Towards a regional understanding of Sherbrook Supersequence Gross Depositional Environments, offshore Otway Basin

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SUMMARY

The Sherbrook Supersequence (Sherbrook SS, Campanian–Maastrichtian) is the youngest of four Cretaceous supersequences in the Otway Basin and was deposited during a phase of crustal extension that culminated in breakup. This study presents a basin-scale gross depositional environment (GDE) map for the Sherbrook SS, and the significance of the map for the Austral 3 (upper Cretaceous, lower Cenozoic) petroleum system is discussed. Supersequence thickness is typically less than 1,000 ms TWT across the inboard platform. Beyond the platform edge up to 2,800 ms TWT of Sherbrook SS sediments were deposited in the deep-water Morum and Nelson sub-basins. Analysis of wireline logs and cores from wells yielded fluvial, deltaic, coastal, and shelf gross depositional environments (GDEs). As the number of regionally mappable seismic facies is much less than the number of well-derived GDEs, the integration of well-based environmental interpretations with seismic facies resulted in three main regional GDEs (RGDEs); Fluvial Plain, Coastal/Deltaic Plain, and Shelf. The Fluvial Plain and Coastal/Deltaic RGDEs are almost entirely restricted to the inboard platform areas of the basin. The mud-prone Shelf RGDE is widespread across the deep-water part of the basin where it forms the depocentres of the Morum and Nelson sub-basins. The Shelf RGDE is well imaged on the Otway 2020 2D seismic data that was acquired over the deep-water Otway Basin. In the Morum Sub-basin, the Shelf RGDE is strongly influenced by growth on extensional faults. In contrast, the Shelf RGDE in the Nelson Sub-basin is a relatively unstructured progradational complex. The presence of mass-transport and incision complexes are consistent with tectonism during Sherbrook SS deposition. Reservoir rocks in the deep-water basin are expected where the Coastal/Deltaic RGDE encroaches into the Morum Sub-basin. In this setting, the Austral 3 petroleum system was potentially active within the Sherbrook SS.

Key words: Otway Basin, Sherbrook Supersequence, gross depositional environment, seismic facies.

INTRODUCTION

The Otway Basin (Figure 1) comprises unconformity bound seismic supersequences (Figure 2) formed in response to rifting and thermal subsidence phases linked to the separation of Australia and Antarctica (Krassay et al., 2004). The Sherbrook Supersequence (Campanian–late Maastrichtian) was deposited during a phase of rifting that concluded with the onset of continental breakup in the latest Maastrichtian. An isochron map (Figure 1b) of the offshore Sherbrook SS (Nicholson et al, 2022) was constructed using seismic interpretations from the recently acquired 2020 Otway Basin 2D seismic survey covering the deep-water part of the basin, together with ~40,000 line-km of legacy 2D seismic data. The map confirms the influence of syn-sedimentary extension on the development of Sherbrook SS depocentres across the deep-water basin.

The Sherbrook Supersequence (Sherbrook SS) is a progradational succession (e.g. Partridge, 2001), composed of shelfal marine mudstone overlain by deltaic, coastal, and fluvial sediments. Numerous well intersections across the inner Otway Basin (Figure 1a) constrain the distribution of these environments. In the deep-water part of the basin, the Sherbrook SS is only intersected by 3 wells so the distribution of depositional environments (DEs), and hence play elements such as source, reservoir and seal, is poorly constrained.

This study presents a gross depositional environment (GDE) map for the upper Sherbrook SS. Well-based environmental interpretations yielded a variety of fluvial, coastal, deltaic, and shelf GDEs. Seismic facies calibrated to well-based GDEs were then mapped to predict the GDE distribution across the offshore basin, including in the deep-water region. This integrated approach has yielded a map that shows lower delta plain GDE extending into the Morum Sub-basin. The presence of deeply buried Sherbrook SS deltaic sediments indicates that the Austral 3 petroleum system, which is thermally immature across platform areas (Totterdell et al., 2014), may be productive in the Morum Sub-basin.

SHERBROOK SUPERSEQUENCE

The Sherbrook SS (Figure 3) is bound at its base by the Lower Cretaceous 2 unconformity (LC2, base *N. aceras* dinocyst zone) and at its top by the Tertiary 1 unconformity (T1, intra Upper *M. druggii* dinocyst zone). Across platform areas, where minor fault-growth is locally evident, supersequence thickness is typically less than 1 000 ms TWT.

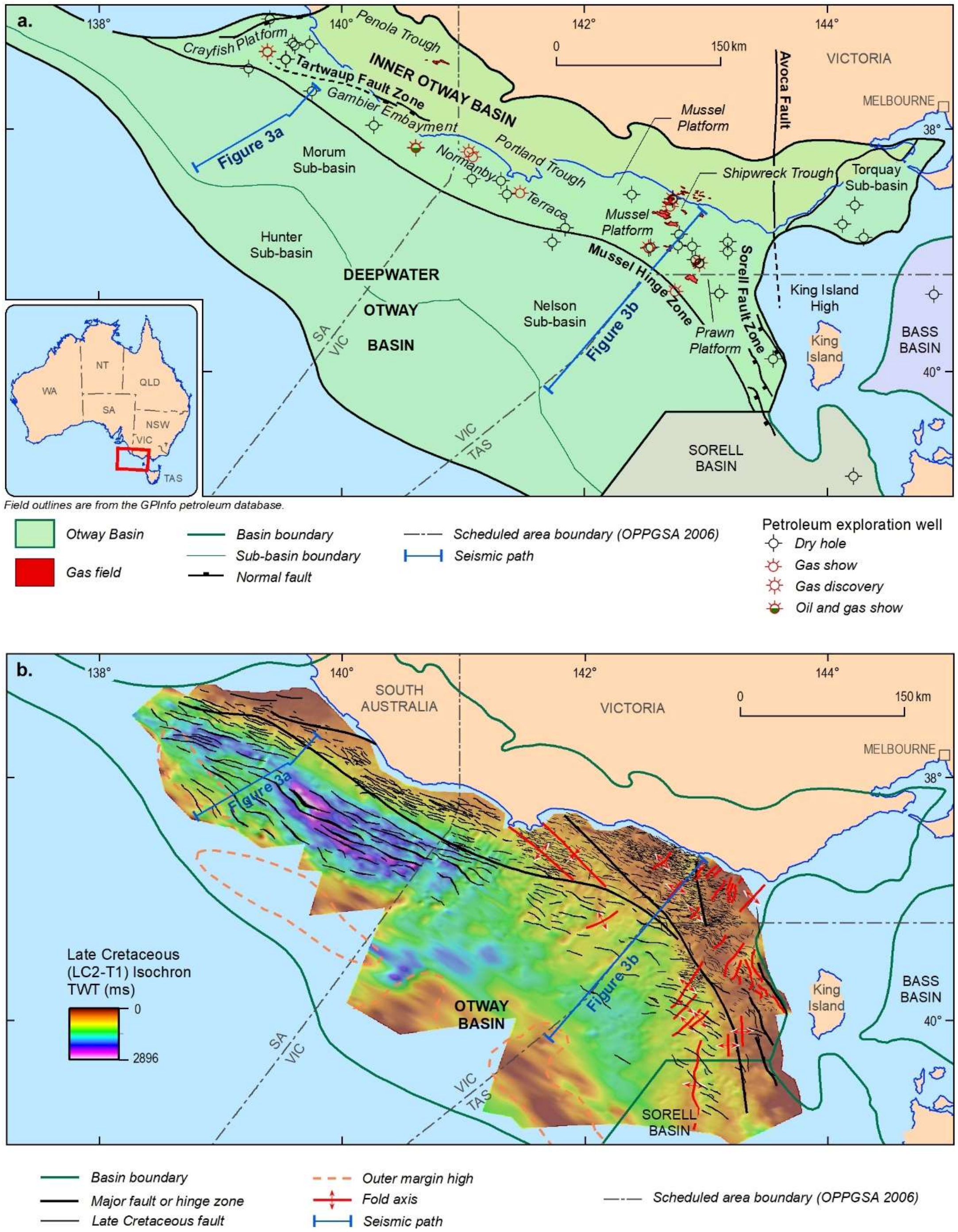

Figure 1. (a) Structural elements map of the Otway Basin showing petroleum wells and fields, and the locations of Figure 3 seismic transects. Basin and sub-basin outlines are after Totterdell et al. (2014). (b) Sherbrook SS isochron map, faults, showing faults, fold axes, and outer margin highs. Faults on the SE inboard platform areas are from Romine et al. (2020). Modified from Nicholson et al. (2022).

In the Morum Sub-basin (Figure 3a) the Sherbrook depocentre attains a thickness of up to 2,800 ms TWT and is accommodated in large growth wedges. In the Nelson Sub-basin where fault- growth is relatively minor, the Sherbrook depocentre (< 2,000 ms TWT) is a progradational complex (Figure 3b). The contrasting tectonostratigraphic style of the outboard sub-basins is also expressed in the relationship between the outboard edge of the supersequence with the outer margin highs. Extensive erosion is evident in the Morum Sub-basin, whereas in the Nelson Sub-basin, a downlapping relationship is observed. In the deep-water region between the outboard sub-basins the Sherbrook SS is disrupted by mass-transport complexes (MTCs).

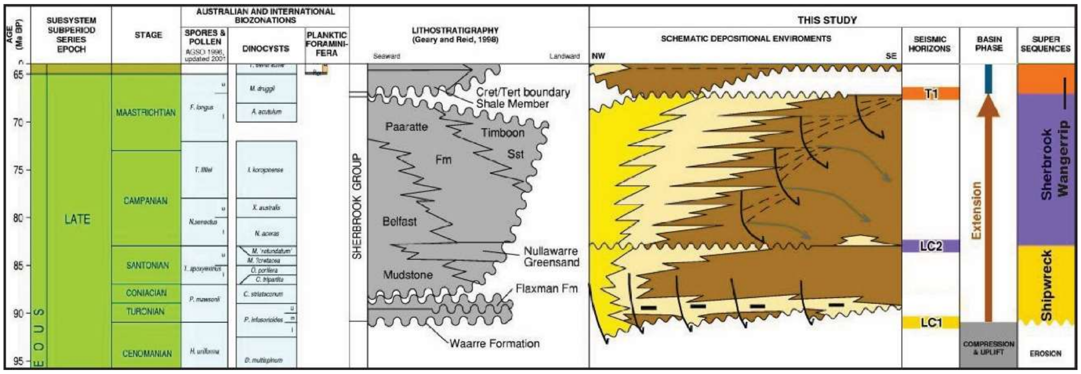

Figure 2. Stratigraphic column for the Late Cretaceous of the Otway Basin (excerpt from Krassay et al. 2004).

REGIONAL GDE FROM SEISMIC FACIES AND WELLS

Across most of the platform areas of the offshore Otway Basin, GDE mapping of the Sherbrook SS is supported by a relative abundance of well data. The deep-water part of the basin is an exploration frontier where GDE mapping relies almost exclusively on widely spaced 2D seismic lines. The compilation of GDE maps therefore necessarily depends on the integration of well data with seismic facies to develop a simple GDE classification that is robust enough to be applied at the basin-scale while providing a meaningful indication of source, reservoir and seal distribution.

For each of the 40 wells selected for DE/GDE analysis, observations from core, cuttings, and wireline logs were used to subdivide the Sherbrook interval into DEs and GDEs using the nomenclature shown in Figure 4. Fluvial plain, upper delta plain, lower delta plain, delta front, and shelf GDEs are recognised in the Sherbrook SS succession. Figure 5a depicts DE and GDE interpretation of the Sherbrook SS in 3 representative wells. Figures 5b (a detailed core log) and 5c (a core photograph of tidal deltaic sediments) are examples of key inputs of the interpretation workflow.

A standard approach to seismic facies classification was applied that considers reflector characteristics such as frequency, amplitude, continuity, and geometry (Figure 6, Table 1). Seismic resolution across much of the inboard platform areas is compromised by the Cenozoic wedge which includes volcanics, carbonates, incision complexes, and mass transport complexes. Calibration of seismic facies with well-derived GDE is also adversely affected by faults at some well locations. Seismic facies are readily interpreted in the deep-water area where seismic resolution is generally higher but wells are essentially absent.

REGIONAL GDE MAP FOR THE UPPER SHERBROOK SUPERSEQUENCE

Integration of seismic and well-based interpretations yielded Fluvial Plain, Coastal/Deltaic Plain, and Shelf regional GDE (RGDE) (Table 1, Figure 6 a–d) that were mappable at the regional scale. Two subordinate RGDE, mass transport complex (MTC) and incision complex, are only recognised in seismic (Table 1, Figure 6 e–f). RGDE are summarised below and their distribution across the Otway Basin is depicted in Figure 7.

Fluvial Plain RGDE

The Fluvial Plain RGDE corresponds to the fluvial plain and flood plain GDEs, and includes fluvial channel (anastomosing and meandering), crevasse splay, flood plain and abandonment environments (Figure 5a). In seismic, the Fluvial Plain RGDE (Figure 6a) includes discontinuous and locally shingled reflections, in alternation with high amplitude continuous reflections. The discontinuous and shingled reflections represent a variety of channel, crevasse-splay, and channel abandonment environments, while the relatively high amplitude and high continuity reflectors represent floodplain environments. The Fluvial Plain RGDE transitions to the Coastal Plain RGDE over distances of a few kilometres to several tens of kilometres (Figure 3).

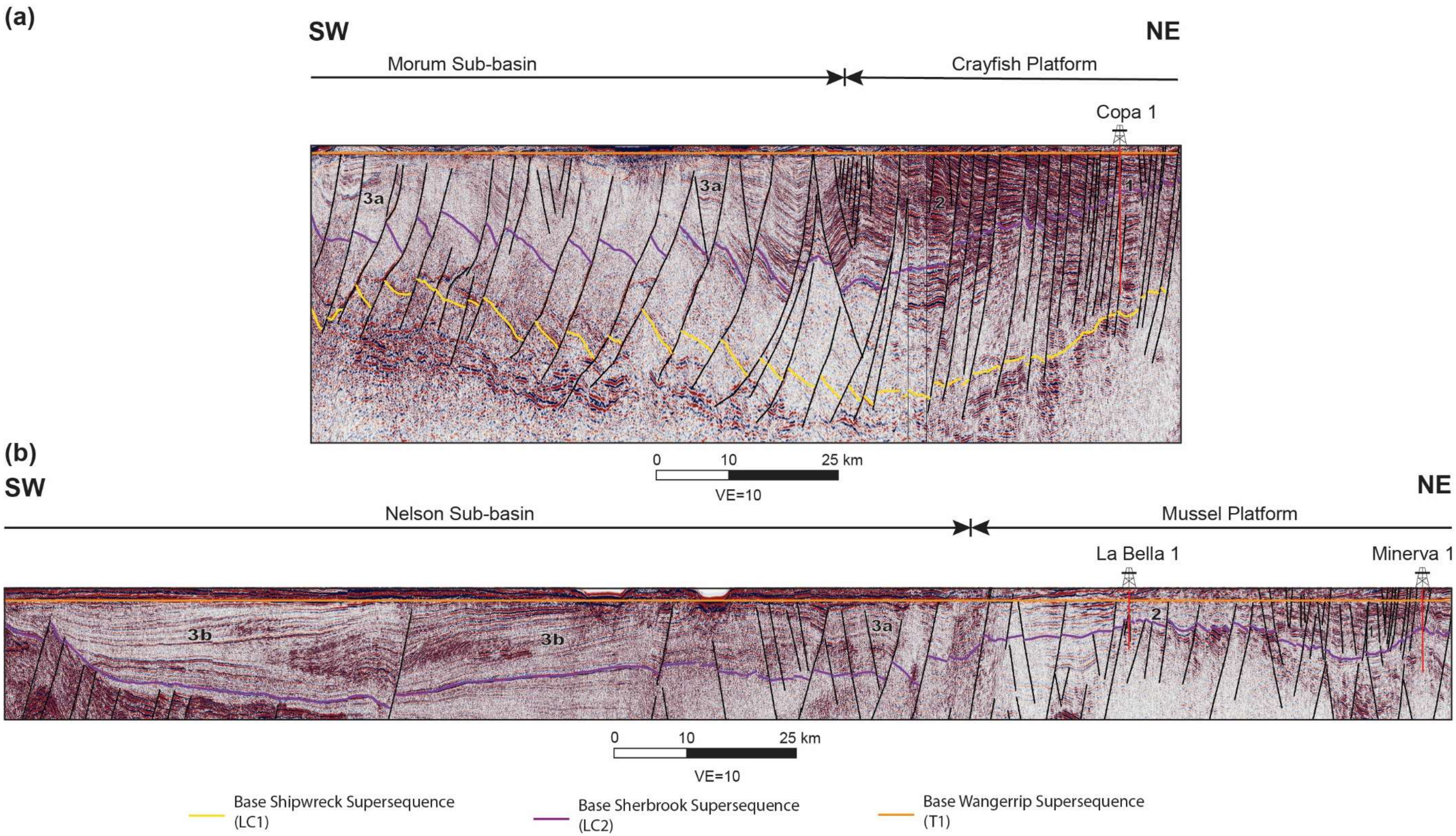

Figure 3. Seismic stratigraphy of the Sherbrook Supersequence. (a) Crayfish Platform to Morum Sub-basin, showing Sherbrook Supersequence growth on listric faults in the Morum Sub-basin. (b) Mussel Platform to Nelson Sub-basin, showing progradational complex in the Nelson Sub-basin. Annotations refer to the seismic RGDE classification in Figure 6 and Table 1. Seismic path locations are shown on Figure 1. Profiles are flattened on T1 and vertical exaggeration has straightened and steepened the appearance of faults.

Seismic Facies	Relative amplitudes	Frequency	Continuity	Geometry	Regional Gross Depositional Environment
1	Variable	Low	Continuous to discontinuous	Parallel, rarely shingled or hummocky	Fluvial plain (Figure 6a)
2	Variable	Low	Continuous to semi-continuous	Parallel, commonly shingled or hummocky	Coastal/Deltaic plain (Figure 6b)
3	Mostly low	Mostly high	Mostly continuous	Parallel, rarely shingled	Shelf
3a	Mostly low	Mostly high	Mostly continuous	Divergent	Shelf (growth-wedge) (Figure 6c)
3b	Mostly low	Mostly high	Mostly continuous	Shelf- and delta-scale sigmoidal clinoforms	Shelf (progradational complex)(Figure 6d)
4	High	Low	Discontinuous	Contorted, chaotic	Mass transport complex (Figure 6e)
5	High	Low	Variable	Channel-fill clinoforms	Incision complex (Figure 6f)

Table 1. Characteristics of seismic scale RGDE.

Coastal/Deltaic Plain RGDE

The Coastal/Deltaic Plain RGDE includes delta plain (upper and lower), coastal plain, estuary, delta front, and shoreface GDEs. Depositional environments include mouth bar, distributary channel, abandonment, shoreface and delta front environments (Figure 5a). The Coastal/Deltaic Plain seismic facies (Figure 6b) is characterised by discontinuous, shingled, and delta-scale clinoform reflections, in alternation with continuous reflections. The discontinuous, shingled and clinoform reflections represent a variety of channel, crevasse-splay, and mouth bar environments, while the high amplitude reflections represent more continuous environments (e.g. pro-delta). The relative abundance of delta-scale clinoform packages is characteristic of this RGDE. These deltaic clinoforms are observed in low quality seismic and confirm the distribution of the Coastal/Deltaic Plain RGDE across much of the inboard platform areas. The outboard edges (“delta limits”) of some delta-scale clinoform packages are depicted in Figure 7. The Coastal/Deltaic Plain RGDE is transitional with the Fluvial Plain and Shelf RGDE over distances of a few kilometres to several tens of kilometres (Figure 3).

Shelf RGDE

The Shelf RGDE includes marine mud-prone inner-, middle-, and outer shelf DEs (Figure 5a). High-frequency, continuous, variable amplitude reflections characterise this seismic facies (Figure 6c). High relative amplitude, low frequency reflections within the Shelf RGDE represent coastal/deltaic facies deposited by high frequency transgressive-regressive shoreline transits. In the Morum Sub-basin, the Shelf RGDE displays prominent growth-faulting associated with a set of listric faults (Figures 3a and 6e). In contrast, fault growth in the Nelson Sub-basin is relatively minor and instead the Shelf RGDE is distinguished by shelf-scale clinoforms (Figure 3b) that consist of delta-scale clinoforms (Figure 6d). This progradational package correlates to a thin (i.e. 100 m or less) mud-rich interval in wells such as Somerset 1. The dominance of marine mud for the Shelf RGDE is consistent with the sigmoidal character of clinoforms within the progradational complex.

Mass transport and incision complexes

Contorted and chaotic MTC deposits (Figure 6e) are up to 70 km across. This seismic facies is best developed in the transition between the Morum and Nelson sub-basins (Figure 7) where in places much of the Sherbrook SS stratigraphy is disrupted. Incision complexes, in places over 200 ms TWT thick, are observed along the inboard boundary of the Morum Sub-basin (Figure 6f and Figure 7).

Core/Wireline Scale		Seismic Scale
Depositional Environments (DE)	**Gross Depositional Environments (GDE)**	**Regional Gross Depositional Environments (RGDE)**
Swamp Crevasse Lacustrine (extensive) Flood Plain (Distal) Flood Plain (Interfluve) Flood Plain (Lacustrine)	Flood Plain	Fluvial Plain (Incision Complex)
Abandonment Fluvial Channel (Braid) Fluvial Channel (Anastamosing) Fluvial Channel (Meander)	Fluvial Plain	
Estuary (Channel) Estuary (Bar) Estuary (Basin Centre) Lagoon Inter-distributary Bay (IDB)	Coastal Plain/Estuary	Coastal/Deltaic Plain
Tidal (Channel) Tidal (Flats) Tidal (Supra) Tidal (Inter) Tidal (Sub)		
Abandonment Distributary Channel Mouth Bar	Lower/ Upper Delta Plain	
Proximal Delta Front (PDF) Distal Delta Front (DDF) Pro Delta Front (PDF)		
Shoreface (Upper) Shoreface (Middle) Shoreface (Lower)		
Shelf (Inner) Shelf (Middle) Shelf (Outer) Mass transport Complex (MTC)	Shelf	Shelf (MTC)
Submarine Feeder Channel Basin Floor Fan (BFF)		

Figure 4. Classification of depositional environments used in this study.

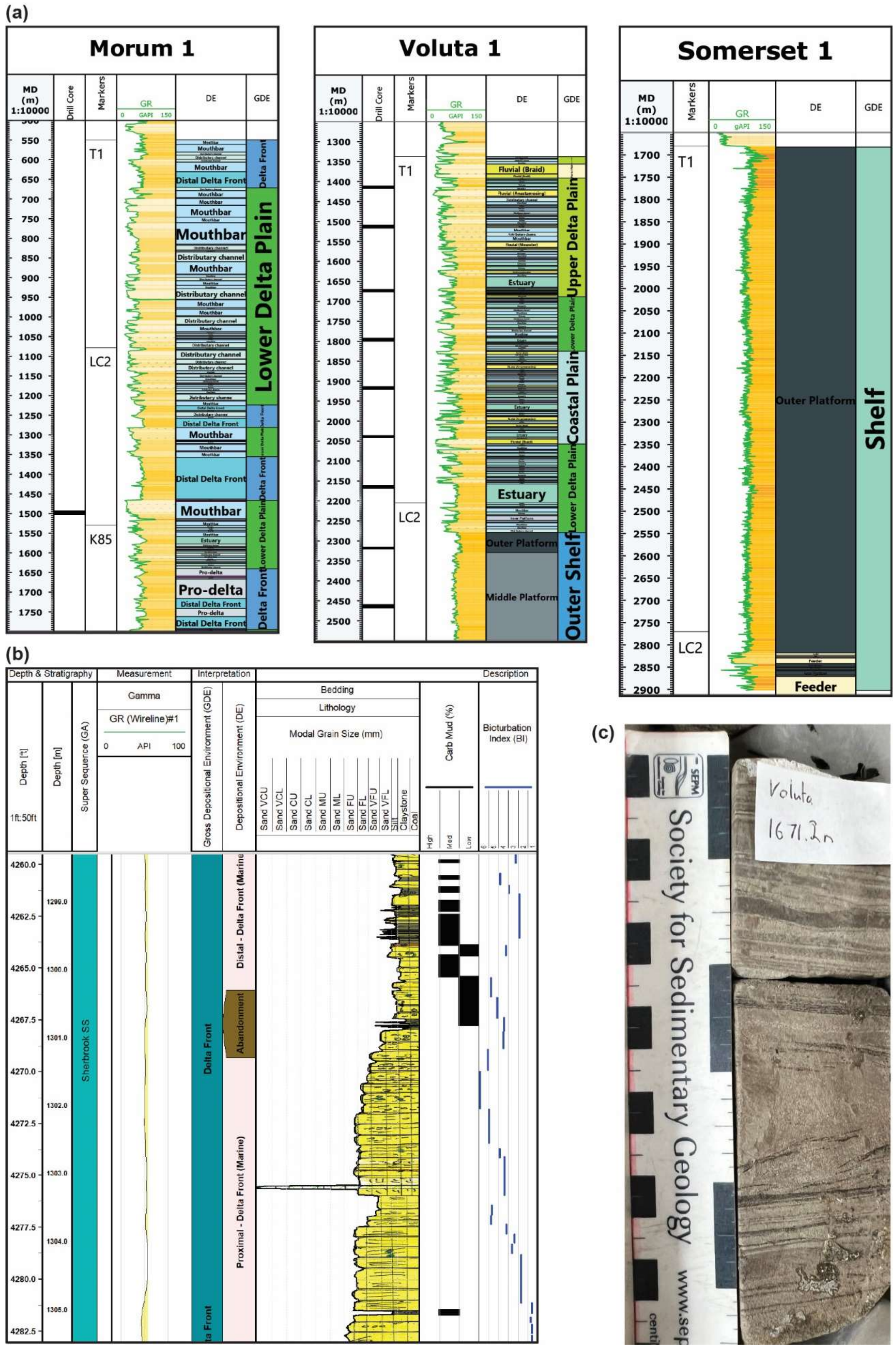

Figure 5. (a) Wells logs representative of Fluvial Plain, Coastal/Deltaic Plain, and Shelf RGDE, showing subdivision into GDE and DE based on core and wireline log interpretation. (b) Prawn A1 core log extract showing delta front DEs and GDE. (c) Example of a DE (inter-tidal mouth bar) in core from Voluta 1 (1671.2 m). Well locations are shown on Figure 7.

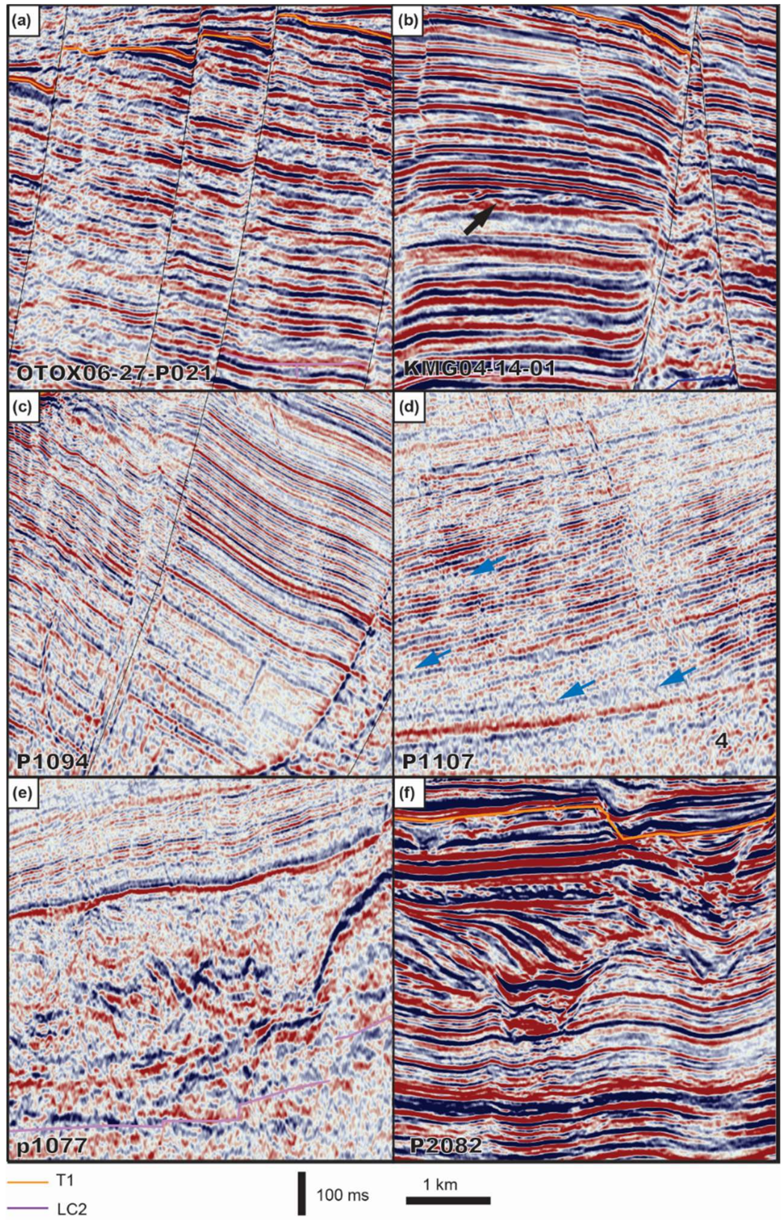

Figure 6. Sherbrook Supersequence seismic facies. (a) Fluvial Plain RGDE. (b) Coastal/Delta Plain RGDE. Arrow indicates delta-scale clinoforms. (c) Shelf RGDE. High amplitude, low frequency reflections indicate the transition between Shelf and Coastal Plain RGDE. (d) Shelf RGDE clinoform complex composed of sigmoidal (muddy) delta-scale clinoforms. Blue arrows point to examples of downlap. (e) Mass transport complex. (f) Incision complex within Coastal Plain/Deltaic RGDE. See Figure 7 for seismic path locations.

DISCUSSION AND CONCLUSIONS

The Sherbrook SS is a tectonostratigraphic package of some 15 Ma duration that was deposited during a second phase of Otway Basin extension, prior to the breakup of Australia and Antarctica. Plate tectonic reconstructions show that the Otway Basin was a NW-SE oriented embayment, flanked by the Australian continent to the north and east, Antarctica to the south, and faced the incipient Southern Ocean to the west (Williams et al., 2019). The basal Sherbrook SS sequence boundary (LC2) marks marine flooding and a landward shift in environments that was followed by progradation of the supersequence into the basin.

Three seismic-scale facies-belts (i.e. Fluvial Plain, Coastal/Deltaic Plain and Shelf RGDEs) for the upper Sherbrook SS were mapped across the offshore basin (Figure 7). The Fluvial Plain RGDE and Coastal/Deltaic RGDE are confined to the inner Otway Basin, although the latter extends part way into the Morum Sub-basin. Outboard, the Coastal/Deltaic RGDE transitions into the Shelf RGDE and the latter forms the principal fill of the Morum and Nelson sub-basins. MTC and Incised Valley seismic facies indicate tectonic activity, and express slope instability and large variations in base-level, respectively. MTC are especially well developed in the central deep-water part of the basin, in the transition between the Morum and Nelson structural domains. The Sherbrook SS fill of the outboard depocentres contrast markedly in structural and stratigraphic style. In the relatively less structured Nelson Sub-basin, the Shelf RGDE is made up of a mud dominated shelf-scale clinoform package that downlaps the outer margin high. In the Morum Sub-basin gravity-driven listric faulting is linked to high sediment loads and the development of thick growth wedges. In the inner Morum Sub-basin thick growth wedges consisting of Coastal/Deltaic RGDE are present.

Hydrocarbon discoveries across the inner Otway Basin occur in Shipwreck Supersequence (Figure 2) reservoirs charged by Austral 2 (lower Cretaceous) source rocks. O'Brien et al. (2009) concluded that accumulations occur close to source rocks because intense faulting results in poor fault seal and complex migration paths, providing an explanation for the lack of discoveries in the overlying Sherbrook SS. However, petroleum systems modelling and geochemical analysis from outboard wells indicate that the Austral 3 petroleum system (upper Cretaceous to lower Cenozoic) may have operated within the Sherbrook SS in the deep-water part of the basin (O'Brien et al., 2009; Schenk et al., 2023). The presence of thick intervals of marine mudstone (Shelf RGDE) across the deep-water basin indicates the potential for productive source rocks and effective cross-fault seal, corroborating the observations by Totterdell et al. 2014. Reservoir rocks in the deep-water basin are likely best developed in the Coastal/Deltaic RGDE where it encroaches into the Morum Sub-basin.

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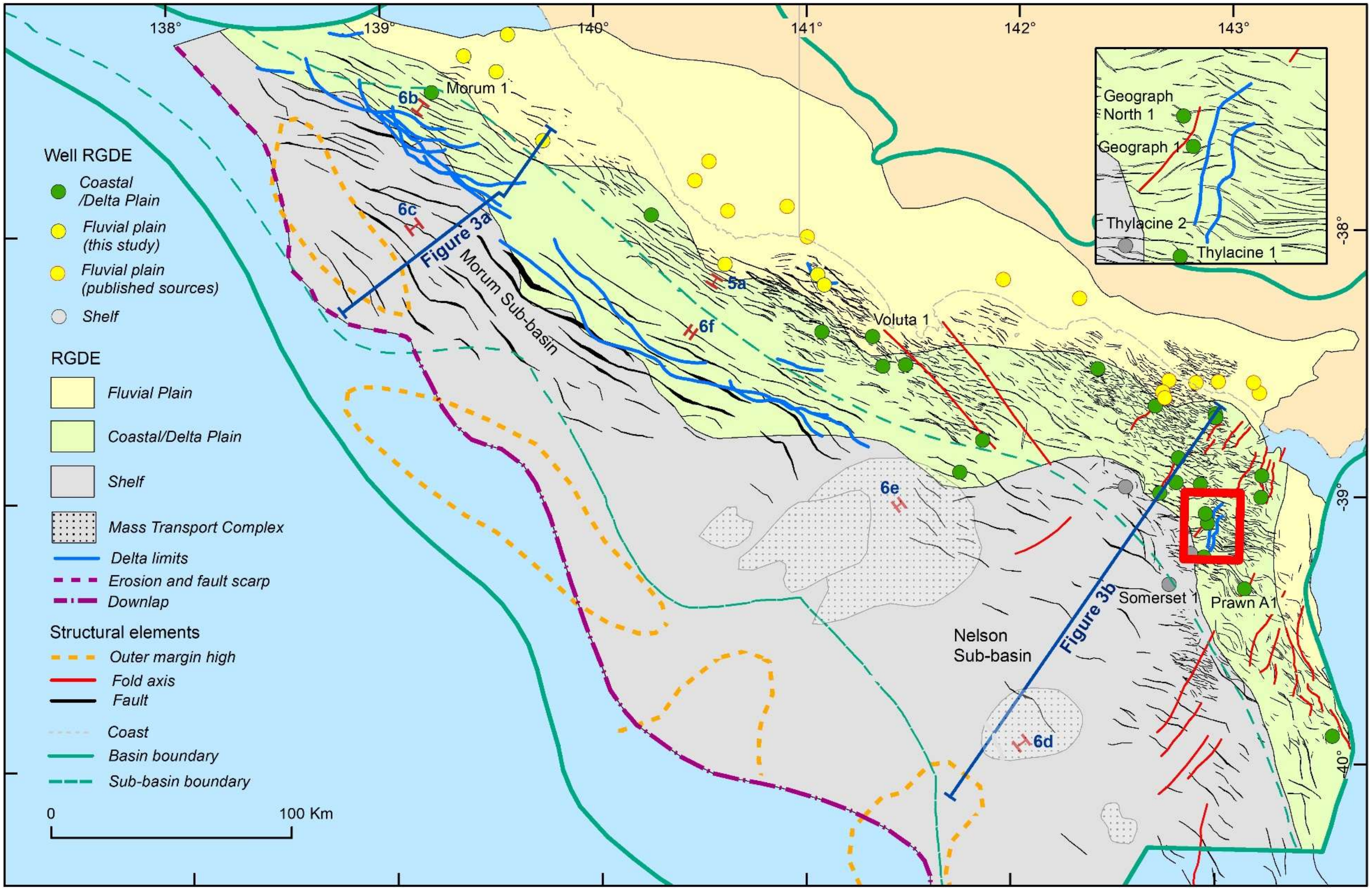

Figure 7. GDE Map of the upper Sherbrook Supersequence. Seismic paths for Figure 3 (seismic transects) and Figure 6 (seismic facies), are indicated. The inset highlights westerly prograding delta limits.