Regional Plan Review

Schedule J - Significant geological features in the coastal marine area

Dr Iain Dawe

For more information, contact the Greater Wellington Regional Council:

Iain Dawe

Wellington
PO Box 11646

T (04) 830-4031
F 04 385 6960
www.gw.govt.nz

June 2014

www.gw.govt.nz
info@gw.govt.nz

Contents

1. Introduction

It has been recognised for a number of years that the Wellington region contains many geological and geomorphological features of outstanding scientific value. In 1975 the Wellington Regional Planning Authority published a report entitled; “Geological Features of the Wellington Region”, which identified the more important regional features and highlighted the need for policies to ensure their preservation. This work was revised and updated in 1985 and published as a second edition. These reports stemmed in part from the controversial quarrying of the Turakirae Head raised gravel beach deposits. At the time it was noted that many of the regionally significant geological sites were inadequately protected.

Since these reports were written, most Local Authorities in the Wellington region have included some geological sites of significance in the heritage/landscape schedules included in Regional and District Plans. The New Zealand Coastal Policy Statement 2010 (NZCPS 2010) now requires local authorities to identify and protect natural features in the coastal environment, including sites with geological values. A small list of outstanding geological features was included in Chapter 7 of the Regional Policy Statement for the Wellington Region (1995), but this was excluded from the Regional Policy Statement for the Wellington Region (2013) (operative RPS) and replaced with a policy that requires the NZCPS 2010 policy to be given effect by regional and district plans.

The operative Regional Coastal Plan for the Wellington Region (2000) contains areas of important and significant conservation and some of these sites, such as the Mana Bridge also have geological values. However, it does not contain a specific schedule of geological sites. The inclusion of geological features of regional significance in the coastal marine area in the Proposed Natural Resources Plan gives effect to the policies in the NZCPS 2010 and the operative RPS.

The coast is a very good place for studying geology as there are very good exposures in eroded cliffs and shore platforms of different rock units and strata that are generally easy accessible for scientific and educational research.

This report contains a summary of the geological assessment criteria and a discussion of the significance of the sites to be included in Schedule J – “Geological features of regional significance in the coastal marine area” (Appendix 1).

2. Statutory requirements

There are statutory reasons for including geological sites of significance in the regional plan. The NZCPS 2010, contains a policy directive to identify and protect natural features through Policy 15 – Natural features and natural landscapes:

“To protect the natural features and natural landscapes (including seascapes) of the coastal environment from inappropriate subdivision, use and development”

Relevant parts of the Policy 15 are:

(c) identifying and assessing the natural features and natural landscapes of the coastal environment of the region or district, at a minimum by land typing, soil characterisation and landscape characterisation and having regard to:

(i) natural science factors, including geological, topographical, ecological and dynamic components.

The operative RPS gives effect to this through Policy 25 - Identifying outstanding natural features and landscapes in district and regional plans:

District and regional plans shall identify outstanding natural features and landscapes having determined that the natural feature or landscape is:

(a) exceptional or out of the ordinary; and

(b) that its natural components dominate over the influence of human activity, after undertaking a landscape evaluation process, taking into account the factors listed below.

Natural science factors

(a) Natural science values: these values relate to the geological, ecological, topographical and natural process components of the natural feature or landscape:

(i) Representativeness: the combination of natural components that form the feature or landscape strongly typifies the character of an area.

(ii) Research and education: all or parts of the feature or landscape are important for natural science research and education.

(iii) Rarity: the feature or landscape is unique or rare within the district or region, and few comparable examples exist.

The Proposed Natural Resources Plan gives effect to these policies with a policy to manage the adverse effects on regionally significant geological sites:

GP.P148: Regionally Significant geological features

The adverse effects of use and development on the regionally significant geological features identified in Schedule J (geological features) shall be avoided.

This report will enable Policy GP.P148 to be given effect by identifying the regionally significant geological sites to be included in Schedule J.

3. Jurisdictional limitations

The Proposed Natural Resources Plan is restricted to considering only those features that lie below the mean high water springs (MHWS). There may be some features that straddle the MHWS jurisdictional boundary, such as Kupe's Sail on the South Wairarapa coast. In these instances, that part of the feature that lies in the coastal marine area (CMA), will be considered for inclusion in Schedule J of the Proposed Natural Resources Plan.

Whilst some sites considered to have geological significance will not able to be included in Schedule J, some sites may be included by default within schedules of other plans. For example, Lakes Kohangapiripiri and Kohangatera have been recognised for their ecological values in the operative RPS and the Hutt City District Plan, but the Lakes also contain a number of notable geological features.

It is important to note that there are often overlapping values at identified sites of significance. For example, features that have significance to mana whenua or for ecological reasons may also have significant geological values, such as Red Rocks/Pariwhero reserve on Wellington's south coast.

4. Previous work on geological sites in the coastal environment

As part of the review of the Regional Policy Statement (1995), Boffa Miskell were contracted to review the coastal sites of regional significance listed in Tables 8-10 of Chapter 7: The Coastal Environment, and to identify new sites to be considered for inclusion in the second generation Regional Policy Statement. Potential sites were assessed on the basis of their landscape, ecological, heritage and geological significance. The criteria by which these values were assessed and by which sites were selected for inclusion, were drawn from a range of published sources and expertise at Boffa Miskell.

Some preliminary geological criteria were developed during this process, but it was acknowledged that there is limited geological expertise within the organisation to develop geological criteria. To address this shortcoming, advice was sought from Professor Mike Crozier, School of Geography, Environment and Earth Sciences, Victoria University of Wellington. Professor Crozier noted that there are currently no best practice criteria available for assessing the significance of geological sites. It was agreed that the geological criteria needed to be developed in conjunction with a qualified expert, such as a geomorphologist.

Following this advice, the criteria were abandoned and sites were instead selected by relying on district plans and associated inventories, previous reviews of geological sites of the Wellington region, and related geological literature. Dr Nick Preston, School of Geography, Environment and Earth Sciences, Victoria University of Wellington, was engaged to review the sites identified and provide input into the site descriptions. Some sites and descriptions were also included at the suggestion of the author.

The majority of the sites identified were drawn from three main sources:

- A report by Kenny & Hayward (1996), "Inventory and maps of important geological sites and landforms in the Manawatu and Wellington regions", published by the Geological Society of New Zealand.
- A guide book by Homer & Moore (1989), "Reading the Rocks: A guide to the Geological Features of the Wairarapa Coast", published by the Institute of Geological and Nuclear Sciences.
- Geological sites listed in the various district and regional plans including: Wellington Regional Policy Statement (1995), Kapiti Coast District Plan (1999), Porirua City District Plan (1999) Hutt City District Plan (2003) Proposed Combined Wairarapa District Plan (2006) and the Wairarapa Coastal Strategy

The information contained within these reports and the Boffa Miskell work was reviewed by Dr Iain Dawe, Senior Natural Hazards Analyst and a report was prepared entitled: "Development of assessment criteria and peer review of geological sites in: Appendix 1: Sites of regional significance in the coastal environment, draft Regional Policy Statement for the Wellington region (2008)". Through the consultation, submissions and hearings process of the regional policy statement it was decided to drop the natural landscape schedules that contained geological sites and rely on Policy 25 to implement the requirements of the NZCPS 2010.

This body of work forms the basis for the current review of sites of regional geological significance for inclusion in the Proposed Natural Resources Plan.

5. Assessment criteria

There is no formally established methodology for assessing the significance of geological sites in New Zealand, but there are a few reports with useful guidance material that can be drawn upon. Two of these were reports identifying geological features for preservation in the Wellington region published by the Wellington Regional Council (Stephenson & Hill, 1975; Turner, 1985). A second group of reports were produced by the Geological Society of New Zealand (Kenny & Hayward, 1992, 1993, 1996) that part of the New Zealand Geopreservation Inventory. In addition, there are some excellent international examples that can be used provide some direction on the type of assessment criteria that can be used. For example, in 2004 a large study was undertaken for the UK Joint Nature Conservation Committee entitled "Assessing the conservation value of geological sites in the marine environment" (Furze & Roberts, 2004). The report was prepared by the Centre for Applied Oceanography based at the University of Wales. A summary of the criteria in these reports can be found in Appendix 2.

The principles outlined within these reports were used to develop a set of assessment criteria suitable for identifying and protecting sites in a Resource Management Act context for the Regional Policy Statement review. This work is contained within the report: "Development of assessment criteria and peer review of geological sites in: Appendix 1: Sites of regional significance in the coastal environment, draft Regional Policy Statement for the Wellington region (2008)."

One of the main adverse effects that can occur to sites of geological significance is damage or destruction from earth works or quarrying activity. However, there are other modifications to a site that may not directly destroy the feature, but act to cover or obscure the site, that prevent or inhibit research and interpretation of the feature. A good example of this occurred in Porirua in 1988. Excavation work during part of the Porirua CBD development, exposed a thick deposit of carbonaceous mud in a fossil gully, that has since been built over. Analysis of the pollen and plant material in the layer was able to provide information on the last 21,000 years of climatic and environmental conditions of the lower North Island (Mildenhall, 1993). Research of this nature is critical to understanding the current changes in the global climate.

In addition to purely geological values, sites have been considered for their coastal geomorphological significance. For example, there are sites that are significant for their geological rock formations and fossils and others for their landform features and process geomorphology. This means there are features of significance that are active and dynamic landforms of the contemporary coastal environment. Some of these are sites that coincide with the coastal environment and not necessarily formed by coastal processes, whilst others are landforms that are intrinsically coastal, ie, part of the CMA and formed by coastal or marine processes. This approach is consistent with the direction given in the NZCPS 2010 and the operative RPS.

The sites assessed contain or display one or more of the following significant geological features:

- Geomorphic landforms
- Earth deformation features
- Structural geology
- Sedimentary geology
- Metamorphic geology
- Igneous geology
- Minerals
- Fossils

5.1 Criteria for geological sites assessment

The criteria developed in the operative RPS report is used as the basis of the assessment to identify sites of geological significance for inclusion in Schedule J of the draft regional resource management plan.

There are four main criteria by which the sites have been assessed:

- The representativeness of the site or feature within the region, ie, rare to common

- The integrity of the site or feature, the degree of modification it has experienced and its potential for protection or restoration

- The vulnerability of the site or feature to disturbance and its potential for remediation if it was disturbed

- The scientific merit of the site or feature and the educational opportunities it presents

(a) Representativeness

The prevalence or rarity of the landform or feature around the region. Rarity may pertain to the unusualness of the landform and the processes responsible for its formation, or it may relate to its rarity in geological time. Several examples of a feature may need be selected if the sites form part of a group necessary for scientific research. For example, a series of uplifted marine terraces at different locations that illustrate a sequence of uplift events through geological time and for which there is only one example in each period. An assessment could use the following categories:

(i) unique or rare; only one or a few examples of its type in the region or nationally

(ii) uncommon; a small number at discrete locations in the region or nationally

(iii) relatively common in the region, but not abundant

(iv) widespread; widely occurring and abundant examples throughout region

(b) Integrity

The degree of modification that the site has experienced from either human activities or natural causes and its present degree of degradation or intactness. Takes into account the potential to protect or restore the site or feature:

(i) unmodified or little changed from original natural state

(ii) partially modified or impacted from original natural state and with good potential for protection and/or enhancement

(iii) modified or impacted from original natural state but with some potential for protection and/or enhancement

(iv) heavily modified from original natural state with little or no potential for restoration

(c) Vulnerability

Threats (eg, subdivision, development, earthworks, quarrying, dredging, sediment disposal) that have the potential to destroy or modify the site, presently and in the future. Takes into account the robustness of the site to impacts and the potential for remediation if the site was disturbed or further impacted:

(i) highly vulnerable to destruction or impacts from human activity with little or no potential for remediation

(ii) vulnerable to impacts from human activity with low potential for remediation

(iii) moderately vulnerable to impacts from human activity but with potential for remediation

(iv) low vulnerability and unlikely to be damaged by subdivision, use or development

(d) Scientific & Educational value

An educated judgment that assigns the site its degree of importance at an international, national, regional, or local level, taking into consideration: a.) previous research conducted at the site and its significance in the scientific literature, especially where this research has made important contributions to our understanding of the geology of New Zealand or the Wellington region; b.) the potential for future research to be conducted at the site that may provide important insights to the geology, geomorphology and active processes shaping the environment, including natural hazards; c.) the usefulness of the site for teaching geology and geomorphology. This measure will be somewhat subjective and based partly on the assessment of the first two criteria:

(i) international; a site of international scientific importance

(ii) national; a site of national scientific and educational importance

(iii) regional; a site of regional scientific and educational importance

(iv) local (ie, within TA district); a site with local importance

5.2 Suggested level of protection for geological sites

The criteria have been assigned a numerical value and ranked on the aggregated total. The rank has been used to define a required level of protection. Sites with an aggregate total of between 4-6 have been classified as Rank 1; sites between 7-11, Rank 2 and; sites 12-16, Rank 3.

Sites ranked 1 or 2 have been included in the Schedule J.

Rank 1: Sites of outstanding geological significance; activities non-complying or prohibited. Recommended for inclusion in Schedule J.

Rank 2: Sites of geological significance; activities restricted discretionary or discretionary. Recommended for inclusion in Schedule J.

Rank 3: Sites of geological importance; activities permitted or controlled. Not recommended for inclusion in Schedule J.

6. Schedule O geological sites of regional significance

A number of references have been drawn upon to identify, characterise and justify the sites of geological significance in the coast for Schedule J of the Proposed Natural Resources Plan including; scientific research articles; books; theses; conference proceedings; consultancy reports (commissioned by government or local government agencies); miscellaneous publications/reports/monographs by incorporated organisations and research institutes and; fieldtrip guides. This has been backed up by expert opinion and field surveys of all the sites.

A total of 24 sites have been chosen, spanning the region from Ōtaki to Mataikona. The full list can be seen in Appendix One.

6.1 Ōtaki River mouth hapua/lagoon

The Ōtaki River mouth is one of the few examples of a fluvially dominated, river mouth lagoon and barrier spit system in the North Island. These landform features are unique to braided gravel rivers and coarse sediment coasts and are internationally rare. New Zealand researchers have recognised them as a distinct landform feature and have granted them a specific name to differentiate them from more conventional river mouth estuaries – Hapua (Fig. 1).

A hapua is a type of river mouth lagoon common on mixed sand and gravel coasts and is characterised by the absence of saltwater flushing with the tides, rather, the flow is dominated by outward flowing freshwater. Hapua are commonly referred to as estuaries or lagoons, but these features are not estuaries or lagoons by any accepted scientific use of the term. They are typically associated with steeply sloping braided rivers delivering greywacke derived mixed sands and gravels. There is low tidal inflow and outflow of coastal water, with water levels controlled by tidal stage and river inflows. They are always fronted on the seaward side by a spits built by longshore sediment transport of sediments under wave action.

Since the 1930s the hapua has been modified by the construction of stop banks that have narrowed the river mouth and lagoon and in addition to semi-regular mouth cutting, this has restricted the growth and movement of the river mouth spits that ultimately control the size of the hapua. Whilst this has impacted on its natural functioning, it is nevertheless the only example of a ‘text-book’ hapua feature in the region. Thus it has scientific and educational merit as an example of the unique geomorphic coastal-river mouth features that are present in New Zealand’s coastline. Flood protection activities and development around the river mouth have the potential to further impact on the hapua and this should be consider when assessing the impacts from use and development activities (Hart, 2007; Kirk, 1991, 2001).

Figure 1. Ōtaki River mouth hapua/lagoon. **[PHOTO: Iain Dawe]**

6.1.1 Ōtaki River mouth hapua/lagoon significance classification

Criteria	Value	Classification
Representativeness	1	Regionally rare
Integrity	3	Modified
Vulnerability	3	Moderately vulnerable
Scientific & Educational Value	2	National significance
Total	9	Rank 2

6.2 Kāpiti Island phyllonite zone

Kāpiti Island is an uplifted and tilted fault block composed of argillite and greywacke of Triassic age (235-195 Ma). The western cliffs of the Island represent a major fault scarp. Okupe lagoon has formed on a low lying piece of land uplifted in the most geologically recent faulting events. This uplift has also stranded sea caves and beach ridges around the Island.

On the eastern side of the Island the NNE-trending Rangatira Fault passes through Rangatira Point and delineates the western side of a 500-700 m wide shear zone running parallel to the Island's eastern margin. Within this shear zone the original sedimentary rocks have been subjected to intense cataclysmic shearing and deformation due to fault movements. This has led to metamorphic reconstitution of the parent minerals into a new rock, known as phyllonite.

The phyllonite zone can be seen in contacts at Rangatira and Kurukohatu Points and on Motungarara and Tahoramaurea Islands and is a visual representation of the shearing and crushing of rocks that occurs along faults. Phyllonite contacts are uncommon in the region, and because this is unmodified by human activities the processes of fault tectonics can be examined for research and used as a teaching aid for students, without resorting to excavation or road cuttings (Fig. 2).

This example sits within a Department of Conservation reserve and faces a low risk of being impacted by use or development. Nevertheless, the risk is not nil, and this needs to be recognised to prevent activities that may impact on the site such as foundation drilling or jetty construction (Moore & Francis, 1988).

Figure 2. Kāpiti Island phyllonite zone. **[PHOTO: Iain Dawe]**

6.2.1 Kāpiti Island phyllonite zone significance classification

Criteria	**Value**	**Classification**
Representativeness	1	Regionally rare
Integrity	1	Unmodified
Vulnerability	4	Low
Scientific & Educational Value	3	Regional significance
Total	9	Rank 2

6.3 Pukerua Bay

Pukerua Bay sits at the southern end of the long coastline that runs from Cape Taranaki, through the Manawatu and Kapiti Coast ending at Wairaka Point. Much of this coast is sandy, backed by sand dunes sitting on top of an alluvial outwash plain. The end of this system ends at Pukerua Bay where it terminates in a steep, interglacial marine cut escarpment, rock shore platform and pocket gravel/cobble beaches. The site includes the scientific reserve and Wairaka Point/Te Ana a Hau (Fig. 3).

The shore platforms have developed in the hard, Wellington belt greywackes. Although there are other places within the region where greywacke shore platforms occur, they are nationally uncommon and the ones in Pukerua Bay are some of the best developed examples in the region. Research on shore platforms in New Zealand is internationally recognised and has contributed to a global understanding of the erosion processes responsible for how these landforms develop.

The well indurated nature of the greywackes has allowed a pronounced fault gouge of the Pukerua Fault to be preserved in the platform at the eastern edge of the site. These fault trace features allow researchers to investigate the seismic geology of the fault in order to understand the occurrence of earthquakes, rupture frequency and magnitudes, which contributes to a greater understanding of the earthquake hazards related to the feature.

Wairaka Point is a large and prominent rock stack composed of resistant greywacke left behind as the surrounding cliffs retreated. Fossils of *Torlessia mackayi* Bather occur on the south side of Pukerua Bay. Together as a group of geological and geomorphological features, Pukerua Bay is an educational and scientific location of regional significance.

The vulnerability of the site ranges from low to moderate with potential impacts coming mainly from erosion protection structures, stormwater infrastructure or slipway construction impacting on the backshore of the site (Litchfield & Van Dissen, 2014; Hughes & Kennedy, in prep; Kennedy et al, 2014; Hancox & Perrin, 2006; Suneson, 1992; Stephenson & Kirk, 2001; Taylor, 2003; Turner, 1985).

Figure 3. Pukerua Bay and Wairaka Point. **[PHOTO: Iain Dawe]**

6.3.1 Pukerua Bay significance classification

Criteria	Value	Classification
Representativeness	2	Uncommon
Integrity	2	Partially modified
Vulnerability	3	Moderate
Scientific & Educational Value	3	Regional significance

Total	10	Rank 2

6.4 Pauatahanui Inlet

The Pauatahanui Arm of Porirua Harbour is a fault controlled river valley system submerged in the Last Postglacial sea level rise known as the last Postglacial marine transgression (PMT). It is the only large estuarine wetland left in the lower half of the North Island and for this reason is a significant geomorphic feature representing this type of landform (Fig. 4).

One hypothesis is that it originally formed in the drowned river mouth and valley of the proto-Hutt River, prior to activation of the Wellington Fault the mid-Pleistocene c. 450 ka. Over time, uplift on the western side of the Wellington Fault formed the Belmont Hills and diverted the course of the river into what is now Wellington Harbour. Subsidence on the eastern side of the Ohariu Fault during the same period has caused the area to remain low-lying and swampy.

The Ohariu Fault passes through the western end of the inlet where it joins the Onepoto Arm. Research has shown that the inlet on the eastern side of the fault has been relatively tectonically stable for the past 8000 years. This is unusual in Wellington’s tectonically uplifted landscape, and is an important finding as the site can be reliably used to benchmark the post-Glacial rise in sea levels around the coast.

Terraces formed in the alluvium of this former river valley can be seen on either side of the inlet. Beach terraces in the northeastern section of the inlet exhibit an almost complete record of late Quaternary (Holocene) sedimentation and sea level fluctuation and due to the absence of deformation are considered representative of former sea levels. Stratigraphy within the sediments of the harbour floor provide a record of climatic, tectonic, geomorphological and sea level changes that have been used to build a picture of the regional tectonics and Last Postglacial sea level changes over the past 14,000 years.

Pressures from development, housing, roading and stormwater infrastructure all have the potential to modify or build over scientific and geological sites around the harbour. Perhaps more significantly, sedimentation rates in the inlet have increased 10 fold over long term geological rates due to human impacts and infilling of the estuary threatens to modify its functioning (Cotton, 1952; Gibb, 2012; Leamy, 1958; Milne, 1980; Turner, 1985).

Figure 4. Pauatahanui Inlet. **[PHOTO: Iain Dawe]**

6.4.1 Pauatahanui Inlet significance classification

Criteria	Value	Classification
Representativeness	1	Regionally rare
Integrity	2	Partially modified
Vulnerability	3	Moderate
Scientific & Educational Value	2	National significance
Total	8	Rank 2

6.5 Whitireia coast

The northwest facing cliffs and shore of Whitireia Peninsula display shore platform and coastal cliff development in the Triassic aged, Wellington belt greywackes of the Torlesse Complex. Torlesse Complex rocks are difficult to map as they do not generally have distinctive bedding and contain few fossils. This exposure displays a flysch sequence of interbedded argillite and greywacke lithofacies with uncommon inclusions of deep ocean derived sedimentary and volcanic rocks including basalt, mudstone conglomerate, chert and limestone (Fig. 5).

Rare trace fossils from the foraminifera *Torlessia mackayi* Bather are present west of Kaitawa Point.

There is evidence in the cliffs and shore platforms of down-folding in Rocky Bay and east of Kaitawa Point.

This site represents a very good exposure, with a range of rock types and rare fossils with easy access for scientific and educational research. The flysch sequence continues under Titahi Bay and is exposed again in the shore platforms along the southern shoreline of the Bay. A more in-depth explanation of the significance of this rock feature and its formation is outlined in section 6.7 (Speden, 1976; Suneson, 1992, 1993; Turner, 1985; Webby, 1959).

Figure 5. Whitireia Coast. **[PHOTO: Iain Dawe]**

6.5.1 Whitireia coast significance classification

Criteria	Value	Classification
Representativeness	2	Uncommon
Integrity	1	Unmodified
Vulnerability	4	Low
Scientific & Educational Value	3	Regional significance
Total	10	Rank 2

6.6 Titahi Bay fossil forest

Buried beneath Titahi Bay beach is a series of carbonaceous silt and peat beds containing in situ subfossil tree stumps (Fig. 6). The beds are around 10 m thick and rest unconformably on the underlying greywacke basement rocks. The assemblage is overlain by rusty stained sands and well rounded gravels. It is thought the stumps are mostly rimu, but matai and totara pollen has also been identified in the associated sediments. Radiocarbon dating indicates the wood is older than 35,000 years (>35 ka) and probably dates from the last Interglacial (120-80 ka). Subfossil tree stumps are not a common occurrence anywhere in the world and the Wellington region is fortunate to have two localities where they can be observed, the other site being the Kaiwhata River mouth in the Wairarapa.

During periods of cold periglacial conditions in the Wellington region, forests retreated from higher elevations, as the snow line dropped, to lowland and coastal refuges where the climate was more suitable for forest tree growth. At the same time, sea levels dropped as water become locked up in ice sheets. During this time the Porirua shoreline was several kilometres westward of its current position. Titahi Bay part of a low lying valley and Mana Island was connected to the mainland. Thus, the fossil beds probably represent a podocarp forest growing a swampy forest valley floor around 100,000 years ago. As sea levels rose during the last Interglacial marine transgression, the beds were drowned and covered over with a layer marine sands and gravels. Evidence for this can be seen in the cliff at the south end of the Bay, which is composed of cemented marine sands and overlies the fossil stump beds. During this time sea levels rose 2-4 m higher than present.

The stumps closest to the surface are intermittently uncovered by storm erosion and are visible around the mid to low tide mark. The stumps have been largely unmodified apart from some abrasion and scuffing where they get exposed to surf processes or have been driven on. However, it has been reported that in the past some of the stumps on the beach were damaged by boat launching activities.

The Titahi Bay fossil forest is internationally uncommon and excellent example of a paleo-environment for scientific and educational research. It provides a record of environmental conditions during the last Interglacial period. Understanding the historical climate is important for climate change research and future climate projections.

The stumps are vulnerable to damage and disturbance from vehicles, boat launching, machinery, beach grooming and vandalism and there would be no way to remediate the damage if it occurred (Begg & Mazengarb, 1996; Campbell, 1996; Gibb, 2012; Mildenhall, 1993).

Figure 6. Titahi Bay fossil forest. **[PHOTO: Iain Dawe]**

6.6.1 Titahi Bay fossil forest significance classification

Criteria	Value	Classification
Representativeness	1	Nationally rare
Integrity	2	Partly modified
Vulnerability	2	Vulnerable
Scientific & Educational Value	2	National significance

Total	7	Rank 2

6.7 Titahi Bay flysch sequence

Along the southern Titahi Bay shoreline is an exposed flysch sequence in the rock shore platform that provides an excellent scientific and educational field research site. It is a continuation of the sequence that occurs around the Whitireia Peninsula.

Flysch is a sequence of alternating or interbedded sedimentary strata deposited in a deep, low energy marine basin punctuated by higher energy turbidity flows. In this instance, the deposition has occurred in a deep trench, also referred to as the New Zealand Geosyncline, from sediments eroded off the Gondwana landmass in the Late Triassic (215-205 Ma). The Titahi Bay sequence provides a record of the erosion and deposition of Gondwana sediments prior to uplift of the present day New Zealand landmass.

The Titahi Bay Flysch consists of repeated sedimentary cycles with upwards fining of the sediments. At the bottom of each cycle are coarser sediments which gradually evolve upwards into sandstone (greywacke) and mudstone (argillite). The coarser layers or turbidites represent higher energy disruptions caused by turbidity currents or submarine landslides off the Gondwana continental slope. The argillite was deposited as fine material (mud, clay, silt) out of suspension, either associated with the turbidity currents or as normal background deposition during the intervals between turbidity flows (Fig. 7).

Analysis of the sediments that make up the flysch can tell us about the original Gondwana rocks they were derived from. The composition of the sandstones indicates that they were derived from a landmass composed of relatively unweathered granites and granodiortites.

The Titahi Bay flysch exhibits graded bedding and lamination, convolute and cross lamination, mud flake inclusions and current markers that are all indicative of the depositional environment of the facies. Within the sequence there is evidence of intense fracturing and folding the whole feature is cut through with small scale faulting.

Because of the important record exposed in the geology at this site, it is popularly used for teaching purposes and has regional significance for this reason. It is moderately vulnerable to damage from development, infrastructure construction, and heavy machinery (Korsch & Morris, 1987; Speden, 1976; Suneson, 1992; 1993; Webby, 1959).

Figure 7. Titahi Bay flysch sequence. **[PHOTO: Iain Dawe]**

6.7.1 Titahi Bay flysch sequence significance classification

Criteria	Value	Classification
Representativeness	2	Uncommon
Integrity	1	Unmodified
Vulnerability	3	Moderate
Scientific & Educational Value	3	Regional significance
Total	9	Rank 2

6.8 The Bridge

The bridge is a shallow submarine bathymetric feature covering an area of seabed 330 ha in extent between Green Point near Titahi Bay and Shingle Point on Mana Island. In the last glacial period, when sea levels were lower, Mana Island was part of the mainland. Effectively, it connects Mana Island to the mainland, making Mana Island a ‘land bridge island’. In fact, there are accounts of early European settlers driving cattle across the bridge at low tide on large sand banks that had deposited in the shallow waters. Presently the water depths vary from 6-9 m across the feature (Fig. 8).

Not a lot of research has been conducted on its formation but there are a number of avenues for research. It is possible that there is an underlying structural cause such as faulting that has gradually uplifted the area. Alternately, it could be an erosion surface ie, the resistant basement of a larger piece of land that has since eroded and left a remnant island.

It is a regionally unique feature in a relatively unmodified state with low vulnerability for impact from development (Williams, 1976).

Figure 8. The Bridge. **[PHOTO: Iain Dawe]**

6.8.1 The Bridge significance classification

Criteria	Value	Classification
Representativeness	1	Regionally Unique
Integrity	1	Unmodified
Vulnerability	4	Low
Scientific & Educational Value	3	Regional significance
Total	9	Rank 2

6.9 Rock Point Triassic fossils

Rock point is significant as a location where some of the very few fossils found in rocks of the Torlesse Complex greywacke's and argillite's can be found (Fig. 9).

During the Middle to Late Triassic (220-200 Ma), as the Wellington belt greywacke facies were being deposited, relatively primitive but large foraminifera lived in the mud and silt layers that eventually became argillite. The foraminifera burrowed through the sediments on the seafloor foraging for organic detritus. As they burrowed, they accumulated grains of sediment on the inside of their tests (shells) that became cemented to form a reinforced lining; a process known as agglutination.

It is thought they lived in deep sea abyssal environments which experienced turbidite sedimentation. Similar trace fossils of interbedded flysch lithofacies have been described worldwide, and this is consistent with the depositional environment of the Wellington belt greywackes within the New Zealand Geosyncline.

This is the only site in the region at which fossils of both *Torlessia mackayi* Bather and *Titahia corrugata* Webby occur together, and it is the type locality of the latter ie, the site at which they were first described. The *Torlessia* dates from the mid to late Triassic and the *Titahia* from the late Triassic.

The site is reasonably unmodified but faces threats from over collection of the fossils. Any development at the site would need to consider the impact on the fossils, because it would be difficult to remedy or mitigate impacts on the site (Hannah & Collen, 1995; Speden, 1976; Webby 1958).

Figure 9. Rock Point and *Titahia corrugata* Webby. [PHOTO: Geological Collections, University of Auckland]

6.9.1 Rock Point fossils significance classification

Criteria	Value	Classification
Representativeness	2	Uncommon
Integrity	1	Unmodified
Vulnerability	2	Vulnerable
Scientific & Educational Value	2	National significance
Total	7	Rank 2

6.10 Pariwhero/Red rocks

The region's Torlesse rocks tell a complex geologic story that can be interpreted in the eroded cliffs and shore platforms around the coast. The Torlesse Complex rocks are largely composed of sediments deposited along the margins of Gondwana in a zone where an oceanic plate was being subducted under a continental plate.

Pariwhero/Red Rocks is a steeply dipping sequence of oceanic metabasalts and coloured argillites incorporated within the basement Torlesse greywackes. It contains minor folds and is traversed by several faults that visibly cut through the strata. It contains a diverse range of minerals and lithological units including, chert, jasper, coloured argillite, malachite, pillow lava and radiolarian micro fossils (Fig. 10).

The metabasalts are associated with the eruption of volcanic material through the seafloor sediments that were accumulating in a marine basin during the Late Triassic period (225-195 million years ago). These were probably seamounts. It is a minor rock type within the Wellington belt greywackes, normally as small, discrete lenses. At Pariwhero/Red Rocks however, dark red and purple pillow lavas are up to 54 m thick. Basaltic pillow lavas were formed by the reaction of hot lava with sea water which broke the lava into a mass of ‘pillows’. It is the best exposed and most easily accessible pillow lava site in the Torlesse Complex rocks in the Lower North Island.

The red, green and grey coloured argillite sequence is the most notable in the region. The chemistry of the coloured argillites is similar to the black argillites, except with the inclusion of several trace metalliferous and biogenic elements including silicon, iron, nickel and manganese. In particular, the red colouring comes from the iron oxide, hematite, which imparts a rusty red colouring of various shades.

With increasing amounts of biogenic silica, the argillites grade into cherts, which range in colour from grey to pink to red. The red cherts grade into jaspilite, from which jasper is derived; a semi-precious stone used in jewellery. The jaspilite has formed from silica being leached by steam from rapidly cooling lava and becoming incorporated into the argillite muds.

Many of the jaspilite beds contain radiolaria fossils. Radiolaria are marine protozoa, 0.1–0.2 mm in diameter, that produce intricate mineral skeletons. They are found as zooplankton throughout the ocean and their skeletal remains make up a large part of the cover of the ocean floor as siliceous ooze. They have the ability to rapidly evolve to changing environmental conditions and consequently they represent an important diagnostic fossil for aging rock strata. The radiolaria at Pariwhero/Red Rocks have been dated as Late Permian age (280-260 Ma) and are some of the oldest known fossils extant in the North Island. The red and grey argillites on the eastern of the Pariwhero/Red Rocks reserve contain ellipsoidal carbonate concretions, some of which contain radiolarian bearing phosphorite.

The cherts and jaspilite are much older than the enclosing Late Triassic greywacke and argillite and this is indicative of the geological processes that have uplifted and created the country. In this instance, it is interpreted as layers of the ocean floor that have been pushed toward the edge of the Gondwana continent, where they piled up and deformed, forming a huge wedge called an accretionary prism. This accretionary prism was then shaved off the oceanic crust as it was subducted under the Oceanic Plate. This has tilted and pushed up a melange (mixture) of different rocks including greywacke, argillite, basalt, limestone, breccia and chert. Evidence of imbrication can be seen in the Torlesse Complex rocks.

Overall, the site has high educational and scientific importance. It contains a wide range of geological processes and rock formations that illustrate the earliest formation of New Zealand. However, is vulnerable to damage from fossicking and development, with little potential for remediation if it was damaged. Pariwhero/Red Rocks was gazetted as a scientific reserve in 1972 and is currently administered by the Department of Conservation (Begg & Mazengarb, 1996; Reed, 1958; Stephenson, 1975; Suneson, 1993).

Figure 10. Pariwhero/Red Rocks. **[PHOTO: Iain Dawe]**

6.10.1 Pariwhero/Red Rocks significance classification

Criteria	Value	Classification
Representativeness	1	Rare
Integrity	1	Unmodified
Vulnerability	2	Vulnerable
Scientific & Educational Value	2	National significance
Total	7	Rank 2

6.11 Island Bay/Taputeranga lawsonite

The Torlesse Complex rocks of the region contain some volcanics and associated mineral assemblages that indicate metamorphic processes. At Island Bay/Taputeranga, a rare occurrence of vein lawsonite occurs within the metabasalt volcanics, that are also seen at Pariwhero/Red Rocks. The lawsonite has a textbook mineral composition with only minor impurities (Fig. 11).

The presence of the lawsonite indicates higher pressure conditions that led to prehenite-pumpellyite grade metamorphism in some parts of the basement rocks of the region. This is significant because the Wellington belt greywackes are only semi-metamorphosed and the lawsonite indicates that other processes were occurring within the development of the basement rocks. It provides information for geologists that can be used to determine the temperature, pressure and depth of burial and provide clues about the conditions that accompanied the uplift and erosion of the Torlesse Complex rocks and in a broader context, the tectonic development of New Zealand.

The lawsonite is important for the scientific research on the geotectonics of the region and New Zealand, but is moderately vulnerable to fossicking and development that could disturb the veins of rock in which it resides (Begg & Mazengarb, 1996; George & Grapes, 1987).

Figure 11. Island Bay/Taputeranga lawsonite. **[PHOTO: Iain Dawe]**

6.11.1 Island Bay/Taputeranga lawsonite significance classification

Criteria	Value	Classification
Representativeness	1	Rare
Integrity	1	Unmodified
Vulnerability	3	Moderately vulnerable
Scientific & Educational Value	2	National significance
Total	7	Rank 2

6.12 Te Raekaihau Point

Te Raekaihau Point forms the western head to Lyall Bay. Much of the exposed reef here was uplifted in the 1855 Wairarapa earthquake. This earthquake was the largest to occur in New Zealand’s recorded history. It is estimated to have been a M8.2 earthquake. The vertical uplift at Turakirae Head was around 6.5 m and Wellington Harbour was uplifted between 1.5 – 2.0 m. In effect, the whole western half of the region from Turakirae Head to Porirua was tilted westward.

A record of this event is recorded in the coastline around the region, including Te Raekaihau Point, as a prominent uplifted beach ridge. The vertical uplift here during the 1855 Wairarapa earthquake is estimated to have been around 1.5 m. In fact, Te Raekaihau Point displays a series of uplifted beach ridges that correspond to different uplift events that can be dated and correlated to similarly elevated beach ridges in the area. One of these sits at 2.4-3.0 m, and is associated with the 1460 Hao-whenua earthquake event. This helps build up a picture of the local tectonics shaping the region and provides valuable information to understanding local seismic hazards (Fig. 12).

The preservation of these beach ridges is most prominent in gravel shorelines, but because they are composed of unconsolidated sediments, they are vulnerable to disturbance from activities such as gravel extraction, boat launching or boat ramp or road construction At many places in the region, the beach ridges have been built over or mined for aggregate. In these instances, the damages are irreparable. The beach ridges at Te Raekaihau Point have been modified somewhat by vehicles and carpark construction, but are still visibly present for scientific and educational analysis (Begg & McSaveney, 2005; Cotton, 1974; Kennedy & Beban, 2005; Stevens, 1973).

Figure 12. Te Raekaihau Point. [PHOTO: Iain Dawe]

6.12.1 Te Raekaihau Point significance classification

Criteria	Value	Classification
Representativeness	2	Uncommon
Integrity	2	Partially modified
Vulnerability	2	Vulnerable
Scientific & Educational Value	3	Regional significance
Total	9	Rank 2

6.13 Moa Point/Hue te Taka

Moa Point forms the eastern head to Lyall Bay. Like Te Raekaihau Point, much of the exposed reef here was uplifted in the 1855 Wairarapa earthquake and represents a continuation of the record of the event as recorded in the coastline around the region.

Moa Point displays a series of uplifted beach ridges that correspond to different uplift events that can be dated and correlated to similarly elevated beach ridges in the area, such as Te Raekaihau Point. This helps build up a picture of the local tectonics shaping the region and provides valuable information to understanding local seismic hazards (Fig. 13).

The preservation of these beach ridges is most prominent in gravel shorelines, but because they are composed of unconsolidated sediments, they are vulnerable to disturbance from activities such as gravel extraction, boat launching or boat ramp or road construction At many places in the region, the beach ridges have been built over or mined for aggregate. In these instances, the damages are irreparable. The beach ridges at Moa Point have been modified somewhat by vehicles and carpark construction, but are still visibly present for scientific and educational analysis (Begg & McSaveney, 2005; Cotton, 1974; Kennedy & Beban, 2005; Stevens, 1973).

Figure 13. Moa Point / Hue te Taka. **[PHOTO: Iain Dawe]**

6.13.1 Moa Point/Hue te Taka significance classification

Criteria	Value	Classification
Representativeness	2	Uncommon
Integrity	2	Partially modified
Vulnerability	2	Vulnerable
Scientific & Educational Value	3	Regional significance
Total	9	Rank 2

6.14 East Harbour coast

The East Wellington Harbour Coastline from Bluff Point, and Pencarrow Head to Point Arthur contains a series of pocket mixed sand and gravel beaches that illustrate the interaction between tectonic, earth building forces and contemporary beach processes and sedimentation (Fig. 14).

Mixed sand and gravel beaches are internationally rare, but in parts of New Zealand are a more common occurrence. The processes and geomorphology of these beaches are different to sandy beaches. This has meant that many of the models developed for sandy beaches do not apply to their gravel and mixed sand and gravel counterparts. New Zealand coastal scientists have made a significant contribution to the international understanding of the dynamics of these beaches. This research has been important because many mixed and sand and gravel beaches are eroding for reasons that have not always been clearly understood. This erosion presents a severe hazard in many places, threatening infrastructure, farm land, private property and houses and in some places, whole communities.

The 1855 Wairarapa earthquake uplifted this section of coast in the order of 2.0 m. There are beach ridges preserved in sections of the shoreline that can be used for comparative analysis of similar beach ridges to both the east and west in order to understand the nature of the uplift during the event. The analysis reveals that uplift was in the order of 6.5 m at Turakirae Head and dipping to the west which has shown up in decreasing elevations of the beach ridges west of the Wairarapa fault.

Research into the mixed sand and gravel beaches along this coast has been used to interpret the process geomorphology and development of this shoreline over the past 160 years, since the Wairarapa earthquake in 1855. In many places along the east harbour coastline the beaches suddenly became sandy in 1855 from the finer material that was uplifted from the seabed nearshore environment. A new equilibrium began to form between the wave and current hydrodynamics and the new shoreline. Over time, the finer material was eroded back onto the harbour floor and many parts of the Eastbourne shoreline began to erode in the early and mid parts of the 20th century. At the same time, large amounts of gravel from landslides caused by the earthquake in the river catchments were being transported out to and along the coast from the Orongorongo and Wainuiomata rivers. This material slowly filled up the pocket beaches, between the rock headlands uplifted in the earthquake, in series from south to north. Eventually the mixed sands and gravels filled all the smaller compartments, allowing the material to bypass the headlands and be transported toward the Eastbourne coast, whereupon is has been replenishing the coast that was previously eroding.

Whilst mixed sand and gravel beaches do occur in other places in the region, they are not overly common, and this stretch of coast is a rare example of the interactions between long term tectonics and dynamic contemporary processes. It has had some modifications from the construction of a road, but the shoreline is intact and well accessible for academic research and teaching. It is moderately vulnerable to development and in particular from hard engineering structures such as seawalls and groynes that can interfere with the natural progression of sediment along the coast (Dunbar et al, 1997; Hull & McSaveney, 1996; Kirk, 1980, 2001; Matthews, 1980a, 1980b; Olson et al, 2012).

Figure 14. East Harbour coast. **[PHOTO: Iain Dawe]**

6.14.1 East Harbour coast significance classification

Criteria	Value	Classification
Representativeness	1	Rare
Integrity	2	Partially modified
Vulnerability	3	Moderate
Scientific & Educational Value	2	National significance
Total	8	Rank 2

6.15 Mukamuka basalt breccia

Red, brown and green volcanic rocks exposed just east of the Mukamuka Stream were formed by Jurassic Period eruptions from seamounts (190-140 Ma). Unlike the older basalt volcanics at Pariwhero/Red Rocks, that were extruded as a series of lobate pillow lavas, many of the volcanics here exploded on contact with the cold sea water. This resulted in a deposit made up of angular fragments of basalt that then became loosely welded together to form a type of rock known as a volcanic breccia. As this process occurred around a submarine seamount volcano, some of the cement that helped weld the breccia was white coloured calcite, a form of calcium carbonate, creating an attractive red-brown, green and white patchwork in the rocks. Pillow lavas also occur here, along with a rarer round-stone volcanic conglomerate and limestone (Fig. 15).

The Mukamuka volcanics are one of the few places where a known stratigraphic contact occurs between the clastic greywacke and argillite sequences and volcanics in the region. Contacts or exposures in other localities are either faulted or not exposed (ie, by more contemporary geomorphic processes such as coastal erosion).

The basalts here erupted into a younger belt of greywackes and argillites within the Torlesse Complex, known as the Rimutaka belt. Basalts are more common in this belt than they are in the Wellington belt rocks and they are generally much thicker and blockier. The volcanics the Mukamuka Stream mouth are around 400 m thick.

The age of the rocks become younger from west to east in the region and the Mukamuka site is part of the scientific jigsaw that contributes to the interpretation of the geological development of the country (Begg & Mazengarb, 1996; Campbell et al, 1993).

Figure 15. Mukamuka basalt breccia. **[PHOTO: Iain Dawe]**

6.15.1 Mukamuka basalt breccia significance classification

Criteria	Value	Classification
Representativeness	2	Uncommon
Integrity	1	Unmodified
Vulnerability	4	Low
Scientific & Educational Value	3	Regional significance
Total	10	Rank 2

6.16 Lake Onoke and barrier spit

The Lake Onoke ‘spit’ and lake complex is a nationally significant site and one of only two such landform features of this type in New Zealand; the other being Te Waihora/Lake Ellesmere. It is a geologically young, Holocene aged feature, having formed only in the last few thousand years, but it reflects a range of tectonic, sedimentological and geomorphological processes that has significance to the national and international scientific community (Fig. 16).

The ‘spit’ is around 3.5 km long and up to 350 m at its widest and is in fact a barrier beach (ie, a beach that separates two bodies of water and is connected to land at both ends). It has formed by sediment transport across the mouth of a shallow embayment, connecting two headlands to impound a shallow, brackish coastal lake. The Lake covers an area of around 6.5 km^2 and is less than 4.0 m deep. The barrier beach is composed of a heterogeneous mix of sand and gravel sediments derived from cliff erosion and rivers and streams draining into Palliser Bay. Erosion of the eastern end of the barrier has created the appearance of a spit that has grown from the west, but sediment transported along the foreshore from southerly waves breaking at an angle to the coast have grown the spit from east to west. Once the distal end of the spit connected to land it enclosed the lake and it became a barrier beach. Intermittent breaching of the barrier beach at the eastern end, near Lake Ferry has eroded this end of the feature, that is now artificially cut. During dry periods the entrance closes off and the salinity declines and it operates as a true Lake. When the entrance is open, seawater can enter the lake and it operates more like a tidal lagoon.

Lake Onoke is the only place in New Zealand where foraminifera have been recorded living above the extreme high water mark. This is higher than previously documented and is a finding that has significance for interpreting biogenic and sedimentary facies from similar locations around New Zealand. Foraminifera are used as markers for dating sedimentary layers and for providing an indication of the depositional environment in which the foraminifera lived, such as whether it was a freshwater or marine dominated.

A study of the foraminiferal fossils indicates that between around 7000-4000 years B.P., the lower 30 km of the southern Wairarapa Valley, from at least the head of Lake Wairarapa, was a large intertidal embayment. Over his time, rivers draining the Valley slowly infilled the bay to create extensive intertidal mudflats. However, it remained marine dominated because the area was experiencing tectonic subsidence of around 1-2 mm/yr that kept apace of the sediment accumulation. Around 4000-3000 years B.P. the subsidence slowed and the rate of infilling increased. This was accompanied with major uplift displacements on the Wairarapa Fault that may also have shifted the course of the Ruamahanga River to a more southerly outlet on the eastern side of the embayment. This caused rapid infilling in the middle section of the embayment that led to the development of a shallow, freshwater ‘ancestral Lake Wairarapa’.

Gravel transported along the coast from east to west under southerly wave action began to build a spit across the remaining embayment. Eventually the distal end of the spit connected back to the mainland to form what is technically a barrier beach and enclosed what is now Lake Onoke. This was aided by a fall in the eustatic sea level from the Postglacial highstand.

In the mid-19th Century the Lake outlet was at the western end of the barrier spit, through what is now Kiriwai Lagoon. After the 1855 Wairarapa earthquake the outlet shifted to the eastern end of the Lake at what is now Lake Ferry, creating the illusion that the spit grew from the west. Sea level is now rising again and this will lead to a renewed phase of geomorphological change that will provide important information for researchers about how gravel and mixed sediment beaches will respond to sea level rise over the coming decades.

The Lake Onoke complex partially modified by reclamation and draining around the edges and is periodically artificially opened and is vulnerable to further reclamation and sediment infilling from runoff. But it is an outstanding feature of this type, that is nationally rare and locally unique. Mixed sand and gravel beaches are uncommon shorelines types and the examples that occur in New Zealand are internationally significant. Moreover, this site offers opportunities for research into both open coast and lacustrine mixed sediment beaches (Rhodes, 2012; Hayward, et al, 2011; Dawe, 2006; Kirk, 2001; Hemmingsen, 1997; Matthews, 1983; Schulmeister & Kirk, 1993; Leach & Anderson, 1974).

Figure 16. Lake Onoke. **[PHOTO: Greater Wellington Regional Council]**

6.16.1 Lake Onoke and barrier spit significance classification

Criteria	Value	Classification
Representativeness	1	Regionally Unique
Integrity	2	Partially modified
Vulnerability	2	Vulnerable
Scientific & Educational Value	2	National significance
Total	7	Rank 2

6.17 Kupe’s Sail/Ngā Rā o Kupe

Ngā Rā o Kupe or Kupe’s Sail, is actually two triangular cliffs of light coloured sandstone that resemble the sails of a Polynesian sailing canoe. According to Māori oral tradition, Kupe and his companion Ngake camped at the site during their travels around New Zealand and argued over who could make a sail the fastest. Kupe completed his sail before Ngake and won the contest, after which they hung the sails up against the cliffs (Fig. 17).

The Sails are outcrops of late Miocene sandstone (ca. 15 Ma) dipping west at an angle of 45 degrees. The sandstone is compacted and well bedded and one of the patches, immediately east of the mouth of Kupe Stream, is a very prominent dip slope. Abundant fossils are present in the sandstone that include the remains of barnacles, sea urchins and brachiopods, indicating the depositional environment was a shallow marine environment close to shore. Similar beds occur further to the west in Hurupi and Putangirua Stream.

The sandstone rests unconformably on darker coloured Wairarapa Belt greywackes and argillites, which continue northwards to form the Aorangi Ranges. The sandstone has been tilted down along a northeast trending fault cutting the coast close to the mouth of Kupe Stream. This down-tilting has preserved the sandstone along the fault.

The Wairarapa Belt greywackes in this area are contain no fossils but are thought to be of late Jurassic to early Cretaceous age (ca. 130 Ma), ie, younger than the Wellington Belt rocks. These rock Terranes become older as they progress from east to west across the region and the outcrops in locations like this provide good access for scientific and educational research.

Late Miocene marine beds formerly covered most of the greywacke and argillites of the Aorangi Mountains, but subsequent uplift and erosion have removed most of them except on the flanks and where they have been downfaulted, such as at Kupe's Sail.

In Kupe Stream these rocks are intruded by igneous pillow lavas (altered submarine basalt flows) that become interbedded with volcanic tuffs towards Cape Palliser.

It is an extremely well defined landform of scientific and educational value. It has been partly modified around its base by road construction, and road and shore protection works from coastal and cliff erosion are the main threats to the preservation of the feature (Challis, 1960; Homer & Moore, 1989).

Figure 17. Kupe’s Sail/Ngā Rā o Kupe. **[PHOTO: Iain Dawe]**

6.17.1 Kupe’s Sail/Ngā Rā o Kupe significance classification

Criteria	Value	Classification

Representativeness	1	Unique
Integrity	2	Partly modified
Vulnerability	3	Moderate
Scientific & Educational Value	3	Regional significance
Total	9	Rank 2

6.18 Cape Palliser/Matakitaki

Cape Palliser is a dramatic geologic feature at the southern most tip of the North Island. The rocks are late Jurassic age volcanic ‘pillow lava’, formed in a series of undersea eruptions over 100 million years ago. It remains because it is harder than the older basement greywackes that have eroded around it leaving a series of long fingers of volcanic rock pointing south into Cook Strait (Fig. 18).

The igneous rocks here contain a mix of different mineral assemblages including spilites, altered dolerites and camptonites. In between the various lava flows, that are up to 5 m in thickness, are thin bands of green and red cherts formed from microscopic Radiolaria fossils. These organisms have silicate skeletons, which can be used to establish the age of the rocks.

Spilite is a partially metamorphosed basalt (metabasalt) that has originally formed from basaltic lava reacting with seawater. The spilites at Cape Palliser are massive, dark greenish-grey rocks that display a good pillow structure. They are more coarse grained than is usual for a spilite with the main mineral constituents being feldspar (albite and orthoclase) and green chlorite, together with crystals of titanium rich pyroxenes.

The greywacke-argillite-chert sequence is punctuated with volcanic dykes and sills that contain altered dolerites and camptonites. The camptonites are considered to be related to the volcanic intrusives found in the Inland Kaikoura Ranges and the Awatere Valley.

Volcanic breccias and random fold axis directions indicate that submarine slumping has occurred in the sediments as they were being laid down.

Overall, this site provides an excellent scientific and educational geological study area that is easily accessible and provides information about the formation of the middle part of New Zealand. The site is little modified, with the only threats coming from potential disturbance from shore protection works (Challis, 1960; Homer & Moore, 1989).

Figure 18. Cape Palliser/Matakitaki. **[PHOTO: Iain Dawe]**

6.18.1 Cape Palliser/Matakitaki significance classification

Criteria	Value	Classification
Representativeness	2	Uncommon
Integrity	2	Partly modified
Vulnerability	4	Low
Scientific & Educational Value	3	Regional significance
Total	11	Rank 2

6.19 Te Rakauwhakamataku Point

Te Rakauwhakamataku Point is a unique geological feature in the region and a surf reef of national significance. There is a striking difference in its appearance from high tide, when it is covered in water, to low tide when it is uncovered to reveal a dumbbell shaped reef feature. The reef is a resistant greywacke remnant of a (formerly) larger rock stack left standing as the softer, sedimentary rock and outwash fans, that characterise this coast, were eroded back more quickly. It is a good illustration of the differential weathering and erosion of landforms in the contemporary environment (Fig. 19).

The nearshore bathymetric profile of the reef combined with its orientation and exposure to a high energy swell environment make it an exceptionally good surf reef. It is an excellent example of the way in which nearshore bathymetry acts to control wave formation and breaking.

It is largely unmodified and faces few threats from development but it is a geomorphic feature of regional significance for the recreational surfing and scientific community alike (Atkin et al, 2015).

Figure 19. Te Rakauwhakamataku Point. **[PHOTO: Iain Dawe]**

6.19.1 Te Rakauwhakamataku Point significance classification

Criteria	Value	Classification
Representativeness	1	Unique
Integrity	1	Unmodified
Vulnerability	4	Low
Scientific & Educational Value	3	Regional significance
Total	9	Rank 2

6.20 Whiterock - Te Kaukau coast

The site at Whiterock contains a number of geologic and geomorphic features of regional significance. The site encompasses Te Kaukau Point, the Whiterock reef and the pocket mixed sediment beach between the two points. The locality forms the western half of a large northeast trending anticline that runs up the coast to Manurewa Point (Fig. 20).

Whiterock is named after the distinctive light coloured limestone that is present in the area. Limestone is a sedimentary rock made from the skeletal remains of marine organisms such as foraminifera. There are five main lithologic units that have been identified in the rocks here, with the dominant unit a slightly sandy, green-grey coloured calcilutite. Calcilutite is essentially a limestone mud that contains, in addition, coarser sized clay and silt sized detrital carbonate grains that have been transported to the depositional beds via currents, for example turbidity currents. It has been burrowed through by marine organisms, including *Zoophycos isp.* and *Chondrites isp.* that have left trace fossil burrows, usually only visible on water worn surfaces. The burrows have become infilled with a green coloured glauconitic sand.

The trace fossils are known as ichnotaxon, in that they are the fossilised work of an organism, rather than the organism itself. *Zoophycos* is an ichnogenus thought to be produced by feeding annelids (worms) and found in deep marine sediment facies, commonly between turbidite beds. *Chondrites* are preserved as small branching burrows that resemble the root system of a plant. They are something of a mystery, in that no organism has ever been observed inside them. One theory is that they are produced by a chemosymbiotic organism that generates methane and hydrogen sulphide which is pumped into the sediments, producing the characteristic dendritic structure.

Research conducted on the limestone sequence at Te Kaukau Point was used to deduce that the calcilutite limestones of the Wairarapa (also present for example at Manurewa Point and Pahaoa) are related to those found in Marlborough and North Canterbury. It is part of a widespread lithologic limestone unit known as the Amuri Limestone that was laid down in the Late Cretaceous to Palaeocene period (50-70 Ma).

The calcilutite limestone rocks are interbedded with laminated sandstone, mudstone and siliceous limestone, all of which are cut through in places by rare glauconitic sandstone intrusives. Pyrite nodules are present in the mudstones.

At Te Kaukau Point, the sequence dips southwest and it shows numerous small scale southwest slumping folds that probably formed when the sediment was still soft. The sandstone beds within the sequence were probably transported in by low density turbidity currents. At Whiterock reef the rocks become more strongly buckled and inclined due to the presence of a fault that runs west of the reef. This has produced an unconformable contact with the much older Wairarapa belt greywackes.

In between the two points a 2.5 km long pocket beach composed of greywacke and limestone mixed sands and gravels has formed that is an excellent representative example of this beach type. The sediments have been derived from cliff erosion and inputs from the Whawanui and Opouawe Rivers. The beach features prominent storm berms and cusps that are indicative of a ‘shore normal’ aligned beach. The Whawanui River mouth migrates freely across the beach and on the true left of the outlet there is a wetland lagoon that has developed in a former outlet. The Opouwae River mouth frequently develops a river mouth hapua lagoon that builds up until it is flushed open by a flood flow. Hapua lagoons are unique to mixed sand and gravel beaches and the process geomorphology of this beach and the interactions of the rivers with the beach are of interest to coastal scientists.

Overall, the collected geological and geomorphological features of this system combine to create a site of scientific and educational significance. The geological rock formations have a low vulnerability, but there is the potential for human activities to impact on the beach by interrupting the sediment transfers in the system. This could occur by inappropriate shore protection structures, groyne construction, road development or by or reclamation in the backshore of the beach (Browne, 1987; Lee & Begg, 2002).

Figure 20. Whiterock – Te Kaukau coast. **[PHOTO: Iain Dawe]**

6.20.1 Whiterock - Te Kaukau coast significance classification

Criteria	Value	Classification
Representativeness	2	Uncommon
Integrity	1	Unmodified
Vulnerability	4	Low
Scientific & Educational Value	3	Regional significance
Total	10	Rank 2

6.21 Honeycomb Rock/Te Kahau coast

The Honeycomb Rock/Te Kahau coast contains a range of different geological and geomorphological features concentrated into a short stretch of coast, including; Honeycomb Rock, concretions, volcanics, shore platforms, a tombolo and pocket mixed sand and gravel beaches (Fig. 21).

Honeycomb Rock is composed of Cretaceous age sandstone (ca. 90 Ma). It takes its name from the unusual cavernous or honeycomb weathering pattern that has developed on the rock from a process of salt weathering and mechanical grinding. It occurs when sea spray seeps into the pores of the sandstone and then repeatedly crystalizes and dissolves, in a series of wetting and drying cycles. This forces apart the sand grains within the structure of the rock through a process called salt heave to form pits in the rock. Once the pits become large enough to collect grains of sand, the process is helped by mechanical grinding from wind action blowing the grains around the inside of the pockets, which become slowly enlarged. Honeycomb rock is the largest and most prominent of number of sandstone outcrops that have developed the distinctive weathering pattern.

Once an offshore rock stack, Honeycomb Rock has been left marooned as a result of tectonic uplift. Repeated uplift events has preserved a number of beach ridges in the area that have been used in the dating of historic earthquake events. Beach ridges are commonly used to determine the timing and vertical uplift of historic events because they contain material that can be dated and their elevations can be correlated with raised beaches on nearby parts of the coast. The raised beaches at Honeycomb have helped researchers to build a record of earthquake events that have previously affected the Wairarapa. Thus, they form an important scientific resource for hazards research.

On the point about 1.5 km north of Honeycomb Rock the sandstone is interbedded with gravel conglomerate layers and cut through by a volcanic dyke that is thought to be around 70 Ma. The lava within the dyke baked and hardened the adjacent sedimentary rocks. The softer surrounding material was subsequently eroded out to leave the harder volcanic rocks. The dyke is connected to the foreshore by a small tombolo feature, by sediment transport from both the northeast and the southeast.

Concretions are also present in the sandstone of the area. Concretions form when minerals precipitate and grow around a nucleus within the pore spaces of a sedimentary unit, in this case the local sandstone. As they grow they cement together the surrounding sediments into large round or ovoid shapes. They form within the sedimentary strata, but early in the burial history whilst the sediments are still soft, which allows the concretions to become quite large. The most famous example in New Zealand being the Moeraki boulders. The precipitating minerals form a cement that makes the concretion harder than the surrounding rock and consequently when the rocks are eroded, the concretions remain behind as a geological curiosity.

The Honeycomb Rock – Te Kahau coast and its associated geological and geomorphological features are relatively intact but are moderately vulnerable to human activities including fossicking and earthworks (Homer & Moore, 1989; Litchfield, et al, 2013).

Figure 21. Honeycomb Rock/Te Kahau coast. **[PHOTO: Iain Dawe]**

6.21.1 Honeycomb Rock/Te Kahau coast significance classification

Criteria	Value	Classification
Representativeness	2	Uncommon

Integrity	1	Unmodified
Vulnerability	3	Moderate
Scientific & Educational Value	3	Regional significance
Total	9	Rank 2

6.22 Kaiwhata/Kaihoata fossil forest

The fossil forest at the Kaiwhata River mouth consists of more than 20 subfossil totara stumps up to 2.0 m high and 1.0 m across. They are considered subfossil because they have not become mineralised or petrified, but rather they are preserved by saltwater. This has enabled the stumps to be carbon dated. They are only visible at low tide and some of them are 30-40 m offshore (Fig. 22).

Based on radiocarbon dating of the wood the stumps are the remnants of a forest that was living on the edge of the coastal plain, around 8000 years ago. The forest was drowned by a rapidly rising sea level following the end of the last glacial and buried by associated marine sediments. Around 7000 years sea ago, the rate of the last Postglacial sea level rise more or less stabilised, but the land continued uplifting at around 1.5 mm/yr. Thus, the buried tree stumps re-emerged above sea level.

South of the river mouth there are a series of tilted sandstone beds that contain numerous small scale structures including ripples, folds and trace fossils that formed when the sediments were being laid down on the seafloor in the Miocene around 15 Ma.

The story behind the formation of the fossil forest provides information about sea levels and regional climate in the early Holocene and is an important part of the record that helps construct the regional historic sea level curve. The way in which sea level has behaved in the past provides clues to its future behaviour. Subfossil wood stumps like this are uncommon in New Zealand and are of national significance to the geological research community.

The site is intact and unmodified, but the stumps are vulnerable to damage from both natural processes and human activity (Gibb, 1986; Homer & Moore, 1989; Lee & Begg, 2002; Moore, 1980).

Figure 22. Kaiwhata/Kaihoata fossil forest. [PHOTO: The Encyclopaedia of New Zealand]

6.22.1 Kaiwhata/Kaihoata fossil forest significance classification

Criteria	Value	Classification
Representativeness	1	Nationally rare
Integrity	1	Unmodified
Vulnerability	2	Vulnerable
Scientific & Educational Value	2	National significance
Total	6	Rank 2

6.23 Castlepoint/Rangiwhakaoma

Castlepoint contains the youngest known pre-Holocene rocks in coastal Wairarapa. The rocks consist dominantly of Pliocene mudstone and siltstone (5 Ma) of which is unconformably overlain by early Pleistocene fossiliferous sandstone and limestone (2 Ma). They are preserved in the Castlepoint fault zone which bounds a large area of graded sedimentary beds known as the Whakataki formation. These beds are occasionally exposed in the beach at Castlepoint after storm events erode the sand into the nearshore (Fig. 23.).

There are two prominent landform features at this site: the Castle (162 m) and the reef. Both have formed from shelly limestone overlain by shelly sandstone (coquina limestone). The limestone is composed of barnacle and shell fragments deposited in a shallow offshore bank around 2 million years ago at the start of the Pleistocene ice ages. Over 70 different species of fossil have been recorded in the area including the scallop *Chlamys patagonica delicatula* which still lives today in deep, cold waters off southern New Zealand. Since other fossil species are known to have lived in warmer water, the limestone at Castlepoint probably formed during a period of climatic change from cool to temperate seas.

At the Castle the limestone formation is more than 100 m thick and overlies grey Pliocene age siltstone that is about 5 Ma. Major faults run along either side of the reef and Castle, that are responsible for its uplift, but they are no longer active.

The reef is 1.3 km long and 50 m high at it crest at the northern end. It has been connected to the main land on its northern side by the transport and deposition of sand into the sheltered leeward area behind the reef. The feature is known as a tombolo and is one the best examples of its type in New Zealand. The ‘basin’, as it’s known locally, is an intertidal lagoon that has formed as part of this structure. It is open to sea at the southern end of the reef through a feature known locally as ‘the gap’.

Collectively, Castlepoint contains a range of young geologic formations and contemporary geomorphic features that make this a excellent site for scientific research and education. It is a regionally unique feature with rare geological units that has been only partly modified by human activities. The beach and basin is moderately vulnerable to impacts from development. The fossils are mainly at risk from fossicking whilst the geological formations are mainly at risk from natural processes of erosion (Homer & Moore, 1989; Johnston, 1973; Kamp, 1992; Lee & Begg, 2002; Moore, 1980).

Figure 23. Castlepoint/Rangiwhakaoma. [PHOTO: Greater Wellington Regional Council]

6.23.1 Castlepoint/Rangiwhakaoma significance classification

Criteria	Value	Classification
Representativeness	1	Rare
Integrity	2	Partly modified
Vulnerability	3	Moderate
Scientific & Educational Value	2	National significance
Total	8	Rank 2

6.24 Whakataki shore platforms

The coast from Whakataki to Mataikona contains one of the largest and most striking shore platform features in the region. This site and the partner site at Mataikona are chosen as representative examples of the entire exposure. At low tide, parallel lines of interbedded sandstone and mudstone are visible as a ‘tongue and groove’ pattern along the shore. This pattern has a resulted from differential weathering and erosion of the two lithologies. The mudstone is softer and more easily eroded whilst the sandstone is harder and forms ridges, creating a distinctive visual effect. Together the lithostratigraphic unit is known as the Whakataki formation (Fig. 24).

The sediments were laid down on the sea floor in the early Miocene (ca. 20 Ma) and have been subsequently compacted and tilted up to 60 degrees from horizontal so that they are seen almost edge-on. They were tilted up at a rate of about 1 degree every 1000 years. Millions of years of deposition are recorded in the strata, with the oldest sediments on the seaward edge of the shore platform grading to the youngest on the landward edge.

The hard sandstone layers contain a series of repeating structures including ripples and laminar beds that indicate the sediments were deposited by fast moving submarine currents. The beds are known as turbidites and were formed by the deposition of material transported from the continental shelf to the deeper sea floor from fast moving submarine debris flows. As the current transporting the sediment slowed, the heavier sands settled out first followed by the finer muds. Each pair of the sand-mud couplet thus represents a single turbidity current transport event. Together, the whole lithological unit is referred to as a flysch. The unit has been faulted numerous times, producing offsets in the beds.

The feature is an excellent illustration for educational purposes of the geological processes of sedimentation, uplift and differential weathering.

It is also an outstanding shore platform feature. New Zealand researcher’s have made a significant contribution to the international literature and scientific understanding of shore platforms. About 20-30% of the New Zealand coastline is shore platform and understanding how these features erode and the processes that created them is important for hazards management.

The site has a high degree of integrity and has a low vulnerability to being modified, however, road and stormwater works could affect the landward edge of the feature (Homer & Moore, 1989; Johnston, 1973; Kamp, 1992; Kirk, 1977; Kennedy, et al, 2014; Lee & Begg, 2002; Moore, 1980; Sunamura, 1992).

Figure 24. Whakataki shore platforms. **[PHOTO: Iain Dawe]**

6.24.1 Whakataki Shore platforms significance classification

Criteria	Value	Classification
Representativeness	2	Uncommon
Integrity	1	Unmodified
Vulnerability	4	Low
Scientific & Educational Value	3	Regional significance
Total	10	Rank 2

6.25 Mataikona shore platforms

The Mataikona shore platforms are a continuation of the Whakataki formation platforms, with the inclusion of a well exposed olistostrome bed. Like the Whakataki coast, differentially weathered, parallel lines of interbedded sandstone and mudstone are visible as a ‘tongue and groove’ pattern along the shoreline. This pattern has a resulted from and erosion of the two lithologies. The mudstone is softer and more easily eroded whilst the sandstone is harder and forms ridges, creating a distinctive visual effect. A description of the facies and its development is outlined in section 6.24.

A short distance north of the Mataikona River mouth is an excellent example of an olistostrome bed can be seen in the lower part of the Whakataki formation. An olistostrome is a sedimentary deposit composed from a heterogeneous mixture of clastic sediments known as a melange. It usually accumulates as a semifluid debris flow by submarine slumping of unconsolidated sediments. It lacks bedding, but is normally found intercalated amongst bedding sequences. The olistostrome here is made up mainly from glauconitic greensand, mudstone and marl (muddy limestone). The olistostromes are conformable within the alternating flysch sequence (Fig. 25).

The feature is an excellent illustration for educational purposes of the geological processes of sedimentation, uplift and differential weathering. The extensive shore platforms provides ample scope for scientific research into the processes that lead to their formation and development.

The site has a high degree of integrity and has a low vulnerability to being modified (Homer & Moore, 1989; Johnston, 1973; Kamp, 1992; Kirk, 1977; Kennedy, et al, 2014; Lee & Begg, 2002; Moore, 1980; Sunamura, 1992).

Figure 25. Mataikona shore platforms. **[PHOTO: Iain Dawe]**

6.25.1 Mataikona Shore platforms significance classification

Criteria	**Value**	**Classification**
Representativeness	2	Uncommon
Integrity	1	Unmodified
Vulnerability	4	Low
Scientific & Educational Value	3	Regional significance
Total	10	Rank 2

7. References

1. Atkin, E., Gunson, M. & Mead, S. (2015), *Regionally Significant Surf breaks in the Greater Wellington Region*. Report prepared for Greater Wellington Regional Council, eCoast Marine Consulting and Research, 82p.

2. Begg, J.G. & Mazengarb, C. (1996), Geology of the Wellington Area *1:50,000 Geological Map 22*. Institute of Geological and Nuclear Sciences, Lower Hutt, New Zealand, 128p + map.

3. Begg, J.G. & Johnston, M.R. (2000), Geology of the Wellington Area *1:250,000 Geological Map 10*. Institute of Geological and Nuclear Sciences, Lower Hutt, New Zealand, 64p + map.

4. Begg, J.G. & McSaveney, M.J. (2005), Wairarapa Fault rupture – Vertical deformation in 1855 and a history of similar events from Turakirae Head. In: Townsend, J. Langridge, R & Jones, A. (eds), *Proceedings of the 1855 Wairarapa Earthquake Symposium: 150 Years of Thinking About Magnitude 8+ Earthquakes and Seismic Hazard in New Zealand*. Greater Wellington Regional Council, GW/RINV-T-05/205, pp21-41.

5. Bell, R.G. & Hannah, J. (2012), *Sea Level Variability and Trends: Wellington Region.* Report prepared for Greater Wellington Regional Council, National Institute for Water and Atmospheric Research (NIWA), HAM2012-043, 74p.

6. Boffa Miskell Ltd (2007), *Regional Policy Statement Review: Coastal Environment Sites of Regional Significance*. Report to Greater Wellington Regional Council, 37p.

7. Browne, G.H. (1987), In situ and intrusive sandstone in Amuri fades limestone at Te Kaukau Point, southeast Wairarapa, New Zealand. *New Zealand Journal of Geology and Geophysics*, 30(4), 363-374.

8. Campbell, H.J. (1996), Titahi Bay fossil forest floor. *Geological Society of New Zealand Newsletter*, No. 110, 22-24.

9. Campbell, H. & Hutching, G. (2007), *In Search of Ancient New Zealand*. Penguin Group New Zealand, 240p.

10. Campbell, H.J., Grapes, R.H. & Handler, M.R. (1993), *Mukamuka: Geology of the Northwest Corner of Palliser Bay, Wairarapa*. Geological Society of New Zealand, miscellaneous publication 66, 28p.

11. Challis, G.A. (1960), Igneous rocks in the Cape Palliser area. *New Zealand Journal of Geology and Geophysics*, 3(3), 524-542.

12. Cotton, C.A. (1952), The Wellington coast: An essay in coastal classification. *New Zealand Geographer*, 8, 48-62.

13. Cotton, C.A. (1974), *Bold Coasts:* annotated reprints of selected papers on coastal geomorphology, 1916-1969 (edited by BW Collins). AH & AW Reed. 354p.

14. Dawe, I.N. (2006), Longshore Sediment Transport on a Mixed Sand and Gravel Lakeshore. Ph.D. thesis, Department of Geography, University of Canterbury, New Zealand, 363p.

15. Dunbar, G.B., Barrett, P.J., Goff, J.R., Harper, M.A. & Irwin, S.L. (1997), Estimating vertical tectonic movement using sediment texture. *The Holocene*, 7(2), 213-221.

16. Furze, M.F. & Roberts, M.J. (2004), *Assessing the conservation value of geological sites in the marine environment.* Joint Nature Conservation Committee, Centre for Applied Oceanography, University of Wales, Bangor, 71p.

17. Gibb, J.G. (1986), A New Zealand regional eustatic sea level curve and its application to determination of vertical tectonic movements. *Royal Society of New Zealand Bulletin*, 24, 386-393.

18. Gibb, J.G. (2012), *Local Relative Holocene Sea Level Changes for the Porirua Harbour Area, Greater Wellington Region*. Report prepared for Greater Wellington Regional Council, Coastal Management Consultancy, C.R. 2012/1, 16p.

19. George, A. & Grapes, R. (1987), Lawsonite-bearing veins in Torlesse rocks. *New Zealand Journal of Geology and Geophysics*, 30(2), 203-205.

20. Hancox, G. & Perrin, N. (2006), *Fieldtrip 3 guide: Landslide and slope instability hazards affecting Paekakariki, the SH1 coastal highway, and the proposed Transmission Gully motorway route*. Lecointre, J., Stewart, B. & Wallace, C. (eds), Geosciences ’06 – Our Planet, Our Future, Geological Society of New Zealand and New Zealand Geophysical Society joint conference. Geological Society of New Zealand, Miscellaneous Publication 122 B, 40p.

21. Hannah, M.J. & Collen, J.D. (1995), An occurrence of the tube fossil *Torlessia mackayi* Bather, 1906 from southwest Wellington, New Zealand. *New Zealand Journal of Geology and Geophysics, 38,* 117-119.

22. Hart, D.E. (2007), River-mouth lagoon dynamics on mixed sand and gravel barrier coasts. *Journal of Coastal Research*, SI50, 927-931.

23. Hart, D.E. & Bryan, K.R. (2008), New Zealand coastal system boundaries, connections and management. *New Zealand Geographer*, 64, 129-143.

24. Hayward, B. (2009), Protecting fossil sites in New Zealand. In Lipps J.H. & Granier, B.R.C. (eds), *PaleoParks: The Protection and Conservation of Fossil Sites Worldwide*. Notebooks on Geology, Brest, Book 2009/03, Chapter 5, pp 49-64.

25. Hayward, B., Greenfell, H., Sabaa, A., Kay, J. & Clark, K. (2011), Ecological distribution of the Foraminifera in a tidal lagoon-brackish lake, New Zealand, and its Holocene origins. *Journal of Foraminiferal Research*, 41(2), 124-137.

26. Hemmingsen, M. (1997), *The Coastal Geomorphology of Te Waihora (Lake Ellesmere)*. MSc. thesis, Department of Geography, University of Canterbury, New Zealand, 206p.

27. Homer, L. & Moore, P. (1989), *Reading the Rocks: A guide to the Geological Features of the Wairarapa Coast.* Institute of Geological and Nuclear Sciences, 64p.

28. Hughes, G.R. & Kennedy, D.M. (*in prep*), *Late Pleistocene evolution of an uplifting coastal basin, Kapiti-Wanganui, New Zealand*. Manuscript, 31p.

29. Hull, A.G. & McSaveney, M.J. (1996), *A 7000-year Record of Great Earthquakes at Turakirae Head, Wellington*. Institute of Geological and Nuclear Sciences, Report 1996/33493B.10, 28p.

30. Johnston, M.R. (1973), Geology of Castlepoint headland and reef, Wairarapa, New Zealand. *New Zealand Journal of Geology and Geophysics*, 16(4), 909-916.

31. Kamp, P.J. (1992), Landforms of Wairarapa: A geological perspective. In: Soons, J. & Selby, M. (eds), *Landforms of New Zealand* (2nd edition). Longman Paul, Auckland, pp367-381.

32. Kennedy, D.M. & Beban, J.G. (2005), Shore platform morphology on a rapidly uplifting coast, Wellington, New Zealand. *Earth Surface Processes and Landforms*, 30, 823-832.

33. Kennedy, D. M., Stephenson, W. J. & Naylor, L. A. (2014), Introduction to the rock coasts of the world. In: Kennedy, D. M., Stephenson, W. J. & Naylor, L. A. (eds) (2014), *Rock Coast Geomorphology: A Global Synthesis*. Geological Society Memoir No. 40, London, 1–5.

34. Kenny, J.A. & Hayward, B.W. (1992), *Inventory of New Zealand sedimentary geology sites of international, national and regional significance* (1st edition). Geological Society of New Zealand, Lower Hutt, 118p.

35. Kenny, J.A. & Hayward, B.W. (eds) (1993), *Inventory of important geological sites and landforms in the Manawatu and Wellington regions.* Regional Geo-preservation Inventory No 1. Geological Society of New Zealand, Lower Hutt, Miscellaneous Publication 73, 43p.

36. Kenny, J.A. & Hayward, B.W. (eds) (1996), *Inventory and Maps of Important Geological Sites and Landforms in the Manawatu and Wellington Regions* (1st edition). Geological Society of New Zealand, Miscellaneous Publication 89, 39p.

37. Korsch, R.J. & Morris, B.D. (1987), Downward-facing fold in the Torlesse accretionary wedge, Titahi Bay, Wellington, New Zealand. *New Zealand Journal of Geology and Geophysics*, 30(4), 375-387.

38. Kirk, R.M. (1977), Rates and forms of erosion on intertidal platforms at Kaikoura Peninsula, South Island, New Zealand. *New Zealand Journal of Geology and Geophysics*, 20(3), 571-613.

39. Kirk, R.M. (1980), Mixed sand and gravel beaches: Morphology, processes and sediments. *Progress in Physical Geography*, 4(2), 189-210.

40. Kirk, R.M. (1991), River-beach interactions on mixed sand and gravel coasts: A geomorphic model for water resource planning. *Applied Geography,* Vol 11, 267-287.

41. Kirk, R.M. (2001), Marine processes and coastal landforms. In: Sturman, A. & Spronken-Smith, R (eds), *The Physical Environment: A New Zealand Perspective.* Oxford University Press, pp290-306.

42. Leach, B. F. & Anderson, A.J. (1974), The transformation from an estuarine to lacustrine environment in the lower Wairarapa. *Journal of the Royal Society of New Zealand*, 4(3), 267-275.

43. Leamy, M.L. (1958), Pleistocene shorelines at Porirua Harbour near Wellington, New Zealand. *New Zealand Journal of Geology and Geophysics*, 1 (1), 95-102.

44. Lee, J.M. & Begg, J.G. (2002), *Geology of the Wairarapa Area: 1:250,000 Geological Map 11*. Institute of Geological and Nuclear Sciences, Lower Hutt, New Zealand, 66p + map.

45. Litchfield, N.J & Van Dissen, R.J. (2014), Porirua Fault Trace Study. GNS Science Consultancy Report 2014/213, 53p.

46. Litchfield, N., Cochran, U., Berryman, K., Ansell, B. & Clark, K. (2013), *Timing and Amount of Uplift of the Youngest Holocene Marine Terrace Along the Honeycomb Rock – Riversdale Beach Coast, Eastern Wairarapa.* GNS Science Report 2013/54, 44p.

47. Matthews, E.R. (1980a), Observations of beach gravel transport, Wellington Harbour Entrance, New Zealand. *New Zealand Journal of Geology and Geophysics*, 23(2), 209-222.

48. Matthews, E.R. (1980b), *Coastal Sediment Dynamics, Turakirae Head to Eastbourne, Wellington.* New Zealand Oceanographic Institute Oceanographic Summary, No. 17, 21p.

49. Matthews, E.R. (1983), Wave disturbance and texture of beaches in Palliser Bay, southern North Island, New Zealand. *New Zealand Journal of Geology and Geophysics*, 26(2), 197-212.

50. Mildenhall, D.C. (1993), Last glaciation/postglacial pollen record for Porirua, near Wellington, New Zealand. *Tuatara*, 32, 22-27.

51. Milne, J.D.G. (1980), *Pauatahanui Inlet: An Environmental Study.* In: Healy, W.B. (ed), Department of Industrial and Scientific Research Information Series, 141, 198p.

52. Moore, P.R. (1980), Late Cretaceous-Tertiary stratigraphy structure and tectonic history of the area between Whareama and Ngahape, eastern Wairarapa, New Zealand. *New Zealand Journal of Geology and Geophysics*, 23(2), 167-177.

53. Moore, P.R. & Francis, D.A. (1988), *Geology of Kapiti Island, Central New Zealand*. New Zealand Geological Survey, Record 28, DSIR, 23p.

54. Mortimer, N. & Campbell, H. (2014), *Zealandia: Our Continent Revealed.* Institute of Geological and Nuclear Sciences. Penguin Group, New Zealand, 271p.

55. Olson, D., Kennedy, D., Dawe, I. & Calder, M. (2012), Decadal-scale gravel beach evolution on a tectonically-uplifting coast: Wellington, New Zealand. *Earth Surface Processes and Landforms*, 37, 1133-1141.

56. Priestley, R. & Crozier, M.J. (1990), *New Zealand landform inventory: second approximation.* Occasional Paper No. 4. Research School of Earth Sciences, Victoria University of Wellington, 164p.

57. Reed, J.J. (1958), Additional data on the volcanic argillites from Red Rock Point, Wellington. *New Zealand Journal of Geology and Geophysics*, 1(4), 635-640.

58. Rhodes, J. (2012), The Shaping of the Lower Valley. In: Grant, I. (ed), *Wairarapa Moana: The Lake and its People.* Wairarapa Archive and Fraser Books, Masterton,

59. Schulmeister, J. & Kirk, R.M. (1993), Evolution of a mixed sand and gravel barrier system in North Canterbury, New Zealand, during Holocene sea-level rise and still-stand. *Sedimentary Geology*, 87, 215-235.

60. Speden, I.G. (1976), Fossil localities in Torlesse rocks of the North Island, New Zealand. *Journal of the Royal Society of New Zealand*, 6, 73-91.

61. Stephenson, G. & Hill, M. (1975), *Geological features of the Wellington region.* Wellington Regional Planning Authority, 52p.

62. Stephenson, W. J. & Kirk, R. M. (2001), Surface swelling of coastal bedrock on intertidal shore platforms. *Geomorphology*, 41 (1),5-21.

63. Stevens, G.R. (1973), Late Holocene marine features adjacent to Port Nicholson, Wellington, New Zealand. *New Zealand Journal of Geology and Geophysics*, 16(3), 455-484.

64. Stevens, G.R. (1991), *On Shaky Ground: A Geological Guide to the Wellington Metropolitan Region.* Geological Society of New Zealand Guidebook 10, Geological Society of New Zealand, 112p.

65. Stevens, G.R. (1990), *Rugged Landscape: The Geology of Central New Zealand, 2nd edition*. A.H. & A.W. Reed, 286p.

66. Sunamura, T. (1992), *Geomorphology of Rocky Coasts*. John Wiley and Sons, 314p.

67. Suneson, N.H. (1992), *Geology Of Torlesse Rocks Around The Wellington Coast Between Paekakariki And Pencarrow Head.* Institute of Geological & Nuclear Sciences, Report 92/8, 52p.

68. Suneson, N.H. (1993), The geology of Torlesse Complex along the Wellington area coast, North Island, New Zealand. *New Zealand Journal of Geology and Geophysics*, 36(3), 369-384.

69. Taylor, A.J. (2003), *Change and Processes of Change on Shore Platforms*. Ph.D. thesis, Department of Geography, University of Canterbury, New Zealand, 387p.

70. Trenhaile A. S. (1980), Shore platforms: a neglected coastal feature. *Progress in Physical Geography*, 4, 1–23.

71. Trenhaile A. S. (1987), *The Geomorphology of Rock Coasts*. Clarendon Press, Oxford, 400p.

72. Turner, M. (1985), *Geological features of the Wellington region* (2nd Edition). Wellington Regional Council, 72p + map.

73. Webby, B.D. (1958), A Lower Mesozoic annelid from Rock Point, southwest Wellington, New Zealand. *New Zealand Journal of Geology and Geophysics*, 1(3), 509-513.

74. Webby, B.D. (1959), Sedimentation of the alternating greywacke and argillite strata in the Porirua district. *New Zealand Journal of Geology and Geophysics*, 2(3), 461-478.

75. Williams, D.N. (1978), Pliocene and Quaternary geology of Mana Island. *New Zealand Journal of Geology and Geophysics*, 21(5), 653-656.

Appendix One: Schedule J - Significant geological features in the coastal marine area

Site Name	Description and Values	Location	Significance
Ōtaki River mouth hapua / lagoon	Ōtaki River Mouth hapua, barrier spit and lagoon system.	Ōtaki River Mouth	Nationally significant
Kāpiti Island phyllonite zone	Phyllonite formed by intense cataclastic metamorphism of quartzofeldspathic grits, sandstone and argillite.	Eastern side of Kapiti Island from south of Rangatira Point to Taepiro Stream	Regionally significant
Pukerua Bay	Extensive greywacke shore platforms, rock stacks; rare Torlesse Complex fossils (*Torlessia mackayi* Bather).	Pukerua Bay coastline along scientific reserve including Wairaka Point / Te Ana a Hau	Regionally significant
Pauatahanui Inlet	Drowned river valley, depositional sedimentary sequence relatively unmodified by recent tectonic uplift; Ohariu Fault trace; uplifted terraces; largest estuary in lower North Island.	Pauatahanui Arm, Porirua Harbour	Nationally significant
Whitireia coast	Whitireia shore platforms; interbedded sandstone and mudstone flysch; fossil worm tubes (*Torlessia mackayi* Bather).	Whitireia peninsula coast from Titahi Bay to Onehunga Bay	Regionally significant
Titahi Bay fossil forest	Titahi Bay Pleistocene aged (last interglacial 120,000-80,000 yr) fossil forest.	Titahi Bay foreshore and nearshore, Porirua	Nationally significant
Titahi Bay flysch sequence	Titahi Bay Triassic interbedded greywacke and argillite Flysch sequence.	Southern side of Titahi Bay from end of boat sheds to point	Regionally significant
The Bridge	Mana Bridge, remnant marine terrace drowned in Holocene Postglacial marine transgression.	Offshore marine area between Titahi Bay heads and Mana Island	Regionally significant
Rock Point fossils	Fossil worm tubes *Titahia corrugata* Webby (type locality) and *Torlessia mackayi* Bather.	Rock Point, west Porirua coast	Nationally significant
Red rocks / Pariwhero	Oceanic metabasalt pillow lava and coloured argillites within Torlesse Complex greywacke. Inclusions of, chert, jasper, malachite, and radiolarian micro fossils.	Red rocks scientific reserve, Wellington South Coast near Sinclair Head	Nationally significant
Island Bay / Tapu te Ranga lawsonite	Island Bay lawsonite and prehinite-pumpellyite facies metamorphism, veined greywacke and pillow lava melange.	Taputeranga Marine Reserve foreshore, Island Bay	Regionally significant
Te Raekaihau Point	Shore platforms and raised beach ridges incl. 1855 uplift ridge.	Te Raekaihau Point and reefs	Regionally significant
Moa Point / Hue te Taka	Rock stacks, shore platforms and raised beach incl. 1855 uplift ridge.	Moa Point / Hue te Taka and reefs	Regionally significant
East Harbour coast	Mixed sand and gravel beach complex; uplifted beach ridges; processes geomorphology and contemporary longshore sediment transport of 1855 Wairarapa earthquake generated sediments.	East Harbour Coastline from Bluff Head, Pencarrow Head to Point Arthur	Nationally significant
Mukamuka basalt breccia	Mukamuka basalt breccia with calcite veins in stratigraphic contact with Rimutaka Belt greywackes.	Western shoreline of Palliser Bay, Fisherman's Rock, Mukamuka Stream mouth northwest 2.3 km	Regionally significant
Lake Onoke and barrier spit	Holocene landform development; spit and barrier beach geomorphology; raised gravel beach ridges; dynamic mixed sand and gravel beach processes and sedimentation;	Lake Onoke and barrier spit beach	Nationally significant

	unusual foraminifera.		
Kupe’s sail / Ngā Rā a Kupe	Fossiliferous sandstone (15 Ma) lying unconformably against greywacke, tilted and uplifted to form Kupe's Sail.	Kupe's Sail, Cape Palliser	Regionally significant
Cape Palliser / Matakitaki	Pillow lava flow (100 Ma) containing spilites, altered dolerites and camptonites within greywacke-argillite- radolarian chert sequence; volcanic dykes and sills.	Cape Palliser, South Wairarapa	Regionally significant
Te Rakauwhakamataku Point	Eroded greywacke basement remnant creating a connected reef producing waves of national significance for surfing.	Te Rakauwhakamataku Point and reef, Southeast Wairarapa	Regionally significant
Whiterock – Te Kaukau coast	Amuri calcilutite limestone rocks (50-60 Ma) interbedded with laminated sandstone, mudstone and siliceous limestone; rare glauconitic sandstone intrusives and pyrite nodules; *Zoophycos isp.* and *Chondrites isp*. trace fossils; faulting and folding. Pocket composite mixed sand and gravel beach and hapua displaying dynamic process geomorphology.	Whiterock reef to Te Kaukau Point	Regionally significant
Honeycomb Rock / Te Kahau coast	Weathered, late Cretaceous aged (90 Ma) sandstone, rock stacks, shore platforms, conglomerates, concretions and volcanic dykes.	Honeycomb Rock coast from *ca.* Waihingaia Stream to point 3 km northeast	Regionally significant
Kaiwhata / Kaihoata fossil forest	Holocene aged (8000 yr) subfossil totara stumps drowned in last Postglacial marine transgression and tectonically uplifted. Miocene aged flysch sequence.	Kaiwhata / Kaihoata River Mouth	Nationally significant
Castlepoint / Rangiwhakaoma	Young Pleistocene aged (2 Ma) coquina limestone and shelly sandstone containing over 70 species of fossils, unconformably overlying Pliocene (5 Ma) siltstone in Castlepoint fault zone. Connecting tombolo beach and lagoon system; contemporary process geomorphology.	Castlepoint / Rangiwhakaoma, reef, lagoon and connecting tombolo beach	Nationally significant
Whakataki shore platforms	Whakataki formation sandstone and mudstone turbidite flysch (20 Ma), tilted and differentially eroded; turbidites and offset faulting and folding.	Whakataki coast from Whakataki River mouth north 6 km	Regionally significant
Mataikona shore platforms	Whakataki formation sandstone and mudstone turbidite flysch (20 Ma), tilted and differentially eroded; turbidites and olistostrome beds.	From Mataikona River mouth north 3.5 km	Regionally significant

Appendix Two: Criteria to assess geological significance

Criteria from the report "Geological features of the Wellington region"

In the report by Wellington Regional Council (1985), Geological Features of the Wellington Region, there were four principles by which sites were selected.

1.) Together, the sites selected should illustrate the various stages in the geological history and processes involved in the formation of the feature. This is desirable for academic and educational reasons.

2.) The sites should, as far as practicable, be able to be understood by the general public, because maximum interest will tend to be associated with sites that lend themselves to interpretation in the field.

3.) Sites should include those areas that have been the subject of intensive scientific research, especially where they have made important contributions to our understanding of the geology of New Zealand or the Wellington region.

4.) Site selection should take into consideration the vulnerability, importance, and scientific nature of the feature. Several examples of a feature should be selected if they are highly vulnerable to destruction, if they are extremely rare or if the sites need to be part of a group for scientific interpretation.

Although sites may be identified, unless some measure of protection or planning controls are put in place to help preserve these features, their significance could be destroyed. One of the main concerns is site modification from earth works or quarrying activity. Other modifications can occur that don't directly destroy the feature, but act to cover over or obscure the site, preventing or seriously inhibiting further research and interpretation of the feature. A good example of this occurred in Porirua in 1988. Excavation work during part of the Porirua CBD development, exposed a thick deposit of carbonaceous mud in a fossil gully, that has since been built over. Analysis of the pollen and plant material in the layer was able to provide information on the last 21,000 years of climatic and environmental conditions of the lower North Island (Mildenhall, 1993). Research of this nature is critical to understanding the current changes in the global climate.

It was recognised in the 1985 report that different planning controls could be applied depending on the vulnerability or rarity of a site. In order to aid this decision, a three tier ranking system was devised and a level assigned to each site:

- Rank 1: Features should be fully protected. Activities not to threaten the natural character of the feature.
- Rank 2: Features should be conserved. Activities are permitted providing they do not modify or destroy the feature.

- Rank 3: Features are recognised. Due to the nature, location or extent of the feature, does not require protection or management.

These principles are a useful start, but require some elaboration. Additionally, there are other important criteria that warrant consideration

Criteria from the report "Inventory of important geological sites"

In the inventory of geological sites by Kenny & Hayward (1996), sites were assessed on the basis of their importance and vulnerability. The importance criteria included three levels:

a) *International* – site of international scientific importance
b) *National* – site of national scientific, educational or aesthetic importance
c) *Regional* – site of regional scientific, educational or aesthetic importance

The vulnerability rating had five categories:

1) highly vulnerable to complete destruction or major modification by humans
2) moderately vulnerable to modification by humans
3) unlikely to be damaged by humans
4) could be improved by human activity
5) site already destroyed (not necessarily by human activity)

The vulnerability and importance criteria are both core values that need to be part of any geological assessment of significance.

Criteria from the report "Assessing the value of geological sites"

In the report by Furze, M.F. & Roberts, M.J. (2004), Assessing the conservation value of geological sites in the marine environment, assessments were made on the basis of three criteria; scientific values, threats to the feature from both local and distant sources, and the integrity and potential for conservation of the site. In turn these three criteria included a range of values that could be assessed for the site and to which a numerical values could be assigned. In addition, a confidence value was assigned to the individual assessment, based on the state of knowledge. The criteria and their assessment values that were used in the report are:

1. Scientific

(i) geomorphological importance
(ii) uniqueness & exceptionality
(iii) representativeness
(iv) existing research
(v) potential future research
(vi) teaching value
(vii) historical interest

2. Threats

- (i) fishing
- (ii) aggregate and mineral
- (iii) hydrocarbon (i.e. oil exploration)
- (iv) cable & pipeline
- (v) other constructions
- (vi) navigational dredging
- (vii) waste/sediment disposal
- (viii) research
- (ix) military
- (x) other

3. Integrity & Conservability

- (i) site preservation
- (ii) conservability
- (iii) regenerative ability