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Lacustrine sequence stratigraphy of the Greymouth Rift Basin, New Zealand: tectonic evolution and distribution of source rock facies

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Summary

Lacustrine sequence stratigraphy provides a useful framework to understand the primary controlling factors of sedimentation in terrestrial rift basins as well as for considering the type and distribution of organic-rich facies. Sequence stratigraphic analysis on detailed sedimentary facies in the Greymouth Rift Basin, New Zealand improves correlation and can be used to predict the lateral extent and variability of source rock lithologies. The geometry indicates alluvial fans/fan deltas along the steep faults to the northwest, lakes alternating with meandering rivers and raised mires along the basin axis, and low gradient meandering river fans to the north- and south-east hinge side of the basin. Four different potential source rock facies have been identified and correlated: lacustrine, marshy shoreline, raised mires, and meandering fluvial abandoned channels. Lowstand Systems Tracts correspond to axial meandering fluvial systems with scattered dirty coals and organic rich mudstones from abandoned channels. Transgressive Systems Tracts start with raised mire complexes subsequently overlain by marshy shoreline facies. Maximum flooding of lakes during Highstand Systems Tracts correlate thick organic rich lacustrine mudstones across the basin. The tectonic-sedimentary models suggest the Greymouth basin evolved from small sub-basins that widened and deepened through time via small-displacement normal fault segments which became progressively more connected until they formed a major border fault. This fault gave rise to the large half graben basin and was responsible for the lateral and vertical facies changes.

Introduction

The Greymouth Basin is part of the Late Cretaceous to Early Paleocene rift system in New Zealand that includes the productive, but deeply buried, Taranaki petroleum basin. The Paparoa Formation of the Greymouth Basin is accessible and has been extensively explored with respect to coal mining as raised and low-lying mire coals are abundant (Figure 1, Newman 1985; Ward 1997; Cody 2015). The basin contains a typical terrestrial rift sequence comprising deposition of fault proximal alluvial fans/braided fluvial facies grading laterally to basin axis lacustrine facies alternating with meandering fluvial systems and raised mires. A lacustrine sequence stratigraphic analysis helps map the distribution of organic-rich lithofacies as well as providing the detailed correlation of sequences required to interpret the tectonic evolution of the rift basin.

Methods:

Detailed sedimentary facies analysis was done to map out lateral as well as temporal variation within the basin. The maximum flooding surfaces of the lacustrine phases are the easiest to identify using the greatest extent of lacustrine and shoreline facies. They can therefore be used for correlation across the basin and to define systems tracts for a lacustrine sequence stratigraphic analysis. A particular focus on identifying shoreline facies and reinterpreting fluvial facies as deltaic resulted in increases in the mapped extent of lacustrine source rocks. Conglomerates mark the locations of faults active at different times in the basin's history. Cross-sections of sedimentary facies and sequence stratigraphy show the lateral variation across the basin. In the final step, block diagrams have been developed to understand the tectonic sedimentary evolution of the rift basin from Late Cretaceous to Early Paleocene time.

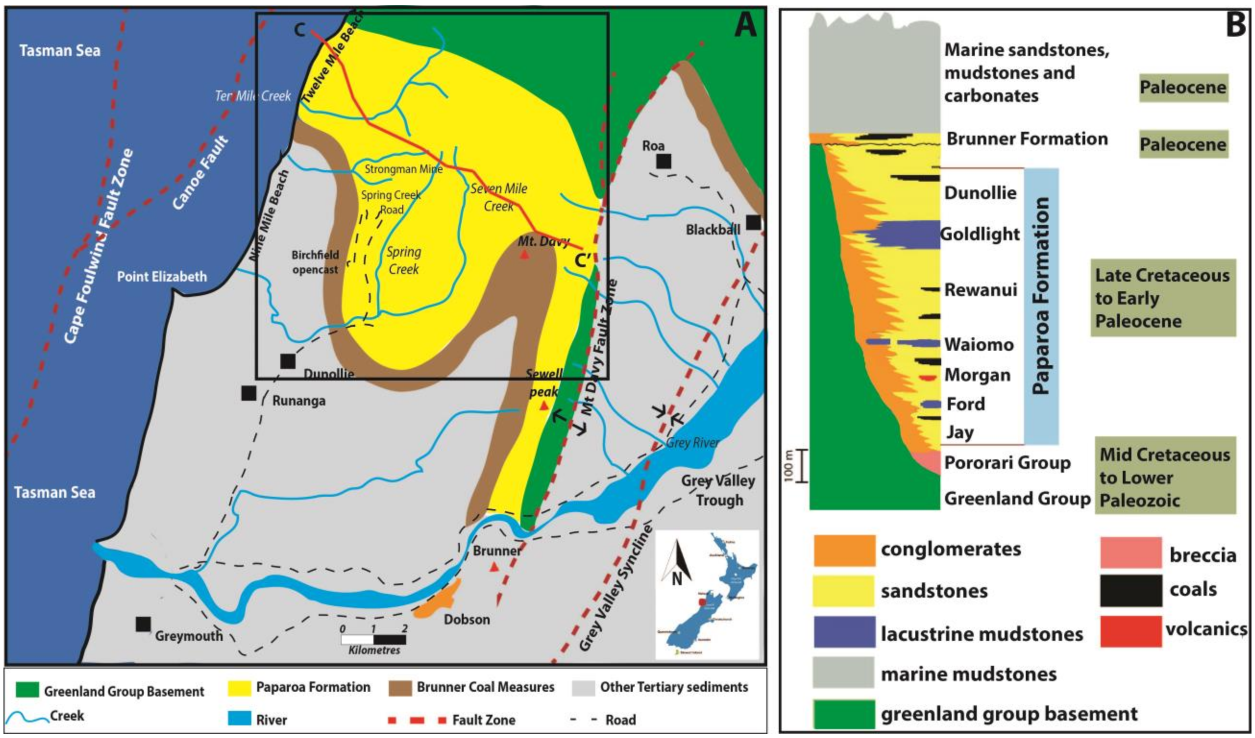

Figure 1: A) Simplified geological and structural map of the study area (black box) based on Gage 1952, Newman 1985, Suggate 2014. Red line shows the cross-section in Figure 2, and **B)** Generalized stratigraphy of the Paparoa Formation of the Greymouth Basin (modified from Boyd and Lewis 1995).

Results: Lacustrine Sequence Stratigraphy

The cross-section (**Figure 2)** shows alternating axial meandering fluvial and lacustrine facies correlated by the maximum flooding surfaces of the three lacustrine phases. Alluvial fan and fan delta conglomerate facies record steep fault-controlled sides of basins with the thickest and largest on the north-west side at the top of the stratigraphy. Sandy meandering rivers generally entered the basin from the north-east and south-west along the basin axis forming low gradient deltas during lacustrine phases or axial fluvial systems during alluvial phases. Marshy shoreline facies and low gradient deltas are common on the hinge side of the basin. Raised and low lying mires are common in the basin's axis and on the hinge side.

The oldest lacustrine phase (Ford Member) records small isolated lakes separated by alluvial fan conglomerate facies marking the locations of small, discontinuous normal faults. Conglomerate deposits step north-westward and thicken up-section as the small faults became inactive or amalgamated to form a single border fault during the youngest lacustrine phase

(Goldlight Member). As a result, the basin widened and deepened through time with ever younger units sitting unconformably on basement toward the northwest.

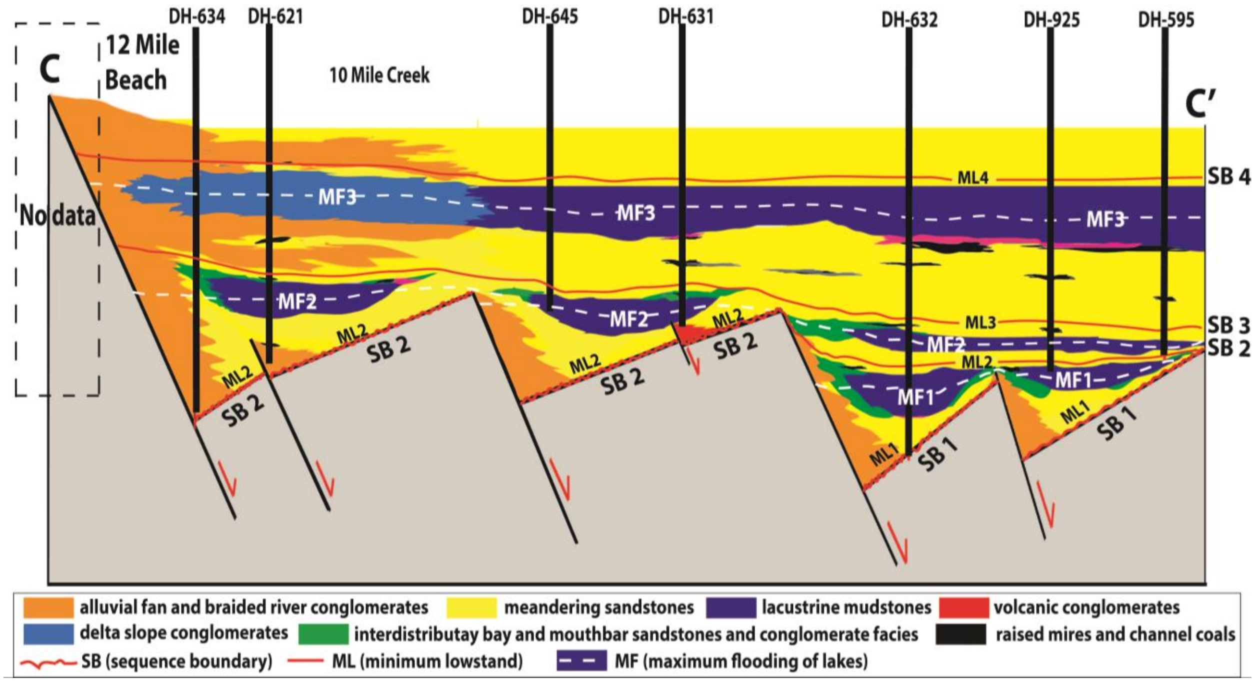

Figure 2: The sequence stratigraphic model indicates three separate phases of lake level changes with deep lacustrine mudstones (blue) separated by shoreline facies (green and pink) from subaerial fluvial facies (orange is conglomerates, yellow is sandstones, black is coal). White broken lines show maximum flooding surfaces for each lacustrine phase. Red wavy lines and red solid lines show the basal unconformity and correlative conformity of the minimum lowstand for each alluvial phase.

Depositional phases in each sequence include alluvial, raised mire, lacustrine and deltaic infill phases that can be interpreted as lacustrine systems tracts. The *Lowstand Systems Tract (LST)* sedimentary facies of alluvial phases are fault proximal alluvial fans and gravelly braided fluvial facies, axial meandering fluvial facies with abandoned channels and crevasse splays. The *Transgressive Systems Tract (TST)* is recorded by the raised mire phase with raised mire coal, low-lying mire coal and marshy shoreline facies in the basin's axis with correlative alluvial fan facies near the faults and fluvial and deltaic facies. The *Highstand Systems Tract (HST)* is marked by the lacustrine phase comprising lacustrine massive mudstone and distal turbidite facies in the basin axis as well as the lateral shoreline and fluvial facies. The *Regressive Systems Tract (RST)* is characterized by the deltaic infill phase comprising lacustrine distal turbidite facies, sandy proximal turbidite facies, mouthbar facies, interdistributary bay and swamp facies, and delta slope facies with the same alluvial facies laterally.

The Greymouth Basin lacustrine sequence stratigraphy records a developing rift basin where faults amalgamated as the basin widened over time. Sequence boundary unconformities form at the bases of newly initiated basins stepping north-westward through time with correlative LST in the older established, continually subsiding basin centers toward the south-east. The sequences start with the onset of alluvial phases across the basin(s) **(Figure 2)**. The TST begins with raised mire development which transform into low-lying mires with the continuing rise in base level. The HST begins with the appearance of sandy proximal turbidite facies overlain by lacustrine massive mudstone facies which marks the maximum flooding and widest extent of lacustrine deposits. This is followed by RST infill phase as the continuous sedimentation occurs and deltas prograde into the lakes. The end of an infill phase and the initiation of the next alluvial phase are marked by both new basal unconformities as faults step north-westward and correlative conformities in the older, still subsiding interior of the basin.

Tectonic basin models (**Figure 3**) illustrate the evolution of the Greymouth Basin from Late Cretaceous small, isolated lake basins (Ford and Waiomo Lakes) to an Early Paleocene large lake basin (Goldlight Lake) through the linkage of north-westward propagating normal faults.

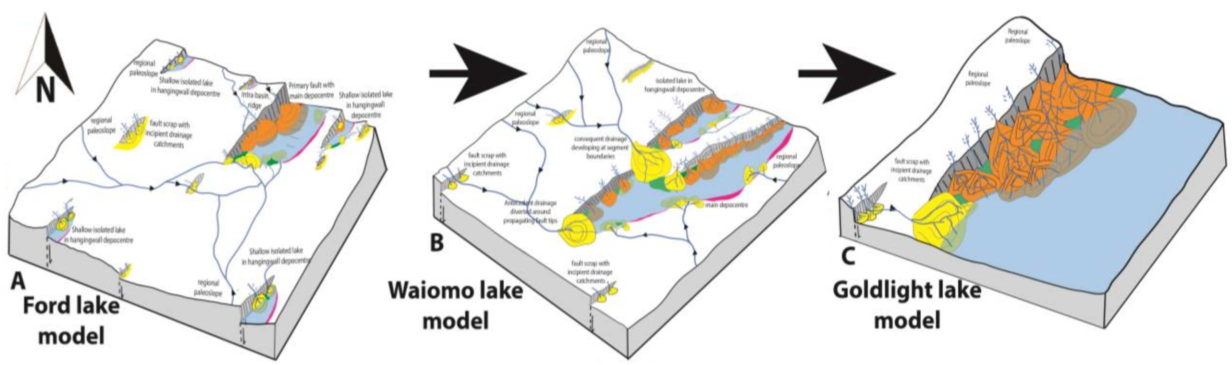

Figure 3: Tectonic model of the Greymouth Basin showing basin evolution A) during the deposition of Goldlight Lake, B) during the deposition of Waiomo Lake and C) during the deposition of Ford Lake. Black arrows indicate oldest (Ford) to youngest (Goldlight) lacustrine phases.

Interpretation: Distribution of Source Rock Facies

Detailed sedimentary facies analysis of the Paparoa Formation indicates a number of potential source rock facies. Subaqueous source rock facies include the *lacustrine massive mudstone facies* consisting of grey to black mudstone/silty mudstone with rare small leaves and fresh water fossils and the *lacustrine distal turbidites facies* consisting of normally graded, thin, brownish grey, fine sandstone and siltstone turbidite beds with conspicuous plant debris. Shoreline source rock facies include the *marshy shore line facies* with thinly interbedded siltstones, sandstones, carbonaceous mudstones and silty coals with abundant leaf matters, spore, pollens and vertical rootlets and the *interdistributary bay facies* with highly bioturbated carbonaceous mudstones and sandstones interbedded with the occasional conglomerate beds or coaly stringers. Subaerial fluvial source rock facies include the *abandoned channel facies* from meandering river channels consisting of carbonaceous silty mudstone/highly carbonaceous mudstone fining up to muddy coals. Subaerial mire source rock facies include the *raised mire facies* of thick, dark black, waxy and clean coals with fragmented leaf fossils and the *low-lying mire facies* of alternating dark grey to black siltstone, highly carbonaceous mudstones to dirty coals located at the top of the raised mire coals.

The type and prevalence of source rock facies can be tied to the lacustrine system tracts. LST contain scattered dirty coals and carbonaceous mudstones from abandoned channel facies.

TST represent raised mire complexes subsequently overlain by marshy shoreline facies. RST and HST correlate to thick organic rich lacustrine mudstones, prograding mouthbar facies and interdistributary bay facies across the basin.

Conclusions

Sequence stratigraphic analysis indicates three separate lacustrine phases separated by axial meandering fluvial phases associated with expansion and maturing of the Greymouth Rift Basin. Highstand Systems Tracts contain organic rich lacustrine massive mudstone facies with potential for both oil and gas. Transgressive Systems Tracts contain waxy and clean raised mire coal facies, an already proven source rock for this basin capable of generating gas. TST marshy shoreline facies and the low-lying mire coal facies also contain a considerable amount of organic material with the potential for generating gas. Lowstand Systems Tracts contain the coals and highly carbonaceous mudstones of abandoned channel facies and also show potential for gas generation.Tectonic models indicate that small normal fault segments became more connected through time until they formed a major border fault on the north-west controlling subsidence and distribution of different source rock facies through time. The basal bounding surface youngs to the north-west with ever younger units sitting directly on basement in sequence boundary unconformities.

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