Appendix 2 of paper “Application of a Deepwater Stratigraphic Framework to the Production of the Wolfcampian Units in the Permian Basin”

Daniel Minisini and Patricio Desjardins

Description and interpretation of 14 sequence stratigraphic intervals in chronological order (follow through Figure 16 and Figure 17).

Lower Foxtrot

Sequence boundaries SB 6–SB 9 interval

The data for this interval are limited to one core, which covers a “hot shale” interval where gamma ray registers high values. Lithofacies above and below maximum flooding surface (MFS) 8 are very similar, which is the reason we do not separately describe intervals above and below MFS 8, as we did for other intervals. This interval is dominated by black mudstones (lithofacies [LF] 1) interbedded with bioturbated mudstones (LF 2), limestones (LF 4) and mixed mudstones (LF 3), and carbonate-rich mass transport deposits (MTD) (LF 9). MTD (LF 9) are more common towards the base of the interval. Bioturbation increases above the MFS. In contrast to most of the overlying intervals, lower Foxtrot shows siliciclastic thin turbidites (LF 11), although in small proportion (2%). The vertical arrangement of lithofacies shows a fining upward trend up to MFS 8, shifting to a coarsening upward above it. The thickest sedimentary column of the entire interval occurs along the northern downthrown side of the Mid Basin fault zone, where accommodation space is high (and where petrofacies record higher clay content) (Figure 16).

Middle Foxtrot

SB 9–SB 10 interval

This interval composes the lower two-thirds of the Foxtrot “high-resistivity bulge.” None of the cores captures this entire interval; thus, stacking patterns are hard to decipher from cores (as well as from logs). The interval consists mainly of black mudstone (LF 1) and mixed mudstones (LF 3). Bioturbated mudstones (LF 2) are very rare, and organic matter is relatively high in the interval (2-4% total organic carbon [*TOC*], Figure 12). The lack of bioturbation and the concomitant high *TOC* may indicate either very high sediment accumulation rates or dysoxia/anoxia at the sea floor, both preventing benthic fauna to colonize the sea floor. In the case of high sediment accumulation rate, the organic matter would be transported from a staging area through the currents that determine the high sediment accumulation rate (e.g., turbidites); in the case of dysoxia/anoxia at the sea floor, the organic matter would be likely derived from fall out in the water column. The variable frequency of calcareous turbidites (LF 4) among wells suggests that the carbonate material was sourced from the Diablo platform as part of gravity flows. The higher proportion of limestone (LF 4) in the Dela State core supports this hypothesis. The Dela State core retrieved the deepest section of the sequence boundary (SB) 9–SB 10 interval and intersected a lean-dolomitic mudstone (LDM) bed (LF-5), which presents a different mineralogical composition, hence suggesting that the Diablo platform was not the only source of sediment delivery.

SB 10–MFS 11 interval

Immediately above SB 10, an increase of MTD (LF 6 and LF 7) is recorded. At the base of this interval, Thunder and Laramie cores present rip-up clast and chaotic breccias (LF 6), whereas to the east, Intrepid core lacks MTD elements and shows calcareous turbidites (LF 4). These observations suggest a western or northwestern source of sediment. The thickness map clearly shows provenance of material from the Diablo platform infilling the downthrown side of the Mid Basin fault zone likely representing well-confined large MTD with short runout. The same map shows isolated local depocenters in the east suggesting provenance from the Central Basin platform (CBP). The interval shows a fining upward trend up to MFS 11, where black mudstones (LF 1) become more dominant towards the top of the interval.

MFS 11–SB 12 interval

Above MFS 11, black mudstones (LF 1) become dominant, suggesting a period of lower sediment accumulation rate in the basin; this is also supported by the basin-wide presence of concretions. In the Thunder core, by contrast to others, the proportion of mixed mudstone (LF 3) increases, indicating lateral variations of lithofacies. Bioturbated mudstone (LF 2) shows an increase in their percentage (27%) with respect to the intervals SB 9-SB 10 (<1%) and SB 10-MFS 11 (9%). Also, a slight increase in LDM lithofacies (LF 5) is recorded. The increase in bioturbation and increase in LDM frequency are in line with the interpreted regressive nature of the interval MFS 11-SB 12.

Upper Foxtrot

SB 12–MFS 13 interval

A major change is recorded above SB 12 in all the investigated cores. North of the Mid Basin fault zone, the SB 12 is overlain by LDM (LF 5), whereas south of the Mid Basin fault zone the SB 12 is overlain by MTD (LF 6 and LF 7). Thickness maps suggest that LDM provenance is from the north, whereas MTD from the south, derived from the Sheffield Channel or the Ouachita orogenic belt. Limestone (LF 4) and mixed mudstones (LF 3), both north and south of the fault zone, represent only a small part of the rock record. In all cores, a fining-upward stacking pattern is observed up to MFS 13.

MFS 13–SB 14 interval

This interval is dominated by black mudstones (LF 1) in all analyzed wells. The proportion of bioturbated mudstones and LDM is less than in the underlying interval, suggesting conditions of very low sediment accumulation rate and low oxygenation at the sea floor during MFS 13. Calcareous turbidites (LF 3, LF 4) and MTD (LF 6) represent episodic gravity flows but do not represent a significant portion of the rock record. The interval is characterized by an aggradational stacking pattern.

Delta

SB 14–MFS 18 interval

In most cores, SB 14 is marked by an abrupt change in lithofacies, mainly by the reappearance of LDM (LF 5). South of the Mid Basin fault zone, some areas show for the first time LDM (LF5) (Oatman core), and some other areas are characterized by MTD (LF 6 and LF 7) (Wiggo core). This variation of lithologies points to the presence of different sediment sources. North of the Mid Basin fault zone, the interval is dominated by LDM. LDM are interbedded with black mudstones (LF 1) and calcareous turbidites (LF 4 and LF 3). Calcareous turbidites are dominant in Thunder and Laramie cores, indicating the vicinity to the source of carbonate material (CBP). Thin section analyses suggests that part of the original petrofacies associated to LDM (PF M9-M10-M11) were diagenetically altered into petrofacies C1 (the most representative petrofacies of LF 8, dolostone). South of the Mid Basin fault zone, the interval is dominated by black mudstones (LF 1), suggesting a more distal position relative to the source of LDM. Interestingly, the abrupt change in lithofacies coinciding with the Mid Basin fault zone corresponds to an abrupt change in shear velocities and *Vp/Vs*, where *Vp* is compressional wave and *Vs* is shear wave.

MFS 18–SB 21 interval

The proportion of LDM (LF 5) and MTD decreases in this interval, while calcareous turbidities (LF 3 and LF 4) and black mudstone (LF 1) increase with respect to the previous interval SB 14-MFS 18. However, in cores north of the Mid Basin fault zone, LDM is still the dominant lithology. Like in the previous interval, the percentage of LDM decreases southward, supporting the interpretation that the LDM deposits were sourced from the NW Shelf. South of the Mid Basin fault zone, some LDM is still present but the abrupt disappearance of LDM in the Oatman and Wiggo cores suggests the Wiggo area was probably off the axis of the sedimentation fairway for LDM. A general retrogradational stacking pattern in the entire Delta unit is recognized in all cores as black mudstone facies increase proportionally upwards. This general retrogradation is also supported by the northward shift of the LDM depocenters (Figure 22).

Lower Beta

SB 21–TS 22 interval

Above SB 21, MTD (LF 6 and LF 7) are observed in all cores, both north and south of the Mid Basin fault zone, whereas LDM (LF 5) are absent or very rare. In the Wiggo core, the proportion of bioturbated mudstones increases above SB 21. Black mudstone (LF 1) proportions vary from well to well, suggesting sectors with different sediment accumulation rates and erosion. This interval presents the most heterogeneous lithology; therefore, it is difficult to recognize a common stacking pattern. Nevertheless, the ubiquitous presence of MTD indicates a basin-wide slope instability which may be related to a drop in the relative sea level.

TS 22–MFS 23 interval

This interval is mainly composed of mixed mudstone (LF 3) and calcareous turbidites (LF 4) deposited by higher-energy sedimentary processes. The frequency and thickness of the calcareous turbidites decrease, geographically, south of the Mid Basin fault zone and, stratigraphically, in the upper part of the interval, which presents a relative thick interval of black mudstone (LF 1), corresponding to the MFS 23. The interval TS 22–MFS 23 is composed of several coarsening upwards cycles.

MFS 23–SB 24 interval

Lithofacies within this interval are very similar to the previous interval; however, black mudstones (LF 1) become even more common. Within this interval, laminated hemipelagites (LF 9), although rare, are recorded for the first time (Thunder and Laramie cores). North of the Mid Basin fault zone, the dominant lithofacies is calcareous turbidites (LF 3), interpreted as deposited in distal environments. South of the Mid Basin fault zone, the dominant lithofacies are black mudstone (i.e., Wiggo core).

Upper Beta

SB 24–MFS 25 interval

Above SB 24, thicker and more frequent MTD (LF 6) are recorded in the Intrepid and Thunder cores, whereas calcareous turbidites (LF 3 and LF 4) are recorded in the core Wiggo, suggesting that the Wiggo area was located in a more distal position with respect to the source of sediment. Black mudstone (LF 1) is almost absent north of the Mid Basin fault zone, and it constitutes less than 25% of the stratigraphy in the southern sector (Wiggo core). However, the top of the interval is characterized in the entire area by black mudstone (LF 1).

MFS 25–SB 26 interval

This interval was only studied in one core. Lithofacies types are similar to those recognized in the previous interval with an increase in the proportion of deformed muddy siltstone (LF 10).

Alpha

SB 26–SB 30 interval

Sandstones and siltstones (LF 11) increase their proportion in this interval compared to all previous intervals. These lithofacies are commonly associated with hemipelagites (LF 9) and deformed muddy siltstone (FA 10). Together they constitute a deposit called “W sands.” Other lithofacies include deposits of calcareous turbidites (LF 3 and LF 4) and black mudstones (LF 1).