Evolution of the Tauranga Harbour Entrance: Influences of tsunami, geology and dredging

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Abstract
The eastern entrance to Tauranga Harbour has been modified by capital and maintenance dredging since 1968, raising concerns that there have been, or will be, adverse impacts. This paper reviews the effects that extreme events, such as tsunami, and the influence that the underlying geological structures have had on the evolution of the present day entrance; and assesses the possible effects of historic dredging.
A regional tsunami around the start of the 15th Century removed ~3 km from the eastern end of Matakana Island. Seismic data indicate the harbour entrance was probably located ~2 km west of the present position. Panepane Pt accreted eastward between the 15th and 19th Centuries displacing the harbour entrance until further migration was prevented by the rhyolite dome of Mauao.
Seismic and core data indicate that the present-day ebb tidal delta consists of a thin veneer of Holocene sediments over a relict topography of Pleistocene volcaniclastic sediments. These form subsurface ridges parallel to the coast and one is connected at the eastern end to Mauao. The Entrance Channel was excavated through this ridge in 1968. Previously, the Pleistocene ridge restricted the depth to which the ebb jet could excavate a channel through the delta to ~10 m.
The first complete bathymetric survey of the harbour entrance was in 1852. At this time the entrance was wide and shallow. By 1954, Panepane Pt had accreted 300 m eastward, and the harbour entrance had deepened in response. Over this period the ebb jet orientation became increasingly oblique to the shoreline, and the width of the jet decreased with an increase in velocity and offshore extent.
Dredging since 1968 has had two main direct effects on the morphology of the entrance: a shallow shelf of boulders has been largely removed, deepening the channel along the flanks of Mauao; and creating a deep channel through the Pleistocene ridge. Indirect effects have included further accretion of Panepane Pt, an increase in the offshore extent of the ebb tidal delta, and the development of multiple lines of swash bars on the swash platform.

Keywords: Dredging impacts, tsunami erosion, tidal hydraulics, shoreline changes, sedimentation patterns.

1. Introduction

The Port of Tauranga is located within the southeastern basin of Tauranga Harbour, a barrier enclosed estuarine lagoon on the northeast coast of the North Island, New Zealand (Figure 1) [13]. The harbour is enclosed by two Holocene barrier tombolos linking rhyolite domes (Mauao and Bowentown) to the mainland, and a Pleistocene/Holocene barrier island (Matakana Island). At present there are two tidal inlets located adjacent to the rhyolite domes: Katikati entrance to the northwest, and Tauranga entrance in the southeast. There is limited exchange of water between the two entrances due to shallow intertidal flats in the middle of the harbour, effectively creating two basins; the Katikati Basin in the northwest and the Tauranga Basin in the southeast [20]. In addition to the Pleistocene remnant within Matakana Island, there are two islands of Pleistocene materials in the Tauranga Basin.

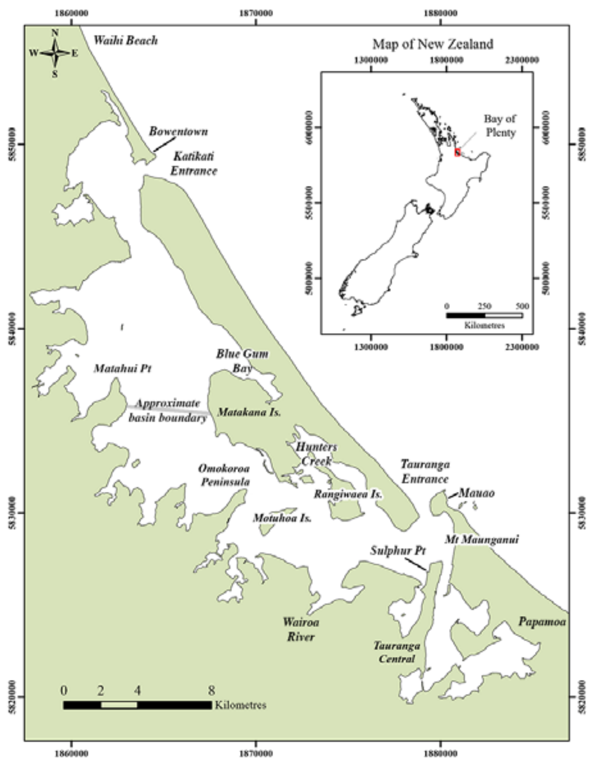

Figure 1 Map of Tauranga Harbour showing locations referred to in the text, and the approximate boundary between the Katikati (NW) and Tauranga (SE) basins within the harbour.

The Port of Tauranga was established by order of the Governor of New Zealand in 1873, but the first berths at Tauranga and a pier at Mt Maunganui were not established until 1919 [17]. The Port expanded in 1927 with construction of the Railway Wharf at Tauranga, and upgraded facilities at Mt Maunganui.

By the 1950s, increasing production of logs, pulp and paper from the central North Island resulted in a rapidly expanding export trade, particularly to Japan and Korea. A 372 m long wharf was constructed at Mt Maunganui to handle these exports, with the first trial shipment being shipped to Japan in November 1957 [17]. Construction of a new rail link to the Waikato via the Kaimai Tunnel started in 1962, which would facilitate transport of products to Tauranga for export.

To handle the increasing volume of exports, which involved progressively larger vessels, dredging of shipping channels commenced around 1965, with the main entrance channel through the ebb tidal delta being dredging in 1968 [20][17]. The Port has continued to expand to handle larger ships, intiating another phase of capital dredging in 1992 followed by the further channel deepening and widening starting in October 2015.
During an appeal to the Environment Court, concerns were raised about the possible destabilisation of the ebb tidal delta as a consequence of dredging, as well as suggestions that previous dredging activities had adversely affected adjacent shorelines. This paper summarises the prehistoric and historic evolution of the tidal inlet at the Tauranga entrance in order to provide a context for any changes that may have occurred.

2. Early to mid-Holocene evolution of Tauranga Harbour

The marine transgression after the Last Glacial Maximum culminated ~7-7.5 ka, although there is evidence that ice melt contributions continued until ~3.5 ka and global glacio-isostatic adjustments in response to ice sheet unloading are still occurring [15]. Adjusting the radiocarbon dates used by Gibb [12] indicates modern sea levels for New Zealand were achieved ~7.2 cal ky BP, while Clement *et al* [5] estimated a date of ~7.55 cal ky BP for the Manawatu and Christophers [4] dated peats overlain by estuarine sands at Omokoroa Peninsula at 7636±30 cal y BP. New Zealand sea level appears to have been slightly higher (0.3-0.5 m) than the present at that time. There is good evidence to show that small sea cliffs were cut into in soft Pleistocene deposits at the shoreline at this sea level (Earliest Holocene Shoreline – EHS), for example along the seaward margins of the Pleistocene cores of Matakana and Rangiwaea Islands (Figure 2) and along the hills inland from Papamoa to the south east of Mt Maunganui [21]. Pleistocene sediments also form a modern small sea cliff along the landward shoreline of the Waihi Beach tombolo adjacent to the Bowentown rhyolite dome, but there is no identifiable seaward sea cliff.

While there is considerable variability and uncertainty in sea level reconstructions for the last 7 ka, as the review by Lewis *et al* [15] for the Australian margin indicates, it is clear that the peak Holocene sea level, the Holocene High Stand (HHS) occurred 4.5-3.5 ka in the Pacific Ocean due to 3-4 m of mid to late Holocene sea level equivalent ice melt, probably from Antarctica [22]. For New Zealand, the HHS ended ~4 ka, with sea levels ~2 m higher than the present [11].

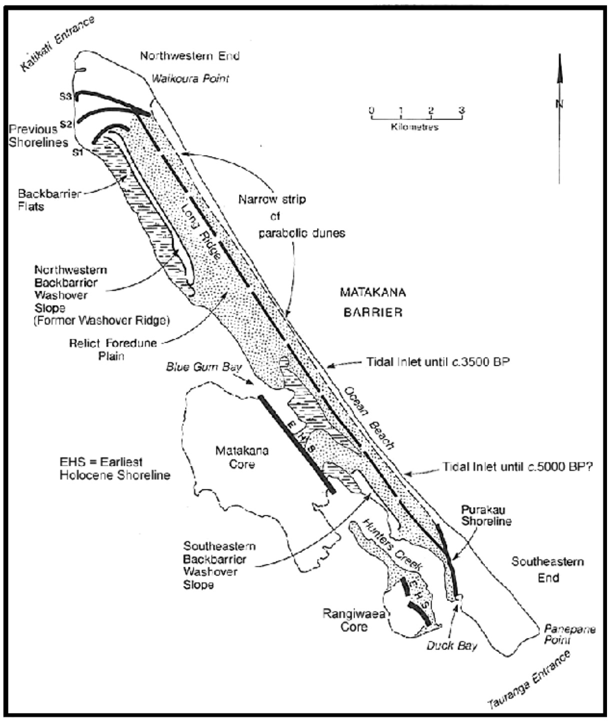

Figure 2 Map of Matakana Island showing the main geomorphic units and former shorelines. EHS = Earliest Holocene Shoreline (marine cliff); S1 and S2 = tsunami eroded shorelines; S3 = shoreline during Kaharoa Eruption (approximate time of Maori arrival in New Zealand). Also indicated are positions of former Holocene tidal inlets. Matakana and Rangiwaea Cores indicate the extent of exposed Pleistocene sediments. After [19].

The oldest Holocene estuarine sediments currently identified for Tauranga Harbour are 8100 ± 80 cal y BP, associated with limited deposits at 14 m below present sea level [6]. More extensive deposits close to present day sea level are dated at ~6.2 cal ky BP, and the oldest Holocene dune soils on the tombolos are ~6.5 cal ky BP [21]. This suggests that the tombolo barriers formed relatively quickly after sea level attained modern levels. It is estimated that 65% of the barrier dunes enclosing Tauranga Harbour formed during the sea-level rise to the HHS [21][19].

However, Shepherd *et al* [19] show that Matakana Island was likely a discontinuous sequence of barrier islands and eroding Pleistocene islands until ~4 cal ky BP. The barrier islands were subjected to episodic storm washover events, producing extensive backbarrier washover slopes (Figure 2).

Based on the absence of key mid- and late-Holocene tephra units and the truncation of geomorphic features, [19] also inferred that tidal inlets existed at the heads of Blue Gum Bay and Hunters Creek (Figure 2). Bathymetric data (Chart NZ5411) indicate the presence of lobe-shaped positive relief features offshore from Matakana Island near these locations that may represent remnant ebb-tidal deltas. There is no evidence to confirm that the modern tidal inlets existed in the early Holocene.

3. Mid- to late- Holocene evolution of Tauranga Harbour

The HHS and subsequent fall in sea level appears to have been associated with significant changes to the tidal inlets and margins of Tauranga Harbour. Rapid accretion of the Holocene dunes on the barrier islands between Bowentown and Mauao resulted in the closing of the tidal inlets at Hunters Creek (~5 ka) and Blue Gum Bay (~3.5 ka), and the formation of the Matakana Island barrier. At this stage it is probable that the present day tidal entrances existed, although seismic reflection cross-sections indicate that the southeastern basin may have drained eastwards through Papamoa towards the modern Maketu Estuary [21].

The oldest Holocene marine sands identified within the ebb-tidal delta at the Tauranga Entrance are dated at 3370 ± 110 cal BP [6]. This suggests that either the ebb-tidal delta formed at this time, or underwent significant accretion. The likely sources of the sediment would have been the ebb-tidal deltas associated with the now closed tidal inlets towards the west.

The coastal plain to the east of Tauranga Harbour (Papamoa) changed from estuarine sediments to mire peats ~4.6 ka [16]. Although, a major fault associated with the Papamoa Range bisects the coastal plain [3], the transition from estuarine to terrestrial sediments occurs simultaneously on the upthrown and downthrown sides of the fault, indicating a change in sea level had occurred.

The Waihi Beach coastal plain to the west of Tauranga Harbour transitioned from estuarine sediments to terrestrial mires ~3 ka. The Waihi mires contain evidence of at least 2 tsunami events over the last 3 ka [1]. The older event was estimated by [1] as ~2.5 ka and has been linked to a tsunami deposit located at Omokoroa dated at 1,652 ± 20 cal BP [4]. Bell *et al* [1] also suggest, based on age, that the event corresponds to a tsunami deposit next to the Wairoa River in the southeastern basin of Tauranga Harbour. This appears to have been a small local event, possibly associated with an earthquake within the Bay of Plenty.

The second tsunami dated to 582 ± 66 cal y BP was a larger regional event [1], which caused significant erosion of the spits at both ends of Matakana Island (Figure 2) with the eastern end (Panepane Point) truncated to the Purakau Shoreline [19]. There is evidence of 3 truncated shorelines at the western end of Matakana Island (Figure 2). The oldest (S1) formed during the HHS, but the actual age is uncertain. The S2 shoreline is estimated to have formed ~1750 cal y BP [19], which suggests that it was eroded by the earlier local tsunami discussed above. The youngest S3 shoreline appears to correlate with the Purakau Shoreline.

The Purakau Shoreline is associated with deposits of Loisels Pumice, which has been linked to the eruption of a submarine volcano, Mt Healy, and subsequent generation of a regional tsunami [8], although the tsunami has also been attributed to a megathrust subduction earthquake along the Tonga-Kermadec Trench [10]. Numerical modelling of this event indicates that Mauao amplified the tsunami inundation over the eastern end of Matakana Island [10], which may explain the more extensive erosion relative to the western end of the barrier island.

Both ends of Matakana Island accreted since the tsunami erosion event, although accretion mostly occurred at the eastern end. Accretion at the western end of Matakana Island predominantly occurred since 1870, although there may have been other storm/wave-related erosion events that are not preserved [19].

Seismic data indicate that the prograding Panepane Point spit buried extensive shell beds that appear similar to the thick shell beds that occur in the modern tidal inlet. The pattern of accreting shorelines over the last 600 years [19] also suggests that the tidal inlet may have been established further west post tsunami, providing more direct discharge to the ocean from the Wairoa River and the major Western Channel draining the middle of the Harbour. It is likely that this entrance was wide and shallow as resistant Pleistocene material restricting incision. The inlet migrated eastwards with ongoing accretion, eventually being confined by the resistant rhyolite dome of Mauao, which allowed increasing constricted and accelerating flows to incise the channel.

4. Recent (historic) evolution of Tauranga Harbour

The earliest hydrographic chart for the Tauranga Entrance was produced in 1852 [2], and for the Katikati entrance the shoreline was mapped in 1870 [19]. Both entrances were wider than the modern inlets, and the Tauranga Entrance was significantly shallower (~12 m maximum depth in 1852 *cf*. ~36 m in 2006).

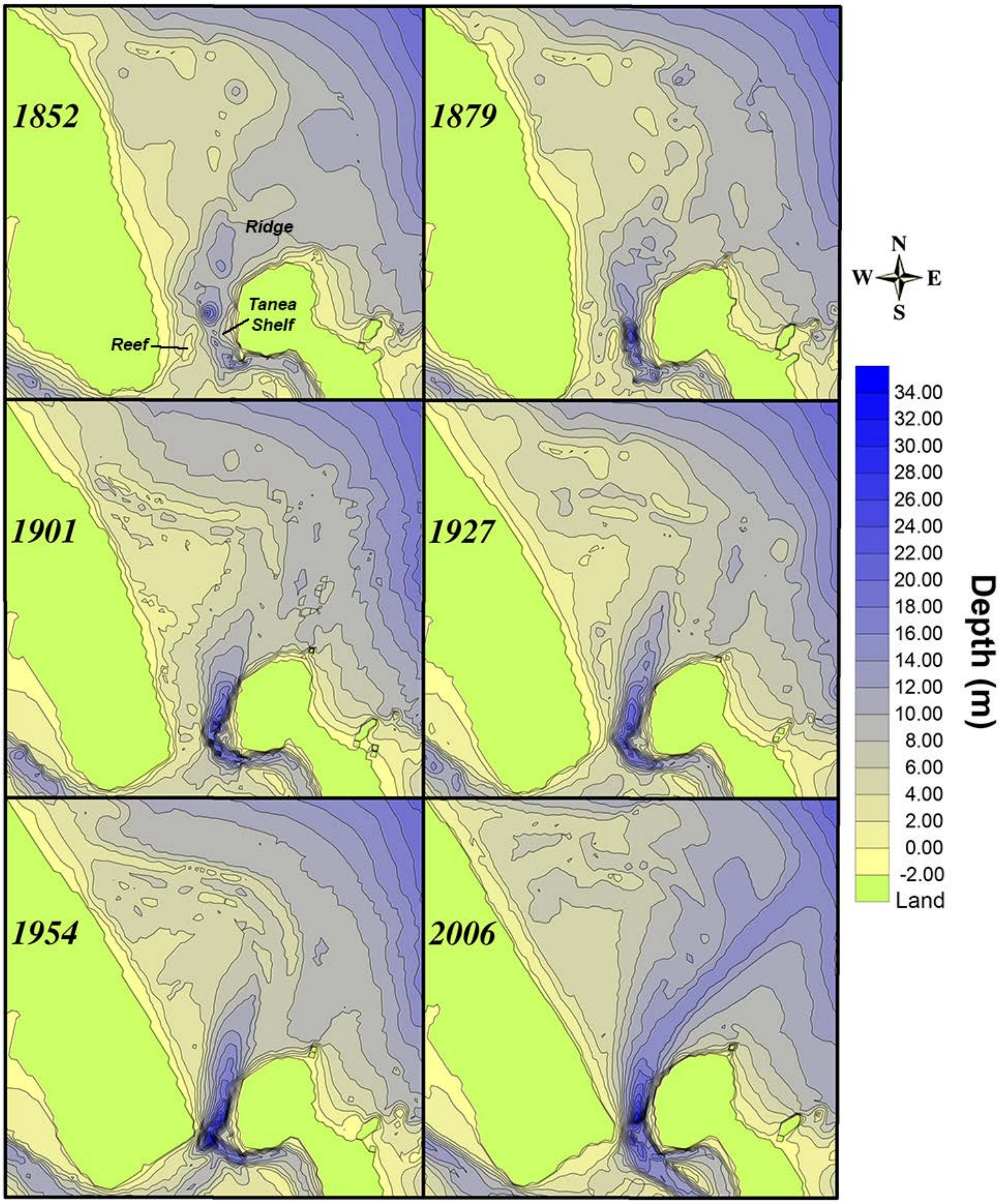

Figure 3 Bathymetry of the ebb tidal delta and tidal inlet compiled from historical survey data by [2]. The data show the progressive narrowing and deepening of the tidal inlet associated with the progradation of Panepane Pt, and the changing morphology of the ebb tidal delta between 1852 and 1954. The final compilation for 2006 shows the additional effects of the dredged shipping channels and their potential impacts on the ebb tidal delta morphology, as discussed in the text. The locations of resistant Pleistocene materials are indicated on the 1852 bathymetry, and the base of the terminal lobe of the ebb tidal delta is located at ~10 m depth contour.

Between 1852 and 1879 (Figure 3), the maximum depth of the Tauranga Entrance increased by ~6 m. There were significant changes to the morphology of the eastern margin of the ebb tidal delta and western margin of the flood tidal delta, with significant progradation of the Matakana Island shoreline landward of the apex of the ebb tidal delta [2]. However, the width of the inlet didn't change significantly, and there were several shallow areas within the channels close to the inlet that didn't change at all (Figure 3). Recent seismic surveys and shallow vibracoring, combined with multibeam echo-sounder and sidescan surveys, indicate these areas are outcrops of resistant Pleistocene deposits [9]. They are now largely buried by Holocene sediment that has accreted since 1879.

Cores taken within Tauranga Harbour do not show any evidence of accelerated sedimentation associated with land use changes beyond the immediate vicinity of freshwater discharges into the harbour [4]. The largest "sedimentation" changes are associated with reclamation and dredging [2]. The likely drivers of the rapid changes between 1852 and 1879 were the Chilean tsunami events of 13 August 1868 and 10 May 1877. While there are no known contemporary reports of scour in the Tauranga Entrance, significant morphological changes were reported for other harbours around New Zealand [7]. The Chilean tsunami of 22 May 1960 was reported to have caused extensive scouring within the harbour around Sulphur Point [7].

By 1954, the Tauranga Entrance had narrowed by 300 m relative to 1852 and the flood tidal delta had increased in size and shoaled significantly This had diverted some of the tidal flow into a deepening channel on the western margin of the flood tidal delta (Lower Western Channel), which caused some erosion of the southern point of Matakana Island and limited eastward extension of Panepane Point.

The ebb-tidal delta shallow swash platform extended further offshore in 1954 relative to 1852, but the longshore extent decreased making the ebb-tidal delta appear more compact although the seaward extent of the terminal lobe didn't change significantly. The ebb jet progressively scoured a deeper channel as the main discharge from the Harbour moved from a northeasterly to a more northerly orientation in response to the constrictions imposed by the resistant rock of Mauao and Panepane Point (Figure 3) [2]. The western flank of the ebb-tidal delta consisted of a main shore attached recurved bar, and scattered swash bars.

Capital dredging in the 1960s and 1992 created deep channels through the ebb and flood tidal deltas, and increased the cross-sectional area of the tidal inlet by lowering the elevation of the Tanea Shelf. The resulting flow structure by 2006 is very similar to the pattern that existed in 1927 [2]. The morphological changes of the ebb-delta in response to dredging are discussed in more detail by [18]. However, the morphology of the swash platform is similar to that in 1927 with the platform extending further northeast than in 1954 (Figure 3), except for the presence of multiple bands of mobile swash bars. The terminal lobe has also moved offshore on the northern side of the dredged Entrance Channel.

Overall it is difficult to separate out the effects of dredging from the pattern of channel migration and associated erosion and accretion since 1852. The main trend before dredging was the accumulation of sediment that extended Panepane Point and increased the area of the shallow swash platform. This trend has largely continued, although the extension of Panepane Point appears to have ceased over the last few decades.

The largest change in behaviour for the ebb-tidal delta appears to have occurred in response to the weakening of the ebb jet by the creation of the Entrance Channel in 1968 [18]. The reduction in tidal flow has allowed ocean-driven wave processes to move sediment onshore from the terminal lobe of the delta as a series of swash bars, and the zone of sediment accretion is now focussed along the Matakana Island shoreline, instead of being spread over the entire western platform of the ebb-tidal delta.

The volume of sand moved as a consequence of these changes seems surprisingly small given the estimated volume of sand within the delta (47.3×10^6 m^3 [14]). However, seismic surveys, CPT measurements and shallow core samples have shown that the ebb-tidal delta consists of a relatively thin veneer of Holocene overlying a Pleistocene topography [9]. In particular a ridge extends WNW from Mauao underneath the delta. This ridge appears to have been responsible for the consistent depth of ~10 m for the tidal channel across the eastern flank of the delta during the period 1852-1968.

Another shallower ridge is associated with a shallow reef on the western side of the tidal inlet evident from 1852-1901, before being largely buried by the advancing Panepane Point in 1927. SCUBA observations by one of the authors in the 1980s indicated that the reef consisted of rhyolite cobbles embedded in Pleistocene sediment. This indicates the assumption of [19] that the Holocene barrier of Matakana Island entirely overlies Holocene marine sand may not be correct.

5. Conclusion

It is evident that the evolution of the tidal inlet and delta system of the Tauranga Entrance is constrained by the underlying Pleistocene topography, in addition to the recognised influence of Mauao and it's flanking reefs [14]. In particular, it is likely that much of the ebb-tidal delta is anchored by the embedded Pleistocene sediments, which is why the observed changes since 1852 have largely involved the changes to surficial swash bars, and minor accumulation on the flanks of the terminal lobe [2].

There are several implications for the Port of Tauranga dredging activities. Firstly, it is unlikely that the proposed capital dredging to extend the depth and width of the Entrance Channel will trigger any instability in the ebb-tidal delta. This is due to the dredging largely occurring within the more resistant Pleistocene sediments.

Secondly, the dredged channel is likely to be quite stable, unless flow velocities increase significantly, opposite to the expected response to increasing the channel cross-sectional area. The deepening of the tidal channel within the ebb-tidal between 1901 and 1954 indicates that high flow velocities can scour the Pleistocene sediments, and the changes between 1852 and 1879 indicate that a future tsunami may cause strong flows capable of scouring the channel.

Finally, while the Pleistocene sediments stabilise the ebb-tidal and Entrance Channel, their "strength" derives from the presence of clays [9], which requires a different approach to dredging and spoil disposal to minimise the generation of turbid plumes.

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