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Deepwater Turbidite Lobe Morphodynamics: Architectural Insights from the Moki Formation, Offshore Taranaki Basin, New Zealand and Correlation with Experimental and Outcrop Data

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Introduction

Submarine fans are formed by the downslope transport of sediment-laden gravity flows across continental slopes and basin floors, and they host some of the most prolific hydrocarbon reservoirs (Normark, 1970; Reading & Richards, 1994). Turbidite lobe morphologies and internal stacking architecture influence heterogeneity in deepwater reservoir systems (Prélat et al., 2009; Spychala et al., 2020). High-resolution seismic datasets capable of resolving lobe-scale architecture bridge the gap between small-scale experimental insights and basin-scale facies interpretation (Fonnesu et al., 2020; Deptuck et al., 2008). The role of unconfined lobe deposition—where flows expand laterally after exiting channels or slope gullies—has become a key focus in understanding how lobe thickness, stacking, and areal distribution vary in both time and space (Prélat & Hodgson, 2013; Spychala et al., 2017).
The current study focuses on submarine lobe systems of the mid-Miocene Moki Formation in the Taranaki Basin, New Zealand (King & Thrasher, 1996). The Moki Formation captures depositional transitions from confined slope systems into unconfined basin-floor lobes. By integrating insights from the Moki Formation with global analogues and upscaled flume experiments, this study aims to identify the stratigraphic relationships between lobe stacking styles and the spatial migration of depocenters, and to examine how compensational processes influence vertical and lateral architectural patterns in seismic-scale deposits.

Data and Methodology

The offshore Taranaki Basin subsurface data were procured from New Zealand Petroleum and Minerals. In the present study, over 175,000 line km of 2D seismic (~1500 2D Seismic lines), 8200 km2 of 3D seismic Pre-STM data, and over 130 well data were used after thorough screening of well tops, a complete suite of basic well logs (gamma, resistivity, density, sonic, and porosity), well-seismic tie and regional seismic correlation from offset wells. Forty wells were utilized for velocity modelling in Petrel (2018, 2024) and depth conversion. After quality screening of the depth-converted surfaces with well tops, final depth-structure maps, isochores, and isopachs were prepared in parallel with the RMS amplitude attribute. RMS amplitudes were overlain by depth structure and isopach contours to correlate structural and depositional frameworks. The lobe dimensions (length, width, and thickness) were estimated from seismic maps and correlated with those from other known subsurface, outcrop, and scaled flume experimental data.

Results and Observations

Regional correlation was achieved by following the continuity of high-amplitude cycles, a signature of the subsurface Moki Formation that extends for tens of kilometers. A regional TWT isochron (time isopach map) for the Miocene in the Taranaki Basin was prepared. It shows thicker,

structurally affected, proximal zones, with thickness decreasing outward from the Miocene shelf break.

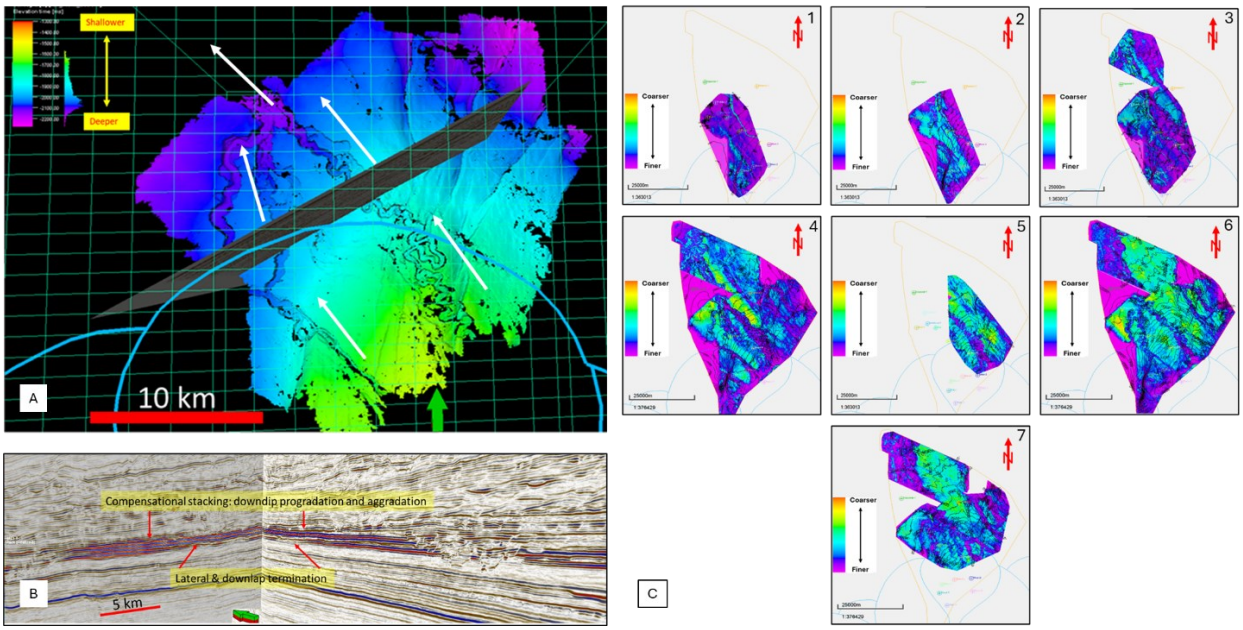


Figure 1. A. TWT structure map of the 4th composite lobe of the Moki Formation. The white arrows indicate paleo-flow direction, such as the downslope pattern of the entrenched channels, and the green arrow at the bottom of the map points to the North. B. Seismic section outlining lateral and downlap termination, downdip progradation and aggradation leading to compensational stacking. The green arrow points towards the north. C. RMS amplitude maps of seven composite lobes of the Moki fan complex, overlain by depth structure contours

Integration of seismic interpretation constrained by Moki Formation well tops, outside the previously demarcated Moki deepwater fan system, shows sinuous channels incising into high-amplitude seismic packages (Bauer et al., 2011; King & Thrasher, 1996). The successive maps of the composite lobes thinning downslope to the northwest, with entrenched meandering deepwater channels, indicate a southeast-to-northwest delivery mechanism within confined channels (Fig.1A). Seismic cross-sections show downlap and lateral terminations, progradation and aggradation, and patterns consistent with compensational stacking—where successive lobes preferentially fill topographic lows created by preceding deposits and/or basin-floor relief (Fig. 1B). Gamma-ray log motifs from drilled wells reveal vertically stacked, blocky, coarsening- and thickening-upward sequences that characterize the prograding Moki fan system. Detailed interpretation helped identify seven previously unmapped, spatially stacked composite lobes within the Moki fan complex (Fig. 1C).
High RMS amplitude zones for each composite lobe are interpreted as coarser-clastic prone axial lobe facies, supported by well logs, with amplitude decay toward fringes/distal zones consistent with thinning and fining. Local erosional truncation by later channels was identified as a complicating factor that can remove or obscure amplitude patterns. Depth structure contours overlaid on RMS maps demonstrate a consistent SE-to-NW sediment dispersal trend, aligned with channel orientations and regional depositional axis. Stacking styles interpreted from

sequential lobe mapping indicate two dominant modes. Vertical aggradation, particularly between Lobes 1 and 2, where the planform geometry is similar, and basinward progradation, expressed by Lobes 3, 4, 6 and 7 along the established dispersal trend. A notable deviation is retrogradational behaviour in Lobe 5, interpreted as a shift in sediment routing and/or accommodation/topographic influence.

Turbidite lobes' thickness distributions were compared with RMS amplitude by overlaying isopach contours onto RMS maps. Most lobes show a positive coupling: thicker regions correspond to higher RMS amplitude (interpreted as coarser, more amalgamated axial zones). Two key exceptions are: Lobe 3 (thicker areas show lower amplitude and thinner areas show higher amplitude, an inverse relationship that raises questions about amplitude fidelity, lithologic/ diagenetic effects, or tuning, etc.) and Lobe 5 (thickness patterns are skewed by the deep incision of an overlying channel). Overall, morphological similarity between some successive lobes (1–2, 3–4, 6–7) suggests repeated development along similar fairways, modulated by compensational behaviour and erosion of the antecedent sea-floor topography by turbidites.

The mapped composite turbidite lobes are elongate, oriented along the principal depositional axis, with length-to-width ratios of ~1.7–2.7. Planform areas define two populations: a smaller group (<650 km²) and a larger group (>1000 km²). Scaling relations indicate lobe length increases more strongly than width with increasing depositional area. Maximum thickness generally increases with depositional area (with the basal lobe as an exception), consistent with published morphometric observations from other lobe systems.

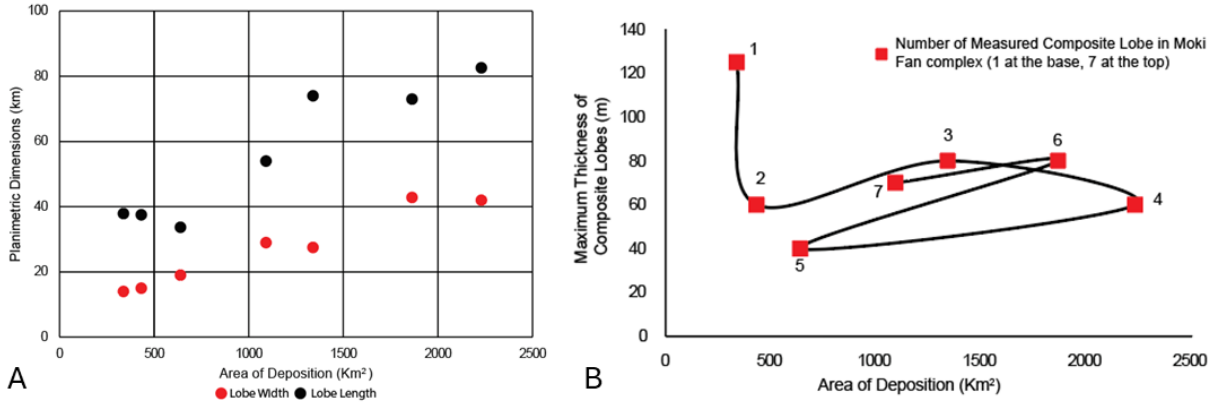


Figure 2. A. Cross plots between length and width with the area of deposition of the Moki composite lobes. B. Cross plots between the area of deposition vs. maximum thickness for measured composite lobes deposited in the Moki fan complex.

When plotted against global datasets (Amazon, Karoo/Tanqua, Golo, Kutai, etc.) and scaled experimental turbidite lobes from the flume study carried out in Queen's University by the authors, the Moki lobes fall within typical unconfined lobe morphometric ranges, supporting interpretation of a mostly unconfined basin-floor lobe setting.

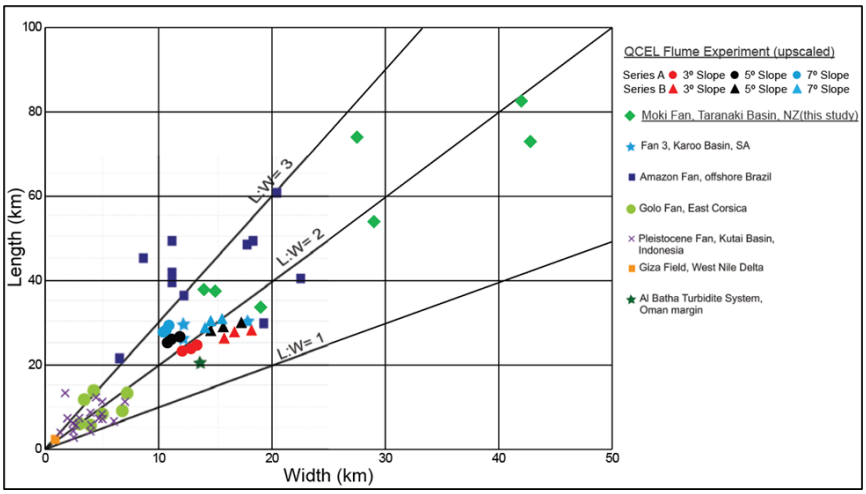


Figure 3. Width versus length values for composite lobes deposited in the Taranaki Basin, New Zealand (this study), upscaled experimental turbidite lobes from Queen's Research Lab (by the authors), Karoo Basin (Prélat et al., 2009), the Amazon Fan (Jegou et al., 2008), the Golo Fan (Deptuck et al., 2008), the Kutai Basin (Saller et al., 2008), the Giza Field (Morris et al., 2014) and the Al Batha Turbidite System (Bourget et al., 2010) and their length: width aspect ratios (after Spychala et al., 2020).

Discussion: Implications on Reservoir Fairway

The composite turbidite lobe architecture indicates a dynamic interplay of autogenic (compensational stacking, lobe switching) and allogenic (basin physiography, variations in sediment supply) controls. The alternation between aggradation, progradation, and rare retrogradation suggests that depositional fairways were not fixed; rather, they migrated laterally and basinward through time. This has direct implications for reservoir distribution, as sand-prone fairways may shift between stratigraphic intervals even within the same gross fan complex.

The generally strong conformity between thickness and RMS amplitude supports RMS as a useful qualitative proxy for sand distribution at the seismic scale (axial vs. fringe domains). However, the documented exceptions (notably Lobe 3 and locally incised units) underline that RMS amplitude cannot be treated as a single-variable predictor of reservoir quality. Amplitude can be affected by tuning, fluid effects, impedance contrasts unrelated to net sand, diagenesis, and erosional removal. Consequently, amplitude-based interpretations should be routinely cross-checked against thickness maps, stratigraphic context, and well calibration.

Moki lobes' morphometrics and stacking behaviour align with both global analogue datasets and upscaled experimental results. This strengthens confidence that scaled physical insights (e.g., relationships between preceding deposit morphology and subsequent flow pathways) can be used to interpret and predict lobe architecture in subsurface seismic datasets—especially where well control is sparse.

Conclusions

The compensational stacking patterns of deepwater Moki turbidite lobes display a combination of vertical aggradation, progradation, and isolated retrogradational behaviour, resulting from the interplay between autogenic and allogenic processes. RMS amplitude distribution indicates a persistent SE–NW sediment delivery trend and typically distinguishes sand-prone axial zones

from fringe/distal facies, though amplitude–thickness decoupling in specific lobes highlights interpretive limitations of solo seismic attributes. Composite lobes are elongate (L: W ~1.7–2.7) and largely consistent with unconfined lobe morphometrics in global datasets. The observed architecture reinforces the importance of compensational stacking and antecedent morphology in controlling depocenter migration—key considerations for stratigraphic prediction and reservoir characterization in deepwater systems. Scaled physical models can also serve as robust analogues for interpreting seismic-scale lobe architectures in frontier or data-poor subsurface settings.

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