Stratigraphy, provenance and localisation of the ironsand deposit at Waikato North Head, South Auckland

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ABSTRACT

The Waikato North Head (WNH) ironsand deposit lies within a ~80-m thick sequence of coastal and river sands near the mouth of the Waikato River. The deposit is currently mined by New Zealand Steel and has a total resource of ~90 Mt Fe, which classes the deposit as a giant placer. We use mineralogical data and stratigraphic correlations to infer the age, provenance and paleogeography of the sand sequence in relation to the Pleistocene-Holocene paleogeography of coastal-sand sequences, resulting in improved genetic and exploration models for west coast North Island ironsand deposits. Comparison of electron probe microanalyses of titanomagnetites in surface and drill hole samples indicates that the bulk of the titanomagnetite in the Waiuku Black Sand and the Entrican Sand is derived from andesites of the Taranaki Volcanoes 220 km to the south. The Waiuku Black Sand may corelate with an influx of andesitic material in the cover beds of the ~400 ka Ararata Terrace in south Taranaki. Ilmenite and minor amounts of titanomagnetite were derived from Ignimbrites of the Taupo Volcanic Zone (TVZ), particularly in the Lower Hood and Entrican sands. Automated mineralogy data indicate some other sources in addition to the Taranaki andesites and TVZ ignimbrites. Minor olivine was likely derived from the late Pleistocene basalts of the South Auckland volcanic field, whereas almandine and epidote were probably sourced from metasedimentary rocks of the Murihiku and Waipapa terranes. The formation of the giant placer at WNH was a multistage process involving: (1) a supply of titanomagnetite-bearing sand eroded from the late Pleistocene-Holocene andesites of the Taranaki volcanoes that was transported northwards along the coast by the prevailing longshore drift; (2) concentration of titanomagnetite by wave action on beach faces and collection in a coastal embayment on the northern side of a headland of basement rocks at Port Waikato; (3) further concentration by wind action into dune sands during interglacial low sea levels; and (4) preservation by coeval subsidence in a fault-angle depression on the north side of the Waikato Fault.

INTRODUCTION

Heavy mineral blacksands (titanomagnetite-rich ironsands) are contained within Pleistocene-Holocene dune and beach sands over 480 km along the west coast of the North Island (Figure 1). The Pleistocene-Holocene sand sequences occur along, and offshore, of the current shoreline, and within a series of coastal terraces parallel to and extending inland from the coastline. The terraces were cut by wave action during high sea level stands of the Pleistocene interglacials. Extensive dune formation probably took place during periods of lower sea level when broad expanses of sand provided a source for the building of dunes by wind action (Kear, 1979). Ironsand deposits at Waikato North Head (WNH), Taharoa and Waipipi have been mined since 1969 for local steel manufacture and for export to Asian steel mills. Ironsands are also present offshore in paleo-shorelines and paleo-river beds that were deposited when sea level was lower, particularly during the early Holocene (~9 ka) (Carter, 1980; Christie, 2016). Previous provenance studies indicate that the main source of titanomagnetite in the ironsands is from erosion of the late Pleistocene-Holocene andesite volcanoes of the Mt Taranaki volcanic field (Kear, 1979; Stokes and Nelson, 1991; Briggs et al., 2009; Brathwaite et al., 2017), although from WNH northwards there is a minor contribution from Pleistocene ignimbrites and rhyolites of the Taupo Volcanic Zone (TVZ), mainly transported by the Waikato River (Hamill and Balance, 1985; Brathwaite et al., 2017, 2020).

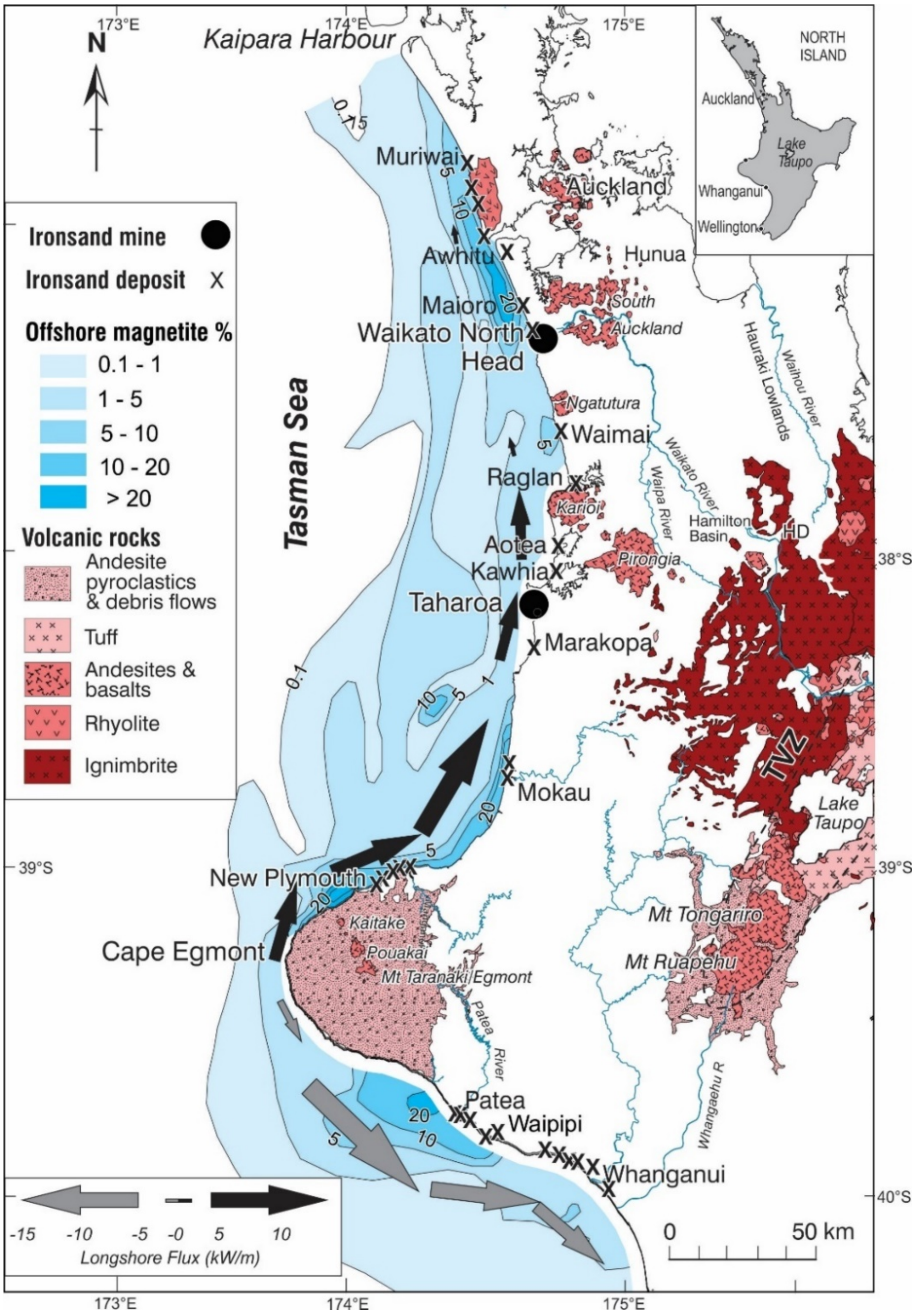

Figure 1 Location of ironsand deposits and distribution of volcanic source rocks along part of the west coast of the North Island (from Brathwaite *et al*., 2017). The offshore magnetite wt.% contours are from Carter (1980). The black and grey arrows show the magnitude of northwards and southwards longshore current directions (from Briggs *et al*., 2009). TVZ = Taupo Volcanic Zone.

The age of the sand sequence is inferred to be early Pleistocene to Holocene from limited palynology, regional stratigraphic correlations and two carbon-14 (C^{14}) dates. This paper is drawn from Brathwaite *et al*. (2020), where mineralogical data and stratigraphic correlations were used to infer the age, provenance and paleogeography of the sand sequence, which enabled interpretation of the formation of the ironsand deposits in relation to the paleogeography of the coastal-sand sequence.

THE WAIKATO NORTH HEAD IRONSAND DEPOSIT

The deposit lies within a ~80-m thick sequence of coastal and river sands at the mouth of the Waikato River (Figure 2). The central and upper parts of the sequence contain several titanomagnetite-rich dune and beach sand units that are mined by New Zealand Steel (Waterhouse and MacArthur, 1989; Barakat and Drain, 2006; Mauk *et al*., 2016). The deposit has a past production from 1969–2018 of about 40 Mt of titanomagnetite averaging 55% Fe, which together with a 2018 Measured Resource of 354 Mt at 20.1% magnetic concentrate (52.7% Fe) and an Indicated Resource of 312 Mt at 13.2% magnetic concentrate (57.0% Fe) (J. Ogiliev pers. com. 2019), constitutes a total resource of about 90 Mt Fe and thus makes the WNH ironsand deposit a giant placer (Stanaway, 2012).

The sequence of coastal and river sands at WNH is located in a fault-angle depression at the southern end of the Awhitu Peninsula, a 40 km-long coastal sand barrier of the Manukau Harbour. The sequence consists of three main formations: Awhitu Sands, Hood Sands and Mitiwai Sands (Figure 2). The top of the Awhitu Sands is defined in drill holes by a fluvial quartz-rich sand (River Sand Member) with minor pumice clasts, which overlies a white clay (Awhitu Clay). The Awhitu Clay represents a weathered tephra (Christie, 1979), which correlates with a prominent tephra that crops out at Oruarangi (OR-6 of Nelson *et al*., 1989) and at Waiuku Inlet (the ~1 Ma Waiuku tephra of Alloway *et al*., 2004), which in turn is correlated with the widespread Potaka tephra (Shane, 1994).

The Hood Sands consists mainly of dune sands with local interdune swamp or lake beds. The Waiuku Black Sand member (SC1) consists of well consolidated, variably limonitised, cross-bedded to laminated, titanomag-netite-rich (average 47%) dune sands, with thin mud layers and a teprha bed (Christie, 1979; Mauk *et al*., 2016). A sample of peat at the base of the Lower Hood Sand, contains a pollen assemblage that indicates a warm, interglacial climate and an age of <1 Ma, based on the absence of extinct Neogene taxa (D. Mildenhall pers. com. 2018).

The Mitiwai Sands are subdivided into the Alder (SS) and Entrican Sand (S1) members, which are both grey dune sands with the Entrican Sand having a higher titanomagnetite content (average 13%; Mauk *et al*., 2016) and a thickness of up to 40 m. The Mitiwai Sands are late Holocene in age; a wood sample from the base of the formation yielded a C^{14} age of 1854 ± 49 BP (Dingley, 2002). A tephra at the base of the Mitiwai Sands is correlated with the 1.85 ka Taupo Pumice erupted from the TVZ.

MINERALOGY AND PROVENANCE

Automated mineralogy data (Figure 2) collected using selected sand samples reveals a suite of silicate and resistate minerals that indicate some other sources in addition to the Taranaki andesites and TVZ ignimbrites. For example, the presence of minor olivine points to derivation from nearby late Pleistocene basalts of the South Auckland volcanic field, and the occurrence of rounded grains of almandine garnet and epidote suggest metamorphic rock sources from metasedimentary rocks of the Murihiku and Waipapa terranes (Figure 3). Titanomagnetite (up to 51%) and ilmenite (up to 2%) abundance is greatest in the Waiuku Black Sand, along with the resistate minerals apatite, almandine, rutile, titanite and zircon. Relative abundance of silicate minerals varies less than the resistate phases, with most samples dominated by pyroxene, feldspar and quartz. The Awhitu Sands have the most diverse silicate composition, with quartz and feldspar being more abundant than in samples from the other units.

Brathwaite *et al*. (2017) compared the results of electron probe microanalysis (EPMA) of titanomagnetite grains in samples of coastal and river sands (sinks), with a dataset of analyses of titanomagnetite in volcanic rocks erupted from the Taranaki and TVZ volcanoes (potential sources). The composition of titanomagnetites at both WNH ironsand deposit and in the coastal ironsands from New Plymouth north to Muriwai Beach (Figure 1) are consistent with the composition of titanomagnetite present in rivers that drain the Taranaki volcanoes and their ring plain debris avalanche and lahar deposits. Christie *et al*. (2009) estimated from GIS modelling that ~485 km^3 of volcanic material containing 39,000 Mt of titanomagnetite has been eroded from the Taranaki andesite volcanoes (Mount Taranaki, Pouakai, Kaitake and Sugarloaf). This estimate is significantly more than the ~1500 Mt of titanomagnetite identified in the known onshore ironsand deposits (Christie *et al*., 2009). A minor proportion of the titanomagnetite grains in the WNH ironsand deposit and in the coastal ironsands from Port Waikato north to Muriwai Beach appear to be sourced from ignimbrites of the TVZ (Brathwaite *et al*., 2017).

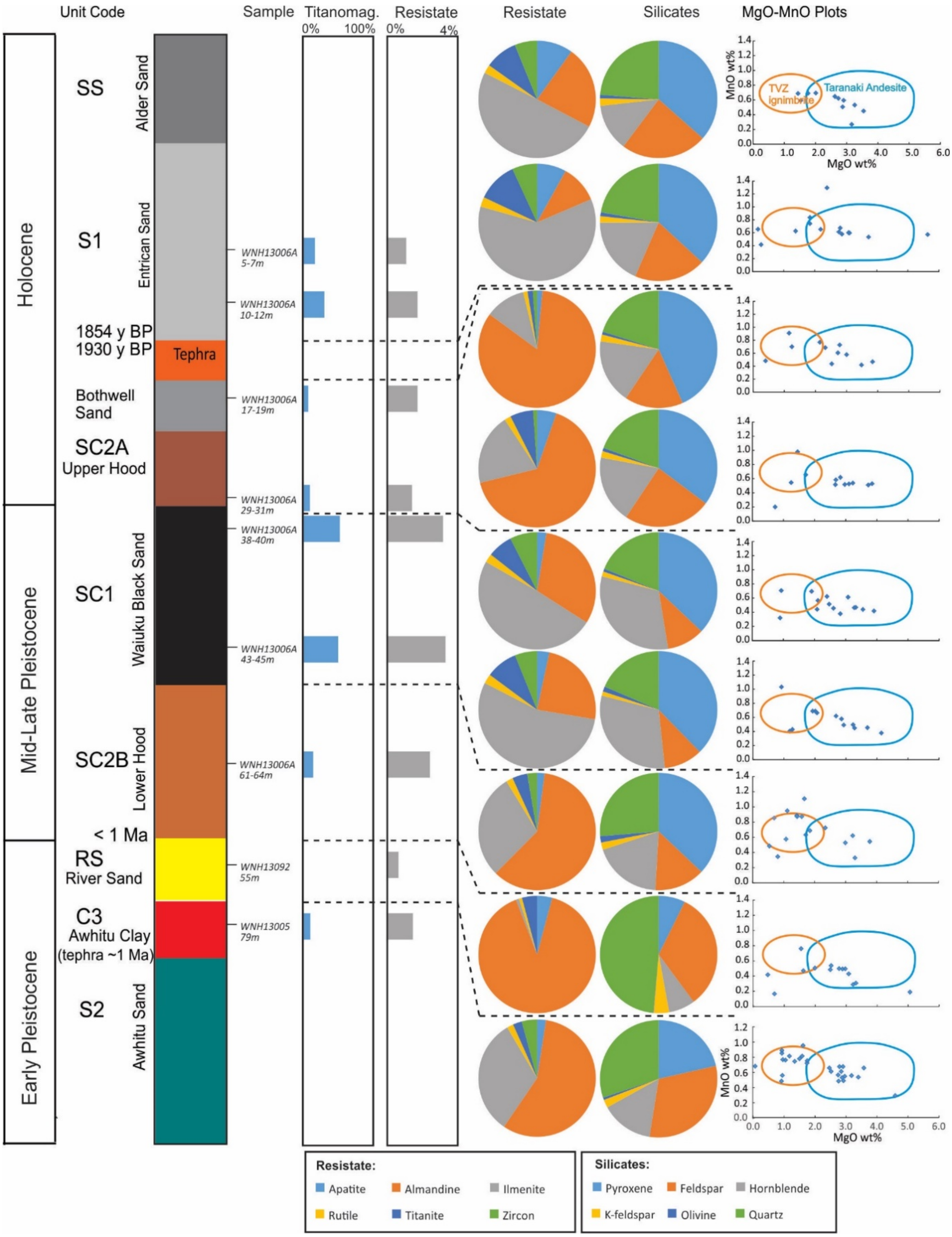

Figure 2 Stratigraphic sequence at Waikato North Head (from Brathwaite *et al*., 2020), showing: automated mineralogy data (titanomagnetite abundance, abundance of resistate phases, and relative abundance of resistate and silicate phases) for samples from drill holes with sample depth in metres, and MgO-MnO plots from titanomagnetite EPMA analyses. Plots show fields for Taranaki andesite and TVZ ignimbrite/rhyolite from Brathwaite *et al*. (2017). Unit codes from Barakat and Drain (2006).

Of the other potential volcanic rock sources, the only published data for titanomagnetite EPMA are from basalts of the South Auckland field (Rafferty and Heming, 1979), which have high TiO_2 contents (19.9–24.9%). The TiO_2 contents of titanomagnetite in the WNH sequence are 1.6–14.8% TiO_2, much lower than those of the South Auckland basalts. The absence of any titanomagnetites with a high-TiO_2 basalt signature may be explained by the titanomagnetites, being confined to the fine-grained groundmass of the basalts (Rafferty and Heming, 1979). Similarly, titanomagnetite in the Ngatutura basalts occurs only as rare microphenocrysts (Briggs *et al*., 1989) that are too small to occur as grains in the coastal sand deposits. Andesitic tuffs from the marine mid-Miocene Mohakatino Group in north Taranaki, are variably altered to clay minerals and carbonate (Sagar *et al*., 2019), with fresh titanomagnetite (<1% by volume) present in only a few samples (Brathwaite *et al*., 2020). These tuffs are therefore unlikely to have contributed significant amounts of titanomagnetite to the coastal sands.

The MgO contents of the titanomagnetites can be used to broadly distinguish andesitic from rhyolite-ignimbrite sources via MgO-MnO plots (Brathwaite *et al*., 2017). The MgO-MnO plots of titanomagnetite grains from samples of the formations from drill holes at the WNH ironsand deposit show that the bulk of the titanomagnetite in the Mitiwai and Hood sands is derived from andesitic rocks of the Taranaki Volcanoes (Figure 2). The Waiuku Black Sand may correlate with an influx of andesitic clasts and mafic minerals in the cover beds of the ~400 ka Ararata Terrace in south Taranaki (Pillans, 1990). There is also a contribution of titanomagnetite and minor ilmenite from the ignimbrites of the TVZ, particularly in the Awhitu Clay, Lower Hood and Entrican sands, with 10–40% of the titanomagnetite grains plotting in the TVZ ignimbrite/rhyolite field defined by Brathwaite *et al*. (2017). Ilmenite constitutes about 10% of grains in the >3.3 SG fraction of samples from these units. These results indicate that a minor proportion of the titanomagnetite grains, together with all the ilmenite, in the sequence at WNH were derived from TVZ ignimbrite/rhyolite sources, via the Waikato River and its pre-cursors in the same location. The presence of a “River Sand” member, locally containing pumice, at the top of the Awhitu Sands is consistent with a TVZ-sourced river at ~1 Ma (Figure 2).

LOCALISATION OF IRONSAND AT THE WAIKATO NORTH HEAD PLACER DEPOSIT

The concentration of titanomagnetite sand grains into the Waiuku Black Sand and Entrican Sand members that make up the ironsand deposit was a multistage process. Initially, a supply of titanomagnetite-bearing sand was eroded from the late Pleistocene-Holocene andesitic volcanic rocks of the Taranaki volcanoes and then transported northwards along the coast from Cape Egmont by the prevailing longshore drift (Figure 1). The presence of a headland of basement rocks at Port Waikato and associated coastal embayment on its northern side would have acted as a collection area for sand transported along the coast (Figure 3). Titanomagnetite, a mineral of high density (5.2 kg/m^3) and moderate resistance to physical and chemical weathering, is readily concentrated by density sorting through wave and wind action. The equant octahedral crystals of titanomagnetite eroded from the Taranaki volcanoes are abraded into grains of high sphericity, which coupled with their high density and magnetism causes the grains to aggregate and concentrate as lag placers (Bryan *et al*., 2007). As observed on present day beaches along the west coast of the North Island, titanomagnetite (blacksand) is concentrated (up to 60 wt.%) in the upper part of the beach face (Bryan *et al*., 2007). The initial process of concentration of titanomagnetite on beach strandlines probably occurred when longshore transport within the breaker zone was interrupted by onshore wave action, particularly during storms, which sorted the denser, smaller and more rounded grains of titanomagnetite from the larger and lighter augite, hornblende and plagioclase grains (Ross, 1963). The titanomagnetite-rich sand deposited at or above the high tide mark was blown across the back of the beach by the prevailing southwesterly winds to form foredunes, which subsequently mi-grated inland as transgressive dunes during storm events (e.g. Stokes *et al*., 1989). In the dunes, further concentration of titanomagnetite took place during strong winds due to lighter and more angular silicate mineral grains experiencing more lift and thus being separated from the smaller rounded titanomagnetite grains (Ross, 1963).

The localisation of a thick accumulation of titanomagnetite-rich sand at WNH was due to its location in a fault-angle depression on the north side of a headland on the down-thrown side of the Waikato Fault (Figure 3). In particular, the up to 45-m thick Waiuku Black Sand Member was preserved due to subsidence during and after its accumulation, whereas an equivalent unit is absent at Taharoa where younger formations (Mitiwai and Bothwell sands) directly overlie greywacke basement (Stokes *et al*., 1989; Mauk *et al*., 2006).

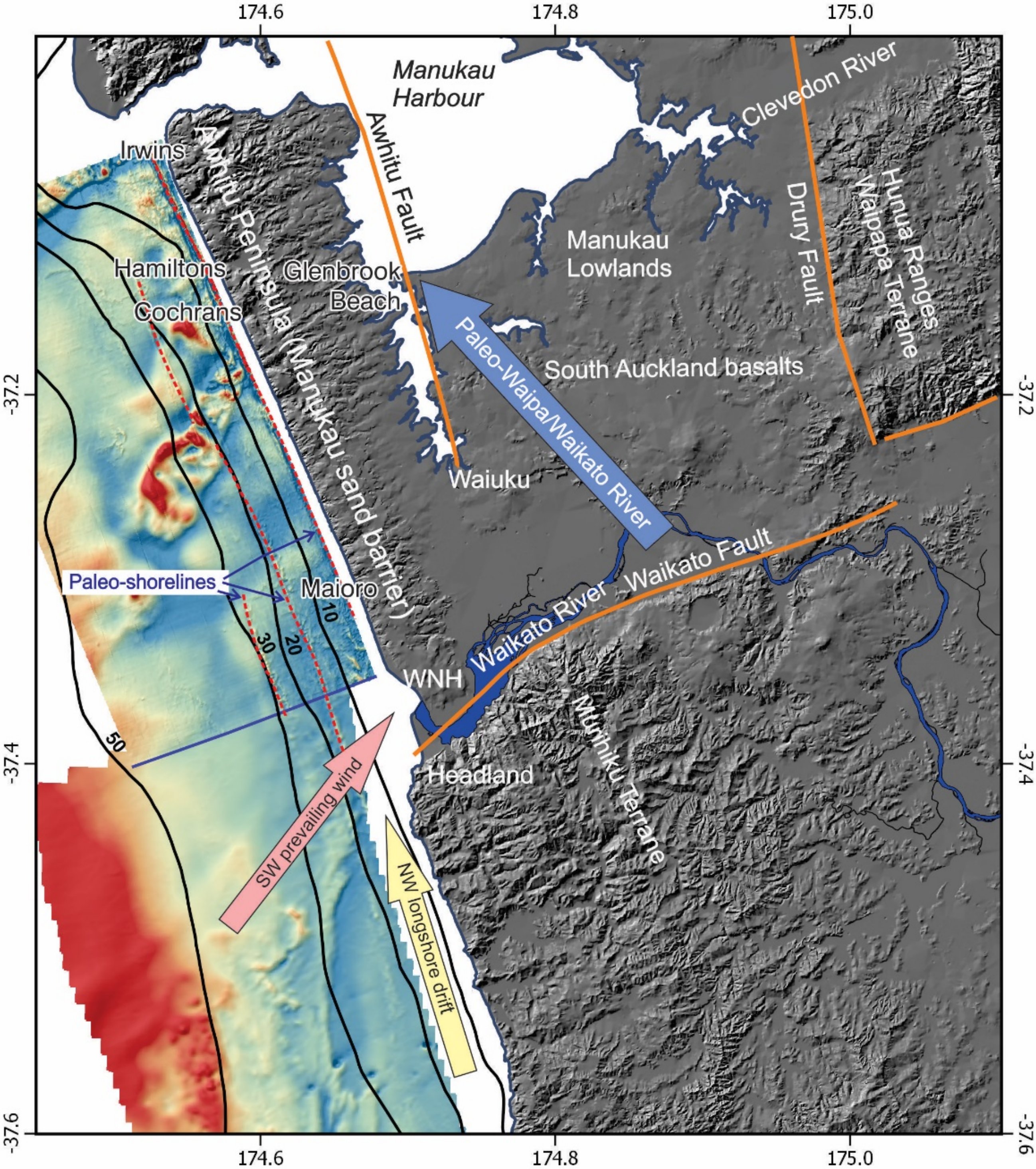

Figure 3 Illustration showing faults and paleo-shoreline, -coastal, and -river features that have contributed to the localisation of the Waikato North Head (WNH) placer deposit (from Brathwaite *et al*., 2020). Aeromagnetic images from offshore surveys by Rio Tinto Exploration Pty Ltd (north of the Waikato river mouth; Hartshorn and Sillani, 2009), and Trans-Tasman Resources Ltd (south of the Waikato river mouth; Vermeulen, 2011). Bathymetric contours in metres below sea level.

REFERENCES

Alloway, B.V., Westgate, J.A., Pillans, B., Pearce, N., Newnham, R., Byrami, M., & Aarburg. S., 2004. Stratigraphy, age and correlation of middle Pleistocene silicic tephras in the Auckland region. *New Zealand Journal of Geology and Geophysics*, **47**, 447–479.

Barakat, M., & Drain, L., 2006. The development of the Waikato North Head ironsand deposit, South Auckland. In: Christie, A.B., & Brathwaite, R.L. eds., Geology and Exploration of New Zealand Mineral Deposits Monograph 25. Australasian Institute of Mining and Metallurgy, p. 219–224.

Brathwaite, R.L., Christie, A.B. & Gazley, M.F., 2020. Stratigraphy, provenance and localisation of the titano-magnetite placer at Waikato North Head, South Auckland, New Zealand. *Mineralium Deposita*, DOI: 10.1007/s00126-020-00968-8.

Brathwaite, R.L., Gazley, M.F., & Christie, A.B., 2017. Provenance of titanomagnetite in ironsands on the west coast of the North Island, New Zealand. *Journal of Geochemical Exploration*, **178**, 23–34.

Briggs, R.M., Itaya, T., Lowe, D.J., & Keane, A.J., 1989. Ages of Pliocene-Pleistocene Alexandra and Ngatutura Volcanics, western North Island, New Zealand, and some geological implications. *New Zealand Journal of Geology and Geophysics*, **32**, 417–427.

Briggs, R.M., Laurent, J.C., Hume, T.M., & Swales, A., 2009. Provenance of black sands on the west coast, North Island, New Zealand. AusIMM New Zealand Branch 42nd Annual Conference proceedings, p. 41–50.

Bryan, K.R., Robinson, A., & Briggs, R.M., 2007. Spatial and temporal variability of titanomagnetite placer deposits on a predominantly black sand beach. *Marine Geology*, **236**, 45–59.

Carter, L., 1980. Ironsand in continental shelf sediments off western New Zealand - a synopsis. *New Zealand Journal of Geology and Geophysics*, **23**, 455–468.

Christie, A.B., 1979. Sedimentary structures in Quaternary ironsands at Waikato North Head, New Zealand. *New Zealand Journal of Geology and Geophysics*, **22**, 213–26.

Christie, A.B., 2016. Exploration of placer titanomagnetite ironsand deposits offshore from the west coast of the North Island. In: A.B Christie (ed.), Mineral Deposits of New Zealand – Exploration and Research Monograph 31. AusIMM, p. 443–450.

Christie, A.B., Heron, D.W., Graham, I.J., & Davy, B.W., 2009. Genetic model for exploration of offshore West Coast ironsands, North Island, New Zealand. In: Williams P.J. *et al*. eds, Smart Science for Exploration and Mining. 10th Biennial SGA meeting of the Society for Geology Applied to Mineral Deposits proceedings, Townsville, Australia, p. 979–981.

Dingley, J., 2002. Stratigraphic, geochemical, mineralogical and physical variations at the Waikato North Head ironsand deposit, South Auckland, New Zealand. Unpublished M.Sc. thesis, The University of Auckland.

Hamill, P.F., & Balance, P.F., 1985. Heavy mineral-rich beach sands of the Waitakere coast, Auckland, New Zealand. *New Zealand Journal of Geology and Geophysics*, **28**, 503–511.

Hartshorn, G., & Sellani, S., 2009. Technical Report on Exploration Activities within PP 39287 for the period 21 February 2007 to 20 February 2009. Rio Tinto Exploration Pty. Limited. New Zealand Petroleum & Minerals, Ministry of Business, Innovation and Employment, Wellington, unpublished open file mineral report MR4747.

Kear, D., 1979. Geology of Ironsand Resources of New Zealand. DSIR, Wellington.

Mauk, J.L., Cocker, H.A., Rogers, H., Ogiliev, J., & Padya, A.B., 2016. Process Mineralogy of Ironsands in the Waikato North Head Deposit, Waikato Region, North Island. In: A.B. Christie (ed.), Mineral Deposits of New Zealand – Exploration and Research Monograph 31. AusIMM, p. 435–442.

Mauk, J.L., Macorison, K., & Dingley, J., 2006. Geology of the Waikato North Head and Taharoa ironsand deposits. In: Christie, A.B., Brathwaite, R.L. eds., Geology and Exploration of New Zealand Mineral Deposits Monograph 25. Australasian Institute of Mining and Metallurgy, p. 231–234.

Nelson, C.S., Kamp P.J.J., & Mildenhall, D.C., 1989. Late Pliocene distal silicic ignimbrites, Port Waikato, New Zealand: implications for volcanism, tectonics, and sea-level changes in South Auckland. *New Zealand Journal of Geology and Geophysics*, **32**, 357–370.

Pillans, B.J., 1990. Late Quaternary marine terraces, south Taranaki-Wanganui. New Zealand Geological Survey miscellaneous series map 18.

Rafferty, W.J., & Heming, R.F., 1979. Quaternary alkali basalt and sub-alkalic volcanism in South Auckland, New Zealand. *Contributions to Mineralogy and Petrology*, **71**, 139–150.

Ross, D.I., 1963. Surface magnetic permeability measurements on some Taranaki ironsand deposits. *New Zealand Journal of Geology and Geophysics*, **6**, 197–208.

Sagar, M., Browne, G.H., Arnot, M.J., Seward, D., & Strongen, D.P., 2019. New U–Pb zircon ages and a revised integrated age model for the late Miocene northern Taranaki coastal section, New Zealand. *New Zealand Journal of Geology and Geophysics*, **62**, 357–370.

Shane, P.A.R., 1994. A widespread early Pleistocene tephra (Potaka tephra, 1 Ma) in New Zealand: character, distribution and implications. *New Zealand Journal of Geology and Geophysics*, **37**, 25–35.

Stanaway, K.J., 2012. Ten placer deposit models from five sedimentary environments. *Applied Earth Science*, **121**, 43–51.

Stokes. S., Nelson, C.S., Healy, T.R., & MacArthur, N.A., 1989. The Taharoa ironsand deposit. In: Kear D (ed.). Mineral Deposits of New Zealand Monograph 13. The Australasian Institute of Mining and Metallurgy, Melbourne, Australia, p. 105–116.

Stokes, S., & Nelson, C.S., 1991. Tectono-volcanic implications of provenance changes in the late Neogene coastal sand deposits of the Kaihu Group, South Auckland, New Zealand. *New Zealand Journal of Geology and Geophysics*, **34**, 51–59.

Vermeulen, P., 2011. 2011 Update on the exploration activities for PP50383 and PP50753, Trans-Tasman Resources Ltd. New Zealand Petroleum & Minerals, Ministry of Business, Innovation and Employment, Wellington, unpublished open file mineral report, MR4747.

Waterhouse, B.C., & MacArthur, N.A., 1989. Geology of Waikato North Head ironsand deposit. In: Kear, D. (ed.), Mineral Deposits of New Zealand Monograph 13. Australasian Institute of Mining and Metallurgy, Melbourne, Australia, p. 99–103.