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Detailed Facies Analysis and Sequence Stratigraphy of Potential Lacustrine Source Rocks, Greymouth Basin, New Zealand

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Summary

Increased interest in the hydrocarbon potential of the lacustrine mudstones of the Late Cretaceous Paparoa Coal Measures (PCM) has led to this recent study in developing a sequence stratigraphic framework for the Greymouth rift basin. The main purpose of this research is to define sedimentary facies criteria to reconstruct the basin's paleogeography thus providing an accessible analogue source rock model for Taranaki and Late Cretaceous frontier basins in New Zealand. Sequence stratigraphic analysis can then be used to interpret intervals of increased subsidence in the basin and tectonic history.

Sedimentary facies analysis indicate that the "transitional lithosomes", defined by Simon Ward (1997), are mostly subaqueous lake edge facies of low gradient delta front and interdistributary bay facies which enlarge the interpreted size of the lakes and increase the volume of potential lacustrine source rocks. Sedimentary facies distribution suggests half graben geometry of the Greymouth basin where the primary basin bounding fault is located on the western side of the basin, probably offshore. The increasing thickness, paleogeographic extent and water depths through time from the oldest to the youngest lacustrine mudstones suggest an expansion and maturing of the rift basin. Maximum flooding surfaces correlate lake-center deposits with their lateral correlatives in facies successions across the basin. Meandering fluvial and coal facies, common gas prone source rocks in New Zealand, replace the lacustrine mudstones in the center of the basin as the lakes contract forming 'lowstand' deposits.

Introduction

The deposits of non-marine sedimentary basins account for a growing segment of current petroleum exploration and exploitation opportunities because of the deposition of both coaly sediments and lacustrine mudstones which might act as gas and oil generating source rocks (Carroll and Bohacs, 2001). The Greymouth coal basin is part of the producing Late Cretaceous Taranaki-West Coast Rift System in New Zealand. However, unlike most parts of the rift which are deeply buried and only available via seismic analysis (Figure 1A), the sedimentary rocks of the Greymouth basin are accessible in outcrop and through extensive drillcore. (Figure 1B; Laird 1993, 1994; Laird & Bradshaw 2004). Thus the Greymouth basin can be used as an accessible analogue for Taranaki and other Late Cretaceous frontier basins in New Zealand.

The Paparoa Coal Measures (PCM) of the Greymouth basin are characterized by Late Cretaceous to early Palaeocene non-marine deposits which are mostly composed of conglomerates, coals, coaly mudstones, sandstones and lacustrine mudstones (Figure 1C; Nathan et al. 1986; Newman and Newman 1992, Boyd and Lewis, 1995). Most previous studies have focused on coal characterization and not the non-coal bearing deposits except where they directly affected the coal (Bowman et al. 1984; Newman 1985; Newman and Newman 1992 & Ward 1997). In particular, thick conglomerates in the basin have been relatively ignored. The lacustrine units have been previously mapped based on the mudstone-rich deep water facies, ignoring the sandier shallow water and shoreline facies which were instead included in the fluvial units (Gage 1952; Ward 1997). Preliminary work has been done by Cody (2015) on the lacustrine source rocks of the PCM. However, the distributions of sedimentary facies across the basin remain uncertain.

The petroleum potential of the basin has been suggested from several surface oil and gas seeps and from promising, but not yet commercially successful, exploration (Beggs et al., 2008). A recent geochemical study of the three lacustrine mudstone units of the PCM indicates they show potential as oil generating source rocks and a shale gas resource (Cody, 2015).

We have undertaken detailed sedimentology and sequence stratigraphy of the PCM to achieve better understanding of basin development, depositional environments and source rock potential of the lacustrine mudstones. Our approach has been to develop a sedimentary facies analysis of different lacustrine sub-facies of the PCM and to construct a sequence stratigraphic framework of the Greymouth basin in order to constrain 1) the distribution of lacustrine facies 2) the history of lacustrine facies development; 3) the overall subsidence history of the basin and 4) the possible volume of source rocks.

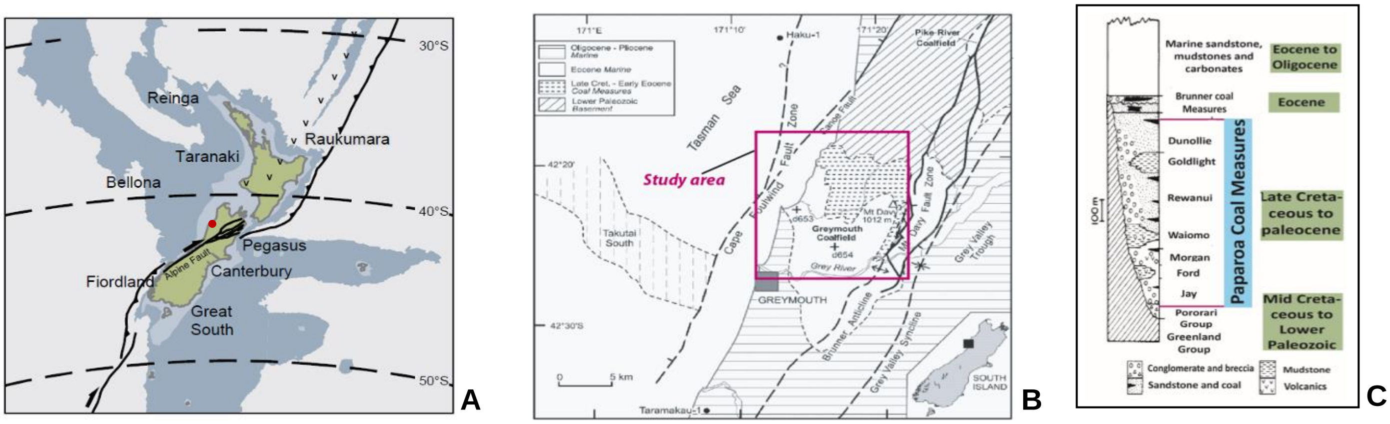

Figure 1: A) Map of New Zealand basins (red dot showing the location of the Greymouth basin). B) Greymouth basin location map showing structural features in the area (from Suggate, 2014). C) Paparoa Coal Measures stratigraphy (from Boyd and Lewis, 1995).

Method

Outcrops as well as extensive drillcore are available throughout the Greymouth coalfield. We have categorized different sub-facies across the basin by studying available cores, outcrops and geophysical log responses, presented in fence diagrams and cross-sections.

The next step is to develop a sequence stratigraphic model to understand the basin subsidence, migration of shorelines and lake highstands. The main focus is to mark the maximum flooding of lakes which are difficult to recognize in non-erosional systems with constant subsidence and aggradation.

Results and Interpretations

There are eight lacustrine sub-facies that have been identified. Deep lacustrine facies are recognized by the presence of thick mudstones with uncommon interbedded turbidite sandstones, rare leaves and fresh water fossils (Fossil Record Database, Gage, 1952, Ward, 1997). Turbidite sandstones become more common proximal to shorelines. Marshy shore line facies are thinly interbedded siltstone, sandstone, carbonaceous mudstone and silty coal with abundant leaf matter and vertical rootlets.

Fan deltas enter the paleolakes from the steep fault-controlled side of the basin to the northwest. High gradient delta slope facies contain interbedded conglomerates, sandstones and mudstones with common convolute bedding and load casts. The associated delta front facies comprise coarsening upward conglomerate channels with enigmatic fitted clast fabrics present. Interdistributary bay and swamp facies are represented by interbedded thin ashy coals or carbonaceous mudstones with rootlets and bioturbation. Thick clast supported conglomerate deposits are categorized as delta plain although these are difficult to distinguish from non-deltaic braided rivers during lacustrine lowstands.

Sandy to muddy meandering river deltas enter the paleolakes from the south-eastern side or along the basin axis from the north-east or south-west. Low gradient delta slope facies comprise mudstone with abundant turbidite sandstone to siltstone beds with organic material and load casts present. Associated mouth bar facies show coarsening upward sequences in gamma ray logs. Coal facies deposited in abandoned channels or interdistributary bays are thin and high in ash.

When lakes are absent in the basin, meandering river channels and floodplain facies contain cross laminated sandstone with considerable deposition of peat, organic matter and bioturbation. Thick, laterally extensive low ash coals are interpreted as ombrotrophic coal facies of raised mires, whereas thin laterally discontinuous, moderate to high ash coal are interpreted as rheotrophic coal facies in abandoned channels.

Sedimentary facies distributions indicate the north-western side of the basin is dominated by alluvial fan deltas alternating with braided rivers (Figure 2). The southern and eastern sides of the basin, on the other hand, are dominated by meandering rivers and floodplains to muddy low gradient deltas. Deep, organic rich, thick lacustrine facies are at the centre of the basin with marshy shore facies at the edge. Thick, low ash coal facies are interpreted as raised mire complexes and commonly replace the lacustrine mudstones in the center of the basin.

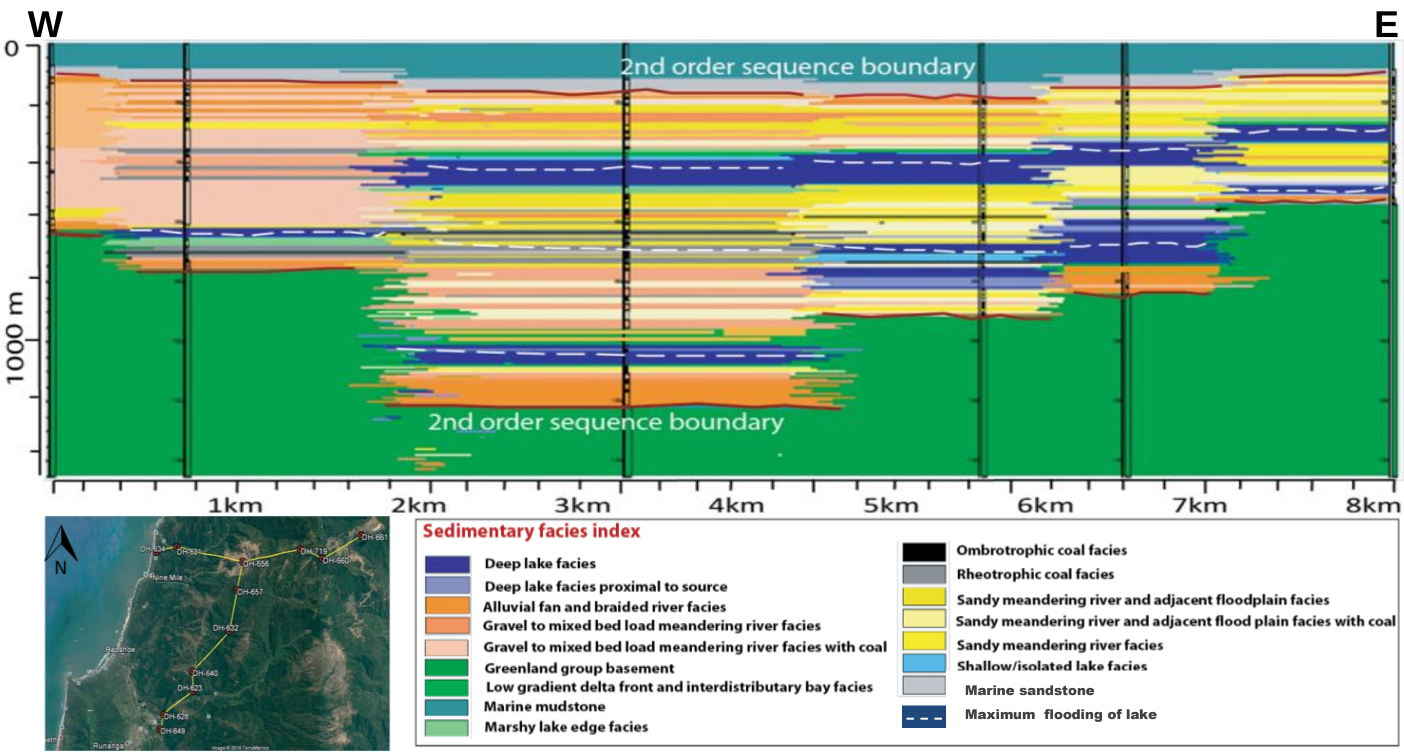

Figure 2: Sedimentary facies distribution and sequence stratigraphy across the basin

Conglomerate grainsize and thickness decreases from boulder conglomerates ~450 m thick in the north-west to pebble to granule conglomerates ~20 m in the south-east. This strongly suggests that uplands and steep topography were located to the north-west.

The main depo-center at the time of the oldest lacustrine mudstone (Ford) was in the center of the basin with a maximum thickness of ~60 m thinning to ~12 m to the south-east (Figures 2 and 3). The younger Waiomo mudstone is both thicker and more widespread ranging from 65 m with a main depo-center on the north-western side of the basin thinning to 25 m to the southeast. The youngest Goldlight mudstone is widely distributed all over the basin and shows two distinct depo-centers in the basin. Maximum thickness reaches ~195 m in both depo-centers decreasing to a minimum of ~60 m.

Sedimentary facies analysis suggests that deep lacustrine facies are easily recognized from cores and outcrops but shoreline facies are more difficult to categorize and map. The “transitional lithosomes” defined by Ward (1997) have been re-categorized as subaqueous lake edge facies of low gradient delta front and interdistributary bay facies. The inclusion of shallow water and shoreline facies in the mapped lacustrine units increases the volume of potential lacustrine source rock.

The lower sequence boundary separates the PCM from underlying highly deformed Greenland Group of early Paleozoic age. The upper bounding surface is widespread and formed when the post rift deposition and subsidence was followed by a marine transgression in the Eocene. Three lake highstand flooding surfaces are mapped from deep water facies into correlative shoreline facies. These are replaced first by raised mire complexes and then fluvial floodplain facies during lowstands (Figure 2).

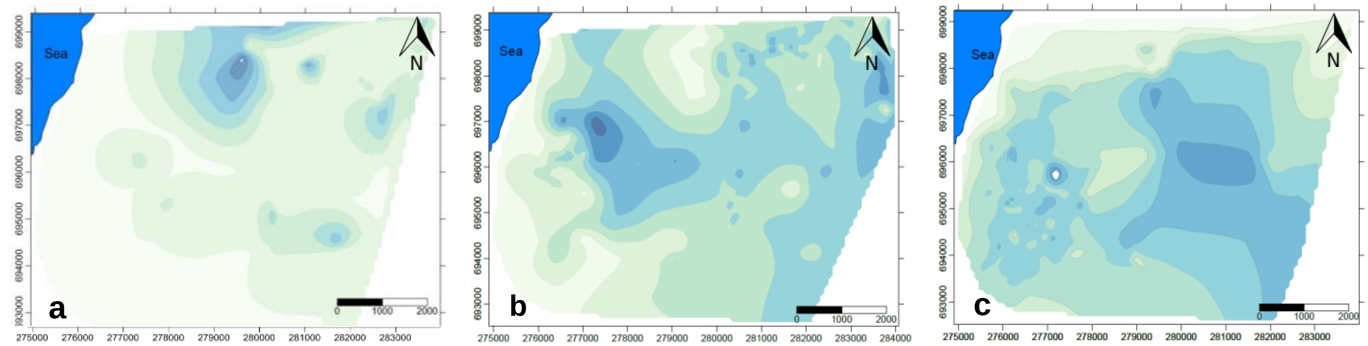

Figure 3: Isopach maps Ford mudstone (a), Waiomo mudstone (b) and Goldlight mudstone (c)

Gradual decrease in boulder conglomerate thickness from north-west to south-eastward suggests the primary basin bounding fault was located nearby to the west. Conglomerate and lacustrine mudstones shifted westward and got thicker as the basin subsided. The basal bounding surface also youngs to the north-west with ever younger units sitting directly on basement. All of these suggest a widening of the basin and the activation of younger faults through time. Periods of thick lacustrine mudstones likely record episodes of faster subsidence which increased accommodation space.

Conclusions

Late Cretaceous–Paleocene lacustrine mudstones in the Paparoa Coal Measures of the Greymouth basin provide the best available geological analogue for lacustrine source rocks that are inferred to be present in some New Zealand offshore sedimentary basins. Sedimentary facies distribution shows alluvial fan and braided river conglomerates are restricted to the north-western side of the basin, whereas floodplains and meandering river facies dominate the eastern and southern parts, suggesting half graben geometry of the Greymouth basin. Sub-facies analysis of the lacustrine mudstones has changed our understanding of lacustrine highstands and basin subsidence. The sequence stratigraphic model indicates three separate phases of lake level changes and shoreline migration associated with expansion and maturing of the basin as a whole. This culminates in the upper sequence boundary which is marked by widespread marine transgression. These results have a wider relevance regarding sedimentology and basin formation that can be applied to the deeply buried Cretaceous sediments of offshore Taranaki basin and other Late Cretaceous rift basins in New Zealand.

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