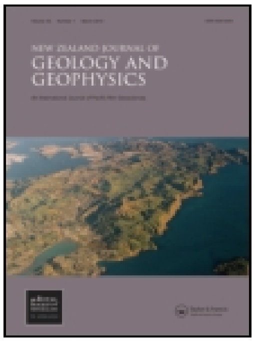

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RESEARCH ARTICLE

High-level stratigraphic scheme for New Zealand rocks

N Mortimer[a]*, MS Rattenbury[b], PR King[b], KJ Bland[b], DJA Barrell[a], F Bache[b], JG Begg[b], HJ Campbell[b], SC Cox[a], JS Crampton[b], SW Edbrooke[b], PJ Forsyth[a], MR Johnston[c], R Jongens[a], JM Lee[b], GS Leonard[b], JI Raine[b], DNB Skinner[b], C Timm[b], DB Townsend[b], AJ Tulloch[a], IM Turnbull[a] and RE Turnbull[a]

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We formally introduce 14 new high-level stratigraphic names to augment existing names and to hierarchically organise all of New Zealand's onland and offshore Cambrian–Holocene rocks and unconsolidated deposits. The two highest-level units are Austral Superprovince (new) and Zealandia Megasequence (new). These encompass all stratigraphic units of the country's Cambrian–Early Cretaceous basement rocks and Late Cretaceous–Holocene cover rocks and sediments, respectively. Most high-level constituents of the Austral Superprovince are in current and common usage: Eastern and Western Provinces consist of 12 tectonostratigraphic terranes, 10 igneous suites, 5 batholiths and Haast Schist. Ferrar, Tarpaulin and Jaquiery suites (new) have been added to existing plutonic suites to describe all known compositional variation in the Tuhua Intrusives. Zealandia Megasequence consists of five predominantly sedimentary, partly unconformity-bounded units and one igneous unit. Momotu and Haerenga supergroups (new) comprise lowermost rift to passive margin (terrestrial to marine transgressive) rock units. Waka Supergroup (new) includes rocks related to maximum marine flooding linked to passive margin culmination in the east and onset of new tectonic subsidence in the west. Māui and Pākihi supergroups (new) comprise marine to terrestrial regressive rock and sediment units deposited during Neogene plate convergence. Rūaumoko Volcanic Region (new) is introduced to include all igneous rocks of the Zealandia Megasequence and contains the geochemically differentiated Whakaari, Horomaka and Te Raupua supersuites (new). Our new scheme, Litho2014, provides a complete, high-level stratigraphic classification for the continental crust of the New Zealand region.

Keywords: igneous rocks; metamorphic rocks; New Zealand; Zealandia; sedimentary rocks; stratigraphy; tectonics

Introduction

It has been 40 years since Carter et al. (1974) proposed a tripartite high-level stratigraphic nomenclature for New Zealand rocks. Their Kaikoura, Rangitata and Tuhua sequences were broad, unconformity-bounded stratigraphic units, with the Rangitata Sequence being subdivided into formal assemblages and zones. Following revisions to the International Stratigraphic Guide, Carter (1988) amended the sequences to synthems.

The high-level nomenclature of Carter et al. (1974) and Carter (1988) has not been widely adopted. The orogenies, assemblages, zones, sequences and synthems proposed for New Zealand's Cambrian–Early Cretaceous basement rocks were supplanted by a different, stable and well-used classification based on provinces, terranes and batholiths (Fig. 1; e.g. Coombs et al. 1976; Tulloch 1988). Carter (1988) defined the Kaikoura Synthem to encompass Late Cretaceous–Holocene cover strata in eastern South Island which he divided into five formal groups onshore, four of which he correlated to informal seismic sequences offshore. While Carter's (1988) use of offshore seismic stratigraphy and his concepts for developing a 'lumping rather than splitting' approach were prescient, his scheme has probably been regarded as too local for national use. It also competed with an alternative stratigraphic classification in eastern South Island (Field et al. 1989). Furthermore, the root name 'synthem' for the fundamental unconformity-bounded stratigraphic unit has not gained much usage internationally (Owen 2009) and there have also been suggestions to abandon it (Murphy & Salvador 1999). King et al. (1999) proposed a national, high-level sequence stratigraphic classification but used conceptual and numerical terms such as 'first-order transgressive systems tract' and 'second-order Cycle 2' to describe their units. Sequence stratigraphic subdivision has also been used in some North Island basins (e.g. Kamp et al. 2004).

The purpose of the present paper is to introduce a new high-level stratigraphic framework that hierarchically organises all rocks and unconsolidated sediments in New Zealand and the surrounding parts of the submerged continent of Zealandia south of 29°S. The reasons for doing this are twofold. The first reason is to provide a geologically concise and useful way to broadly refer to, interpret, categorise and compare rocks across the region. Stratigraphic mapping and correlation is often focused at the 1–100 km horizontal scale but, in order to be most effective, stratigraphy should also convey useful information on a 100–1000 km scale. Secondly, having a high-level stratigraphic name hierarchy embedded in national digital databases such as the New Zealand Stratigraphic Lexicon

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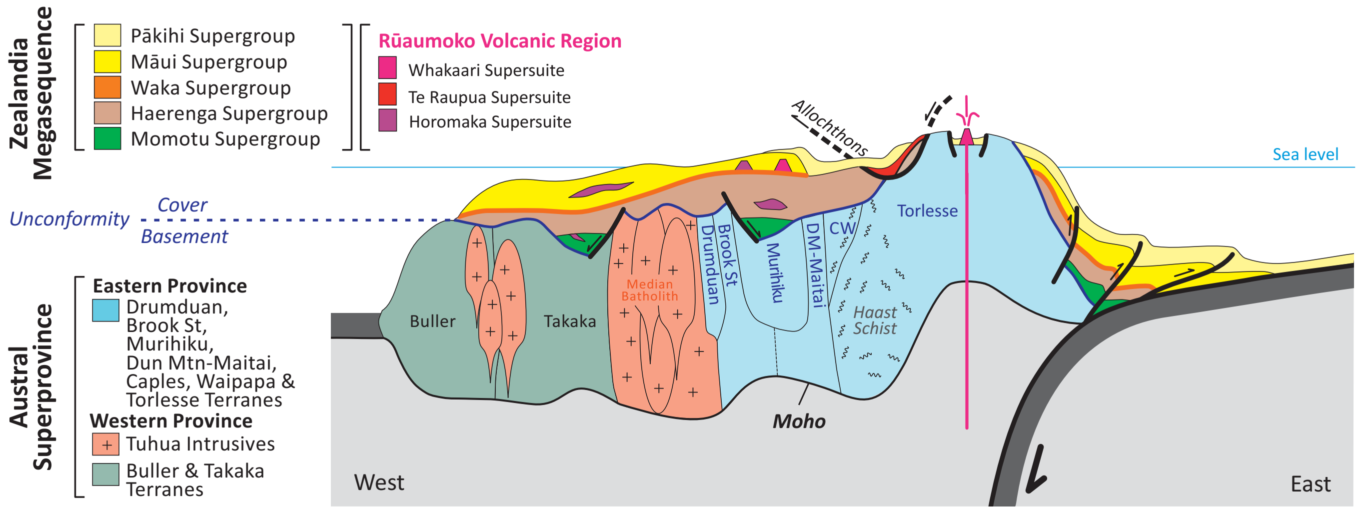

Figure 1 Highly schematic and stylised crustal cross-section across New Zealand showing spatial relationships of Litho2014 high-level stratigraphic units. CW, Caples and Waipapa terranes. Section has strong vertical exaggeration to emphasise stratigraphic relationships; it is not balanced or to scale.

(http://data.gns.cri.nz/stratlex) and the Petlab geoanalytical database (http://pet.gns.cri.nz) enables more efficient and effective querying of those research tools; for example, sandstones sampled from a particular broad stratigraphic unit can be searched for by picking one name instead of (previously) composing a long and complex spatial and temporal query.

We consider that our proposed scheme improves upon the earlier nomenclature of Carter et al. (1974) because it is: (1) comprehensive, explicitly incorporating all unconsolidated sediments and sedimentary, volcanic, plutonic and metamorphic rocks of the New Zealand region including North, South, Kermadec, Stewart, Chatham and Subantarctic islands and neighbouring offshore basins; (2) conservative, using (wherever possible) well-established, high-level stratigraphic units such as terranes, batholiths, supergroups and first- and second-order sequence stratigraphic units; (3) holistic, in that the high-level units are based on aggregations of formation- and group-level lithostratigraphic units in common use (see Appendix); and (4) adaptable and innovative as it provides alternate yet prescribed hierarchies for young volcanic rocks, rocks in North Island allochthons, plutonic rocks and Haast Schist.

There are numerous approaches to differentiation and subdivision of the stratigraphic column (litho-, bio-, chrono- allo-, sequence-, tectono-, chemo-, etc.) and all of them emphasise different aspects of a geological succession. In New Zealand, stratigraphic classification for geological maps has been based mainly on lithology, that is, lithostratigraphic, but with additional biostratigraphic and chronostratigraphic considerations. Within major sedimentary basins, especially those lying offshore, allostratigraphic and sequence stratigraphic approaches have been important additional tools in the classification of the geological successions. The long-standing practice is that stratigraphic unit names are formalised by publishing a definition and description of each unit. There is no formal committee in New Zealand to approve stratigraphic names. The authors of this paper comprise a mix of compilers of the recent 1:250 000 scale QMAP geological map series of New Zealand, regional and basin geologists, petrologists, palaeontologists and database custodians, all of whom recognise the need for a high-level stratigraphic nomenclature and framework that allows ready comparison and correlation of rocks across the New Zealand region.

The present paper does not attempt any rationalisation of medium-level (group or formation) lithostratigraphic units. Our new scheme, along with its embedded hierarchical relationships, has been added to the New Zealand Stratigraphic Lexicon. The units can be identified on the Stratlex search page by the usage label 'Litho2014'.

High-level root names

Until now the highest level of lithostratigraphic hierarchy in New Zealand comprised eight formally defined supergroups: Rangitikei, Akarana, Brook Street, Murihiku, Putakaka, Waipa, Maitai and Torlesse. These were proposed at different times over several decades, largely without context to each other, and occur throughout the stratigraphic column and around the country. Outside these supergroups are c. 168 formally defined sedimentary and volcanic groups in current, common usage, and outside these groups are c. 208 formally defined sedimentary and volcanic formations in current, common usage. As a guide to current, common usage we have used King et al.'s (1999) synthesis of Cretaceous–Quaternary sedimentary successions in onshore and offshore basins and the recently completed QMAP geological map series, which is a synthesis of all onshore rock units (Rattenbury & Isaac 2012).

Basement

All Cambrian–Early Cretaceous basement rocks are mapped in terms of two provinces: Eastern Province and Western Province. Until now these have been New Zealand's highest-level tectonostratigraphic units (Fig. 1). They have been in common use since first proposed by Landis & Coombs (1967) and we retain them, along with their constituent terranes, plutons, suites, batholiths and schist units. The high-level stratigraphic nomenclature of the basement has remained fairly stable in the last few decades (compare Coombs et al. 1976; Mortimer 2004). The only high-level basement units introduced in the past 15 years have been Median Batholith, Waipa Supergroup and Kaweka Terrane (Mortimer et al. 1999; Kear & Mortimer 2003; Adams et al. 2009). In the past, some publications (e.g. Coombs et al. 1976; those of the QMAP series) have not capitalised the root name 'terrane', implying incorrect informality, while others (e.g. Bradshaw 1993; Mortimer 2004; Scott 2013) have capitalised them. In this paper we specifically capitalise terranes, affirming their formal status. We also propose the new highest-level root term 'superprovince' to encompass all rocks of New Zealand's Eastern Province and Western Province basement.

With the exception of the new term 'superprovince', the basement scheme in Figs 1, 2 simply restates established, familiar and formal New Zealand usage of the root names province, terrane, pluton and suite. None of these commonly used terms are sanctioned by the International Stratigraphic Guide, which goes further in specifically recommending against using the terms pluton and batholith (Salvador 1994; Murphy & Salvador 1999). The International Stratigraphic Guide's perennial emphasis on structurally simple sedimentary rocks and on medium- and low-level nomenclature is, unfortunately, of little practical value in regions of varied lithology or where high-level stratigraphic names are needed.

Cover

Carter et al.'s (1974) lament that supergroup is the highest formal lithostratigraphic name remains valid in 2014; the various generations of stratigraphic guides offer no recommendation on how to name, treat or merge lithostratigraphic units at levels higher than supergroup (Salvador 1994; Murphy & Salvador 1999; International Commission on Stratigraphy 2014). Carter (1988) used Kaikoura Synthem as the highest-level term for the entire unconformity-bounded Cretaceous and Cenozoic sedimentary succession above basement in eastern South Island. A recommendation that synthem be used as the 'top dog' in the stratigraphic hierarchy was made by Carter (2007). Conceptually, Carter's (1988) grouping is robust and accords with the approach taken in this paper, but there are terminological difficulties. The first is that the term Kaikoura has historically been applied to an orogeny, which corresponds in time to only part of the stratigraphic sequence within this sedimentary succession. Second, Kaikoura Synthem was not specifically intended for national usage. Third, the term synthem is little-used internationally, especially since the advent of sequence stratigraphy. In helping to devise the concept of sequence stratigraphy, Mitchum et al. (1977) defined 'depositional sequence' as 'a relatively conformable succession of genetically related strata bounded by unconformities or their correlative conformities'. Those authors seriously considered using the term synthem, but gave several reasons for preferring sequence (Mitchum et al. 1977, p. 55). Murphy & Salvador (1999) have since suggested that synthem be discarded in favour of sequence.

Sequence stratigraphy describes cyclic stratal stacking patterns related to temporal changes in depositional relative base level through the interaction of eustatic sea level, tectonic uplift and subsidence, and sediment supply. The sequence root unit has a nominal duration of 0.5–5 Ma, roughly equivalent to a third-order transgressive-regressive depositional cycle (0.5–3 Ma; Vail et al. 1991). Several third-order cycles make up a second-order cycle (of up to 50 Ma duration with average c. 10 Ma), the stratigraphic signature of which is a supersequence (Vail et al. 1991). Entire basin fill or continent-wide marine onlap–offlap cycles of first-order periodicity (>50 Ma time span) are referred to as megasequences (Vail et al. 1991).

Sequence stratigraphy offers a ready-made high-level conceptual framework into which groups and supergroups can potentially be placed. Indeed, Fulthorpe (1991) has demonstrated this approach for the entire sedimentary succession in offshore Canterbury Basin and King et al. (1999) described New Zealand's supra-basement Cretaceous–Cenozoic succession as a transgressive-regressive megasequence of c. 100 Ma duration. 'Megasequence' is already in formal use in some countries, for example, Australia (Brakel 2000) and USA (Fritz et al. 2012).

In the absence of any clear consensus or guide on nomenclature of high-level unit root names, we introduce the following practical solution based on established usage and suited to New Zealand circumstances. We take the simple step of formalising King et al.'s (1999) first-order megasequence as the Zealandia Megasequence. In this paper, we nominate this as the highest-level stratigraphic name for the New Zealand cover rocks and do not attempt any further sequence stratigraphic classification or analysis. We do nevertheless associate this overall transgressive-regressive megasequence with a rift to post-rift to convergent margin tectonic continuum. The lithostratigraphic supergroups of the cover rocks therefore fit into a megasequence that primarily reflects tectonic influences, just as the groups and supergroups of the basement fit into tectono stratigraphic terranes. Although medium-level lithostratigraphy and high-level tectonostratigraphy are technically different schemes, in practice they dovetail well.

For New Zealand's geographically scattered Late Cretaceous–Holocene volcanic rocks in North, South and offshore islands, we propose 'Volcanic Region' as a formal topmost-level root name. The term was introduced informally by Fisher & Schmincke (1984) as a 'geographic area of large size which includes more than one volcanic province in which volcanism spanned eras of geologic time'. Fisher & Schmincke's (1984) volcanic region was at the top of a hierarchy of volcanic region, province, district/field, centre, volcano and vent, that is, based on stratigraphy, geography and physical volcanology. They defined a volcanic province as a 'geographic area of volcanic rocks which includes more than one volcanic field (or district) of the same or differing time spans. Rocks within a province may overlap in time and space, form a continuous zone or be erosionally disconnected'. On this basis New Zealand would have several defined volcanic provinces, so 'Volcanic Region' seems an appropriate single term with which to describe the diversity and longevity of New Zealand's Late Cretaceous–Holocene volcanic rocks.

High-level stratigraphic units

The new, high-level stratigraphic units are shown in Figs 1, 2 and are described in approximate age order (oldest to youngest) in the following sections. A tabulation of constituent units is given in the Appendix. Stratigraphic units are typically named after geographic features but, as for 'Kaikoura', these can impart an unintended local connotation for high-level units that are essentially national in coverage. Furthermore, a lot of appealing geographic names are already in use for lower-level stratigraphic units. Many of our new high-level names are from the Māori language, with the meaning of each word being relevant to the geological context of the unit. Māori words include macrons to assist pronunciation, but for digital database use we suggest that these can be omitted.

Austral Superprovince

Name and rank

New tectonostratigraphic unit above province, that collectively describes all New Zealand basement rocks. The name Austral Superprovince conveys that the unit had southern origins in the Gondwana supercontinent and is an amalgamation of its constituent provinces. The name 'Austral' has not previously been used as a New Zealand stratigraphic name.

Content

Comprises Eastern Province and Western Province of Landis & Coombs (1967) and Coombs et al. (1976). Includes all terranes, plutonic rocks and metamorphic rocks of Early Cretaceous, or older, age that are regarded as geological basement.

Regional aspects

Despite the longstanding high-level division of basement into Eastern and Western Provinces, there has never been a single formal name for all basement rocks. The tectonised, metamorphosed and intruded Cambrian–Early Cretaceous sedimentary basins (terranes) of the Austral Superprovince typically form acoustic basement to New Zealand's Late Cretaceous–Cenozoic sedimentary basins. The Austral Superprovince term and name provides a single stratigraphic search term for basement rocks in digital databases.

Western Province

Name and rank

Existing tectonostratigraphic unit originally introduced by Landis & Coombs (1967) to describe the plutonic and metasedimentary rocks that lie west of the Median Tectonic Line (MTL).

Content

Western Province comprises Takaka Terrane, Buller Terrane and Tuhua Intrusives (Fig. 2), as well as minor sedimentary and metamorphic units that rest unconformably on the terranes (Parapara Group, Topfer Formation) and high-grade metamorphic rocks in Fiordland whose correlation with Buller or Takaka Terrane is unclear.

Regional aspects

Although the MTL has been supplanted as a concept by the eastern edge of the Median Batholith (Mortimer et al. 1999), the definition and extent of Western Province as used by Landis & Coombs (1967) needs no modification and is retained. In the past, some authors have excluded Median Batholith from the Western Province and some have included it. Here, we explicitly include Median Batholith in the Western Province, as a component of the Tuhua Intrusives (following section). Western Province rocks contain a record of early Palaeozoic terrane accretion and Cambrian–Early Cretaceous plutonism.

Tuhua Intrusives

Name and rank

Originally conceived by Grindley et al. (1959), Tuhua Intrusives was used to describe all plutonic rocks in northwest Nelson and Westland. Although Tulloch (1988) proposed it be discontinued, here we revive and redefine it as a formal term for all plutonic and hypabyssal rocks in the Western Province.

Content

Tuhua Intrusives includes plutonic rocks of the igneous suites and batholiths shown in Fig. 2. Most rocks of the Median, Karamea, Paparoa, Hohonu and Rangitoto batholiths as well as isolated plutons, stocks and dykes outside the batholiths, for example in south Westland and Fiordland, are included in Tuhua Intrusives. We exclude Late Cretaceous intrusive rocks, formerly considered as 'basement', from Tuhua Intrusives, for example the West Coast high-level alkaline French Creek Granite and granite near Whataroa (Nathan et al. 2002; Cox & Barrell 2007). These are now placed in the Rūaumoko Volcanic Region of Zealandia Megasequence (see 'Zealandia Megasequence' section below).

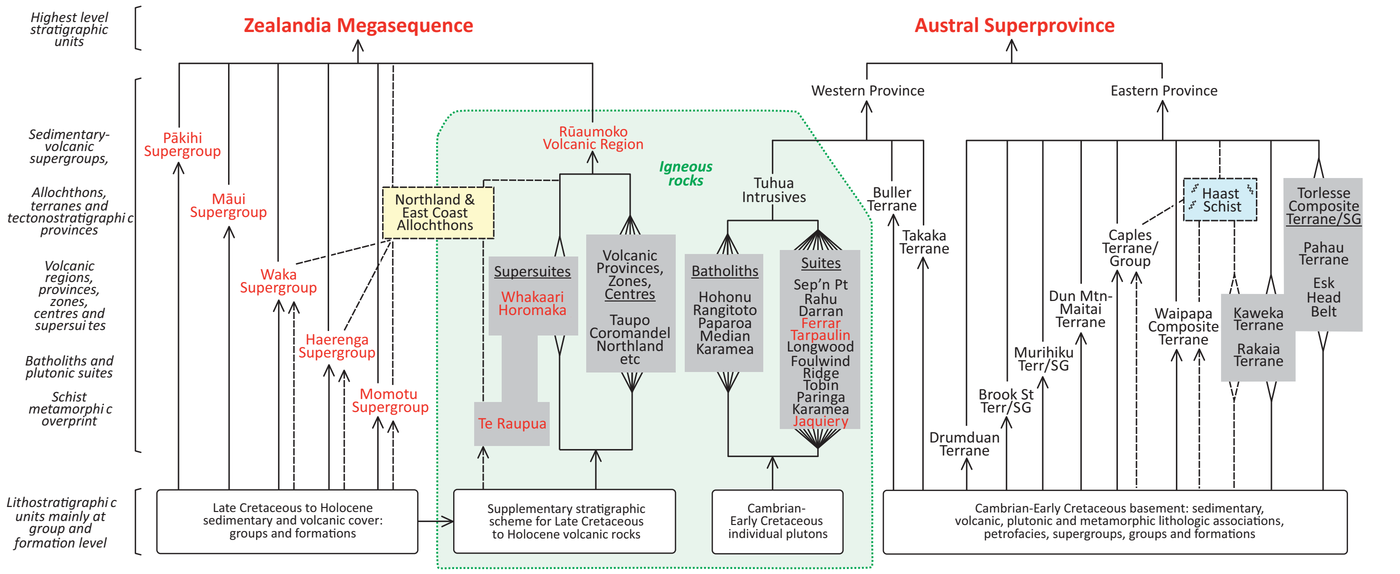

Figure 2 'Road map' style hierarchy of the Litho2014 high-level New Zealand stratigraphic scheme. New names are in red, existing names in black. SG, supergroup; terr, terrane. Volcanic formations of the Zealandia Megasequence can be described either within their supergroups or, if the situation demands, as rocks of a separate Rūaumoko Volcanic Region. Haast Schist can be further formally distinguished on a geographic basis into Kaimanawa, Terawhiti, Marlborough, Alpine, Otago and Chatham Schist. See Appendix for more details.

Regional aspects

Tulloch (1988) emphasised that the pluton is the basic map unit of intrusive igneous rocks, and proposed that New Zealand plutons be grouped physically into batholiths and geochemically and geochronologically into suites. The Litho2014 scheme adopts the same twin classification of Tuhua Intrusives plutons into batholiths and suites (Fig. 2). This allows the rocks to be classified by their spatial geometry (batholiths, composed of contiguous plutons, stocks and dykes, potentially of markedly different emplacement age and petrogenesis) as well as by their geochemical and geochronological affinities (suites, comprising compositionally related and generally coeval but not necessarily contiguous plutons).

Tulloch (1988), Tulloch et al. (2009b) and Turnbull et al. (2010) defined and used eight Palaeozoic and Mesozoic plutonic suites based on interpreted age and chemical characteristics: Separation Point, Rahu, Darran, Foulwind, Tobin, Ridge, Paringa and Karamea. To these we add the Late Permian Longwood Suite (McCoy-West et al. 2014), and three new suites defined as follows (see also Appendix).

JAQUIERY SUITE (new) is named after the Jaquiery River in Fiordland for gneissic I-type granodiorite and tonalite of Cambrian age. The Jaquiery Granitoid Gneiss and Pandora Orthogneiss plutons belong to the Jaquiery Suite (Turnbull et al. 2010) and are the oldest plutonic bodies yet found in New Zealand.

TARPAULIN SUITE (new) is named after Tarpaulin Beach in Stewart Island which is the type locality of the Tarpaulin Pluton, an A-type granite of Early Cretaceous age that occurs in north Stewart Island (Turnbull & Allibone 2003). Peralkaline Electric Granite and Pomona Island Granite of Fiordland (Turnbull et al. (2010) are also included in the Tarpaulin Suite. Tarpaulin Suite represents episodic A-type plutonism towards the end of Darran Suite plutonism.

FERRAR SUITE (new) is named after the Ferrar Glacier in southern Victoria Land, Antarctica for subalkaline basaltic hypabyssal rocks of Jurassic age. The Kirwans Dolerite near Reefton is the only known correlative in Zealandia (Nathan et al. 2002). It represents part of an intraplate large igneous province that formerly extended across much of Gondwana.

Suites are arguably more useful than batholiths to petrologists as a high-level subdivision but, as additional analytical data are acquired, are more prone to change than a mapping-based classification. Following conventional New Zealand use, igneous rocks that are clearly confined to stratigraphic or structural parts of an individual tectonostratigraphic terrane (e.g. Cobb Ultramafics of Takaka Terrane and Dun Mountain Ultramafics of Dun Mountain–Maitai Terrane) are treated as formations or groups of that terrane and are not included in Tuhua Intrusives (e.g. Rattenbury et al. 1998; Turnbull 2000).

Eastern Province

Name and rank

Existing tectonostratigraphic unit originally introduced by Landis & Coombs (1967) to describe the plutonic and metasedimentary rocks that lie east of the Median Tectonic Line (MTL).

Content

Drumduan, Brook Street, Murihiku, Dun Mountain–Maitai and Caples terranes, along with Waipapa and Torlesse composite terranes and Haast Schist. Within the Eastern Province, Brook Street, Murihiku and Torlesse supergroups are retained because they are lithostratigraphic units synonymous with Brook Street and Murihiku terranes and Torlesse Composite Terrane (Coombs et al. 1976; Carter et al. 1978; Campbell et al. 2003).

Regional aspects

See comments on Western Province above. The longstanding tectonostratigraphic nomenclature of the Eastern Province needs little modification and the Litho2014 scheme follows recent usage adopted in the later maps and texts of the QMAP series (e.g. Turnbull et al. 2010; Lee et al. 2011). We exclude Waipa Supergroup (Kear & Mortimer 2003) from the Litho2014 scheme principally because its validity is not supported by the detrital zircon data of Adams et al. (2009); its constituent rocks revert to Murihiku Supergroup, Manaia Hill Group and Torlesse Supergroup. We exclude the term Maitai Supergroup because the QMAP programme supplanted this with Maitai Group (e.g. Turnbull & Allibone 2003). Drumduan Terrane is used after Scott (2013) to include Mesozoic volcano-sedimentary units between the Brook Street and Takaka terranes. The Houhora Complex of Northland was previously assigned to the Mount Camel Terrane of the Eastern Province (Isaac 1996). In the light of more recent dating and chemistry (Tulloch et al. 2009a), we now treat Houhora Complex as a volcanic part of the Zealandia Megasequence (see 'Rūaumoko Volcanic Region' below) and not as part of the Eastern Province.

The three terranes that are partly overprinted by Haast Schist are Waipapa, Torlesse and Caples terranes. The Litho2014 scheme (Fig. 2) uses the optional formal name Haast Schist, thereby allowing a flexible classification by terrane (protolith) or by schistose/non-schistose nature. Haast Schist can be further formally subdivided on a geographic basis into Kaimanawa, Terawhiti, Marlborough, Alpine, Otago and Chatham Schist (Mortimer 1993).

Zealandia Megasequence

Name and rank

New highest-level stratigraphic unit above supergroup. The name Zealandia conveys the idea that the rocks and sediments are both widespread and that they are either native to (were formed on) the continent of Zealandia after the break-up of Gondwana and/or are related to the rifting phase that immediately preceded break-up. Zealandia has not previously been used as a stratigraphic name.

Content

Comprises Momotu, Haerenga, Waka, Māui and Pākihi supergroups and includes the Rūaumoko Volcanic Region (see below), in other words, New Zealand's entire package of Late Cretaceous and Cenozoic sedimentary and volcanic cover rocks and sediments. It fully encompasses the Kaikoura Synthem of the eastern South Island (Carter 1988).

Regional aspects

The cover rocks and sediments of the Zealandia Megasequence constitute a c. 100 Ma long first-order transgressive-regressive stratigraphic cycle (Fig. 3; Carter 1988; King et al. 1999). Zealandia Megasequence deposits infill all post-Early Cretaceous sedimentary basins and have a substantial offshore extent. Indeed, the most complete record of the Zealandia Mega sequence is in offshore basins where uplift and erosion has been comparatively minor. The Zealandia Megasequence's five supergroups (Figs 3, 4) are based on the seven second-order hybrid sequence stratigraphic, allostratigraphic and tectonostratigraphic cycles of King et al. (1999). The second-order cycles are generally correlatable between basins as major, sometimes (but not always) unconformity-bounded packages, each with internally diachronous trangressive or regressive depositional trends that primarily reflect a changing balance between basin subsidence and sediment supply, ultimately controlled by plate tectonic setting (King et al. 1999). For the purposes of this paper we have grouped the stratigraphic units of cycles 2–3 and 5–6 into single supergroups, because lithologies do not significantly change across these paired cycle boundaries in most New Zealand sedimentary basins (King et al. 1999). In places where a given cycle onlaps basement or an older cycle, its base is strongly diachronous. Elsewhere, boundaries between the individual supergroups may straddle a range of ages, depending on their degree of unconformity. However, the causative changes in tectonic setting generally occurred over a relatively short span of geological time (i.e. less than the duration of a biostratigraphic stage in the New Zealand timescale); at a regional scale, the cycle boundaries are therefore approximately isochronous for many practical purposes.

Momotu Supergroup

Name and rank

New lithostratigraphic unit above group level, part of Zealandia Megasequence. Momotu is a Māori word meaning to separate, sever or break apart. This is an appropriate name for the rocks that were formed during the break-up of Gondwana just prior to separation of Zealandia. Momotu has not previously been used as a stratigraphic name.

Content

Major sedimentary constituent units are Matawai, Ruatoria, Mangapurupuru, Pororari, Coverham, Wallow, Waihere Bay, Hoiho and lower Matakea groups, and Taniwha Formation. Major igneous constituents are Tapuaenuku Igneous Complex, Houhora Complex, part of Tangihua Complex, part of Matakaoa Volcanics, Pitt Island and Mount Somers Volcanics groups, Gridiron and Lookout formations, and French Creek Granite.

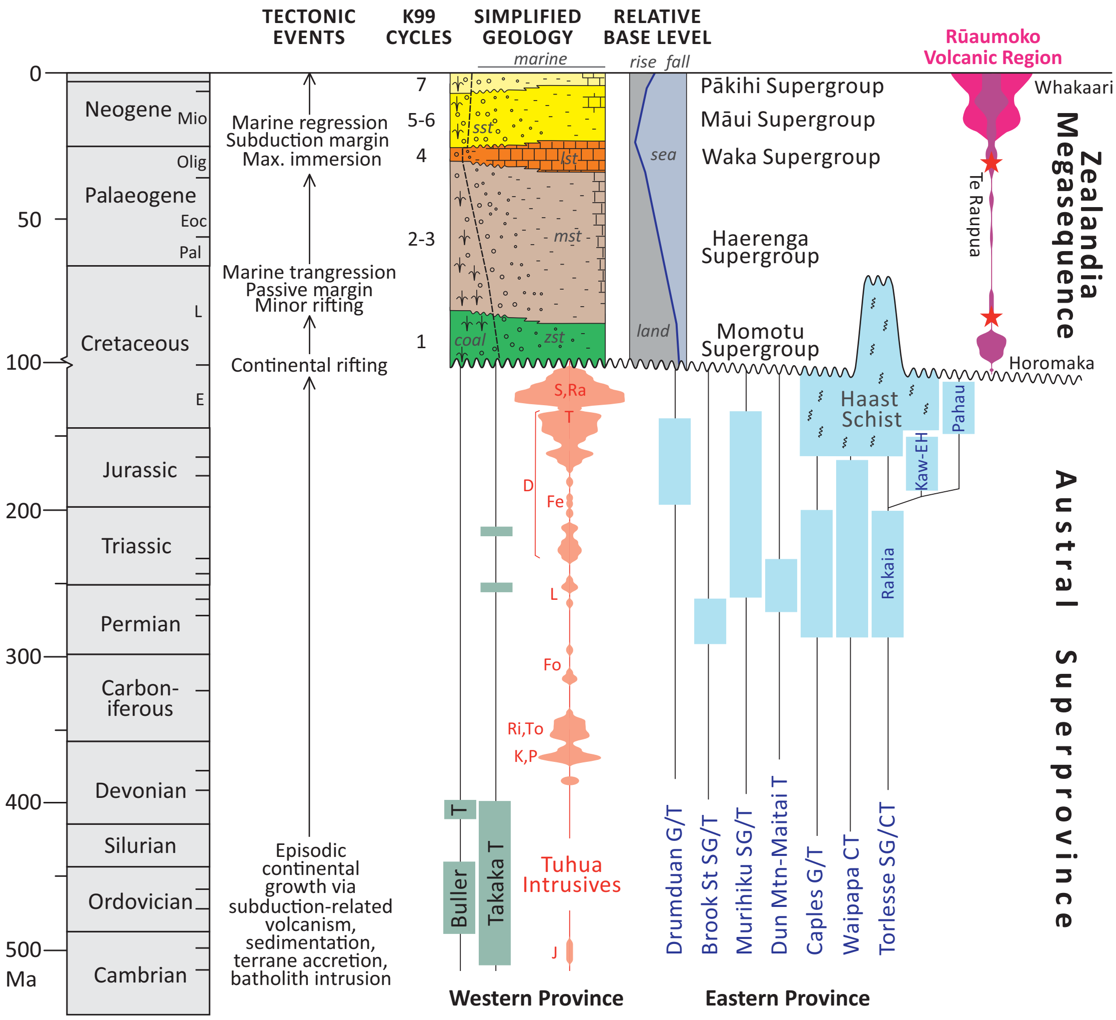

Figure 3 Generalised age ranges of the Litho2014 high-level stratigraphic units. Note change in vertical scale at 100 Ma. Austral Superprovince units are arranged in approximate west–east order, but no spatial pattern is implied for Zealandia Megasequence. Columns with black headers apply to Zealandia Megasequence. Allochthons are not shown. Tuhua and Rūaumoko igneous pulses are schematic only. Plutonic suite abbreviations: S, Separation Point; Ra, Rahu; D, Darran; T, Tarpaulin; Fe, Ferrar; L, Longwood; Fo, Foulwind; R, Ridge; T, Tobin; P, Paringa; K, Karamea; J, Jaquiery. Other abbreviations: G, group; K99, King et al. (1999) second-order cycles; SG, supergroup; T, terrane.

The Momotu Supergroup includes units that are part of the Northland and East Coast allochthons. See Appendix for a list of all constituent units.

Regional aspects

In most places, Momotu Supergroup rests unconformably on Austral Superprovince. The exceptions are in the Northland and East Coast allochthons (Ballance & Spörli 1979) where no stratigraphic base is seen. The basement-cover unconformity represents prolonged sub-aerial erosion during the first-order lowstand, and the stratigraphic base of Momotu Supergroup marks the onset of ensuing sedimentation and is strongly diachronous. The oldest well-dated part is the 112 Ma Kyeburn Formation (Tulloch et al. 2009a). Momotu Supergroup marine strata, of poorly dated Korangan–Piripuan (117–84 Ma; Aptian) age, occur in Raukumara Peninsula, eastern Taranaki Basin and the northeast South Island. Momotu Supergroup non-marine strata were primarily deposited in widespread but localised grabens and half grabens (Figs 1, 4) during the c. 105–85 Ma intra-continental rifting phase in eastern Gondwana that ultimately led to the formation of Zealandia (Laird & Bradshaw 2004). Intraplate volcanism accompanied rifting (Tulloch et al. 2009a) and these intercalated deposits are included (see above and Appendix). The top of Momotu Supergroup is marked at many (but not all) places by a prominent unconformity and/or correlative conformity. In places, this is also equivalent to the oldest (c. 85 Ma) parts of the Waipounamu Erosion Surface (Crampton et al. 1999; Landis et al. 2008).

The Momotu Supergroup corresponds to second-order cycle 1 of King et al. (1999). The presence of marine strata within this interval led those authors to infer that it also represented the start of continental flooding (first-order transgression), although they noted that more widespread marine onlap of basement did not start until the next second-order cycle (lower Haerenga Supergroup).

Haerenga Supergroup

Name and rank

New lithostratigraphic unit above group level. Part of Zealandia Megasequence. Haerenga is a Māori word meaning a journey, trip or parting. This is an appropriate name for the rocks which were formed after Zealandia broke away from Gondwana, accompanied by the opening of the Tasman Sea and the Southern Ocean. Haerenga has not previously been used as a stratigraphic name.

Content

Major constituent units are Moa, Kapuni, Tinui, Rapahoe, Pakawau, Eyre, Muzzle, Seymour, Annick, Onekakara, Ohai, Nightcaps, Pakaha, Rakiura and upper Matakea groups, and Paparoa Coal Measures. The lower parts of Motatau Complex and the Te Kuiti, Mangatu and Balleny groups are also included. Volcanic rocks are minor but include View Hill, Grasseed and Northern volcanics. Haerenga Supergroup includes units that are part of the Northland and East Coast allochthons (Ballance & Spörli 1979). See Appendix for a complete list of constituent units.

Regional aspects

In many places in coastal eastern New Zealand, the base of the Haerenga Supergroup is marked by the c. 85 Ma unconformity described in the previous section ('Momotu Supergroup'; see also Figs 1, 4), but in other places this unconformity is strongly diachronous with much younger rock units overlying it. Haerenga Supergroup spans second-order cycles 2 and 3 of King et al. (1999). There is no consistent lithologic change across the c. 55 Ma boundary between cycles 2 and 3 in New Zealand's nearshore and onland sedimentary basins, so we do not distinguish these cycles at supergroup level (but see Bache et al. 2012). In the basins of west Southland, West Coast and southern Taranaki the lower part of the Haerenga Supergroup (cycle 2 of King et al. 1999) includes sediments deposited within localised rift basins inferred to have been part of a rift transform zone (King & Thrasher 1996). In northwest South Island, Taranaki Basin and basins in eastern New Zealand, thick sedimentary successions reflect major Late Cretaceous–Late Eocene marine onlap (Fig. 3). Haerenga Supergroup is a package of laterally equivalent terrestrial, marginal marine and fully marine facies that record overall marine transgression as a result of palaeobathymetric deepening from the Late Cretaceous to the Late Eocene. Intraplate volcanic rocks are present but are less voluminous than in the Momotu Supergroup (Fig. 3). The top of the Haerenga Supergroup is commonly marked by greensands, unconformities and other indicators of enhanced marine transgression and reduction in clastic sediment supply around the Eocene–Oligocene boundary.

Waka Supergroup

Name and rank

New lithostratigraphic unit above group level. Part of Zealandia Megasequence. Waka is the Māori name for a canoe. Ocean-voyaging waka were used by Māori to travel between New Zealand and their ancestral homelands. This is an appropriate name for the rocks which were formed during the maximum marine inundation of Zealandia. Waka has not previously been used as a stratigraphic name.

Content

Major constituent units are generally carbonate-dominated and comprise the Ngatoro, Nile, Kekenodon and Alma groups, the stratigraphically upper parts of Motatau Complex, Te Kuiti, Mangatu and Balleny groups and the lower parts of Motunau Group. The middle carbonate-dominated part of the Waiau Group (Tunnel Burn Formation) in west Southland is also part of the Waka Supergroup. Rare volcanic rocks include Cookson Volcanics Group and Brothers, Deborah and Waiareka volcanics. Waka Supergroup includes units that are part of the Northland and East Coast allochthons (Ballance & Spörli 1979). See Appendix for a complete list of constituent units.

Regional aspects

Waka Supergroup rocks are equivalent to second-order cycle 4 of King et al. (1999) and the Te Kuiti Sequence of Kamp et al. (2004). They represent the widespread expression and culmination of first-order marine flooding of Zealandia. As well as limestones, the Waka Supergroup also typically includes greensands, calcareous mudstones and some calcareous sandstones. Condensed sedimentary sections of very slow sediment accumulation and unconformities are present (Figs 1, 3, 4) and volcanic rocks are minor. Of all the newly introduced supergroups, the Waka Supergroup is the most distinctive (carbonate dominated) with the least lateral lithogical variability, but is also the least well defined in terms of its upper and lower limits. This is partly because the onset and cessation of carbonate deposition was diachronous and gradual, particularly in distal areas, and partly because unconformities occur at different stratigraphic levels rather than a single clear unconformity, particularly in proximal areas. Several existing lithostratigraphic groups containing carbonate-dominated strata have a wide age range and/or also encompass a wide range of other lithologies (e.g. Motatau Complex and Te Kuiti, Mangatu, Motunau, Waiau and Balleny groups), which makes their assignation to supergroups difficult. However, lithostratigraphic breaks definable at the formation level (Appendix) allow these groups to be split such that most carbonate intervals are assigned to the Waka Supergroup and non-carbonate strata to either the Haerenga Supergroup or Māui Supergroup, as appropriate.

The Early–middle Oligocene Marshall Unconformity (Carter 1988; Lever 2007) presents another conundrum with respect to defining the Waka Supergroup. In its type area of the onshore Canterbury region, the Marshall Unconformity is middle Oligocene in age and forms a distinctive depositional break between carbonate-dominated intervals; here, Carter (1988) used it as a group boundary marking the regional transition from peak marine transgression to onset of regression. In other places however, such as in Taranaki Basin and adjacent basins to the east, peak marine inundation occurred significantly later during the latest Oligocene (Kamp et al. 2014; Strogen et al. 2014). Moreover, the Marshall Unconformity is not recognised everywhere, has different ages and potentially different origins and occurs variably within or beneath the overall Oligocene carbonate-dominated succession (King et al. 1999; Lever 2007). All things considered, our preference in this paper is not to use the Marshall Unconformity *sensu stricto* as a defining boundary between supergroups, as it is only one of many local unconformities developed in this period (see also McMillan & Wilson 1997). Latest Eocene–Early Oligocene carbonate units that underlie the Marshall Unconformity in its type area (e.g. Alma Group) are best placed within the Waka Group based on their lithology and given that these are even deeper-water units than the carbonates overlying the Marshall Unconformity in this area. Conversely, Paleocene–Eocene carbonates in the Kaikoura region (Amuri Limestone within Muzzle Group) are considered to represent distal facies of the earlier transgressive phase and are best placed within the Haerenga Supergroup.

Māui Supergroup

Name and rank

New lithostratigraphic unit above group level. Part of Zealandia Megasequence. Māui Supergroup is named after the Māori legend of the demigod Māui, who, while in a waka, fished the North Island out of the sea, metaphorically analogous to the widespread emergence of land following maximum marine immersion. Sharing a name with important petroleum wells and a gas field in the Taranaki Basin, Māui Supergroup also serves as a reminder of the extensive Neogene rock mass that underlies the New Zealand offshore region. The Māui wells drilled through a considerable thickness of Māui Supergroup clastic strata before encountering the underlying reservoir intervals (Fig. 4). Maui Formation has previously been used as an obscure term for a unit in the Kapuni Group of offshore Taranaki Basin (Robinson & King 1988). However Maui Formation was replaced by one or other of McKee, Mangahewa or Kaimiro formations in the reference works of King & Thrasher (1996) and King et al. (1999) and it is not in contemporary use. Our new Māui Supergroup is unlikely to be confused with it but we nonetheless formally rescind the former name Maui Formation.

Content

Constituent sedimentary units are generally clastic-dominated and include the Reinga, Parengarenga, Waitemata, Wai-iti, Whangamomona (excluding Matemateonga Formation), Mokau, Mahoenui, Tolaga, Blue Bottom, Rappahannock, Burnt Hill, East Southland, Otakou, Manuherikia, Waiau and Penrod groups, as well as the upper part of the Motunau Group (excluding the Kowai and Greta formations) and the lower part of the Hawkdun Group. Volcanic rocks locally dominate and include Coromandel, Waitakere, Whitianga, Kiwitahi, Diamond Harbour, Mount Herbert, Akaroa, Lyttelton and Dunedin Volcanic groups. Māui Supergroup mainly depositionally overlies the Northland and East Coast allochthons (Ballance & Spörli 1979) but some small piggyback basins structurally underlie and/or are included within the allochthons. See Appendix for a complete list of constituent units. We note the previous use of Akarana Supergroup for Late Oligocene and Early Miocene sedimentary and volcanic rocks of Northland and Auckland (Ballance et al. 1977). While Akarana Supergroup may still be used in the Northland region, Akarana is too local a name for use in the national Litho2014 scheme.

Regional aspects

Māui Supergroup represents the initial part of the first-order regional regression that started after the Late Oligocene–Early Miocene maximum flooding. The late Cenozoic convergent plate boundary developed during this interval and the sedimentary response (increased input of detrital clastic sediment eroded from rising mountain ranges) is seen in all New Zealand basins (e.g. Figs 3, 4). The Māui Supergroup includes second-order cycles 5 and 6 of King et al. (1999). The volcanic response to the convergent plate boundary inception was the development of chains of Miocene subduction-related volcanoes in the northern North Island and a pulse of intraplate volcanism in the South Island.

Pākihi Supergroup

Name and rank

New lithostratigraphic unit above group level, part of the Zealandia Megasequence. Pākihi is a Māori word meaning open grasslands or open, barren country and is well suited to the flat landscapes of the North and South islands, whose surfaces are underlain by New Zealand's youngest sedimentary deposits. Pākihi has not previously been used as a stratigraphic name.

Content: Constituent units comprise Pliocene, Pleistocene and Holocene non-marine and marine sedimentary and volcanic deposits. The QMAP project mapped and classified many of these on a chronostratigraphic basis and existing stratigraphic names are generally local and numerous. Pākihi Supergroup includes Karioitahi, Awhitu, Tauranga, Rotokare, Shakespeare, Kai-iwi, Okehu, Maxwell, Nukumaru, Okiwa, Paparangi, Whenuakura, Utiku, Kidnappers, Onoke, Mangaheia, Old Man and Tadmor groups and Matemateonga Formation of Whangamomona Group. Volcanic rocks are common, especially in

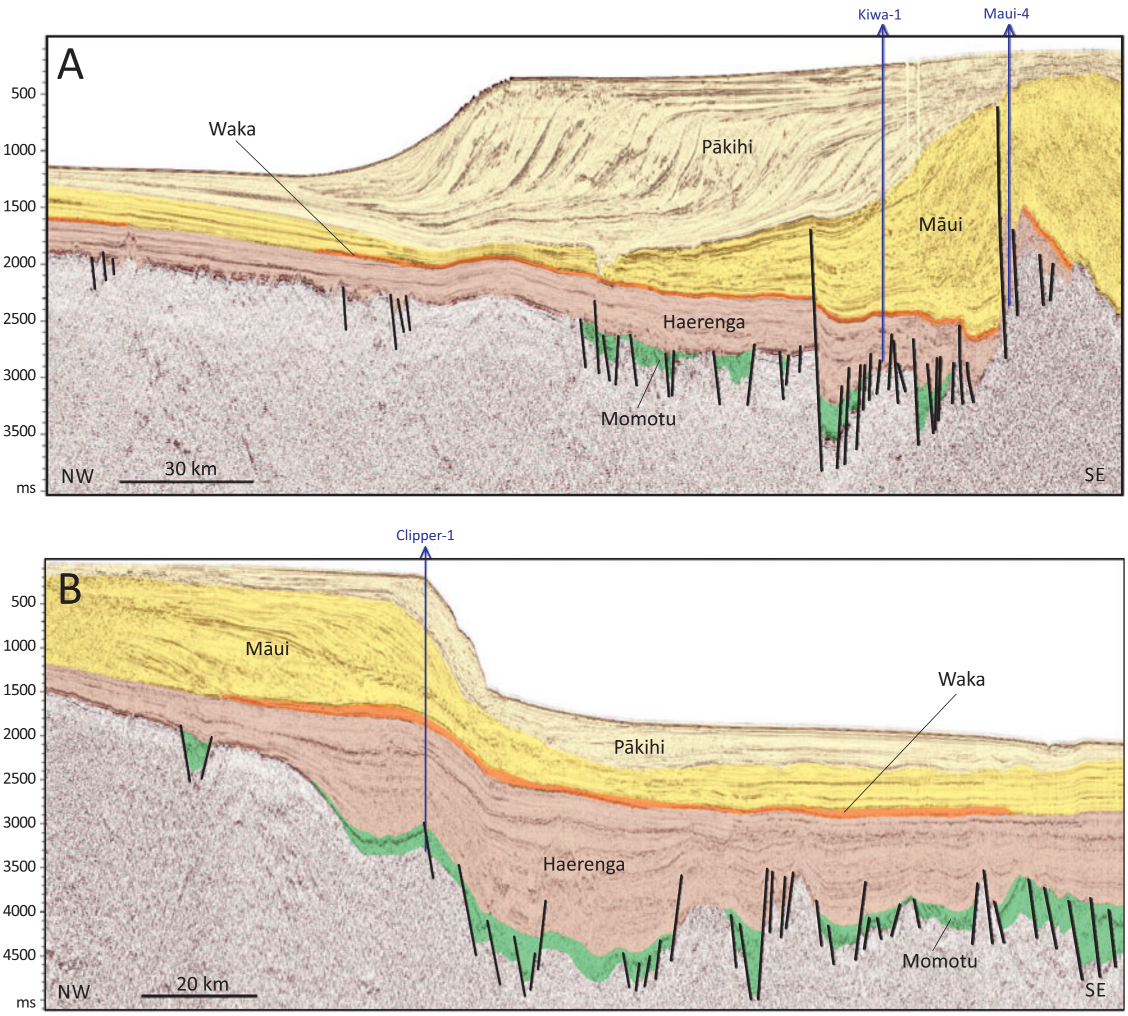

Figure 4 Offshore seismic reflection lines **A**, Taranaki Basin (PEGI6) and **B**, Canterbury Basin (CB82), interpreted in terms of Litho2014 high-level stratigraphic units. See Fig. 5 for line locations. Vertical axis divisions are two-way travel time (milliseconds).

central North Island and include Mayor Island, Kerikeri Volcanic, Alexandra Volcanic, Whakamaru, Pakaumanu, Ongaroto, Maroa, Taupo, Okataina and Ruapehu groups and Solander Island Volcanics. See Appendix for a complete list of constituent units.

Regional aspects

The Pākahi Supergroup represents an acceleration of the regional first-order regression, exemplified by development of piedmont and fluvio-glacial outwash plains and outbuilding of the continental shelf. The base of the Pākihi Supergroup is placed at the base of second-order cycle 7 of King et al. (1999). At many localities across New Zealand, this base is highly diachronous. The unconformity is most conspicuous where Quaternary deposits rest directly on Austral Superprovince basement. In some marine sedimentary basins there is a marked unconformity between Miocene and Pliocene strata and a basinwards shift in depositional facies (base level fall). For example, the Early Pliocene shelfal Titiokura Formation overlies deeper-water strata in the eastern North Island basins (Bland et al. 2004). A similar facies change and boundary is seen at the base of the shelfal Matemateonga Formation in the contiguous eastern Taranaki–Wanganui Basin. For Pliocene–Pleistocene marine strata in the Wanganui Basin, the term Rangitikei Supergroup has previously been used (Kamp et al. 2004; Townsend et al. 2008). Arguably, many of its constituent groups are best described as formations and its constituent formations as members. As such, and because Rangitikei is a local geographic term, we have not included Rangitikei Supergroup in the Litho2014 scheme. Most volcanic rocks of the Pākihi Supergroup are subduction-related, lie within Taupo Volcanic Zone and erupted from topographically well-preserved volcanic centres and calderas, including currently active volcanoes. Scattered intraplate basalts are present in and near Auckland, Kerikeri and Timaru.

Rūaumoko Volcanic Region

Name and rank

New volcanic-stratigraphic unit above group level incorporating numerous mapped volcanic zones, fields, complexes and centres. Part of Zealandia Megasequence. Rūaumoko Volcanic Region is an alternative and/or additional high-level stratigraphic name, separate from the aforementioned supergroups, with which to describe the Late Cretaceous–Holocene igneous rocks of the Zealandia Megasequence using physical volcanological criteria. Rūaumoko Volcanic Region is named after the Māori god associated with volcanoes and earthquakes; Rūaumoko has not previously been used as a stratigraphic name.

Content

Rūaumoko Volcanic Region comprises all igneous rocks of the Zealandia Megasequence (Figs 2, 3, 5). As the name implies, the rock content of Rūaumoko Volcanic Region is >99% volcanic, but does include rare hypabyssal and plutonic units. The QMAP project separated primary and near-primary fragmental volcanic rocks from those that were sufficiently reworked to describe as sedimentary rocks (e.g. Townsend et al. 2008; Leonard et al. 2010). This provides a practical means to define the constituent units of Rūaumoko Volcanic Region at 1:250 000 scale. Any volcanogenic units, from groups to individual thin tephra horizons, can be included in Rūaumoko Volcanic Region if it is convenient and useful to do so. Some constituent groups and formations are listed below under supersuites, and a complete list is given in italics in the Appendix. The development of a comprehensive New Zealand volcanic-stratigraphic hierarchy of volcanic provinces, zones, centres, volcanoes and vents is outside the scope of this paper.

Regional aspects

Traditionally in New Zealand, volcanic groups, formations and members have been included as integral parts of their sedimentary-dominated higher-level stratigraphic units. Examples include Triassic Park Volcanics Group in Murihiku Supergroup (Turnbull & Allibone 2003), Eocene Deborah Volcanics in Alma Group (Forsyth 2001), Miocene Waiatarua Formation basalts in Waitakere Group (Edbrooke 2001) and ignimbrites and tephra in Quaternary Kidnappers Group (Lee et al. 2011). Indeed, many clastic sedimentary rocks are locally derived from, and intimately associated with, coeval and adjacent volcanic rocks, for example Miocene Mohakatino Formation from a chain of now-buried volcanoes within the Mohakatino Volcanic Centre in Taranaki Basin (Bergman et al. 1992; King & Thrasher 1996) and Quaternary Hinuera Formation alluvium from Oruanui Formation ignimbrite (Leonard et al. 2010). On a broader scale there is also a tectonic link between controls on the sequence stratigraphy of sedimentary basins and the production of igneous rocks, for example rift-related volcanics in the Momotu Supergroup and inception of subduction-related volcanism at the base of the Māui Supergroup. A holistic view of New Zealand sedimentary basins does not ignore volcanic rocks and vice versa. Volcanic rocks also obey the law of superposition. All these are sound reasons to continue to stratigraphically classify New Zealand's Late Cretaceous–Holocene volcanic rocks with their enclosing sedimentary strata, that is, as part of Momotu, Haerenga, Waka, Māui and Pākihi supergroups.

However, volcanic rocks are a distinctive lithology and are often studied in isolation using specialist physical volcanological and/or geochemical data and terminology. We see these as useful reasons to define a Rūaumoko Volcanic Region. This alternative volcanic classification sits alongside, and is separate from, the five supergroups. It provides different organisational criteria and names between the Zealandia Megasequence and low-level volcanic groups and formations (Fig. 2), based on volcanic centres and geochemistry. As for terranes, plutons and suites, these may be unfamiliar terms to those used to dealing with just stratified sedimentary rocks. We argue that, because they are based on features of members, formations and groups and are hierarchical in nature, they are a valid stratigraphic construct. Established names of volcanic zones and volcanic centres can be found on QMAP map legends (e.g. Okataina Volcanic Centre is part of Taupo Volcanic Zone; Leonard et al. 2010).

As a further addition to the Litho2014 scheme we propose three new high-level petrological divisions of Rūaumoko Volcanic Region: the Whakaari, Horomaka and Te Raupua supersuites. These are based on broad mineralogical, geochemical and age characteristics. The supersuite distinction is higher level, but otherwise comparable to the suite subdivision of Tuhua Intrusives in the Austral Superprovince (Fig. 2). The supersuites could, in principle, be subdivided into igneous suites but this is outside the scope of this paper.

WHAKAARI SUPERSUITE (new) is named after Whakaari (White Island, Bay of Plenty) where active subduction-related volcanism is taking place. Whakaari has not previously been used as a stratigraphic name. Whakaari Supersuite is a collective name for all generally porphyritic basalts, andesites, dacites and rhyolites and minor intrusive rocks, whose geochemistry is subalkaline and which have an interpreted subduction-related origin. All Whakaari Supersuite rocks are of Miocene–Holocene age (Fig. 3) and only occur in the North, Kermadec and Solander islands. Examples include Taupo, Ruapehu, Coromandel and Waitakere groups. An overview of the rocks we assign to Whakaari Supersuite is given by Cole (1986).

HOROMAKA SUPERSUITE (new) is named after the Māori term for Banks Peninsula where the largest single intraplate volcanic centre in New Zealand is exposed. Horomaka has not previously been used as a stratigraphic name. Horomaka Supersuite lavas are generally aphyric to moderately porphyritic basalts, andesites, trachytes, phonolites and associated intrusive rocks, whose geochemistry is mildly to strongly alkaline and which have an interpreted intraplate origin (i.e. not directly associated with a subducting slab). Horomaka Supersuite rocks range in age from Late Cretaceous to Holocene, but with distinct pulses in the Late Cretaceous and Middle Miocene (Fig. 3). They are widespread across Zealandia, including Chatham and most Subantarctic islands. Examples include the Houhora Complex and Mount Somers Volcanics Group and the

Akaroa, Dunedin and Kerikeri Volcanic groups. An overview of the rocks we assign to the Horomaka Supersuite is given by Weaver & Smith (1989).

TE RAUPUA SUPERSUITE (new) is named after the highest peak in Northland. This is underlain by basaltic and gabbroic-dominated volcanic and plutonic rocks of the Tangihua Complex. Te Raupua has not previously been used as a stratigraphic name. Te Raupua Supersuite describes the Late Cretaceous–Oligocene igneous rocks of the Tangihua Complex (Northland Allochthon, Ballance & Spörli 1979), the correlative Matakaoa Volcanic Group (East Coast Allochthon) and minor, possibly allochthonous, petrologically-correlative basaltic rocks of the East Coast North Island. Geochemical interpretations are less clear cut than for Whakaari and Horomaka supersuites and their tectonic settings similarly ambiguous, with back-arc basin and/or suprasubduction zone origins being cited (Nicholson et al. 2000; Cluzel et al. 2010).

Utility of the Litho2014 scheme

Stratigraphy has been described as the triumph of terminology over common sense (attributed to PD Krynine). Some might regard the high-level units in Figs 1–5 as an unacceptable mix of old, new, lithostratigraphic, tectonostratigraphic and sequence stratigraphic terms and associated allostratigraphic, chronostratigraphic and volcanological concepts. But many of the formal and well-established groups of sedimentary rocks in New Zealand have not been erected on a strict lithostratigraphic basis in which constituent formations have significant and diagnostic lithologic properties in common. The QMAP project (Rattenbury & Isaac 2012) used a partly lithostratigraphic, partly tectonostratigraphic and partly chronostratigraphic approach, and this same pragmatic approach underpins Litho2014. We think no single methodology will yield a workable stratigraphic scheme for the whole range of plutonic, volcanic, sedimentary and metamorphic rocks present in New Zealand. The new high-level tectonostratigraphic and sequence stratigraphic framework and nomenclature presented here provides a fundamental utilitarian grouping of these rocks with clear hierarchical relationships to previously defined medium-level lithostratigraphic units (Fig. 2; Appendix). Igneous, metamorphic and allochthonous rocks are also specially catered for.

In constructing the Litho2014 scheme, we have attempted first and foremost to preserve current New Zealand usage and conventions (e.g. Eastern Province); Litho2014 is not a 'clean slate'. The only casualties of the new scheme are the non-use of four of the eight existing local supergroups (Rangitikei, Akarana, Waipa, Putakaka) and shifting of some 'basement' Late Cretaceous igneous rocks (e.g. Houhora Complex) into Rūaumoko Volcanic Region and/or Momotu Supergroup. Where there is a need for a high-level unit that does not exist we have introduced one (e.g. Māui Supergroup). We have only created new top-level root names (e.g. Zealandia Megasequence, Austral Superprovince) as a last resort and because there are no recommendations from the International Stratigraphic Guide. We believe the Litho2014 scheme is one to which most New Zealand geologists will readily relate.

For many rocks the Litho2014 scheme allows some flexibility in stratigraphic classification depending on purpose and context. For example, Late Cretaceous–Holocene volcanic and volcaniclastic rocks can be described using either their interstratified supergroup names or their parent supersuites within the Rūaumoko Volcanic Region. Basement plutons of Tuhua Intrusives can be subdivided according to suite affinity or batholith occurrence. Stratified Murihiku rocks may be described either as a terrane (tectonostratigraphic context) or as a synonymous supergroup (lithostratigraphic context, appropriate to seismic stratigraphy).

The principal value of the stratigraphic framework outlined in this paper is that it provides a simple, direct and unified way to describe the entire continental crustal geology of onland and offshore New Zealand from surface to Moho (Fig. 1, 4, 5). An additional benefit is the enhancement of the efficiency and effectiveness of digital geoscience database tools. With the connecting of the Petlab database to the New Zealand Stratigraphic Lexicon digital database, it is now possible to make queries that could not formerly be done, for example identify previously collected Waka Supergroup basalts within a particular area.

In the manner of Carter (1988), we believe that the new supergroup framework will be a very useful template for correlating and interpreting broad sedimentary packages (supersequences) mapped on seismic reflection profiles. This will be most important in remote frontier areas where there is no stratigraphic control from drill-holes, such that any attempt to correlate (at formation and group level) to neighbouring regions will be somewhat speculative.

Conclusions

Many of New Zealand's medium-level lithostratigraphic volcanic, plutonic, sedimentary and metamorphic rock unit names have been in existence for many years and their adoption by GNS Science's Basin Studies and QMAP projects (King et al. 1999; Rattenbury & Isaac 2012) reflects their ongoing usefulness. By using existing high-level stratigraphic names and introducing 14 new stratigraphic names, we have created a new, complete and holistic stratigraphic classification for onland and offshore New Zealand from the Kermadec to the Subantarctic islands. The newly introduced superprovince, megasequence and volcanic region root names adapt and build on the important earlier stratigraphic contributions of Carter (1988), King et al. (1999) and other workers. Unlike many stratigraphic schemes, Litho2014 is flexible and inclusive rather than prescriptive and exclusive when it comes to classification of the wide range of igneous, sedimentary and metamorphic rocks found in New Zealand.

Cambrian–Early Cretaceous basement rocks and Late Cretaceous–Holocene sedimentary and volcanic cover rocks and

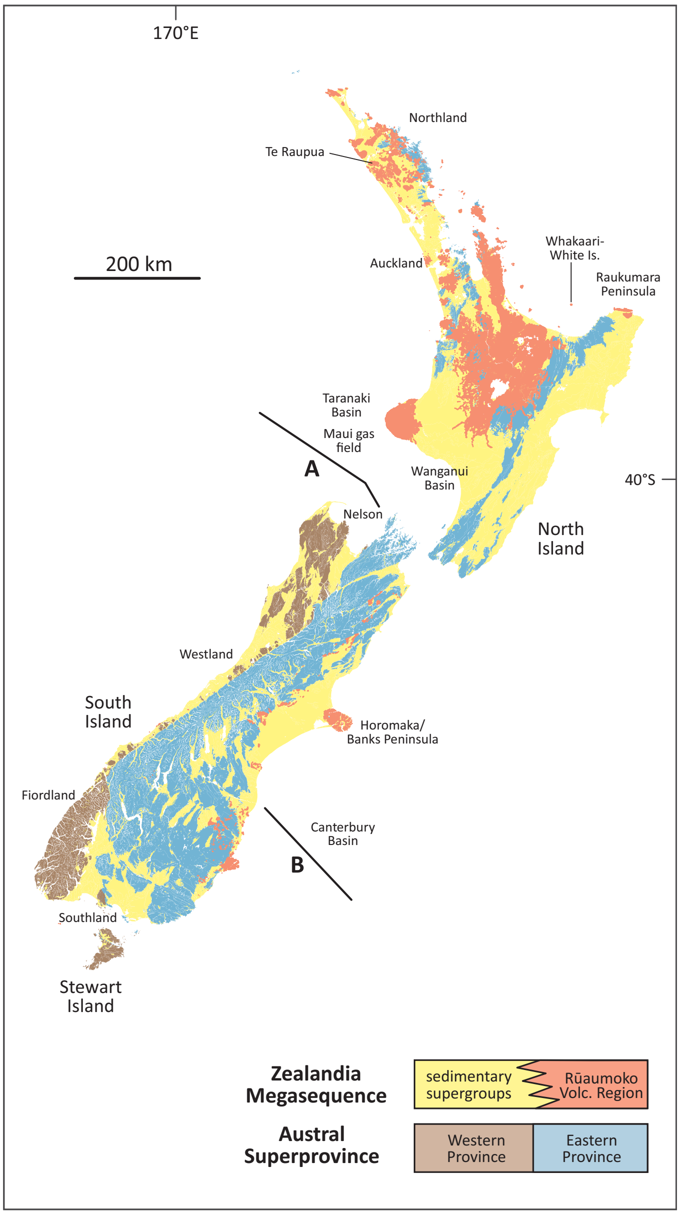

Figure 5 Onland extent of Zealandia Megasequence (with included Rūaumoko Volcanic Region) and Austral Superprovince (with constituent Eastern and Western provinces) in New Zealand. Black lines A and B show the locations of the seismic lines in Fig. 4.

sediments are termed Austral Superprovince and Zealandia Megasequence, respectively. Apart from the reintroduction of the term Tuhua Intrusives to describe the plutonic rocks of the Western Province, and introduction of the Jaquiery, Tarpaulin and Ferrar suites, the high-level nomenclature of the Austral Superprovince does not need any revision although we have clarified some hierarchical relationships. Zealandia Megasequence comprises five new high-level, predominantly sedimentary, units named Momotu, Haerenga, Waka, Māui and Pākihi supergroups. The Rūaumoko Volcanic Region is defined as a parallel umbrella term for the igneous rocks of the Zealandia Megasequence.

As emphasised by Carter (2007), stratigraphy is not an end in itself but is a research tool. The high-level names in this paper provide a contemporary and adaptable scheme for all New Zealand rocks and sediments. Other stratigraphic approaches are of course possible and will doubtless be proposed as needs arise. Our new scheme, termed Litho2014, has been embedded in the New Zealand Stratigraphic Lexicon where the hierarchical relationships can be explored. We consider that Litho2014 represents an important conceptual and practical advance in New Zealand stratigraphic classification that, we hope, will be useful and long-lasting.

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Appendix

Relationship between high-level names of Litho2014 and commonly used medium-level stratigraphic names. Based principally on King et al. (1999, fig. 6) and QMAP compilations of Bishop & Turnbull (1996), Isaac (1996), Rattenbury et al. (1998, 2006, 2010), Begg & Johnston (2000), Mazengarb & Speden (2000), Turnbull (2000), Edbrooke (2001, 2005), Forsyth (2001), Lee & Begg (2002), Nathan et al. (2002), Turnbull & Allibone (2003), Cox & Barrell (2007), Forsyth et al. (2008), Townsend et al. (2008), Edbrooke & Brook (2009), Leonard et al. (2010), Turnbull et al. (2010) and Lee et al. (2011).

Rūaumoko Volcanic Region units in italics with Whakaari, Horomaka and Te Raupua supersuites shown as superscripts W, H and R, respectively. Northland Allochthon and East Coast Allochthon units shown in square brackets [NA] and [ECA].

Only some of the formation-level units that belong to groups are listed.

In order to create a consistent, bottom-up, many-to-one hierarchy of formations, groups and supergroups in the Stratlex database, we have informally subdivided the Te Kuiti, Whangamomona, Matakea, Motunau, Waiau, Balleny, Hawkdun and Mangatu groups, and the Motatau Complex into informal upper and lower parts (e.g. Mangatu group [lower]). Without this new subdivision, existing groups would span supergroup boundaries.

Takaka Terrane

GROUPS
Haupiri Group, Devil River Volcanics Group, Mount Patriarch Group, Mount Arthur Group, Ellis Group, Edgecumbe Group, Cameron Group and Pegasus Group.

NON-GROUPED FORMATIONS
Baton Formation, Junction Formation and Russet Formation.

OTHER
Balloon Melange, Waingaro Schist Zone, Deep Cove Gneiss, Lyvia Gneiss, Mackenzie Schist, Mount Barber Gneiss, Stella Psammite, Townley Calc-silicate and Irene Complex.

Buller Terrane

GROUPS
Greenland Group, Golden Bay Group, Reefton Group and Fanny Bay Group.

OTHER
Victoria Paragneiss, Pecksniff Metasedimentary Gneiss and rocks of Fenella Fault Zone.

Tuhua Intrusives

BATHOLITHS
Karamea, Paparoa, Hohonu, Rangitoto and Median.

SUITES
Separation Point, Rahu, Darran, Tarpaulin, Ferrar, Longwood, Foulwind, Ridge, Tobin, Paringa, Karamea and Jaquiery.

Ferrar Suite comprises Kirwans Dolerite.

Jaquiery Suite includes Jaquiery Granitoid Gneiss, Pandora Orthogneiss and Straight River Granite.

Longwood Suite comprises Hekeia Gabbro, Pourakino Trondhjemite and Bluff Intrusives.

Tarpaulin Suite includes Tarpaulin Pluton, Electric Granite and Pomona Island Granite.

Note that it is not yet possible to supply a comprehensive listing of New Zealand plutons with cross-references to batholiths and suites (but see Turnbull & Allibone 2003; Turnbull et al. 2010).

Undifferentiated Western Province

Parapara Group, Topfer Formation, Fraser Complex, George Sound Paragneiss, Complex Point Group.

Drumduan Terrane

GROUPS
Pepin Group, Drumduan Group, Teetotal Group, Largs Group and Paterson Group.

NON-GROUPED FORMATIONS
Wakapuaka Phyllonite and Loch Burn Formation.

Brook Street Terrane/Supergroup

GROUPS
Brook Street Volcanics Group (including Takitimu, Eglinton and Skippers subgroups), Greenhills Group and Productus Creek Group.

NON-GROUPED FORMATIONS
Barretts Formation, Tin Hut Melange, Lone Stag Ultramafics, Gunn Dolerite, Hokuri Intrusives, White Hill Intrusives, Mackinnon Peak Intrusives and Knobs Gabbro.

Murihiku Terrane/Supergroup

GROUPS
Huriwai Group, Apotu Group, Kirikiri Group, Rengarenga Group, Newcastle Group, Richmond Group, Diamond Peak Group, Ferndale Group, Mataura Group, North Range Group, Taringatura Group, Kuriwao Group and Park Volcanics Group.

NON-GROUPED FORMATIONS
Berneyboosal and Barrier formations.

Dun Mountain-Maitai Terrane

GROUPS
Dun Mountain Ultramafics Group, Livingstone Volcanics Group (including Glennie and Tinline formations), Maitai Group (=Waiua Formation, Greville Formation, Little Ben Sandstone, Tramway Sandstone, Wooded Peak Limestone and Upukerora Formation) and Willsher Group.

OTHER
Patuki Melange, Upukerora Melange, Windon Melange and Otanomomo Complex.

Caples Terrane/Group

FORMATIONS
Haukawakawa Sequence, Wakamarina Quartzite, Star Formation, Ward Formation, Wether Formation, Bold Peak Formation, Crescent Formation, Harris Saddle Formation, Kays Creek Formation, Momus Sandstone and Upper Peak Formation.

OTHER
Omahuta Unit, Puketi Unit, Greenstone Melange, Croisilles Melange, Chrystalls Beach Complex and West Burn Semischists.

Waipapa Composite Terrane

Waipapa Group (= Hunua facies).

Manaia Hill Group (=Morrinsville facies and Arapawa Lithologic Association).

Torlesse Composite Terrane/Supergroup

TERRANES
Pahau Terrane (including Waioeka petrofacies (formerly terrane), Omaio petrofacies), Kaweka Terrane, Rakaia Terrane (including Wanaka Lithologic Association, Aspiring Lithologic Association, Pounamu Ultramafics, Mt Potts Group, Mt Taylor Group, Otematata Group, Corbies Creek Group, Blue Mountain Formation, Haldon Formation, Mt St Mary Formation and Kohurau Schist).

OTHER
Esk Head Belt (including Pohangina Melange and Whakatane Melange), Pahaoa Group, Clent Hills Group, Wakaepa Formation, Pember Diorite and Te Akatarawa Lithologic Association.

Haast Schist

Partially overprints Rakaia Terrane, Kaweka Terrane, Caples Terrane and Waipapa Composite Terrane. Distinguished geographically into Kaimanawa Schist, Terawhiti Schist, Marlborough Schist, Alpine Schist, Otago Schist and Chatham Schist.

Momotu Supergroup

King et al. (1999) second-order cycle 1.

COMPLEXES
Houhora Complex^H, *part Tangihua Complex*^{R} *[NA],* Tupou Complex [NA], *Ngahape Volcanic Complex*^{H}, *Mandamus Igneous Complex*^{H} and *Tapuaenuku Igneous Complex*^{H}.

GROUPS
Matawai Group, Ruatoria Group [ECA], part *Matakaoa Volcanics*^{R}*[ECA]*, Mangapurupuru Group, Pororari Group (including Hawks Crag Breccia and *Stitts Tuff Member*^{H}), Hapuku Group, Coverham Group, Wallow Group (including *Gridiron Formation*^{H} and *Lookout Formation*^{H}), *Mount Somers Volcanics Group*^{H}, Waihere Bay Group, *Pitt Island Group*^{H}, Puysegur Group, Matakea group (lower) (=Kyeburn Formation, Henley Breccia and Horse Range Formation) and Hoiho Group.

NON-GROUPED FORMATIONS
Taniwha Formation, Oponae Melange, Glenburn Formation, *French Creek Granite*^{H}, Beebys Conglomerate, Otumotu Formation, Buttress Point Conglomerate, Monro Conglomerate, Coal Hill Formation and Hewson Formation.

Haerenga Supergroup

King et al. (1999) second-order cycles 2 and 3.

COMPLEXES
Motatau complex (lower) [NA] (=Taipa Mudstone and Omahuta Sandstone), Mangakahia Complex [NA], *part Tangihua Complex*^{R}*[NA]*

GROUPS
Te Kuiti group (lower) (=Kamo Coal Measures, Mangapa Mudstone, Ruatangata Sandstone and Waikato Coal Measures), Moa Group, Kapuni Group, Tinui Group [part in ECA], Mangatu group (lower) [part in ECA] (=Wanstead and Whangai formations), part *Matakaoa Volcanics*^{R}*[ECA]*, *Rip Volcanics*^{R}*[ECA]*, Tora Group, Jenkins Group, Rapahoe Group, Pakawau Group, Paparoa Coal Measures, Eyre Group (including *View Hill Volcanics*^{H}), Muzzle Group (including *Grasseed Volcanics*^{H}), Seymour Group, Tioriori Group, Kekerione Group (including *Red Bluff Tuff*^{H} and *Northern Volcanics*^{H}), Annick Group, Onekakara Group, Matakea group (upper) (=Shag Point Formation and Kaitangata Coal Measures), Ohai Group, Nightcaps Group, Balleny group (lower) (=Macnamara Formation), Pakaha Group, Rakiura Group and Campbell Island Group.

NON-GROUPED FORMATIONS
Maruia Formation, Brunner Coal Measures, *Arnott Basalt*^{H}, Tauperikaka Coal Measures, Whakapohai Sandstone, Tokakoriri Formation, Abbey Formation, *Otitia Basalt*^{H}, Hump Ridge Formation, Mako Coal Measures, Blue Spur Conglomerate, Hogburn Formation, Camp Cove Conglomerate and Sand Hill Point Formation.

Waka Supergroup

King et al. (1999) second-order cycle 4.

COMPLEXES
Motatau complex (upper) [NA] (=Puriri Mudstone, Mahurangi Limestone).

Part Tangihua Complex^R *[NA].*

GROUPS
Te Kuiti group (upper) (=Whangarei Limestone, Otorohanga Limestone, Waitomo Sandstone, Te Akatea Formation, Orahiri Limestone, Aotea Formation, Whaingaroa Formation, Glen Massey Formation and Mangakotuku Formation), Ngatoro Group, part *Matakaoa Volcanics*^{R}*[ECA]*, Mangatu group (upper) (=Weber Formation), Nile Group, Motunau group (lower) (=Hanmer Marble, Isolated Hill Limestone, Omihi, Tekoa, Spyglass and Whales Back formations), *Cookson Volcanics Group*^{H}, Kekenodon Group (including *Brothers Volcanics*^{H}), Alma Group (including *Deborah Volcanics*^{H}, *Kakanui Mineral Breccia*^{H}, *Waiareka Volcanics*^{H}, *Tokarahi Sill*^{H} and *Lorne Pyroclastics*^{H}), Balleny group (upper) (=Chalky Island Formation, Green Islets Breccia Formation), Waiau group (lower) (=Kaherekoau Formation, Hope Arm Formation, Point Burn Formation, Turret Peaks Formation, Stuart Formation, Blackmount Formation, Hauroko Formation and Tunnel Burn Formation).

NON-GROUPED FORMATIONS
Torehina Formation, Muaupoko Greensand, Otaihanga Quartzite, Picton Conglomerate, Elevation Mudstone, Shakespeare Bay Sandstone, Matiri Formation, Jackson Formation, Awarua Limestone, *Thomas Formation*^{H} and Bobs Cove Beds.

Māui Supergroup

King et al. (1999) second-order cycles 5 and 6.

GROUPS
Reinga Group, Parengarenga Group, *Coromandel Group*^{W}, *Waitakere Group*^{W}, Otaua Group, *Ti Point Group*^{W}, *Whitianga Group*^{W}, Waitemata Group (including Timber Bay Formation [NA], Pukepoto Formation [NA], Onemama Formation [NA]), *Kiwitahi Volcanic Group*^{W}, *Whakamarama Group*^{W}, Wai-iti Group, Whangamomona group (lower) (=Kiore Formation, Urenui Formation, Mount Messenger Formation,

Otunui Formation and Mangarara Sandstone), Mokau Group, Mahoenui Group, Tolaga Group (preferred over Eketahuna, Soren and Palliser groups), Awatere Group, Blue Bottom Group, Rappahannock Group, Motunau group (middle) (=Mt Brown, Waikari and Waima formations), Burnt Hill Group (including *Harper Hills Basalt*[H]), *Diamond Harbour Volcanic Group*[H], *Mt Herbert Volcanic Group*[H], *Akaroa Volcanic Group*[H], *Lyttelton Volcanic Group*[H], Mairangi Group (including *Rangitihi Volcanics*[H]), *Dunedin Volcanic Group*[H], East Southland Group, Otakou Group, Manuherikia Group, Hawkdun group (lower) (=Wedderburn Formation), Waiau group (upper) (=Borland Formation, Waicoe Formation, Duncraigen Formation, Monowai Formation, Te Waewae Formation, Rowallan Sandstone, Goldie Hill Formation, Port Craig Formation, Clifden Subgroup, McIvor Formation) and Penrod Group.

NON-GROUPED FORMATIONS
Mercury Basalts[W], Whakai Formation [ECA], Puhokio Formation, Mangles Formation, Rotokohu Coal Measures, Longford Formation, Tititira Formation, Halfway Formation, *Alpine Dike Swarm*[H], *Allandale Rhyolite*[H], *Governors Bay Andesite*[H], Shoal Point Formation, Musgrave Formation and *Menhir Gabbro*[H].

Pākihi Supergroup

King et al. (1999) second-order cycle 7.

All Holocene (Q1) and Pleistocene (Q2–Q103) sedimentary (alluvium, talus, dunes, beach sand, etc.) and volcanic (lava, tephra, etc.) deposits. Q numbers refer to international Marine Oxygen Isotope Stages and were used by the QMAP geological map series for many of its Quaternary mapping units.

GROUPS
Ngaio Group[W], *Macauley Group*[W], *Haszard Group*[W], *Herald Group*[W], Karioitahi Group, Awhitu Group, Tauranga Group, *Hauturu Volcanic Group*[H], *Mayor Island Group*[H], *Kerikeri Volcanic Group*[H] (*includes Auckland Volcanic Field and South Auckland Volcanic Field*), *Alexandra Volcanic Group (Okete Volcanic Formation*[H], *Karioi Volcanic Formation*[W], *Pirongia Volcanic Formation*[W], *Kakepuku Volc. Formation*[W] *and Te Kawa Volcanic Formation*[W]), *Orangiwhao Intrusive Group*[W], *Whakamaru Group*[W], *Pakaumanu Group*[W], *Ongaroto Group*[W], *Maroa Group*[W], *Taupo Group*[W], *Okataina Group*[W], *Ruapehu Group*[W].

Rotokare Group, groups and formations of former Rangitikei Supergroup (=Shakespeare, Kai-iwi, Okehu, Maxwell, Nukumaru, Okiwa, Paparangi, Whenuakura, Utiku Group, Orangipongo, Mangaonoho, Vinegar Hill, Tikapu, Makohine, Mangarere and Tangahoe formations), Whangamomona group (upper) (=Matemateonga Formation), Kidnappers Group, Onoke Group, Mangaheia Group, Old Man Group, Tadmor Group, Motunau group (upper) (=Greta and Kowai formations), Karewa Group, Hawkdun group (upper) (=Maniototo Conglomerate), *Solander Island Volcanics*[W].

NON-GROUPED FORMATIONS
Kermadec Islands: *Moumoukai Formation*[W], *Hutchison Formation*[W], *D'Arcy Formation*[W] *and Boat Cove Formation*[W].

Taupo Volcanic Zone and Waikato: Kaawa Formation, *Whale Formation*[W], *Hamilton Ash Formation*[W], *Kauroa Ash Formation*[W], *Oruanui Formation*[W], Waimarino Formation, Hauhungaroa Formation, *White Island Formation*[W], *Kaingaroa Formation*[W], *Pokai Formation*[W], *Chimp Formation*[W], *Mamaku Plateau Formation*[W], *Matapan Formation*[W], *Johnson Rd Formation*[W], *Rolles Peak Formation*[W], *Titiraupenga Formation*[W], *Maungatautari Formation*[W], *Hewson Formation [2]*[W], *Waiotapu Formation*[W], *Awakaponga Formation*[W], *Manawahe Formation*[W] *and Pureora Formation*[W].

Egmont Volcanic Centre: *Maero Formation*[W], *Skeet Lavas*[W], *Staircase Lavas*[W], *Peters Lavas*[W], *Fanthams Peak Andesite*[W], *Warwick Lavas*[W], *German Hill Andesite*[W], *Pouakai Andesite*[W], *Kaitake Andesite*[W], *Sugar Loaf Andesite*[W], Hangatahua Formation, Te Popo Formation, Ngatoro Formation, Opua Formation, Kahui Formation, Warea Formation, Pungarehu Formation, Ngaere Formation, Opunake Formation, Stratford Formation, Okawa Formation, Motunui Formation, Maitahi Formation, Eltham Formation and Old Formation.

Tongariro Volcanic Centre: *Ngauruhoe Andesite*[W], *Te Mari Andesite*[W], *Red Crater Andesite*[W], *Tama Lakes Pyroclastics*[W], *Half Cone Pyroclastics*[W], *Blue Lake Andesite*[W], *Te Tatau Andesite*[W], *Makahikatoa Andesite*[W], *Pukeonake Andesite*[W], *North Crater Andesite*[W], *Waihohonu Lavas*[W], *Summit Formation*[W], *Pukekaikiore Andesite*[W], *Tama Trig Lavas*[W], *Mangahouhounui Lavas*[W] *and Tama Formation*[W].

Other: *Waimarino Basalt*[W], *Pihanga Andesite*[W], *Kakaramea Formation*[W], *Pahoka Formation*[W], *Maungakatote Andesite*[W], *Maungaku Andesite*[W], *Karewa Volcanic Formation*[W], Hillersden Gravel, Wairau Conglomerate, Porika Formation, Plateau Gravel, Kowai Formation, Teer Formation, *Timaru Basalt*[H], *Geraldine Basalt*[H], Glentanner Beds, Kisbee Formation, Gore Piedmont Gravels, Prospect Formation [1], Orepuki Formation, Pebbly Hill Gravels, Wairaurahiri Formation and Enderby Formation.