Geoconservation Research

Original Article

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## Abstract

**The Manawatu and Wairarapa regions, lower North Island, are an important geological archive for New Zealand but are not among the iconic geotourism attractions of New Zealand. Recently the geoheritage values of the region have been discussed by various groups including Massey University and Horizons Regional Council with an aim to promote the region to visitors seeking destinations with geological significance. The suggestion has been made the Manawatu River form the backbone of a geopark. While Manawatu River is regionally significant, we argue it lacks the unique attributes needed for globally significant geoheritage value. Here we demonstrate the wider region has at least two globally unique and geologically superb features that should be evaluated using global comparative studies. Exceptional turbidite successions representing accretionary prism successions are exposed in the Wairarapa region. These are comparable to the iconic "flysch" locations of the North American Cordillera, the Alps, the Pyrenees and the Carpathians. Furthermore, a succession of thrust faults and related mélange sequences are among the best exposed and most accessible in New Zealand. These undoubtedly carry high geoheritage value and we propose that these two geological features, with community support, regional council funding and the local university (Massey) facilitating the transfer of knowledge to the community, should be signposted and promoted to visitors. In the long term the stunning geological succession of the Wairarapa Mudstone Country should gain international recognition and form the basis of a UNESCO Global Geopark.**

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## Introduction

Geoheritage research is an increasingly important aspect of Earth Science education (Barasoain and Azanza 2018; Justice, 2018; Reynard *et al.* 2018; Zecha and Regelous 2018; AlRayyan *et al.* 2019; Lee *et al.* 2019; Migon and Pijet-Migon 2019; Rapprich *et al.* 2019), nature conservation (Brilha, 2002; Henriques *et al.* 2011; Németh and Moufti 2017; Escorihuela 2018; Gordon 2018; Melendez 2018; Prosser 2018; Brocx and Semeniuk 2019) and geotourism (Hose 1997; Hose 2006; Newsome and Dowling 2006; Hose *et al.* 2011; Hose 2012a; Hose 2012b; Lim 2014; Németh *et al.* 2017; Dowl-

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ing and Newsome 2018; Erfurt 2018; Newsome and Dowling 2018; Rozycka and Migon 2018; Suzuki and Takagi 2018; Vasiljevic *et al.* 2018; Beraaouz *et al.* 2019; Guo and Chung 2019; Maghsoudi *et al.* 2019). Identifying the geoheritage values of the natural environment is an important aspect of this research (Reynard and Brilha 2018). Methods used to define the value of geological sites include systematic quantification of their main (e.g. scientific, educational, aesthetic, protection etc) and additional (e.g. functional touristic etc) values (Brilha 2016; Sa dos Santos *et al.* 2016; Brilha 2018; Brilha *et al.* 2018; Forte *et al.* 2018). While there is no general agreement on the best practice for doing this, such valorisation defines the fundamental roles in land-use planning, development of various geotourism activities or geoeducation opportunities. The ultimate goal of the work is to develop thematic geoconservation sites with recognised local, regional or international (global) geoheritage values that will promote Earth Science and the fundamental role of the geosystem in understanding Planet Earth (Reynard *et al.* 2011b; Brocx and Semeniuk, 2015; Chakraborty *et al.* 2015; de Vries *et al.* 2018; Gray 2018a). The formal geoconservation aspect of such projects is to establish local geoparks and promote geotourism (Joyce 2010b; Zeng 2014; Errami *et al.* 2015; Warowna *et al.* 2016; Németh and Moufti 2017; Dowling 2018; Gray 2018b; Beraaouz *et al.* 2019; Mikhailenko and Ruban 2019). Depending on the significance of the geosites identified during the research some features may be sufficiently important as to warrant the establishment of an UNESCO Global Geopark. UNESCO Global Geoparks are protected and managed regions with geological and geomorphological features of global significance (Eder 1999; Keever and Zouros 2005; Dowling 2011; Petrovic *et al.* 2013; Turner 2013; Henriques and Brilha 2017; Justice 2018; UNESCO 2018). Achieving UNESCO Global Geopark status requires scientific expertise and the involvement of local communities, including indigenous peoples and cultures. Visitor experiences are the key to provide real, hands on information about Earth history and the processes that shape the non-living natural environment to promote geoheritage (Clary 2018; Dowling 2018; Farsani *et al.* 2018; Lagally 2018). The geosites need to be destinations keenly sought by visitors either as individual tourist activities or more structured ways, such as guided visits (Migoń, 2018; Newsome and Dowling 2018). Their scientific significance must be clearly articulated (Brilha 2016; Brilha 2018). To ensure this the geosites need to be presented in an appealing and informative manner which can take many years of work (Hose 2006; Migoń 2018). Defining the geoheritage values is the key and is best achieved through ongoing research and dissemination of the findings to the wider community by publication in local media and discussion or workshop opportunities to share knowledge with the local population. Geoheritage research will often define the scientific values of geosites and these findings can be distributed through academic journals (Brilha 2016; Brilha 2018). The geodiversity of sites is also an important factor that warrants inclusion in the research (Gray 2018a; b; Reynard *et al.* 2018).

Geoheritage values tend to be biased toward the tourism values of geosites in particular the visual landscape (Panizza 2001; Reynard *et al.* 2007; De Waele and Melis 2009; Ielenicz 2009; Ilies and Josan 2009; Reynard *et al.* 2009; Erhartic 2010; Joyce 2010b; Pereira and Pereira 2010; Coratza *et al.* 2011; Doniz-Paez *et al.* 2011; Miccadei *et al.* 2011; Pellitero *et al.* 2011; Reynard *et al.* 2011a; Serrano *et al.* 2011; Harmon and Viles 2013; Reynard and Coratza 2013; Zglobicki and Baran-Zglobicka 2013; Reynard *et al.* 2018). However, research is concluding that geoheritage itself has absolute values that are not based solely on morphology of the landscape and its visual aspects  so often (Brilha 2002; Brilha 2016; Brilha 2018). Tourism driven geoheritage is too often based on the preconception of what visitors wish to experience at a geological site. However, for many sites the geological value is not limited to the visual scene (Dowling and Newsome 2018). When the focus is primarily on geotourism, especially where there is government support for tourism (Hayes and Lovelock 2017), tourist hot spots develop and tourism routes tend to build around a network of popular sites while less well known sites, some of which are off the beaten track, are rarely promoted and not considered as valuable  (Pearce 2000; Morrow and Mowatt 2015; Migon and Pijet-Migon 2016). Recently there appears to have been shift away from focusing only on popular geosites  to studying less well known regions where new  sustainable tourism developments could be established (O'Connor, 2008; Gerner *et al.* 2009; Joyce 2010a; Bitschene and Schueller, 2011; Boley *et al.* 2011; Burlando *et al.* 2011; Cutler 2011; Dowling 2011; Farsani *et al.* 2011; Gordon, 2011; Grant 2011; Letos and Muntele 2011). The recent COVID-19 pandemic and the resultant absence of international tourists to New Zealand has demonstrated that "hot spot" driven tourism with its narrow view of the geoheritage values is unsustainable long term. Other crisis situations such as various natural disasters, for example the eruption of Whakaari White Island on 9 December 2019, demonstrated the impact such an event can have and how  recovery, if any, can take a very long time (Orchiston and Higham 2016; Tucker *et al.* 2017). In addition, global changes, such as COVID-19 and the accompanying cessation of international visitors, can alter the tourism portfolio dramatically. A profit centered approach to attracting tourist visitors to a few select destinations is unsustainable long term. To avoid fragility there is a need for a more comprehensive portfolio of sites with a more even distribution pattern that appeal to the local tourist market as well as international visitors (Stewart *et al.* 2016; Vikneswaran *et al.* 2016; Fang *et al.* 2018). COVID-19 has had a shock effect on tourism (Assaf and Scuderi 2020; Ateljevic 2020; Baum and Hai Nguyen Thi 2020; Benjamin *et al.* 2020). It has long been known that the numbers of international visitors fluctuate widely and the countries they come from changes quickly (Bozzato *et al.* 2020; Brouder *et al.* 2020; Chang *et al.* 2020; Edwards 2020). COVID-19 has reinforced that a static tourism model is not sustainable long term (Balli and Tsui 2016; Bremner and Wikitera 2016; Divisekera 2016; Nair *et al.* 2016). An alternative paradigm, "slow tourism" (Caffyn, 2012; Guiver and McGrath 2015; Weaver, 2016; Agyeiwaah *et al.* 2017; Pike 2017), is a better fit to the fundamental goals of geotourism away from the main-stream tourist networks (Gravis *et al.* 2020).

Locations with strong geological heritage in regions that are considered to be outside of major tourism hot spots are commonly disadvantaged. They tend to be remote and not well-promoted despite having high geoheritage values. Post COVID-19 will provide an opportunity to develop local programs focussing on sites with valuable scientific values that are also attractive to tourists (both domestic and international), recreation, conservation or education (Farzanegan *et al.* 2020; Fong *et al.* 2020; Galvani *et al.* 2020). There is also opportunity to include topical subjects such as climate change, sea level rise and geological processes. This is behind a new trend in geoeducation to share research findings to the wider community both within and outside of the formal education systems (Fang *et al.* 2018).

Understanding global changes and the geological processes in a New Zealand context will raise awareness about our ever-evolving landscape.  This includes New Zealand's rising landmass, creation of new coastal regions such as around Kaikoura and the neotectonic processes that occur along a convergent plate margin responsible for earthquakes and tsunamis (Mortimer *et al.* 2014; Mortimer *et al.* 2017).

In this paper we explore the geological record of rapidly rising terrestrial environments, sea level changes and an accretionary prism that has been active since early Miocene. It is represented by an interbedded succession of mudstone, siltstone and sandstone that are generally considered to be "unattractive" (Palmer and Németh 2018). We will demonstrate the visual attractiveness of the succession, that stretches a few hundreds of kilometres along the eastern part of the North Island of New Zealand, lies with their genesis and significance to the neotectonic development of Zealandia along an active subduction zone.

## Geological setting

Wairarapa region is located within the southern part of the East Coast Basin, in southeastern North Island, New Zealand (Fig. 1). It is flanked to the west by the North Island Axial Ranges which separate Wairarapa from Whanganui Basin to the west (Lee and Begg 2002; Mortimer *et al.* 2014). The region is the onshore part of the deformation front associated with the Hikurangi subduction margin between the Pacific and Australian lithospheric plates (Fig. 1) that has been active since the early Miocene (c. 25Ma)(Cole and Lewis 1981; Nicol *et al.* 2007; Sutherland *et al.* 2009). The active subduction margin is located 65-125km east and southeast of the Wairarapa coast (Lee and Begg 2002; Mortimer *et al.* 2014).

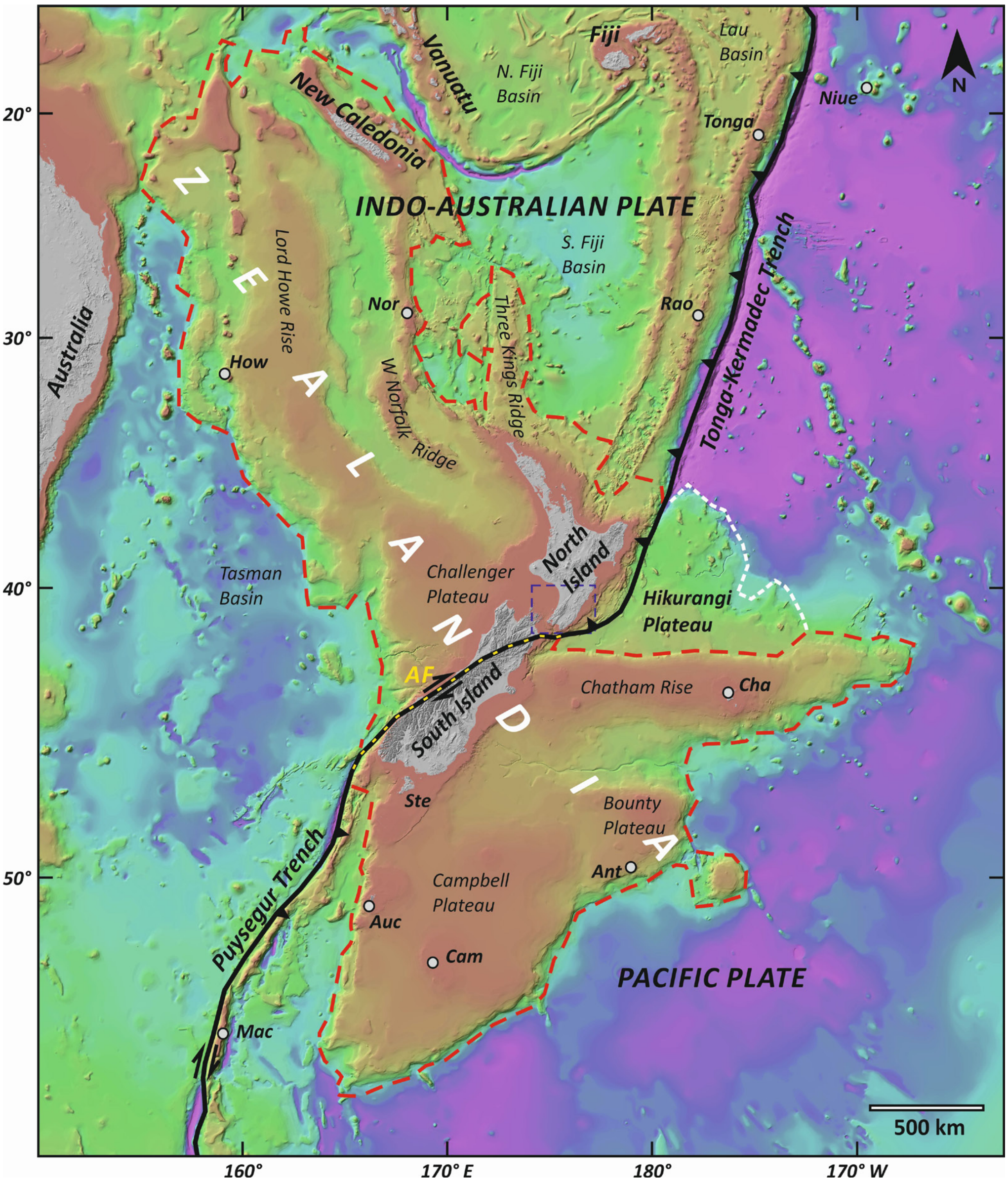

Figure 1. Geotectonic situation of the Te Riu-a-Māui/Zealandia dominantly submerged continent. The Te Waipounamu/ South Island and Te Ika-a-Māui/North Island are the two largest landmass that together form the mainland of Aotearoa/ New Zealand. Dashed rectangle show the Lower North Island of New Zealand presented on figure 2. Abbreviations: Mac – Macquarie Island; Cam – Motu Ihupuku/Campbell Island; Auc – Auckland Island; Ant – Antipodes Islands; Ste – Rakiura/Steward Island; Cha – Rekohu/Wharekauri/Chatham Islands; AF – Alpine Fault; How – Lord Howe Island; Nor – Norfolk Island; Rao – Raoul Island. Bathymetry data is from GNS and NIWA.

The geology of Wairarapa is complicated by deformation resulting from uplift of west dipping thrust faults and congruent folding and the presence of later NE-SW orientated strike-slip faulting (Lee and Begg 2002). This deformation, associated with shortening along the Hikurangi margin, most likely commenced around the inception of the subduction margin c. 25Ma, that intensified in early Pliocene and continues today (Ilies and Josan 2009).

The North Island Axial Ranges are composed of four lithologically distinct sedimentary units collectively known as the Torlesse composite terrane (Mortimer *et al.* 2014). They are well exposed in the Manawatu Gorge and crop out in upthrown fault blocks farther east (Lee and Begg 2002). These Torlesse rocks consist of intensely deformed, indurated marine sandstones and mudstones of Mesozoic age and are the oldest rocks found in Wairarapa (Fig. 2). The North Island Axial Ranges are a Quaternary feature of the region. Uplift of the ranges began well north of the Manawatu Gorge about 2.4Ma (Rees *et al.* 2018). At that time a shallow sea extended across the entire region now known as Whanganui and East Coast basins. In the early Quaternary northern and southern landmasses formed dividing the western and eastern regions of the southern North Island (Rees *et al.* 2018). The region likely became an archipelago with small islands fringed with limestone producing a paleoenvironment that evident in today's geological architecture of the region.

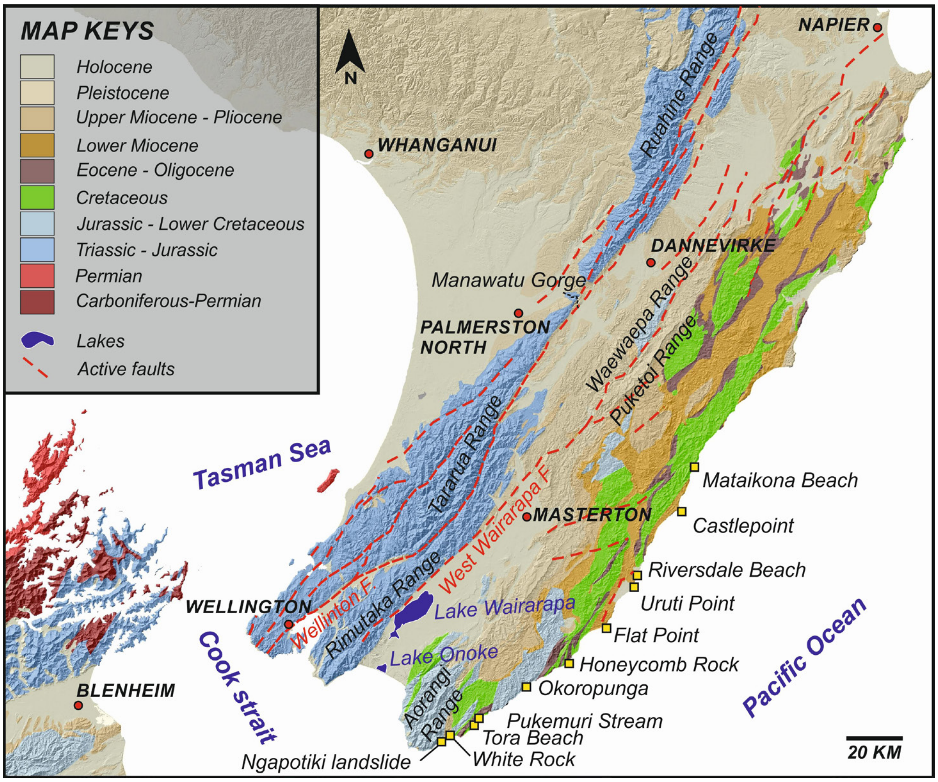

Figure 2. The geological setting of lower Te Ika-a-Māui/North Island. Major towns are marked with red dots. Rock units are ordered by their ages. Rocks older than Cretaceous from the basement that were part of Gondwana. The so-called Axial Ranges, geographically named as Rimutaka, Tararua and Ruahine Ranges dominantly composed of Mezosoic greywackes part of the Torlesse Composite Terrain. East from the Axial Ranges along the axis of the Wairarapa region forearc basin sediments form Pliocene and younger rock assemblages. Along the coastline faulted and folded successions of early Cenozoic to Miocene rocks are part of the accretionary prism. In this succession siliciclastic sediments dominate the exposed rocks among the Lower Miocene thick flysch successions provide the surface rocks as mud and sandstones. Cretaceous and early Cenozoic rocks form exposed axis of folded rocks. Key locations along the coastline marked with yellow rectangles. Topographic data is from the LINZ NZ 8m Digital Elevation Model (2012).

Wairarapa is located on the overriding Australian Plate of the Hikurangi margin (Fig. 1). Pre-Miocene the region lay in a passive margin tectonic setting where the Cretaceous to Oligocene stratigraphic succession consisted initially of coarse clastic sediments (Fig. 2) that were succeeded by progressively finer grained mudstones and marls (Neef 1995). The tectonic regime changed in the early Miocene with the inception of the plate boundary resulting in regional uplift involving reverse/thrust faulting and congruent folding (Neef 1997; 2000) (Figs. 2 & 3). While much of the area continued to occupy a continental shelf to slope position along the eastern sea border of Zealandia some areas experienced shallowing conditions with terrestrial deposits recorded in places. Where the tectonic regime resulted in the subsidence of basement the increased accommodation space together with a ready sediment supply into the basin resulted in olistostrome, breccia and turbidite sandstone and mudstone deposits (Neef 1992) dominating the Miocene basin fill (Lee and Begg 2002). There was a gradual emergence of Wairarapa from early Pliocene and the development of local marine basins flanked by uplifted blocks led to laterally restricted depositional facies that created a mosaic of marine mudstones and bioclastic limestone deposits over much of the northern Wairarapa (Fig. 3) (Palmer and Németh, 2018). A major new sediment type appeared about 1.8Ma with the arrival of calc-alkaline volcanic deposits from the central North Island. Primary air-fall and reworked volcanic ash from some of the largest central North Island volcanic events are found throughout the Wairarapa providing valuable marker beds and chrono-horizons within the succession (Pillans *et al.* 1993; Shane *et al.* 1995; Wilson 2001). This volcanism marks the southward propagation of Central Volcanic Zone with the mega-eruption events that occurred from that time. Lee & Begg (2002) suggest this volcanism was a response to reactivation of west to southwest directed subduction along the plate boundary. By the Pleistocene glacio-eustatic sea level fluctuations were a global phenomenon and are recorded in the Quaternary landscapes and sediments of Wairarapa. Wairarapa was never glaciated except for one known small valley glacier in the heart of the axial ranges (Lee and Begg 2002). A distinctive and widespread landscape feature is river terraces which begin their development during cold climates when the tree line is lowered, and areas of high elevation are subjected to intensive erosion. The resultant gravels choke up the river channels and during floods thick successions of fluvial gravels are spread out as sheets across the floodplain. Known as aggradational gravels these surfaces become incised when the river cuts its channel into the gravels leaving much of the floodplain elevated forming a landscape feature known as a river terrace.  Preservation of these terraces is enhanced by regional uplift that progressively elevates the terraces beyond the reach of the river. During cold climate, glacial, periods the floodplain, barren of vegetation, is subject to strong winds that entrain silt sized material depositing it on the terraces adjacent to the floodplain. This wind-blown silt is known as loess. Where loess preservation is good the age of the terraces can be determined using the number of loess units in the cover beds. Loess preservation is not good everywhere so alternative dating methods such as TL, OSL (Litchfield and Rieser 2005) and tephras (Rees *et al.* 2018) are used. Marine terraces form near the coast when sea level is high during interglacial periods. The uplift occurring in Southern Wairarapa means the marine terraces are preserved as they become elevated beyond the reach of future sea level high-stands.

## Geoheritage Values of "mudstone" Country

Mudstones or sandstones are common rock types associated with an accretionary prism or wedge (Meschede 2014). While they are not the most attractive rock types their geological context and features introduce fundamental principles of geology. The rocks are clearly bedded and when the bedding extends into the distance it captures people's attention and they start to ask why? This is the perfect opportunity to introduce visitors (tourists and locals) to the principles of stratigraphy through visitor experiences (Hose 2006; Lim 2014). The first observation will be the bedding and that each bed (or

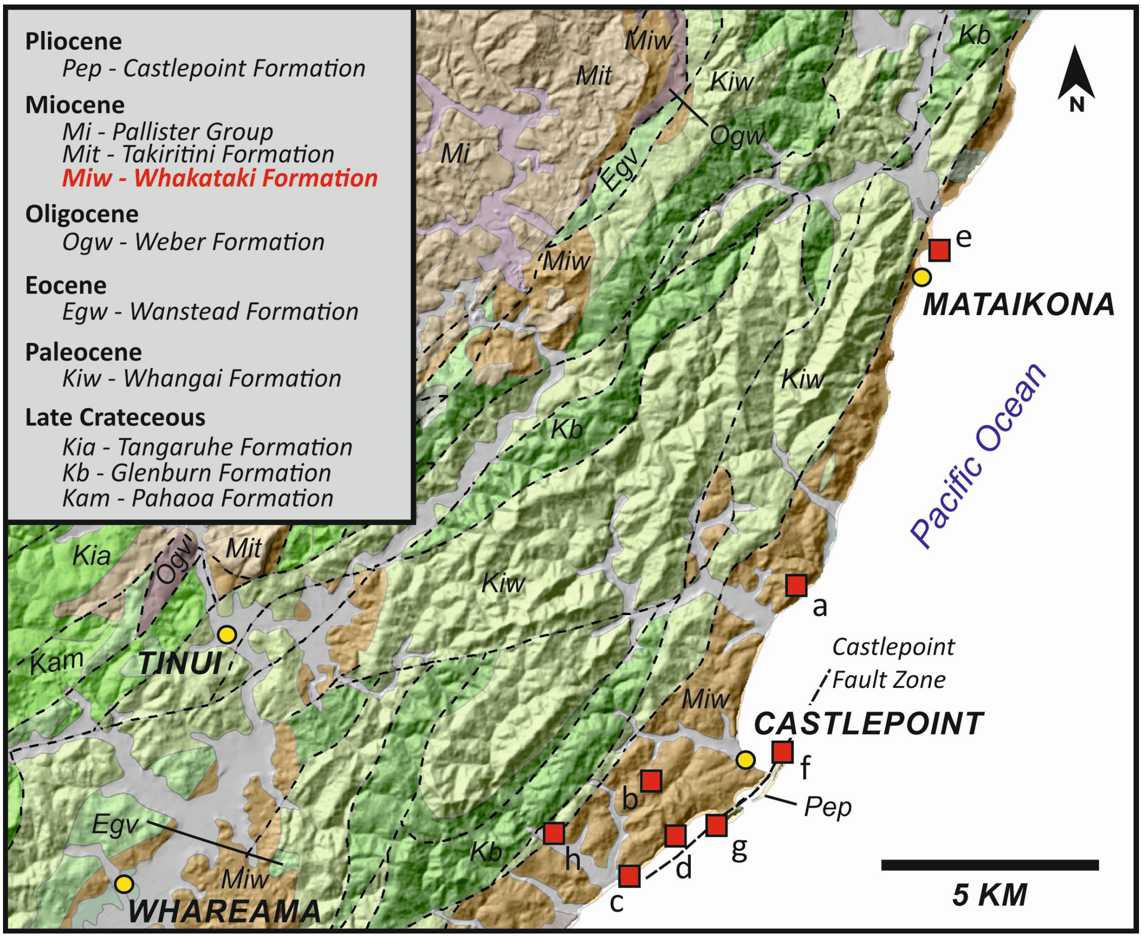

Figure 3. Geological map of the Castlepoint region. Geological data is from the QMap 1:250,000 scale Wairarapa sheet. Topographic data is from GoogleEarth Pro satellite imagery. Geosites mentioned in the text labelled by black rectangles; a – Waipouri's Mark shore platform with turbidite succession of Whakataki Formation; b – inland exposure of turbidite succession of Whakataki Formation; c – coastal cliffs of the turbidite succession of the Whakataki Formation; d – coastal cliffs of the turbidite succession of the Whakataki Formation with thick Quaternary cover beds; e – Mataikona coastline with tectonic melange and exotic rocks as olistoliths in the Whakataki Formation; f – reef of the Castlepoint section; g – the castle of the Castlepoint section, h – exposed steeply inclined succession of the Whangai Shale. Little needle-like signs show the bedding attitudes with a number referring to the bed angle. Topographic data is from the LINZ NZ 8m Digital Elevation Model (2012).

layer) looks different from that above and below it. The first principle is that of Original Horizontality (This is based on the premise that sediment particles deposited in water under the influence of gravity form essentially horizontal sediment layers). The fact you can see the layers means these beds are no longer horizontal. First challenge question: how can that be? This is an opportunity to explain how when layers of rocks are no longer horizontal rocks it means they have been tectonically disturbed after deposition and lithification. But before we talk about tectonics and how it might move rocks let's first consider which rocks in the layer might be oldest and which are youngest. This is the Law of Superposition and it applies to an undeformed succession of layers of sedimentary rocks. The youngest beds are always at the top and the oldest at the bottom of the succession. Reading features preserved within the layers it is possible to distinguish the bottom and top of the layers. The layers of rock can be seen extending away into the distance and that introduces the Principle of Lateral Continuity. In simple terms, and under normal conditions, deposits originally extend in all directions until they thin, pinch out, or terminate along the edge of the depositional basin. In places, you may observe a fault or intrusion (e.g., igneous) cut through the rock layers. When this happens, the feature cutting through is younger than the rock it cuts; this is called the Law of Cross-Cutting Relationships. Sometimes a layer may include an inclusion of another rock type. These inclusions are older than the rock that contains them (Principle of Inclusion). In any succession of sedimentary rocks there are always “breaks in the rock record”. These are called unconformities and they result from interruptions to sedimentation by erosion or non-deposition of sediments. Where the layers of rocks have been tilted or deformed between depositional episodes an angular unconformity can form. Here the tilted or folded sedimentary rocks are overlain by more flat-lying strata. The thick successions of bedded rock such as those present in Wairarapa are ideal for showing superb examples of stratigraphic features and unconformities. Even better is when the rocks contain fossils. These preserved remains of ancient organisms are a record of past life on Earth. Finding fossils is the ideal opportunity to open the conversation about how similar or different the organism is from those living today and introduce the concept of Faunal Succession.

The repetitive nature of the sandstone – mudstone beds reinforces the concept that geological events take place at regular intervals and with similar intensity over long periods of time (Fig. 4A). Sedimentary features characteristic of processes operating during sediment transport (such as low versus high sediment concentration, cohesive versus non-cohesive materials, and low versus high intensity/sediment flux) make such successions very valuable for introducing the concept of subaqueous sediment density flows in geology (Talling *et al.* 2012) to visitors. Furthermore, the accessibility of the locations makes them useful destinations for educational fieldtrips.

Subaqueous sediment density flows are one of the main processes responsible for producing a thick pile of sediments. The sediment clasts are eroded from a landmass and transported across the continental shelf to deep-water bathyal regions. The moving sediment can either be confined within an under-water canyon or unconfined as broad sediment fans that accumulate where there is change slope such as happens at the foot of the continental slope where it meets the abyssal plain. Extensive, multilobed deposits of sediment build out into the basin forming fans. Such fans and their sedimentary deposits are commonly called flysch and they composed of alternating layers of mudstone, sandstone and other coarse clastic rocks.

Flysch successions are often the result of deposition from turbidity currents, gravity driven flow of sediment laden water, and may be referred to as turbidites (Fig. 4B). Turbidity currents are an integral part of transporting sediment from the terrestrial to deep marine environments in what has been described as the sediment conveyor belt. Turbidites are the product of gravity driven sediment flow that form a Bouma sequence (either complete or partial) that have recognised bedding features relating to the flow conditions at the time of deposition (Bouma 1964; Bouma 2000b, a; Bouma and Rozman 2000; Stelting *et al.* 2000; Bouma 2004; Bouma and Ravenne 2004; Talling *et al.* 2012). Classical Bouma sequences are preserved in Wairarapa flysch deposits.

“Mudstone countries” are common features along convergent plate margins where long lasting subduction processes transport copious amounts of sediment from eroding landmasses into the deep marine environment. In such settings the complete to incomplete Bouma sequences explicitly demonstrate the ruling sedimentary regime that governed the formation of the rocks.

Well known flysch successions are common along the convergent orogenic belts of the Africa – Eurasia where they provide a geographically continuous, well exposed successions ideal for studying the processes associated with accretionary prism formation

Figure 4. A) Steeply bedded spectacular shore platform of the turbidite succession of the Whakataki Formation at Waipouri's Mark. Youngening of the section is marked by an arrow. B) Typical Bouma sequence at Waipouri's Mark with Tb, Tc and Td-e units. C) The Castlepoint view toward the south showing steeply bedded limestone as capping unit. D) The Castlepoint from the south.

along numerous subduction fronts since the Palaeozoic (Robinson *et al.* 1995; Boiano 1997; Kurz *et al.* 1998; Nemcok *et al.* 1998; Baas *et al.* 2000; Bielik *et al.* 2004; Sylvester and Lowe 2004; Braid *et al.* 2010; Forte *et al.* 2010; D'Errico *et al.* 2014; Kovac *et al.* 2017; Wang *et al.* 2018; Lapcik 2019; Tet'ak *et al.* 2019). Over time, active accretionary wedges have been uplifted by compressional tectonic events to become part of a newly emerging landmass. Here are the ideal places to study thrust fold belts where flysch deposits are exposed in complex and tectonically active zones.

Such regions are huge in geoheritage value. The common sandstone and mudstone rocks they host are ideal for educating the public in fundamental geological processes. In addition, the layered nature of the commonly steeply inclined strata produces a visually attractive array of bedded rocks. The layers are fascinating and when presented with appropriate explanations the stratigraphy of the rocks becomes an interesting and challenging task.

Sharing the geological heritage of geologically significant regions is the premise behind the establishment and promotion of dedicated UNESCO Global Geoparks that have been established based on their geological entity. The Basque Coast UNESCO Global Geopark in Spain is one of the world's finest examples of geopark established for geoheritage value of the exposed, in places steeply dipping, bedded mudstones and sandstones (Poch and Llordes, 2011; Henriques *et al.* 2019). The geological value of the geopark is centered around the various flysch successions deposited in the upper Triassic (215 million years old) to Middle Eocene (45 million years old) during the opening and closure of the Bay of Biscay (Tenkate and Sprenger 1993; Alegret and Ortiz 2010; Giannetti 2010). The present-day coastline exposes various stages of this major tectonic event recorded in the accumulation of nearly 5000 m thick flysch deposit. The exposed rock records one of the most recent mass extinctions in the Earth's history commonly referred to as the K/Pg or P/E extinction event (Zili *et al.* 2009). This extinction event is inferred to be the result of an impact by a large asteroid striking the Earth some 65.5 million years ago in Chicxulub (Mexico). The Basque geopark includes two Global Stratotypes (GSSP) defined by the IUGS – UNESCO at the base of the Selandian and Thanetian stages (Schmitz *et al.* 1998; Arenillas *et al.* 2008; Molina *et al.* 2009). In 2001 the "*Ruta del Flysh*" was awarded a regional tourism prize from the Basque Government in appreciation of the importance of the geological heritage aspects of the region and for its role in promoting regional geotourism.

Such a rich geological heritage for a single well-defined and relatively small territorial geopark is rare. Flysch successions play an important role in the geological heritage aspects of other UNESCO Global Geoparks such as the Muroto UNESCO Global Geopark in Japan. The geopark slogan expresses well the nature of the geology of that geopark; "*where the ocean and the land meet for the birth of a new habitable land*". While the flysch succession itself has not been defined and promoted as the backbone of the geopark, its significance is evident in the geology of the region.

The Muroto UNESCO Global Geopark is considered a typical accretionary complex. It is Late Paleogene to Early Neogene and located at the plate boundary between the Eurasian Plate and the Philippine Sea Plate. The sediments of the Nankai Trough are attached to the continental plate to form a mass of built-up sedimentary rock, called an accretionary complex (Moore *et al.* 2015). Exposed to Cape Muroto, visitors can see and touch the succession which provides a rich geoeducational resource for local schools (Yuhora *et al.* 2016). The region has also experienced magmatic intrusions that have been metamorphosed and uplifted where they have an important role demonstrating how geological processes can present a present-day hazard in the region. This region has close geological similarities with the East Coast of the North Island of New Zealand from a geoheritage and geological processes perspective.

Rocks that are part of a flysch or accretionary prism succession are common in many other UNESCO Global Geoparks and regional geoparks, however, well-exposed and dedicated localities are rare. The region along the East Coast of the North Island of New Zealand has spectacular sites with superb exposures in a modern subduction system. The same area is a focus for geohazard and neotectonic research as it is subjected to regular earthquakes, active uplift and is at risk of tsunami. The geoheritage value of this region needs promotion through geoeducation and geotourism to preserve its unique qualities. It should be also be included in formal conservation policies.

The East Coast of the North Island is a location that is considered the haven of locals rather a destination for visitors. Consequently, it is underdeveloped and less visited when compared to other geologically interesting regions of New Zealand. Access to much of the region is by secondary, often unsealed, roads. Many outcrops are accessed along the spectacular coastline.

One popular destination on the east coast is Castlepoint, about 30km east of Masterton.  Castlepoint is a small settlement with about 100 permanent residents with basic service facilities. It is an end of the road location from where key sites pertinent to understanding New Zealand's most recent geological history can be accessed. Castlepoint itself is a spectacular landscape feature standing 160 m above the present-day sea level. Its steep eastern side faces directly out to the Pacific Ocean (Fig. 4C). These young strata are fault bounded on the landward side from Miocene turbidite rocks (Whakataki Formation) (Lee and Begg 2002). This structural relationship has created a castle-shaped cliff, consisting of the Castle and the Reef, and a partially open laguna (Fig. 4D). The main rock types are accessible cliffs in the area that dip gently westward and consist of limey sandstone and fossiliferous limestone. The succession records marine sedimentation about 2 million years ago (Johnston 1973). The fossil assemblages were thought to record environmental changes from a cold marine environment to warmer conditions within the Pleistocene (Johnston 1973), but a recent study provided a different interpretation of the complex geology of Castlepoint (Buckeridge *et al.* 2018). The main lithostratigraphic unit cropping out in the region is early Pleistocene (early Nukumaruan) Castlepoint Formation (Fig. 5A). It contains a diverse molluscan, bryozoan and barnacle assemblage, with a few brachiopods, corals, echinoids, crabs and polychaetes, comprising mixed warm- and cool-water taxa and outer shelf and shallow-water taxa (Buckeridge *et al.* 2018). Early studies of this mixture of warm and cool-water faunal assemblage were interpreted as suggesting some sort of time-progressive change from one climate to another and linked to specific stratigraphic horizons. However, a recent study has demonstrated that most of the fossils are mixed together, they are commonly fragmented (Fig. 5B) and accompanying sedimentary structures within the beds include fluid release structures (Fig. 5C), steep original dips, large load casts (Fig. 5D) and displaced blocks (Buckeridge *et al.* 2018). All of these are better explained by an energetic and very dynamic sedimentary environment. In the latest interpretation it is suggested Castlepoint consists of a rock succession that formed by gravity sliding into a narrow canyon, which collected variously sourced remains of shells and sedimentary grains or semi-consolidated blobs of sediments. The barnacle- and bryozoan-rich molluscan coquina, named as barnamol and bryomol respectively, that makes up much of the Castlepoint Formation comprises a thanatocoenoses resulting from transportation of shallow-water elements, which accumulated deeper-water taxa in transit, to settle in a shelf-edge canyon environment (Buckeridge *et al.* 2018). This new model fits very well to recent geosystems on the seafloor around the convergent plate margins in the New Zealand realm (Micallef *et al.* 2014), hence the Castlepoint geosite itself tells a very important story that can be utilized for public geoeducation. The site could also be used to demonstrate the dynamic sea-floor processes commonly linked to major thrust earthquakes along a convergent margin (Reyners 1998), such as the active Hikurangi subduction zone about 100 km away from the present day location of Castlepoint.

To the north of Castlepoint, via a sealed road, is the Whakataki Coast where a 20 km long, broad coastal platform exposes the most spectacular turbidite successions in New Zealand. Most of the sites are exceptionally well exposed during low tide enabling visitors to access an impressive succession of tilted mudstone – sandstone interbeds preserving complete to near-complete Bouma sequences (Fig. 6A). The beds record various dynamic processes that operating on the sea floor when sediment is transported from a landmass to deep marine environment over a period of tens of thousands of years. The succession is impressive and includes various turbidity current channels containing central to marginal facies showing how sediments are dispersed from the shelf region into abyssal depths. Individual beds can be traced along the shore platform and facies changes can be observed directly. Thickly bedded, channelized Bouma sequences, some complete and some partial, represent turbidite channels or main arteries, whereas in areas where the units are more regularly bedded and missing Ta (sand) sections of Bouma sequences more likely represent overbank of turbidite facies (Field 2005).

Thin-bedded turbidites of the early Miocene Whakataki Formation are superbly exposed along the shore platform at Mataikona (Lee and Begg,

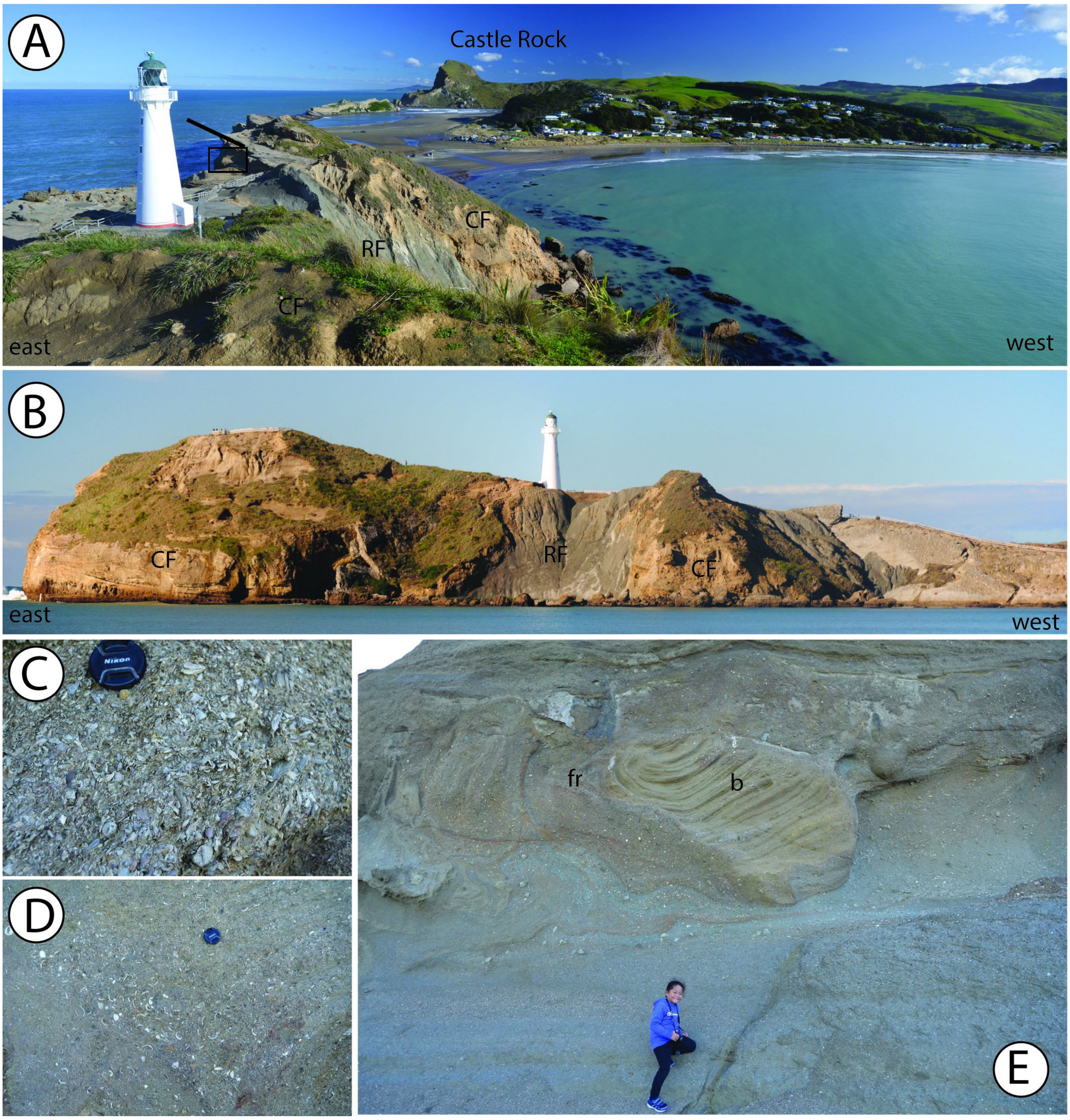

Figure 5. A) Overview from the top of Castlepoint toward Castle Rock. Note the grey mudstone (Rangiwhakaoma Formation – RF) between the cream coloured limestone (Castlepoint Formation) – CF). Also note the steep bedding toward west (line). Box mark the location of the major load structures shown of E. B) Overview of Castlepoint from the north. Note the steep contacts between the Rangiwhakaoma (RF) and Castlepoint Formation (CF) marking a partially in situ canyon morphology formed by the Pliocene mudstone of RF filled and partially incorporated into the CF. C) Complex fossil assemblage with broken and fractured shells indicate mass flow transportation from differently sourced material into a submarine canyon. D) Fluid-release features indicate a dynamic sedimentary environment commonly affected by sudden mass emplacement over wet, soft sediments commonly accompanied with syn-sedimentary faults. E) Large load casts and blocks (b) and convolute bedding features with fluid release (fr) structures suggest sudden and energetic mass movement on the seafloor.

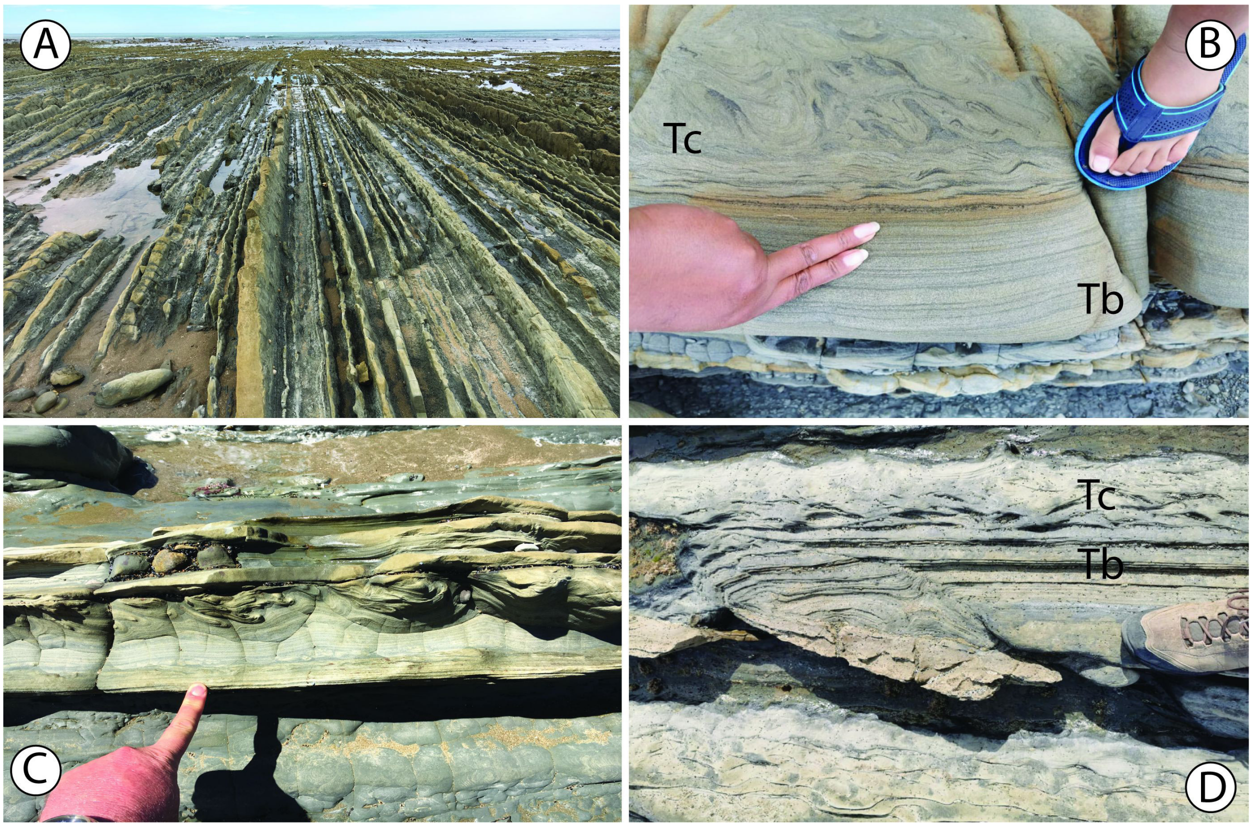

Figure 6. A) Steeply bedded turbidite succession just north of the Waipouri's Mark. Bedding dip direction is perpendicular to the location at Waipouri's Mark. B) Soft sediment deformation features showing dish structures with uniform creeping direction of the dune-bedded Tc unit of the Bouma sequence at Waipouri's Mark. C) Soft sediment deformation with convolute bedding at Riversdale Beach. D) Syn-depositional fault and soft-sediment deformation features of the flysch succession at Waipouri's Mark.

2002). A study on the Waipouri's Mark shore platform made a detailed record of the number and thickness of beds and their position utilizing aerial photography, field measurements and some geophysical techniques (Field 2005). The detailed study identified about 360 sandstone beds across a 32 m thick section and three (3) lithofacies associations recognised (Field 2005). The data were integrated into a detailed sedimentology study of the location to establish the time and process needed to form the exposed rocks. The study found the Whakataki Formation accumulated over a 3 million year long time period somewhere between 23.5 and 20.5 Ma (Morgans *et al.* 1996).

Bouma sequences show the variability of sediment input, depositional regime and post-depositional processes that operated. Dewatering features, such as dish structures or creeping sediments on the gently inclined paleo-seafloor, are examples of post-depositional features found in turbidites (Figs . 6B & C). The classic complete Bouma sequence consists of five units. At the base is an erosional contact overlain by Ta, a sandy, coarse-grained unit which is often normally graded. Tb, a stratified, laminated fine sand unit; Tc, with ripples and wavy laminae; Td, a parallel laminated silt and Te, hemipelagic mud overlay the basal unit. This general sequence varies depending upon whether the turbidity current has a low or high particle concentration. Over the years the original turbidite model has been refined and many variations on the combination of units comprising the turbidite recognised (Talling *et al.* 2012). Turbidites are complex and their units cannot easily be accurately generalised nevertheless they are valuable geoeducation resources because of their strongly stratified nature. The geosite at Mataikona is superb with its very regular bedding and clearly recognisable features. Here the thickly bedded, basal sand layer (Ta) is mostly absent. Instead most of the turbidites start with a laminated sand (Tb) and are capped by the thinly laminated fine mud (Te). Studies suggest some 1500 m total thickness of the Whakataki Formation accumulated over about 3 million years (Morgans *et al.* 1996; Field, 2005). Using this rate of accumulation, it's estimated the 32 m thick succession at Mataikona consists of about 360 sandstone beds (proxy for the number of Bouma sequences). This accumulation rate is consistent with a Bouma sequence-forming turbidite event occurring on average each 177 years (Field, 2005). This is an exceptional story to tell the general public as it puts into context the concept of deep time and the resulting rock assemblage.

Direct observations of active turbidite fans are uncommon. In regions with high sedimentation rates, such as where the Amazon River enters the Atlantic, it's estimated that turbidity currents could occur frequently. In a study of a 30 ky record it appears there could have been as little as 2 years between turbidite events (Pirmez *et al.* 2000; Pirmez and Imran 2003). However, most studies are on older deposits and the inferred time periods for turbidite recurrence is far longer. For example, for the Zumaya flysch on the Basque Coast UNESCO Global Geopark recurrence is more likely 5000 – 7000 years (Tenkate and Sprenger 1993). Interestingly, recurrence of turbidite events in the order of thousands of years is a common conclusion in many older flysch successions. Estimates of recurrence intervals for modern turbidite deposits along the Hikurangi Subduction Margin over the last 16,000 years average at 400 years. These turbidites are believed to have been initiated by major mass movement events such as landslides or earthquakes with a frequency of a few hundred years so it is not surprising that the recurrence of each is strikingly similar r (Pouderoux *et al.* 2014). Twenty of these turbidites exposed along the shore platform between Mataikona and Castlepoint are correlated with subduction interface earthquakes with a calculated average recurrence of c. 800 yr. This aesthetic succession comprises numerous geosites conveying a fascinating and important geological story that will surely fascinate visitors. Its accessibility and the scientific archive of this outstanding coastal section make it a highly valuable geoheritage region.

In addition to the turbidite Bouma sequences syn-depositional faults (Fig. 6D) and various soft sediment deformation features can also be seen at these geosites. Such structures form when recently deposited, unconsolidated marine sediments are subjected to intermittent faulting and associated creep at the time of deposition. The succession exposed along the shore platform shows very clearly the dynamic processes operating on the seafloor of an active accretionary prism along an active convergent plate margin.

Another very interesting feature along this coast is a structural zone (Fig. 7A) where sediments are fractured, folded (Figs. 7 B & C), displaced and display a minor metamorphic overprint (Fig. 7D). In places rocks from Early to Mid Cenozoic successions have been caught up in the flysch successions forming small to medium size olistoliths of exotic rocks. These olistostromes provide another geological perspective of the active processes that are operating out into the deep marine environment (Lee and Begg 2002).

To the north of Castlepoint there is a spectacular coastal cliff section where the flysch sediments have a strikingly different bedding attitude to those on the coastal platform (Fig. 8A). Cross cutting faults provide a picture of syn-sedimentary tectonic processes operating as the accretionary prism developed in the region.

Farther inland the Miocene flysch successions form steeply dipping bedded mudstone and sandstone hills. These stratigraphically younger units tectonically overlie older late Cretaceous marine successions that were deposited along the Gondwana

Figure 7. A) Tectonized section of the flysch succession at Mataikona Beach. B) Bright white olistoliths from the older Eocene marls transported by turbidites that formed the Whakataki Formation. C) Folded and faulted block of an olistolith at Mataikona Beach D) Folded limy mud with boudinage textures from the Whakataki Formation at Mataikona Beach.

eastern margin. These are the older Glenburn Sandstone, which forms the indurated, more erosion resistant westward dipping set of hills that crop out near and along the coast. While it is not straight forward distinguishing between the Miocene and Cretaceous sandstone and mudstone successions in inland sections, their co-existence in a narrow belt provides an outstanding example of the longevity of siliciclastic sedimentary basin processes. The persistence of similar units through long periods of geological time together with the challenge of identifying individual units is an excellent geoeducational opportunity highlighting the challenges of research in complex geological settings.

The Glenburn Sandstone is best exposure along the coast around Glenburn Station. Here Honeycomb Rock (Fig. 2) forms a spectacular coastal cliff erosion (Fig. 8B) by the pounding Pacific Ocean has created a characteristic honeycomb-pattern in the hard sandstone rock that is texturally different from the Miocene sandstones (Fig. 8B). The Honeycomb Rock itself emerged as a coastal landscape feature about 6500 years ago. It is a well exposed section of Late Cretaceous Glenburn Formation comprising quartz-rich sandstone (Lee and Begg 2002). Farther south at Tora Beach (Fig. 2) it is exposed in a spectacular anticline on the shoreline platform (Fig. 8C). Here younger post-Cretaceous rocks can be traced into a stream valley canyon where the K/T boundary

Figure 8. A) Spectacular coastal section south of Castlepoint exposing flysch successions that are commonly folded and faulted. B) Cretaceous Glenburn Formation forming spectacular coastal erosional features such as Honeycomb Rock near Glenburn Station. C) Axis of an anticline exposing Cretaceous Glenburn Formation in the shore platform of Tora Beach. D) Steeply inclined Paleocene well-bedded muddy limestone (Mungaroa Limestone) as part of the Tora Group forming the White Rock. Along the right side of the view the Ewe Fault inferred to runs as a major thrust fault.

is visible in a spectacular gorge (Laird *et al.* 2003). This section is unique as it provides an insight to the thickness of sediment that has accumulated since Zealandia detached from eastern Gondwana.

Another extensive sedimentary unit present in the east coast of the North Island is the Whangai Formation, informally referred to Whangai Shale (Neef 1995; Lee and Begg 2002). This sedimentary succession accumulated in a deep in places anoxic marine environment. Not as resistant as the Glenburn Formation, the Whangai Shale tends to erode easily commonly forming narrow gullies and steep scree slopes (Parkner *et al.* 2006). These features impact on farming in the district and the impact the local economy. Locally small quarries for race metal on farms are common. The soils that develop on these shales are fertile but prone to land sliding.

Southwards along the coastline features with geoheritage potential include White Rock (Fig. 8D) and the eastern margin of the Aorangi Range where there is outstanding exposure of greywacke basement rocks and huge landslide fans. Along the shore platform regular uplift has preserved an outstanding sequence of raised beaches that have been correlated with major earthquakes (Figs. 9A & B). These raised beach sites, such as those at Tora (Fig. 2), provides a unique neotectonic record of the region. Immediately inland there is archaeological evidence of human occupation of the fertile coastal zones and the tsunami events that almost certainly impacted

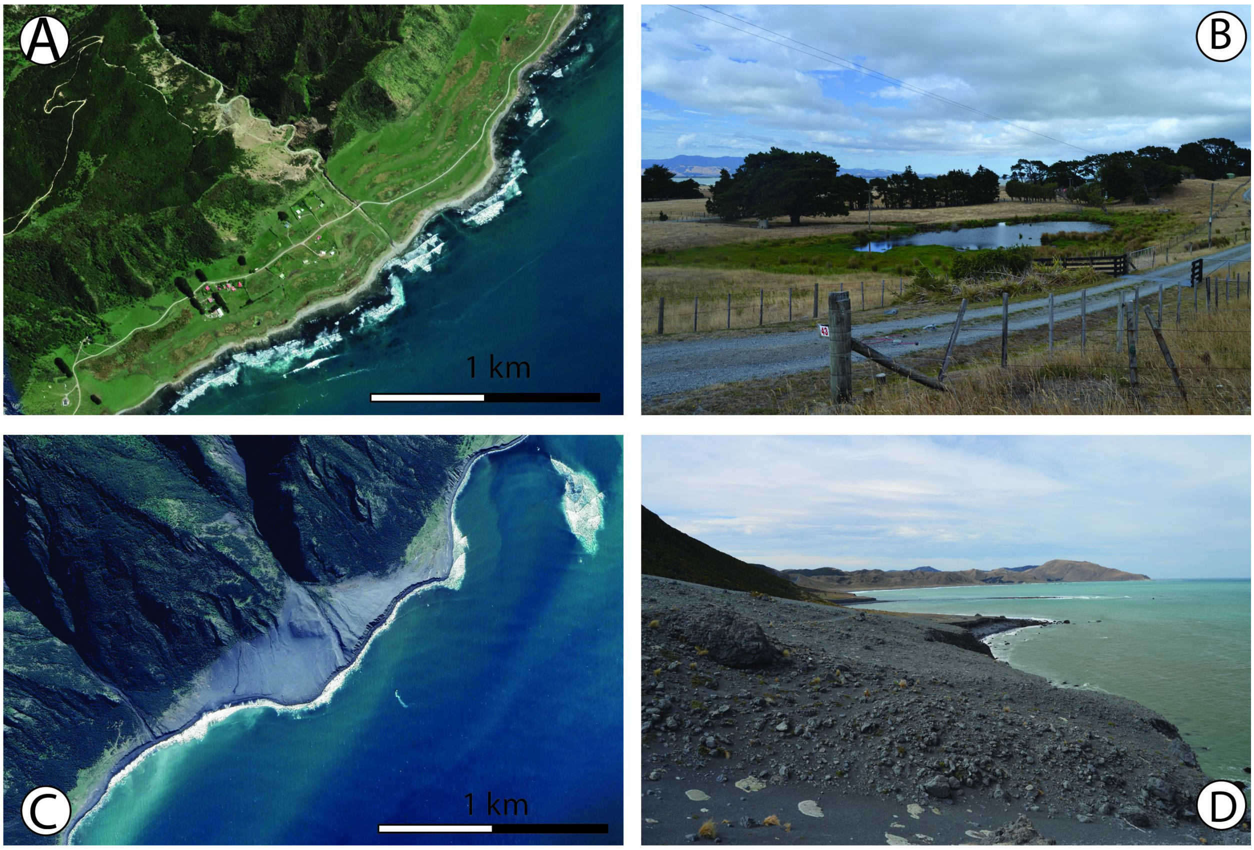

Figure 9. A) GoogleEarth satellite image of the Tora Beach showing a series of raised beaches. Along the Pukemuri Stream (middle of image) exposes a complete Late Cretaceous to early Cenozoic successions in a spectacular canyon. Along the Pukemuri Stream in the Lower Member of the Manurewa Formation, the K-T boundary is also exposed adding an extra dimension of the geoheritage value of the location. B) Tora Beach raised beach platforms commonly forming wetlands. C) Ngapotiki fan on a GoogleEarth satellite image. D) Ngapotoki fan demonstrates well the mass movement on steep hillslopes of the Mesozoic basement rocks of greywackes along the Aorangi Range. The fan estimated to start to form about 1800 years ago.

them. These features are pristine due to the remoteness of area and this gives them added geoheritage value such as young landslide fans along the Aorangi coast (Figs. 9C & D).

## Geoeducational Potential

The East Coast area is accessible by secondary road and has been the destination of day field trips by researchers and students from Massey University Earth Science programs (Figs. 10A, B, C & D). The enormous geoeducation potential is undoubted. Student field trips have explored the complex accretionary prism geology from basic geological principles (Supplementary Material 1). The journey from Palmerston North traverses a dynamic landscape from the Axial Ranges comprising Mesozoic (mostly greywacke-dominated) lithologies (Fig. 10A), through the “flysch” succession dominated by Miocene aged rocks (Fig. 10B) to the older harder Cretaceous successions. Pliocene, fossiliferous limestone deposits can be visited at many locations (Fig. 10C) and the impact of some of the largest volume rhyolitic explosive events from the Central North Island have their record as tephra layers embedded in loess sections. We present a field guide of selected key locations that are readily accessible by school or Earth Science groups (Supplementary Material 1). The fieldtrip also provides excellent examples of the active neotectonic setting of the region, in particular strike slip fault systems bounding the axial ranges and accretionary prism deformation. These features complement the outstanding examples in iconic regions such as along the San Andreas Fault in California.

Massey University Earth science undergraduate field courses have undertaken mapping projects in the East Coast, from Makuri east of Dannevirke to Castlepoint Station (Fig. 10D) and south to Honeycomb Rock and White Rock. Here students tackle complex geological problems involving faulting and folding related to accretionary prism development. The experience and knowledge gained during these field courses have led the authors to realise the enormous geoheritage value of the region and the need for it to be promoted to the general public through geoeducation programmes.

The area around Castlepoint provides superb exposures of layered sedimentary rocks ideal sections, both coastal and inland, illustrating the basic principles of geology (Fig. 10D). Geosites access along coastal shore platform is easy at low tide and here exposures of classic Bouma sequences associated with turbidity current deposits are clearly visible (Fig. 10D). There are locations where textbook style exposures can be seen and these could be developed into dedicated geo-educational sites where the basic concepts of geology could be passed to the general public.

Figure 10. A) First year BSc Earth Science fieldtrip visit to the Manawatu Gorge's greywacke sequences. B) First year BSc Earth Science fieldtrip visit to the Whakataki Formation turbidite sequences near Pongaroa. C) First year BSc Earth Science fieldtrip visit to the Pliocene mudstone sequences accumulated in a forearc basin west of Pongaroa. D) Third year geological mapping exercise for BSc Earth Science graduates along the Mataikona Coast, north of Castlepoint.

## Geotourism Potential

The East Coast area of the lower North Island is not one of New Zealand's iconic tourism destinations despite outstanding aesthetic vistas accompanied by a wealth of geological history on the development of Zealandia. Sealed roads take the traveller from Masterton to Castlepoint in about 1.5 hours (somewhat longer from the SH1 where most of the tourist travel occurs). The region is clearly detached from the main tourism routes so at present has limited facilities available for visitors. To many locals the region is a holiday destination where fishing and surfing are popular activities. There is an annual horse racing event held on the beach and few tourists venture here.  Local councils have developed some information boards in Castlepoint explaining the geology of the reef and explaining the conservation rules. There is very little information available for independent visitors about what to see and where to see or explore. There is an opportunity to promote the fascinating and important geological processes one can see in the rock record at this convergent plate margin locality.

The rich and growing geological information about the region can provide a strong basis to consider investment in geotourism. Geotourism has been originally defined as a "type" of tourism, nowadays it is viewed more as a new "approach" to tourism (Newsome and Dowling 2006). As this view gained more traction conceptual models were proposed to define geotourism that can be undertaken either as "independent visits" or "guided tours" (Newsome and Dowling 2010a,b). As its original definition, geotourism was considered as a geology-based tourism and it has been viewed as a the provision of interpretative and service facilities to let visitors gain knowledge to understand the geology and geomorphology of selected sites more than just their pure aesthetic beauties (Hose 1997). In the most recent definition, geotourism is viewed as a form of natural area tourism that specifically focuses on geology and landscape. It promotes tourism to geosites and the conservation of geodiversity and an understanding of Earth sciences through appreciation and learning. This is achieved through independent visits to geological features, use of geo-trails and viewpoints, guided tours, geoactivities and patronage of geosite visitor centres (Newsome and Dowling 2010a). The area presented here has the potential to provide the fundamental elements for geotourism such as the unique geological history, dramatic viewpoints, and specific geologically and geomorphologically significant locations that are specific to geological processes associated with convergent plate margin environment. In this respect, the Wairarapa Mudstone country needs significant attention and work to document and present geosites through educational panels (both on site and through virtual mediums), geotrails (both on site and virtually), establish visitor centers and develop programs where local communities can be engaged in activities revolving around the rich geology of the region. So far neither the local to regional focused initiative nor the development funds to establish the geotourism infrastructure are in place.

The region has an adequate secondary (unsealed) roading network. However, many of the roads run through private farmland so  future planning needs to include collaboration with local landowners to provide information about the geoheritage value of their land and to establish a relationship whereby increased visitor numbers will be viewed positively and not as an inconvenience.

The geological aspects of geotourism has recently become more important in the modern definition as a niche type of tourism. Geotourism hence needs to include opportunities to visit specifically and geologically centered geosites either independently or through organised (commonly guided) tours. It should include conservation elements and accurately transfer geological knowledge to visitors (Dowling 2014; Dowling 2015). All the necessary fundamentals for geotourism are present in Wairarapa Mudstone Country and priority needs to be given to its promotion in the next few years.

Based on this research work we plan an open discussion with local communities to establish how this work could be expanded, and its results utilized to grow geotourism in the region.

## Core of a Future Geopark?

The geological setting, outcrop exposure and accessibility of East Coast region of the North Island of New Zealand has all the elements necessary for a future geopark. Currently, New Zealand has only one application for UNESCO Global Geopark status under consideration. The Waitaki Whitestone Aspiring UNESCO Global Geopark is located in the east coast of the South Island of New Zealand. Its geological heritage is strongly linked to the geological evolution of Zealandia since its separation from Gondwana [https://www.whitestonegeopark.nz/], hence its geological context is different to that of the East Coast region of the North Island of New Zealand.

Convergent plate margins, such as the eastern region of the North Island of New Zealand, with a well-exposed sedimentary succession of a typical flysch environment are not uncommon, but a region where the processes are still on going and the succession records sedimentary environment changes since the early Miocene, and before, with superb, easy to access outcrops in a spectacular coastal scene are rare. In addition, very important cultural heritage locations for New Zealand are present in the region. These include archaeological locations where early Māori settlements flourished and contributed to the geocultural landscape evolution for the region (McFadgen 1980; Leach 1981; Chrisp 1993). The eastern coastal regions of New Zealand, including the Wairarapa, records many catastrophic geological events including earthquakes and tsunamis (Goff *et al.* 2000; Berryman *et al.* 2011; Clark *et al.* 2011; King *et al.* 2017), many of them likely responsible for the early Māori settlements to decline and move away (Goff and McFadgen 2001; 2002; 2003; Goff *et al.* 2004; McFadgen and Goff 2007). In the early colonial period, the region functioned as a major sheep and cattle station area, providing strong link to the global economic assets of the world that has transformed dramatically over the last 150 years (Hedley *et al.* 2010; Day 2011). Now the region seems an abandoned part of New Zealand in spite its globally significant social geology that can be defined as a complex geoheritage of the region. On the basis of this, it is clear, that the region has all that is needed, from geoheritage perspective, to be promoted and structured into a geopark, that might even reach global status if the local communities and the respected governing councils decide to move toward that plan.

## Conclusion

The East Coast of North Island, New Zealand, lies about 150km east of SH1, the main North Island tourist route of travellers. The region is home to outstanding geological features consistent with its convergent plate tectonic setting. Set in the accretionary prism the exposed succession includes an exceptional sequence of turbidite deposits. Elsewhere in the world, similarly impressive deposits are the foundation of UNESCO global geoparks, such as on the Basque Coast in Spain. To date New Zealand has fostered few geoparks despite the spectacular setting and fascinating geological history of many areas. The East Coast mudstone country, for example, is comparable to the iconic flysch deposits found in the North American Cordillera, the European Alps, the Pyrenees and the Carpathians, and warrants protection and geopark status.

East Coast of the North Island has spectacular sites with superb exposures in a modern subduction system. Regular earthquakes and the associated tsunami risk have left a record of geohazard events including faults, folds and tsunami deposits. The area has been the focus for geohazard and neotectonic research but its geoheritage value needs promotion through geotourism and formal conservation policies to preserve its unique qualities.

The geoheritage and cultural value of the East Coast needs to be acknowledged through geotourism and geoeducation so the results of the important geohazard and neotectonic research can be appropriately disseminated to both the local communities and visitors.  The region is accessible, and the uninterrupted views of the landscape and coastline means it offers a unique visitor experience to an area of global geological significance.

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## Supplementary Material 1

Field trip study guide for exploring the Wairarapa accretionary wedge ("mudstone country") is presented in separate file in the website.

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