# Mass Transport Complexes from a Late Miocene Deep-Water Succession, Taranaki Basin, New Zealand: Scales, Styles, and Significance in Relation to Tectonic, Eustatic, and Autocyclic Drivers*

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## Geologic Setting

The North Taranaki coastal section, New Zealand, displays some spectacular examples of mass transport complexes. Outcrops of Late Miocene (Tortonian), bathyal submarine fan and coeval slope sediments of the Mount Messenger and Urenui formations (Figure 1), respectively, are exposed in a near-continuous 50 km section. The succession of sandstone, siltstone, and rare conglomerate and tuffaceous gravity flow deposits is 2 kilometres thick, and a comparable succession is imaged in adjacent offshore seismic lines. Several 4$^{th}$ and 5$^{th}$-order equences are exposed along this 2-D outcrop transect. Mass transport complexes (MTC's) make up a significant part of the succession.

In the northern part of the 50 km long section, north of Rapanui Stream, MTC's are associated with volcaniclastic Middle and Late Miocene sediments and form spectacular folded and faulted complexes, 10's of meters thick. MTC's tend to form thinner <10 m thick intervals to the south, and are less likely associated with volcaniclastic sediment.

## Types of Mass Transport Complexes (MTC's)

Three types of MTC are recognized in outcrop. Each has a distinctive style and significance within the deep-water depositional setting. They are defined largely on the basis of scale. Type 1 are "seismic-scale" MTC's, and consist of intervals >10 m thick with complex fold and shear structures. These occur north of Rapanui Stream. Those north of Awakino form an interval several hundred meters thick, of open and recumbently folded strata (Figures 2 and 3). Type 2 examples are "outcrop-scale" MTC's, typically up to 10 m thick (Figure 4). Fault orientations from both seismic and outcrop-scale examples of Type 1 and 2 MTC's are generally consistent with the regional NE-SW fault trend. Both types have fold axes with variable orientations and generally low-angle plunges. Axial plane data is consistent with their transport toward the NW, down the regional paleoslope, though the data from seismic scale examples may have a more southward directed transport direction. Type 3 MTC's are bed-scale and only a few meters thick, and involve single beds with plastic, low shear strength deformation features.

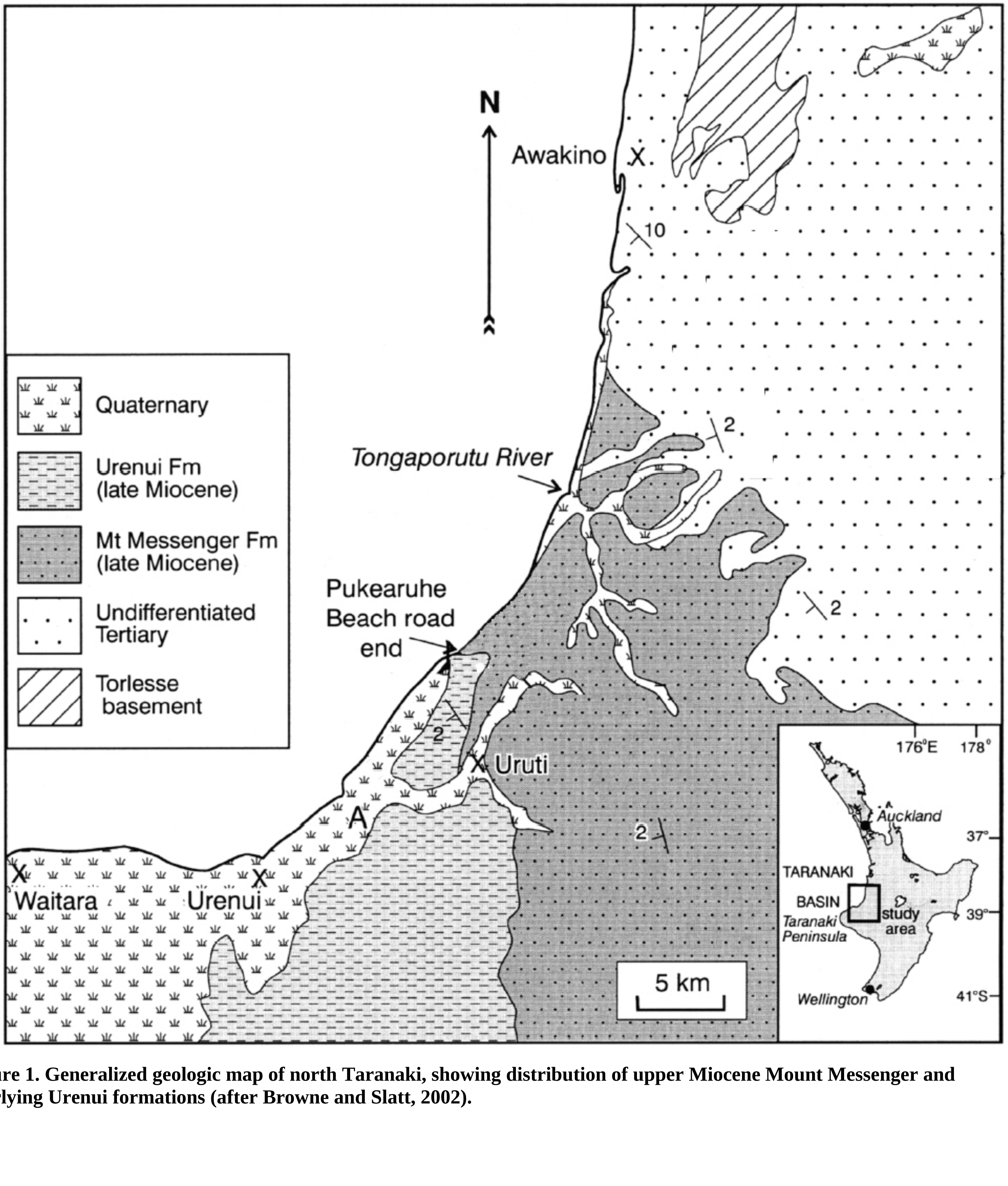


**Figure 1. Generalized geologic map of north Taranaki, showing distribution of upper Miocene Mount Messenger and overlying Urenui formations (after Browne and Slatt, 2002).**

**Figure 2. Type 1 MTC successions, north of Awakino, Mount Messenger equivalent (person for scale). Upper photo: Broad-scale folding; Middle photo: Recumbent folds and shear surfaces; Lower photo: Co-planar fold axes.**


**Figure 3A. Type 2 complexly folded tight and recumbent folds with basal slide plane, Jam Roll Bay, Mount Messenger Formation. Outcrop is approximately 80 m wide at beach level. Slump interval is c. 10 m thick, and is unconformably overlain by Quaternary deposits (brown).**

**Figure 3B. Type 2 MTC with large sandstone rafts and upper fine-grained interval. A sequence boundary is marked by the sharp color change to light brown sandstones in the upper part of the outcrop.**

**Figure 3C. Folded Type 2 MTC strata (gray-colored, c. 5 m thick) at Rapanui Stream, Mount Messenger Formation. The same sequence boundary as in Figure 3B immediately overlies the MTC interval.**

Type 2 MTC's occur stratigraphically below sequence boundaries. The sequence boundaries themselves are variable in character. In the north, in older and more distal paleogeographic settings, the sequence boundary is typically planar, with a sandstone on shale contact, overlain by thick-bedded basin floor fan sandstones. Sequence boundaries associated with Type 2 MTC's exposed toward the south in younger sequences in a shallower middle to upper bathyal paleogeographic setting, display local erosional relief. Sequence boundaries in these settings are variable. They are marked either by the incoming of toe-of-slope channelized conglomerate and sandstone, or by clastic-filled slope channels (Figure 4). All the Type 2 MTC's, occur immediately below, or several meters below the associated sequence boundary. In the latter instances an interval of siltstone between the top of the MTC and the sequence boundary is taken to represent a period of high stand quiescence between the initial disturbance that created the MTC and the relative fall of base level marked by the sequence boundary.

Type 2 MTC's may include large blocks of sandstone that were incorporated in the mass flow (Figure 3B), and may display a bi-partite internal stratigraphic hierarchy from a relatively coarse-grained basal lithofacies comprising debris flow and slump material to a fines-enriched fluidized upper interval (Figure 3B). This lithological and textural partitioning is considered to represent flow transformations that reflect continued slump translation and transport distance, with debris flow development evolving into an upward movement of sediment laden pore fluids and migration of fines toward the top of the deforming MTC, resulting in the upper fine-grained lithofacies.

Bed-scale Type 3 MTC's may exist throughout the outcrop section and differ from Type 2 MTC's by occurring within 4th and 5th-order sequences, rather than stratigraphically associated with the upper portion of the stratigraphic sequence and its sequence boundary (Figure 5). Examples include a range of soft sediment deformation structures– folds, injection structures and loading structures.

## Transportation Processes

Styles of deformation within the MTC's reflect the transportation processes occurring within the flows. Type 1 and some Type 2 intervals are thought to relate to regional tectonic drivers, most likely contemporaneous seismic triggers from nearby andesitic volcanic centres or adjustments on the deep-seated basin bounding Taranaki Fault. Other Type 2 MTC's were likely instigated by falls in relative base level caused either by hinterland uplift or eustatic sea level fall. We interpret these as mass failures produced at latest highstand, when excess pore fluid pressures developed as sediment accumulated on the outer shelf upper slope. Localized autocyclic factors such as slumping from paleo seafloor bathymetric highs and collapse (e.g., from channel or lobe margins), or *in situ* loading, and settling, are more likely triggers for Type 3 MTC'.

## Reference

Browne, Greg H., and Roger M. Slatt, 2002, Outcrop and behind-outcrop characterization of a late Miocene slope fan system, Mt. Messenger Formation, New Zealand: AAPG Bulletin, v. 86, p. 841-862.

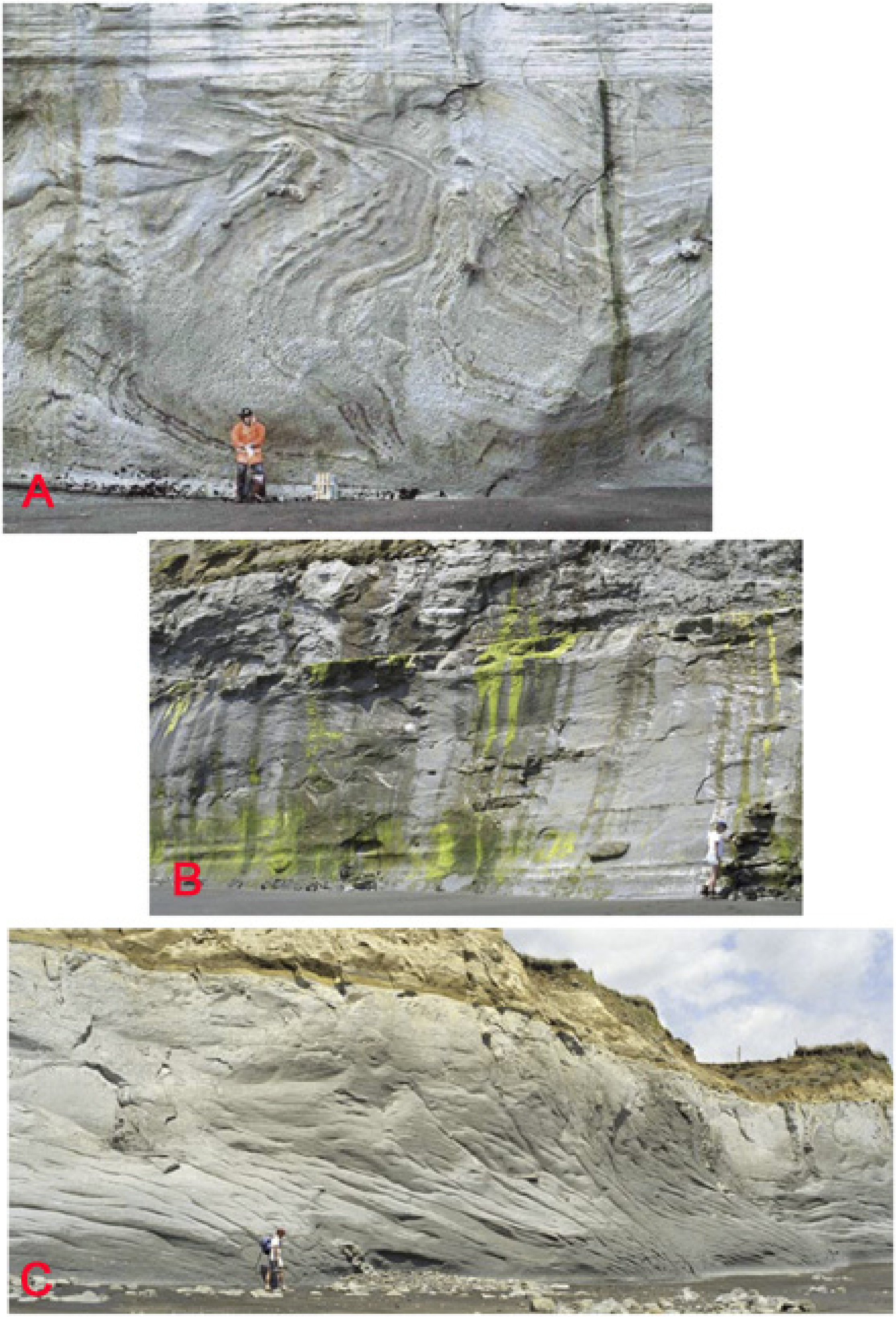


**Figure 4A. Type 2 MTC with a sharp planar upper surface marking the sequence boundary, overlain by alternating sandstone and siltstone, Waikorora Stream (Mount Messenger Formation).**
**Figure 4B. Type 2C MTC at top of photo; Urenui Formation, Wai-iti north. The base of the MTC is the obvious surface in the middle of the image. Underlying slope siltstones contain in situ Paramoudra concretions (an example is being viewed by person in lower right).**
**Figure 4C. Type 3 MTC at Waiau Stream (Urenui Formation), consisting of subtle open folds within uppermost slope siltstones below a slope-filled channel (exposed farther to the right out of picture). Upper interval (brown) is Quaternary deposits.**


**Figure 5A. Type 3 MTC exposed in the middle portion of the photo, Patangata Island, Tongaporutu (labeled i). The bed labeled (i) comprises a 2-m-thick slumped interval stratigraphically bounded by thick-bedded basin-floor fan sandstones, Mount Messenger Formation.**
**Figure 5B. Detail of Type 3 MTC bed (i) at Patangata Island, Tongaporutu. The bed displays fluidized load structures and water escape features and overlies another more sand-rich MTC bed (ii) at the base of the outcrop. Scale bar in center of photo near (ii) is 1 m long.**