EVOLUTION AND DEPOSITIONAL SETTING OF THE LOWER MOUNT MESSENGER FORMATION, UPPER MIOCENE, TARANAKI BASIN, NEW ZEALAND: A PROGRESS REVIEW

Larisa U. Masalimova, Jonathan R. Rotzien and Donald R. Lowe

Department of Geological and Environmental Sciences, Stanford University, Stanford, California, USA 94305

ABSTRACT

The continuous outcrops of the Upper Miocene Mount Messenger formation exposed along the western coast of the Taranaki region, North Island, New Zealand provide an opportunity to study ancient deep-water depositional systems at the bed scale up to a few centimeters in scale. These outcrops are of great interest for oil industry and thus were studied to some extent in the past as they represent surface analogs for offshore subsurface oil and gas reservoirs in Kamiro and Ngatoro fields nearby. Despite extensive study and data collection on the Mount Messenger and related formations within the Taranaki Basin there are many uncertainties and questions about the depositional setting and provenance of the Mount Messenger Formation. The main goal of this outcrop study is to give insight into processes and setting of sediment deposition and its influence on geometry and architecture of deep-water deposits in the lower part of the Mount Messenger Formation. The reservoir heterogeneity documented will be valuable data for input into subsurface analogue models.
INTRODUCTION

This study focuses on deep marine basin-floor sediments outcropping north of the modern Taranaki Peninsula (Fig. 1, 2). The Mount Messenger Formation is exposed almost continuously along the coast for nearly 25 km with a subtle dip of 2-5° degrees with a vertical thickness of 10 kilometers (King et al., 1996).

Previous studies (King et al., 1993; King and Thrasher, 1996; Browne and Slatt, 2002; Browne et al., 2005; Johansson, 2005) have focused on determination of reservoir properties and provenance of deposited sediments in order to assist the oil exploration (King & Browne, 2001; King & Slatt, 2002). Thus, only analogs of oil reservoirs were sampled. In this study, the examination of various lithofacies will show subtle changes in sedimentation rate and mineral composition, type of sediment influx, and flow properties of individual beds to cm-scale. Thin section study will lend insight into depositional structures that can not be observed in outcrop-scale.

Remaining questions include: 1) What are the constituents of volcanic rock fragments and what was their source?, 2) Why is fine- and very fine-grained sand predominant in the lower Mount Messenger Formation, 3) What are the sources for these fine-grained sediments?, and 4) What is the depositional setting for the lower Mount Messenger Formation?

GEOLOGIC SETTING

The Taranaki Basin is a large sedimentary basin filled by sediments from Cretaceous to Quaternary in age (King et al., 1993). It is located offshore along the west coast of the North Island and comes onshore in Taranaki Peninsula and northernmost South Island (Hansen & Kamp, 2004). It is separated into two structural grabens of late Miocene to Pleistocene age (King et al., 1993). The basin
has had a complex tectonic history since the late Oligocene associated with the evolving Pacific-Australian plate boundary (King, 2000). Following its initial Cretaceous development within a synrift setting, the Taranaki Basin evolved as a passive margin (King and Thrasher, 1992). Basement blocks began to overthrust along the Taranaki fault in the Early Miocene (Fig. 3), forming the eastern boundary of the basin (King & Browne, 2007).

Several Miocene formations are exposed near to or along the north Taranaki coast, including the Mokau, Manganui, Mohakatino, Mount Messenger and Urenui formations (King et al., 1993). The Mount Messenger Formation is placed stratigraphically between overlying Urenui Formation and underlying Mohakatino Formation (Fig. 4).

With the continued subsidence of the basin, the eroded hinterland was the source of clastic material that was deposited on a “slope”: Urenui and Upper Mount Messenger Formation, and “basin floor”: Lower Mount Messenger Formation (King & Browne, 2007). Those sediments were mixed with volcaniclastic material derived from submarine volcanoes (King and Trasher, 1996). The exposed basin floor to slope system is characteristic of Miocene depositional patterns throughout the Taranaki Basin. In sequence stratigraphic terms, these formations appear on a broad morphological scale to represent a single complete lowstand systems tract from basin-floor fan to prograding complex, deposited over a period of c. 4 m.y. (3rd-order cycle) in the Late Miocene (King et al., 1993). The rapid and continuous supply of sediments caused basin-floor aggradation and the progradation of the slope (Fig. 5) sourced from uplifted and eroded eastern and southern hinterlands (King and Browne, 2007). This study focuses on basin floor deposits of the Lower Mount Messenger Formation (Fig. 6).
STUDY METHOD

The research includes detailed measurements of sedimentation units, grain size data and paleocurrent analysis. It will be based on measurements from grain size in thin sections and cm-scale measurement of sedimentation units and bed sets from the outcrop to seismic scale examination of the on-to off-shore distribution and character of the sedimentary units. The goal is to create a continuous stratigraphic section and correlate the discontinuous coastal outcrops that are often juxtaposed by faults. A complete sample suite throughout the section was taken to determine the grain size distribution and sorting as well as for provenance studies and dating. Based on the forthcoming interpretation of that data, we will determine depositional settings of the lower Mount Messenger and the factors that controlled sedimentation, including horizontal and vertical stacking patterns, the changes in lithofacies, and the evolution of the depositional environment.

Ash layers are quite abundant throughout the section (King et al., 1993), which makes it a good place to produce radiometric dating for the sedimentary sequence and calculate sedimentation rates (Maier, 2008). A cumulative sedimentation rate of approximately 60 cm/1000 years has been calculated by King at al, 1993. As part of this study and work done by Katherine Maier, high-precision dating of detrital zircons will be undertaken within the sands in order to better constrain sediment provenance. Also, dating of volcanic ash beds will help to constrain chronostratigraphy in the area. Zircon provenance data analysis will be done using the SHRIMP-RG at Stanford. In addition, major, trace, and rare earth element analysis will be used to determine the provenance of the interbedded mudstone.

Petrophysical analysis of thin section will be conducted at Stanford based on 93 evenly spaced samples taken from coastal exposures. Provenance studies
and point counting will be made with a few sandy samples of medium grain size. Suites of samples were taken at 20 cm intervals from one particular massive sandstone bed in order to evaluate the vertical grain size distribution. Total number of samples from one bed varies from 10 to 16.

Paleoflow direction is determined from rippled sandy units and imbrications of pebbles in clast-supported conglomerates.

**MAIN LITHOFACIES**

The sediments represented in outcrops are mostly fine- to very fine-grained sand, and the maximum is medium-grained. The outcrops are represented by several lithofacies: thick massive sandstones sometimes amalgamated with internal primary and secondary sedimentary structures (dunes and anti-dunes, cross stratification, water escape structures) and thin sandstone units. Also lithofacies are represented by thin siltstone beds interbedded with thin sandstone beds showing well preserved turbidite units with current structures (flame structures, ripples, and plane lamination), massive bioturbated siltstone and mass transport deposits (MTD) or slump deposits.

**Sandstone lithofacies**

*Thick-bedded sandstone (S₃- Ta)*

The most abundant lithofacies observed in the lower Mount Messenger Formation are thick-bedded sandstones (Fig. 7). The thickness of individual sandstone beds varies from 50 cm to 3 meters. Due to post-depositional erosion the sandstone beds may appear lacking sedimentary structures, but quite often lateral observation can reveal dish structures, plane lamination and dunes (Fig. 8). One bed can be massive or show size grading and/or primary water-escape structures developed during mass settling (Lowe, 1982). The thick-bedded sandstones represent S₃ division (Lowe, 1982) or Tₐ division (Bouma, 1962).
Erosive bases, amalgamation surfaces, and mud clasts were observed within the individual beds. The lithofacies can be observed laterally for long distance due to depositional setting and outcrop exposure. Large variations in thickness were not noticed with a few local exceptions. The subtle fining upward can be observed in field, but will be carefully observed in thin sections that were cut from samples taken vertically every 20 cm from one unit.

The erosive base, amalgamation surfaces and mud clasts of mostly all units indicate that the turbidity currents had high velocity and energy. Those beds were deposited by high-density turbidity currents through suspension sedimentation when the flow unsteadiness increased (Lowe, 1982). At high suspended-load fallout rates, there is insufficient time for development of either a bed-load layer or an organized traction carpet (Lowe, 1982). Water-escape structures indicate that the deposits due to high liquefaction at the time of fall-out were disturbed after deposition (Lowe, 1975).

Sandstone with plane lamination (Tb) and ripples (Tc)

Most often the lithofacies is found above thick-bedded sandstones. The sand is very fine to fine grained, and is well sorted. The thickness is less than 50 cm. These lithofacies represent waning of the current energy (Lowe, 1982). Most often Thick-bedded sandstone (S3- Ta) lithofacies is capped by Te divisions that are less than 10 cm in thickness. These caps show flame structures and soft sediment deformation (Fig. 9).

Bioturbated Siltstone

The biorutbated siltstone (Fig. 10) overlays the major turbidity events, and are represented by thick massive sandstones and thin sand-silt interbeds above. This lithofacies represent the time of relatively quite environment between major turbidity cycles. The most common types of bioturbation are Scolicia & Chondrites.
burrows (King et al., 1993). The bioturbation is very intense. The beds are grey in color and easy to recognize in outcrop. The thickness varies and can be less than 1 meters and up to 9 meters if above.

**Interbedded siltstone and sandstone**

They lie on the upper part of major turbidity events, overlay thick-bedded sandstones (Fig. 11). They are represented by 10-50 cm sandstone beds, very fine to fine grain size and siltstone intervals 10-20 cm, bioturbated. The basal contact between the beds is erosive. The sequences of beds show overall fining upward.

**Mass Transport Deposits (MTD)**

MTD (Fig. 12-14) are represented by contorted sandstone and siltstone beds with sandy or muddy matrix sometimes with debris of shells. There are two kinds of MTD in outcrops: one is predominantly silt dominated and another is sand dominated. The total thickness in outcropped section is from 5 to 10 meters. MTD’s in central parts of the outcrop section are restricted to fine-grained intervals near the top of depositional fan cycles (King et al., in press). MTD accumulated as slumped deposits.

**Conglomerate lithofacies**

*Pebble conglomerates*

This lithofacies is not abundant and can be found in the upper part of the lower Mount Messenger Formation. Conglomerates were likely distributed in closer proximity to source and slope setting, where channels are (Fig. 15). The thickness can be up to 50 cm. Pebbles up to 25 cm, average 5 cm float in a sandy matrix. The conglomerates are either matrix-supported or clast-supported. The
latter is more common and shows clast imbrications. The matrix is very fine to medium sand, sometimes with shell debris. The subtle fining upward is rare. Clasts are rounded to well-rounded and sometimes imbricated. The contact with underlain strata is erosional. This lithofacies represent R\textsubscript{3} to R\textsubscript{1} (Lowe, 1982) high density division.

**Mud-clast conglomerates**

These lithofacies (Fig. 16-19) are abundant as the channels filling and in the base of scours in the upper part of the lower Mount Messenger Formation. They are mostly clast supported with sandy matrix sometimes with shell debris. The abundance of clasts proves proximity of these deposits to the source of erosion.

**SEDIMENT ARCHITECTURE OF THE LOWER MOUNT MESSENGER FORMATION**

The overall architecture of outcropped deposits in the Lower Mount Messenger Formation reflects the gradual transition from more distal part of sediment accumulation to proximity to the source as one move from North to South. Distal part is represented by thick sheet-like massive sandstones with thin interbedded mud, often eroded. These deposits can be accumulated on basin floor as lobes or fans. These sandy cycles is topped by abundant thick mass transport deposits and interbeds of silt and sand. These MTD can be sourced from failure of walls of sediment conduits. The upper part of formation shows abundant scours, channel-like features and filling of these conduits by conglomerates deposited in proximity to the source.
PRELIMINARY CONCLUSIONS

Sheet-like thick-bedded sandstones in the lower part of the section were deposited in a compensation style as a basin floor fan. The high rate of sediment supply caused by plate-convergent related uplift and erosion of hinterland can explain the considerable thickness of sandstone beds in the lower part. It agrees with the previous interpretation (King et al., 2003). As we move up the section and closer to the source and slope, overall fining upward can be noticed. In the uppermost part of the studied section, channels and scours become more abundant with mud clast and pebbly conglomerates filling. The high density sand-dominated turbidity currents were capable to erode the underlying strata. Deep-water sedimentary architecture is characterized by sheet-like, laterally continuous, thick bedded sandstones with interbedded thin silty and sandy beds. Mass-transport deposits triggered most probably by tectonic movements.

FUTURE RESEARCH PLANS

During next field season in 2010, a complete stratigraphic section will be created by additional measurements of section. Correlation of units between the points of access will assist in developing a sound story of sediment accumulation through time. More samples if needed will be taken for petrophysical studies. Ash samples will be taken to complete the dating of the lower Mount Messenger Formation. Petrophysical analysis of 93 thin sections will be done and careful examination of grain size changes within the units will be documented. More paleocurrents measurements will be obtained and incorporated into the depositional architecture in order to constrain flow direction and geometry of sand bodies.
ACKNOWLEDGEMENTS

Funding for petrophysical analysis was provided through a McGee Grant from the Stanford University School of Earth Sciences and support from the industry sponsors of SPODDS. I would like to thank my field assistant Jonathan Rotzien. Steve Graham and SPODDS students helped in preparation of this manuscript. The work will continue in collaboration with Peter King and Greg Browne, Geological and Nuclear Sciences (GNS). Thanks to Katherine Maier for editing of the manuscript. Thanks to all companies who funds SPODDS: Aera Energy, Anadarko, Chevron, ConocoPhillips, Devon, ExxonMobil, Hess, Marathon, Nexen, Occidental, Petrobras, RAG, Reliance Industries, and Shell.

REFERENCES CITED

Johansson M., 2005, High-resolution borehole image analysis in a slope fan setting: examples from the late Miocene Mt. Messenger Formation, New Zealand; Submarine Slope Systems: Processes and Products, Geological Society, Special Publication 244, p. 75-88
King, P.R., 2000, Tectonic reconstructions of New Zealand: 40 Ma to present: New Zealand Journal of Geology and Geophysics, v. 43, p. 611-638.
King, P.R., and Browne, G.H., 2001, Miocene turbidite reservoir systems in the Taranaki Basin, New Zealand: established plays and analogues for deep-water exploration.

King, P.R., Browne, G.H., and Robinson, P.H., 1993, Description, correlation and depositional history of Miocene sediments outcropping along North Taranaki Coast, New Zealand: Institute of Geological and Nuclear Sciences, Monograph 5, p. 21.

King, P.R., Bradley R. Ilg, Arnot M., Browne G. H., Strachan L.J., Crundwell M., Helle K., in press, Outcrop and seismic examples of mass transport deposits from a Late Miocene deep-water succession, Taranaki Basin, New Zealand, Society for Sedimentary Geology


Figure 1: General Map of New Zealand, location of studied outcrops in red circle, A-B cross section (Fig.3)

Figure 2: Location map of outcrops in Taranaki Region: Mohakatino river, Jam Roll, Rapanui Stm, Tongaparutu South and North, Waikieki Stream; after King et al, Taranaki Field Guide, 2007

Figure 3: Cross section through North Taranaki region after King et al Taranaki field guide, 2007. For Location refer to figure 1.
Figure 4, modified from King et al., GNS, 1993

Figure 5: Outcrop transect NE-SW through Mt. Messenger-Urenui succession, after King et al., Taranaki field guide, 2007

Figure 6: Geological map, North Taranaki after King et al., Taranaki field guide, 2007
Figure 7: Massive sandstone units, Mohakatino River

Figure 8: Dunes and water escape structures, Tongaporutu River, south

Figure 9: Soft sediment deformation in thick-bedded sandstone, Mohakatino River

Figure 10: Bioturbated siltstone, Jam Roll

Figure 11: Interbeds of sand and silt (Fining upward is shown by red arrow)
Figure 12: MTD, Rapanui Stream

Figure 13-14: MTD, Jam Roll

Figure 15: Conglomerate filling of the channel like features, 
(Surface of erosion is shown by red line)
Figure 16-17: Mud clast conglomerates, filling of the channel
(Red line is the base of the channel)

Figure 18-19: Mud clast conglomerates, closer view