Department of
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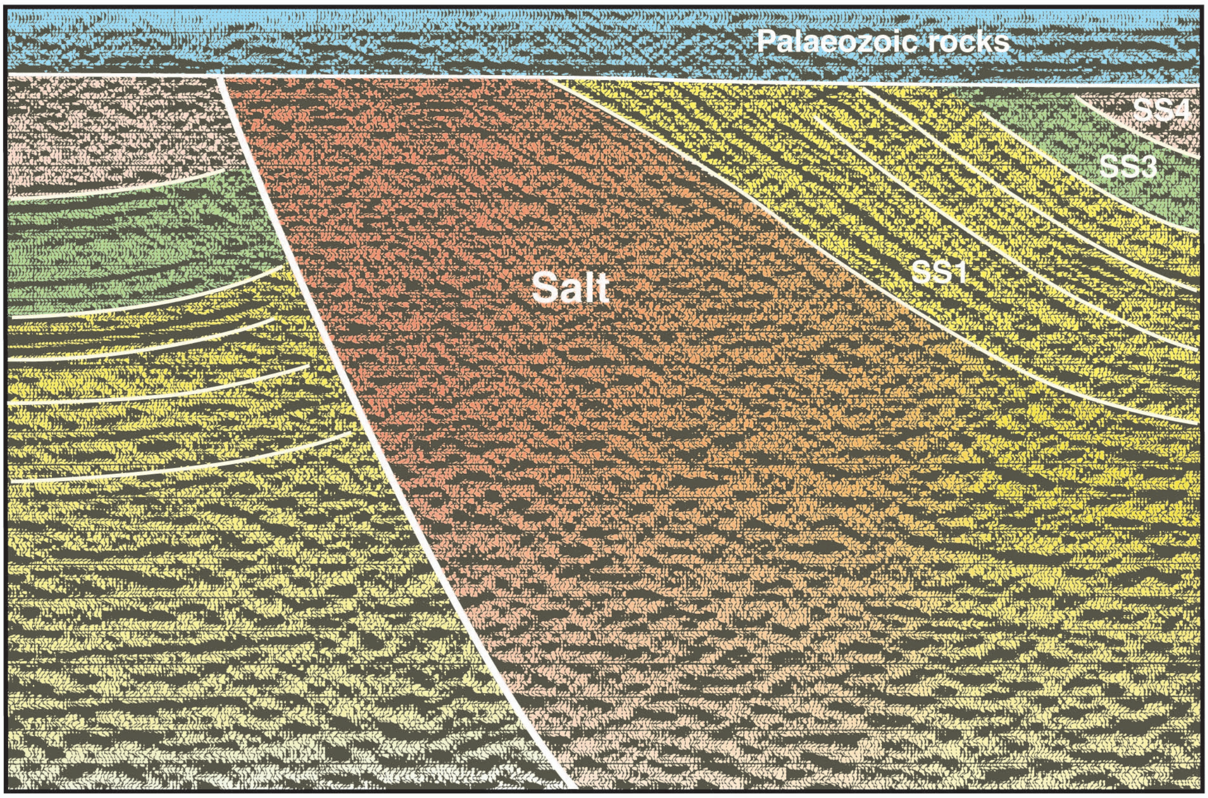
REPORT
80

BASIN DEVELOPMENT AND PETROLEUM EXPLORATION POTENTIAL OF THE GIBSON AREA, WESTERN OFFICER BASIN WESTERN AUSTRALIA

by H. T Moors and S. N. Apak



Geological Survey of Western Australia

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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BASIN DEVELOPMENT AND PETROLEUM EXPLORATION POTENTIAL OF THE GIBSON AREA, WESTERN OFFICER BASIN WESTERN AUSTRALIA

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H. T. Moors and S. N. Apak

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Cover photograph:
Seismic line N83-7 showing late-stage salt emplacement and erosion of Supersequence 1, 3, and 4 strata, Gibson area, western Officer Basin.

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Basin development and petroleum exploration potential of the Gibson area, western Officer Basin, Western Australia

by

H.T. Moors and S. N. Apak

Abstract

The Officer Basin covers an area of 320 000 km^2 in Western Australia, with a Neoproterozoic sedimentary section in excess of 6 km thick. The Gibson area, in the western Officer Basin, contains 1071 km of regional seismic data and two petroleum wells: Dragoon 1 and Hussar 1. The sedimentary succession has a mostly uniform thickness, which gradually thins towards the basin margin. The consistent seismic character of the Browne, Hussar, Kanpa, and Steptoe Formations allows them to be confidently correlated from the geologically better understood Yowalga area to the Gibson area. In these formations, the depositional facies of the Neoproterozoic succession are similar and the two regions are not individual sub-basins, but merely sub-areas of the larger western Officer Basin. During deposition of Supersequences 3 and 4 the Gibson area was more tectonically active than the Yowalga area, subsiding at a faster rate, with halokinesis drastically changing local geometry.

From measurements in Hussar 1 and by analogy with the Yowalga area, adequate source rock, reservoir, and seal are present in the Gibson area. Seismic control is inadequate to define structural and stratigraphic prospects and data quality can be improved with reprocessing. Nevertheless, a large variety of trapping styles, from simple fault traps, simple anticlines, stratigraphic traps (depositional and erosional), and halokinetic traps are recognized. Some of these are potentially large. In particular, large salt emplacements at different times suggest that halokinetic traps could have been formed within the younger units. Geothermal modelling of a deep location indicates three periods of hydrocarbon generation: during deposition of the later part of Supersequence 1, during deposition of Supersequence 3, and during deposition of Supersequence 4. For the deepest source rock (Browne Formation), production of up to half of its generative potential may have taken place before the major structuring phase, and accumulation would require a stratigraphic trap for this charge. For less deeply buried source rock, the timing of trap formation is favourable with respect to generation. The Kanpa Formation and younger source rocks have not commenced substantial petroleum expulsion.

The available data, though sparse, indicate that the petroleum potential of the Gibson area could be significant.

KEYWORDS: geological structure, stratigraphy, sequence stratigraphy, basin analysis, structural evolution, geochemistry, petroleum potential, Gibson area, Officer Basin, Western Australia.

Introduction

The Officer Basin (Fig. 1) is the third largest onshore basin in Australia. It covers an area of 320 000 km^2 and contains a Neoproterozoic sedimentary section in excess of 6 km thick. The sedimentary succession contains a high content of carbonate and salt that are commonly associated with prolific petroleum reserves elsewhere in the world (Warren, 1989; Alsharan and Nairn, 1997). Furthermore, Neoproterozoic giant oil and gas fields are known in Russia (Kontorovich et al., 1990; Kuznetsov, 1997) and Oman (Alsharan and Nairn, 1997). Consequently, the petroleum potential of the Officer Basin has been considered significant by recent workers (Perincek, 1997, 1998; Carlsen et al., 1999; Apak and Moors, 2000a,b, 2001).

To encourage the petroleum exploration industry to recognize the potential of the Officer Basin, the Geological Survey of Western Australia (GSWA) commenced a review of available data in 1994. This was supplemented by additional data from stratigraphic diamond drilling, geophysical surveys, geochemical analyses, and field studies in selected areas. The initial study was carried out in the Yowalga area of the central Officer Basin where the most seismic and well data are available. This provided the foundation for studies of other portions of the basin (e.g. Lennis area; Apak and Moors, 2000b). The current study on the Gibson area (Fig. 1) is the third in a series

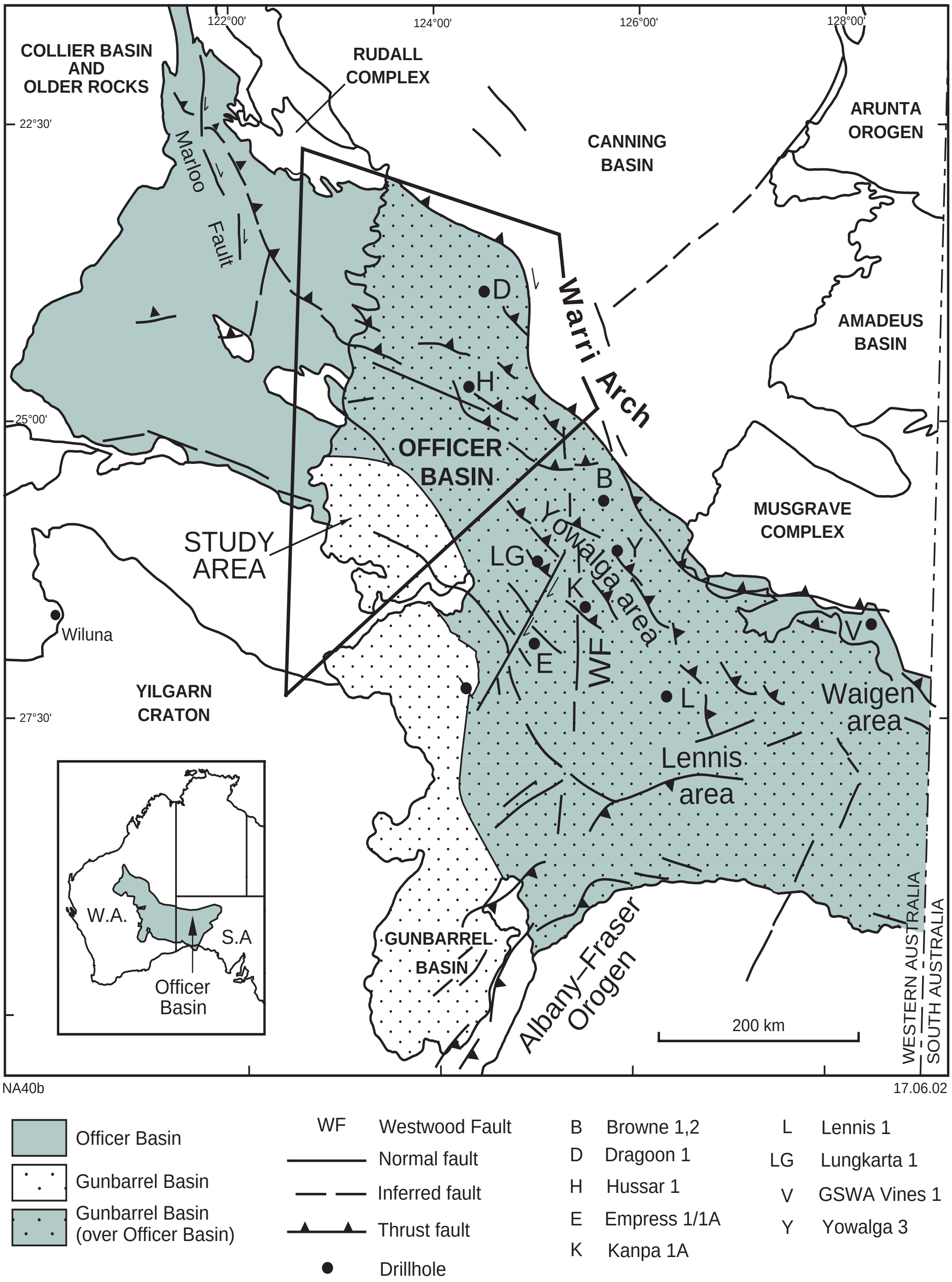

Figure 1. The western Officer Basin showing major structural elements and sub-areas

of detailed reports on specific regions within the western Officer Basin, and covers all or parts of the following 1:250 000 geological map sheets: RUNTON*, MADLEY, MORRIS, WARRI, HERBERT, BROWNE, and ROBERT (Fig. 2). The Gibson area, located immediately northwest of the Yowalga area, contains 1071 km of regional seismic data and two petroleum wells — Dragoon 1, total depth (TD) 2000 m, and Hussar 1, 2040 m TD (Fig. 3). Part of this Report, particularly **Stratigraphy**, therefore refers to the preceding Report on the Yowalga area (Apak and Moors, 2000b). The Gibson area adjoins the Savory area, where there is discontinuous outcrop of the Officer Basin succession, but no seismic control.

The Gibson area covers the region previously defined as the Gibson Sub-basin, based mainly on potential-field data (Townson, 1985; Hocking, 1994). However, where

* Capitalized names refer to standard 1:250 000 map sheets, unless otherwise indicated.

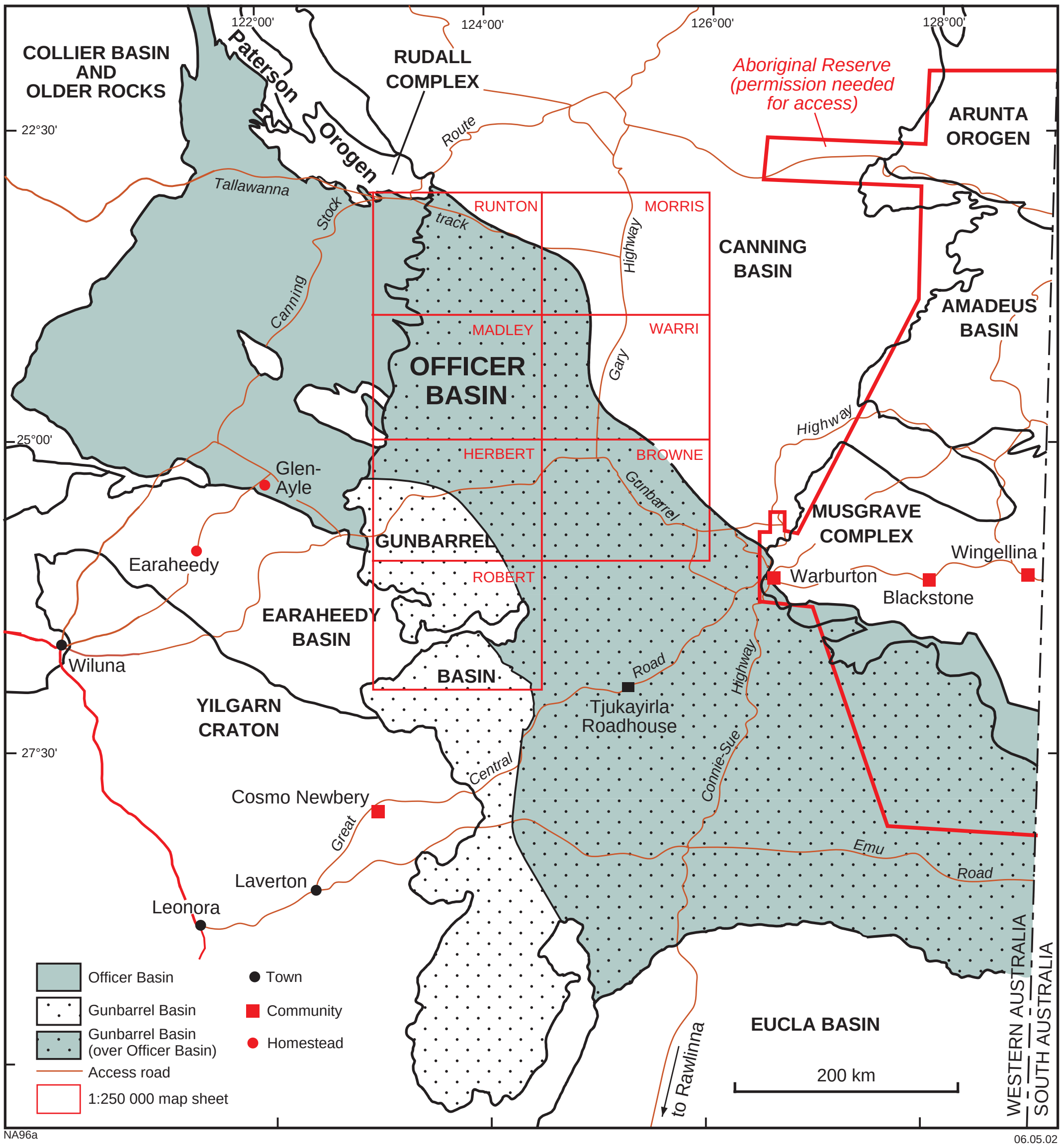

Figure 2. Access routes in the western Officer Basin and location of 1:250 000 map sheets covering the Gibson area

seismic data are available, there is no clear evidence for an individual depocentre in this region. For this reason, as with the previous study areas, we prefer to regard the region simply as the Gibson area (see **Structural interpretation**).

A sequence stratigraphic analysis of the Gibson area has been attempted using the limited data available and relying on comparisons with the Yowalga area where there is more control. In the Yowalga area the mid-Neoproterozoic Supersequence 1 (Walter and Gorter, 1994; Walter et al., 1995) has been subdivided into genetic units (Apak and Moors, 2000a). Seismic data indicate that Supersequence 1 strata are also present in the Gibson area. Basic sequence concepts and terminology (Galloway, 1989; Van Wagoner et al., 1990) applied to the Yowalga area by Apak and Moors (2000a) are also used in the Gibson area. The sequence stratigraphic units of Supersequence 1 coincide closely with the lithostratigraphic subdivisions previously defined by Townson (1985). The greater thickness of Supersequence 1 strata in the Yowalga area (Apak and Moors, 2000b) indicates a more rapid rate of subsidence than the Gibson area during deposition of these units. In contrast, the younger Wahlgu Formation (Supersequence 3) and McFadden Formation equivalent (Supersequence 4) are thicker in the Gibson area, indicating a shift in depocentres from the Yowalga area to the Gibson area. Analysis of the sequence stratigraphy was integrated with the structural interpretation to provide a better understanding of the petroleum system of this area, and to identify untested petroleum plays.

The petroleum potential of the Gibson area is assessed with reference to the Yowalga area, utilising seismic data, wire-line logs, sequence stratigraphy, palynology, and outcrop studies to reconstruct broad-scale depositional systems for the Neoproterozoic successions in relation to the structural development of the Gibson area.

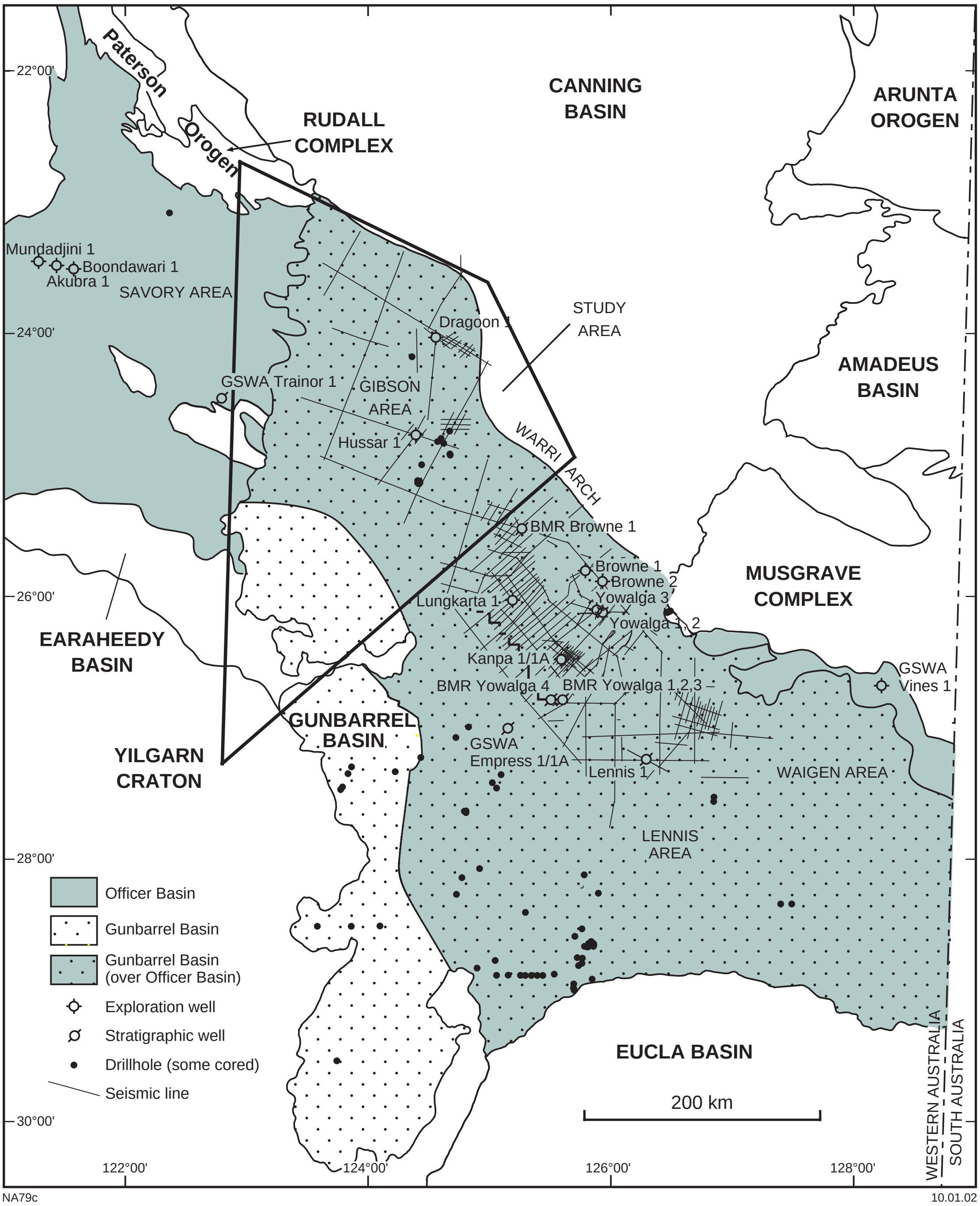

Figure 3. Location of petroleum exploration wells, stratigraphic tests, mineral exploration drillholes, and complete seismic coverage over the Officer Basin

Previous investigations

The Officer Basin has previously received little geological attention because of its isolation and difficult access. Petroleum exploration commenced in the early 1950s (e.g. Frome Broken Hill, Australasian Oil Exploration), but only the Phanerozoic succession was investigated. Early exploration activities relied mainly on surface mapping (e.g. Alliance Petroleum NL) until a consortium comprising Hunt Oil, Hunt Petroleum, Placid Oil, and Exoil were granted exploration permits in the 1960s. These companies acquired aerial and ground magnetic data, gravity data, and 1033 km of reflection seismic data (partly in the Gibson area), and drilled five wells (Browne 1 and 2, Yowalga 1 and 2, and Lennis 1) with a combined penetration depth of 2896 m. Only minor oil and gas shows were encountered in Browne 1 and 2 within the Yowalga area (Hunt Oil Company, 1965), and all tenements were subsequently relinquished.

The early exploration discovered salt diapirs, which the Bureau of Mineral Resources (BMR, now Geoscience

Australia) began to investigate in the 1960s. In 1967, GSWA started mapping in the area as part of its statewide 1:250 000 geological mapping program (Fig. 2), initially concentrating on the Musgrave Complex (Daniels, 1974). In order to accelerate the program, GSWA and BMR jointly mapped the Officer Basin (van de Graaff, 1974; Kennewell, 1974, 1975; Jackson, 1976, 1978; Crowe and Chin, 1979). As well as surface mapping, gravity data and 19 km of refraction seismic data were acquired, and a joint BMR–GSWA Bulletin on the Officer Basin was published (Jackson and van de Graaff, 1981).

As a result of this improved understanding, Shell Company of Australia (Shell) acquired exploration permits in the Yowalga and Lennis areas. The company recorded 4682 line-km of reflection seismic data (mostly in the Yowalga area) and drilled three deep wells; the deepest being Yowalga 3, which reached 4196 m. As a result of these investigations, Shell divided the Officer Basin into sub-basins, refined the stratigraphic subdivision by introducing additional formations, and interpreted the basin development from the petroleum exploration perspective (Townson, 1985). In the absence of significant shows, Shell relinquished its tenements in 1984 and 1985.

At the same time Shell acquired its tenements, a consortium consisting of The News Corporation, Eagle Corporation, and Swan Resources obtained two tenements in the Gibson area. They first interpreted Landsat imagery and existing gravity and magnetic data before conducting a 106 km regional seismic survey in 1981, and 1065 km of infill and detailed seismic surveys in 1983 and 1984. Following the initial survey, two wells were drilled: Dragoon 1 drilled to 2000 m encountered a salt diapir at 407 m, and Hussar 1 drilled to 2040 m intersected the Officer Basin strata, stopping at the top of the Browne Formation. Only minor hydrocarbons were detected and the tenements were subsequently surrendered. Phillips et al. (1985) presented prospectivity conclusions for the Gibson area.

Japan National Oil Corporation (JNOC) under a special prospecting authority (SPA No. 1/95–96) undertook the most recent petroleum investigation in the basin, covering most of the Yowalga area (Apak and Moors, 2000b, fig. 2a). A high-resolution aeromagnetic survey was flown (totalling 86 782 line-km) and 50 key seismic lines (2165 line-km) were reprocessed. In addition, drill cuttings from wells in and around the Yowalga area were analysed for source-rock potential, and detailed thermal maturation histories were constructed. The SPA has since expired and basic data containing JNOC's interpretations are now on open file (Japan National Oil Corporation, 1997).

A detailed review of the earlier phases of exploration in the Officer Basin, including statistics on drilling, and geophysical and geochemical surveys are discussed in Jackson and van de Graaff (1981), Ghori (1998a), and Perincek (1998).

The initial phase of the current investigation by GSWA comprised the collection of all open-file data on the Officer Basin, validation of the data, and construction of an integrated reinterpretation. All seismic lines were reinterpreted, formation tops were repicked in all wells, and additional organic geochemical analyses were performed on samples from key wells (Perincek, 1996, 1997, 1998). Stevens and Carlsen (1998) reviewed data on the 'Savory Sub-Basin', now referred to as the northwestern Officer Basin (Bagas et al., 1999). Stratigraphic wells Trainor 1 (Stevens and Adamides, 1998) and Empress 1 and 1A (Stevens and Apak, 1999) provided additional information for Carlsen et al. (1999), who focused on the petroleum potential of the basin, with reference to a source-rock model developed from Empress 1 and 1A. Apak and Moors (2000b) described the Yowalga area, which has the most available seismic and well data, and applied a sequence stratigraphic approach to provide a new interpretation for the evolution of the basin and an updated understanding of the petroleum system. Apak and Moors (2001) assessed the petroleum potential of the adjoining Lennis area using the concepts established for the Yowalga area. This was done because the Lennis area has less seismic control and no significant well control (Fig. 3).

Location and access

The Gibson area is a remote and sparsely populated region of Western Australia (1100 km northeast of Perth). Nearby communities include Warburton, Wiluna, and Cosmo Newbery. There are no active pastoral properties in the area and infrastructure is therefore basic. A number of unsealed roads such as the Great Central Road, Emu Road, and parts of the Gunbarrel Highway (Fig. 2) are maintained. Sealed roads end at Laverton and Wiluna, the closest towns. The remaining tracks are gravel or sand and of varying quality, and include the well known Canning Stock Route. Numerous roads and tracks constructed during mineral and petroleum exploration still exist and provide additional 4WD access.

Physiography, climate, and vegetation

The area has subdued relief, the elevation varying between 325 and 550 m Australian Height Datum (AHD). Mesas, buttes, breakaways, low hills, and adjoining pediments consist of relatively undeformed Permain–Carboniferous and Cretaceous strata. Low hills such as the Runton Ranges comprise folded Proterozoic strata. Extensive undulating laterite and sand plains cover areas of little or no outcrop. The sand dunes reach a height of 10–15 m above the interdunal areas. Large depressions, marking old palaeochannels, form the lowest elevations. Salt lakes and claypans, such as Lake Carnegie and Lake Disappointment are in the lowest parts of these depressions and may hold water for long periods after rain.

The climate is arid with an irregular annual rainfall between 150 and 200 mm. Maximum temperatures commonly reach 40°C between November and March, whereas during the winter months the minimum temperature commonly falls below 0°C.

Ground cover consists of spinifex and other grasses on the sandy soils with such vegetation being more prolific on the dunes. Numerous varieties of shrubs are present between the spinifex and open areas. Stunted tree cover is dominated by mulga (shrubby acacia). Other tree varieties are scattered between the mulga or form copses in favourable growing conditions (van de Graaff, 1974; Kennewell, 1974, 1975; Jackson, 1976, 1978; Crowe and Chin, 1979; Jackson and van de Graaff, 1981). Beard (1974) gives specific data on vegetative and climatic conditions.

Basin setting

In Western Australia the Officer Basin is bounded to the northeast by the Rudall Complex and to the northwest by the Musgrave Complex (Fig. 3). The Musgrave Complex consists of igneous complexes emplaced in Mesoproterozoic granulites and amphibolites (Ballhaus and Glikson, 1995). Along the southern margin of the Musgrave Complex, the Neoproterozoic Townsend Quartzite (the lowest unit in the Officer Basin) outcrops and unconformably overlies the Mission Group (Daniels, 1974; Jackson and van de Graaff, 1981).

The Rudall Complex (Hickman and Bagas, 1999) forms part of the northern boundary of the Gibson area (Perincek, 1996). It consists of deformed and metamorphosed Palaeoproterozoic to Mesoproterozoic sedimentary and igneous rocks. A gravity ridge, the Warri Arch, runs with a right lateral offset from the Rudall Complex to the predominantly Mesoproterozoic Musgrave Complex (Fig. 1), and separates the Canning Basin from the Officer and Gunbarrel Basins. The Tarcunyah Group unconformably overlies the Rudall Complex (Williams and Bagas, 2000). To the west and south of the Gibson area (in the Savory area), the Neoproterozoic Sunbeam Group of the Officer Basin unconformably overlies, or is faulted against, the late Mesoproterozoic Collier Group of the Collier Basin (Bagas et al., 1999; Tyler and Hocking, 2001).

The Gibson area, like the Yowalga and Lennis areas, is best regarded as a remnant of the far larger Officer Basin. This basin was dominated by shallow water deposition that mostly kept pace with subsidence. The basin was of very low relief, but with greater creation of accommodation space for sedimentation along the northern edge of the basin (Plate). This resulted in an asymmetric pile of sediments with a long, gentle sloping southern flank and a short, steep sloping northern flank. The Gibson area also shows thinning of the depositional section towards the west (Plate). Due to overall poor seismic data and massive salt emplacement in the northern portion of the Gibson area, the exact nature of the northern boundary is uncertain. However, one seismic line (N83-3A) provides evidence for a northern depositional margin in the Gibson area. Interpreted Supersequence 1 strata onlap and step north onto older units of the Warri Arch (Fig. 4). This indicates a pre-existing topographic high and possible basin margin to the north along the Warri Arch, which controlled the deposition of Supersequence 1 in the Gibson area.

Seismic data in the Gibson area, although poor, suggest that the Officer Basin succession lies on ?Mesoproterozoic strata, and that both the Officer Basin and the older strata thin towards the west (Plate). The relationships between the Officer and underlying basins are seen in core from

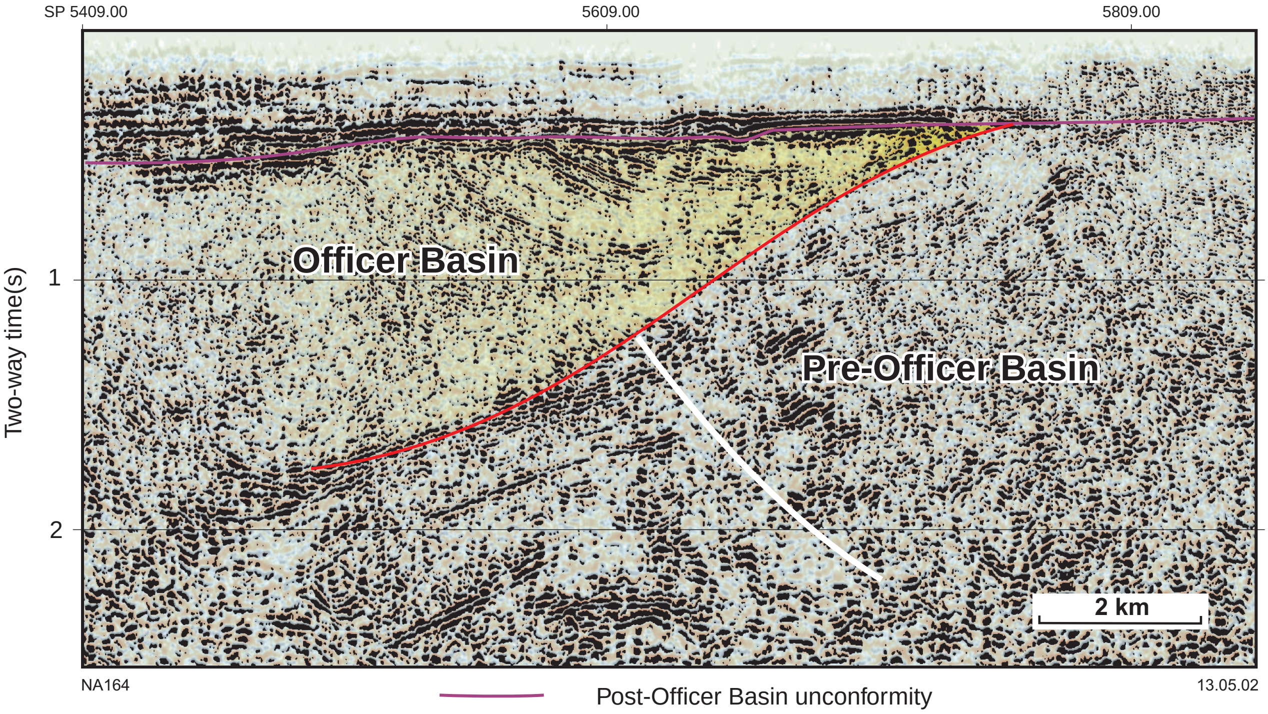

Figure 4. Seismic line N83-3A showing the relationships between the Neoproterozoic Officer Basin and an underlying Mesoproterozoic basin. For location of seismic line see Figure 7

two stratigraphic wells: Empress 1A and Trainor 1. Empress 1A was drilled in the Yowalga area (1624.6 m TD) and the ?Mesoproterozoic rocks intersected comprise mudstone-dominated strata in the upper part and continental basaltic rocks (1058 ± 13 Ma) in the lower section (Stevens and Apak, 1999). In Trainor 1, drilled in the Savory area, the McFadden Formation (9.1 – 83.1 m) of the Officer Basin unconformably overlies a succession (83.1 – 709 m TD) of indurated shale, with minor interbedded dolomite, sandstone, and chert (Stevens and Adamides, 1998). Hocking et al. (2000) interpreted the lower succession as part of the Quadrio Formation, which on regional geological considerations they correlated with the Edmund Group (1620–1465 Ma; Martin and Thorne, 2001) of the Edmund Basin. Age constraints for the Quadrio Formation in Trainor 1 are very poor, with maximum detrital zircon ages of c. 700 Ma (Stevens and Adamides, 1998) and a detrital zircon age of 511 Ma or younger (Nelson 1997). These ages were not accepted by Hocking et al. (2000), because all other indications of age in the area point to the Quadrio Formation being the oldest in the succession.

Stratigraphy

The major obstacles in establishing a reliable stratigraphic framework for the Officer Basin, particularly in the Gibson area, are poor outcrop, the limitations of Neoproterozoic biostratigraphy, and a sparsity of fossil and seismic data. Parts of the stratigraphic section are unknown in outcrop and have only been documented in exploration wells, although they can be mapped from seismic data. Other parts mapped from seismic data remain untested by drilling. Dragoon 1 and Hussar 1 are the only petroleum wells in the Gibson area (Fig. 5).

The stratigraphy in parts of the Officer Basin has been described by numerous authors including Jackson and van de Graaff (1981), Townson (1985), Phillips et al. (1985), Iasky (1990), Williams (1992, 1994), Perincek (1997), Carlsen et al. (1999), and Apak and Moors (2000a,b, 2001). Field studies and analysis of Empress 1A core have established the stratigraphic relationship of the *Baicalia burra* (Kanpa and Steptoe Formations) and *Acaciella australica* (Browne Formation) Stromatolite Assemblages (Grey, 1999), enabling these common fossils to be used as stratigraphic correlation tools throughout the basin. Advances in acritarch biostratigraphy (Grey and Cotter, 1996; Grey and Stevens, 1997; Cotter, 1999; Hill et al., 2000) are also useful to constrain the stratigraphy of the basin. In addition, isotopic curves derived from organic carbon, carbonate carbon, oxygen, and strontium throughout the Empress 1 and 1A core were correlated with equivalent curves from other basins (Hill et al., 2000). In Empress 1 and 1A, the K–Ar age of continental flood basalt in the basement is 1058 ± 13 Ma, whereas the age of the overlying Table Hill Volcanics (also a continental flood basalt) is 484 ± 4 Ma (AMDEL, 1999), thus constraining the age of the basin to the intervening period.

The stratigraphic column presented in Figure 6 is the current interpretation of the depositional ages of the sedimentary units and intervening tectonic events present within the western Officer Basin. Of immediate concern is the establishment of the chronological range and magnitude of the various tectonic phases described for the Officer and adjacent basins. As new data become available, it is expected that refinements will be made to some of these events.

The geology of the Neoproterozoic strata in the Gibson area is the main focus of this Report. With very limited outcrop in this area, except for the lower units adjacent to the western margin of the basin, and only one significant well control point, we have been forced to extrapolate information from formations collected from other areas of the Officer Basin that have better well and seismic data (Figs 3 and 7). The continuity and character of the seismic data suggest that most of the succession in the Gibson area is very similar to that deposited in the Yowalga area to the southeast. Therefore, the following summary has been condensed from observations in the Yowalga area (Apak and Moors, 2000a,b) and is supplemented by observations in the Gibson area.

Neoproterozoic succession

Supersequence 1

Townsend Quartzite and Lefroy Formation

There are no known outcrops of Townsend Quartzite in the Gibson area. In addition, the limited seismic coverage and thick salt sequence in the Gibson area make it virtually impossible to predict the presence of a basal sandstone unit.

Though previously published papers (e.g. Walter et al., 1995) have suggested a uniformly thick blanket of sandstone deposited ubiquitously throughout the Centralian Superbasin, there is no local evidence to support this hypothesis. Apak and Moors (2000b) suggested that the distribution of the Townsend Quartzite is more limited in the Officer Basin of Western Australia. Bagas et al. (1999) suggested correlations between the Sunbeam Group and the Lower Tarcunyah Group to the west of the Gibson area with the Townsend Quartzite along the northern margin of the Yowalga area. On seismic line 83-3A in the northern portion of the Gibson area, interpreted Supersequence 1 strata onlap the older Warri Arch (Fig. 4). Here, Supersequence 1 strata cannot be subdivided, and may comprise the entire supersequence as a condensed section (Townsend Quartzite to Steptoe Formation), or some parts of it.

The interpreted depositional environment of the outcropping Townsend Quartzite (limited to the southern margin of the Musgrave Complex) and its correlative units in the Savory area (Bagas et al., 1999) is shallow marine to fluvial (Daniels, 1974; Jackson and van de Graaff, 1981; Grigson, 1982; Watts, 1982).

Data on the Lefroy Formation is available only from outcrop and shallow drillholes near the Musgrave Complex (BMR Talbot wells), and a possible thin intersection in Empress 1A (Stevens and Apak, 1999). The formation has not been found in outcrop or intersected in

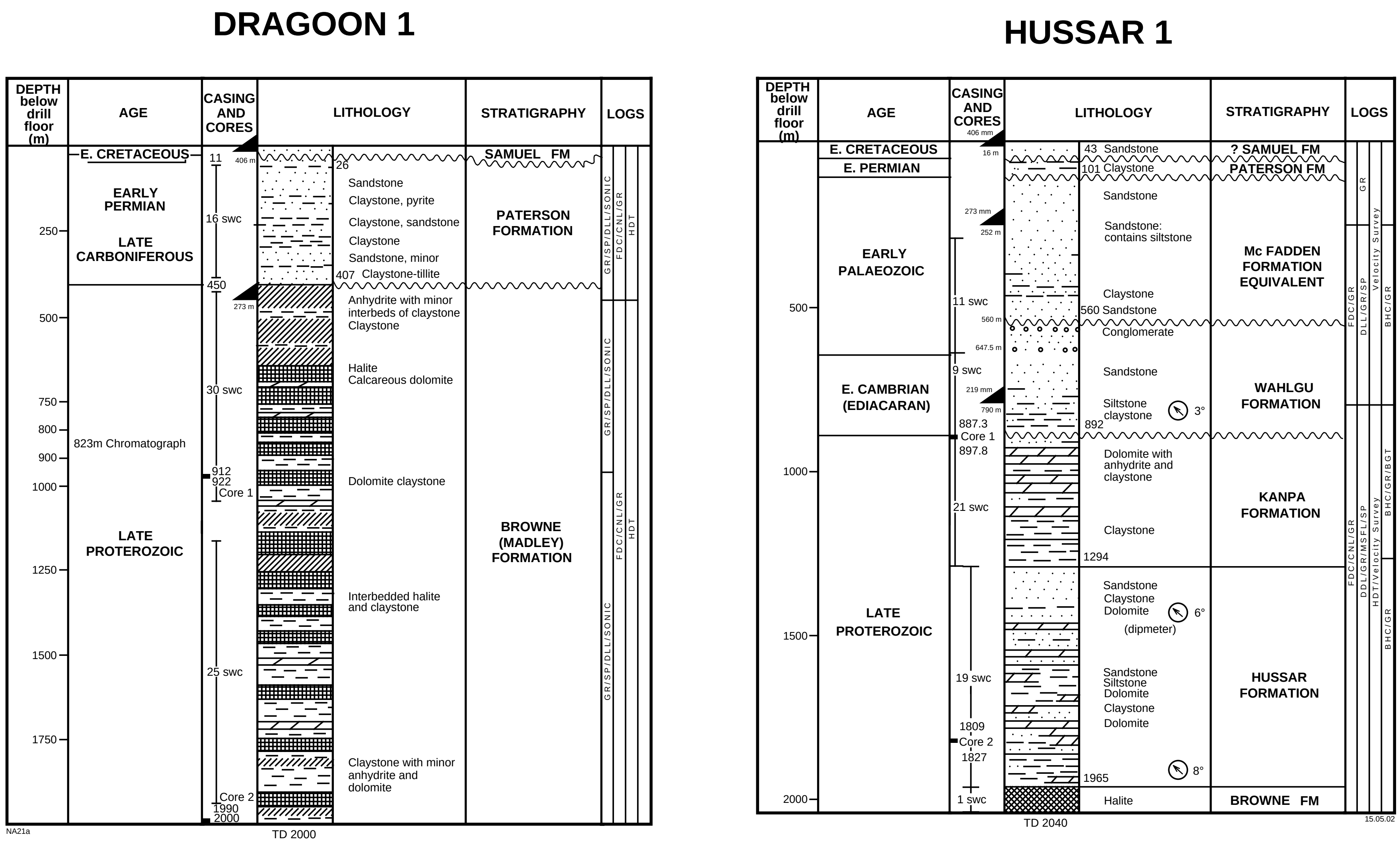

Figure 5. Stratigraphy of Dragoon 1 and Hussar 1 (after Perincek, 1997)

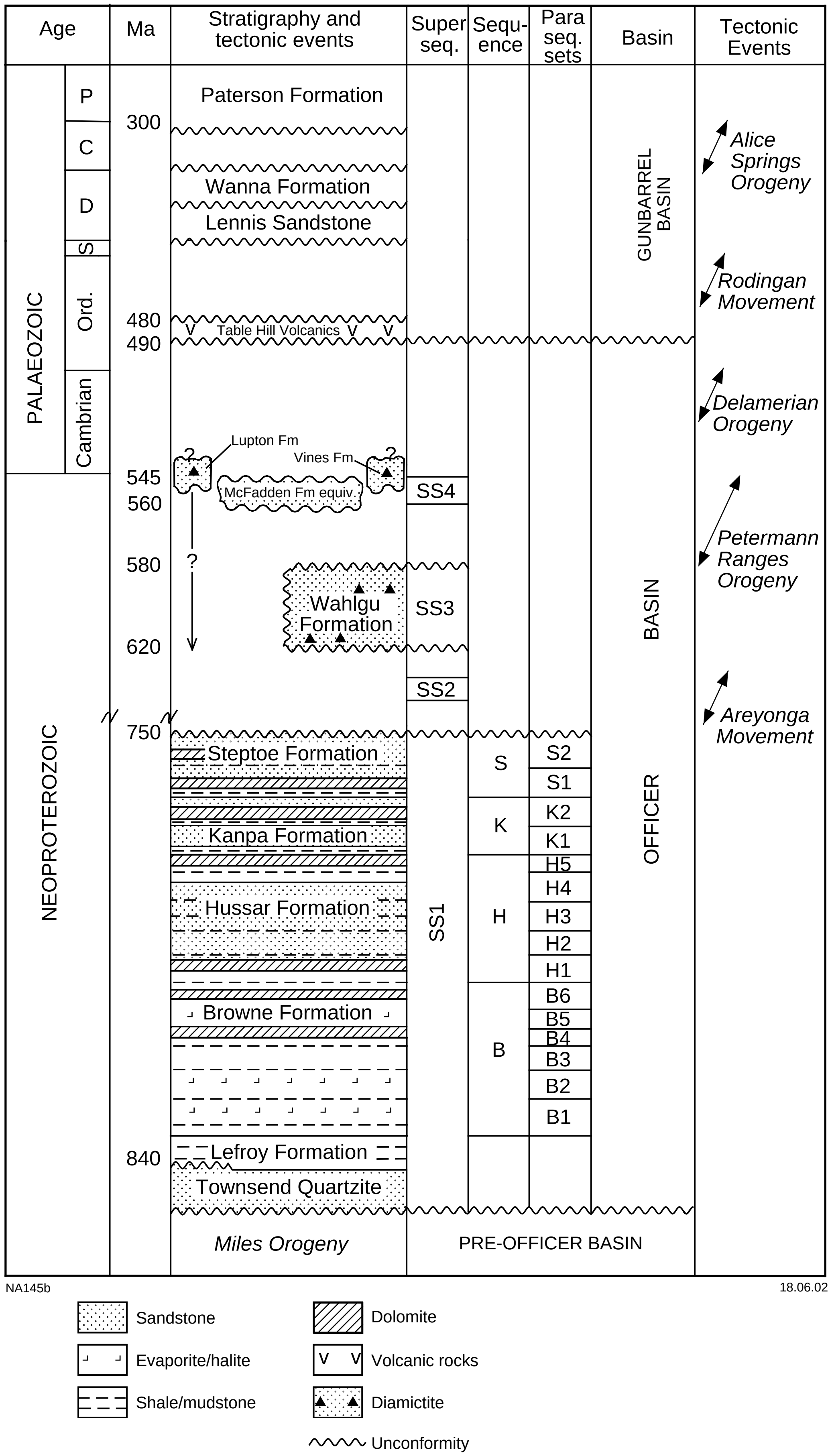

Figure 6. Generalized stratigraphy and tectonic events in the Officer Basin

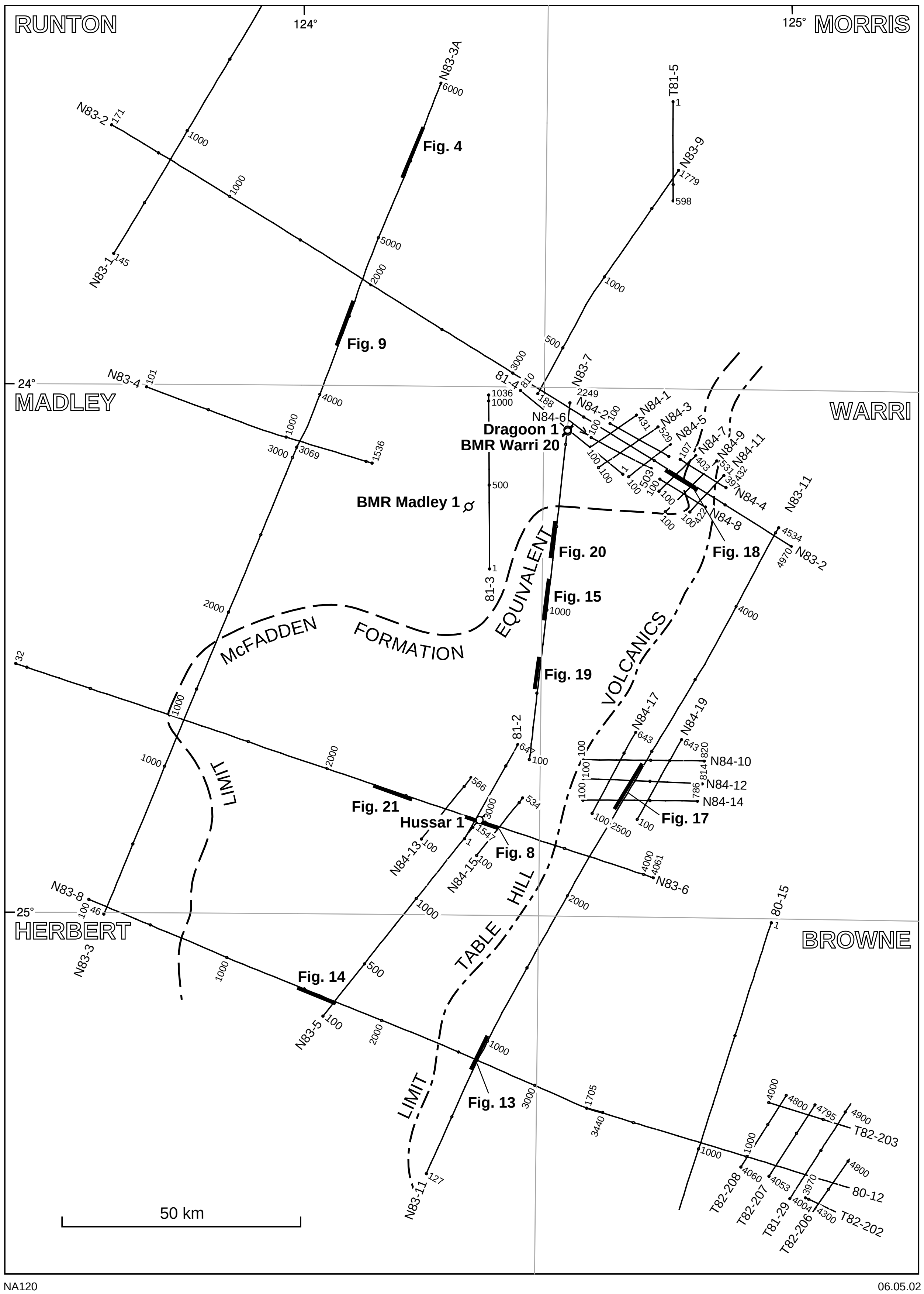

Figure 7. Location and subcrop map showing seismic coverage, wells, figure locations, and 1:250 000 map sheets within the Gibson area, used in this Report. Erosional limit of the Table Hill Volcanics and McFadden Formation equivalent in the area is also shown

wells drilled in the Gibson area. In Empress 1A, a thin basal lag conglomerate of the ?Lefroy Formation unconformably overlies the pre-Officer Basin succession. Lithologies identified are grey or maroon, well-bedded siltstone, claystone, and fine sandstone. The sediments were deposited in a low-energy, deep water marine environment, close to or below wave base. Apak and Moors (2000b) suggested that the Lefroy Formation is a deeper water facies of the Townsend Quartzite. The Lefroy Formation may be present in NJD1 (Hocking, R. M., written comm., 2001).

Browne Formation

The Gibson area is one of the few parts of the Officer Basin where the Browne Formation outcrops. Thin remnants are exposed along the basin's western margin, where salt, incorporated in sedimentary rocks, has been forced to the surface in a number of diapiric structures (Madley and Woolnough Hills diapirs). The Woolnough Hills and Madley diapirs are classic salt diapirs. In outcrop, their residual caprock contains blocks of displaced Browne Formation and possibly other formations that the diapirs intruded. The diapiric units (Woolnough and Madley) were upgraded to formation status by Cockbain and Hocking (1989). This is not warranted as they are merely mobilized random portions of the Browne Formation. Jackson (1976) first used the name 'Browne Evaporites' for the evaporites in shallow wells on BROWNE. Significant intersections were made in Yowalga 3 and Kanpa 1A, and Cockbain and Hocking (1989) revised the name to the Browne Formation.

The lower contact of the Browne Formation is disconformable on the ?Lefroy Formation in Empress 1A and the Townsend Quartzite in Kanpa 1A. Its upper contact is conformable with the overlying Hussar Formation, except in areas of diapiric intrusions such as in Browne 1 and 2 where it may be unconformably overlain by Palaeozoic or younger strata. The formation is intersected in the Yowalga area in Browne 1 and 2, Empress 1A, Kanpa 1A, and Yowalga 3, which has the thickest section (>2308 m).

The Browne Formation is composed of red shale and siltstone, interbedded with stromatolitic dolomite, halite, minor anhydrite, and sandstone. Thick halite beds were found in Empress 1A (approximately 10 m). Well data also indicate much thicker halite beds interbedded with thin silty and shaly horizons in Yowalga 3 and Kanpa 1A (Apak and Moors, 2000a,b). The *Acaciella australica* Stromatolite Assemblage has been identified in the dolomite of the Browne Formation in Yowalga 3 (Grey, 1996) and Empress 1A (Grey, 1999)

In the Gibson area, the Browne Formation has not been fully penetrated by drilling. Dragoon 1 penetrated nearly 1600 m of section within a diapiric structure (Woolnough Hills diapir), which consists of an incoherent mixture of halite, dolomite, and claystone (Eagle Corporation Ltd, 1983a). The presence of a 250 m-thick anhydrite cap zone suggests that a further substantial volume of halite was dissolved below the overlying Late Carboniferous unconformity. In Hussar 1 (Fig. 5), drilling stopped after the first thick halite intersection at 2040 m, and therefore little is known about the formation in this well (Eagle Corporation Ltd, 1983b). Seismic data show that cyclic deposits of the Browne Formation continue from the Yowalga area into the Gibson area (Fig. 8), and although not intersected by Hussar 1, these cycles persist beneath the total depth of the well (Fig. 8). Except in areas of salt movement, the formation thins gradually to the west (Plate). Because of the salt emplacement, associated thrusting, and subsequent tectonism, the Browne Formation, like the overlying units, has been eroded, particularly in the northern part of the Gibson area. However, erosional remnants of the Browne and overlying Hussar, Kanpa, Steptoe, and Wahlgu Formations can be seen between salt diapirs in many places (Fig. 9).

A depositional model for the Browne Formation is shown in Figure 10. The facies range from shallow marine to sabkha, indicating tectonic stability and a balance between sediment input and accommodation creation during deposition. It is difficult to define any structural control on deposition because of the poor resolution of sub-salt seismic data and the lack of wells that fully penetrate the formation.

In the Savory area, west of the Gibson Area, the Skates Hills Formation comprises conglomerate, in places overlain by sandstone, shale, dolomite, and siltstone (Walter et al., 1994). The Skates Hills Formation contains distinctive stromatolites, *Acaciella australica* and *Basisphaera irregularis* Walter 1972, and has been correlated with the Browne Formation (Walter et al., 1994; Stevens and Grey, 1997). Based on the known lithologies and stromatolite assemblages, the Skates Hills Formation can be regarded as a marginal correlative of the Browne Formation. The Skates Hills Formation has also been correlated with the Mundajini Formation of the Sunbeam Group (Bagas et al., 1999).

Hussar Formation

The informal Hussar beds of Townson (1985) was elevated to Hussar Formation by Cockbain and Hocking (1989). The formation is conformable with the Browne Formation below and the Kanpa Formation above, and was intersected in Hussar 1, Kanpa 1A, Lungkarta 1, Yowalga 3, and Empress 1A. The greatest thickness intersected (897 m) is in Yowalga 3.

The Hussar Formation is composed of sandstone, mudstone, dolomite, minor evaporite, and locally developed conglomerate. It contains repeated progradational cycles deposited in shelf, shoreline, tidal flat, and fluvial environments, in which upward-coarsening shoreface sandstones predominate. Some of the sandstones within these facies are considered to be the principal reservoirs in the western Officer Basin. The depositional models and facies variations for the Hussar Formation in the Yowalga area are shown in Figure 11. A very low relief basinal setting is proposed. In Empress 1A, the dolomitic units contain *Tungussia* form indet. and the *Baicalia burra* Stromatolite Assemblage, and the planktonic acritarch *Cerebrosphaera buickii* is present in the siltstone and mudstone section (Grey, 1999).

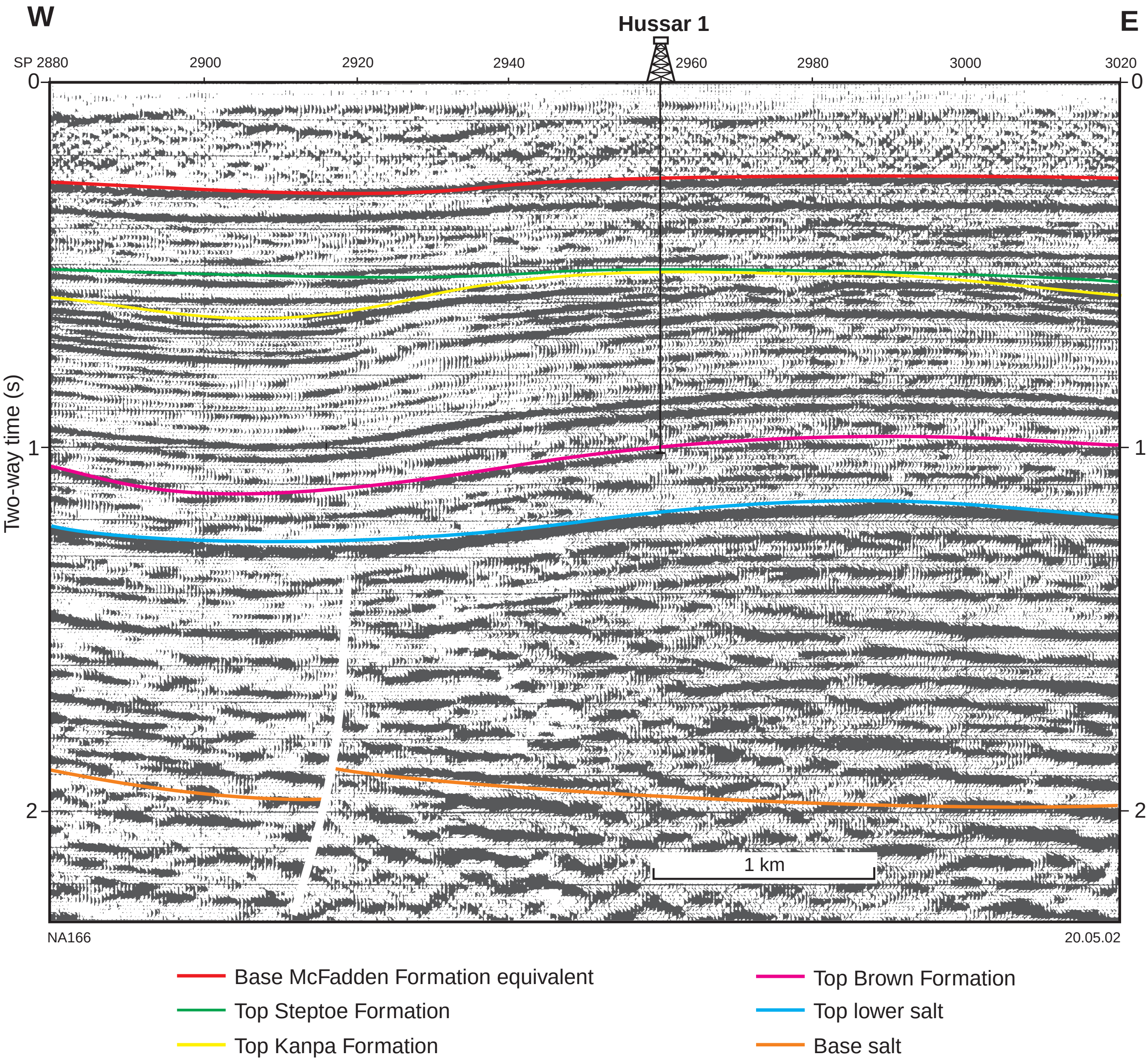

Figure 8. Seismic line N83-6 showing Hussar 1 structure and the absence of the Steptoe Formation. Note that the Kanpa Formation is overlain unconformably by the Wahlgu Formation (previously called as McFadden Formation). The McFadden Formation equivalent is also assigned to the unnamed unit that overlies the Wahlgu Formation in this well

The formation's similar seismic character within both the Gibson and Yowalga areas implies that the sedimentary successions are also similar; the same parasequence sets recognized in wells of the Yowalga area can be recognized in Hussar 1 (Fig. 11b). Based on seismic data, the formation thins to the west (Plate).

Kanpa Formation

The 'Kanpa beds' were proposed informally by Townson (1985) for intersections in Yowalga 3, Kanpa 1A, and Lungkarta 1, and later upgraded to formation status by Cockbain and Hocking (1989). The formation conformably overlies the Hussar Formation and is conformably overlain by the Steptoe Formation in Empress 1 and 1A, and Kanpa 1A. The Steptoe Formation is absent in Yowalga 3, Lungkarta 1, Hussar 1, and in places within the Gibson area, based on seismic data (Fig. 8). In these areas, the top of the Kanpa Formation is variably eroded and overlain by post-Supersequence 1 strata.

The thickest penetrated section of the Kanpa Formation is in Kanpa 1A (516 m). The formation consists of dolomite, mudstone, shale, siltstone, and sandstone, with minor evaporite and chert; clear-water carbonate lithologies are dominant. Based on data from the Yowalga area, the predominant depositional setting was probably shallow marine to tidal flat (Fig. 12), with sabkha facies locally developed during regressive phases (Apak and Moors, 2000a,b).

The interpreted depositional environments and facies variations for the Kanpa Formation are similar to those of the Hussar Formation; both formations having been deposited on a gentle ramp sloping into the basin axis.

Individual depositional cycles of shallow-marine carbonate and sandstone can be correlated between wells in the Yowalga and Gibson areas (Fig. 12b), and their lateral persistence beyond these wells is clearly expressed on seismic data. The Kanpa Formation thins to the west.

In Empress 1A, dolomite of the Kanpa Formation commonly contains stromatolites of the *Baicalia burra* Stromatolite Assemblage, and mudstone units contain abundant cyanobacterial filaments and fragments of cyanobacterial mats (Grey, 1999).

Steptoe Formation

The Steptoe Formation does not outcrop in the Gibson area. The name ‘Steptoe beds’ was proposed informally by Townson (1985) for a unit penetrated in Kanpa 1A, and later upgraded to formation status by Cockbain and Hocking (1989). The Steptoe Formation conformably overlies the Kanpa Formation, whereas its upper boundary is an erosional unconformity. The Steptoe Formation was eroded in many places throughout the western Officer Basin during the Areyonga Movement and Petermann Ranges Orogeny (Apak and Moors, 2000b).

In the Yowalga area, the Steptoe Formation comprises dolomite, mudstone, claystone, and sandstone and was deposited within a range of restricted low-energy shallow-marine shelf or lagoonal depositional environments. Dolomite contains stromatolites of the *Baicalia burra* Stromatolite Assemblage, including *Tungussia wilkatanna* in Empress 1 and 1A (Grey, 1999). The formation has not been penetrated in the Gibson area, but it can be inferred from seismic character that the lithology is similar to that in the Yowalga area. In some places within the study area, the Steptoe Formation has been eroded (Fig. 8).

Supersequence 3

Wahlgu Formation

In Empress 1 and 1A, a glacially influenced marine deposit disconformably overlies the Steptoe Formation and is unconformably overlain by the Table Hill Volcanics (Apak and Moors, 2000b). This deposit consists of predominantly massive and cross-bedded sandstone, and in the upper part contains a thin dolomitic horizon that has been interpreted to be the Marinoan ‘cap dolomite’ (Grey et al., 1999; Stevens and Apak, 1999). The Marinoan cap dolomite forms the top of the Marinoan glacial strata of Supersequence 3 in the Amadeus Basin and Adelaide Rift Complex (Preiss et al., 1978; Walter et al., 1979). This glacial unit is therefore also considered to belong to Supersequence 3 (Grey et al., 1999). An unnamed sandstone that overlies the cap dolomite with a gradational contact (Stevens and Apak, 1999) is included as part of the unit (Apak and Moors, 2000b).

The glacial unit in Empress 1 and 1A was tentatively correlated to outcrops of Lupton Formation and named ?Lupton Formation by Stevens and Apak, (1999). In its type area at Lupton Hills on the southern flank of the

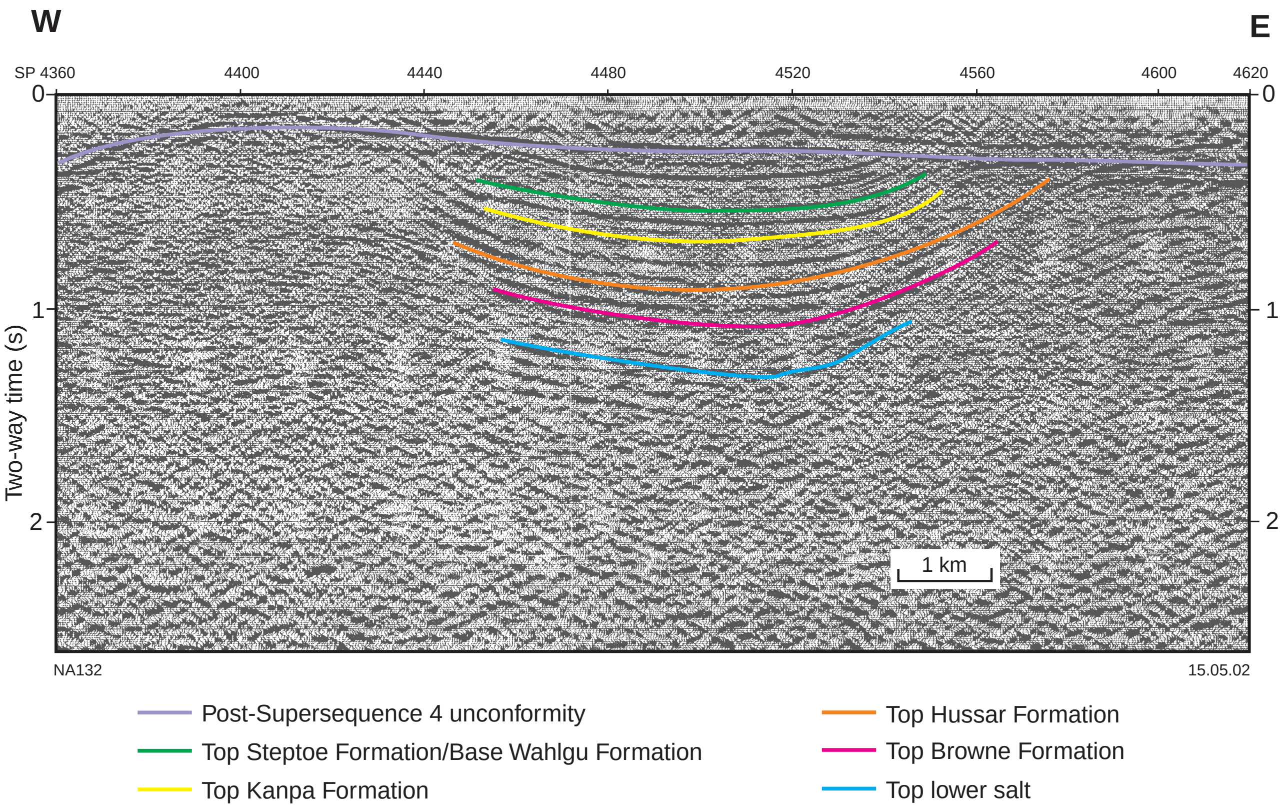

Figure 9. Seismic line N83-3A showing a residual of Supersequence 1 and Wahlgu Formations between the salt emplacements. For location of seismic line see Figure 7

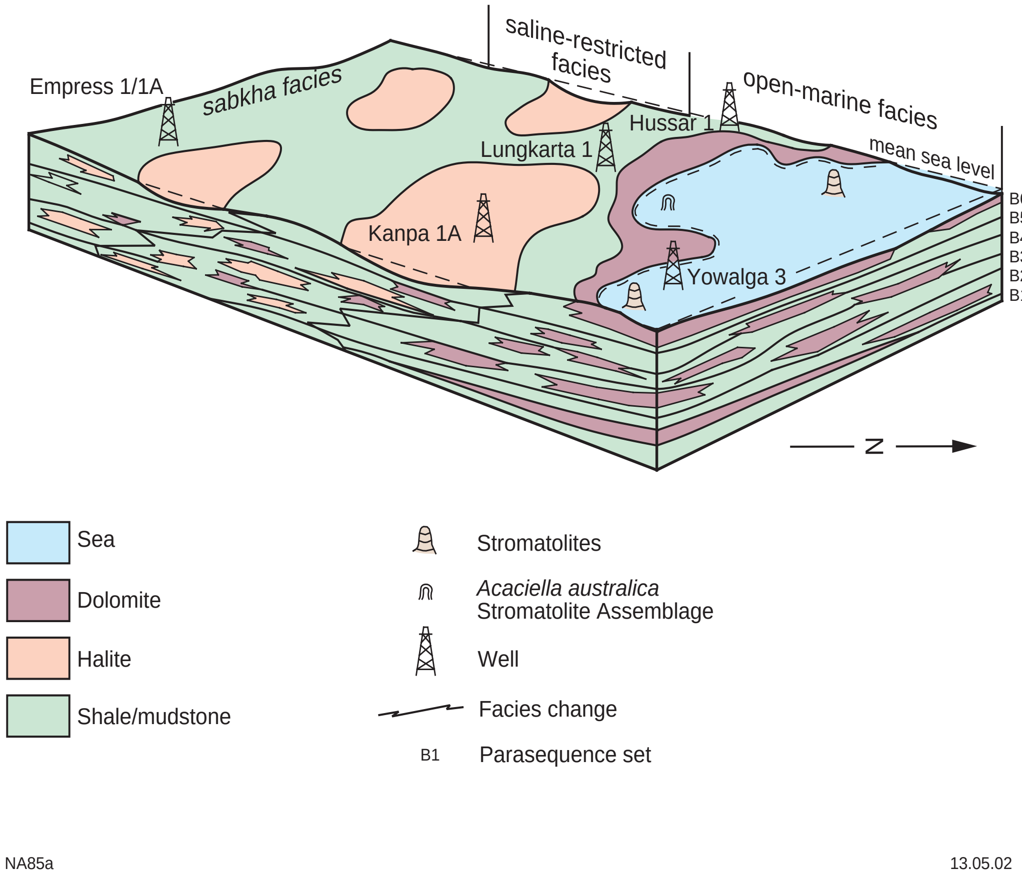

Figure 10. Depositional model for the Browne Formation in the Yowalga area (after Apak and Moors, 2000a) showing a large, flat basin with numerous shallow ponds flooded during storms, a sequence-stratigraphic correlation, and the lateral facies distribution within the formation. A similarity in seismic character indicates that it can be extrapolated to the Gibson area

Musgrave Complex, the Lupton Formation consists of massive conglomerate with scattered boulders, and sandstone interbedded with siltstone and diamictite (Jackson and van de Graff, 1981). Elsewhere, the formation lies unconformably on the Townsend Quartzite and the Lefroy Formation (Jackson and van de Graff, 1981), indicating a substantial erosional period prior to its deposition. The age of the Lupton Formation is uncertain, and in the light of new information from Vines 1 it may be younger than Supersequence 3 (Apak et al., 2001). A new name, the Wahlgu Formation, is therefore proposed for the Supersequence 3 glacial deposits to replace ?Lupton Formation in Empress 1 and 1A. The name is introduced here and will be formally defined by Grey et al. (in prep.)

In the Savory region (Bagas et al., 1999), which adjoins the Gibson area, the stratigraphic equivalent of the Wahlgu Formation is the Boondawarri Formation, which outcrops extensively and is irregularly distributed over Supersequence 1 strata (Williams, 1992; Bagas et al., 1999). The Boondawarri Formation is approximately 800 m thick and consists of a basal glacigene sequence that grades upward into a shallow marine sequence, and then into a near-shore marine sequence with phases of carbonate accumulation (Williams, 1992).

In the Gibson area, Hussar 1 intersected the Wahlgu Formation. Based on seismic and well data, the formation lies between the Steptoe Formation below and the McFadden Formation equivalent above. Where the Steptoe Formation is absent, it is underlain by the Kanpa Formation (Fig. 8). The base of the Wahlgu Formation represents a major unconformity — here referred to as the Base Wahlgu Formation unconformity — and shows very strong erosional features in many places. Large channels are present, which in places have penetrated the Kanpa Formation (Fig. 13) and the Steptoe Formation (Fig. 14). Above the Kanpa Formation horizon, seismic line N83-7 (Fig. 15) also shows numerous large intraformational channels cut within the Wahlgu Formation.

We are confident that both the Base Wahlgu Formation unconformity, characterized by deep erosional features, and the overlying major unconformity between the Wahlgu Formation and the McFadden Formation equivalent are correlatable throughout the Gibson, Yowalga, and Lennis areas. Although the formation has been eroded in many places, particularly between the Gibson and Yowalga areas, it is still widely present above Supersequence 1 successions, within areas of seismic and well control. In some places within the Gibson area (towards the basin

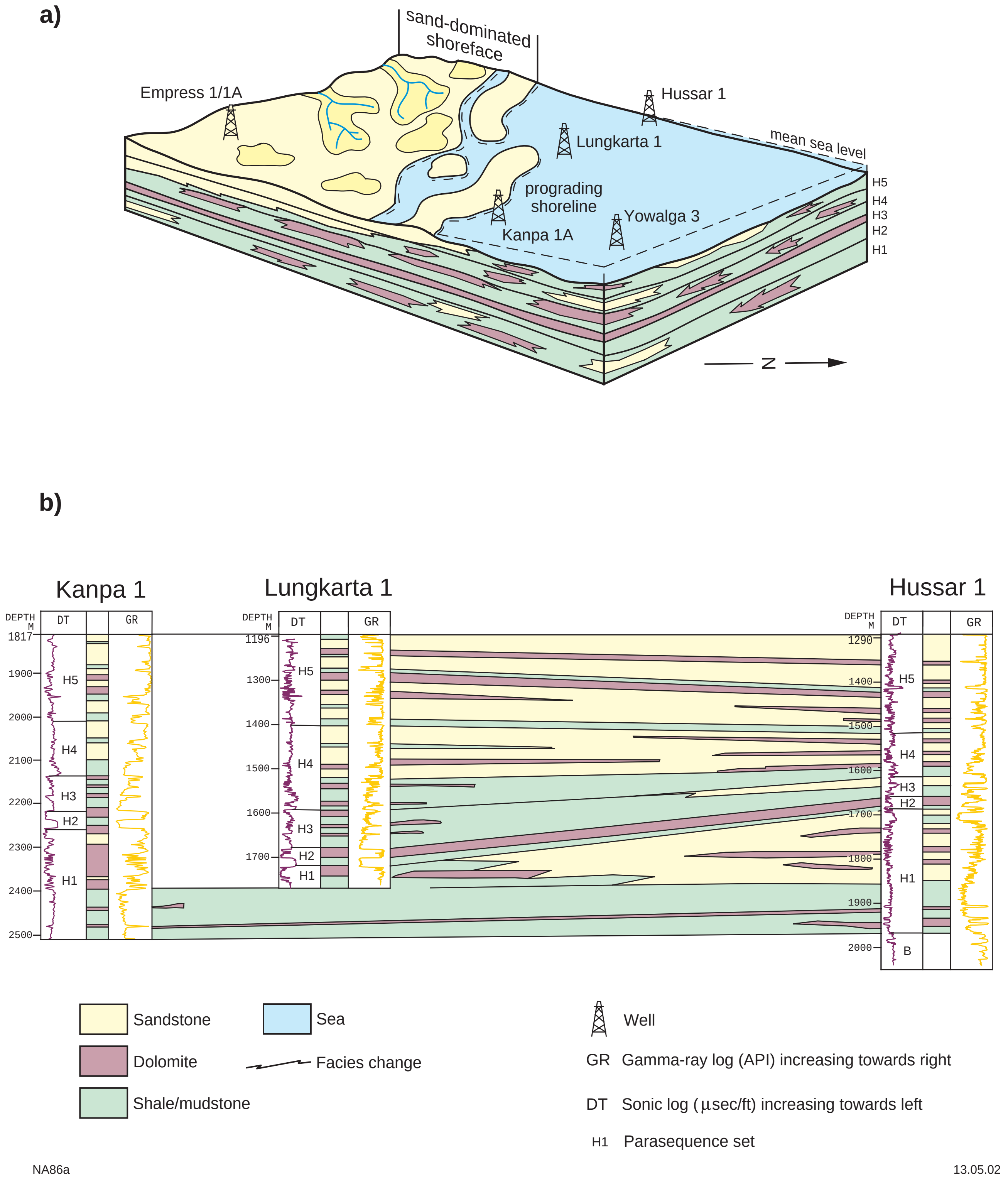

Figure 11. Depositional model for the Hussar Formation in the Yowalga area (after Apak and Moors, 2000a): a) model showing a very low relief basinal setting with multiple prograding carbonate and siliciclastic cycles; b) sequence-stratigraphic correlation showing the lateral facies distribution between Hussar 1, Lungkarta 1, and Kanpa 1A

margin to the north), the Wahlgu Formation and underlying Supersequence 1 strata are severely eroded following salt emplacement and complex folding (Fig. 9). The Wahlgu Formation is thicker in the Gibson area than in the Yowalga area, having an average thickness of 300 m calculated from seismic data. The formation in the Gibson area, as interpreted from seismic data, should be more similar to the Boondawarri Formation outcrops than to the Wahlgu Formation in the Yowalga and Lennis areas, a considerable distance to the southeast.

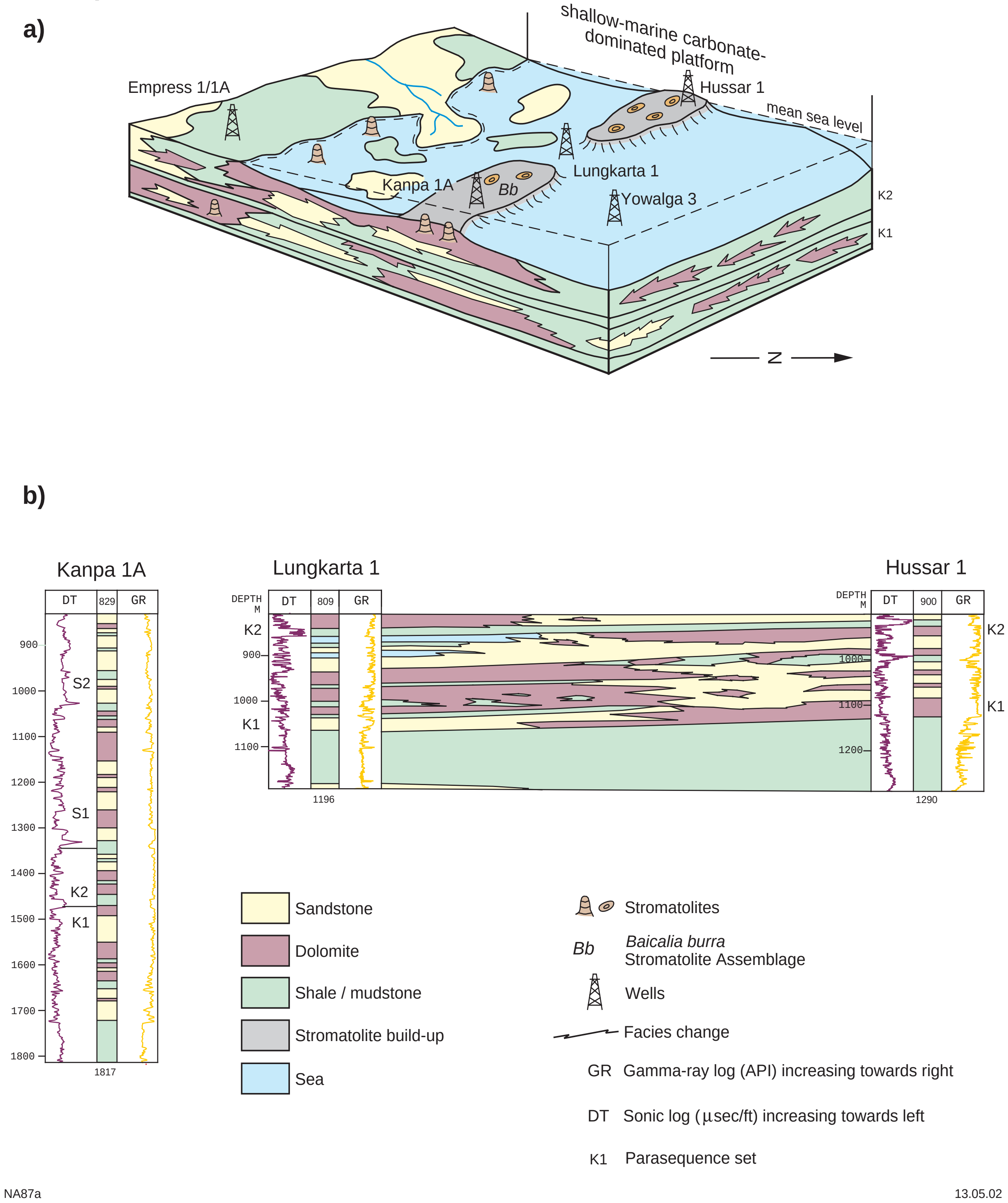

Figure 12. Depositional model for the Kanpa Formation in the Yowalga area (after Apak and Moors, 2000a): a) model showing carbonate and siliciclastic cycles within shallow-marine to lagoonal and sabkha environments; b) sequence-stratigraphic correlation showing the lateral facies distribution between Hussar 1, Lungkarta 1, and Kanpa 1A

Supersequence 4

McFadden Formation equivalent

The McFadden Formation equivalent, intersected in Hussar 1, Kanpa 1A, and Lungkarta 1, was previously interpreted as the Babbagoola Formation (Phillips et al., 1985; Townson, 1985). The formation equivalent is separated from both underlying and overlying units by seismically identifiable unconformities (Townson, 1985; Perincek, 1997). This led Perincek (1997) to correlate the unit with the McFadden Formation, which outcrops in the Savory area. Apak and Moors (2000b, 2001) considered the unit to be a lateral equivalent of the McFadden Formation in the Yowalga and Lennis areas, and referred to it as McFadden Formation equivalent.

The lithologies of the McFadden Formation equivalent are poorly known in the Gibson area; Hussar 1 was the only well to penetrate the formation (101–560 m; Fig. 16). In some areas, such as salt-withdrawal rim synclines adjacent to diapiric features, lithologies may be different due to inclusion of the strata being uplifted by the movement of salt. Typically, the McFadden Formation equivalent consists of medium- to coarse-grained sandstone, minor shale and siltstone, and represents prograding deltaic to shallow-marine shelf depositional environments (Williams, 1992; Perincek, 1997).

Studies on the POISONBUSH 1:100 000 map sheet (Williams and Bagas, 2000) suggest that the McFadden Formation has been weakly deformed during the closing stages of the Paterson Orogeny, which is correlated with the Petermann Orogeny of central Australia (Bagas et al., 1995; Perincek, 1997; Tyler et al., 1998).

Based on seismic data in the Gibson area, the base of the McFadden Formation equivalent is characterized by a major unconformity — here referred to as the Base McFadden Formation unconformity — that overlies the Wahlgu Formation or older units (Fig. 17). In areas adjacent to salt emplacements, this unconformity is angular (Fig. 17, SP 2800–2900), whereas in other areas distant from salt walls, the contact between the Wahlgu Formation and McFadden Formation equivalent is disconformable (Fig. 18, SP 4400). The contact of the McFadden Formation equivalent with the overlying Table Hill Volcanics is also unconformable (Fig. 18, SP 4400). The Table Hill Volcanics are limited to the eastern part of the Gibson area (Fig. 7), which is attributed to substantial erosion post-dating its extrusion, probably during the Palaeozoic Rodingan Movement and Alice Springs Orogeny (Fig. 18, SP 4280–4400). The upper contact of the McFadden Formation equivalent in the southern part of the Gibson area is unmappable due to poor seismic resolution. In this area, a thin cover of sedimentary rocks belonging to the Palaeozoic and Mesozoic Gunbarrel Basin, or younger deposits, overlies the formation.

In some areas, such as on seismic line N83-11 between SP 2700 and 2900 (Fig. 17), salt movement took place along a fault-controlled fold axis prior to the deposition

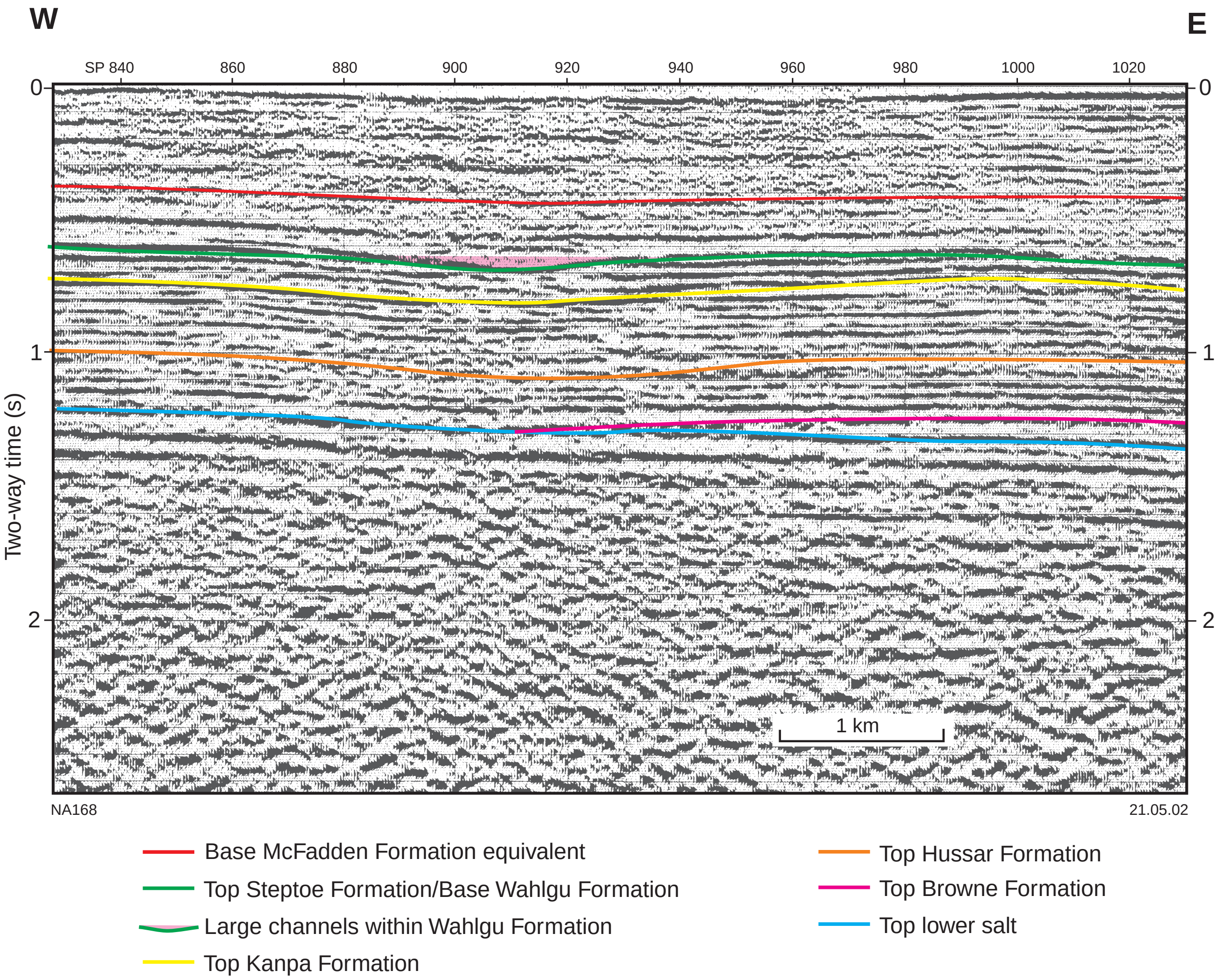

Figure 13. Seismic line N83-11 showing a channel incised into the Steptoe Formation. For location of seismic line see Figure 7

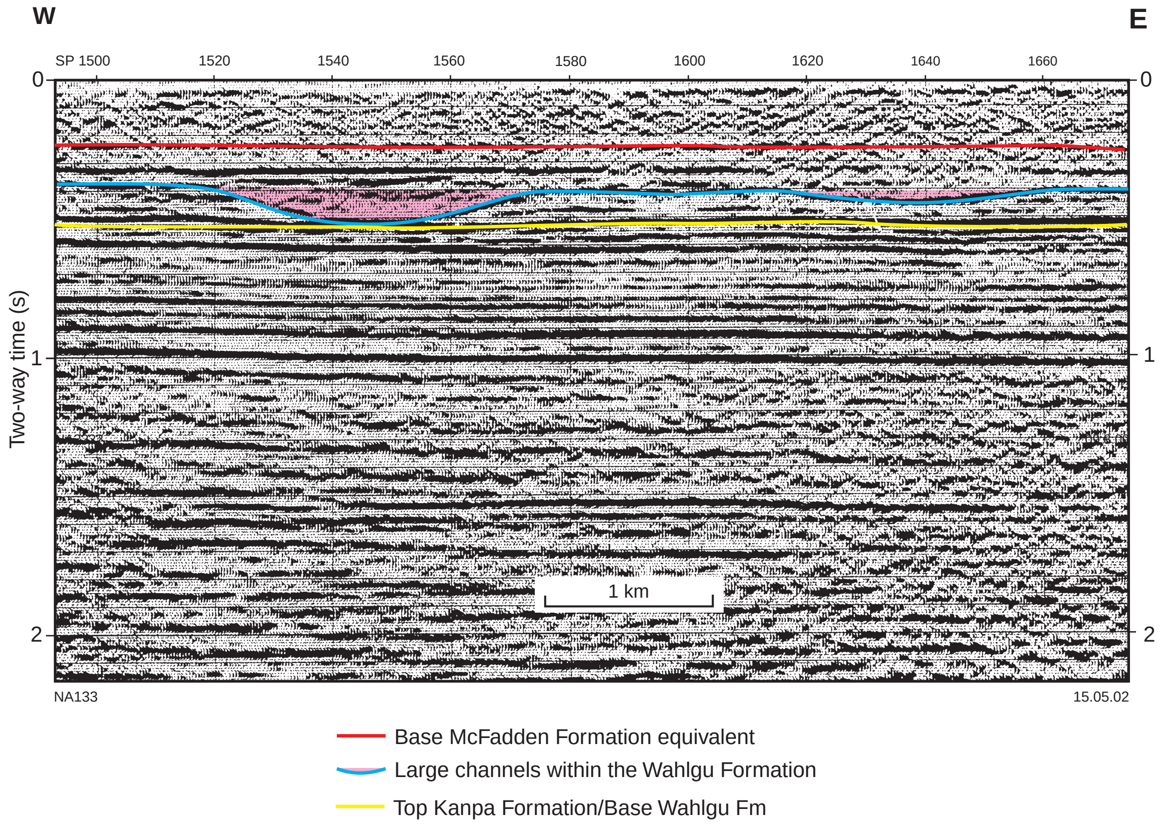

Figure 14. Seismic line N83-8 showing deep channels, which incised into the Steptoe Formation, within the Wahlgu Formation. For location of seismic line see Figure 7

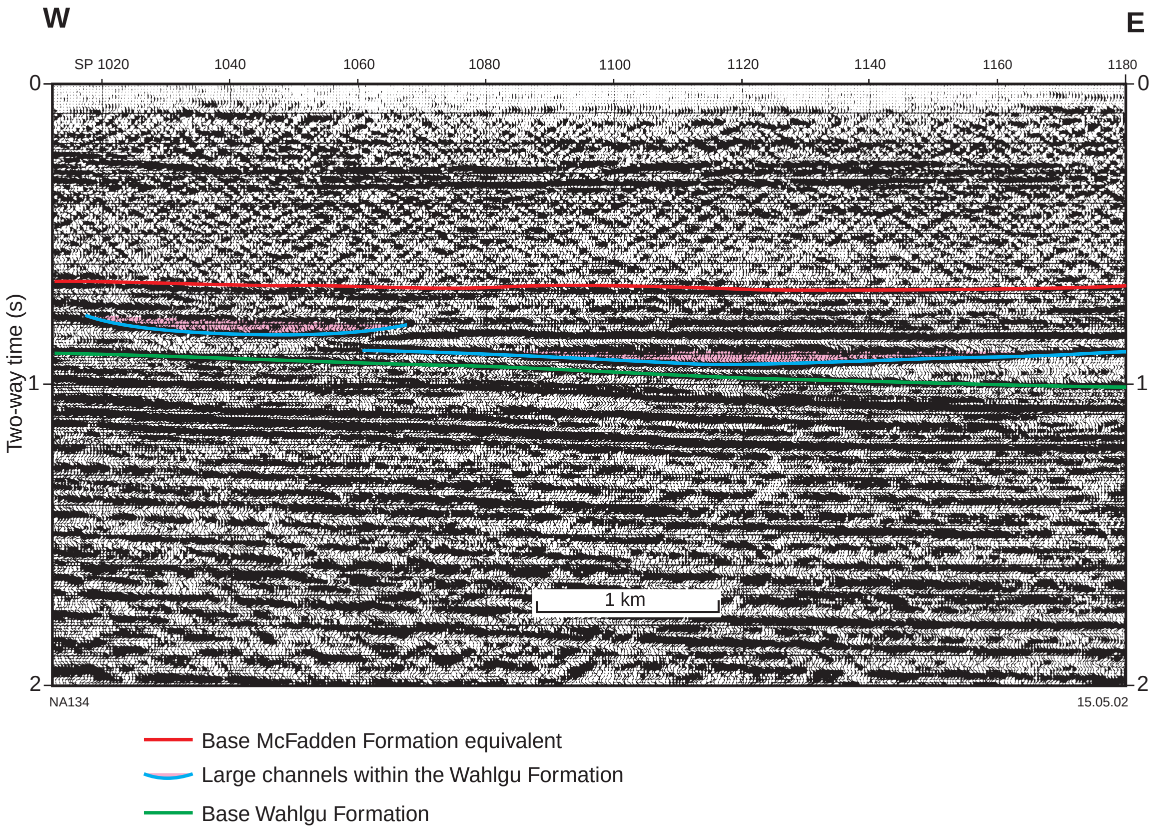

Figure 15. Seismic line N83-7 showing very large channel development within the Wahlgu Formation. Note the potential seal at the top of channels. For location of seismic line see Figure 7

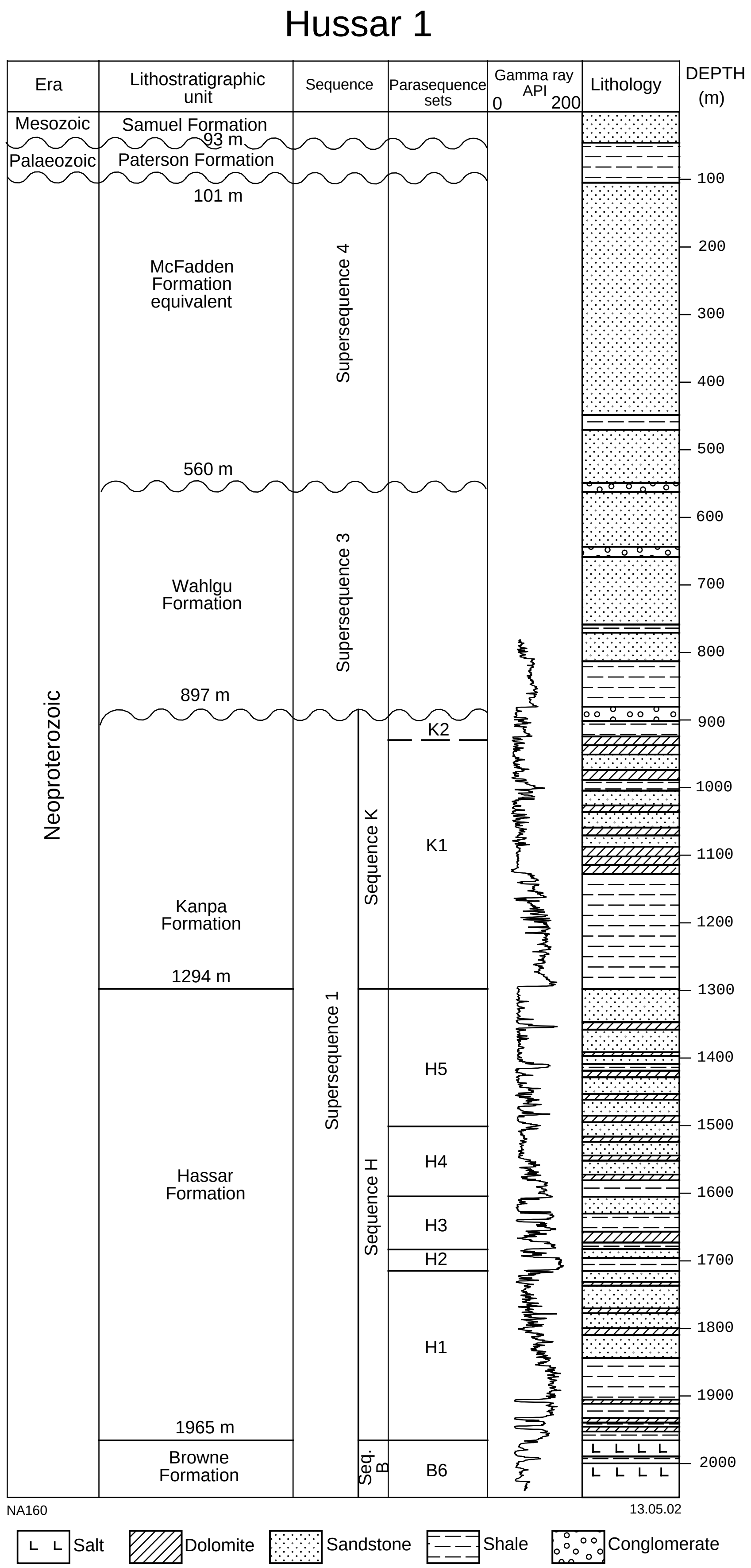

Figure 16. Hussar 1 simplified composite log, showing sequence-stratigraphic and lithostratigraphic units

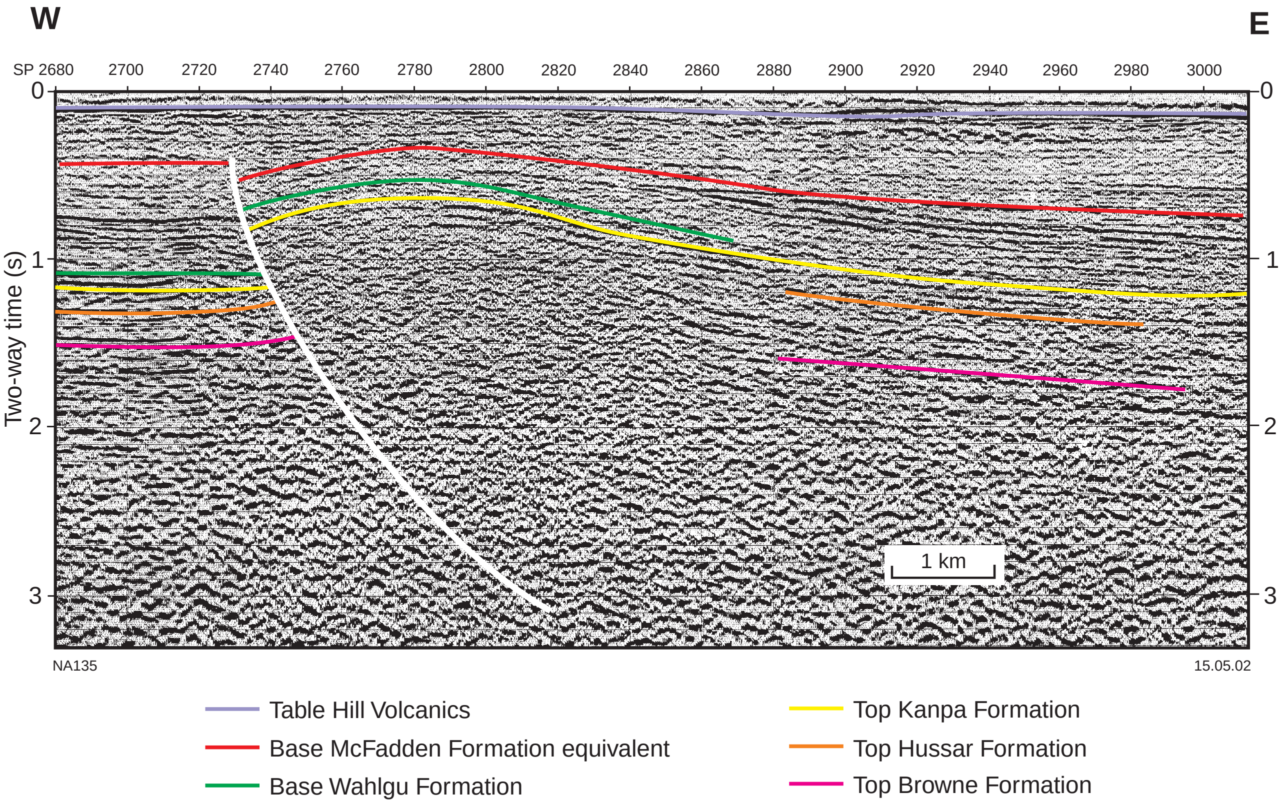

Figure 17 Seismic line N83-11 showing an angular unconformity between the Wahlgu and the McFadden Formation equivalent. The Wahlgu Formation is deeply eroded in this location. For location of seismic line see Figure 7

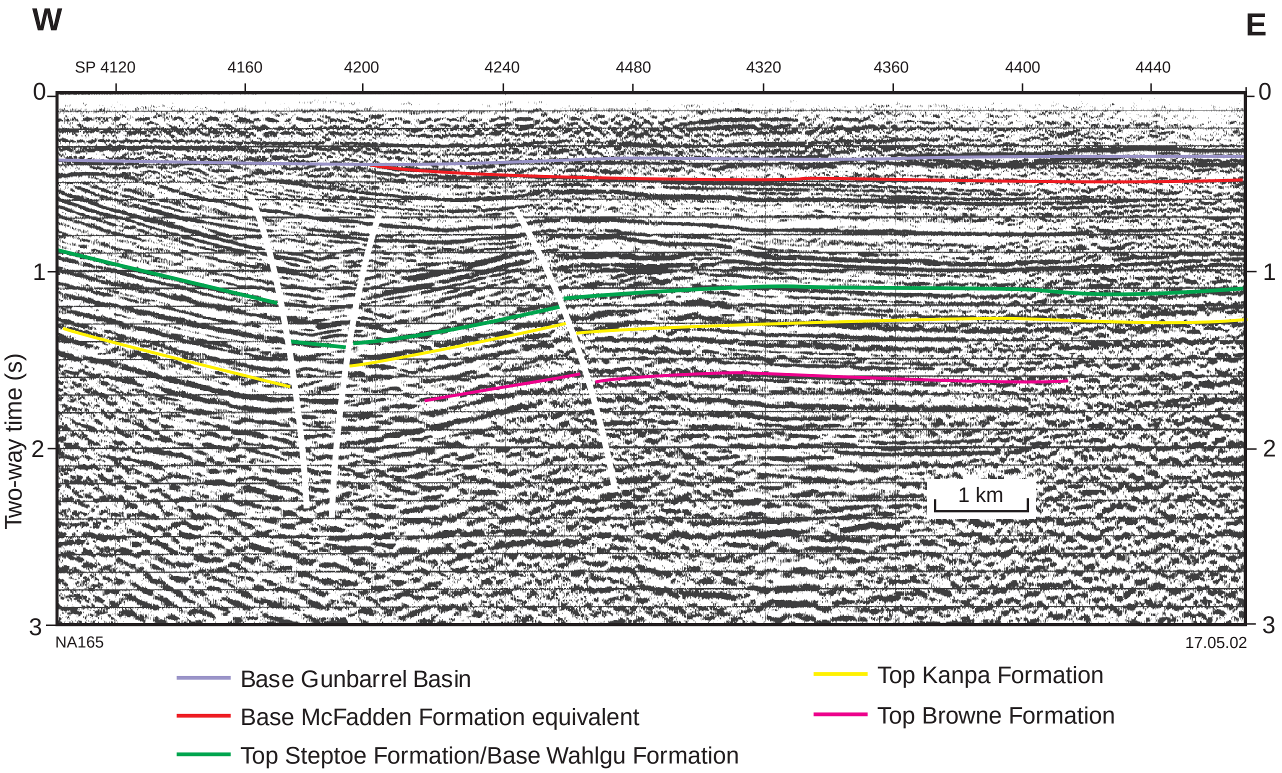

Figure 18. Seismic line N83-2 (SP 4400) showing disconformable relationships of the McFadden Formation equivalent with the Wahlgu Formation below, and the Table Hill Volcanics above. For location of seismic line see Figure 7

of the McFadden Formation equivalent. Thinning and onlapping of the formation over the underlying unconformity clearly indicates the timing of deformation (Fig. 17). However, elsewhere, late diapiric salt movement has pierced the overlying strata, upturning it and resulting in relatively high dips (Fig. 19, SP 540–760). In some areas, the formation (Fig. 20) and the entire underlying succession are folded, significantly displaced, and truncated by later deformation. These more regional truncation events are better seen towards the west where the McFadden Formation equivalent has in places been removed entirely (Fig. 7). Other than these erosive areas, the depositional thickness of the formation thins towards the west.

Palaeozoic succession

Table Hill Volcanics

Extrusion of the Table Hill Volcanics marks the commencement of a new depositional cycle, which is assigned to the Gunbarrel Basin (Hocking, 1994). The Table Hill Volcanics outcrop on the northeastern margin of the basin, near the South Australian border, but can be correlated seismically over a large portion of the western Officer Basin. The formation may have once extended across the Gibson area, but later erosion has mostly removed it (Figs 7 and 18). They consist of porphyritic and amygdaloidal tholeitic basalt for which various ages have been proposed; K–Ar and Rb–Sr dating methods provided a 575 ± 40 Ma age for the basalts (Compston, 1974), whereas later workers proposed a Middle to Late Cambrian age (Moussavi-Harami and Gravestock, 1995; Perincek, 1997). Recent K–Ar radiometric dating of samples from Empress 1 and 1A (AMDEL, 1999) indicates an Early Ordovician age of 484 ± 4 Ma.

Thin deposits of Permian and Cretaceous rocks, together with Cainozoic deposits overlie the western Officer Basin. These deposits do not have any hydrocarbon potential in the Gibson area.

Sequence stratigraphy

In the Gibson area, the presence of only one well for control of the Officer Basin succession precludes regional sequence stratigraphic analysis. However, the availability of a reasonably good dataset in the adjacent Yowalga area, immediately to the southeast of the Gibson area, is a starting point for an attempted sequence stratigraphic study. This data consists of deep exploration wells, core data (in particular from Empress 1 and 1A) and seismic lines. Figure 16 illustrates the lithostratigraphic and the sequence-stratigraphic units in Hussar 1. The similarity in seismic character of the Officer Basin succession in both the Yowalga and Gibson areas suggests that the same sequence stratigraphic hierarchy persists into the Gibson area. Unfortunately, the quality and quantity of seismic data do not allow correlation at all levels and we have therefore not attempted a detailed study for the Gibson area.

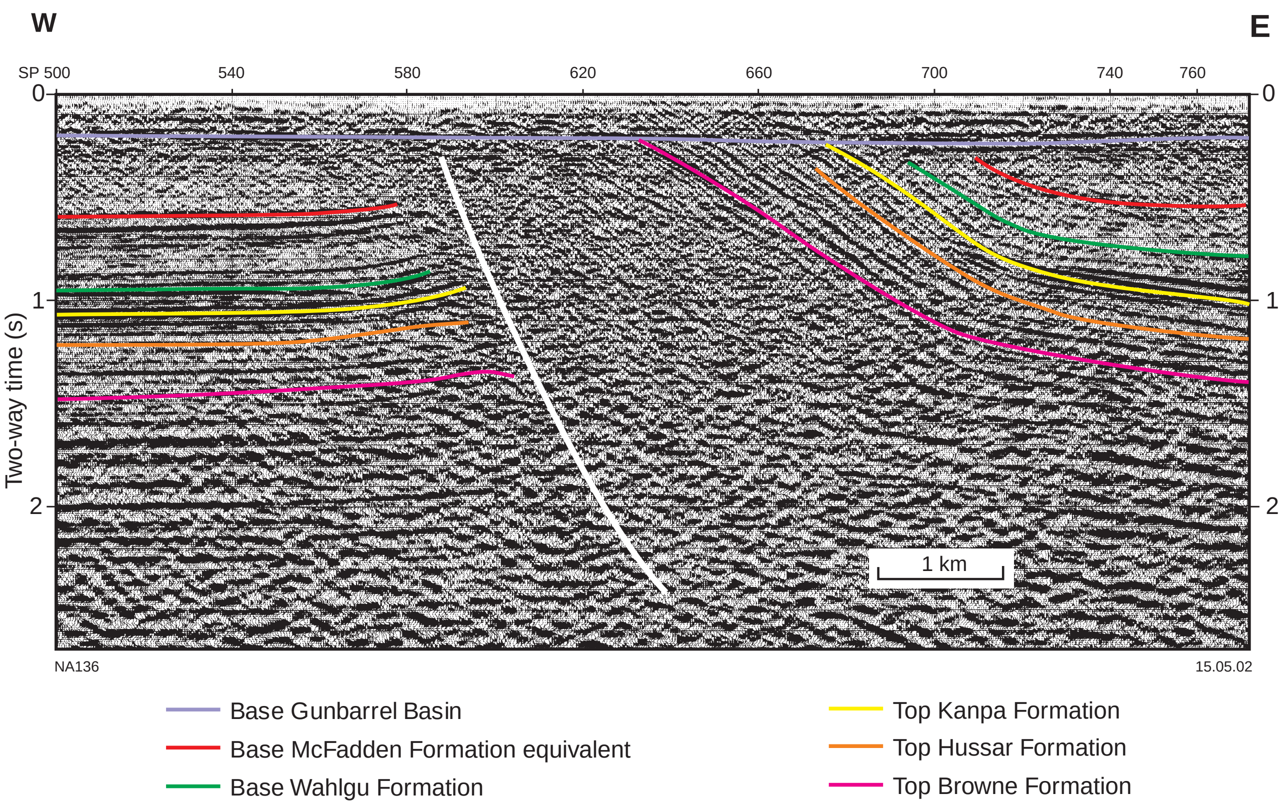

Figure 19. Seismic line N83-7 showing late-stage salt emplacement and erosion of Supersequence 1 strata, Wahlgu Formation, and McFadden Formation equivalent. For location of seismic line see Figure 7

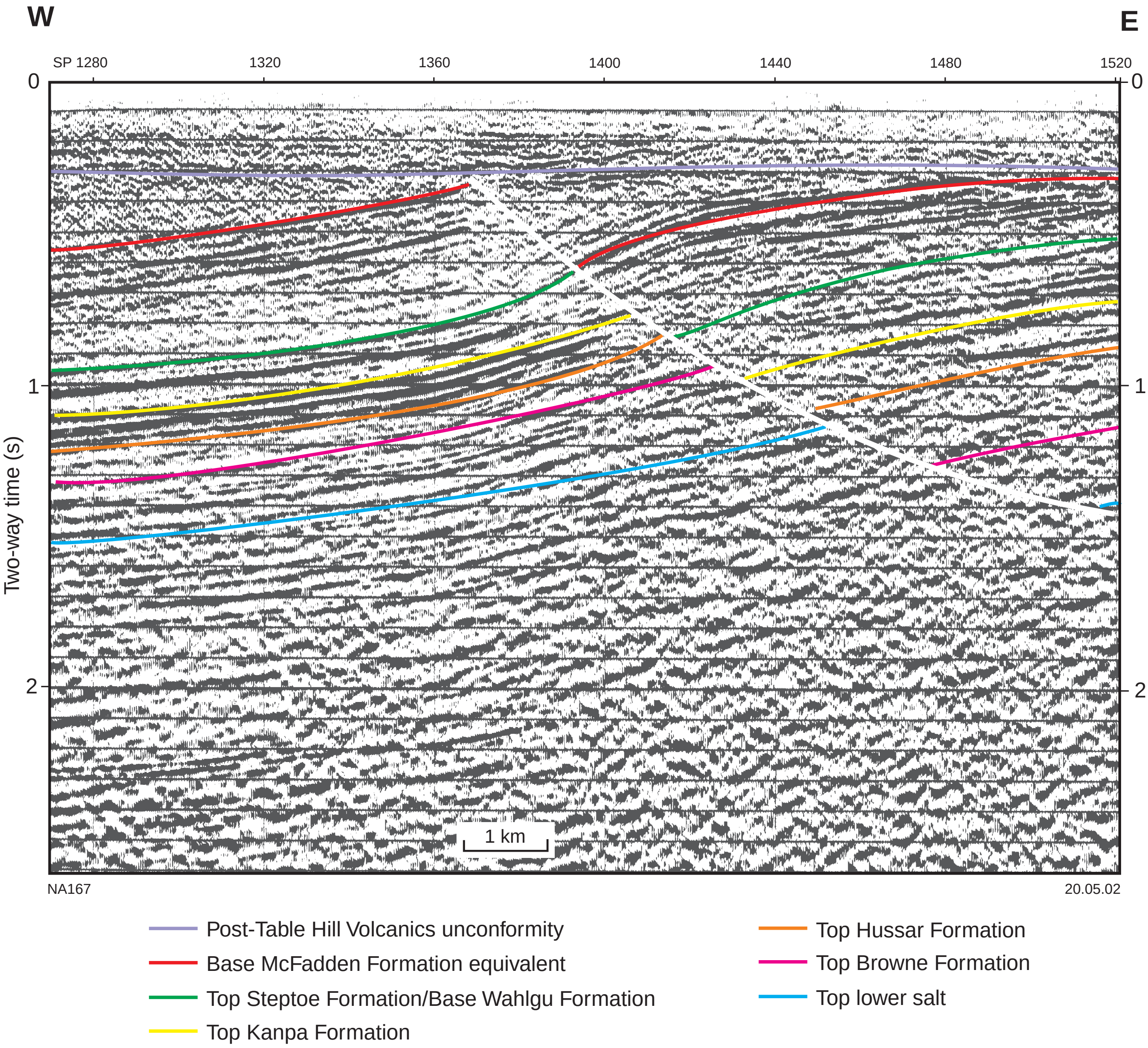

Figure 20. Seismic line N83-7 showing late faulting event post-dating the McFadden Formation equivalent. Faulting event resulted in significant displacement of Supersequence 1 strata, Wahlgu Formation, and McFadden Formation equivalent. The McFadden Formation equivalent was eroded and later covered by the younger Gunbarrel Basin strata. For location of seismic line see Figure 7

The sequence stratigraphy of the Yowalga area (Apak and Moors, 2000a,b) provides a rationale for the evaluation of basin history and petroleum potential of the Gibson area. A brief summary of facies and lithologies of each sequence is presented, with the understanding that although details may change, lithological associations should remain similar between the two areas. The lower two units of the Officer Basin succession — the Townsend Quartzite and Lefroy Formation — lack adequate control, and therefore only the overlying Browne to Steptoe Formations are reviewed here.

Within the Browne Formation (Sequence B) in the Yowalga area, six parasequence sets have been identified in well intersections and are correlateable on seismic data over wide areas (Apak and Moors, 2000a,b). The same seismic character in the Gibson area suggests that the Browne Formation is composed of similar parasequence sets, some of which may be continuous between the two regions. Each depositional cycle commenced with a basal transgression, followed by dominantly shallow-water facies in distal areas and sabkha to restricted-hypersaline and shallow-water facies in proximal areas.

Within the overlying Hussar Formation (Sequence H), five parasequence sets have been identified in well intersections and can be correlated seismically over wide areas (Apak and Moors, 2000a,b), including the Hussar 1 (Figs 11 and 16) area. The dark-grey mudstone at the base of each parasequence in the Yowalga area was probably deposited in a quiet environment, below storm wave-base. These deposits indicate rapid and widespread transgression, suggesting relative sea-level rises. Sandstone horizons exhibit mostly sharp upper and lower surfaces and represent high-energy depositional events in a shallow-marine environment, probably shoreface to lower shoreface. They are interbedded and overlain by laminated to thinly bedded, shelf to lagoonal mudstone facies. The seismic character in the Gibson area suggests that the Hussar Formation consists of cycles similar to those described in the Yowalga area.

In the Yowalga area, two parasequence sets are present in well intersections within both the Kanpa Formation (Sequence K) and Steptoe Formation (Sequence S), and can be correlated using seismic data over wide areas. However, in some places the Steptoe Formation was severely eroded during the Areyonga Movement and Petermann Ranges Orogeny, and therefore cannot be correlated laterally with confidence. As discussed above, the similar seismic characters in the Gibson area suggest that the Kanpa and Steptoe Formations probably comprise similar parasequence sets to those identified in the Yowalga area (Figs 12 and 16).

Geophysics

Geophysical coverage of the Gibson area includes gravity, magnetic, radiometric, and seismic surveys. More specific data on individual surveys can be found in Perincek (1998). Below is a discussion of our interpretation of the available seismic data, and of the interpretation by Durrant and Associates (1998).

The first recognition of sub-basins within the Officer Basin was based on field mapping and potential-field (gravity and aeromagnetic) data, which was conducted by BMR in 1954 using 3000 km-long aeromagnetic traverses. Union Oil carried out an aeromagnetic survey (line spacing 1600 m; flying height 300 m) in 1965 that covered most of the Gibson area. The southern part of the area was covered by an aeromagnetic survey (line spacing 3000 m; flying height 150 m) conducted by BMR in 1975–76. They also carried out regional (11 km grid) gravity surveys within the area between 1962 and 1971.

Later, seismic surveys and oil exploration drilling in the western Officer Basin provided additional control points. However, potential-field solutions are model dependent and substantial adjustments have had to be made to depth-to-basement maps following stratigraphic drilling. The potential-field data of the Lennis Sub-basin is not supported by seismic data for the Neoproterozoic section (Apak and Moors, 2001). Similarly, the Gibson Sub-basin was also originally defined by the potential-field data as a sedimentary trough (Phillips et al., 1985). However, seismic data show that the Officer Basin succession gradually thins towards the basin's margin (Plate) without any significant local depositional thinning or thickening. The gravity lows within the Gibson area (Plate) are sedimentary successions that include substantial pre-Officer, Officer, and post-Officer Basin strata. Late Mesoproterozoic rocks that may be part of this succession (the Salvation Group) are described by Hocking and Jones (in prep.). Therefore, there is no evidence to separate the Neoproterozoic strata of the Gibson area as a depocentre distinct from the Yowalga and Lennis areas to the southeast.

Seismic data

Seismic control in the Gibson area is very limited. The 1983 seismic survey (News Corporation Ltd, 1983) provided a grid of four dip lines and four strike lines spaced about 50 km apart (Fig. 3). In addition, two small areas of detailed seismic were acquired, with a line spacing of about 10 km. Consequently, structural control on time-structure maps is very loose, and comments about structural closure or thickness trends are tenuous.

GSWA contracted Durrant and Associates (1998) to provide an interpretation of the seismic data, using final stack processed sections and migrated processed sections where available. This seismic data was tied to the synthetic seismograms of Hussar 1, Dragoon 1, and Kanpa 1A, using formation tops interpreted by GSWA. The following horizons were interpreted in the Gibson area by Durrant and Associates (1998): Lennis marker, Top McFadden Formation equivalent, Base McFadden Formation equivalent, Top Steptoe Formation, Top Kanpa Formation, Top Hussar Formation, Top Browne Formation, Intra-Browne Formation marker (near-top mobile salt), near-base salt (Browne Formation), and near-Base Neoproterozoic. Only selected horizons are included in this study (Plate). Steep dips induced by salt diapirism produced data out of the plane of the seismic sections, therefore making interpretation in their proximity difficult. This is especially apparent on the seismic lines acquired parallel to the main salt walls in the northern portion of the area (Plate). These walls disrupted the sedimentary succession and necessitated jump-correlating seismic events to continue the interpretation across them. This methodology, though reasonable in most cases where there are sufficient seismic data (Durrant and Associates, 1998), is unreliable in the Gibson area where there are widely spaced regional seismic lines.

Data coverage

In 1981, Swan Resources conducted the Geoflex-sourced Gibson North and South Seismic Surveys, comprising four short seismic lines totalling 106 km (Fig. 7; Plate). News Corporation conducted the Traeger Seismic Survey in 1983, which comprised 11 regional Thumper-sourced lines totalling 1063 km. Most of this survey consisted of widely spaced, long regional lines that exceeded 100 km. In 1984, News Corporation conducted two small detailed reflection surveys, the Hancock and Salt Pan Seismic Surveys, which comprised 17 short Thumper-sourced lines that totalled 270 km.

Data quality

The quality of the early 1980s seismic data is moderate for most parts of the basin (Fig. 17; Perincek, 1997), with the exception of some 1981 seismic data. Strong amplitude events that represent the major unconformities (e.g. Fig. 18, Base Table Hill Volcanics, SP 4400) and transgressive surfaces associated with the parasequences, can mostly be correlated with confidence. However, they are discontinuous in some places, mainly due to salt emplacement and complex faulting particularly in the northern margin of the Gibson area. In the adjacent Yowalga area, Japan National Oil Corporation (1997) reprocessed similarly acquired seismic data with dramatic improvement in quality (Apak and Moors, 2000b). Modern reprocessing should also improve the data in the Gibson area to a comparable quality.

Structural interpretation

The Officer Basin has been affected by a number of regional events (Fig. 6). Major structures (Fig. 1) were present in the basement rocks before Neoproterozoic deposition commenced (Myers et al., 1996), and deformation of the Officer Basin was at least partially controlled by these basement structures during subsequent tectonic events. However, none of these tectonic phases were particularly severe in the Gibson area. The presence of relatively poor seismic data, salt emplacements, and faulting in the western part of the area has resulted in only approximate correlation of Officer Basin strata between the salt features.

Faulting

The northwestern part of the Gibson area adjoins the Paterson Orogen, which consists of multiply folded and thrust-faulted sedimentary and igneous rocks of Proterozoic age (Hickman and Bagas, 1999). In contrast to the Yowalga and Lennis areas (based on seismic studies by Durrant and Associates, 1998), faulting is more localized in the Gibson area, and faults are fewer, but have larger offsets associated with basement structures and salt movements (Plate). All available seismic data in the area indicate that the faults are associated with a compressional regime, as indicated by the presence of thrust and strike-slip faults (e.g. Figs 17 and 18).

Erratic thickness variations of some units, both in the hangingwall and footwall of some faults, is interpreted as evidence of periodic syndepositional strike-slip faulting. For example in Figure 21, between the Base Neoproterozoic and the near-base salt horizons, the lower part of the Browne Formation is significantly thicker on the downthrown block. In contrast, the overlying near-base salt – top lower salt interval is thicker on the upthrown block. Post-Supersequence 1 reactivation of this fault resulted in substantial erosion of the Steptoe Formation on the upthrown block, and later reactivation caused minor displacement of the Base McFadden Formation unconformity.

Another fault with possible strike-slip movement, seen in seismic line N83-2 (Fig. 18) probably formed by the reactivation of an older basement offset. This fault has a complex shape, and the thick section of Wahlgu Formation that overlies the fault area indicates that it is a negative flower structure. This gently folded structure was truncated during a post-Wahlgu Formation erosional phase. Between SP 4120 and 4200, the Base McFadden Formation unconformity truncates the Base Wahlgu Formation unconformity and underlying formations. The same seismic section (between SP 4200 and 4460) also shows that a younger structural event, or events, interpreted as either the Rodingan Movement or Alice Springs Orogeny, or both, caused severe erosion of the Table Hill Volcanics and the McFadden Formation equivalent (Fig. 18). Substantial truncation of the Wahlgu Formation beneath the Base McFadden Formation unconformity is also seen on seismic line N83-11 at SP 2900 (Fig. 17).

Many of the compressional faults are high-angle reverse faults, even though they exhibit a listric geometry. Seismic line N83-11 (Fig. 17) shows thrust faults associated with salt emplacement that predated or were synchronous with the basal part of McFadden Formation equivalent. Earlier salt emplacement is evident by folding of the Wahlgu Formation and erosion of the crest of the fold, prior to deposition of the McFadden Formation equivalent. This angular unconformity is only apparent where it is associated with salt diapirs. On seismic line N83-7 (Fig. 19), thrusting and associated diapirism penetrated Supersequence 1, the Wahlgu Formation, and the McFadden Formation equivalent. These observations demonstrate that various styles of structural reactivation took place at different times along the structural trends in the Gibson area.

In Figure 20 a normal fault interpreted by Durrant and Associates (1998) post-dates the McFadden Formation equivalent and shows significant displacement of strata. However, thickness variations of picked horizons across the fault indicate multiple reactivations. Unfortunately, the quality and resolution of seismic data, particularly in the northern part of the Gibson area, is poor to very poor. The age, style, and orientation of the faults in the northern area are poorly controlled, but they probably have a similar age to the faults in other parts of the basin. The linearity and orientation of the salt walls in the Gibson area is similar to the Lennis area, and suggests that they are fault controlled.

Folding

Tectonic folds in the Gibson area are gentle to open and of low amplitude, reflecting the low strain nature of the deformation. The limited seismic control over the area means that the nature, size, and distribution of folds can not be fully defined. In the Gibson area the largest and highest amplitude structures are associated with salt movement. Most of the folds recognized are associated with drape over deeper salt-enhanced features. For example, seismic line N83-11 (Fig. 17) shows a low-amplitude fold with an amplitude in excess of 100 msec. On seismic line N83-7 (Fig. 19), folding is a result of late salt emplacement. These emplacements do not always penetrate the complete Officer Basin succession, so four-way dip closure is sometimes present. More commonly, however, diapirism at the deeper horizons is complete and the initial anticlinal trap is split into two facing, salt-sealed three-way dip closures.

Salt movement

The wide spacing and orientation of seismic lines in the Gibson area (Plate) does not provide a complete picture

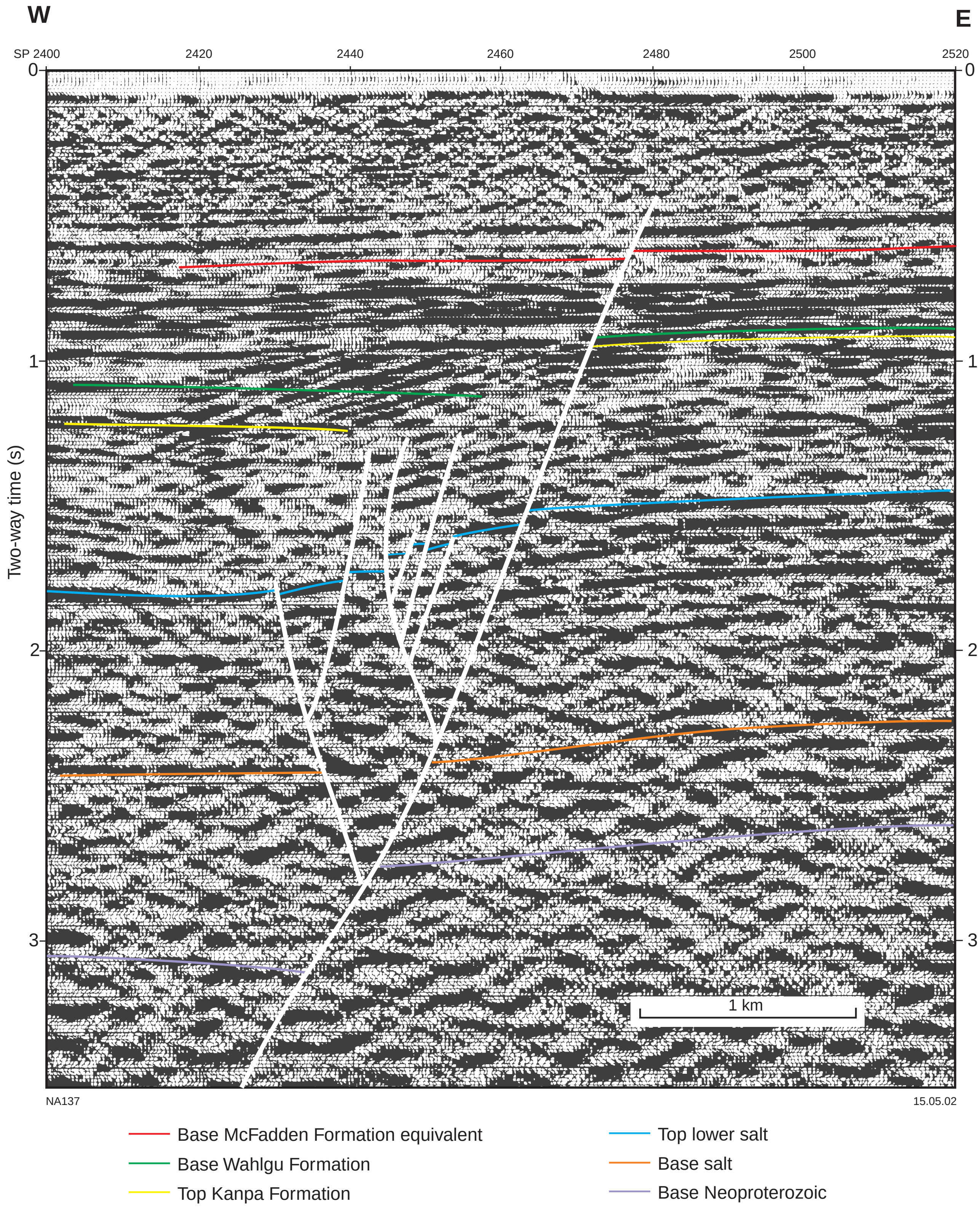

Figure 21. Seismic line N83-6 showing late strike-slip faulting event post-dating the Wahlgu Formation and displaced base McFadden Formation equivalent unconformity. Note that the Steptoe Formation was eroded on the upthrown side of the fault block. For location of seismic line see Figure 7

of the distribution of salt in the Browne Formation. For example, seismic line N83-002 (Plate) runs parallel to a salt wall that passes in and out of the section; the apparent large areas of salt are due to the proximity of the seismic line to this feature. Durrant and Associates (1998) mapped a large area of salt intrusion in the northwestern part of the region (Plate). This is based on the presence of incoherent reflectors, not solely the result of mobile salt. The incoherence could be partly or wholly due to surface conditions or structural complexity, the effects of which could be removed by better processing

The BMR first identified diapiric evaporites in the Officer Basin from aerial photography and geological mapping. Alliance Petroleum Australia NL mapped the ‘Madley line’ of diapirs (Wilson, 1967); a linear trend of diapiric features extending for 65 km with various degrees of salt penetration. The central six diapirs show the maximum invasion, some having a salt core (now a residual gypsum cap) exposed at the surface. The flanking structures contain overlying deformed Paterson Formation, and show displacement of the Tertiary laterite profile, suggesting repeated phases of injection that has continued to the present time. Salt movement, however, did not persist for this length of time at all locations. Where the ‘Madley line’ intersects the seismic grid east of Dragoon 1, the Paterson Formation is flat lying and onlaps a residual salt-induced high (Fig. 18, SP 3960–4060). Clearly, salt movement ceased before the Paterson Formation was deposited, with no later rejuvenation.

The existence of laterally persistent salt diapirs on the surface provides greater confidence for the interpretation of these features on seismic sections. Extensive salt walls have been mapped from potential-field and seismic data in the Yowalga area (Apak and Moors, 2000b) and on closely spaced seismic in the Lennis area (Apak and Moors, 2001). These walls probably have a common origin as they are located on the same structural trend along a 500 km stretch of the northern edge of the western Officer Basin. Based only on limited seismic control, a tentative interpretation is that the salt moved along faults paralleling the basin margin.

Structures produced by salt movement in the Yowalga (Apak and Moors, 2000b), Lennis (Apak and Moors, 2001), and Gibson areas are similar. All the salt-associated features seen in both the Yowalga and Lennis areas are found in the Gibson area. These include salt walls described above, individual diapirs (e.g. Woolnough diapir), complex salt-injected listric thrusts, simple salt-lubricated thrusts, salt swells, salt welds, and salt rollers. Rim synclines in the Wahlgu Formation and McFadden Formation equivalent are also present and are useful indicators of the timing of salt movement. Because of the sparsity of seismic data in the Gibson area, the clearest examples of these are found in the Lennis area, where timing of movement is best observed.

The major conclusions deduced from the Lennis area (Apak and Moors, 2001) are as follows. The Areyonga Movement initiated the first mobilization of salt in the Gibson area, but significant flow also took place during a number of subsequent tectonic phases. This can be seen in the multiphase movement of salt-lubricated faults, such as the listric fault on seismic line N83-11, between SP 2700 and 2900 (Fig. 17). Clearly, the major displacement post-dates the Wahlgu Formation, with Supersequence 1 strata thrust over itself. Further salt movement, post-dating the deposition of the McFadden Formation equivalent, is shown in Figure 20. Salt movement folded the Supersequence 1 strata, Wahlgu Formation, and McFadden Formation equivalent before cessation. After peneplanation, the younger Gunbarrel Basin strata were deposited over the area.

The deposition of a substantial thickness of Supersequence 3 (Wahlgu Formation) and Supersequence 4 (McFadden Formation equivalent) successions probably accounts for the continued mobility of the salt (depositional loading). As already mentioned, salt movement also displaces the Paterson Formation and even the Tertiary laterite profile in the Madley diapirs, suggesting that in some regions minor salt movement may have continued up to the present time.

Structural history

A number of basin-forming models have been proposed for the origin of the Officer Basin (Lambeck, 1984; Walter and Gorter, 1994; Zhao et al., 1994; Carlsen et al., 1999). The sequential evolution of the Officer Basin, and particularly the Yowalga and Lennis areas, was discussed by Apak and Moors (2000a,b, 2001).

Most of the models above envisaged a sag-basin origin, and some proposed that the Officer Basin was part of a seamless Centralian Superbasin that extended over 2000 km in length (Walter et al., 1995). Although in agreeance with the contemporaneity of these Neoproterozoic basins, Apak and Moors (2000b) proposed that the Officer Basin was a discrete entity, with unique architecture and history. Evidence presented in this Report emphasizes local variation in structural style and timing, and lateral facies variation within depositional units.

Apak and Moors (2000b, 2001) highlighted the lateral facies variation within Supersequence 1 strata, as illustrated from seismic and drillhole examples. They interpreted these variations as having formed by asynchronous structural deformation across the basin. Although absolute dating is poor in the Officer Basin succession, the variable rate and the long duration of subsidence suggest a prolonged or sequential deformation event, or events, rather than a decaying thermal regime. Subsidence was probably intermittent, characterized by abrupt water-depth increases followed by rapid sedimentary progradation across the basin. The cycles are typified by a basal transgressive quiet-water facies (fine-grained lithology) followed by a shallowing coarsening-upwards facies. Supersequence 1 comprises a series of such cycles, as illustrated by Apak and Moors (2000b, 2001).

Apak and Moors (2000b) proposed that the Officer Basin was a foreland basin, with subsidence initiated by intermittent loading of the thrusted northern margin. A few seismic lines elucidate basement structure and demonstrate a tectonically interleaved thrusted-basement complex (e.g. Fig. 4). None of the seismic data in the Officer Basin demonstrates large-scale normal faulting, though many faults exhibit listric geometry that suggest thrust- or normal-fault kinematics (Fig. 17) and a combination of thin- and thick-skinned deformation. Strike-slip or transcurrent fault movement is apparent from the fault and fold geometry (Fig. 21) and sedimentary architecture. Halokinetic deformation has modified the geometry of many of the basin structures, making it difficult to determine their tectonic style. The basin dynamics are not yet fully understood from outcrop, or seismic data. Sedimentary architecture has therefore proved a powerful tool in defining the history of the Officer Basin.

In the absence of well data, time–structure maps have been used to investigate structural geometry, in particular basement control on structure and stratigraphy. The following summary is based on currently available geophysical data, including interpreted seismic lines and time–structure maps (Plate) produced by Durrant and Associates (1998). The same structural conclusions are shown as a fence diagram (Plate), constructed from the regional seismic lines.

The oldest-known stratigraphic units of Supersequence 1 are the Townsend Quartzite and the overlying Lefroy Formation. Since well data are lacking and the quality of seismic reflectors from such deep horizons is poor, an interpretation was not attempted for these basal units in the Gibson area.

The overlying Browne Formation is better understood; several wells have intersected the formation — although only Kanpa 1A and Empress1A in the Yowalga area have penetrated the entire unit — and better quality seismic reflectors can be mapped at this level. The presence of diapiric injection and salt-lubricated thrust faulting has resulted in structural complexity, which makes seismic interpretation difficult.

Due to the overall poor quality of seismic data, only selected horizons will be discussed in this section.

Near-Base Neoproterozoic horizon

Because the near-Base Neoproterozoic is a deep horizon commonly masked by overlying salt, this marker is not a prominent reflector. Its resolution is further complicated by the fact that the Officer Basin succession lies, in part, on an apparently similar bedded succession (Plate, seismic line N83-8) of Mesoproterozoic sedimentary rocks. However, where the contact relationship is angular, the horizon can be picked with more confidence (Fig. 4). This horizon can be recognized in the southern portion of the mapped area (Plate, seismic line N83-8), whereas most of the northern portion is masked by massive salt bodies. Seismic line 83-3A, however, shows the contact between the Officer and underlying basins strata. Based on the time–structure map (Plate) of the southern part of the area, the horizon dips gently towards the north.

Few faults displace the near-Base Neoproterozoic horizon (Plate), suggesting that many of the faults identified in shallower horizons sole out in the salt-rich Browne Formation.

Near-base salt horizon

The near-base salt horizon is a poor reflector; however, it is picked as the base of a variably thick salt package. The time–structure map indicates that the horizon dips regularly towards the northeast (Plate). A synclinal axis is shown along seismic line N83-7 (Plate), although there are little data on its precise location and orientation. Faults present in the near-Base Neoproterozoic horizon may persist to this level. Better seismic resolution is required for any further interpretation, particularly in the north of the area.

Top Browne Formation horizon

The Top Browne Formation horizon has a much gentler northeasterly dip than the underlying horizons (Plate). It reflects a thinning of the Officer Basin succession towards the southern and western margins of the basin, and is strongly contorted by salt-piercement features in the north. Invasion and evacuation of salt also affects structures in both the upper and lower salt-rich intervals. The Hussar 1 structure was initiated by salt swells in the lower Browne Formation and enhanced by a salt weld in the near-top mobile salt horizon. Relief of the closure is approximately 300 msec over a large loosely controlled area on seismic line N83-6 at 1200 msec (Fig. 8). Other one-line high features with relief in the order of 100 msec are indicated on seismic line N83-11 (Plate). Possible salt-sealed three-way dip closures can also be ascertained elsewhere.

Top Hussar Formation and Top Kanpa Formation horizons

Because of the relative uniformity of the Top Hussar and Top Kanpa Formations across the Gibson area, these horizon maps show similar features to the Top Browne Formation. The faulting and structure of the top Browne Formation is replicated in both horizons.

Top Steptoe Formation horizon

The Top Steptoe Formation was mapped as a horizon below the Base McFadden Formation equivalent (Durrant and Associates, 1998). However, in the Yowalga and Lennis areas (Apak and Moors, 2000b; Apak and Moors, 2001) this horizon shows deep erosional features, which correlate to the similar seismic character of the Base Wahlgu Formation unconformity. Therefore, we interpret the unit that overlies the Steptoe Formation as the Wahlgu Formation instead of the McFadden Formation. The location and shape of structures and faults at the Top Steptoe Formation horizon are very similar to the underlying horizons, with salt movement taking place during and after the Areyonga Movement (see Fig. 17).

End of Supersequence 1

Following the Areyonga Movement, gentle subsidence coincided with deposition of the glacigene Wahlgu Formation in the early Marinoan (Grey et al., 1999). Although tillites have been described within the unit (Jackson and van de Graaff, 1981), these are now interpreted as poorly sorted mass-flow deposits of a submarine fan (Carlsen et al., 1999). Although striated and faceted pebbles are present, we consider they are more representative of the provenance of the material than the environment of deposition. The massive sandstone, cross-bedded sandstone, and minor laminated sandstone and diamictite seen in outcrop and in Empress 1 and 1A are interpreted as mass-flow or turbidite deposits. Local topographically high salt-injection features could also be a substantial source of redeposited material. Following deposition of the Wahlgu Formation, the Petermann Ranges Orogeny resulted in the base McFadden Formation unconformity in the western Officer Basin (Fig. 17).

The McFadden Formation equivalent is a siliciclastic sequence, which varies between sand- and shale-dominated and is present throughout the western Officer Basin. The formation thins towards the west and is limited to the east of the Gibson area (Plate).

The Officer Basin depositional phase ended with the Delamerian Orogeny during which tectonic highs were rejuvenated and eroded. Extensive flows of the Table Hill Volcanics heralded the beginning of the Gunbarrel Basin depositional cycle.

Table Hill Volcanics horizon

The Table Hill Volcanics are a series of thin tholeitic basalt flows of near uniform thickness. The seismic response of the top of the formation is clear and distinct on most Officer Basin seismic lines interpreted for this study, and is used as a regional tie marker in both the Yowalga and Lennis areas. However, the Table Hill Volcanics have been eroded from most of the Gibson area (Plate).

The shallow depth of the overlying sedimentary succession makes it difficult for them to be effectively imaged by the existing seismic data. After the Rodingan Movement, the shallow-marine Lennis Sandstone was deposited over the basin. Lithologies range from shale to sandstone, with local matrix-supported conglomerates (Jackson and van de Graaff, 1981; Stevens and Apak, 1999). Uplift associated with the Alice Springs Orogeny terminated deposition in the Gunbarrel Basin.

When deposition recommenced during the latest Carboniferous – Early Permian (Backhouse, 1999), a veneer of glacigene sediment belonging to the Paterson Formation was deposited over much of the underlying rocks. The region was emergent from the Permian to the Cretaceous and then was transgressed following the next major sea-level highstand, which deposited the argillaceous Samuel Formation over this low-relief area. Since the Cretaceous, the subdued relief of the area has been maintained, with periodic phases of river flow and erosion during wet periods, followed by pediplanation and wind deflation during arid periods (Jackson and van de Graaff, 1981). A thin, superficial blanket of sand and clay has accumulated, which overlies a deep weathering profile that has leached the underlying sedimentary rocks.

Petroleum potential

Previous drilling

In 1972, following the identification of diapiric structures in the Gibson area, the BMR drilled a number of stratigraphic wells on the Woolnough and Madley features. Twenty holes (Warri 1 to 20) were drilled on the Woolnough diapir (near Dragoon 1); most had a total depth of only 3–4 m, but Warri 20 was drilled to a total depth of 265.5 m. The drillcore helped to confirm the nature of the caprock and also identify the original diapir material. A Neoproterozoic age was assigned to the intrusive succession. Madley 1 was drilled on one of the outcropping Madley diapirs, reaching a total depth of 207.6 m. Wireline logs were run and detailed chemical analyses conducted on Warri 20 and Madley 1 in an attempt to identify the commercial potential of the diapirs.

Only two deep wells have been drilled in the Gibson area, Dragoon 1 and Hussar 1, by a consortium led by Eagle Corporation (Eagle Corporation Ltd, 1983a,b). Their interest in the Officer Basin stemmed from the oil and gas shows in the Browne 1 and 2 exploration wells (Hunt Oil Company, 1965), and recovery of oil from the South Australian Department of Minerals and Energy (SADME) Byilkaoora 1 stratigraphic well in 1979 (Phillips et al., 1985). Dragoon 1 was drilled in 1982, and was plugged and abandoned at a total depth of 2000 m. The well was located on the northwesterly flank of the outcropping Woolnough Hills Diapir, and thus not at the structural culmination. It was hoped to intersect upturned reservoir beds abutting the salt. At a depth of 450 m, Dragoon 1 intersected the top of the diapir below the Paterson Formation, and then penetrated an upper residual anhydritic cap rock and lower halite–dolomite–claystone core to a total depth of 2000 m. In the upper part of the diapir (407–935 m), the mud gas detector measured values up to 1%; chromatographic analysis identified methane, ethane, propane, butane, and pentane.

Drilled in 1982, Hussar 1 was essentially a stratigraphic well on the crest of a structure identified on a single seismic line. The location of the structural culmination was not known at the time of drilling. Subsequent seismic work showed the well to be near the centre of the overall structure, but located in a saddle between the two highest portions in a conformable section (Durrant and Associates, 1998; Plate). It was planned for a total depth of 2850 m, but due to drilling difficulties the well was terminated at 2040 m after penetrating the main objective and reaching the salt horizons of the Browne Formation.

Due to the lack of palaeontological and seismic control at the time of drilling, the correlation of units intersected in Hussar 1 was dependent on regional considerations. Eagle Corporation interpreted that below the Paterson Formation unconformity, the Wanna Beds or Lennis Sandstone (upper units), and Babbagoola Beds (lower unit) unconformably overly Supersequence 1 sedimentary rocks. With the subsequent availability of seismic data, it became evident that the succession lay below the Ordovician Table Hill Volcanics and was Officer Basin strata (Perincek, 1996). Hence, the Wanna Beds or Lennis Sandstone were not possible correlations. Perincek (1996) correlated the upper units with the Durba Sandstone, which outcrops in the Savory region to the west, and the lower unit with the McFadden Formation. Our seismic correlations suggest that Perincek's McFadden Formation is in fact the Wahlgu Formation (the Boondawarri Formation equivalent of the Savory region) that lies unconformably over Supersequence 1. The Wahlgu Formation is unconformably overlain in turn by the McFadden Formation equivalent, which was interpreted by Perincek (1996, fig. 2) as the Durba Sandstone. The unconformity between the Wahlgu Formation and the McFadden Formation equivalent was re-picked at 560 m in Hussar 1. A stratigraphic correlation between Hussar 1 and Lungkarta 1 is shown in Figure 22, and a simplified composite log for Hussar 1, with our picks, is shown in Figure 16.

Between 1140 and 1158 m, and 1200 and 1222 m in Hussar 1, the mud gas detector recorded values in excess of 1000 ppm, although no fluorescence was observed in the cuttings. Log evaluations suggested the presence of immovable hydrocarbons in thin, tight sandstone within this interval, but a drill stem test (DST) recovered only formation water (Phillips et al., 1985). On returning to normal rotary drilling at 1908 m after an airlift attempt, the gas detector registered 4.6% total gas, which was analysed as dry 53 400 ppm methane, 2780 ppm ethane, 242 ppm propane, and 80 ppm butane (Phillips et al., 1985). Some bituminous material at 1823 m was recognized in polished shale samples by Keiraville Konsultants (Eagle Corporation Ltd, 1983b).

Hussar 1 proved the existence of reasonable reservoir sandstone (12–21% porosity) in the Neoproterozoic succession (Hussar Formation), but a thick intersection of source rock was not encountered.

A number of other commercial drilling programs were undertaken (Fig. 3), but provide little information on the Officer Basin succession. In 1982–83, PNC Exploration (Australia) drilled several exploration holes in the Gibson area; PNC CA5, CA13, and CA15 were drilled to depths up to 129 m. They penetrated a 20–80 m-thick, sand-dominated, interbedded sandstone–claystone succession considered to be Late Proterozoic age (Perincek, 1998), below a thin Cretaceous to Permian section.

In 1990, CRA Exploration drilled two series of exploration holes in the Gibson area (Fig. 3). RCWA 9 to 12 were drilled to depths of 130–250 m, but did not penetrate below the Paterson Formation. RCHE 001, 003, 004, and 005 were drilled to depths of 140–170 m and penetrated as deep as the Table Hill Volcanics. Only one well (RCHE 003) penetrated the Officer Basin succession, intersecting 20 m of McFadden Formation (Perincek, 1998).

In late 1997, Amadeus Petroleum drilled three petroleum exploration wells in the Savory area: Mundadjini 1, Boondawari 1, and Akubra 1. All three targeted potential reservoirs within the Spearhole Formation. Minor oil shows were recorded in core from the Spearhole Formation in Mundadjini 1 at 361 m, and Boondawari 1 at 353.6 m (Stevens and Carlsen, 1998).

Petroleum generation

Due to the sparsity of available geochemical data specific to the Gibson area, deductions about the area's petroleum generation were made mainly based on data from the Yowalga area to the east (Apak and Moors, 2000b). Information on petroleum generation requires an understanding of the quality, quantity, and distribution of potential source rocks within a sedimentary section, as well as the burial and thermal history of the section. Such information for the western Officer Basin has been reported by Perincek (1998) and Ghori (1998a,b, 2000). Interpretations of these data suggest that good quality oil-prone source rock exists throughout Supersequence 1 strata. Maturation modelling was undertaken for Hussar 1, a representative location for the Gibson area, to try and quantify the timing of petroleum generation for this region.

Source-rock type

The principal source of organic material in the Neoproterozoic was restricted to cyanobacteria and to less abundant planktonic acritarchs. Due to their reliance on photosynthesis, such organic material was produced mostly in relatively shallow water to periodically emergent conditions. Gelatinous cyanobacterial mats were common, as illustrated by the abundance of stromatolites in Empress 1A in the Yowalga area. A detailed description of the source-rock facies, including production, transportation, and the preservation of organic material, is presented in Carlsen et al. (1999). Additional comments on the accumulation of organic material in shallow-water oxic conditions typical of most of the Supersequence 1 strata are provided by Apak and Moors (2000b).

All the source-rock intervals so far identified in the Officer Basin have been in thin beds. This makes their detection and quantification from ditch-cuttings virtually impossible, as each source-rock bed is diluted by non-source material in the composited ditch-cutting samples. By selecting only the most reliable data (Fig. 23), source rocks in the Officer Basin are characterized by type II kerogen (Ghori, 2000; Fig. 24), which is as expected from a marine deposit of this age. The spread of source-rock quality towards type III is interpreted as being due to oxidation and degradation of the original biological contribution, depleting some of the hydrogen. Pyrolysis of the samples releases a light-oil product with a substantial aromatics component, thus reflecting the tendency towards a type III kerogen (Ghori, 2000).

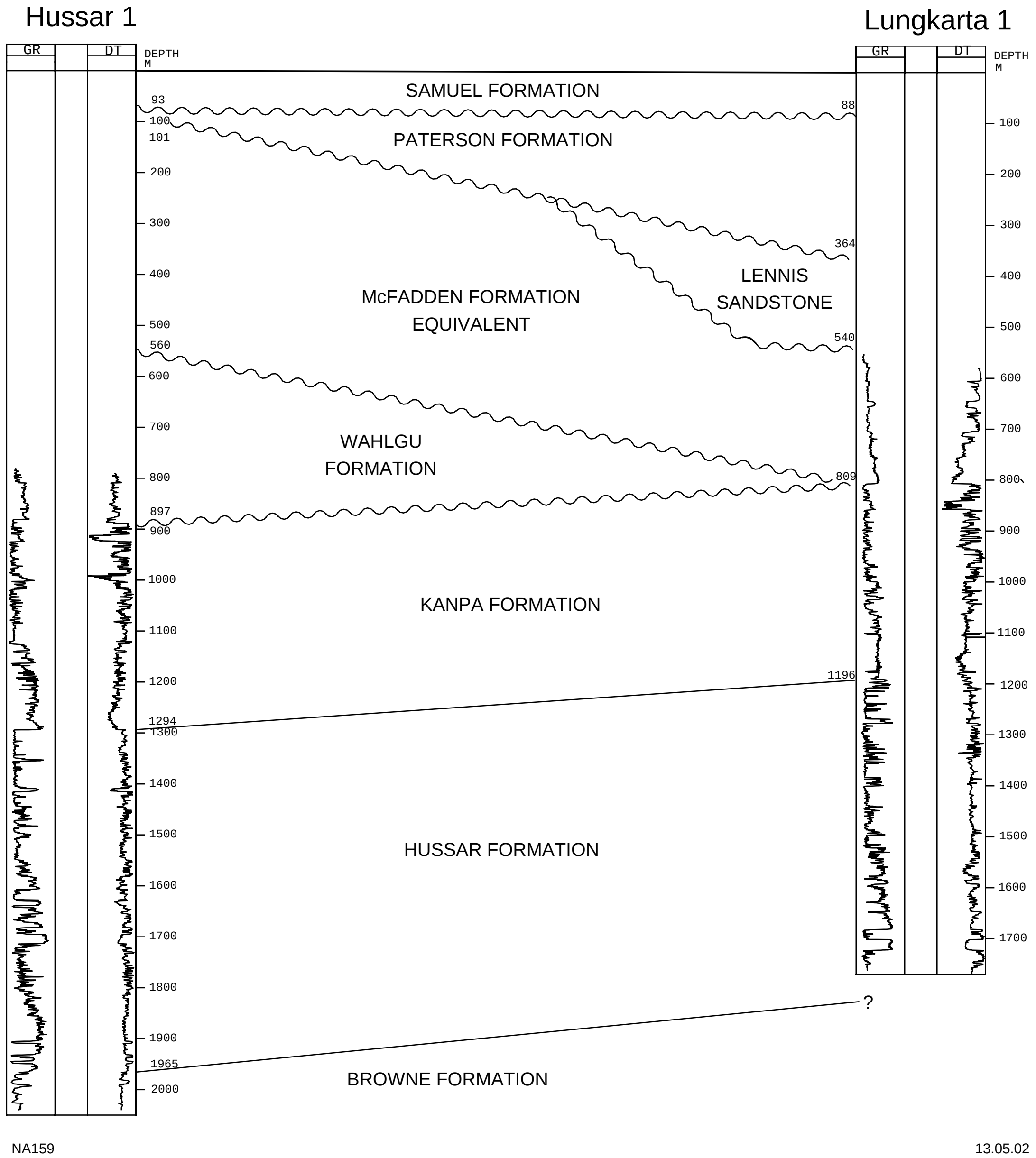

Figure 22 Stratigraphic correlation between Hussar 1 and Lungkarta 1

Strata that can be characterized as source rocks have been identified by Rock-Eval in most formations of Supersequence 1. These include the Browne Formation (Kanpa 1A and Yowalga 3), the Hussar Formation (Empress 1A and Yowalga 3), the Kanpa Formation (Empress 1A), and the Steptoe Formation (Empress 1 and 1A, Kanpa 1A). These intervals may be correlated with other wells in the Yowalga area (Ghori, 1998, figs 5–7) that mostly show at least some enrichment of the equivalent beds. Bearing in mind the limitations of cuttings to quantify thinly bedded source rocks, these correlations are extremely encouraging and suggest that source rocks are widespread, even across the depositional dip.

Not all the formations have been adequately sampled; for example, the Lefroy Formation has no analyses. The Lefroy Formation was probably deposited in deep water, possibly with extensive areas of quiet anoxic conditions. In this case, widespread thick source rocks could have been deposited, and as the Lefroy Formation probably interfingers with the Townsend Quartzite, lateral migration of petroleum into these sands would have been relatively easy if they still retained porosity. Shale or salt seals could be effective in this petroleum system.

Source-rock maturation and petroleum generation

Geochemical modelling of Hussar 1 was undertaken in an attempt to identify the petroleum generating potential of various portions of the Gibson area and the timing of such generation. Information from this well permitted specific data on each formation to be incorporated into the modelling package. Its location is also reasonably

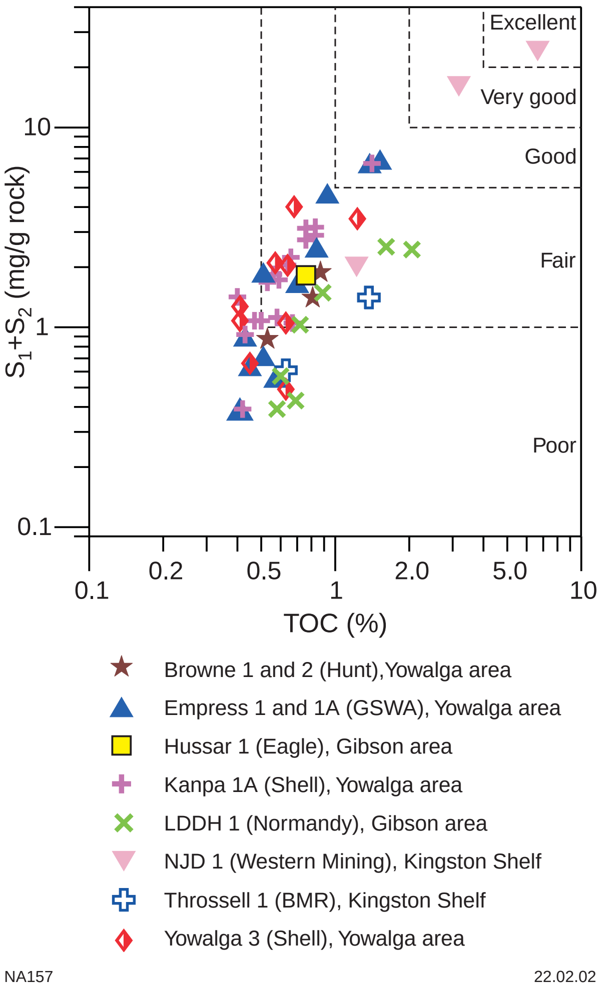

Figure 23 Petroleum generating potential as a function of organic richness versus potential yield for samples interpreted as reliable (after Ghori, 2000)

representative of the entire Gibson area. Examination of the seismic times to the various formations (Plate) shows only minor areas where the section is buried more deeply than at the Hussar 1 location. The modelling shows that petroleum generation was controlled by depositional phases and was paused during uplift and erosion. In sections deeper than at Hussar 1, additional burial will have enhanced the maturity levels for each depositional phase, whereas shallower sections will have undergone less maturation.

Using thermal and maturation constraints available from well data (Fig. 25), we assume that heat flow throughout the Gibson area is uniformly similar to the value derived for Hussar 1. However, experience in the better-controlled Yowalga area has shown that this parameter can be very variable on a basinal scale (Apak and Moors, 2000b). The results of the above modelling should therefore be regarded as indicative only until additional control becomes available. The present-day heat flow at Hussar 1 has been calculated at a moderate 40 mW/m^2, but to reach the present-day measured maturity levels it must have been higher in the past. Therefore, a heat flow of 69 mW/m^2 is proposed for the 120–800 Ma depositional phase, which dropped uniformly to the present day value. In the petroleum generation modelling, the source rock is assumed to have a total organic carbon content of 1% and kerogen that comprises 10% type I, 70% type II, and 20% type III material.

The burial history curve for Hussar 1 (seismically extrapolated to basement) with the equivalent vitrinite reflectance values marked is shown in Figure 26. The curve indicates that most of the Browne Formation and younger sedimentary rocks have now passed through the oil window, the Hussar and Kanpa Formations are in the middle of the oil window, and the Wahlgu Formation is only just entering the oil window. Younger sedimentary rocks are still immature.

The different phases and rates of petroleum generation are more clearly defined on Figure 27, which shows the rates and qualities of oil and gas generation from a source rock at Top Browne Formation, Top Hussar Formation, and Top Kanpa Formation. Three phases of generation are recognized, with the best defined at the top Browne Formation level. The first phase is associated with the rapid deposition of thick Supersequence 1, which is sufficient to place the Browne Formation within the oil

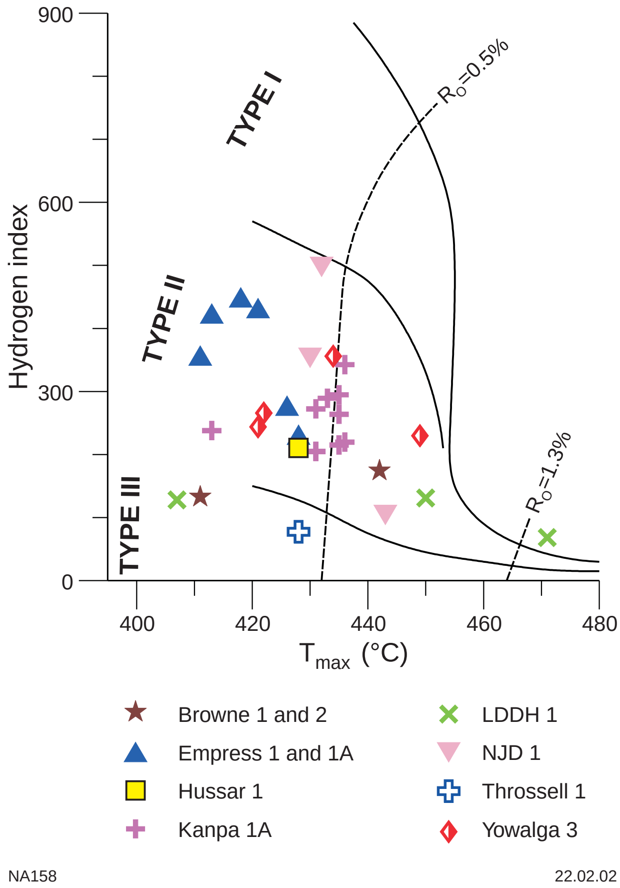

Figure 24. Kerogen type as a function of T_{max} versus hydrogen index from Rock-Eval pyrolysis (after Ghori, 2000)

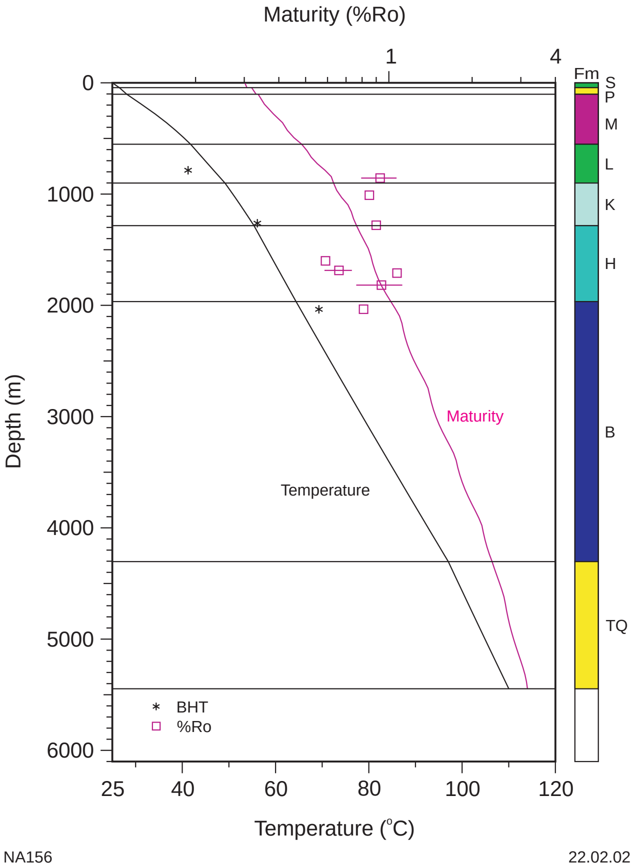

Figure 25 Measured and modelled temperature and thermal maturity in Hussar 1. The sedimentary sequences indicated on this figure are the Samuel Formation (S), Paterson Formation (P), McFadden Formation equivalent (M), Lennis Sandstone (L), Kanpa Formation (K), Hussar Formation (H), Browne Formation (B), and Townsend Quartzite (TQ)

window, together with the generation of some gas. However, as seen in Figure 26, most of the Browne Formation is already in the oil window at this time. Generation ceased for a period when the Areyonga and Souths Range Movements created uplift with associated erosion of the sedimentary succession. A second smaller phase of oil and gas generation took place during deposition of the Wahlgu Formation, but at a slower rate. Uplift and erosion associated with the Petermann Ranges Orogeny almost stopped this generation, but a third important phase began during deposition of the McFadden Formation equivalent. Uplift and erosion associated with the Delamerian Orogeny halted all further petroleum generation.

The top of the Hussar Formation was not sufficiently buried during deposition of Supersequence 1 and did not commence petroleum generation (minor oil and trace gas generation) until deposition of the Wahlgu Formation. However, significant oil and gas were generated during deposition of the McFadden Formation equivalent. The Kanpa Formation was buried even less than the Hussar Formation, and hence no petroleum was generated until deposition of the McFadden Formation equivalent; even then generation of oil and gas was minimal.

The level of petroleum generation efficiency for the defined source rock in Hussar 1 can be estimated from Figure 28. The Browne Formation reached 50% of its total generating potential before the end of Supersequence 1 deposition. A further 10% was generated during deposition of the Wahlgu Formation and virtually all the remaining 40% was achieved during deposition of the McFadden Formation equivalent. For the Hussar Formation, approximately 40% of the ultimate oil generation was achieved during deposition of the McFadden Formation equivalent. Formations younger than the Kanpa Formation have generated, but not expelled, some petroleum. This petroleum generation model can be adapted for any other similar location in the Gibson area by comparing the burial depths of the formations with those encountered in Hussar 1.

Reservoir potential

The presence of both carbonate and siliciclastic sedimentary rocks in the Officer Basin has produced many opportunities for reservoir development. Potential siliciclastic reservoirs are present in the Lennis Sandstone, McFadden Formation equivalent, Wahlgu, and Lefroy Formations, and the Townsend Quartzite, whereas the Steptoe, Kanpa, Hussar, and Browne Formations contain potential hydrocarbon reservoirs in both siliciclastic and carbonate lithologies.

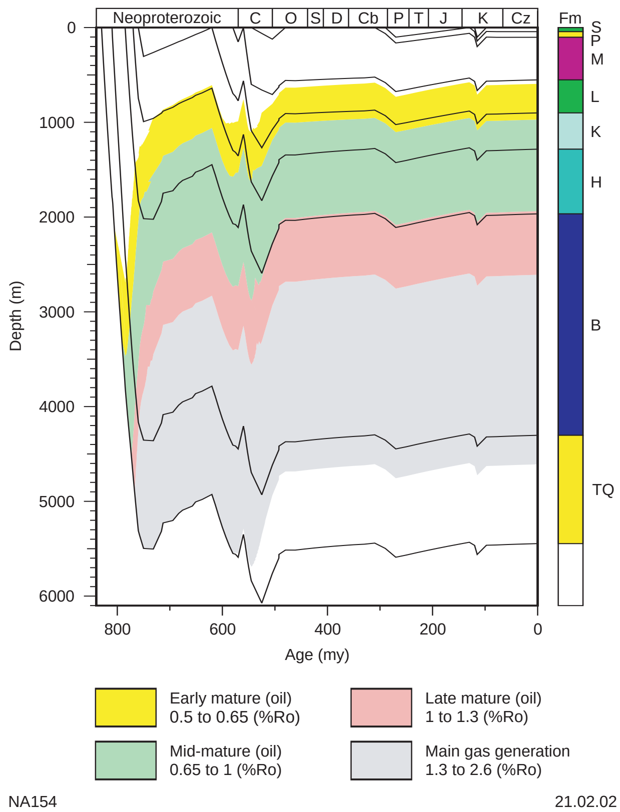

Figure 26. Burial history curve for Hussar 1 showing modelled equivalent vitrinite reflectance values. See Figure 25 for formation abbreviations

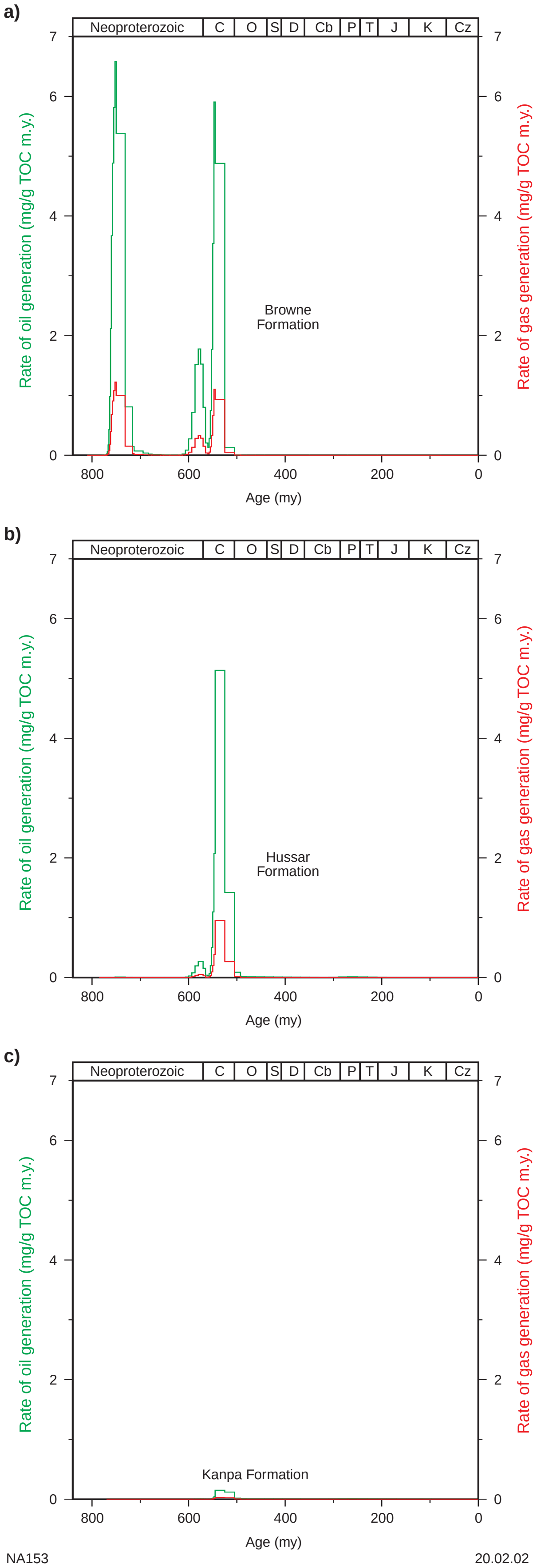

Figure 27 Rates of oil and gas generation at selected horizons in Hussar 1: a) Browne Formation; b) Hussar Formation; c) Kanpa Formation

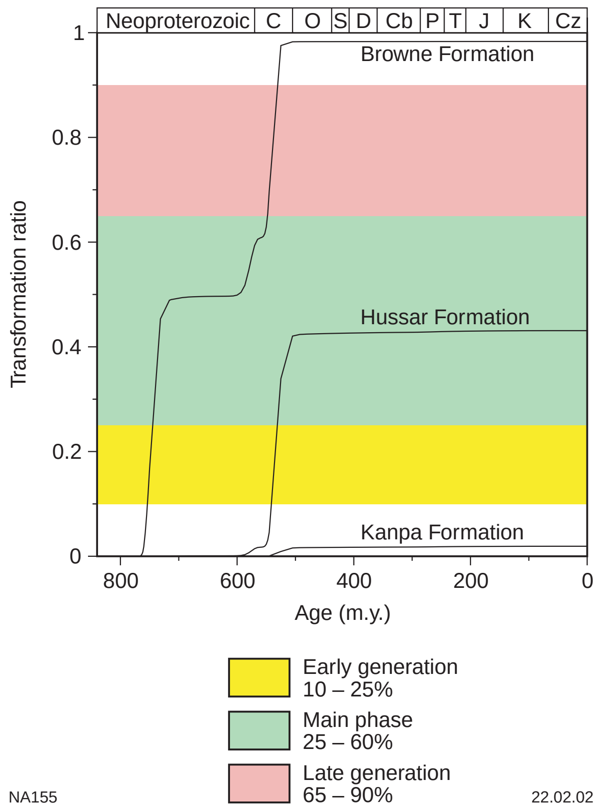

Figure 28. Modelled transformation ratio for source rock in Hussar 1

In the Yowalga area, the continuous core from Empress 1 and 1A has allowed detailed measurement of both porosity and permeability of the Neoproterozoic sandstones. Values in excess of 20% porosity and 1 Darcy (D) permeability were recorded (Stevens and Apak, 1999, appendix 10). The availability of core data and a full suite of electric logs enabled the comparison of measured and log derived-porosity, and proved that log-derived values are reliable (Stevens and Apak, 1999, plate 1). Most of the carbonate beds are dolomite, although they were originally calcite. There is no secondary porosity associated with the transformation from calcite to dolomite, because the replacement is mimetic and complete down to the finest detail. Other opportunities for the creation of porosity exist in the evaporite facies, where the dissolution of halite or other evaporites may result in leached secondary porosity.

Townsend Quartzite

The distribution of units older than the Browne Formation is poorly known from existing data. The available seismic data indicate the presence of an additional section of Supersequence 1 beneath the lower salt of the Browne Formation, which we consider are probably lower Browne Formation, but they may also consist of locally developed older siliciclastic deposits. This has yet to be proven and for this reason reservoir potential of the Townsend Quartzite is unknown. Because of its diagenetic history and stratigraphically low position and consequent deep burial, it typically lacks reservoir quality, unless depositional porosity has somehow been preserved.

Lefroy Formation

The Lefroy Formation is unknown in the Gibson area. Apart from an outcrop south of the Musgrave Complex, it has only been intersected in Empress 1A, where its lithology of siltstone and claystone has no reservoir potential. The Lefroy Formation is not regarded as a reservoir objective in the Gibson area.

Browne Formation

The Browne Formation consists primarily of mixed carbonate–siliciclastic strata and a few thin-bedded sandstones. Unfortunately, all the initial depositional porosity in the carbonate was occluded during early diagenesis by grain-rim cements and equant-cement cavity fillings of calcite, anhydrite, or halite, thus resulting in a tight non-reservoir rock. The carbonate is dolomite, which has mimetically replaced original calcite down to the finest details. The porosity is low, with most log-derived values being around 2%. However, log-calculated values of up to 15% have been interpreted for Yowalga 3 (Shell Company of Australia, 1981) and measured porosities of up to 9.5% were recorded from some core.

The abundance of halite and other evaporite minerals, which are easily dissolved, could result in the development of secondary solution porosity. Potential exploration targets include unconformity traps with reservoirs enhanced by karstification. Any migration path containing fluids capable of dissolving dolomite, anhydrite, or halite may result in secondary leached porosity. No means of predicting such porosity is known at this time.

Hussar Formation

In wells within the Officer Basin, the Hussar Formation is a mixed siliciclastic–carbonate succession. Because there is more sandstone than carbonate in the formation, sandstone is the main reservoir objective. Although individual sandstone beds are present, they are mostly stacked in thicker sandy intervals up to 50 m thick. Maximum log porosities of 15–17% were calculated for sandstones in Yowalga 3, Kanpa 1A, and Lungkarta 1 (Townson, 1985). Permeabilities in fully cored Empress 1A reach beyond 1 D, but are more commonly around 100 md. Within the H5 parasequence set (Apak and Moors, 2000b) in Hussar 1, more than 100 m of sandstone has log porosities of between 12 and 21%.

The Hussar Formation contains less carbonate than the Browne Formation; the carbonate does not form thick sections, but it contains the same shallow-water to emergent facies lithotypes and evaporites as the Browne Formation. Although halite is absent, anhydrite is common. As in the Browne Formation, cements have occluded the original porosity and the carbonate now consists of dolomite that has stoichiometrically replaced calcite with no resultant porosity. Log-derived porosity is approximately 1–2% and has been confirmed by core-plug measurements. Permeabilities are virtually zero.

The creation of porosity by the dissolution of anhydrite is possible, but the most likely areas for such secondary porosity development would be associated with unconformities where karsting may have occurred.

Kanpa Formation

In the western Officer Basin, the Kanpa Formation has only been completely penetrated in Kanpa 1A and Empress 1A, where it is a mixed siliciclastic–carbonate sequence. In Kanpa 1A, the formation contains 30% carbonate and 28% sandstone, whereas in Empress 1A it contains 37% carbonate and 17% sandstone. Siltstone and claystone make up the remaining lithologies. In Hussar 1, the formation is nearly complete, with only a small part of the upper parasequence set eroded. Siltstone and claystone dominate (52%) with lesser carbonate (33%) and sandstone (15%).

As with the older formations, the carbonate in the Kanpa Formation is a shallow-water facies with evidence of emergence, desiccation, and erosion. The formation does not contain halite although anhydritic zones are present. The dolomitization is again stoichiometric, with no porosity formed during the transformation from limestone. Log analyses shows a 6.5 m interval of dolomite with 14.9% porosity in Lungkarta 1, but typically log porosity is less than 5% (Shell Company of Australia Ltd and Schlumberger, 1985). This low carbonate porosity has been confirmed by core-plug measurements in Empress 1A. Permeability values from core-plugs in Empress 1A are virtually zero. The carbonate rocks can overall be regarded as non-reservoir rocks; however, substantial leached secondary porosity may be found in unconformity traps.

Sandstone present in the Kanpa Formation comprises thicknesses of less than 10 m and, consequently, is not an attractive reservoir target. In Empress 1A, log-derived porosities reach 15% and are supported by core-plug measurements, although core-plug permeabilities are only in the order of 1 md.

Steptoe Formation

As with the Kanpa Formation, the Steptoe Formation has only been penetrated in Kanpa 1A and Empress 1 and 1A. In both cases the formation is truncated by an unconformity. The composition of the full section is unknown, but in these wells the Steptoe Formation is a mixed siliciclastic–carbonate succession with a basal argillaceous unit overlain by interbedded sandstone and carbonate deposits. In Kanpa 1A, the formation contains 30% sandstone and 39% carbonate, whereas in Empress 1 and 1A it contains more sandstone (40%) than carbonate (28%).

In Kanpa 1A, 128 m of sandstone with porosity in excess of 15% was recognized on wireline logs (Shell Company of Australia Ltd, 1983a,b,c). Appropriate log coverage is absent in Empress 1 and 1A, but a single measured porosity was in excess of 22%, with a permeability of around 30 md. Sandstone in the Steptoe

Formation is an attractive reservoir target, particularly as it can be reached at depths of less than 600 m in the crests of many anticlinal structures and unconformity traps.

As with the older formations, the carbonates are of shallow-water origin, with evidence of emergence, desiccation, and erosion. The dolomitization is again mimetic, with no porosity formed during the transformation of calcite to dolomite. In Empress 1 and 1A, only a single core-plug was cut in the Steptoe Formation carbonate, which when tested gave a low porosity and virtually zero permeability. However, numerous permeameter readings indicate a permeability of around 0.1 md. These carbonates are not an exploration target unless secondary porosity, such as that near an unconformity can be found. Significant vuggy porosity and karsting were observed in Empress 1 and 1A, although all the large karst cavities were filled with sedimentary material from the overlying Wahlgu Formation.

A significant exploration risk for the Steptoe Formation is that it may have been removed by structural and subsequent erosional phases, as in Yowalga 3 and Hussar 1.

Wahlgu Formation

The Wahlgu Formation does not outcrop in the Gibson area, but was penetrated in Hussar 1. The formation consists of a siliciclastic glacigene succession dominated by mass-flow sandstone. In Hussar 1, the basal 100 m comprises siltstone and the upper 150 m is sandstone with thin shale horizons in a transition zone with the siltstone. The sandstone cuttings are friable to loose, locally consolidated, and with a grain size ranging from fine to coarse. These are characteristics of a good reservoir. The 200 m-thick section of Wahlgu Formation in Empress 1 and 1A consists mainly of sandstone with several mudstone beds about 5 m in thickness. Measured core-plug porosity ranges between 10.9 and 32%, with an average for the five values of 23.5%. Permeability varies between 0.04 and 831 md. Additional minipermeameter values are between 200 and 2000 md (Stevens and Apak, 1999).

The Savory region lies close to the Gibson area and may be representative of the sedimentary rocks in the western portion of the Officer Basin. In the Savory region the stratigraphically equivalent Boondawarri Formation shows the same lithological associations of poor reservoir-quality diamictites and fine-grained sedimentary rocks, but sandy intervals are also present. Some of the sandstone is a wacke and may be a poor reservoir, but other coarse, thick sandstones (Williams, 1992) could have reservoir potential. Some outcrops west of Trainor 1 are porous, fluvial deposits (Hocking, R. M., written comm., 2001), which if present at depth to the east could have reservoir potential. No quantitative data is currently available from this region.

Because of its sandy nature and shallow depth of burial, the Wahlgu Formation could be a reservoir target in the Gibson area, given adequate seal and lack of breaching. Seismic data show it is present in the area, but it intersects the Rodingan or Alice Springs Orogeny unconformity, and hence may be at least partially missing in the western portion (Fig. 19).

McFadden Formation equivalent

In Hussar 1, the 450 m-thick McFadden Formation equivalent is almost entirely sandstone; however, in the lower part there is a 40 m-thick interbedded sandstone–claystone section. The sandstones are fine to coarse grained, mostly friable and locally loose, and with some clay matrix or pyrite cement. It is lithologically similar to outcrop of the McFadden Formation in the Savory region (Williams, 1992), which consists of medium- to coarse-grained sandstone. Visual porosity is moderate to good. The formation is less sandy in Kanpa 1A, where thin sandstone beds have a log-determined porosity of up to 18.9% (Shell Company of Australia Ltd, 1983a,b,c).

Based on seismic data, the McFadden Formation equivalent has a limited distribution in the Gibson area, due to erosion by several tectonic phases (Delamerian Orogeny, Rodingan Movement, and the Alice Springs Orogeny). The erosional edge is shown in Figure 7; the formation being present only east of this boundary, with the full section lying east of the Table Hill Volcanics erosional edge.

With its sandy nature and shallow depth of burial, the McFadden Formation equivalent could be a reservoir target in the Gibson area. The biggest risk, however, is that it may contain a top, an intraformational seal, or be absent over much of the area due to erosion.

Seals

Seals in the Officer Basin need to be considered from a number of perspectives. Local seals can be effective in four-way dip-closed traps or fault-controlled traps, and as lateral seals in stratigraphic traps. However, regional seals are necessary to control the migration paths of petroleum, especially for long-range migration. The effectiveness of a seal over time is also important, as thermal-maturation modelling shows that a petroleum charge has been available from the Neoproterozoic and would need to have been contained for more than 600 m.y. (see **Petroleum generation**).

Within the Officer Basin, most formations contain lithologies that would make effective seals at all scales. All formations contain both carbonate and shale that are suitable for seals; thinner intervals act as local seals, and thicker packages have a more regional effect. From well intersections and seismic data we have been able to establish the extensive nature of many of these intervals (e.g. Fig. 11). Seal risk is highest for the less deeply buried sand-prone units such as the Wahlgu Formation and the McFadden Formation equivalent.

The carbonates are dolomitic and have no porosity (see **Reservoir potential**) and could form an effective seal, but their brittle nature increases the risk of lost integrity in a fault trap. Similarly, in a fault-seal trap, their brittle nature suggests a higher seal risk from the viewpoint of both cross-fault sealing and fault-plane gouge seal.

The best shale seals were deposited on flooding surfaces and form the bases of the Kanpa, Hussar, and Steptoe Formations. These shale units reach thicknesses of over 100 m (e.g. in the Hussar Formation, Kanpa 1A), and can be correlated between wells and picked on seismic lines extending into the Gibson area. The units could form effective seals to individual traps, but more importantly they could act as a control on migration pathways for fluids migrating updip.

The Browne Formation in the Yowalga area contains massive units of halite, but individual salinas may have had a more local distribution because not all the salt packages can be correlated between all wells. This is probably a depositional constraint rather than a result of salt flow. From seismic data, a similar distribution of salt is predicted for the Gibson area. The lateral extent of the salt is adequate for sealing all the structural traps, and such an excellent seal would control petroleum migration pathways over a large portion of the region.

Salt walls penetrate from the lower part of the Browne Formation through most of the overlying section, and may reach the surface. Seismic mapping shows that they extend laterally for over 100 km (Plate). Salt walls provide effective barriers to petroleum migrating from structural dips, causing a migration shadow updip. The timing of these walls with respect to the generation of petroleum is important.

Traps

Because of the geographic isolation and lack of infrastructure, petroleum accumulations within the Officer Basin need to be substantial to be commercially viable. The nearest pipelines are the Goldfields pipeline in Western Australia and the Alice Springs pipeline in the Northern Territory. The current availability of low-cost gas supplies to the surrounding markets also indicates that oil would be the favoured petroleum product. A screening economics study of the South Australian portion of the Officer Basin by Alexander and McDonough (1997), concluded that oil reserves of 20 million barrels could be commercially attractive under their constraints.

The presence of salt within the Officer Basin has resulted in a wide range of possible trapping configurations. Warren (1989) has defined 22 possible salt-related trap styles, based on structure and porosity development (or occlusion). Many of these could apply in the Gibson area. In petroleum-rich Oman, the Ara Salt is considered a critical parameter for petroleum entrapment (Gavin et al., 1982). The salt acts as a top-seal, with many fields located in sub-salt and intra-salt reservoirs. It also acts as a regional seal, with breaches resulting in the remigration of Huqf-sourced hydrocarbons into overlying reservoirs of Permian and Cretaceous age (Terken and Frewin, 2000). Salt is expected to have the same significance within the sedimentary section of a similar age in the Officer Basin. Many other conventional structural and stratigraphic plays are also present and provide attractive targets for petroleum exploration.

No effort has been made to quantify the trap sizes within the Gibson area as seismic control is inadequate, but there is the potential for some to be very large. The main play types are summarized in Figure 29 and a brief outline for each type is presented below.

Fault traps

Few faults have been identified in the Gibson area, and although their low frequency can be attributed, at least in part, to the poor seismic control, little extension has probably taken place in this very stable area.

Normal faults

Because of the paucity of seismic control, normal faults are drawn with short lateral extent in the report by Durrant and Associates (1998; Plate). Fault orientation cannot be determined from one-line intersections, but has been shown with a northwest strike that is parallel to the general structural grain. The size of structures associated with such faults is mostly too small to be of commercial interest at present. If proven to have greater lateral extent, such structures could be attractive drilling targets. Thick salt beds in the Browne Formation could make excellent seals and tight-dolomite intervals could be effective as cross-fault seals, although their brittleness is more likely to result in a fault–fracture system that would leak.

Thrust faults and folding

Thrust faults are present within Supersequence 1 formations. They typically initiated within the Browne Formation salt units, but penetrate upwards into the overlying formations. They may create drag rollover structures within the units they penetrate, or deform the overlying units into anticlinal features (Fig. 17). The resultant structures may be large. With the presence of salt on the fault plane, fault-plane sealing would be excellent. A serious risk is that deformation will result in numerous tensional crestal faults that may leak. Another risk would be reactivation of structural growth during subsequent tectonic phases, which would release any hydrocarbon accumulation.

Drape folding

Salt movement within the Browne Formation by solution, withdrawal, or injection has resulted in irregularities in the shape of the overlying strata (Hussar structure, Plate). These gentle folds can be of substantial size (over 250 km^2). The possibility of multiple pays is very likely, but the prospect of tensional crestal faults in the overlying carbonate beds may be a risk. Because much of the salt flow is likely to have taken place during the Areyonga Movement, the timing of such structuring is favourable with respect to charge. The salt walls in the north of the study area were remobilized and penetrated younger strata, but the higher portions of the structure that were not

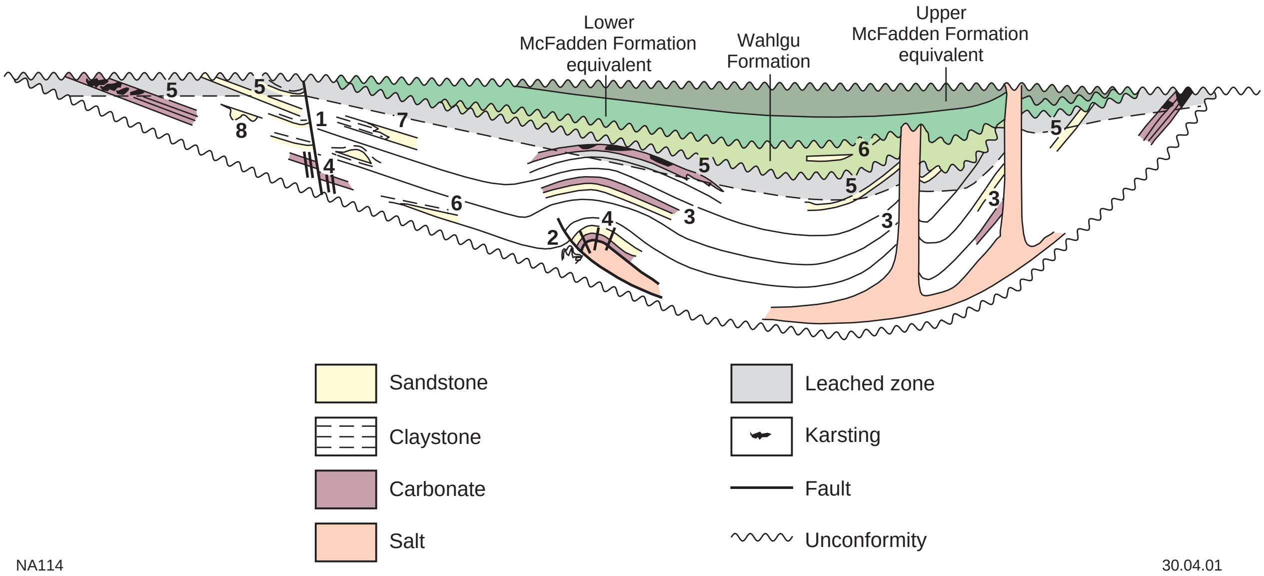

Figure 29. Schematic petroleum play types present in the Gibson area: 1) normal fault trap; 2) drape over salt high; 3) lateral salt seal; 4) fractured reservoir; 5) leach-enhanced porosity; 6) pinchout traps; 7) lateral facies change; 8) erosive channel or valley

penetrated should still maintain their integrity (e.g. Base McFadden Formation equivalent; Fig. 17).

Lateral salt seal

In the Gibson area, salt injection is evident along the northern edge of seismic control as salt walls controlled by faulting (Plate). The forcible injection of the salt has upturned the adjacent strata, creating potentially large structures with considerable relief; multiple pays could further enlarge the total trap configuration. In addition, highs abutting the salt could make excellent traps. The salt, which is able to maintain its integrity over a long period, is an effective seal. Timing of the diapiric phase with respect to petroleum charge is good, as the structures were available before petroleum expulsion was completed.

Fractured reservoir

In the Tertiary carbonate reservoirs of the Middle Eastern Zagros Basin, the main control on porosity is the fold-related fracturing system (Beydoun et al., 1992). Without this fracturing the porosity of the carbonates is typically less than 5% and their permeability is about 1 md. Wells that do not intersect fractures are dry. In the Zagros Basin, reservoir capacity and performance have been sufficiently enhanced by fractures resulting in the production of up to 80 000 barrels of oil per day. Similar fracture systems may be present within folded carbonates in the western Officer Basin. Fracture zones that have developed during the thrusting associated with these folds are also possible. Although the carbonates here are not as thick as the Asmari Limestone of the Zagros Basin, the possibility of stacked pays increases the potential reserves.

Fracture zones associated with any of the other faults also have the potential to create reservoirs; however, their extent is probably limited.

Stratigraphic traps

Stratigraphic traps may represent significant opportunities for the discovery of petroleum in the Officer Basin. A number of stratigraphic traps are discussed below.

Unconformity truncation

There are large areas adjacent to salt injection features (Fig. 17) and along basin margins where Supersequence 1 strata have been tilted and severely eroded. During erosive periods, a vertical leached profile may develop and result in increased porosity (Fig. 29). Leaching of the more soluble components (e.g. halite, anhydrite, and carbonate) from the sandstone and carbonate, and development of karst within carbonates, may create extensive porosity. Evaporite cements and nodules are common within all Supersequence 1 formations. Erosional unconformities at the base Paterson Formation, the McFadden Formation equivalent, and Wahlgu Formation could create or enhance porosity in the eroded units below.

Another strength of the unconformity play is the fact that unconformities are commonly regional migration pathways for fluids being expelled from compacting basins. These fluids could enhance porosity by dissolving soluble components and could also transport petroleum into the newly created traps.

A weakness of unconformity trap configurations below the major unconformities is that the overlying strata may not be an effective seal. In the Wahlgu Formation the principal lithology is sandstone, which although of glacigene provenance is likely to be an inadequate seal. In Empress 1 and 1A, porosity of the basal sandstone was in excess of 25% and permeabilities range between 100 and 1000 md, which results in an ineffective seal. In Hussar 1, the lower 100 m of the Wahlgu Formation is dominated by siltstone/claystone and could be an adequate top seal; however, more work is required to establish the distribution of this shaly unit. In areas where the Wahlgu Formation is absent, especially over diapiric structures, the McFadden Formation equivalent may provide an effective seal, for example, in Kanpa 1A, which contains a massive shale unit (70 m thick). In Hussar 1, the lithology of the McFadden Formation Equivalent is also predominantly sandy, with the only substantial shaly interval being near the base, sandwiched between thick sandstones. Seismic control is inadequate and our understanding of charge timing and potential reservoir and seal distribution for this play is uncertain; however, such traps could contain large petroleum accumulations.

Pinchout traps

As the authors' understanding of the evolution of the western Officer Basin has improved from studies in the Yowalga and Lennis areas, it has become clear that differential subsidence resulted in depositional pinching out of Supersequence 1 units (Fig. 29). For example, the bottom two parasequences of the Browne Formation in Yowalga 3 and Kanpa 1A are not present in Empress 1A, and the lowest Steptoe Formation parasequence in Kanpa 1A is absent in Empress 1 and 1A (Apak and Moors, 2000b). Other examples are found in the Wahlgu Formation and McFadden Formation equivalent within the salt rims adjacent to the salt walls. Figure 17 clearly shows sedimentary units onlapping the sides of the salt rims, creating numerous potential pinchout traps. The key component for an effective trap of this type is a reservoir pinching out between top and basal seals. From a petroleum-charge perspective, the timing of such traps is excellent and there is a good chance that such a configuration could be maintained over a long period of time, preserving any petroleum accumulation.

Facies changes

An improved understanding of the Neoproterozoic stratigraphy has shown that lateral facies changes are present in the successions. For example, Apak and Moors (2000b) showed that the dolomitic zone in the H1 succession present in Kanpa 1A (2260–2400 m) is absent in the equivalent intersection in Empress 1A. In Kanpa 1A, it is overlain by shaly strata, which would make good top and bottom seals. In Empress 1A, however, sandstone is present above H1 and would locally invalidate the top seal. Sandy intervals may also juxtapose suitable shale or carbonate seals. Deposition of isolated shoreface sands within fine-grained facies, such as an offshore bar, may also develop into possible stratigraphic traps (Fig. 29). The early timing of such traps is excellent with respect to charge, and the stable, low-angled ramp configuration of the area should enable the maintenance of the trap integrity over long period of time.

A possible variant of this type of trap is the occlusion of porosity by evaporites that may be present in more marginal settings. There are numerous horizons where halite and anhydrite have been formed in desiccation zones, plugging the porosity of the sediments either during or just after deposition. Such traps are also early with respect to charge and could be expected to retain any accumulation over a long period of time.

Erosive channels or valleys

Frequent emergence is well documented for much of the Supersequence 1 strata, and any channels could later be filled with high-energy, reservoir-quality sediments and sealed by subsequent transgressive shale (Figs 13–15). Again, the timing with respect to charge is excellent, and the retention of petroleum in this very stable area is likely to be good.

Numerous channel features characterize the Base Wahlgu unconformity. With appropriate orientation with respect to regional dip, these could be large and effective traps. The internal filling of these channels may also form isolated sand bodies, which could be an appropriate trapping configuration. If filled or lined with sealing material, these channels could also create stratigraphic traps by isolating the underlying sandstones.

Another significant consequence of the erosive nature of the channels is that they may cut through a regional seal and capture the petroleum migrating below this seal.

Prospectivity

Application of modern depositional, geochemical, and sequence-stratigraphic concepts has refined the prediction of the distribution of the various components required to define petroleum systems that may be present in the western Officer Basin. The lack of past success is not surprising — the few exploration wells drilled are mostly poorly sited as to structure, and commonly did not reach key objectives. However, the minor shows encountered prove that petroleum systems exist in the basin. Key wells, such as the continuously cored Empress 1 and 1A, provide information previously unavailable from conventional oil exploration. The following comments are based on the prospectivity of the Gibson area using the Yowalga and Lennis areas as models.

The lack of source rocks was seen as a negative factor in earlier assessments of the petroleum potential of the western Officer Basin (Phillips et al., 1985). However, the presence of source rocks has now been confirmed in most of the Supersequence 1 formations (Apak and Moors, 2000b). Although the intervals with identified potential are thin, favourable conditions for source-rock accumulation are present. The lateral persistence of these intervals indicates that the conditions controlling their deposition are regional, rather than local. Greater development of source rocks is possible in untested parts of the basin. All the source rocks are very similar, and contain type II kerogen, which has both oil- and gas-generating potential.

Geochemical modelling has suggested that the timing of oil generation was very early, and hence retention of this charge is considered a problem. However, in the Gibson area, as shown by modelling Hussar 1, much generation and expulsion took place after the main tectonic phases of the Areyonga Movement and Petermann Ranges Orogeny, and therefore structures were available to trap migrating petroleum. Later salt movements have modified some of the halokinetic traps, and there is a suggestion of repeated movement to the present day. This may have resulted in some petroleum loss, but the salt seal itself may not have been breached.

As pointed out in the **Petroleum generation** section, the heat flow in the Gibson area at present and in the past is poorly constrained. As in the Yowalga area, heat flow is likely to have been variable across the study area. Thus, if the temperature in the basin is higher than that in the modelled pseudowell location, the amount of petroleum generated would be larger. However, the timing does not change, so charge and trap relationship for both structural and stratigraphic traps remains very favourable.

Although many uncertainties exist, a number of generalizations can be made about petroleum generation for the Gibson area. For plays in specific areas, the most favourable traps can be tested against models with different parameters.

Reservoir presence and quality have not been considered a problem in the Officer Basin. However, by analogy with lithologies found in the Yowalga area, the presence of carbonate and siliciclastic units within the sedimentary succession opens up the possibility of a very large range of porosity types.

Assuming that the formations in the Yowalga area continue throughout the Gibson area, the distribution of the Townsend Quartzite is unknown. The Lefroy Formation is poor in sandstone and hence not a reservoir target. Sandstone is thin and uncommon in the Browne Formation, but carbonates and evaporites are present in significant quantities and have some potential for reservoir development. The carbonates have been dolomitized without any porosity formation, but secondary porosity could have developed as a result of fracturing during flexure or by solution during erosion (karsting). The evaporites (halite and sulfates) are prone to solution, which may result in leached porosity. The Browne Formation, where such secondary porosity has developed, is the oldest potential reservoir target.

The Hussar, Kanpa, and Steptoe Formations are predicted to contain sandstone with reservoir potential. The best reservoir-quality sandstone present is within the Hussar Formation, which contains stacked beds of sandstone over 50 m thick. Good porosities, and permeabilities in the range of 100 md to 1 D, have been measured. This is also expected to be the most sandstone-prone interval in the Gibson area, as shown by Hussar 1, but the availability of a sand source throughout this region is not yet proven. The Hussar, Kanpa, and Steptoe Formations should also contain significant carbonate, similar to those in the Browne Formation, with minor primary porosity, but a potential to develop secondary porosity. Multiple pays are likely in these three formations. The Wahlgu Formation in the Yowalga area is an entirely siliciclastic sequence containing sandstone units with porosity up to 30% and permeability in excess of 1 D. This should be a target in the Gibson area where the formation is thicker than in the Yowalga area. The McFadden Formation equivalent is not well represented in wells, but thick sandstone beds with reservoir potential have been identified in Hussar 1.

Seals are a low risk in the Officer Basin and should be present at all stratigraphic levels in Supersequence 1 of the Gibson area. Seals in the Wahlgu Formation and McFadden Formation equivalent are a higher risk. The best seal is salt, which because of its plasticity has excellent retention properties. Substantial thicknesses are found in the Browne Formation, as proved on seismic sections, and salt walls may form lateral seals to substantial structures. Sub-salt plays in the Gibson area as well as other areas could be significant for the lower parts of the Supersequence 1 strata, but this cannot be proven with the existing data sets. Thick shale is present in most supersequence units, and may be over 100 m thick at the base of parasequence sets. These shales are excellent top and lateral seals, and in fault traps they have the potential to form a fault-gouge or cross-fault seals wherever the fault throw is less than their thickness. Carbonates can be an effective seal, but are prone to fracturing in structured areas. Salt, shale, and carbonate units have a large lateral extent in the basin, and also need to be considered as significant controls on petroleum migration. Other local seals include diagenetic barriers, dolomitized carbonates, and evaporites.

A wide range of trapping configurations are present in the Gibson area, including depositional stratigraphic traps, folds, faults, and unconformity traps. The presence of salt further enhances the potential of the area, as it is associated with large accumulations elsewhere in the world. There have been no valid tests to date in the Gibson area.

The ultimate petroleum potential of the Officer Basin is unproven, but it may be very significant. Although beyond the scope of this study, the presence of significant evaporite deposits in the Officer Basin sequence may also have significant mineralization potential. Many world-class mineral resources are associated with salt deposits. As demonstrated by Warren (2000), the control on fluid movement by impervious salt beds and the contribution of reactive ions to the brines from the evaporites is considered critical to the formation of commercial mineral accumulations through their concentration and deposition. The significance of diapiric structures in the control of mineral deposition is also now being recognized.

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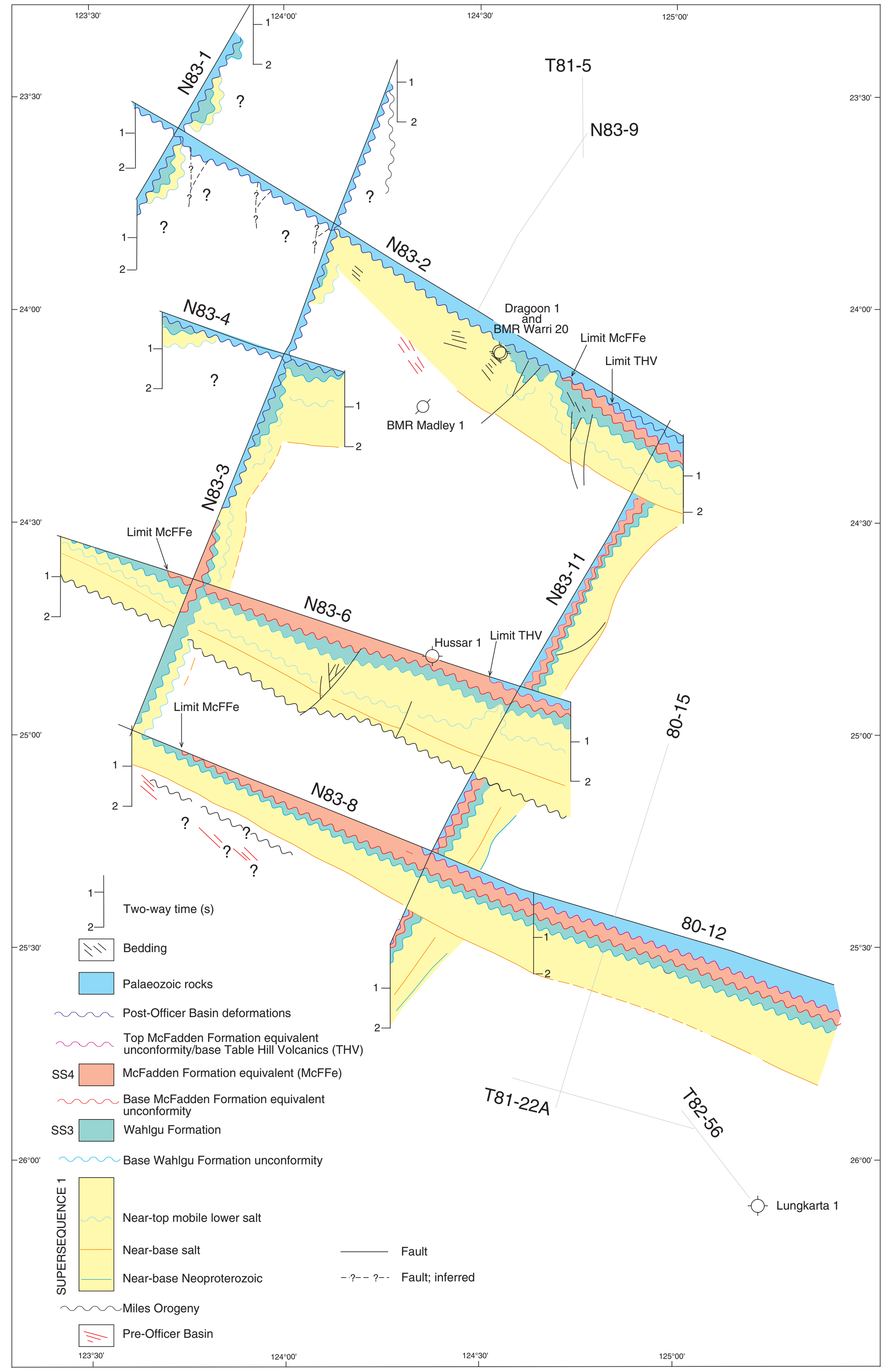
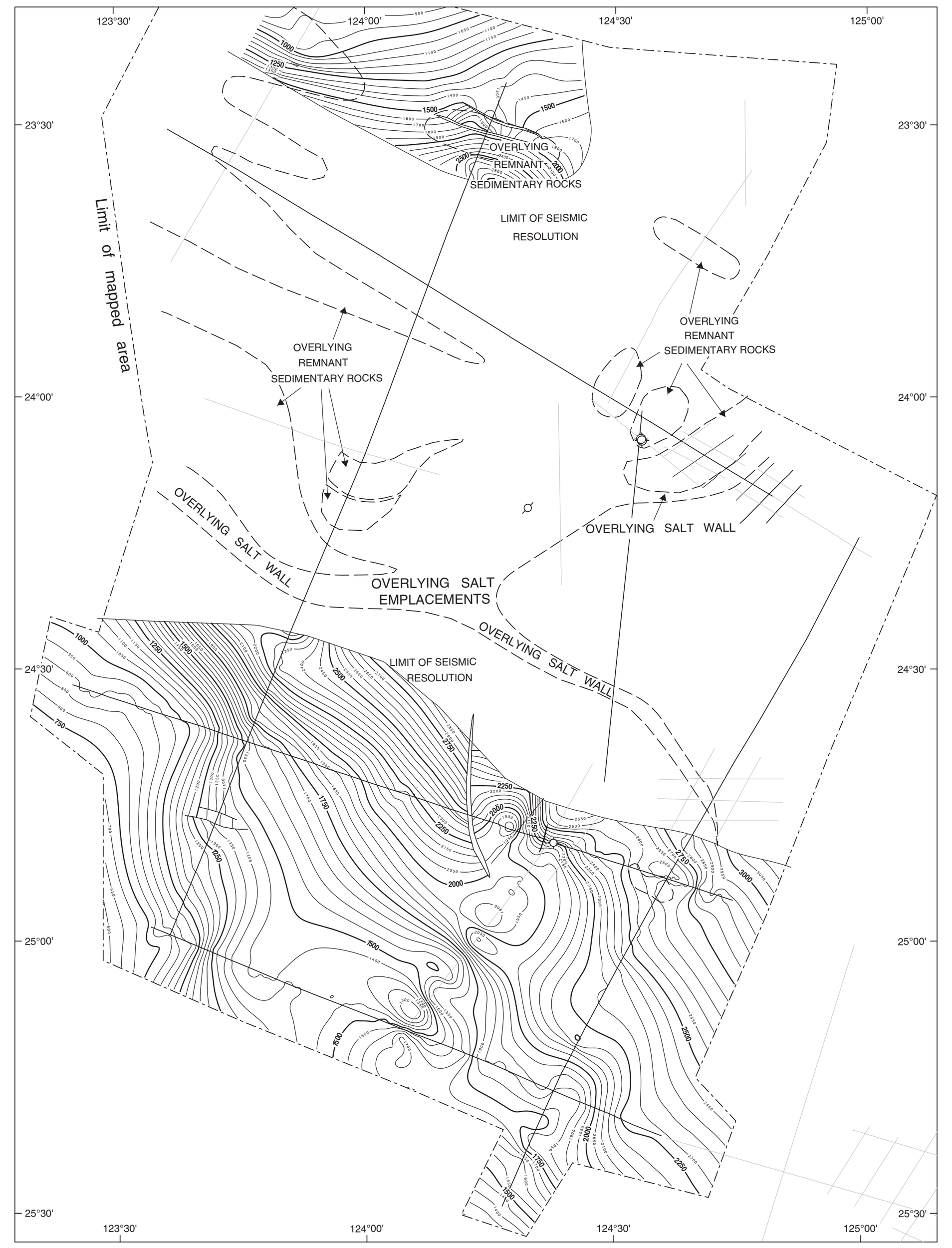
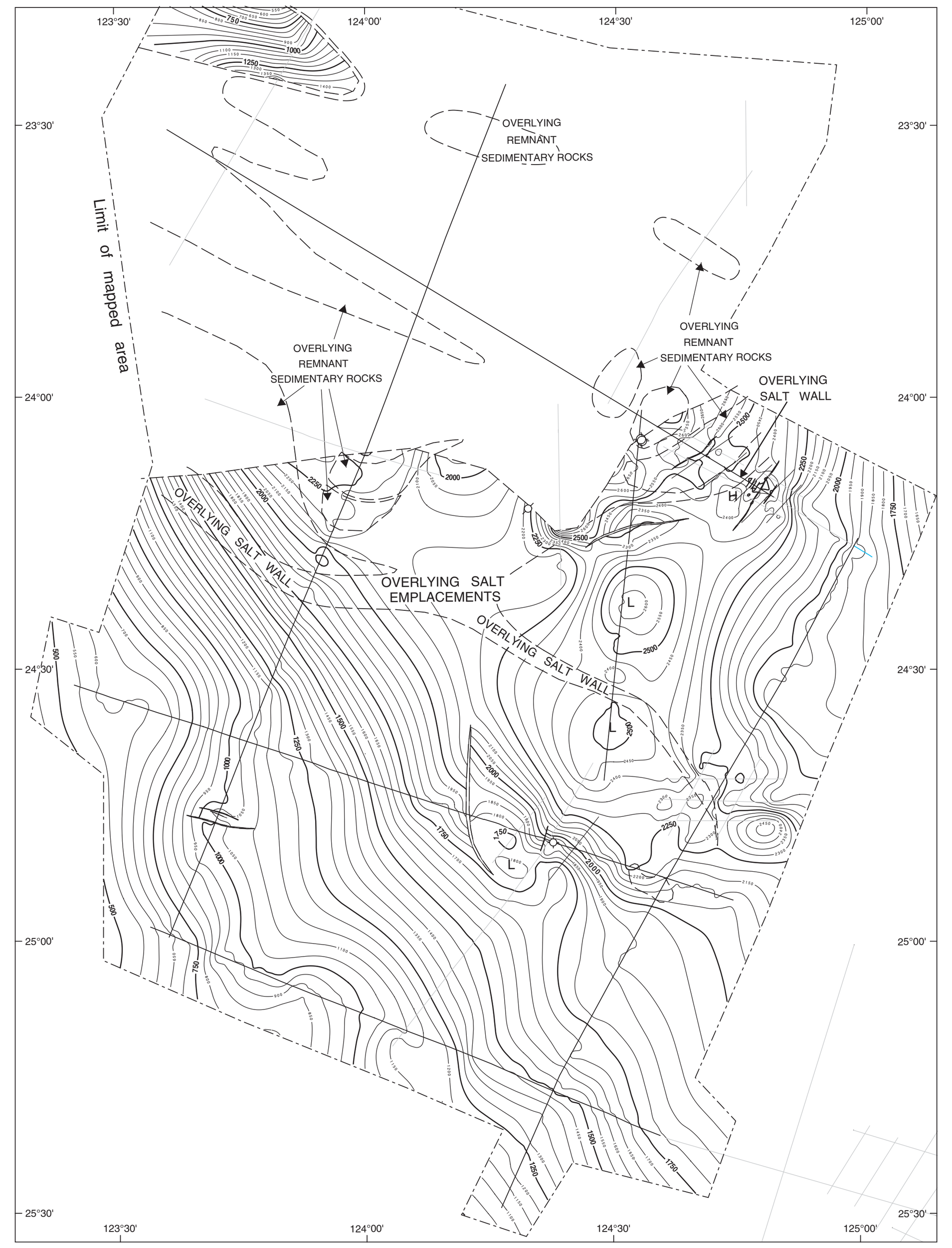
SEISMIC FENCE DIAGRAM (SELECTED LINES)



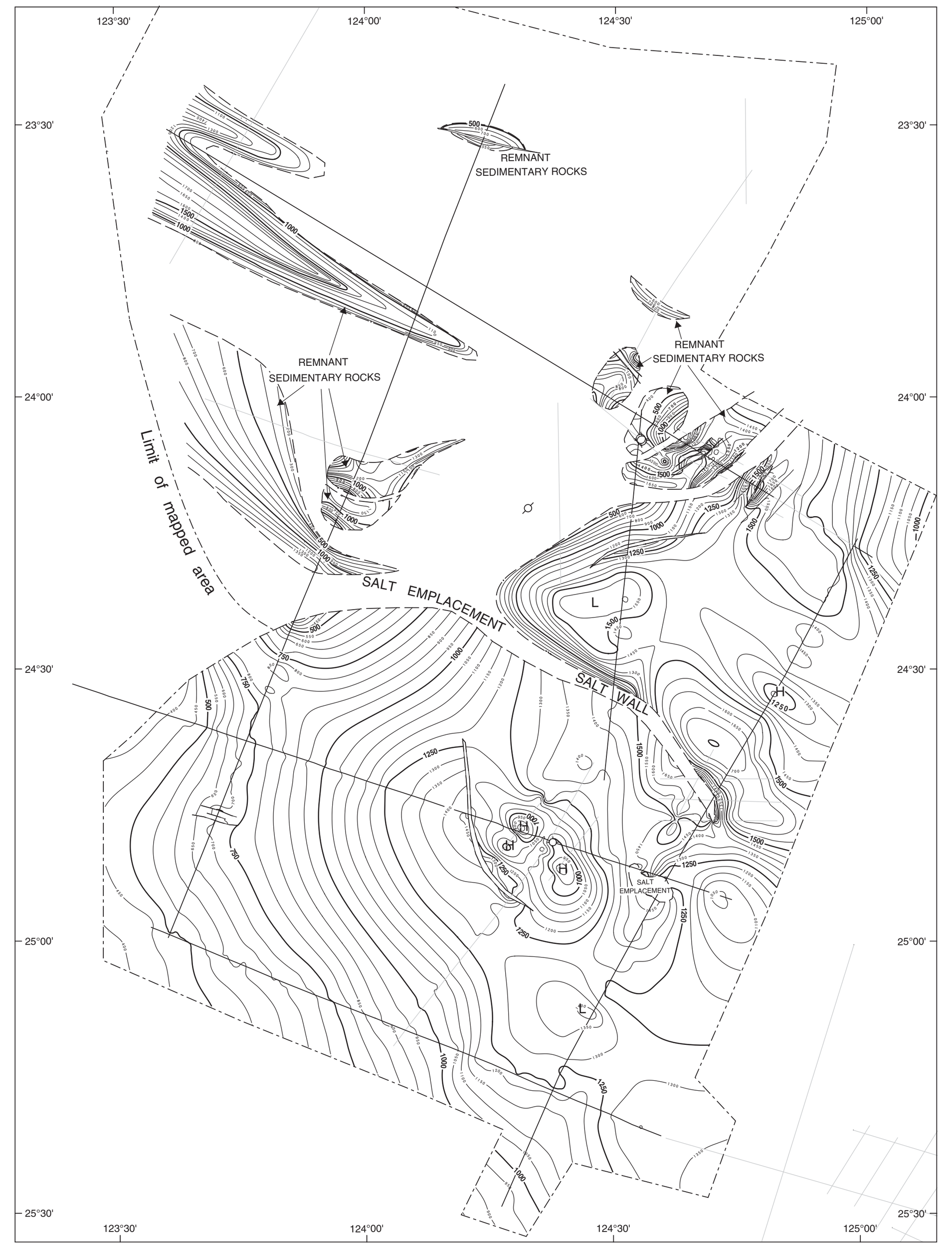
NEAR-BASE NEOPROTEROZOIC



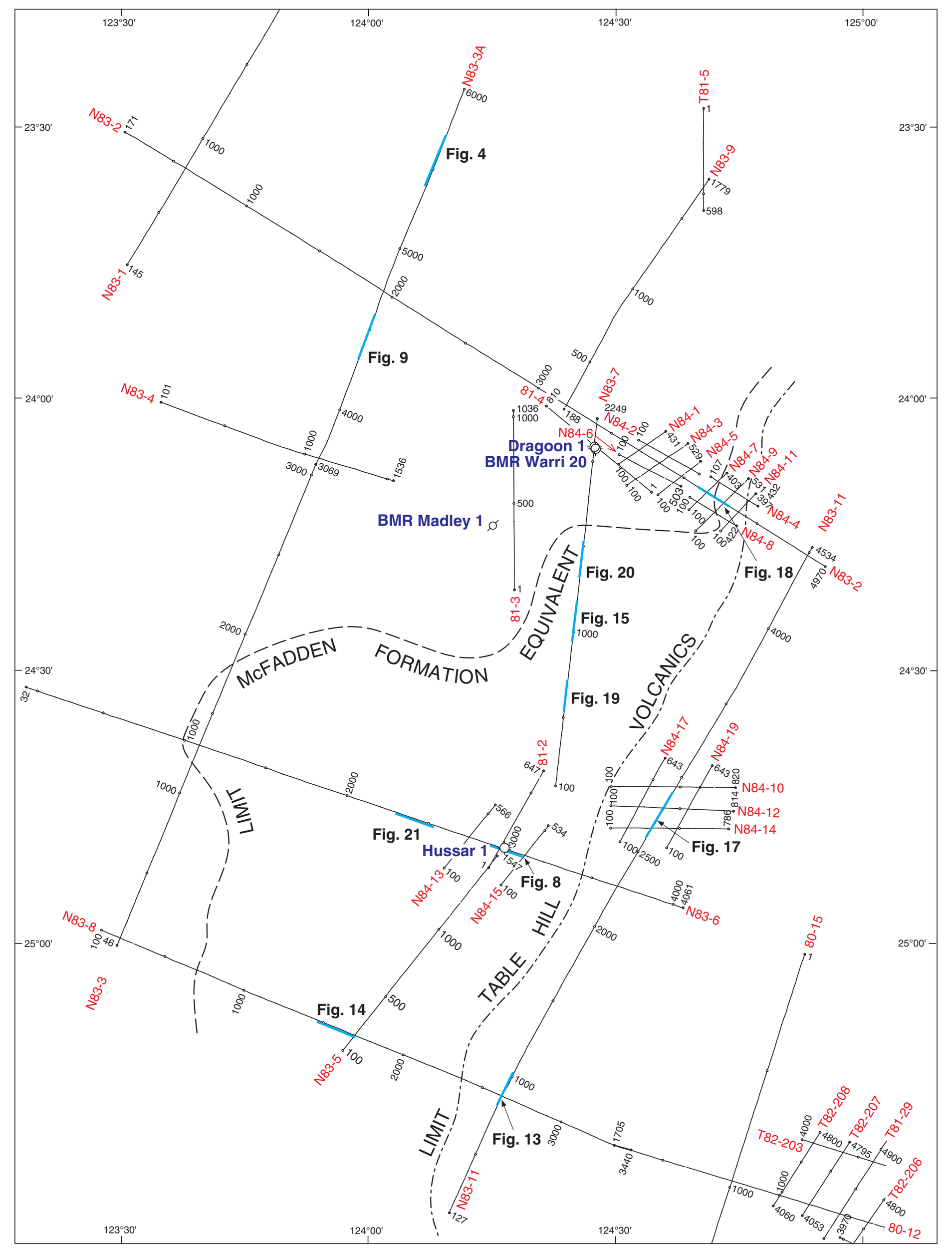
NEAR-BASE SALT



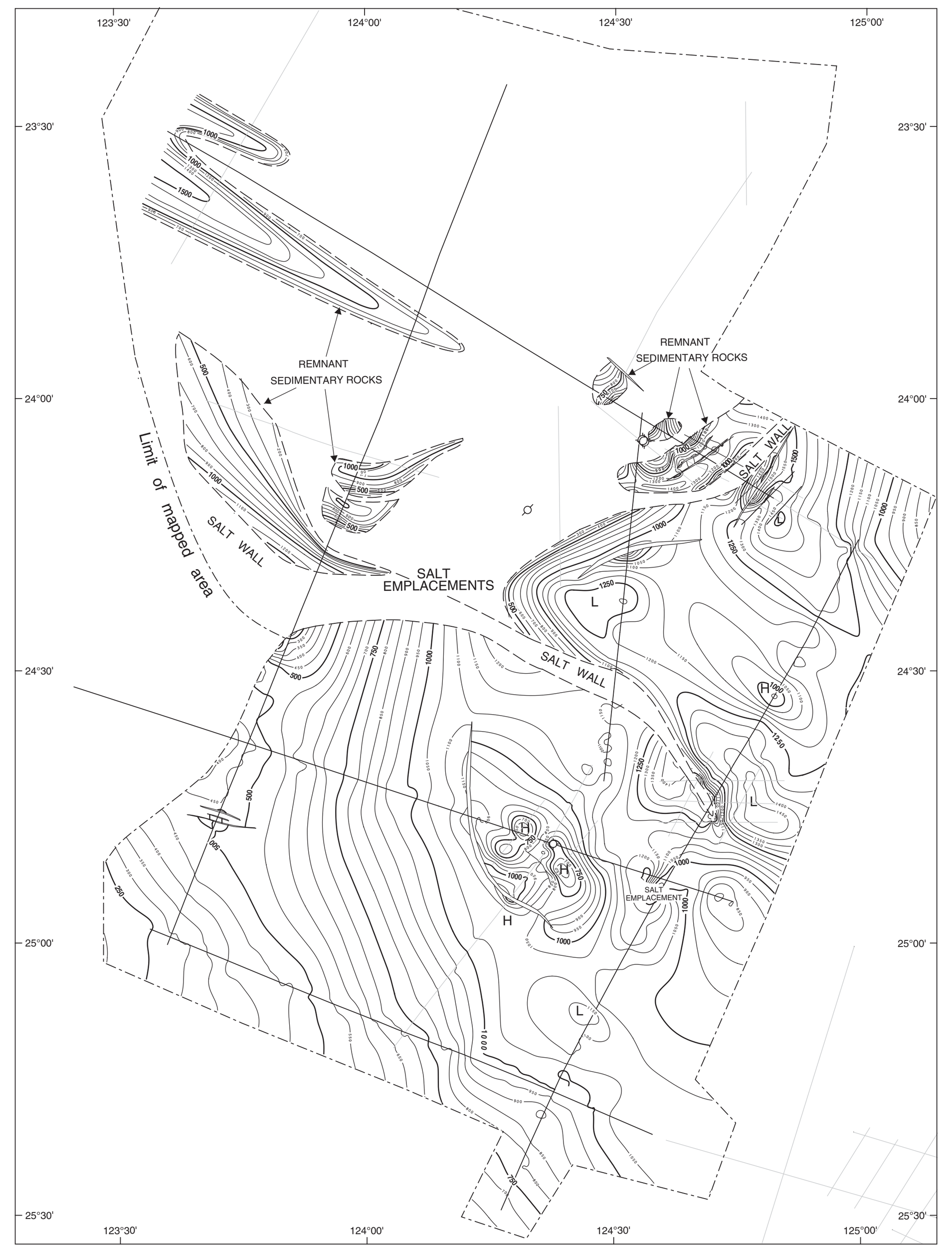
TOP BROWNE FORMATION



SEISMIC LINE LOCATION MAP



TOP HUSSAR FORMATION



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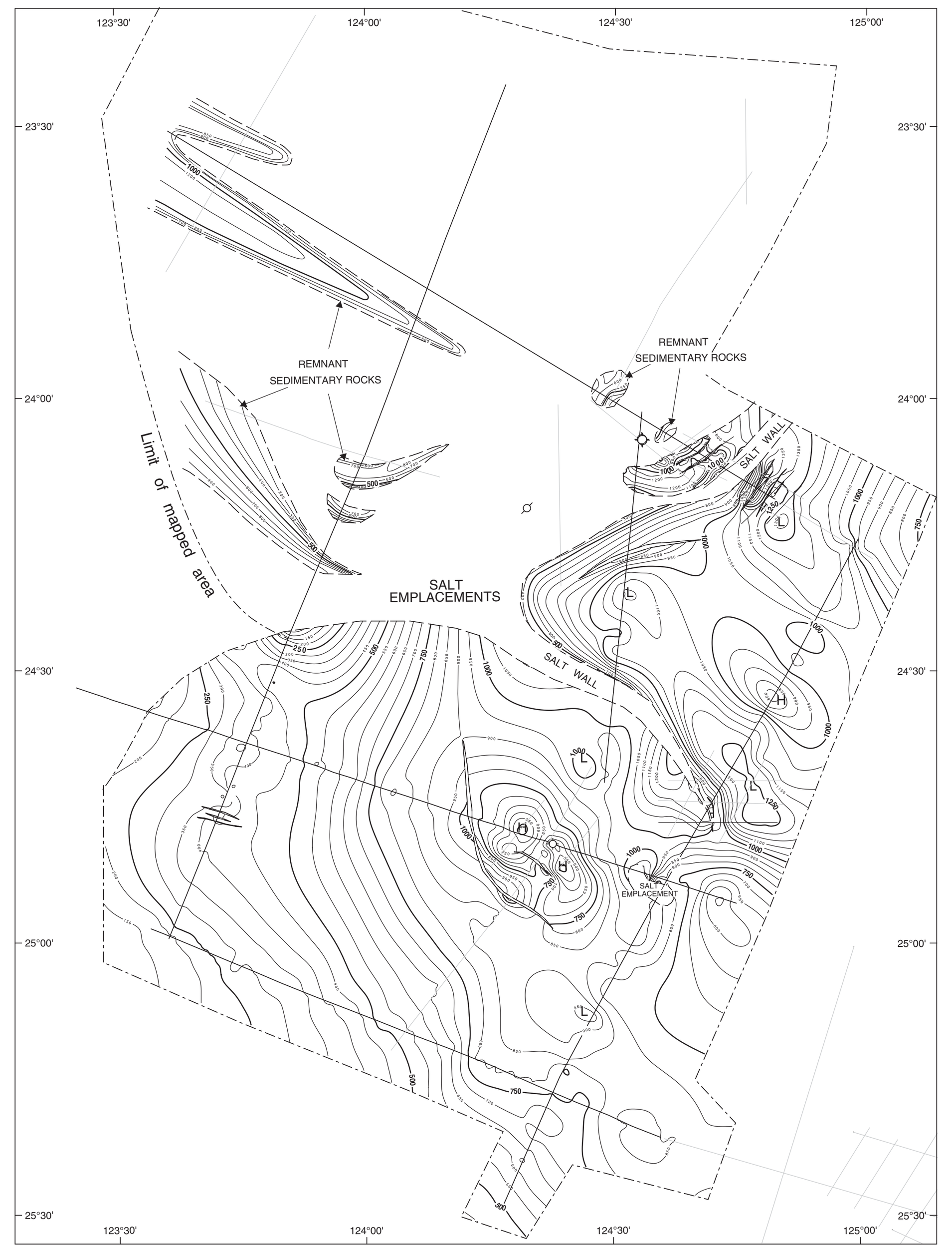
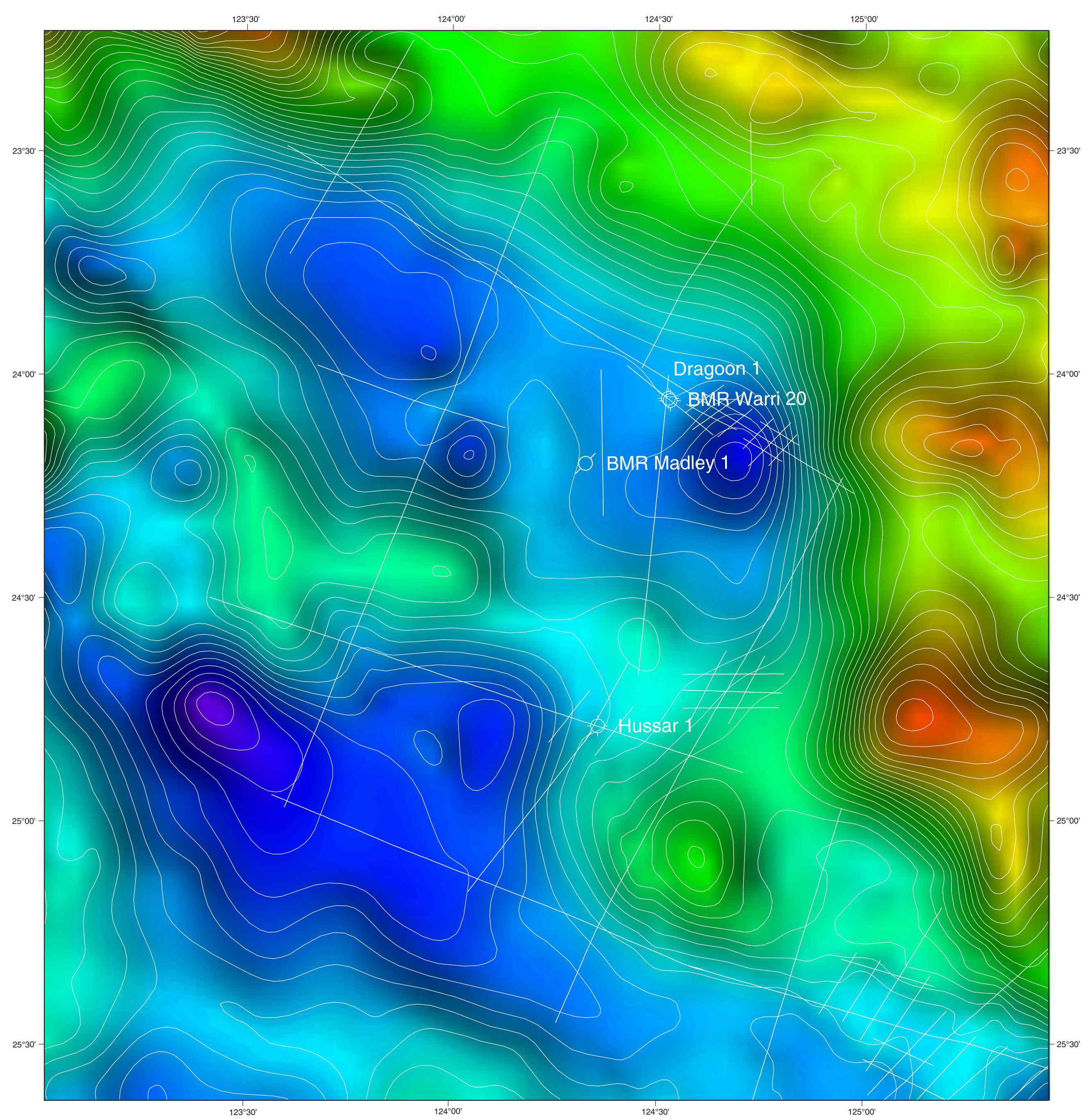
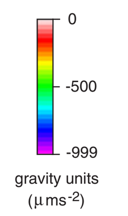
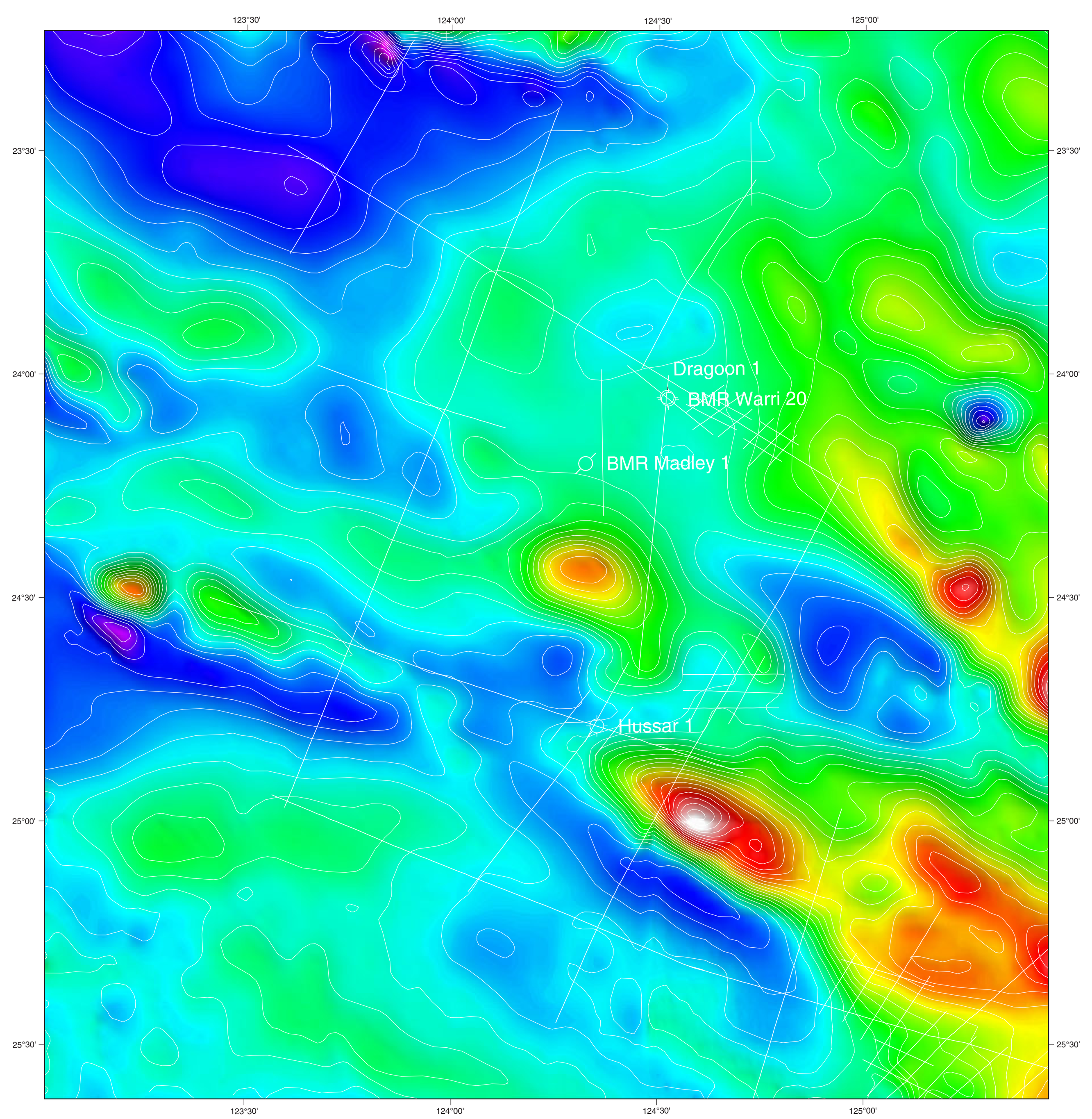


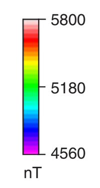




Bouguer gravity image

Gravity data gridded from Geoscience Australia 1995 database.
Bouguer anomaly values calculated using a density of 2.67 tm^{-3}.
Grid cell size is approximately 5 km.
Contour interval is 10 gravity units.
Illumination from southwest.

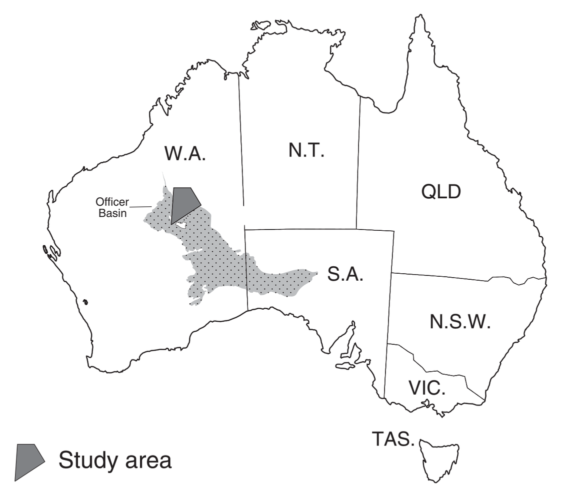




Total magnetic intensity image

Total magnetic intensity from 1996 Geoscience Australia data.
Grid cell size is 250 m.
Contour interval is 50 nT.

Seismic line (in Report)
Seismic line (not in Report)
Exploration well
Stratigraphic well
Contours in milliseconds
Fault
H High areas
L Low areas
Approximate extent of salt wall



GIBSON AREA GEOPHYSICAL MONTAGE WESTERN OFFICER BASIN

50 km

This PDF is best printed at a custom page size of 2250 mm x 840 mm

Department of Mineral and Petroleum Resources

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