MIOCENE SLOPE TO BASIN-FLOOR SEQUENCES EXPOSED IN NORTH TARANAKI, NEW ZEALAND

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The Insitute of Geological & Nuclear Sciences conduct a variety of field trips and workshops to the north Taranaki coastal section, and to other key stratgraphic localities in New Zealand. These can be customised for particular interest groups, and range from 2-5 day excursions. For further information see http://www.gns.cri.nz/help/services/petrolleum/reservoir.html

Introduction and significance of section

Spectacular outcrops of Middle and Late Miocene sediments occur along the north Taranaki coast. The overall succession exposed comprises a range of siliciclastic and volcaniclastic sediments deposited in shelf, slope, and basin floor marine environments on the northeastern margin of the Taranaki Basin. This field guide describes five localities visited during a two-day trip undertaken prior to the 2002 New Zealand Petroleum conference (Fig. 1), in which aspects of the deep-water Mount Messenger Formation and overlying Urenui Formation were examined at seismic to reservoir scales. This field guide also briefly describes the depositional context of the exposed strata. Key references (e.g. King et al. 1993, 1994; Browne et al. 2000; Browne and Slatt in press), together with other useful background references, are listed at the back of the guide.

The North Taranaki coastal section is significant for several reasons. It offers:

- one of the few areas where Taranaki Basin sediments are exposed, and it thus provides an invaluable window for interpreting laterally equivalent subsurface successions in the basin.
- excellent exposures of a wide range of basin floor to slope depositional facies, providing insight into a variety of sedimentary flow mechanisms (e.g. debris flow, sandy mass flow, turbidity current), and morphological processes (e.g. slope progradation, retrogradation and canyon development, base-of-slope fan development).
- outcrop analogues of producing oil and gas reservoir units in the nearby Kaimiro and Ngatoro fields.
- general outcrop analogues for thin-bedded and thick-bedded deep-water sandstone reservoirs.
- seismic-scale to thin-section scale observations, that can be linked to high-resolution and regular industry seismic reflection data, exploration well log data, stratigraphic drillhole core and log data.
- cyclic stacking of strata which provides opportunities to test deep-water sequence stratigraphic models, and component facies within the generic lowstand systems tract.
- the stratotype for the New Zealand Late Miocene Tongaporutuan Stage, with several anoxic zones with distinctive microfaunal assemblages.

Geological setting

The Taranaki Basin has had a complex tectonic and depositional history, with multiple episodes of rifting and convergence (King and Thrasher 1992, 1996). In the present-day coastal region, basement rocks of the Murihiku Supergroup were overthrust from the east along the Taranaki Fault in the Early Miocene. The leading edge of this basement thrust block was emplaced into deep-water, but the basement surface rose towards the east, forming the eastern margin of the Taranaki Basin (Tongaporutu-Patea High). With subsequent subsidence, and a massive influx of clastic sediment from eroding hinterlands to the east and south, the basement margin was progressively onlapped and overtopped through the Miocene by shelf sediments (Mokau and Manganui formations), deep-water volcaniclastic sediments (Mohakatino Formation), and deep-water clastic sediments (Mount Messenger and Urenui formations; Fig. 2). Miocene to Pliocene sediments that overtop the Tongaporutu-Patea High are contiguous with those in the neighbouring Wanganui Basin, to the east. For a period in the Middle to Late Miocene, deep-water sandstones (Mount Messenger Formation) inter-fingered with volcaniclastic sediments (Mohakatino Formation) (Fig. 3). The volcaniclastic detritus was derived from now-buried submarine volcanoes located offshore to the west (Fig. 4).

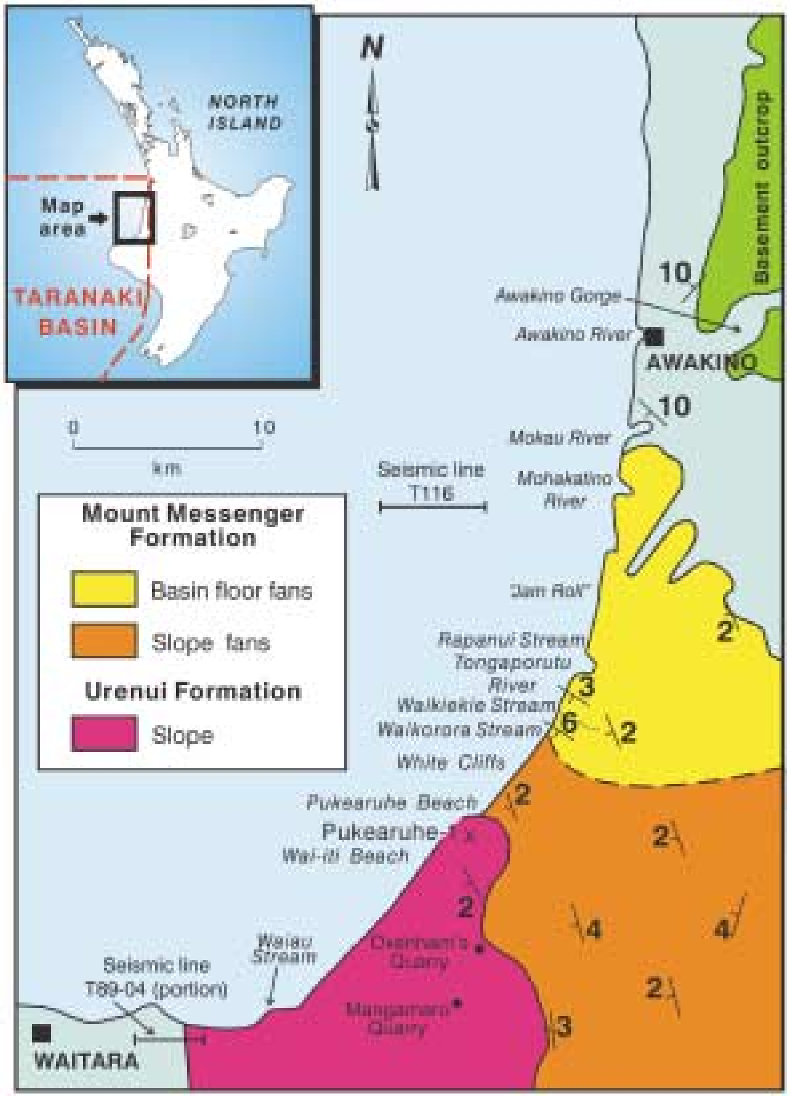


Figure 1: North Taranaki locality map showing localities mention in the field guide.

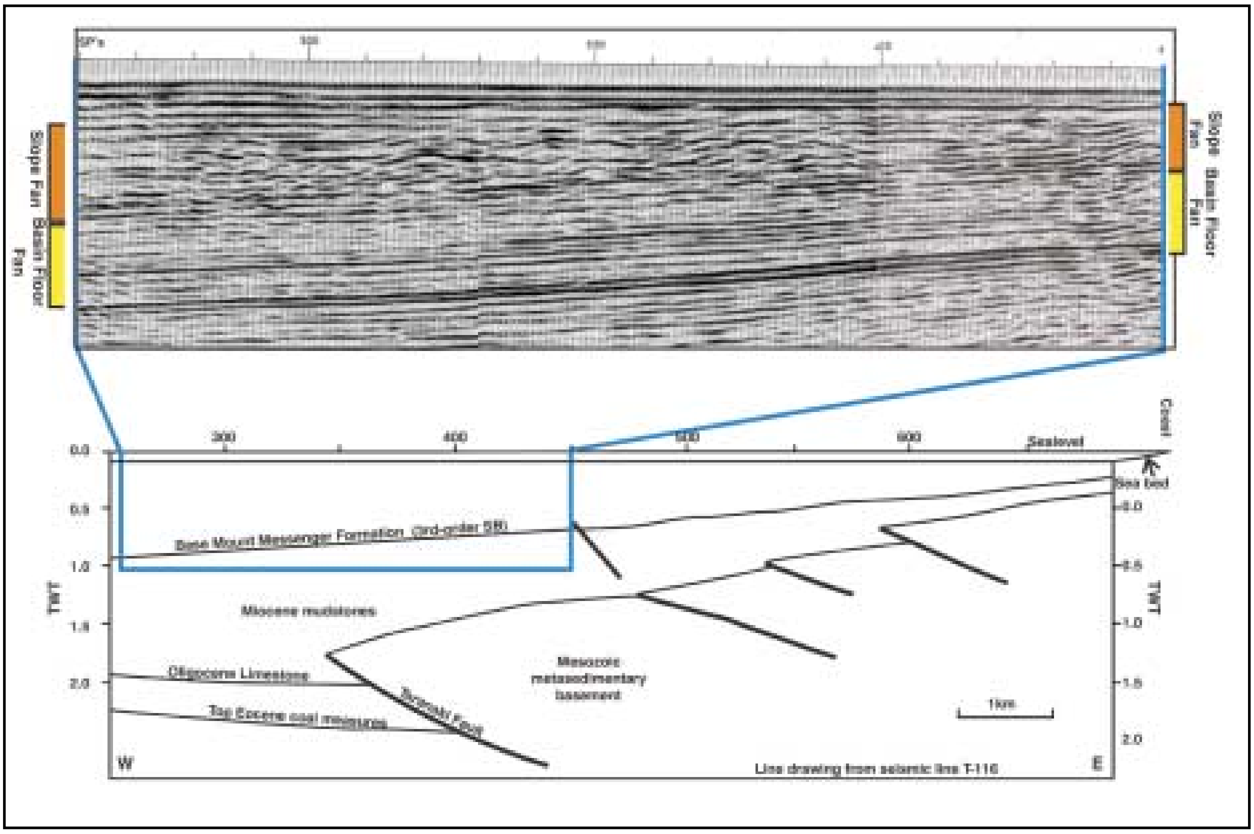


Figure 2: Seismic line T116 located offshore from the outcrop transect (Fig. 1), showing relatively continuous reflection character of Mount Messenger Formation basin floor fans, and more interleaved and channelised character of overlying base of slope fans.

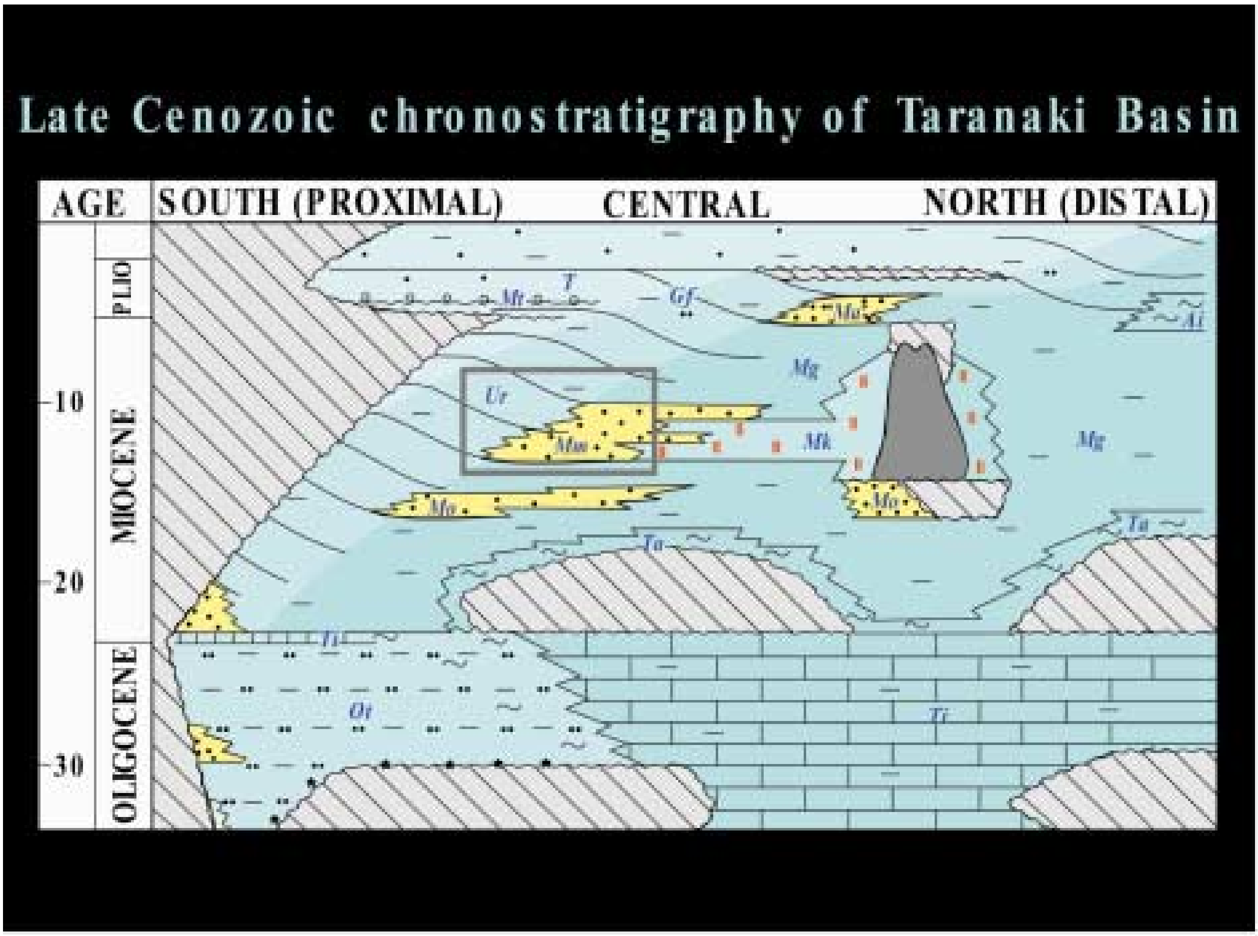


Figure 3: Chronostratigraphic units examined in coastal North Taranaki include the Mount Messenger Formation (Mm) and Urenui Formation (Ur). Volcaniclastic Mohakatino Formation = Mk.

A phase of late Neogene uplift and tilting has exposed Miocene strata in the study region, as well as basement rocks in the Herangi Range to the north. The oldest Tertiary sediments unconformably overlying basement in the vicinity are highly calcareous rocks of the Oligocene Te Kuiti Group. These outcrop on the southeastern flank of the Herangi Range at the northeastern margin of the basin.

The Miocene succession exposed in the north Taranaki coastal region is mostly continuous, although an interval is missing across a major unconformity that outcrops in the Awakino vicinity. Beds generally dip gently to the southwest though in places the coastline parallels structural strike. Along the entire coast, with the exception of White Cliffs, Miocene sediments are truncated by a late Quaternary marine wave-cut platform (Rapanui highstand surface; c. 120 k.a.), and are variously overlain by terrace cover-beds of terrestrial, shallow marine and volcanic origin.

Mount Messenger-Urenui depositional system

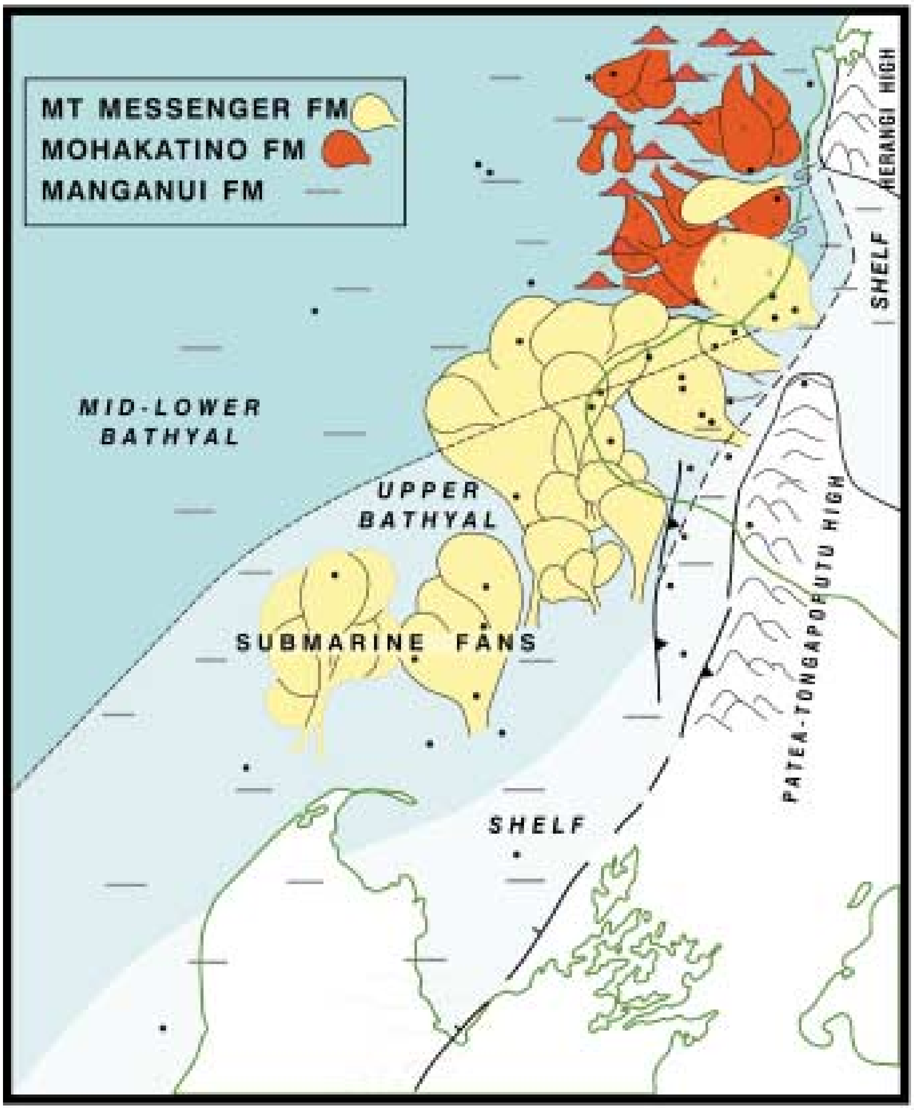


Figure 4: Late Miocene paleogeographic map of the Taranaki Basin.

The overall Late Miocene Mount Messenger to Urenui Formation transect in outcrop, from Awakino in the north to near Waitara in the south, is a broadly fining-upwards interval, as is also evident in the subsurface on well logs. Paleobathymetry changes up-section from lower bathyal to upper bathyal/outer shelf, and the entire succession is an excellent example of a progradational and aggradational system that ultimately reflects the arrival of the continental slope in the region. This exposed basin floor to slope system is characteristic of Miocene depositional patterns throughout the Taranaki Basin.

In sequence stratigraphic terms, the Mount Messenger and Urenui 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. This outwardly reflects the relatively rapid and continuous basin floor aggradation and slope outbuilding during this period, a consequence of high volumes of sediment supply caused by plate-convergent-related uplift and erosion in the eastern and southern hinterland (King et al. 1993; King et al. 1994).

The stratigraphically lower part of the succession (lower Mount Messenger Formation) corresponds to the deepest-water, basin floor fan portion of the 3rd-order cycle, and comprises a series of stacked fan lobe deposits. Each fan lobe is represented by a fining-upwards cycle of thick-bedded, sheet-like or channelised sandstones with very thin siltstone interbeds, overlain by thin-bedded sandstones and siltstones, and capped by mudstones. Individual lobes appear to be relatively extensive and laterally continuous, but probably compensate over horizontal distances of several kilometres. The middle part of the outcrop section (upper Mount Messenger Formation) corresponds to the base-of-slope fan portion of the 3rd-order cycle, and is characterised by fine-grained, thin- to medium-bedded sandstone turbidites, interbedded siltstones, and occasional debris flow conglomerates. These sediments were deposited in channel and levee overbank environments, and in coalescing sand aprons, at the base of the advancing slope.

Sandstones of both the lower and upper parts of the Mount Messenger Formation consist of litharenites and feldspathic litharenites, with metamorphic, sedimentary, and igneous rock fragments present in respectively decreasing order of abundance (Fig. 5). Probable source areas include the

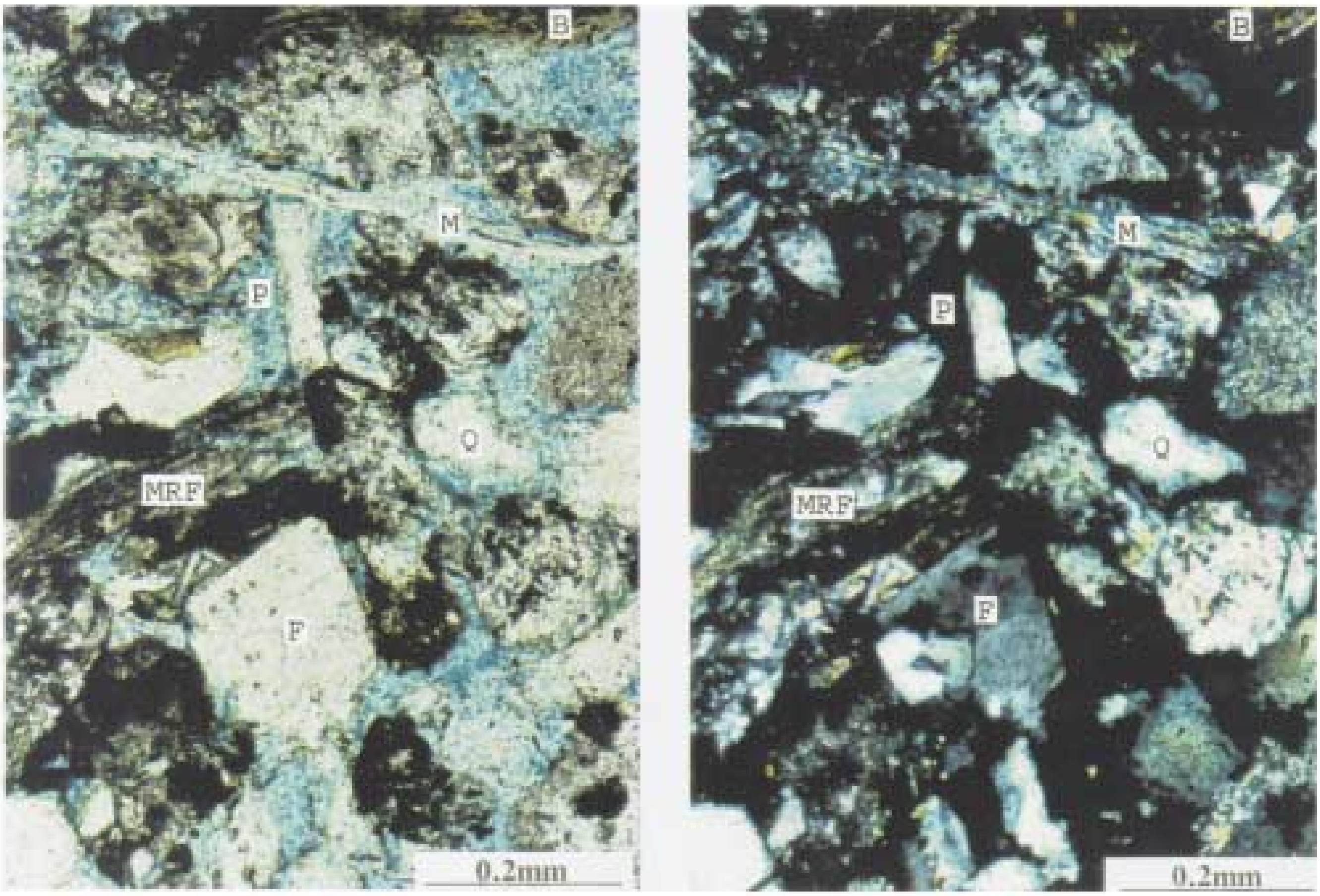


Figure 5: Thin section photomicrographs from Kaipikari-1, 1137.85 m, Mount Messenger Formation in plane polarised (left image) and cross polarised light (right image). Framework grains are quartz (Q), feldspar (F), biotite (B), muscovite (M), and metamorphic rock fragments (MRF). Images from Petroleum Report 2195.

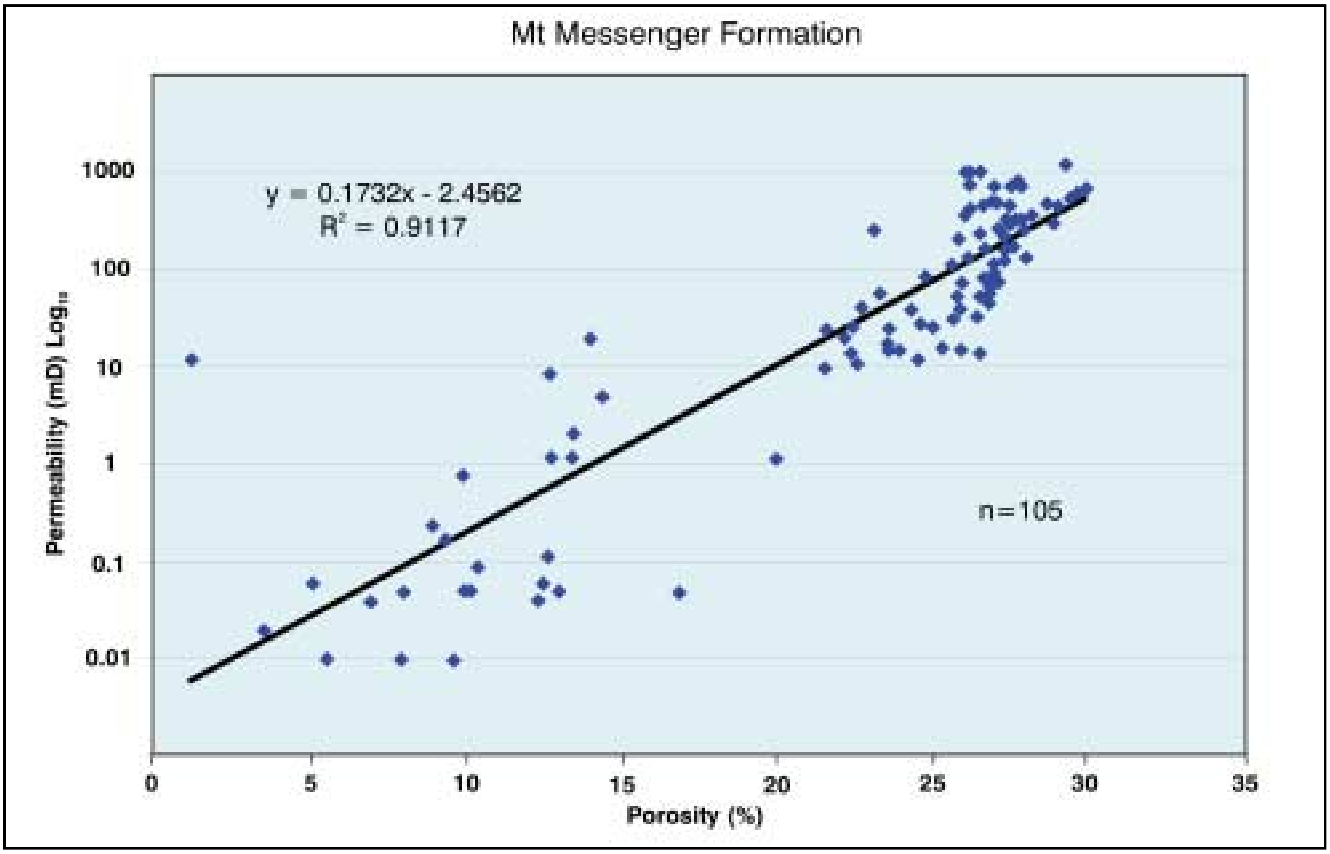
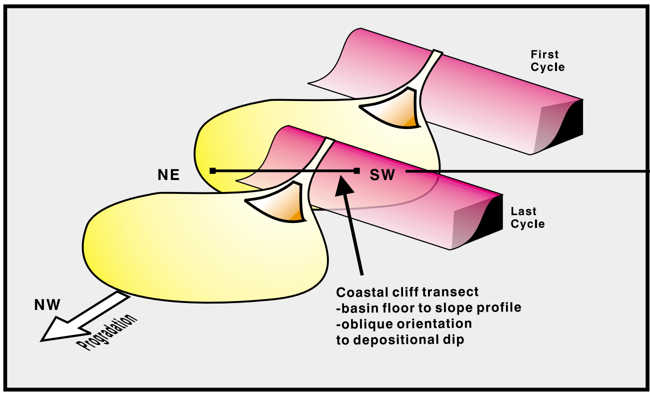
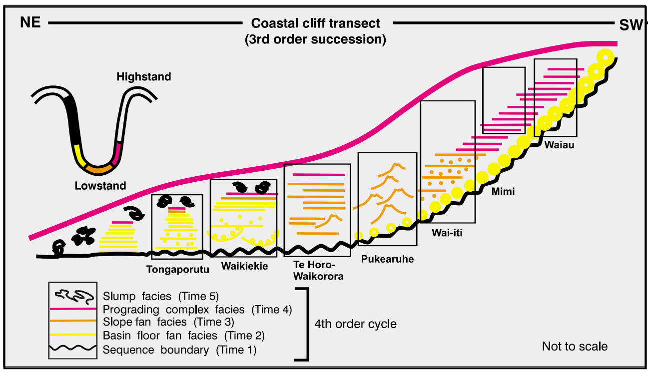


Figure 6: Porosity-permeability relationships, Mount Messenger Formation, from wells Burgess-1, Kaimiro-2, -5, Kaipikari-1, Ngatoro-2, and –4.





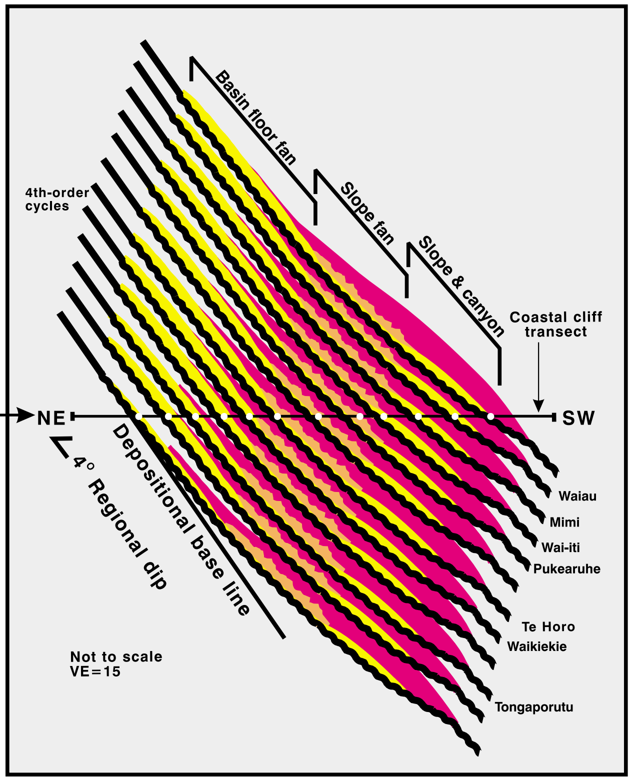


Figure 7: Cartoon illustrating the orientation of the present-day coastal outcrop transect relative to the Late Miocene progradational system: oldest basin floor fan deposits in the northeast and youngest slope deposits in the southwest.
Figure 8: Internal facies architecture of constituent 4th-order cycles identified at various localities, within the overall 3rd-order Mount Messenger-Urenui succession. Roughly time-equivalent facies are colour-coded, and correlate to generic base-level cycles.
Figure 9: Progradational stacking pattern of the 3rd-order Mount Messenger-Urenui succession exposed along the north Taranaki coast. The position of 4th-order cycles at Tongaporutu, Pukearuhe and other localities are shown.

Waipapa terrane in the central North Island axial ranges and the Eastern Province terranes of the North Island axial ranges and South Island (King and Thrasher 1996). Porosities range up to 32% and average 20%, and permeabilities range up to 1230 mD and average ~200 mD (Fig. 6).

The upper part of the succession (Urenui Formation) corresponds to the prograding complex portion of the 3rd-order cycle, and is characterised by fine-grained sediments (predominantly siltstones). The Urenui succession is punctuated by several channels or canyons that are variously infilled with thick-bedded sandstones, thin-bedded turbidites, and debris flow conglomerates.

The overall Mount Messenger-Urenui succession bears a strong resemblance to the Mutti Type I, II, III turbidite model. The over-riding control on deposition was the very high rates of sediment supply. However, tectonic subsidence and eustatic variations (e.g. lowstand shelf exposure) probably also influenced overall depositional architecture. In detail, several sequences of inferred 4th-order cyclicity are identified in the coastal section (Figs. 7, 8 & 9). These are superimposed upon the 3rd-order succession, and attest to periodic higher-frequency variations in relative base level. Differing facies architecture and bed geometries within successive stacked 4th-order lowstand cycles are illustrated at each of the localities visited along the coastal transect. The oldest (basin floor fan) cycles are located in the north, and youngest (slope) cycles in the south.

The three main components of the lowstand systems tract (basin floor fan; early lowstand wedge or slope fan; and late lowstand wedge or prograding complex) are generally present in each of the stratigraphically older 4th-order cycles. However, with ascending stratigraphic position the dominant facies within these stacked sequences systematically changes, as the coastal cliffs bisect successively higher positions within the 3rd-order cycle. From the various facies relationships seen, the composite internal architecture of a generic 4th-order cycle can be postulated (Fig. 8). This model serves as a useful tool for predicting sandstone facies character and distribution up-slope and down-slope of any given location. The presence or absence of transgressive and highstand systems tract components in the outcrop succession is debatable. Contiguous shelf strata to the east, have been largely removed by erosion. The best examples of shelf-equivalent facies occur in younger strata to the south (in Wanganui Basin) and west (Giant Foresets Formation).

Stratigraphy and lithofacies

Basin floor fan lithofacies, Mount Messenger Formation (north of White Cliffs)

The Mount Messenger Formation is exposed on the coast as far north as the Waikawau region (where it was described as Waikaretu Formation by Nodder et al. 1990 a, b). The

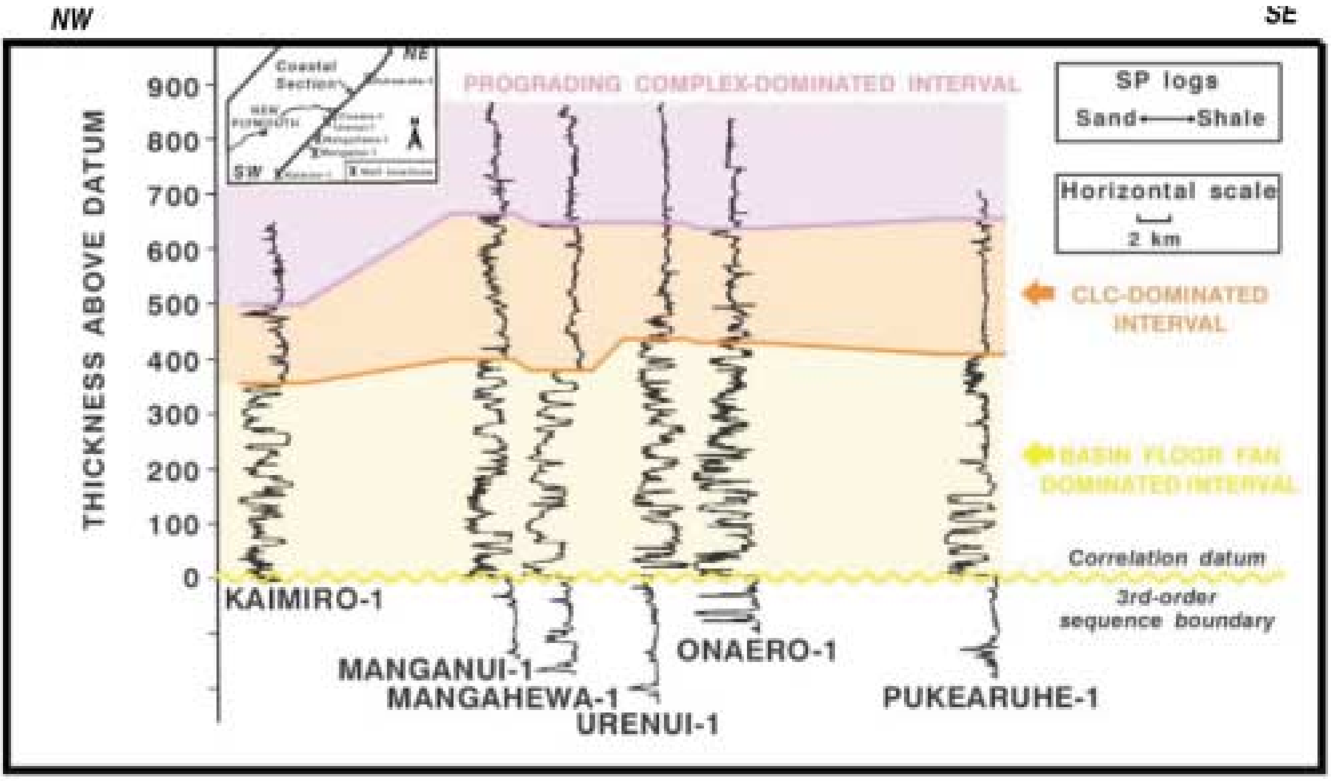


Figure 10: SP log correlation from wells Pukearuhe-1 in the northeast, to Kaimiro-1 in the southwest.

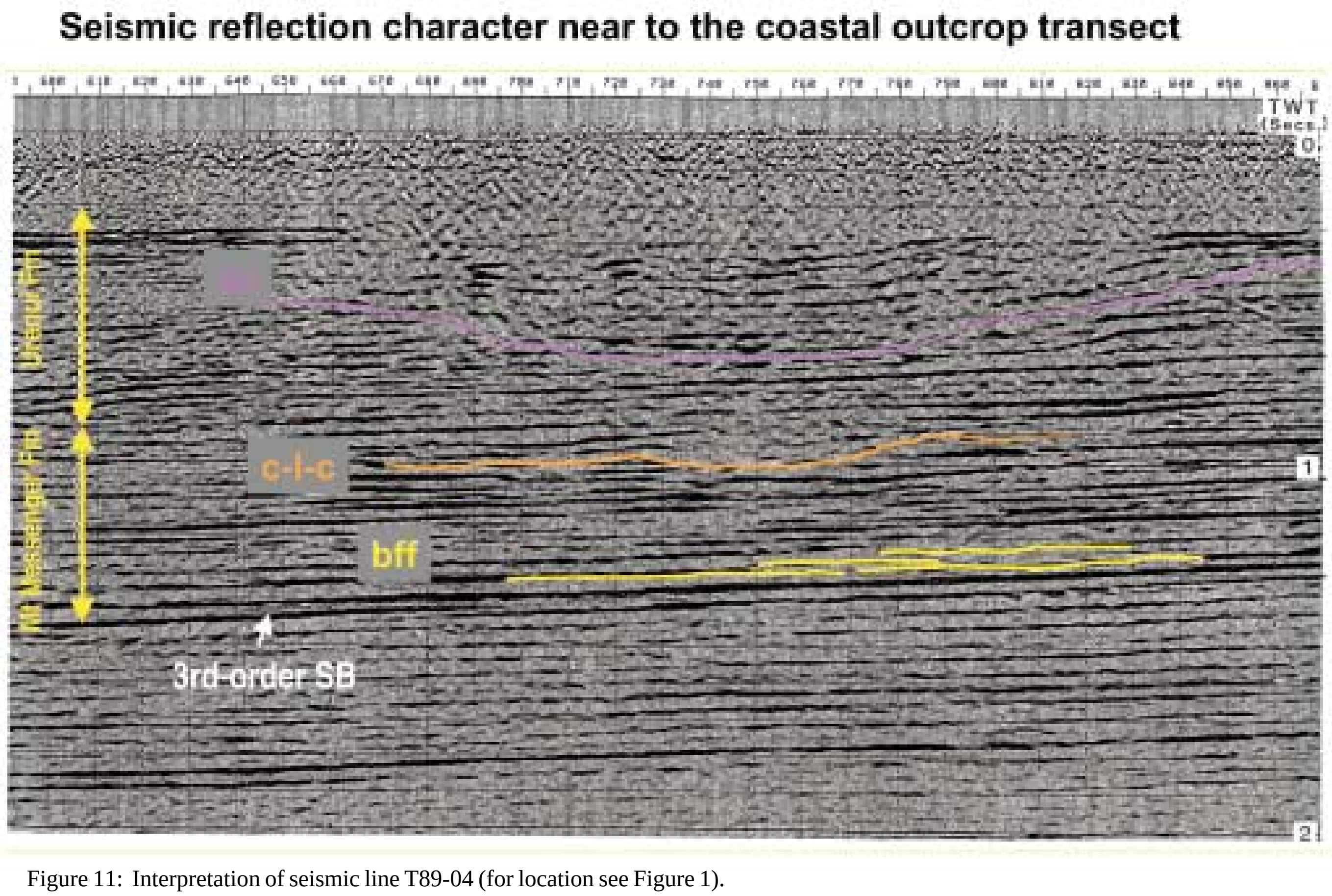


Figure 11: Interpretation of seismic line T89-04 (for location see Figure 1).

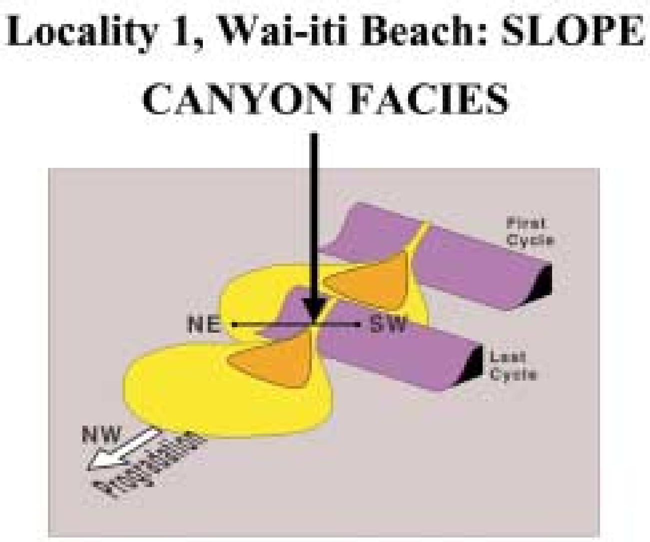


Figure 12: Conceptual model for Locality 1, Wai-iti Beach.

formation comprises interbedded sandstone and siltstone (King et al. 1994; Jordan et al. 1994; Browne et al. 1996; Manley and Lewis 1998; Browne et al. 2000). Sandstones are thin- to thick-bedded, often amalgamated, well sorted, and fine- to medium-grained with variable proportions of broken shell and fine carbonaceous debris. The bases of sandstones are sharp and either planar or are erosive into underlying siltstones. Sandstone beds are overtly massive, but under favourable lighting and weathering conditions, display horizontal, inclined, and convolute lamination and dish structures. Upper portions of many beds show ripple lamination and rare climbing ripple lamination. The sandstones are interpreted as high-density, sand-rich mass flows. Both massive and horizontal laminated siltstones are present; some have a sharp planar contact with underlying sandstones, others are gradational into underlying lithologies. They are interpreted as both fine-grained tails of the underlying sediment gravity flow, and as beds deposited from pelagic sedimentation.

Siltstones and sandstones are highly contorted and folded along a considerable length of coastline (King et al. 1993). The deformation is attributed to post-depositional slumping and folding, with sea-bed instability most likely triggered by tectonic movements of the underlying basement thrust block and /or eruptions of Mohakatino volcanic centres.

Base-of-slope fan lithofacies, Mount Messenger Formation (south of White Cliffs)

The upper portion of the Mount Messenger Formation comprises variable proportions of interbedded sandstone and siltstone with well-developed Bouma cycles (Browne and Slatt in press). In particular, Bouma Tb planar bedded sandstone, Tc climbing-ripple laminated sandstone, and Te massive siltstone are most common. Broad scour and fill structures and interleaving channel packages are present in several localities, some of the channels lined with perigenic siltstone and mudstone clasts, shell debris, and basement clasts. Turbidity currents were the prevalent flow mechanism in the base-of-slope fan, associated with within-channel debris flow deposition.

Slope Lithofacies and associated channels, Urenui Formation

The Urenui Formation is in fault contact with the stratigraphically underlying Mount Messenger Formation in the coastal section. The Urenui Formation is several hundred metres thick and comprises mainly siltstones and silty mudstones. The siltstones are commonly massive to weakly bedded; bedding is often only discernible from the presence of parting lineations or frequent concretion layers and thin tuff horizons. The siltstones are usually heavily bioturbated. They are punctuated at several stratigraphic levels by seismic-scale channels or canyon systems, filled with conglomerate, fine- to medium-grained sandstone and siltstone (King et al. 1993).

Based on benthic foraminiferal assemblages, the Urenui Formation was deposited in progressively shallower water, from uppermost bathyal at the base of the formation to perhaps mid-outer shelf depths at the top.

Subsurface expression

In subsurface sequences, the sandstone-dominated Mount Messenger Formation can be divided into upper and lower units, based on log signatures (King et al. 1994). The lower sandstones are better developed, with greater SP and gamma shifts and induction log separations. Many of these units display cylindrical log motifs, perhaps indicative of rapid, mass-emplaced sheet deposition (Fig. 10). Their nature is comparable to sandstones in outcrop from Mokau River to south of Tongaporutu River. Upper Mt Messenger sandstone bodies generally have more pronounced bell-shaped fining-upwards or coarsening-upward funnel-shaped profiles. These probably represent a variety of depositional settings, including channel-fill, migrating fan-lobe or interfingering fan apron, and levee overbank.

On seismic reflection profiles the Mount Messenger succession is characterised by a series of sub-parallel, laterally continuous reflectors interpreted as basin floor fan deposits, overlain by an offlapping sequence of chaotic, arcuate (channel-form), or truncated reflectors interpreted as slope fan, channel-levee and slump deposits.

The Urenui Formation displays a generally uniform siltstone SP and gamma response, with isolated sandstone intervals. Seismic reflection lines of the Urenui Formation interval have a clinoform character, but are disrupted by broad channels that cut into background sediments. Channel fills are characterised either by seismically opaque, or bright discontinuous reflectors, thought to represent a variety mudstone, slumps, sandstone and conglomerate lithologies (Fig. 11). Channel-filling rocks both onlap and drape channel margins, and display multiple phases of cut-and-fill.

Figure 13: Aerial views of the Whakarewa Conglomerate from south and north perspectives, Wai-iti Beach.

Figure 14: Channel-fill lithofacies within the Urenui Formation at Wai-iti Beach.

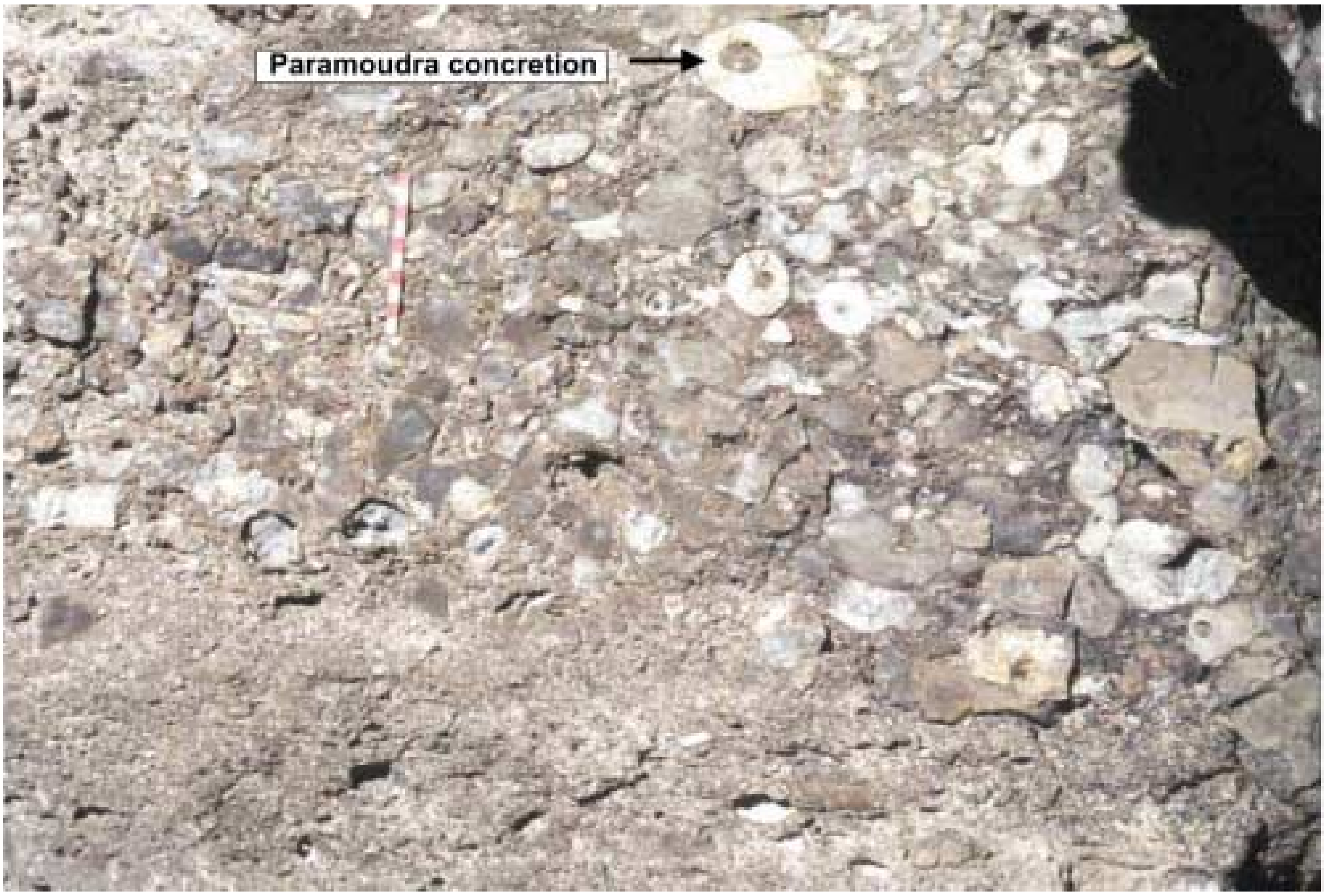


Figure 15: Conglomerate filling the axis of the channel, Wai-iti Beach. Scale bar is 50 cm, with 5 cm divisions.

Figure 16: Thick-bedded sandstone and thin interbedded siltstone from within the channel, Wai-iti Beach.

Section descriptions and locations

Day One

Location 1: Wai-iti Beach

The Urenui Formation in outcrop is a fine-grained (dominantly siltstone) slope lithofacies, cut by spectacular seismic-scale channels at several stratigraphic intervals. One such channel is exposed ~1 km north of Wai-iti Beach. This channel is inferred to represent the base of one of the youngest 4th-order cycles exposed (Figs. 12 and 13). The channel is approximately 60-70 m thick and several hundred metres wide. Underlying siltstones of the Urenui Formation outcrop at either end of the beach.

A conglomeratic facies (Whakarewa Conglomerate) forms the axial fill of the channel, and is exposed at the prominent headland (Fig. 14). The conglomerate comprises intra-formational siltstone clasts many cemented by dolomitic and calcium carbonate, with shell debris, distinctive elongate cylindrical paramoudra concretions, and pebbles and cobbles of Mesozoic basement rocks (Fig. 15). Laterally adjacent to, and overlying the conglomeratic axial-fill facies is a broad (several hundred metre wide) sandstone channel fill comprising well sorted, fine- to medium-grained, medium- to thick-bedded sandstones and thin siltstone (Fig. 16). These thick-bedded sandstones have a similar texture, bedding style, and overall appearance to thick-bedded basin floor fan sandstones that we will observe tomorrow at Tongaporutu Beach and Rapanui Stream in basin floor fan lithofacies. The essential difference between these two facies is that the Wai-iti sandstones are laterally confined, and can be seen to pinch out rapidly against the canyon margin.

Location 2: Pukearuhe Beach

Magnificent coastal cliff exposures of slope fan units occur from Pukearuhe Road end as far as White Cliffs, 4 km to the north. These represent slope fan deposition at the base of the slope (Fig. 17). This section is the uppermost portion of the Mount Messenger Formation (contact with overlying Urenui Formation at Pariokariwa Point to the south), and is near to the drilling location of Pukearuhe-1 on terrace to south (Fig. 18).

Several interleaving and coalescing slope fan apron or channel-levee complexes are well exposed. Well-developed Bouma turbidites, with Bouma Tb Tc, and Te are common in the section, with less abundant Ta and Td (Mutti Facies C and D; Figs. 19 and 20). Climbing ripple portions of beds (Tc) are commonly relatively thick, indicating rapid deposition of sediment (on channel-levees and/or fan aprons). Many of these climbing ripple laminated beds contain vertical burrow escape structures of *Scolicia*; Fig. 21).

This section has been the subject of a detailed reservoir characterisation study, funded by a multi-company international consortium. This included outcrop section description, 2-D and (subsequent) 3-C seismic profiles along the beach, and two fully cored behind-outcrop stratigraphic holes logged with Schlumberger's FMI and Platform Express

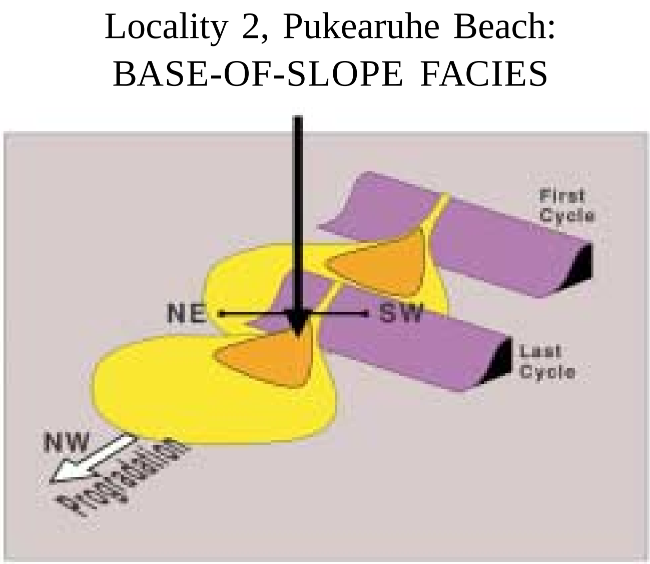


Figure 17: Conceptual model for Locality 2, Pukearuhe Beach.

tools. Three facies variants are displayed in the coastal section:

1. channel-fill lithofacies occur at the south end of the beach, the channel filled initially by bioturbated siltstone, but at higher stratigraphic levels within the channel, by multiple phases of cut-and-fill turbidites (Fig. 22);
2. proximal channel and levee lithofacies comprise multiple nested channels, conglomerate, sandstone and mudstone filled channels (Fig. 23);
3. distal levee and overbank rocks dominated by low net:gross, siltstone-dominated units with relatively thin interbedded sandstone (Browne and Slatt in press).

Day two

Location 3: Tongaporutu River mouth

This locality, and localities 4 and 5, represent some of the stratigraphically lowest of the 4th-order cycles in the coastal section (Fig. 24). It encompasses part of the lower portion of the Mount Messenger Formation. Three main basin floor fan facies are present within a 4th-order cycle: in ascending order these are: thick-bedded sandstone, thin-bedded sandstone/mudstone, and mudstone. A sharp contact between the basal thick-bedded sandstones and underlying slumped siltstones is inferred to be a 4th-order sequence boundary.

Thick-bedded facies (base of 4th-order cycle) comprises up to 5 m thick, often amalgamated, moderately to well sorted, fine- to very fine-grained bioturbated sandstone (Mutti facies B), interbedded with cm-thick bioturbated mudstone (Figs. 25 and 26). Sandstone beds are overtly massive (Bouma Ta) or show massive bases and parallel to convolute laminated (Bouma Tb-Tc) tops. Loading, flame structures, sole marks, convolute bedding, and mild scouring is present. Less abundant intra-formational clast conglomerate, coal fragments, and tuffaceous bands also occur. The sandstones are interpreted as the products of high density, sand-rich mass flows deposited in basin floor lobes. Interbedded mudstones are inferred to represent pelagic deposition.

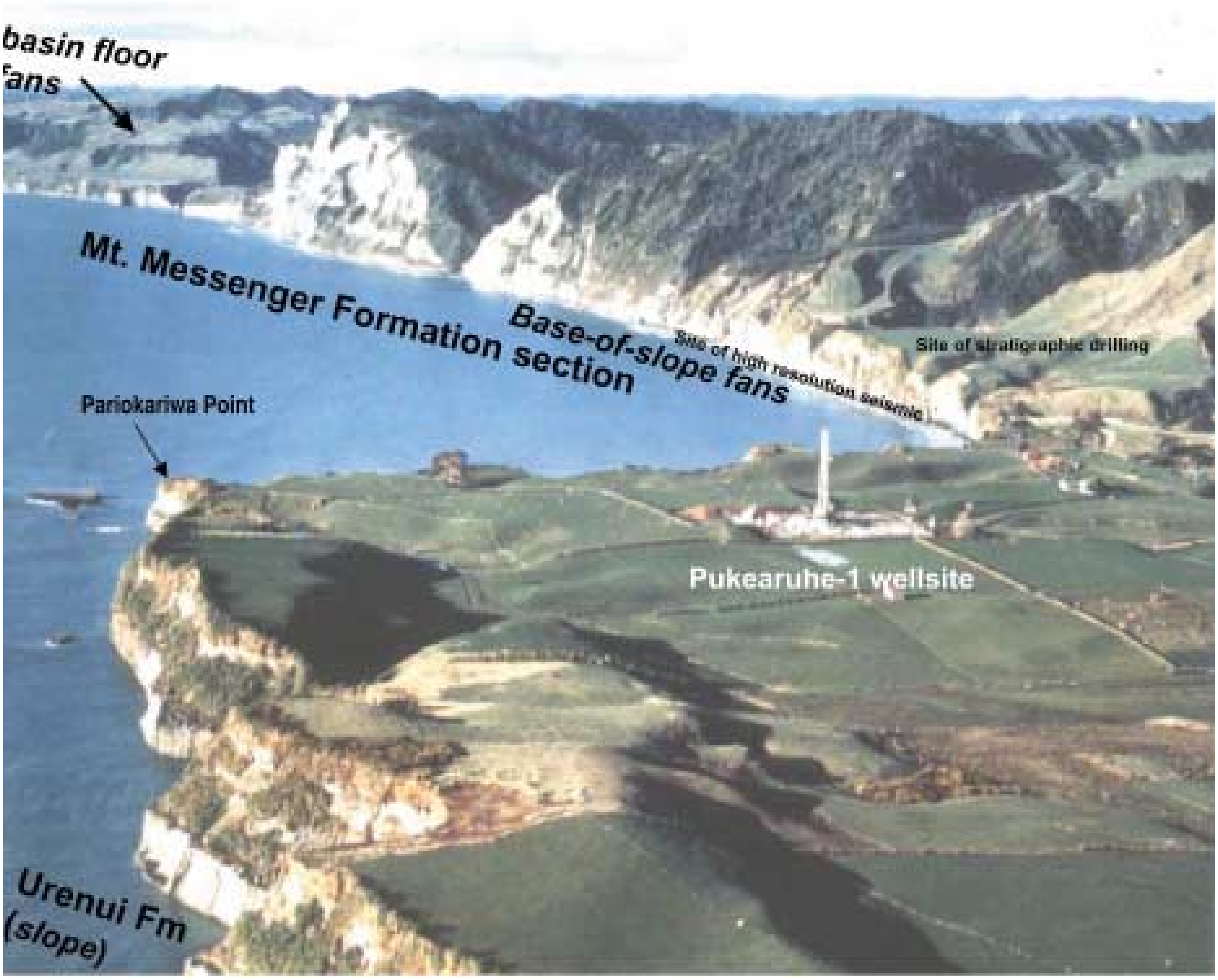


Figure 18: Pukearuhe Beach study location.

Figure 19: Mount Messenger Formation slope fan facies, Pukearuhe Beach. Well-developed turbidites are dominated by planar laminated sandstone (Bouma division Tb), climbing ripple laminated sandstone (Bouma division Tc), and massive siltstone (Bouma division Te).

The thin-bedded interval (mid-cycle) grades abruptly up from the thick-bedded facies. It consists of cm- to dm-thick, moderately to well-sorted, fine- to very fine-grained, bioturbated sandstone, interbedded with bioturbated mudstone (Mutti facies C and D; Figs. 27 and 28). The mudstones are often tuffaceous, indicative of background fallout of volcanic debris from ongoing episodic eruptions within the Mohakatino Volcanic Centre to the northwest. Lateral bed thinning (compensation-style bedding) occurs (e.g., Fig. 28). The sandstones are interpreted as lobe fringe facies, deposited by mass flows or turbidity currents. The siltstones could represent background pelagic deposition between flows. Alternatively, they could represent the tails of turbidity flows, in which case the sharp contact between sandstone and siltstone beds would indicate an element of flow by-pass at this site.

A detailed bed correlation study has been undertaken at the southern end of the beach in a flat lying portion of the thin-bedded facies (Browne et al. 1996). This site was chosen as a likely outcrop equivalent to the thin-bedded reservoir facies of the Mount Messenger Formation in the Kaimiro Field. What appeared to be a site with simple layer cake stratigraphy (Fig. 29), showed, in detail, considerable depositional thinning of individual beds in a compensation-style geometry (Fig. 30). A cross-plot of the number of beds that could be correlated across the 200 m-wide study area versus lateral distance, illustrates that approximately 50% of the beds disappear over a horizontal distance of 100 m, and most beds have disappeared over 200 m (Fig. 31).

At the top of the section is a ~10 m-thick siltstone with thin interbedded sandstone beds (Fig. 28). It is interpreted as late-stage prograding complex siltstone.

Location 4. Rapanui Stream

Rapanui Stream, 2 kilometres to the north of Tongaporutu, exposes the basal portion of the preceding 4th-order cycle. The base of the cycle is marked by a sharp-based sandstone exposed at a small island south of the river. Below this is an interval several metres thick, that contains slumped siltstones and large blocks of sandstone floating as rafts within the siltstone. The same interval is exposed north of the stream.

Location 5. "Jamroll" Bay

At this stop, complex folded and sheared interbeds of well-bedded siltstone and thick-bedded massive medium-grained sandstone occur in variously deformed masses (Fig. 32). Sandstone beds were pre-compacted, and remained relatively intact during deformation. Based on broad stratigraphic position, a basin floor setting is inferred. Mudstones contain common tuff layers. Tectonic movement of the underlying basement block and/or contemporaneous active submarine volcanism caused the disruption to strata, but the exact nature of the deformation is uncertain.

Figure 20: Slope fan facies, Mount Messenger Formation, Pukearuhe Beach. Massive sandstone (Bouma division Ta), climbing ripple laminated (Bouma division Tc), and flame structures (F) are prominent. Scale bar is 50 cm, with 5 cm divisions.

Figure 21: Slope fan facies, Mount Messenger Formation, Pukearuhe Beach. Climbing ripple laminated sandstone (Bouma division Tc), with *Scolicia* burrow, including the remains of the echinoid that formed the burrow preserved at the top of the structure.

Figure 22: Broad angular discordance (marked by red arrows) marking channel margin and onlapping channel-fill beds, slope fan interval, Pukearuhe Beach.

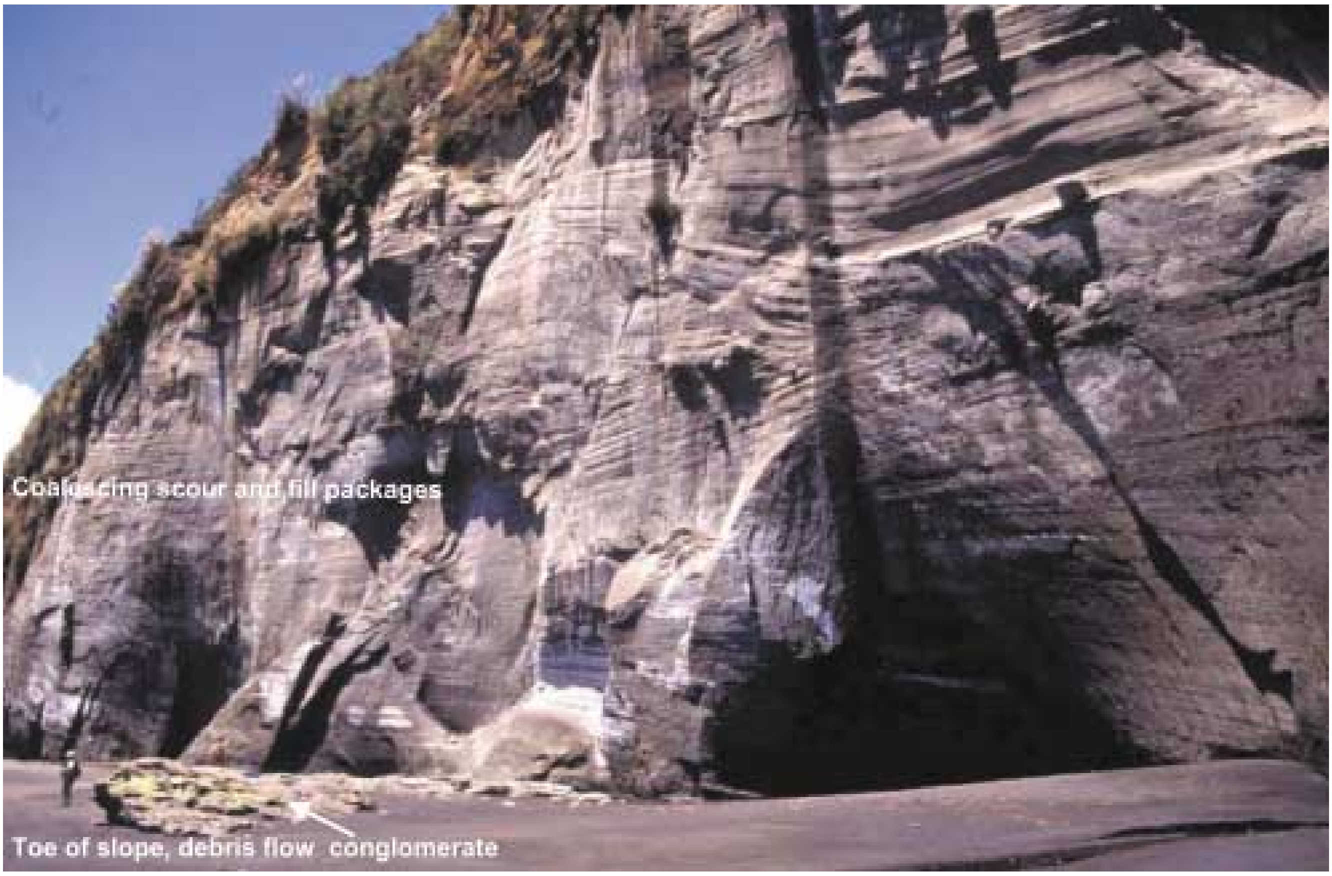


Figure 23: Numerous stacked, interlerleaved channel elements, slope fan lithofacies, Mount Messenger Formation, Pukearuhe Beach.

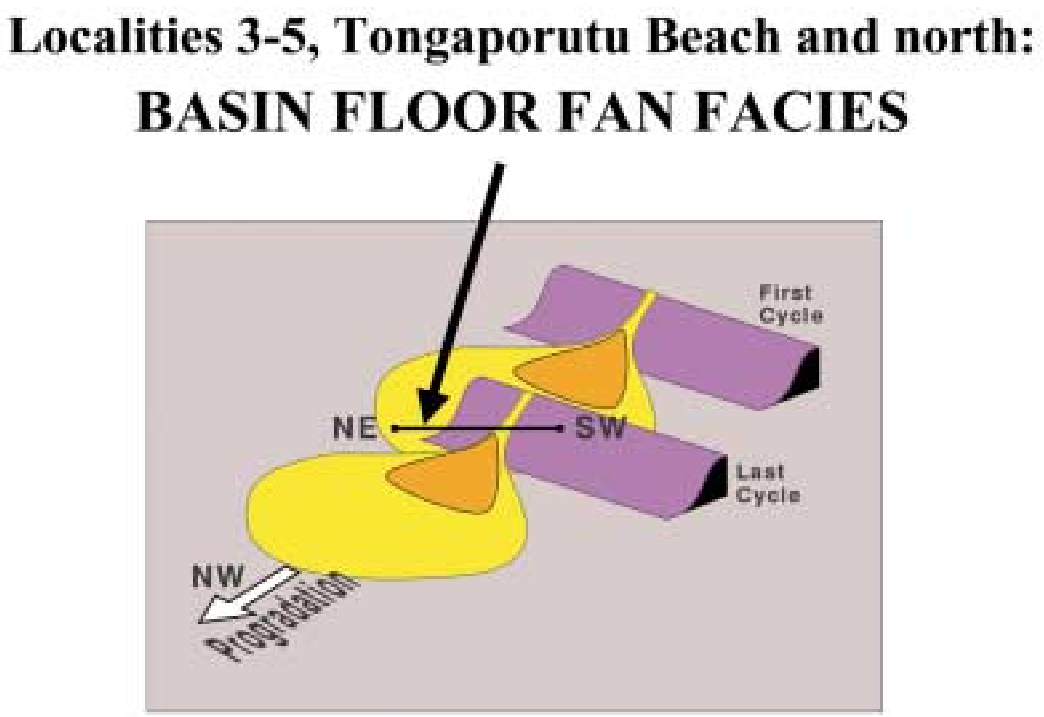


Figure 24: Conceptual model for Localities 3-5, Tongaporutu Beach, Rapanui Stream, and the “Jamroll.”

Figure 25: Thick-bedded (metre-decimetre) and amalgamated sandstones, basin floor fan interval (inner-mid fan facies), Tongaporutu north. Note that the siltstone interbeds are pale in colour, while the sandstones are darker in colour.

Figure 26: Thick-bedded sandstone and interbedded siltstone of the basin floor fan facies, Mount Messenger Formation, Tongaporutu Beach. Note that the siltstone interbeds are pale in colour, while the sandstones are darker in colour. Scale bar is 50 cm with 10 cm divisions.

Figure 27: Thin-bedded sandstone and interbedded siltstone of the basin floor fan facies, Mount Messenger Formation, Tongaporutu Beach. Note that the siltstone interbeds are pale in colour, while the sandstones are darker in colour. Sandstone beds have sharp tops and bases, and may be ripple laminated in the upper portions such as the bed on which the pencil rests.

Figure 28: Basin floor fan lithofacies of the Mount Messenger, Tongaporutu Beach, showing mid-cycle thin-beds and upper cycle siltstones. Some sandstone beds show compensation-style thinning in the upper part of the mid-cycle thin-bedded interval. Note that the siltstone interbeds are pale in colour, while the sandstones are darker in colour.

Figure 29: Basin floor fan thin-bedded lithofacies, Mount Messenger Formation, Tongaporutu Beach. Note that the siltstone interbeds are pale in colour, while the sandstones are darker in colour.

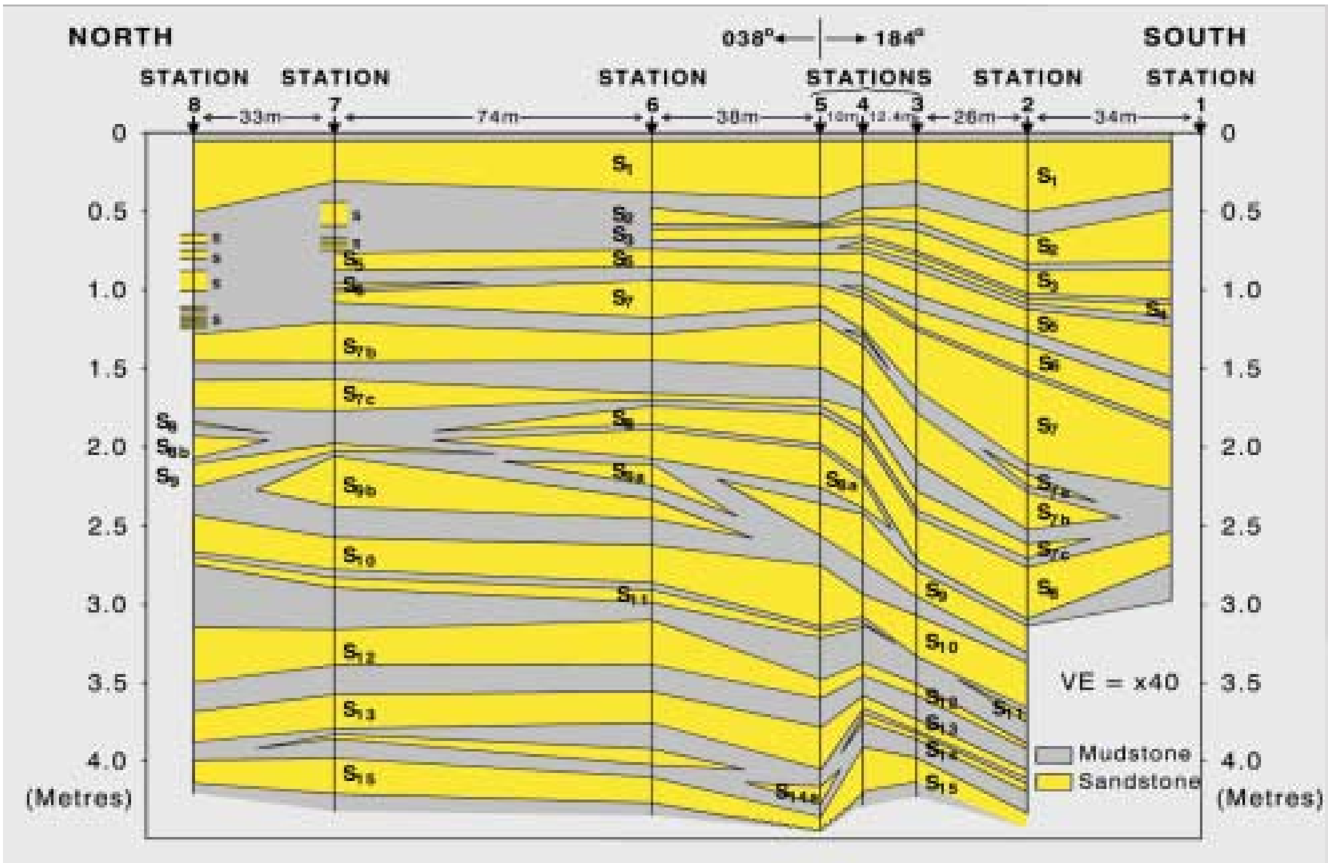


Figure 30: Bed correlation study, basin floor fan thin-bedded lithofacies, Mount Messenger Formation, Tongaporutu Beach.

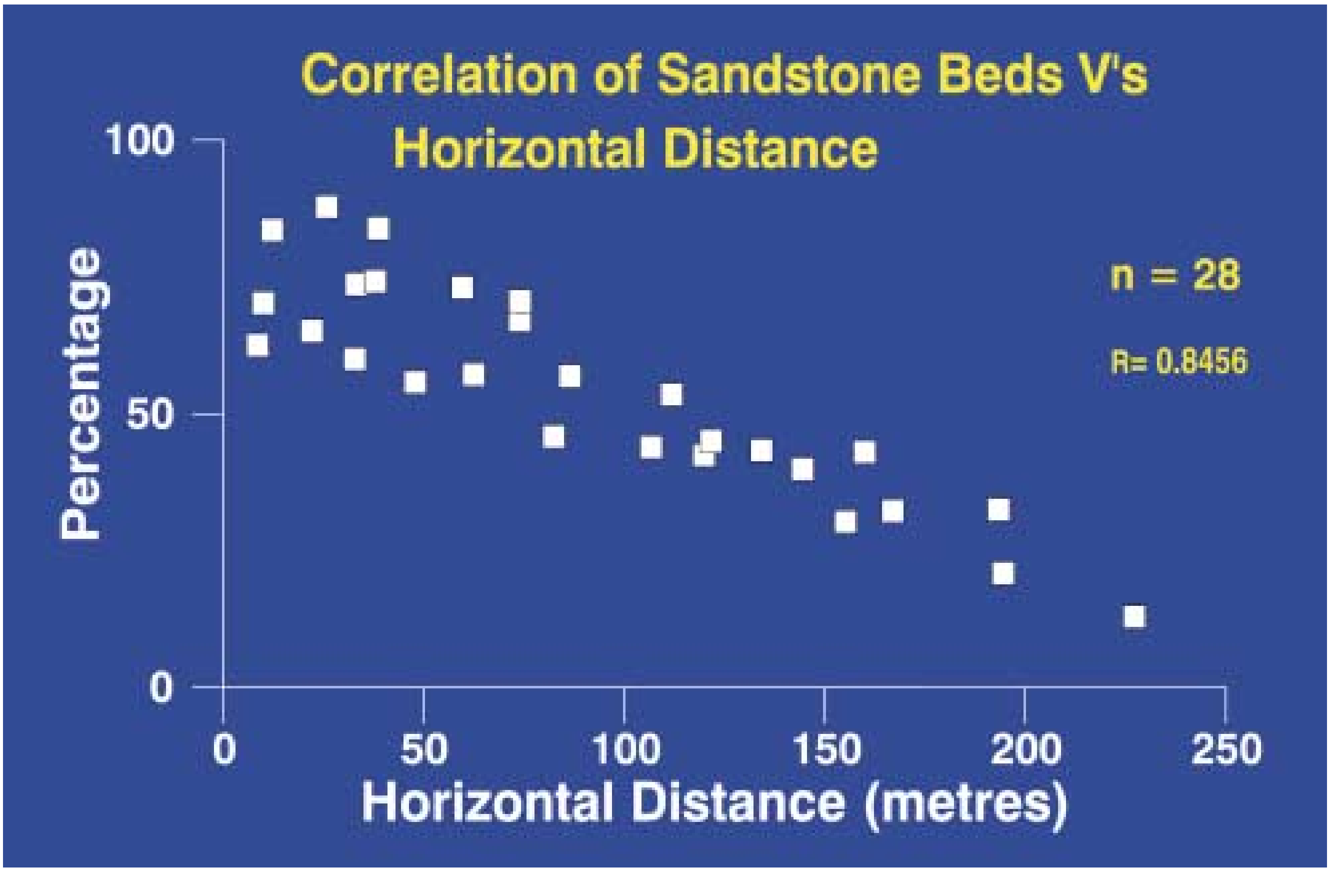


Figure 31: Percentage of beds that correlate V's horizontal distance within the thin-bedded basin floor fan lithofacies, Mount Messenger Formation, Tongaporutu Beach.

Figure 32: Slumped strata at the "Jamroll" within the basin floor fan interval of the Mount Messenger Formation. Consolidated beds (mainly out of the picture) imply that deformation was post-depositional, probably triggered by movement of the Taranaki Fault or volcanically –induced earthquakes.

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