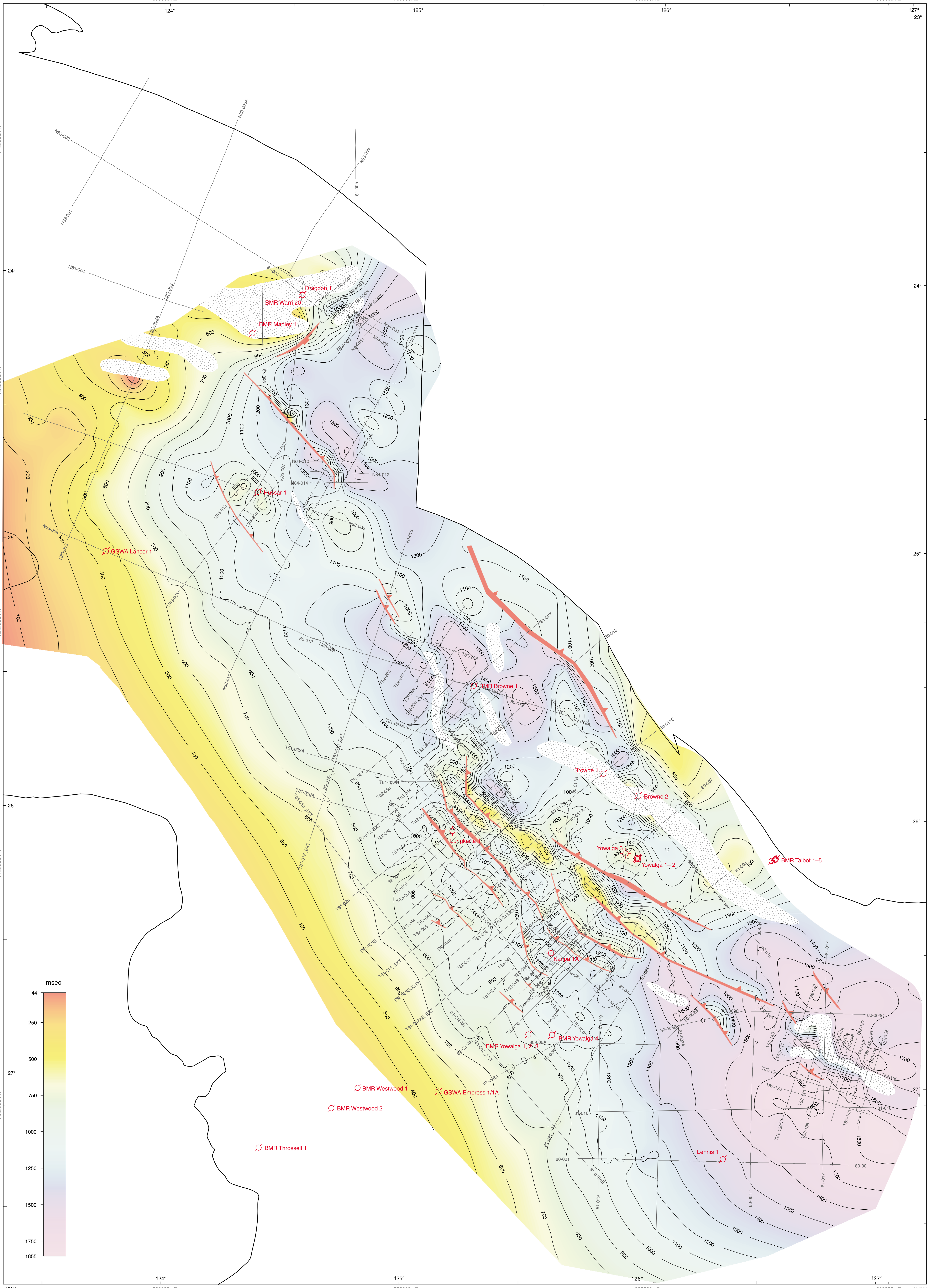
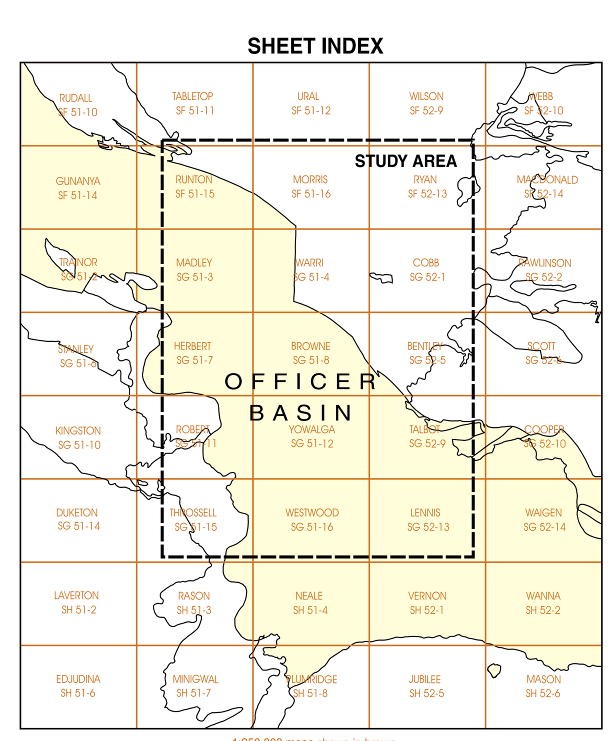
REPORT 98 PLATE 4

TWO-WAY TIME THICKNESS MAP OF THE BROWNE FORMATION, CENTRAL WESTERN OFFICER BASIN, WESTERN AUSTRALIA





Stratigraphic well
Petroleum exploration well
Officer Basin boundary
Two-way-time contour;
Contour interval = 100 msec
Normal fault
Reverse or thrust fault
T82-052 Seismic line
Salt wall or diapir

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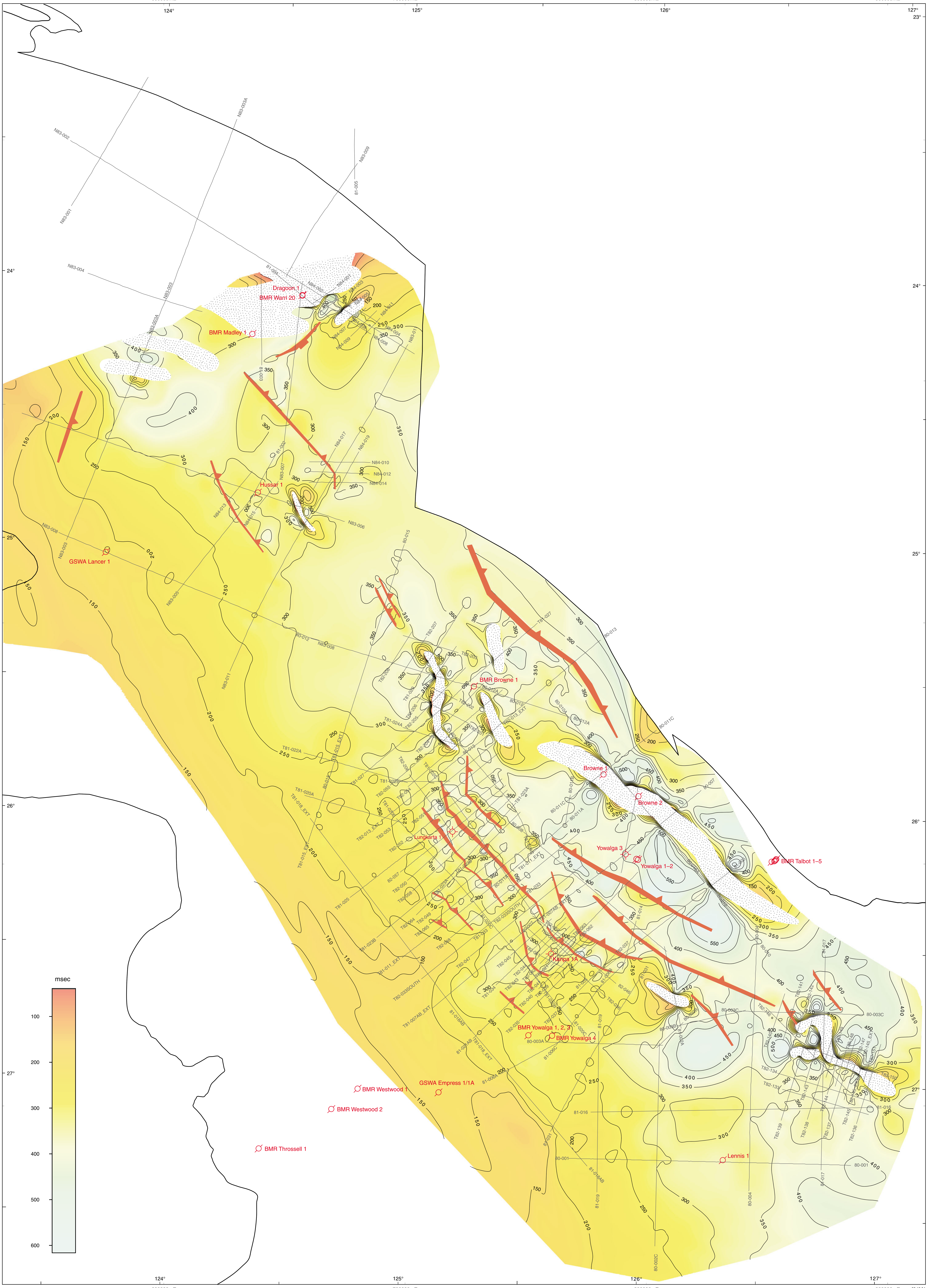
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
REPORT 98 PLATE 5

TWO-WAY TIME STRUCTURE MAP OF THE TOP HUSSAR FORMATION HORIZON, CENTRAL WESTERN OFFICER BASIN, WESTERN AUSTRALIA



- Stratigraphic well
- Petroleum exploration well
- Officer Basin boundary
- Two-way-time contour; Contour interval = 50 msec
- Normal fault
- Reverse or thrust fault
- T82-052 Seismic line
- Salt wall or diapir

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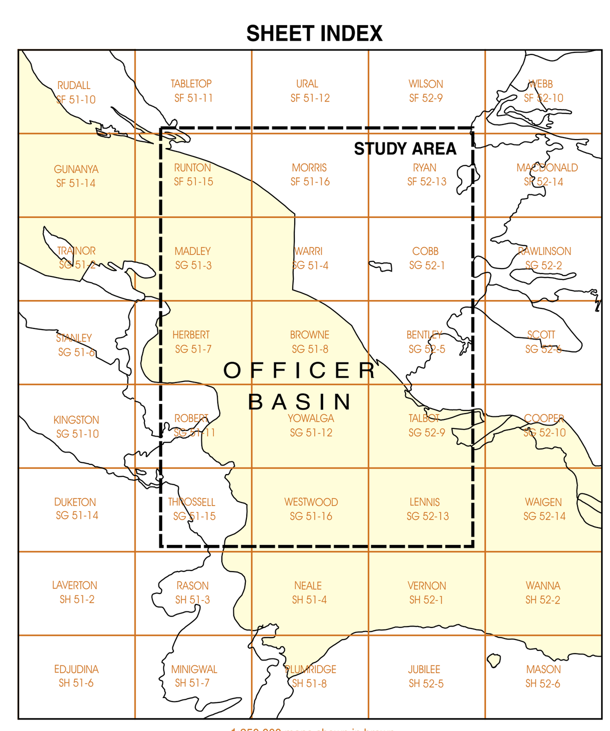

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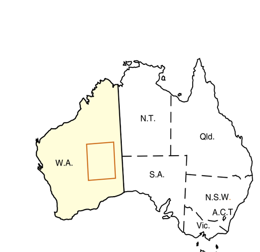

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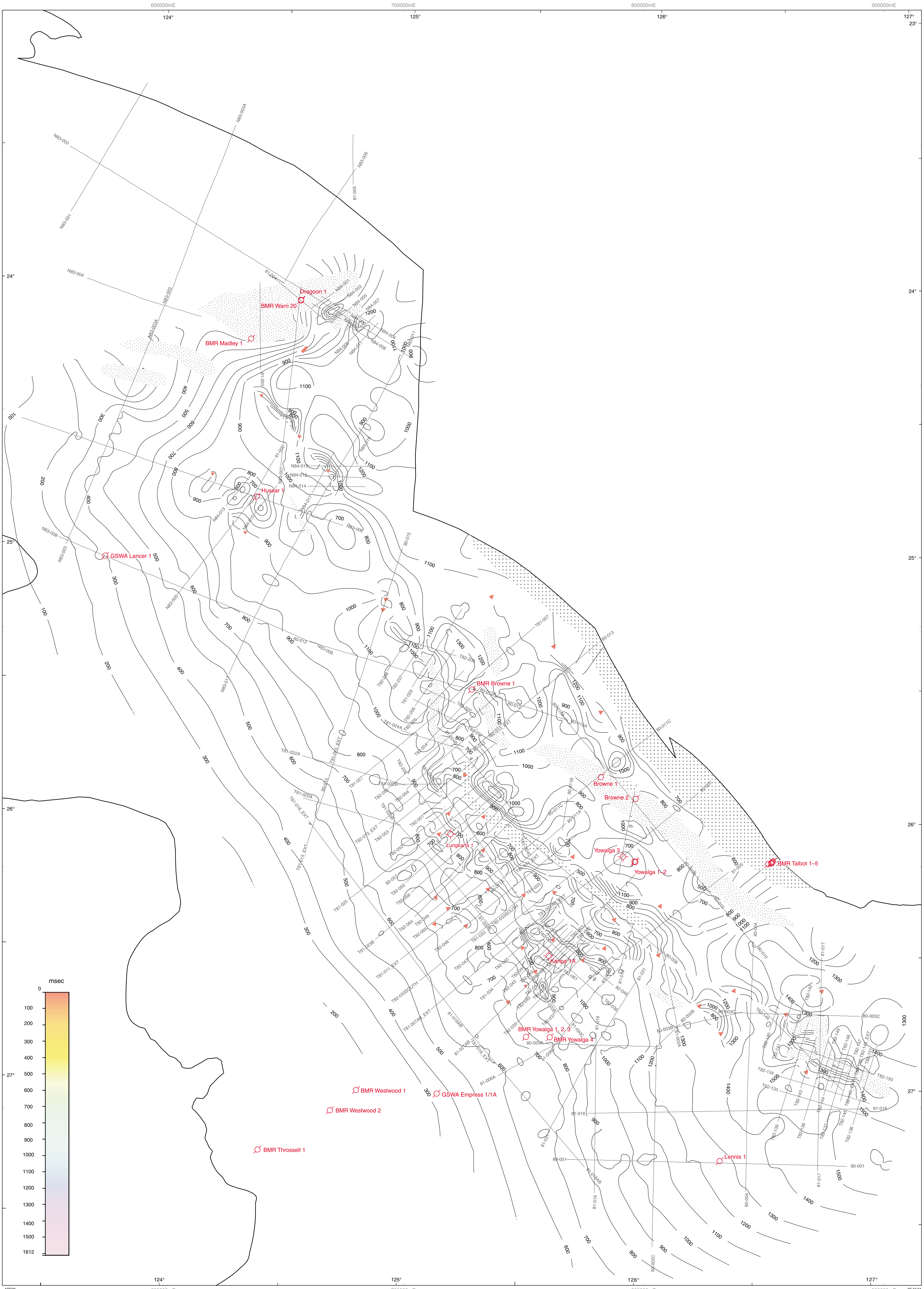
TWO-WAY TIME THICKNESS MAP OF THE HUSSAR FORMATION, CENTRAL WESTERN OFFICER BASIN, WESTERN AUSTRALIA



- Stratigraphic well
- Petroleum exploration well
- Officer Basin boundary
- Two-way-time contour; Contour interval = 100 msec
- Normal fault
- Reverse or thrust fault
- T82-052 Seismic line
- Salt wall or diapir
- Completely eroded Kanpa Formation

Compiled by A. Simeonova and R. Iasky

Edited by K. Blundell

Cartography by M. Maron

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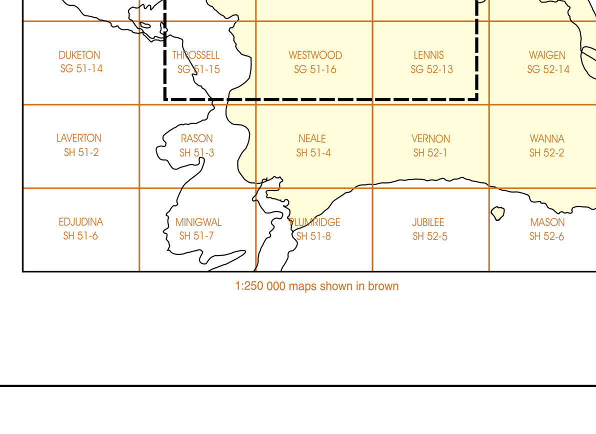
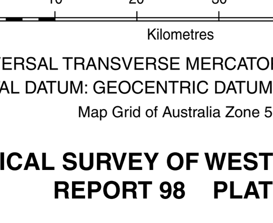
SHEET INDEX





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MINISTER FOR STATE DEVELOPMENT
JIM LIMERICK
DIRECTOR GENERAL

Geological Survey of Western Australia
TIM GRIFFIN
DIRECTOR

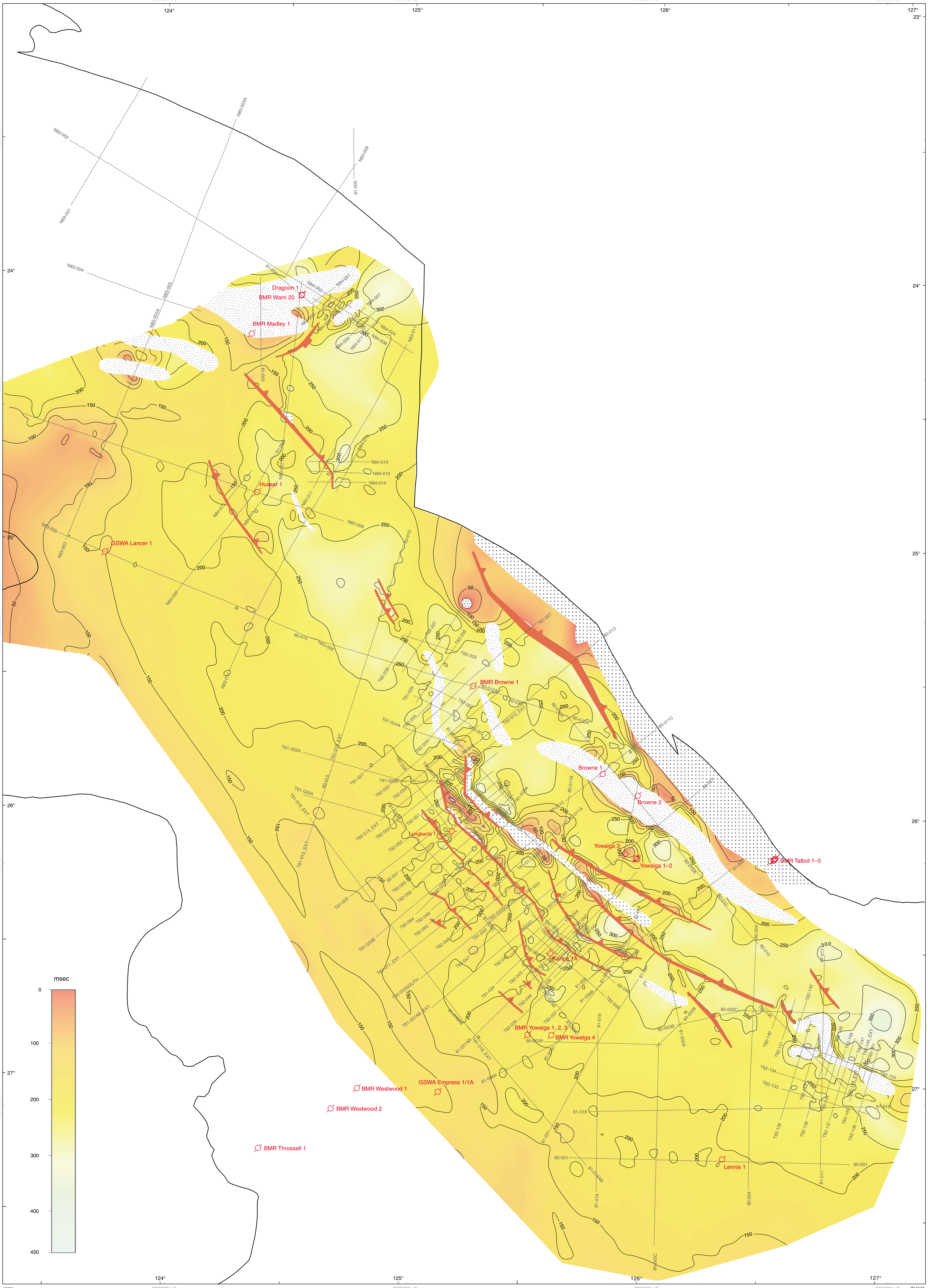
SCALE 1:750 000

0 10 20 30 40 50
Kilometres

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994
Map Grid of Australia Zone 51

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
REPORT 98 PLATE 7

TWO-WAY TIME STRUCTURE MAP OF THE TOP KANPA FORMATION HORIZON, CENTRAL WESTERN OFFICER BASIN, WESTERN AUSTRALIA



- Stratigraphic well
- Petroleum exploration well
- Officer Basin boundary
- Two-way time Contour; Contour interval = 50 msec
- Normal Fault
- Reverse or thrust fault
- T82-052 Seismic line
- Salt wall or diapir
- Completely eroded Kanpa Formation

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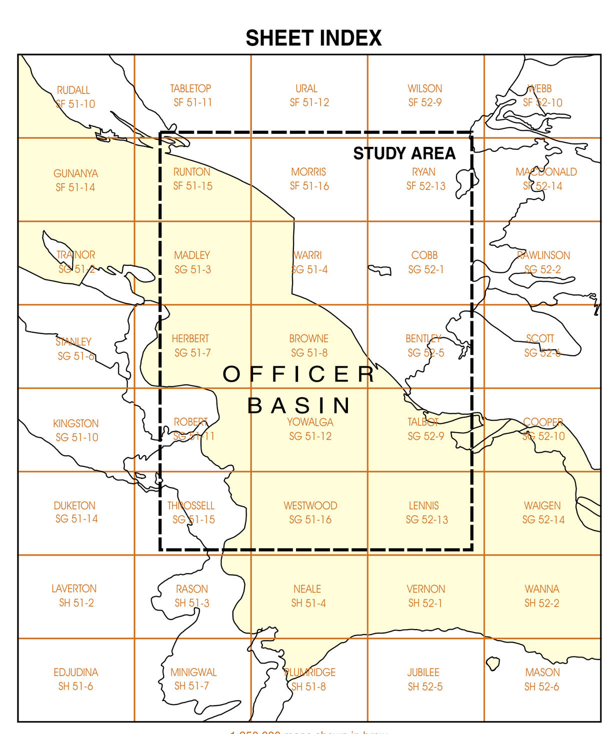

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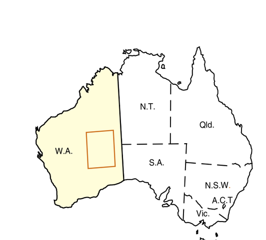

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0 10 20 30 40 50

Kilometres

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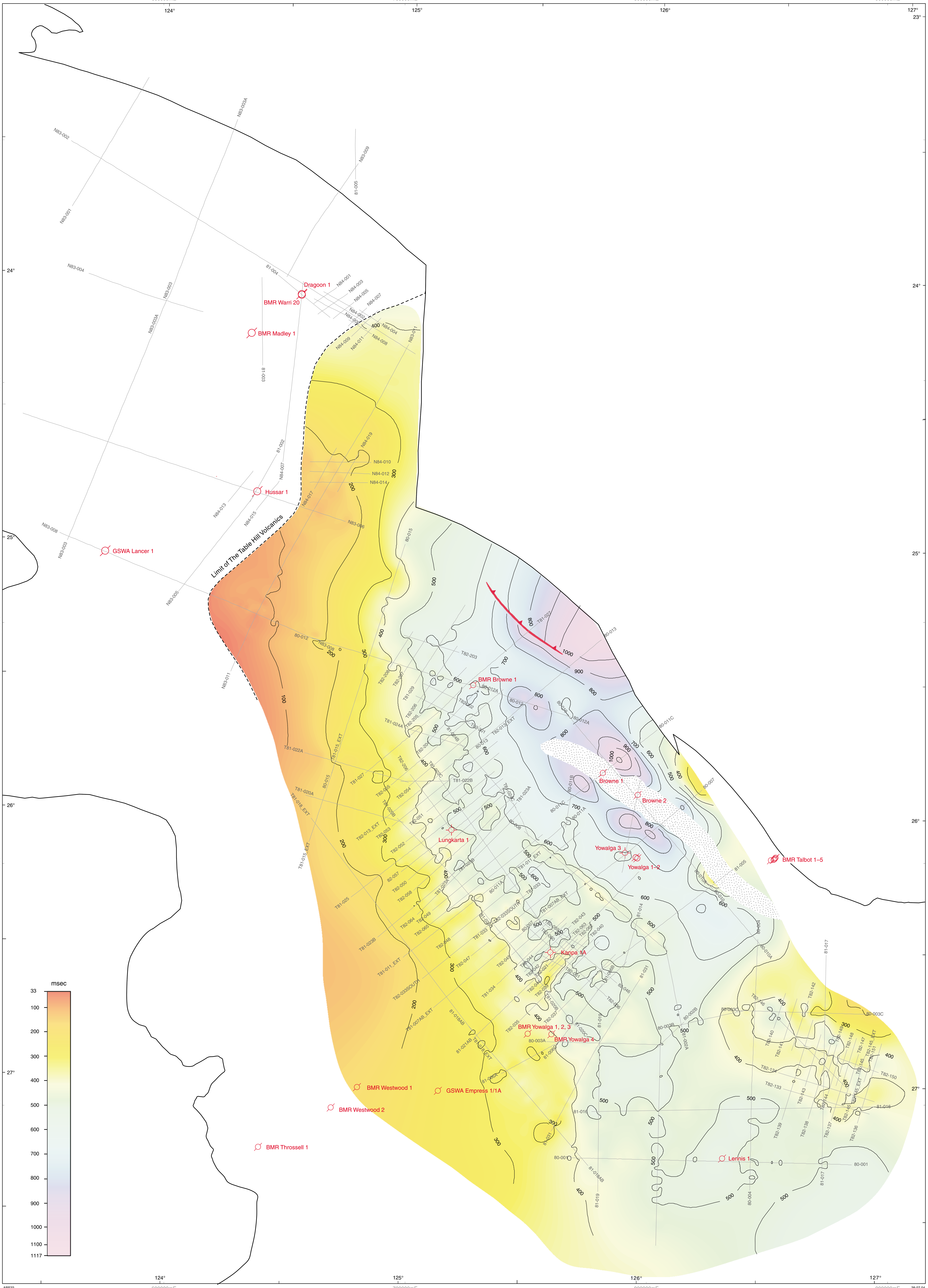
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
REPORT 98 PLATE 8

TWO-WAY TIME THICKNESS MAP OF THE KANPA FORMATION, CENTRAL WESTERN OFFICER BASIN, WESTERN AUSTRALIA



Stratigraphic well

Petroleum exploration well

Officer Basin boundary

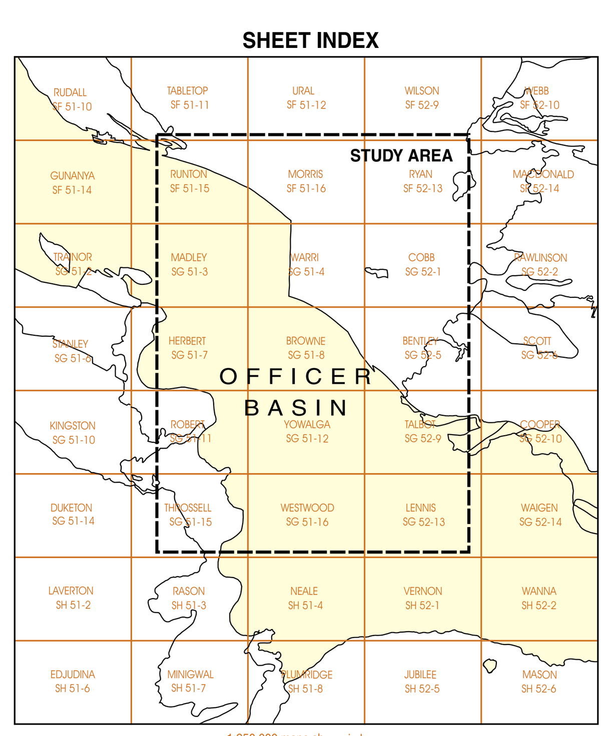
Two-way-time contour;
Contour interval = 100 msec

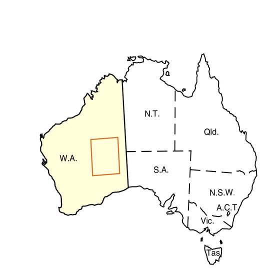
Normal fault

Reverse or thrust fault

T82-052 Seismic line

Salt wall or diapir





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0 10 20 30 40 50

Kilometres

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
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TWO-WAY TIME STRUCTURE MAP OF THE BASE TABLE HILL VOLCANICS HORIZON, CENTRAL WESTERN OFFICER BASIN, WESTERN AUSTRALIA