Seismic stratigraphic framework of the Neoproterozoic successions, Officer Basin, Western Australia

by S. N. Apak[1] and G. M. Carlsen[2]

Abstract

Three unconformity-bound sedimentary successions are present in most parts of the Officer Basin in Western Australia: Supersequences 1, 3, and 4. These supersequence sets are now further subdivided into parasequence sets. Seismically, Supersequence 1 unconformably overlies poorly imaged older rocks and is characterized by continuous parallel reflectors that truncate against younger unconformities.

The Areyonga Movement (c. 750 Ma) is responsible for the strongest thrust-related deformation in parts of the Officer Basin, initiating salt movement that pierced through the strata creating salt-cored folds. This tectonic movement created the regional unconformity that separates Supersequence 1 from Supersequence 3. There are no preserved Supersequence 2 rocks in the Officer Basin. Supersequence 3 and 4 strata fill structural and topographic lows, and onlap and overlap highs. Later deformations including further salt movement during the Petermann Ranges Orogeny and Palaeozoic tectonic events resulted in greater stratigraphic diversity within Supersequences 3 and 4.

KEYWORDS: Structure, stratigraphy, sequence stratigraphy, basin analysis, Yowalga, Lennis, Gibson, Officer Basin, Western Australia.

Introduction

The Neoproterozoic sedimentary rocks of the Officer Basin in Western Australia were deposited unconformably over the Archaean Yilgarn Craton, the Palaeoproterozoic and Mesoproterozoic sedimentary and volcanic rocks of the Earaheedy, Edmund, and Collier Basins, and the Mesoproterozoic igneous and metamorphic rocks of the Musgrave Complex and Albany–Fraser Orogen. The 6–10 km-thick Officer Basin sedimentary succession is still poorly known due to limited seismic, outcrop, and well control, particularly in the Waigen, Lennis, and Gibson areas (Fig. 1). Information on the Officer Basin is provided by Jackson and van de Graaff (1981); Iasky (1990); Stevens and Apak (1999); Carlsen et al. (1999); Apak and Moors (2000b); Apak and Moors (2000c); Tyler and Hocking (2001); Moors and Apak (2002).

The interpreted seismic data illustrated in this paper benefited from the data reprocessing and interpretation of Japan National Oil Company (1997), Perincek (1998), and Durrant and Associates (1998). Most of these data have since been reinterpreted and seismic stratigraphic concepts applied to establish a regional distribution of the Neoproterozoic strata in the Officer Basin (Apak and Moors, 2000a,b; Moors and Apak, 2002).

[1] neil.apak@doir.wa.gov.au
[2] greg.carlsen@doir.wa.gov.au

Seismic stratigraphy

Four major unconformities and three supersequences were previously recognized within the Western Australian part of the Officer Basin (Fig. 2; Apak and Moors, 2000a,b; 2001; Moors and Apak, 2002):

- the basal unconformity;
- Supersequence 1;
- post-Supersequence 1 unconformity;
- Supersequence 3;
- post-Supersequence 3 unconformity;
- Supersequence 4;
- post-Supersequence 4 unconformity.

There are no preserved Supersequence 2 rocks in the Officer Basin succession in Western Australia.

Apak and Moors (2000a,b) demonstrated the presence of laterally correlative sequences within Supersequence 1. Sequences B, H, K, and S coincide closely with the previously defined stratigraphic units of the Browne, Hussar, Kanpa, and Steptoe Formations respectively (Townson, 1985). Each sequence comprises numerous parasequence sets (e.g. B1 to B6 in Sequence B; Fig. 2) that show progradation, with coarse clastic beds or tidal flat to supratidal carbonate to evaporitic deposits spread across the deeper water deposits.

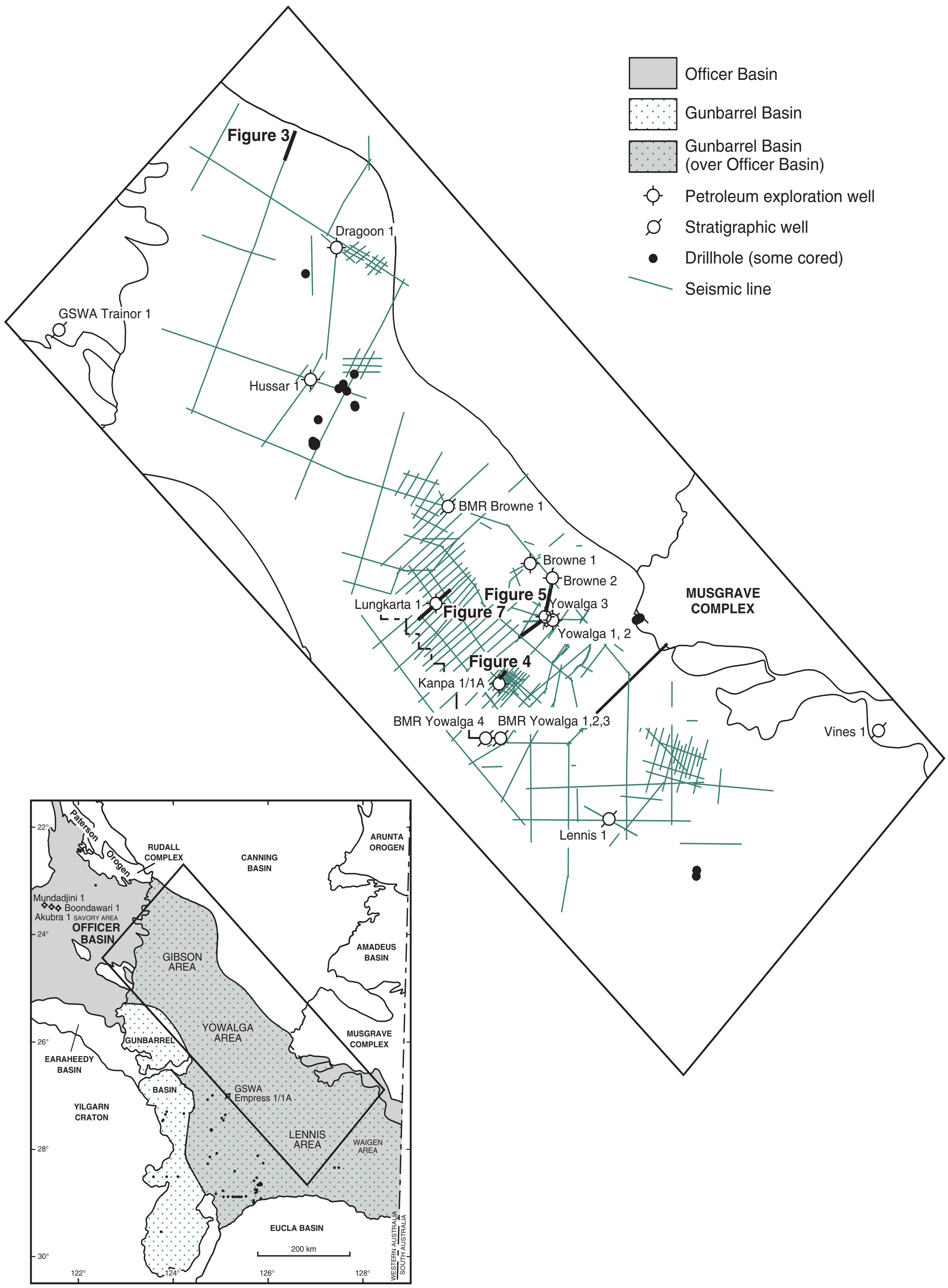

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Figure 1. Location map showing seismic coverage and wells in the Officer Basin

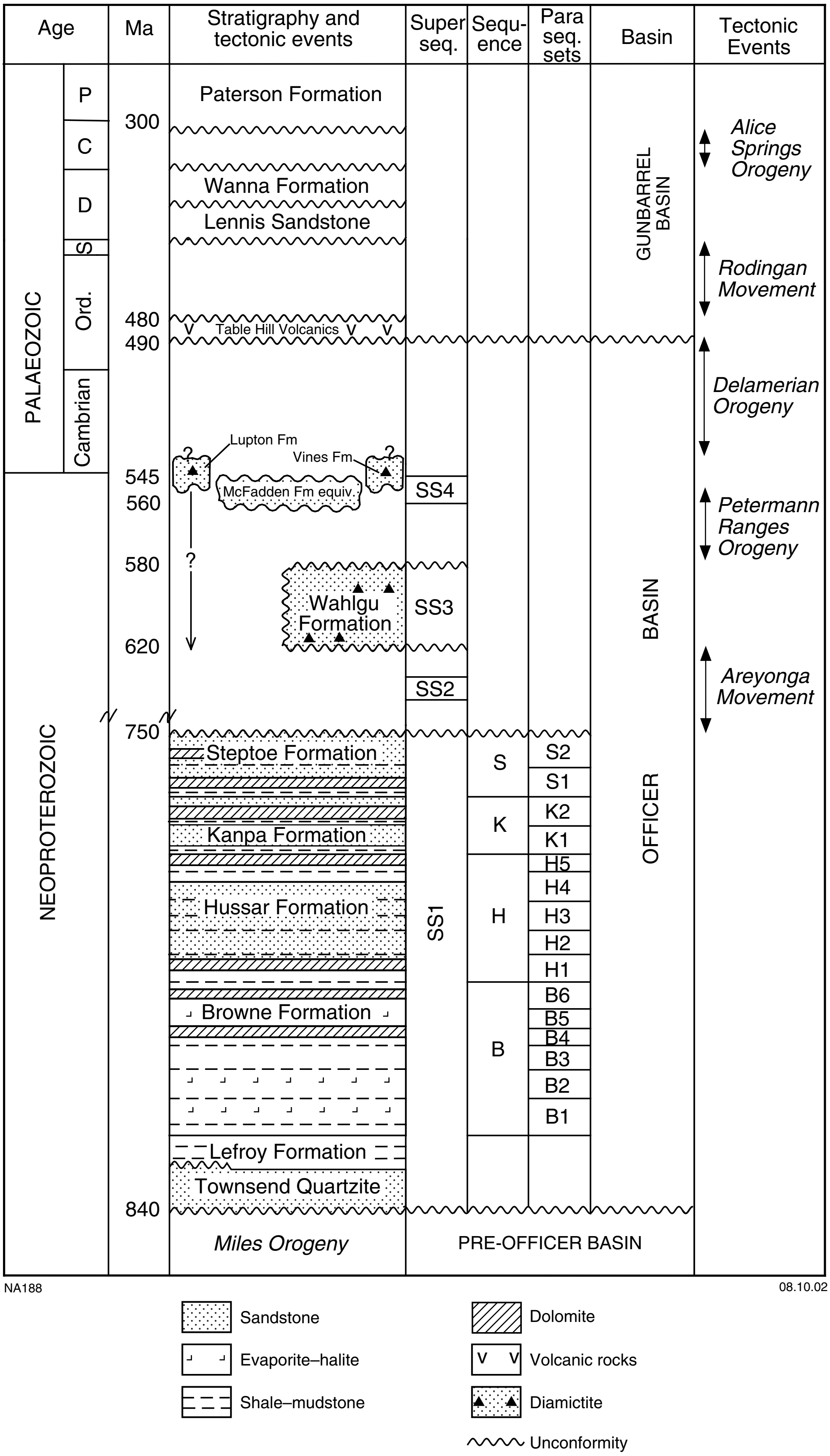

Figure 2. Stratigraphic column showing lithostratigraphy, sequence-stratigraphic units, and tectonic events in the western Officer Basin

The basal unconformity

The basal unconformity separates the Officer Basin from the underlying Mesoproterozoic and older rocks. This unconformity is not a prominent reflector because it is commonly masked by overlying massive salt. Elsewhere, such as in the Gibson area, the Officer Basin succession disconformably overlies similarly bedded Mesoproterozoic sedimentary rocks (Moors and Apak, 2002). However, where the contact relationship is angular the horizon can be picked with some confidence (Fig. 3).

Supersequence 1 stratigraphy and structure

The Townsend Quartzite, the lowest unit of Supersequence 1, contains fluvial to nearshore marine sandstones and is conformably overlain by marine sandstone, siltstone, and shale of the Lefroy Formation (Jackson and van de Graaff, 1981; Perincek, 1996, 1997, 1998; Apak and Moors, 2000b). The overlying Browne Formation (and the correlative Skates Hills Formation) correlates with part of the Alinya Formation from the eastern Officer Basin in South Australia and consists of mudstone, argillaceous siltstone, dolomite, and evaporite including halite. The Hussar, Kanpa, and Steptoe Formations consist of sandstone, dolomite, shale, and minor evaporite deposits. Major transgressions at the base of each sequence and secondary transgressions that separate parasequence sets are characterized by high-amplitude continuous seismic reflectors (Fig. 4). The thick halite deposits of the Browne Formation were actively mobilized (plastic deformation and flow) during several tectonic phases resulting in dramatic redistribution — both laterally and vertically — of the salt, producing complex structures (Fig. 5). In most seismic lines Supersequence 1 strata overlying the salt sequence of the Browne Formation are characterized by continuous parallel reflectors, which are traceable in most parts of the basin except where the reflectors are truncated by unconformities (Figs 4 and 5).

Salt mobilization was initiated in most parts of the basin during the Areyonga Movement. Japan National Oil Company (1997) subdivided the Yowalga area along structural boundaries largely imposed at this time. Their subdivision includes a salt-ruptured zone (closest to the Musgrave Complex), a central thrusted zone, and western platform (Fig. 6).

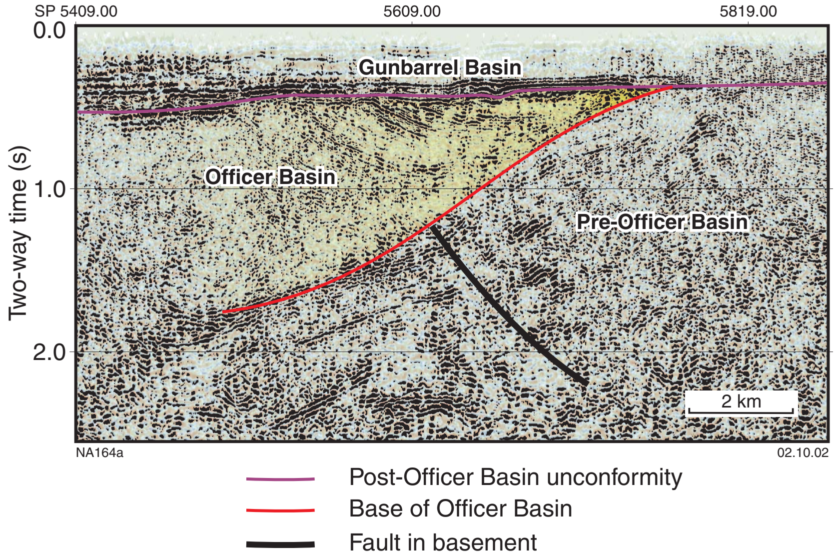

Figure 3. Seismic line N83-3A showing the unconformable relationships between the Neoproterozoic Officer Basin and the underlying Mesoproterozoic strata in the Gibson area. For location of seismic line see Figure 1

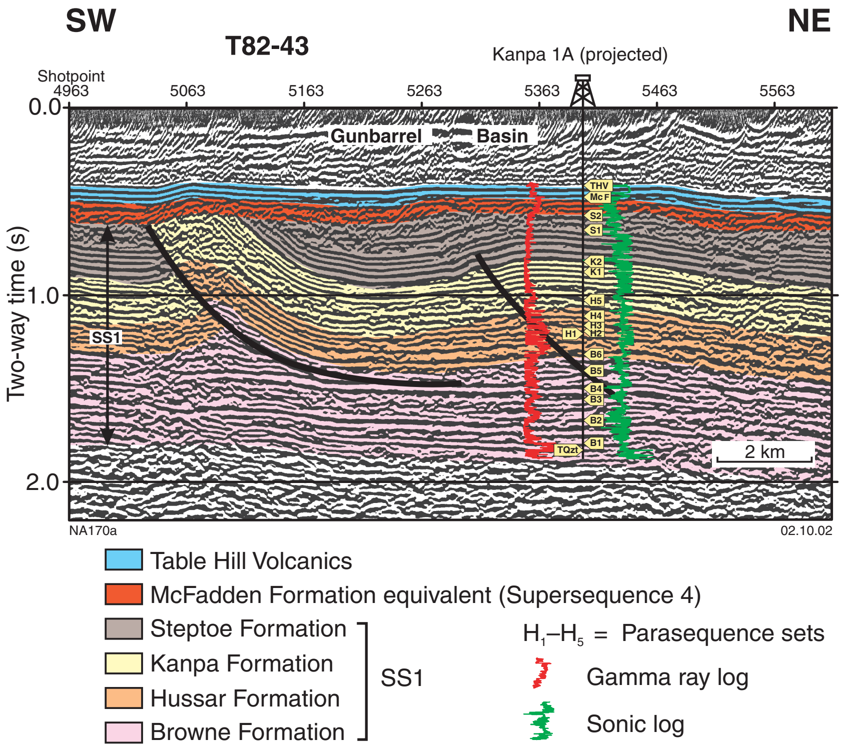

Figure 4. Seismic line T82-43 showing a salt-lubricated thrust fault in Sequence B (Browne Formation) and erosion of Supersequence 1 strata. Supersequence 3 strata are absent and Supersequence 4 strata unconformably overlie Supersequence 1. For location of seismic line see Figure 1

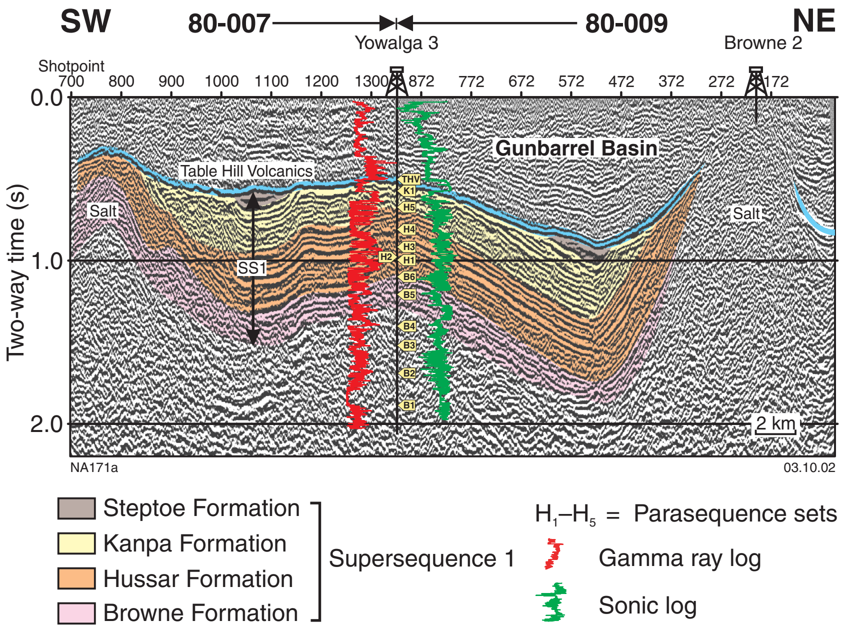

Figure 5. Composite seismic section of lines 80-007 and 80-009 showing the Yowalga 3 well and erosion of Supersequence 1 strata between salt emplacements in the Yowalga area. For location of seismic line see Figure 1

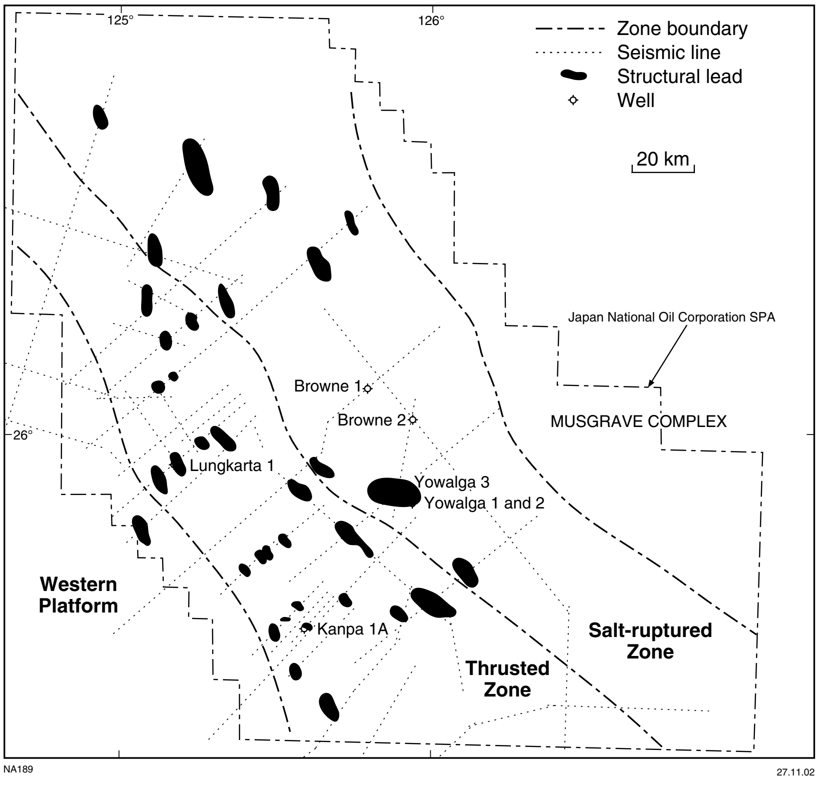

Figure 6. Distribution of structures and tectonic zoning in the Yowalga area (after Japan National Oil Company, 1997)

The salt-ruptured zone is an area of salt diapirism defined within the seismic dataset, and some salt diapirs, such as the Browne, Woolnough, and Madley diapirs, have been recognized from surface mapping. The Mount Samuel Salt Wall of the salt-ruptured zone is more than 10 km wide and 100 km long.

The thrusted zone is characterized by low-angle thrust faults. In the Yowalga area most faults are thin-skinned listric thrust faults that are detached along the salt horizon in Sequence B. Fault ramps are common below salt intrusions, indicating that the salt movement was activated along pre-existing zones of weakness (Durrant and Associates, 1998). Most displacements are confined to the Supersequence 1 strata (Figs 4 and 7), but exhibit minor reactivation that later extended the faults into younger units. Most large-scale folds are either halokinetic or ramp anticline folds (Fig. 4).

Listric faults lubricated by salt are less common in the Lennis area. In the Gibson area many of the thrust faults are listric and form high-angle reverse faults at shallow depths. Although the reflection record below salt is poor, these faults appear to flatten with depth and probably detach near the base of salt-forming, basal thrust planes.

Deformation that produced the thrusting pre-dates the deposition of Supersequence 3, and is correlated with the c. 750 Ma Areyonga Movement (Fig. 2). It represents a compressional event, and thrusting may be directly linked to basement uplift, represented by the Musgrave Complex to the northeast. Alternatively, it may represent gravitational collapse of the uplifted sedimentary pile adjacent to the Musgrave Complex, which became unstable, detached along the salt beds, and slipped to the southwest.

The thrusted zone is bound to the west by the western platform. This is a gentle structural ramp that flanks the entire southwestern margin of the Officer Basin. It is defined by drillholes Jubilee 1 and 2, Mason 1 and 2, Weedy 1 and 2, NJD 1, Empress 1A, and the seismic data.

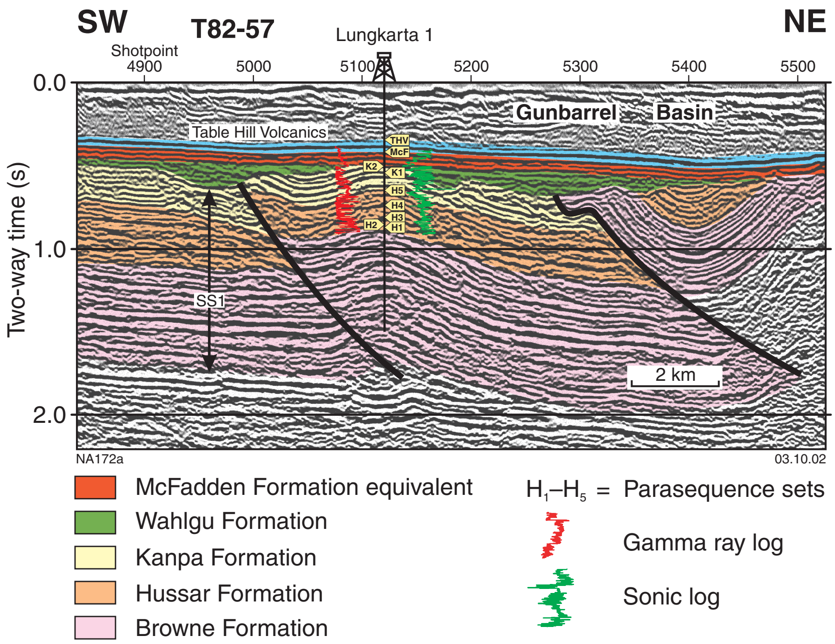

Figure 7. Seismic line T82-57 showing the Lungkarta 1 well drilled on a ramp anticline fold and the deep erosional surface of the post-Supersequence 1 unconformity. For location of seismic line see Figure 1

Post-Supersequence 1 unconformity

Following the Areyonga Movement, a significant amount of Supersequence 1 strata was eroded, particularly over salt-emplacement structures and along the basin margins. The major unconformity developed over these structures is characterized by sharply erosive valleys and channel-like features at the base of the overlying Wahlgu Formation (Fig. 7). The post-Supersequence 1 unconformity is correlatable throughout large parts of the basin. However, in places the Wahlgu Formation (Supersequence 3) and part of Supersequence 1 have been removed by younger erosional events (Figs 4 and 5).

Supersequence 3

Gentle subsidence coincided with the deposition of the Wahlgu Formation (Supersequence 3), which represents the Marinoan glaciation in the Officer Basin (Grey et al., 1999). Supersequence 3 has been eroded over many later formed structures (Fig. 7), particularly between the Gibson and Yowalga areas, but it still extends through most of the basin. Large channels are in places incised into the Kanpa Formation (Moors and Apak, 2002).

Post-Supersequence 3 unconformity

The Petermann Ranges Orogeny terminated deposition of Supersequence 3. The post-Supersequence 3 unconformity between the McFadden Formation equivalent and the underlying Wahlgu Formation or older units in the western Officer Basin developed over structures formed during this major deformation event. More than 15 km of uplift is recorded in the northern part of the Musgrave Complex during this orogeny with large-scale folding and thrusting of the southern Amadeus Basin; however, structures formed in the western Officer Basin at this time are of relatively small scale and there is no evidence for involvement of the basement underlying the basin.

In areas adjacent to salt emplacements this unconformity is angular (Moors and Apak, 2002), but within a few kilometres of the salt walls the contact between the Wahlgu Formation and McFadden Formation equivalent is merely disconformable.

Supersequence 4

Supersequence 4 consists of the McFadden Formation in the Savory region and a correlative unit, the McFadden Formation equivalent (Lungkarta Formation of Grey et al., in prep.), in the remainder of the basin. The formation onlaps and thins over pre-existing structural highs (Moors and Apak, 2002). Williams and Bagas (2000) suggested that the McFadden Formation in the Savory area was weakly deformed during the closing stages of the Paterson Orogeny, which is correlated with the Petermann Ranges Orogeny of central Australia (Bagas et al., 1995; Perincek, 1997; Tyler et al., 1998).

The Vines Formation defined in GSWA Vines 1 (Fig. 1) was deposited syntectonically with the uplift of the Musgrave Complex during the Petermann Ranges Orogeny (Apak et al., 2002). Gravity and magnetic data are consistent with the igneous and metamorphic rocks of the Musgrave Complex being thrust over the northeastern margin of the Officer Basin in this area. There are no correlative units interpreted from existing drillholes or seismic data in the western Officer Basin.

Post-Supersequence 4 unconformity

The Delamerian Orogeny terminated deposition of Supersequence 4 (Fig. 2). The Ordovician Table Hill Volcanics and younger rocks unconformably overlie the Supersequence 4 unconformity. High-amplitude and high-continuity reflections are commonly associated with the Table Hill Volcanics (Figs 4, 5, and 7). In some areas, particularly in the Gibson area, the McFadden Formation equivalent and parts of the underlying successions have been truncated by the Delamerian Orogeny and younger deformations (Moors and Apak, 2002).

In the Gibson area late salt movement in some structures penetrates Supersequences 1 through 4 and the overlying Gunbarrel Basin succession. Late salt movement does not affect all structures and is interpreted to be driven by overburden density imbalance. The deposition of a substantial thickness of Supersequence 3 (Wahlgu

Formation) and Supersequence 4 (McFadden Formation equivalent) successions in mini-basins formed by salt evacuation probably accounts for the continued mobility of the salt. Salt movement also displaces the Permian Paterson Formation and the Cainozoic deposits in the Madley diapirs, suggesting that in some regions minor salt movement may have continued up to the present time.

Gunbarrel Basin

The Table Hill Volcanics mark the commencement of a new depositional sequence that has been assigned to the Gunbarrel Basin (Hocking, 1994). The Table Hill Volcanics consist of Lower Ordovician (484 ± 4 Ma), porphyritic and amygdaloidal tholeitic basalt in Empress 1 and 1A (Stevens and Apak, 1999). The Table Hill Volcanics are widespread across the basin, but absent from some parts of the Gibson area. The seismic response of the top of the Table Hill Volcanics is clear and distinct on many seismic lines and is used as a regional marker in the eastern part of the Gibson area, and in the Yowalga and Lennis areas. Salt diapirs have penetrated or folded the Table Hill Volcanics in some structures. Salt-cored structures affect the Gunbarrel Basin sedimentary rocks in all areas, and other structural features such as the Westwood Fault post-date deposition of the Palaeozoic Gunbarrel Basin. The thickness and distribution of Gunbarrel Basin sedimentary rocks must be considered when defining the petroleum systems of the Officer Basin.

Conclusion

The application of seismic stratigraphic concepts has improved our understanding of the depositional and tectonic history of the Officer Basin. Three unconformity-bound supersequences are present. The unconformity at the top of Supersequence 1 correlates with the Areyonga Movement, which caused the strongest deformation in the basin. Younger unconformities at the top of Supersequences 3 and 4 correlate with the Petermann Ranges Orogeny and Delamerian Orogeny respectively. Salt movements related to these tectonic periods created further structural and stratigraphic variations in the basin. Understanding these features will assist in the identification of prospective areas for hydrocarbon exploration.

References

APAK, S. N., and MOORS, H. T., 2000a, A sequence stratigraphic model of Neoproterozoic strata, Yowalga area, Officer Basin, Western Australia: APPEA Journal, v. 40 (1), p. 15–25.

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

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

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

BAGAS, L., GREY, K., and WILLIAMS, I. R., 1995, Reappraisal of the Paterson Orogen and Savory Basin: Western Australia Geological Survey, Annual Review 1994–95, p. 55–63.

CARLSEN, G. M., APAK, S. N., GHORI, K. A. R., GREY, K., and STEVENS, M. K., 1999, Petroleum potential of the Neoproterozoic western Officer Basin, Western Australia, based on a source-rock model from Empress 1A: APPEA Journal, v. 39 (1), p. 322–341.

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

GREY, K., APAK, S. N., EYLES, C., EYLES, N., STEVENS, M. K., and CARLSEN, G. M., 1999, Neoproterozoic glacigene successions, western Officer Basin, W.A.: Western Australia Geological Survey, Annual Review 1998–99, p. 74–80.

GREY, K., STEVENS, M. K., APAK, S. N., and CARLSEN, G. M., in prep., Revised lithostratigraphy of the Officer Basin, Western Australia: Western Australia Geological Survey, Record.

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

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

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

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

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

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

PERINCEK, D., 1997, The stratigraphic and structural development of the Officer Basin, Western Australia — a review: Western Australia Geological Survey, Annual Review 1995–96, p. 135–148.

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

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

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

TYLER, I. M., and HOCKING, R. M., 2001, Tectonic units of Western Australia (scale 1: 2 500 000): Western Australia Geological Survey.

TYLER, I. M., PIRAJNO, F., BAGAS, L., MYERS, J. S., and PRESTON, W. A., 1998, The geology and mineral deposits of the Proterozoic in Western Australia: Australian Geological Survey Organisation, Journal of Australian Geology and Geophysics, v. 17 (3), p. 223–244.

WILLIAMS, I. R., and BAGAS, L., 2000, Geology of the Throssell 1:100 000 sheet: Western Australia Geological Survey, 1:100 000 Geological Series Explanatory Notes, 24p.