# New Zealand Volcanoes*

**Wes Gibbons 2018**

A journey from smaller to super eruptions

*Steaming sinter terraces produced by earthquake faults in 131 A.D. at the Orakei Korako geothermal area in the Taupo Volcanic Zone, the site of the world's most recent supervolcano eruption.*



**North Island, New Zealand** is one of the most accessible, safe and scenically attractive places in the world to visit active volcanoes and geothermal areas, and you don't have to be a geologist to appreciate it all. In this online Holiday Geology guide we describe a journey that takes in not just the obvious "must-see" volcanic sights but also visits places off the beaten track, interspersing the driving and sightseeing with opportunities for walking in the glorious Kiwi countryside. You will also learn about why the volcanoes are there and how they have evolved through time. An online guide to New Zealand geology, written by Peter Ballance (1936-2009), can be found at:

https://www.geotrips.org.nz/downloads/Ballance_NZ_Geology-V2.pdf

An online book chapter on New Zealand volcanism, written by Phil Shane, is available on:

https://www.springer.com/cda/content/document/cda_downloaddocument/9789462392366-c2.pdf?SGWID=0-0-45-1597944-p180330929

Allow at least two weeks in NZ, initially staying in Auckland for 2 nights, then heading north by hire car to Whangarie for 2 or 3 nights in Northland before driving back past Auckland and on via various basaltic volcanoes on route to the classic andesitic volcanic peak of Taranaki in southwest North Island, staying overnight in Waitara (or nearby) and then in Whanganui. From here the route runs northeast to traverse the length of the Taupo Volcanic Zone from Mount Ruapehu and on across the supervolcanoes of the Taupo and Rotoroa area. Consider a minimum of one night in Turangi and one or two nights each in Taupo and Rotorua. Finally allow a minimum of one night in Whakatane as a base for a day trip out to White Island for the volcanic experience of a lifetime.

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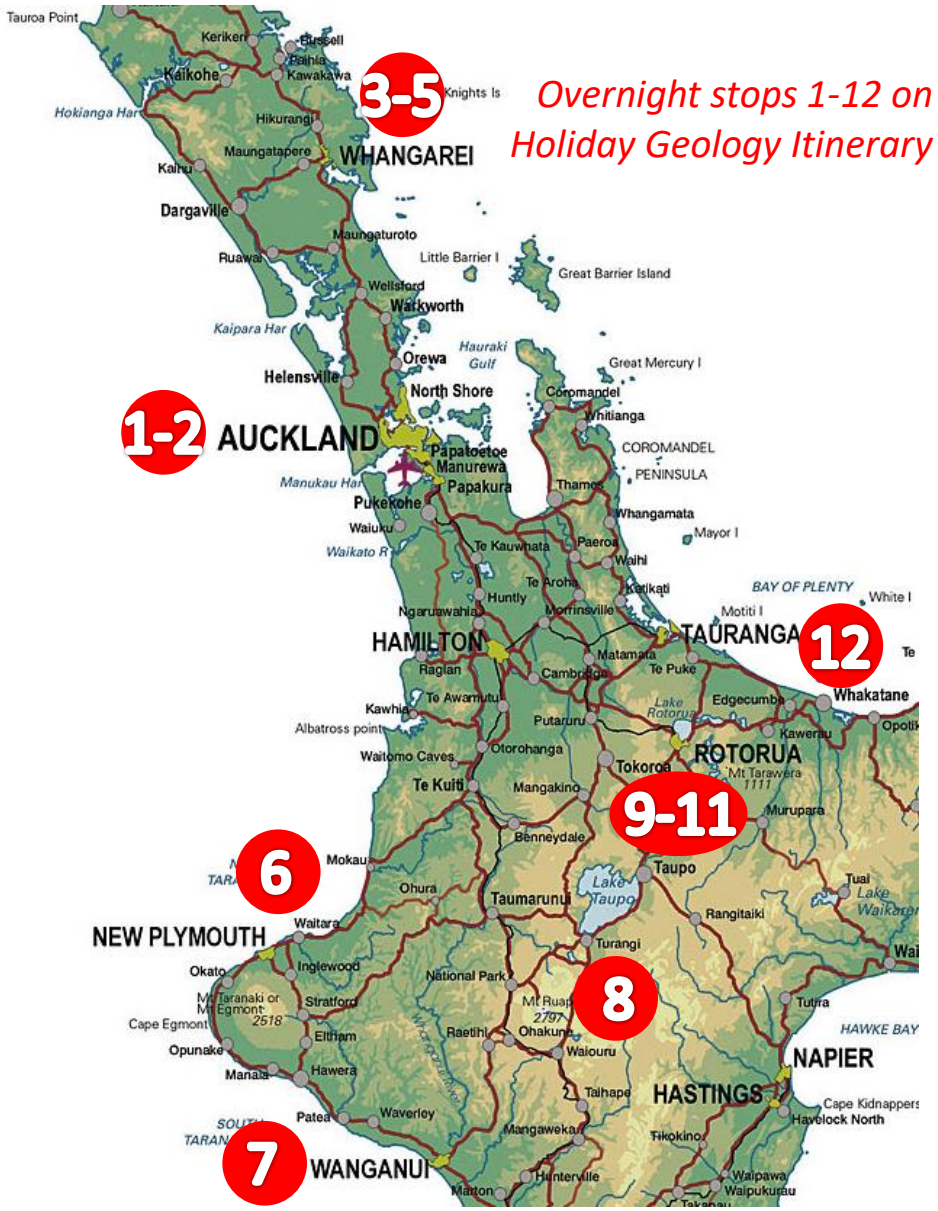
**Getting There.** The first challenge is to fly to Auckland, which is a little over 20,000 kilometres from its antipodal point: Ronda, in Andalucía, Spain. If flying from Europe we strongly recommend an overnight stopover because catching two 11- or 12-hour flights back-to-back is inhuman. We flew from Barcelona with Korean Air and stopped over in Seoul, using a hotel a short shuttle bus ride from the airport, which worked fine. The following excursion is divided into 12 days but this is only a suggestion: other ways of organising the journey are possible.

**Accommodation.** We recommend choosing accommodation well in advance using the major websites such as booking.com, checking the most recent comments, and opting for "free cancellation" in case events force a change of plan. Our itinerary (January 2018) involved staying at the following choices, all of which we were happy with except that in Rotorua (which we decline to mention): Auckland (Adina Apartment Hotel), Whangarie (Continental Motel), Waitara (Masonic Hotel), Whanganui (Asure Cooks Gardens Motor Lodge), Turangi (Creel Lodge), and Taupo (Chantillys Motor Lodge).




*Map reproduced from Land and Information Department of New Zealand.*
*http://www.nztourmaps.com/north_island_physical_map.html*

## Day 1: Arrival in Auckland.

On a clear day as you come in to land you will be able to spot volcanoes belonging to the currently dormant Auckland Volcanic Field, which comprises over 50 basaltic vents and has been active on and off over the last quarter of a million years or so. A highlight on the Skybus route to town is passing the prominent volcanic hill of Mount Eden (Maungawhau) which erupted about 15,000 years ago.

Reference: Leonard, G. A. and Roberts , R. C., 2017. Volcanic hazard from the Auckland Volcanic Field: http://www.nzgs.org/library/nzgs20_roberts/

After hotel check-in walk to the ferry terminal for lunch and to buy tickets for Rangitoto the following day, allowing at least 3 hours between ferries (e.g. 12.30 out, 15.30 back, which will allow a late afternoon visit to Devonport and North Head).

**Auckland Domain.** Start from the Auckland War Memorial Museum in the Domain, two kilometres to the south of the ferry terminal. Auckland Domain offers an extensive area of beautiful parkland that includes the explosion crater of the Pukekawa Volcano:

https://walksinauckland.com/wp-content/uploads/2014/12/domain_volcano_walk.pdf

From the front of the museum looking west there is a view across one side of the ring-shaped explosion crater over to a wooded volcanic hill in its centre. The hill is known as Pukekaroro and was a pre-European Maori *pa* site. The explosion crater was originally a lake but became filled in by sediment and plants to form a swamp which was drained by Europeans who made it into a playing field: walk across the playing field to the foot of the hill where there are rocks exposed in a low bank by the toilets:



The basaltic rocks forming Pukekaroro are full of small holes, a honeycomb texture produced by bubbles ("vesicles") once filled with gas as frothy, fiery, degassing lava fountained and spattered out of a central vent like hot, black, heavy champagne and built up a cone which now forms the hill. These fire-fountaining eruptive deposits are known as "scoria", thrown out of the vent as lumps of hot magma, and scoria cones like this one are very common in the Auckland Volcanic Field (Mount Eden is another example).

*Honeycomb texture in basaltic scoria fragment exposed on the flanks of Pukekaroro.*

Climb up onto Pukekaroro and walk around the cone, taking in the shape and size of the wide explosion crater all around. The violent explosion producing this crater was a result of hot magma interacting with cold groundwater which flashed to steam, a process referred to as "phreatomagmatic":



*Suddenly events spin out of control and there is a paroxysmal explosion…. The eruption cloud resulting from this phreatomagmatic detonation is initially full of white steam but quickly fills with ash and flying rock debris as it billows upwards to a height of several thousand metres and outwards to form a classic mushroom shape. A basal surge, like that first observed in the Bikini Atoll nuclear bomb tests during the 1940's, radiates out from the explosion site. Broken rock is blasted horizontally at speeds exceeding one hundred and fifty kilometres per hour, ripping up mature trees for several kilometres in all directions. Chunks of rock falling back into the newly excavated crater become recycled and mixed in a series of further explosions, ground surges and crater wall collapses.*

*After repeated explosions so much of the groundwater has been evaporated that the rocks have simply dried up. Now the basalt magma is free to reach the surface without being frustrated by encounters with water underground, and relative calm can reign over the scene of volcanic devastation. But the calm is definitely only relative as the lava erupts exuberantly from a fissure inside the crater to form a magnificent incandescent liquid fire fountain that spurts hundreds of metres into the air. The glowing, spattering lava fragments freeze as they shower over the surrounding ground where they accumulate as black pumice-like bombs and smaller stones ("lapilli").*

Excerpt from: *Volcanoes in Girona*, Barcelona Time Traveller, Bimón Press 2016.

Now descend the south side of the hill to locate and immerse yourself in the fernery at the back of the Wintergardens, housed in a quarry dug into the southern end of the scoria cone.

## Day 2: Rangitoto Island and North Head

*Rangitoto volcano from Maungauika volcano on North Head.*

**Rangitoto.** Leave from Auckland ferry terminal, buying all food and (lots of) water before boarding the ferry: Rangitoto has no shops or cafes. The ferry out to the island passes Devonport with its two main volcanoes, Takarunga (Mount Victoria) and Maungauika (North Head), forming prominent hills behind and to the right of the town.

Once onshore in Rangitoto follow the main track north from the wharf to the summit, climbing steadily for an hour up through red-flowering pōhutukawa (*Metrosideros excels*) forest which now covers much of the young basalt forming the island. Such an abrupt colonisation directly from bare basalt lava to forest is unusual, but is also seen in Hawaii with the related species *Metrosideros polymorpha*. The evergreen coastal pōhutukawa tree is endemic to much of North Island, although in places under threat from leaf-eating possums, and has been introduced to other areas with similar climates (e.g. parts of Australia, California and South Africa). In Spain the tree has been adopted with enthusiasm by the city of A Coruña in Galicia, probably after having been introduced there by British sailors in the 18th century.



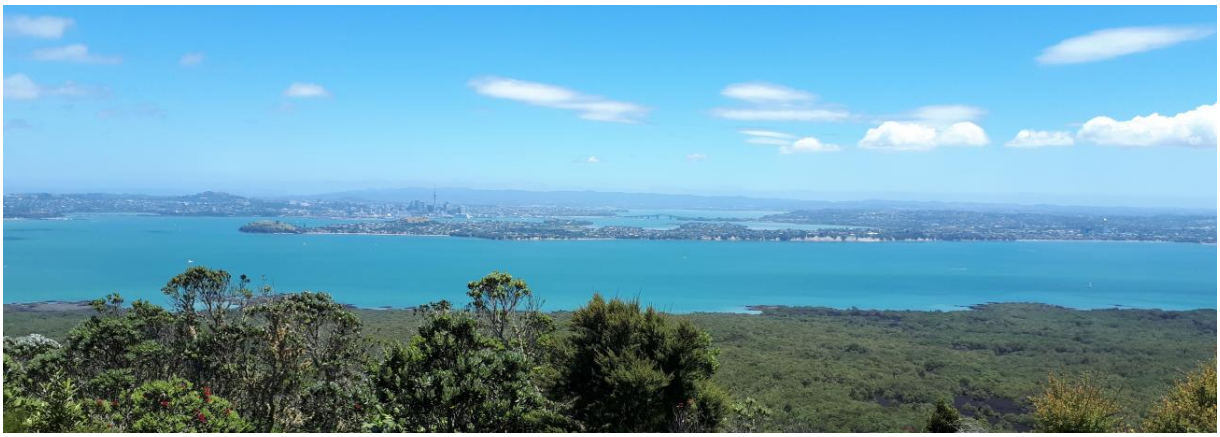
*Fragmented, blocky basalt lava flow forming a rough, rubbly ("clinkery") surface texture known as 'a'ā (a Hawaiian word, pronounced ah-ah) on the main summit track on Rangitoto, looking west over the pōhutukawa forest to distant Auckland. The broken up clinkery cooled surface of the flow originally covered a slowly moving hot core of the lava flow, erupted at around 1,000°C.*

After passing a track to the right leading to the lava caves (do this on the return), the main track steepens as it climbs the central scoria cone to reach a viewpoint over the heavily vegetated volcanic crater. The 19th century photo displayed at this viewpoint showing Rangitoto almost bare of vegetation is a reminder of how this is the youngest volcano in the Auckland Volcanic Field. Recent work (Linnell et al., 2016) has concluded that volcanic rock began to be erupted here as long as 6,000 years ago, but that the main period of lava extrusion occurred during the 14th century AD, after Polynesian people had arrived in NZ, some of whom would presumably have witnessed the eruptions. This main eruptive phase formed the gently rising, nearly symmetric, 6km-wide basaltic shield volcano seen today. During the first part of the 15th century the volcanic activity shifted to become more violent and localised, producing the scoria cones at the summit. This long-lived and complex history of eruptive activity of Rangitoto contrasts with most of the older Auckland volcanoes which typically erupted just once then froze (a type of basaltic volcano referred to as "monogenetic" and usually being built up over months rather than years). Given the long history of eruptions so far, Rangitoto is probably dormant rather than extinct and so may well erupt again.

*Pōhutukawa trees among the mixed flora of the central crater of Rangitoto Volcano: 60m deep and 150m wide*



Walk anticlockwise around the crater rim, taking in the extensive views, to finally reach the summit viewing platform at 259m above sea level. On a summer day you are unlikely to be alone here.



*View southwest from the summit of Rangitoto volcano across to the Devonport Peninsula which terminates (left) at Maungauika volcano which forms the low hill of North Head.*

On the descent take the short excursion to the lava caves which record the channels of underground streams of lava that drained out of the channel to leave linear cave systems. The first caves seen (on the right) are small, but a more impressive example comes later: you can clamber down through this one to the end and take the path back. Your mobile phone torch will be useful.

References:

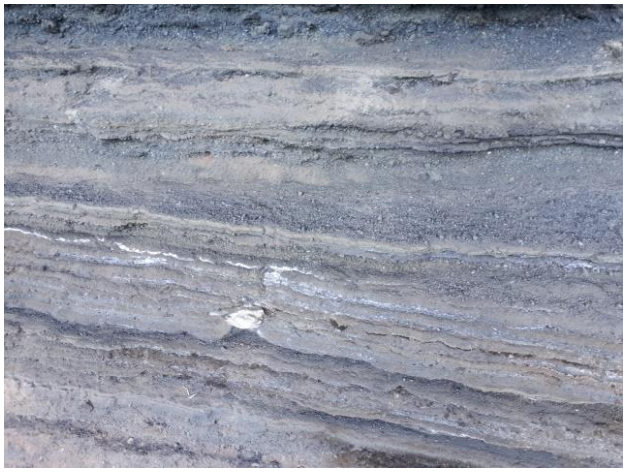
Linnell et al., 2016. Long-lived shield volcanism within a monogenetic basaltic field: the conundrum of Rangitoto volcano, New Zealand. Geological Society of America Bulletin 128, 1160-1172.

For a comprehensive illustrated guide to Rangitoto, available freely online, see: Lowe et al., 2016. Guidebook for Rangitoto Island AQUA Field Trip, Auckland, 2016.

https://researchcommons.waikato.ac.nz/bitstream/handle/10289/10828/Rangitoto%20guide_AQUA_all.pdf?sequence=2

**Devonport and North Head.** Disembark at Devonport (travelling either using the frequent shuttle service from Auckland ferry terminal or on the way back from visiting Rangitoto: if you do the latter note that your Rangitoto return ticket does not allow a break of journey so you will need to buy a single ticket later to return from Devonport to Auckland). Walk east along the sea front for one kilometre then turn left into Cheltenham Rd which climbs to the second junction right into Takarunga Rd (signposted North Head) at the end of which you enter the park area. Here, leave the road to turn left onto a path that runs around the NW side of the peninsula, with views over to Rangitoto, circling around the hill clockwise then descending to the shoreline (via steps) to locate the layered volcanic "pyroclastic" deposits (or "tephra") exposed in the sea cliff:





*Layers of basaltic tephra blasted out of Maungauika Volcano and now exposed on the northern cliffs of North Head, Devonport. Note pale fragments of the Miocene-aged sedimentary bedrock ejected in tephra jets as small volcanic bombs and falling back onto the surface of the tephra cone. Much of the tephra comprises small fragments (2-64mm in size) referred to as "lapilli" (latin: "little stones"), some of which are rounded due to accretion of ash around a central nucleus (like volcanic hailstones and called "accretionary lapilli").*

Sea level is estimated to have been around 15 metres higher than present during the emergence of this volcano about 120,000 years ago (Agustín-Flores et al., 2015). The initial phase of eruption of this volcano therefore involved seawater-magma interaction, building up a 48m-high cone of fragmented airfall and surge deposits containing clasts of sedimentary bedrock and lava blown violently out of an

open central vent. This volcanic behaviour is similar to that exhibited by the Icelandic Surtsey eruption in 1963. As such it provides a classic example of what happens when a relatively minor basaltic eruption occurs in a shallow marine basin, and contrasts with the significantly more violent eruption of the Auckland Domain volcano which erupted above sea level and was produced by the explosive interaction between hot magma and cold groundwater.

As the Maungauika volcanic system dried out and the vent wall became sealed, the basalt lava was able to access the surface without significant interaction with water and so built up a late-stage spatter cone during fire-fountaining (these spatter deposits can be seen in places high on the volcanic hill).

https://www.researchgate.net/publication/276320076_Construction_of_the_North_Head_Maungauika_tuff_cone_a_product_of_Surtseyan_volcanism_rare_in_the_Auckland_Volcanic_Field_New_Zealand

From the beach exposures shown in the photos above, either turn right and continue clockwise around the volcano along the coastal path which later climbs upwards towards the hill summit, or turn left and take the shorter route back via Cheltenham Beach Battery (passing more exposures of tephra layers dipping outwards from the volcanic centre), descend to Cheltenham Beach and follow this to turn left into Cheltenham Road which leads back to the ferry. There are three walking routes around North Head for those who wish to spend more time exploring the military history of the peninsula.

We have so far visited three volcanoes: Pukekawa, Rangitoto, and Maungauika. All three are basaltic, relatively small, and demonstrate different eruption styles within the Auckland Volcanic Field. The modern Auckland volcanoes are the youngest manifestation of volcanic activity that started over 100km further south and has moved progressively northwards, so far producing four volcanic fields (Okete, Ngatutura, South Auckland, and Auckland).



Auckland lies some 300km west of the nearest plate tectonic boundary, the Hikurangi Trench (or Trough), where the Pacific Ocean plate begins to slide down (subduct) westwards under the continental Australian plate. The Hikurangi Trench continues north to become the Kermadec Trench (one of the world's deepest oceanic trenches). West of these trenches, the plate subduction is producing a line of classic "arc volcanoes" running down from the oceanic Kermadec Arc to the Taupo Volcanic Zone in New Zealand. The Auckland basaltic eruptions lie behind the arc ("backarc") and further inside the Australian plate ("intraplate"). They are thought to owe their origin to the fact that the crust in this area is stretching (under tension), this allowing the slow upwelling of hot mantle which decompresses as it rises. Reducing the pressure on hot rock reduces the melting point so that the mantle begins to melt ("decompression melting"), producing batches of basaltic magma which rise up towards the surface to form volcanoes. The depth at which melting takes place will produce basalts with subtle chemical differences, study of which demonstrates that melting is likely to have occurred over a wide depth range of 30km to over 100km:

https://academic.oup.com/petrology/article/46/3/473/1438731).

We now move north from Auckland to study the volcanic rocks in Northland. Here once again we find examples of intraplate basaltic volcanoes, but in Northland these were preceded by an important episode of subduction-related arc volcanism which suddenly ceased 15 million years ago (middle Miocene times) and switched to locations south of Auckland.

## Days 3-4: Whangarie and Whangarie Heads.

Subtropical Whangarie is the most northerly city in New Zealand, has plenty of accommodation choices, and is around 3 hours' drive from Auckland. The direct route following Highway 1 is congested with traffic, and a scenic, more leisurely alternative is offered by the winding Highway 16 which follows the west coast with views over the wide Kaipara Harbour, one of the largest such harbour-estuary complexes in the world. If you arrive early, consider an afternoon visit to Whangarie Falls (see below).

Here we describe a 90km return route southeast from Whangarie Falls to Ocean Beach near the tip of the Whangarie Heads peninsula, taking in a number of scenic and geologically interesting locations that include waterfalls, caves, sheltered beaches and the wild Pacific shoreline.

**Whangarie Falls**. Although the waterfall can be accessed directly via a car park next to the falls, a more scenic and enjoyable approach is to walk up from the A H Reed Memorial Park, which takes about 30 minutes. Drive northwest of Whangarie on Whareora Road for <2km to park (left) in the lower car park of the A H Reed Memorial Park. Walk east through the forest then north on the Canopy Walk then west on the Elizabeth Track to turn right into the Hatea Track that runs up the river to the 26m-high cascade of the Whangarie Falls.

The intraplate basalts exposed here form part of the "Kerikeri" volcanic rock group erupted on and off in northeast Northland since late Miocene times. There are two main volcanic fields, one around Kaikohe and the Bay of Islands, and the other here at Whangarie. Whereas volcanoes have been erupting in the Bay of Islands area since around 10 million years ago until almost the present day, those around Whangarie are less than 2.5 million years old and appear to have stopped erupting about half a million years ago (making them all Pleistocene in age). These basalts, like those in Auckland, owe their origin to partial melting in the hot mantle beneath northern North Island.



Smith et al., 1993. New Zealand Journal of Geology and Geophysics, Vol. 36: 385-393: https://researchspace.auckland.ac.nz/bitstream/handle/2292/4845/Age%20relationships%20and%20tectonic%20implications....pdf;sequence=1

Huang et al., 2000. Geochemistry of late Cenozoic basaltic volcanism in Northland and Coromandel, New Zealand: implications for mantle enrichment processes. Chemical Geology, 164, 219-238.

In the Whangarie area the Pleistocene basalt lava flows often fill valleys, forcing the pre-existing river to run alongside and across the flow until it can find a place to cascade over the basaltic obstruction. At Whangarie Falls the 30-metre thick basalt flow was erupted over an ancient basement of sedimentary rocks around 200 million years old ("Waipapa Terrane"), deposited long ago off the shores of the supercontinent of Gondwanaland.

The waters of the Hatea River flow abruptly over the basalt flow, the base of which corresponds with the base of the falls. Columnar jointing forming mostly hexagonal "organ pipe" shapes is well developed in the lower part of the basalt (a rock structure called "colonnade" jointing), whereas above this the flow is more irregularly jointed ("entablature" jointing). The striking regularity of the colonnade structure develops as the basalt cools and contracts to produce cracks that propagate up into the flow. The less regular entablature joint structure has been attributed to flooding of the hot lava surface by dammed river water, freezing the basalt too rapidly to allow slower growth of more regular columns.

*Hexagonal columnar "colonnade" jointing overlain by a higher zone of less regular "entablature" jointing in the Whangarie Falls basalt flow. For further discussion on jointing in basalts see: Phillips et al., 2013. Bull Volcanol https://www.researchgate.net/publication/237090469_The_formation_of_columnar_joints_produced_by_cooling_in_basalt_at_Staffa_Scotland*

The younger volcanic rocks in Northland, represented here by the basalt at Whangarie Falls, record an important change in plate tectonics and volcanicity that took place in late Miocene times: the switch from arc to back-arc volcanoes in Northland. A new line of arc volcanoes was established in the Coromandel Peninsula as the Pacific Plate boundary retreated southeast so that Northland found itself now lying behind the volcanic arc. Regional extension in this back-arc area encouraged the rise of basaltic magmas sourcing from the mantle and the emergence of new volcanoes. This process continues to the present day and has extended south, so that the volcanoes of Auckland are all part of the same plate tectonic process. We shall see evidence for the older Northland arc volcanoes later during this day traverse.



**Abbey Caves Reserve.** Return to the A H Reed Memorial car park and continue driving on Whareora Road for c.1km to turn right into Abbey Caves Road and in 500m park on the left at the entrance to the public reserve. At this locality Whangarie Limestone has been downfaulted against the "Waipapa Terrane" basement, creating karstic scenery with an extensive cave system. The limestone belongs to the Te Kuiti Group, is in places over 100m thick, contains fragments of marine fossils, and is Oligocene in age (around 30 million years old). The Te Kuiti Group is extensively exposed in North Island (especially southwest of Auckland) and comprises up to several hundred metres of sediment deposited in Late Eocene-Oligocene times when the area was undergoing regional extension.

Allow about an hour to explore the circular route through this karstic reserve. The footpath initially runs downhill through attractively verdant country, with the first underground entrance (Organ Cave) seen on the right (climb a stile). From here the path continues southwest to pass Middle Cave then Ivy Cave. All these caves contain glow-worms, but their exploration can be tricky, wet, and prone to roof falls, and so is not recommended for the fainthearted or poorly equipped. The circuit continues with the path running through more exposures of the grey limestone karst to reach the site of the Clotworthy

Homestead. Nathaniel and Amelia Clotworthy, of Irish descent, lived here with their 13 children in the late 19th century. The site was later bought by a mining company who did not exploit the limestone but later sold it on to the local City Council who created the scenic reserve.

*Bouldery remnants of the Whangerie Limestone weathered by karstic dissolution produced by the chemical action of acidic rainwater on calcium carbonate: Abbey Caves Reserve.*

Continue driving south on Abbey Caves Road, with the hill of Parahaki on the right. This hill defines the outcrop of the southernmost of three dacite volcanic domes that have found their way towards the surface along a prominent geological fracture running NW-SE and called the Harbour Fault. The Parahaki Dome has yielded a Miocene age (20 million years old) and formed when the Northland Arc was active.



At the end of Abbey Caves Road turn left into Old Parua Bay Road, forking right into Konini Street which becomes Mackesy Road and finally joins the main road (Riverside Drive) at the coastal estuary. Turn left, with the waterside on the right, and drive southeast towards Whangarie Heads. The road curves south as it climbs a prominent ridge made of a Pliocene basalt flow which, like the example at Whangarie Falls, once erupted into a valley. The valley sides have been eroded, leaving the harder basalt now forming a linear hill on top of which is perched the local airport in the suburb of Onerahi. This peculiar trick of geology and scenery is a fine example of “inverted topographic relief”.

In Onerahi turn left at the roundabout into Whangarie Heads Road and follow the coast, passing Tamaterau, with views right across to Limestone Island (more Oligocene carbonates), and then on past Parua Bay. Around 13km from Onerahai turn sharp right at a junction on the road towards Ocean Beach. This road initially passes white-weathering exposures of dacite before descending into McLeod Bay some 7km after the junction.

**McLeod Bay.** Drive to the end of the bay then turn right into Stuart Road, just as the main road leaves the bay, and park on the right. Walk 10 minutes along Stuart Road to where it ends at the start of the Reotahi walking track, with exposures of andesite in the low cliffs on the left and low tide foreshore exposures of deformed Whangarie Limestone and Miocene sediments on the right.

https://www.researchgate.net/publication/256552449_Field_trip_3_Part_2_Whangarei_Heads_geology

Walk another 10 minutes along the Reotahi walking track to where the path begins to climb: don't climb but instead access the beach on the right. The cliffs here expose grey porphyritic andesite with phenocrysts and dark clusters of pyroxene and hornblende.

The Whangarie Heads peninsula exposes large areas of volcanic and intrusive rocks, dated at 16-22 million years old and mostly andesitic in chemical composition (although dacite and, locally, diorite-granodiorite also crop out). These igneous rocks were produced in a "Northland Arc" which was the earliest manifestation of Cenozoic plate subduction volcanism in North Island. This andesitic arc volcanism later moved south, first to Coromandel and then to the currently active Taupo Volcanic Zone.

*Dark clots of mafic minerals in Lower Miocene andesite exposed on the southern shoreline of McLeod Bay. These andesites are typical calc-alkaline igneous rocks produced by plate subduction, and formed in the Northland Arc, which extended for at least 500km through northern North Island and beyond in Early Miocene times around 20 million years ago. Andesite is typically grey in colour and has a silica ($SiO_2$) content of 57-63% which is intermediate between darker coloured and more fluid basalt magma (42-55% $SiO_2$) and more viscous (and explosive) rhyolites (>65% $SiO_2$). Andesites typically form large, multi-layered, conical "stratovolcanoes" built up during a long history of eruptions, in contrast to the smooth-sloped basaltic shield volcanoes typified by Rangitoto or the short-lived monogenetic basaltic cone volcanoes punctuating the Auckland landscape.*

Return to the vehicle and continue the drive towards Ocean Beach. The road climbs between the volcanic massifs of Mounts Aubrey (right) and Mt Manaia (left), both of which expose Lower Miocene andesitic breccias and lava flows. These hills, although merely the ancient remains of a great stratovolcano once active here, are impressive in their own right; especially Mount Manaia which displays dramatic pinnacles formed by erosion down vertical joints. The volcanic and intrusive rocks of Whangarie Heads and off lying islands are referred to collectively as the Taurikura Volcanic Complex.

Three kilometres beyond McLeod Bay the road reaches Taurikura Bay (car park on the left at the far end of the bay), immediately south of the Mount Manaia volcanic rocks, exposures of which (in the form of volcanic breccias) can be visited at mid- to low tide in the cliffs at the north end of the bay.

*Volcanic breccias made of andesite fragments on the beach south of Mount Manaia. The breccias originally formed in the cone area of a large Miocene stratovolcano*.

The geological highlight of Taurikura Bay, however, is in the middle of the bay where an andesitic dyke forms the best example of a natural jetty in New Zealand.



*"Natural Jetty" andesite dyke in Taurikura Bay. The dyke, segmented by vertical joints, has intruded a country rock of grey limestone, seen on the lower right of the image.*

*Close up of the "Natural Jetty" dyke revealing the fine grained chilled margin where the andesitic magma cooled against the grey limestone country rock (the 10cm-long voice recorder lies at the dyke-country rock contact).*



Continue driving towards Ocean Beach. The road initially heads south between the coastline and a prominent hill comprising intrusive dacite which has contact-altered the limestone country rock. The road then turns east, with the forested ridge underlain by Lower Miocene andesites running out to Bream Head on the right. Six kilometres from Taurikura Bay turn right on Ranui Road which leads to the car park at Ocean Beach.

**Ocean Beach**. This wide sandy beach faces the open Pacific Ocean, with Easter Island the next landfall over 7,000km to the east. Porphyritic andesites are exposed to north and south of the beach, mostly as multiple dyke clusters. The andesites here contain abundant phenocrysts of dark pyroxene, and those at the southern end of the beach have become famous for containing crystals of garnet which crystallised from the magma at temperatures of around 850$^{o}$C and pressures of 11Kb. Such pressures translate to depths of around 35km or more, which implies that these andesitic magmas were initially crystallising unusually deep before volcanic eruption allowed them to rise quickly towards the surface and preserve their garnet phenocrysts (which, unfortunately, are hard to spot).

References:

Booden et al., 2011. Journal of Volcanology and Geothermal Research, 199, 25-37.

Bach et al., 2012: https://academic.oup.com/petrology/article/53/6/1169/1564415

*Abundant phenocrysts (mostly of dark pyroxene) in porphyritic andesite on the south side of Ocean Beach. Such crystals form deep in the slowly cooling magma chamber beneath the volcano but their growth is interrupted by eruption, when the magma (containing its phenocrysts) rises rapidly towards the surface and freezes too quickly for any other large crystals to grow.*



In some places on the northern headland of Ocean Beach baked remnants of the grey-blue country rock limestone can be recognised, as shown in the photo (lower right):

*Left: Ocean Beach looking south; Right: grey-blue limestone country rock remnants attached to Lower Miocene andesitic dyke.The andesites here formed part of the high-level magmatic plumbing system of a huge Miocene stratovolcano in the Taurikura Volcanic Complex.*

Return to Whangarie and either stay another night or drive north to overnight in Paihia.

## Day 5: Bay of Islands Circular Tour.

The stay in Northland can be extended as a day loop by continuing north on Highway 1 to visit the famous Bay of Islands area, the Haruku Falls basalts, and the Waiariki Pools at Ngawa Hot Springs, before returning to Whangarie via the Whangarie Volcanic Field. From Paihai take the passenger ferry to Russell to enjoy a walk north, passing the Duke of Marlborough Hotel then along the beach (low tide), clambering over Waipapa Terrane basement rocks to locate the path leading up through the Kororareka Point Scenic Reserve to Flagstaff Hill. The cliffline exposures of Waipapa rocks at Russell comprise grey-green disrupted sediments (mostly fine sandstones, mudstones and cherts) once deposited in the deep ocean and later disrupted as they entered a subduction zone and became accreted to the continent ("accretionary rocks"). This disruption virtually destroyed the original bedding, creating a texture referred to as "broken beds" or "mélange". These rocks record part of the long history of plate convergence that occurred along the eastern side of Gondwanaland from Middle Permian to Early Cretaceous times.

Adams et al., 2013: https://www.cambridge.org/core/journals/geological-magazine/article/detrital-zircon-geochronology-and-sandstone-provenance-of-basement-waipapa-terrane-triassiccretaceous-and-cretaceous-cover-rocks-northland-allochthon-and-houhora-complex-in-northern-north-island-new-zealand/53E3A3A095E4D4FF1A6B5A4C5F3EC253/core-reader

The return jouney south to Whangarie can be made via an inland loop (130km) that initially passes Haruku Falls, where the Waitangi River cascades over the Pleistocene-age, columnar-jointed Horeke Basalt (around 1.24 million years old) into the Bay of Islands estuary. The scenic locality is popular and parking is easy: drive west from Paihia for 3km on Highway 11 and turn right to locate the falls.



From Haruku Falls the inland route to Whangerie continues following the H11 west towards the Kaikohe Volcanic Field where a dozen or so basaltic (and locally rhyolitic) volcanoes have left their mark on the landscape. Turn left (south) on H10 then right (west) into H1 then left on H12 to Kaikohe. Most of the Kaikohe Volcanic Field volcanoes lie to the south of H1 and are Pleistocene in age, but a notable exception is provided by the Te Puke basaltic cone cluster which lies just a few kilometres northwest of Haruku Falls and erupted only around 1,500 years ago. Such a young age indicates that, as with the Auckland Volcanic Field, volcanism in the Kaikohe-Bay of Islands area cannot be considered as extinct.

Further reminder of the active nature of this volcanic field is provided by the Waiariki Pools at Ngawa Hot Springs which lie 2km south of the N12 and offer relaxing opportunities for smelly immersion in a rustic setting. The area is also the site of the Ngawa Geothermal Power Station, which supplies much of Northland's electricity. Ngawa is pronounced "nah-fah" and means "hot pool" in Maori. It is the only high temperature geothermal system in New Zealand outside the Taupo Volcanic Zone and is hosted in fractured Waipapa Terrane basement rocks overlain by younger sediments. Its unique position in New Zealand is reflected by the water chemistry which is unlike those found further south in North Island.

At Kaikohe, a town built on the south side of the scoria cone forming Kaikohe Hill, turn left to follow H15 south for 10kms to pass Tauanui Volcano, the scoria cone of which rises 150m on the left. Tauanui erupted around 60,000 years ago, sending lava flows that flowed west down the Taheke Valley for almost 20km. Highway 15 continues south past Twin Bridges then southeast to eventually enter the Whangarie Volcanic Field, passing more young basaltic scoria cones as the route turns left into H14 and enters Whangarie.

## Day 6: South to Taranaki.

The drive south from Whangarie via Auckland to Taranaki volcano in southwestern North Island can be made in one long day (allow 10-11 hours) or relieved by an overnight stop in Raglan on the west coast. An early start from Whangarie and use of the western route via H16 may help to lessen the inevitable traffic congestion encountered when passing Auckland. A useful refuelling break just before the first geological/historical stop can be made by leaving the hectic Auckland Southern Motorway (H1) at Bombay (230km south of Whangarie). Turning left (east) away from the motorway immediately leads to two service stations (Caltex on the left and Waitomo over to the right: right at the roundabout). The low Bombay Hills here mark the southern boundary of the Auckland Region, a geographical and cultural divide that to many people defines the boundary between the old and the new, and hence the expression "New Zealand stops at the Bombay Hills". Which side it stops depends on where you live, as does the preferred choice of the third word for the acronym JAFA (Just Another Friendly Aucklander)

**Pukekohe East Historic Church and Tuff Ring**. Drive west from Bombay towards the town of Pukekohe, crossing over the Southern Motorway. Just over 3km from the motorway turn right into Runciman Road and in 1km park on the left by the Pukekohe East Presbyterian Church, built in 1863 on the northeastern rim of the Pukehohe East Tuff Ring. This volcano lies at the southern side of the South Auckland Volcanic Field (SAVF), an area including more than 80 active basaltic volcanoes erupted 1.5 to 0.5 million years ago. Here at Pukehohe East is one of the best preserved explosive tuff rings in the SAVF and it has been dated as around 680,000 years old. There are extensive views from the church graveyard over the oval explosion crater (1.1 x 0.8km in size), which has been breached to the west. On the lower left side of the graveyard is a stone boulder monument to a group of Maoris killed here in 1863 during the Waikato War.



*View west from the graveyard at Pukehohe East church with the boulder monument (left) to Maoris killed in a skirmish on 14 September 1863 during the Waikato War. The low ground behind the trees marks the explosion crater of a tuff ring erupted in Middle Pleistocene times.*

**South through the Alexander Volcanic Field.** Return to the H1 motorway and drive 1hr south, making a comfort stop at Coffee Club The Base in Te Rapu Road just north of Hamilton. Rejoin H1 for a short distance before heading west then south on H39. Ahead lies the deeply dissected Pirongia Volcanic Centre (2.5-1.6 million years old), which rises to nearly 1,000m to form the highest mountain in the Waikato district. Pirongia is the most prominent stratovolcano in the Plio-Pleistocene aged Alexandra Volcanic Field (AVF), which runs inland southeastwards from the coast at Raglan (where the prominent Karioi Volcano forms the cliffline south of the town). The AVF is the most southerly of the volcanic areas that lie in a backarc position behind the currently active Taupo Volcanic Zone. These backarc volcanoes become progressively young northwards towards Auckland (Alexandra Volcanic Field: 2.74-1.6Ma; Ngatutura Volcanic Field south of Port Waikato: 1.83-1.54Ma; South Auckland Volcanic Field: 1.56-0.51Ma; Auckland Volcanic Field: mostly <0.35Ma). The AVF is interesting because, unlike the others, it includes not only basalts but also andesites, indicating that it likely represents some kind of transition between arc and backarc magmatism.

A scenic approach to Pirongia volcano can be made by taking the road signposted to the Pirongia Forest Park (turn right off H39 on to Te Pahu Road just before Pirongia village: care needed here). Te Pahu Road crosses a single lane river bridge after which turn left into Hodgson Road then left again into Grey Road which runs south to the Pirongia Forest Park Lodge and a parking/picnic area with toilets. Here we recommend the <1hr Mangakara Nature Walk for a little exercise before continuing the drive south.

**Taranaki Coastline.** Return to the H39 and drive south for 1hr, initially through Pirongia village then on past the prominent isolated basaltic volcano of Kakepuku (Plio-Pleistocene) which rises (left) to 449m, to reach Otorohanga and turn right into the H3 (stock up in the Countdown supermarket immediately on left). Continue 100km on the H3 passing the famous Waitomo glowworm caves then on through the scenic Awakino Gorge (Triassic rocks) to arrive at the west coast where a sequence of young sediments lies unconformably on the Triassic basement. The oldest of these sediments are Eocene and Oligocene age, but the thickest part of the sequence is Miocene. Continue south to the village of Tongaporutu (by now some 9 hours south of Whangarie). Just after crossing the estuarine road bridge turn right to the Three Sisters/Elephant Rock car park and walk out to the estuary beach: this excursion can only be completed at low, preferably outgoing tide. Be very aware that this coast is dangerous on a rising tide.



*The coastline at Tongaporutu is a tourist attraction for the extensive development of sea stacks isolated from the cliffline by continued erosion of these soft, vulnerable sediments. As erosion has progressed, so the "Three Sisters" have been reduced to Two, and the Elephant Rock has lost its trunk.*

The coastal cliffs here expose Late Miocene (9-10 million years old) sediments of the Lower Mount Messenger Formation, deposited deep underwater in the marine Taranaki Basin. The sediments are mostly thick brown sandstones, with some interbedded siltstones and mudstones. The thick sandstones have been interpreted as deposited underwater by sediment-charged, fast-moving turbidity currents. In places there are beds of disrupted sediment caused by slumping (or "mass wasting"), recording episodes of instability caused by some trigger such as an earthquake or simply sediment overload.

https://pangea.stanford.edu/researchgroups/spodds/sites/default/files/2010_Maier_NEWZEALAND_FIELDGUIDE.pdf

*Prominent bed of contorted, disrupted sediment (a "slump") sandwiched between two thick sandstone units; mouth of Tongaporutu River.*

Continue south on H3 for 45 minutes, crossing the challenging road over Mount Messenger, to arrive at Waitara. On a clear evening there are views to Taranaki Volcano: the objective for the following day.

*Taranaki andesite volcano from the Masonic Hotel in the coastal town of Waitara.*

## Day 7: Taranaki to Whanganui.

The province of Taranaki forms a rounded peninsula of verdant farmland underlain by mostly Miocene and younger sediments and punctuated dramatically by the enormous stratovolcano of Taranaki/ Mount Egmont. Miocene sediments such as those seen at Tongaporutu were originally deposited offshore in the Taranaki Basin but some were later raised above sea level as the Hikurangi subduction system (east of North Island) and the Alpine Fault (running up from South Island) made the area tectonically active. The Taranaki Basin supplies New Zealand's only reserves of oil and gas, with over 400 wells having been drilled since 1950. These hydrocarbons source from Jurassic, Cretaceous and Palaeogene coaly sediments and shales, and have accumulated in reservoir rocks of Cretaceous to Pliocene sediments (including Miocene turbidites such as those seen at Tongaporutu).

Drive south on H3A to Inglewood to join the H3 south to Stratford and turn right into Pembroke Road for the Taranaki/Egmont National Park which you enter in 10km. Park at the Potaema Track (left) 3km into the park, and walk up the path for 15minutes through forest and across swampland to a view of the volcano. The peak of the main andesitic stratovolcano rises steeply to a height of 2,518m, with the secondary cone of Fantham's Peak reaching 1,966m on the south side. Taranaki volcano is currently (May 2018) dormant, having last erupted in the mid-19$^{th}$ century. The oldest eruptions are thought to have been around 130,000 years ago. Volcanicity has occurred on the Taranaki peninsula area since Early Pleistocene times, with the focus for eruptions moving slowly southeastward from New Plymouth to Fantham's Peak.

As will be immediately obvious from the viewpoint at Potaema, this is an extremely dangerous volcano, with the most serious potential hazards being volcanic debris avalanches and lahars. The volcano has collapsed several times in its history, sending fast moving and catastrophic rock avalanches out as far as 40kms, in some cases reaching the coastline. Lahars formed by water mixed with volcanic material can occur after heavy rain, or crater lake expulsion, or simply unexpected collapse due to the presence of hydrothermally altered and softened rocks on the volcanic flanks, sending streams of material flowing like wet concrete rushing down the mountainside. Such events present a constant threat to those farming the low ground below the volcano.



Any future eruption of Taranaki will generate andesitic lava flows, although these will be viscous and not travel far from the volcanic vent. Material ejected in the eruption cloud as ash, lapilli and blocks from the vent (general term: "tephra") and driven by the wind has the potential to cover large areas and cause great damage to farmland, transport infrastructure, aircraft and telephone communications, as well as presenting an immediate inhalation hazard to anyone downwind. Much more alarming, however, will be the effects of unpredictable outbursts of hot gas and rock fragments ("pyroclastic flows") capable of moving down the mountainside at high speed (several 100km/hr), especially if directed laterally such as during the Mount St Helens eruption of 1980. Such flows have the potential for causing total destruction of anything in their path.

https://www.gns.cri.nz/Home/Learning/Science-Topics/Volcanoes/New-Zealand-Volcanoes/Volcano-Geology-and-Hazards/Taranaki-Egmont-Volcano-Geology

Return to the vehicle and continue the drive for 7km west up the eastern side of the volcano, passing Stratford Mountain House to reach the large parking area at Stratford Plateau (1,172m). There are extensive views from here across the valley-incised volcanic flanks out to the ring plain of volcanic material spread across the countryside below. There are several options for walks from here, such as up

into the Manganui Gorge, passing exposures of andesite, although be warned that this is a hazardous area, especially in winter or after heavy rain.

*Avalanche shelter on track into Manganui Gorge on the eastern slopes of Taranaki volcano, with andesite lava flows forming the cliffs behind.*



*Porphyritic andesite from Taranaki. Note the dark crystals ("phenocrysts") that define the porphyritic texture. The phenocrysts crystallised deep in the magma chamber but their growth was interrupted by sudden eruption of the magma which cooled and froze quickly to produce a fine pale grey matrix of tiny crystals in which are embedded the earlier-formed phenocrysts. Although most phenocrysts in these lavas are pyroxene, the amphibole mineral hornblende is also common which, combined with an unusually high potassium (K) content makes the Taranaki andesites chemically and mineralogically different from those to be visited at Ruapehu in the Taupo Volcanic Zone. The reasons for this will relate to differences in the amount and composition of melts generated and reworked in the magmatic plumbing system of the mantle and deep crust below the volcanoes. Such geochemical subtleties are the stuff of petrogenetic studies such as: https://academic.oup.com/petrology/article/40/1/167/1572845.*

Drive back down the road to park (left) at the Stratford Mountain Lodge and consider walking the excellent Patea Loop Track (1hr minimum: good footwear needed). This climbs steeply through spectacular, slippery Kāmahi rainforest west of the car park to cross the road in 30 minutes, then makes a delightful descent through the forest back to the Mountain House. Kāmahi (*Weinmannia racemosa*) is a common tree in New Zealand and here is draped with ferns, mosses and lichen to produce the "Goblin Forest".

The drive south on the N3 via Stratford and Hawera to Whanganui takes two hours. An overnight stop here allows a visit to the splendidly peculiar and ancient Durie Hill Elevator, accessed by a 230m-long tunnel into the hillside on the left bank of the Whanganui River.

*Spooky tunnel access to the Durie Hill elevator, Whanganui.*



## Day 8: Whanganui to Turangi.

From Whanganui drive north for 75 minutes on the H4 and at Raetihi turn right for Ohakune, with the huge Mount Ruapehu rising ahead to the northeast, the largest active andesite stratovolcano in New Zealand. After 10km, as the road curves left, turn right on the narrow Lakes Road and after a few 100 metres U-turn and park on the left at the track signposted Scenic Reserve. You have entered the Taupo Volcanic Zone. Perhaps not the most dramatic place to start but nevertheless interesting because this is as far southwest as the volcanic zone has penetrated and erupted through the New Zealand crust.

Walk for 10 minutes along the forest track then turn left at a junction to reach a view over an explosion crater lake. The phreatomagmatic eruptions that produced the Ohakune Volcanic Complex here took place around 30,000 years ago. The eruptions combined violent phreatomagmatic activity with the build-up of Strombolian scoriaceous spatter cones both here at Ohakune Lakes and adjacent to Ohakune town, 3km further northeast. It has been estimated that the magma rose from a depth of

around 17km over a period of a couple of days, before interacting with groundwater to produce the phreatomagmatic explosions (Kósik et al., 2016: not freely available on the web).

*30,000-year old explosion crater lake and adjacent volcanic scoria cone belonging to the Ohakune Volcanic Complex at the southwest end of the Taupo Volcanic Zone.*

Walk clockwise around the crater lake (15 minutes), return to the vehicle, and drive on to the junction with H49 at Ohakune. From here there are two ways to Turangi: clockwise via highways 49, 4 and 47, or anticlockwise via H49 and H1 (both take just over one hour). Here we describe the anticlockwise route, which allows a visit to the Tangiwai rail disaster memorial. However, if the weather is good and tomorrow's forecast bad then we recommend the clockwise route, visiting Mount Ruapehu at Whakapapa before bad weather sets in (see next day description after Turangi).



**Tangiwai.** Turn right on to H49 and follow it for 18km to the Tangiwai Memorial (signposted on left), where the Wellington-Auckland rail line crosses the Whangaehu River. On the late evening of December 24th 1953 a huge amount of water (by some estimates >1.5 million cubic metres) was released suddenly from the crater lake on the summit of Mount Ruapehu. The crater lake had been slowly refilling after an eruption in 1945, becoming progressively unstable with the weight of water held by a weakening barrier of ice and volcanic debris. The direct cause of the catastrophic release of water has been attributed to the collapse of an ice cave. Following the collapse, a wave of water and rock debris poured down the mountainside as a lahar, entrained by the drainage channel of the Whangaehi river. The lahar was reaching its peak velocity at Tangiwai, tens of kilometres below the volcanic peak, just as the Wellington to Auckland express train was approaching the bridge crossing at 22.21, packed with 285 people travelling north for the Christmas holidays. The bridge, built in 1906, had been damaged and repaired after previous lahar events (especially by one in 1925).

The train driver, Charles Parker, realised something was wrong (either because he saw the raging flood and/or he was alerted by a local man named Arthur Cyril Ellis waving a torch) and hit the brakes 180m from the bridge. The momentum of the slowing train however still took it on to the damaged bridge which collapsed, unable to sustain the weight of the train and the damage caused by the lateral force of the lahar. The engine and front carriage nosedived across the river channel, hitting the opposite

riverbank as the four carriages behind them fell into the swollen waters and were carried downstream. A sixth carriage (the leading first class coach) was left dangling over the river bank but, as Ellis and the train guard William Inglis tried to get people out, the coupling snapped and the carriage fell into the water, rolling before finally coming to rest with water pouring through it. Ellis then smashed several windows and, aided by a passenger named John Holman, began helping people to escape to the outside of the carriage where they remained as the waters subsided enough to enable a human chain to form and get people to the bank. The rear carriages, all first class (second class carriages were towards the smoky front of the train), remained on the track with no casualties.

Ellis and Holman were awarded the George Medal in 1954, the citation for Ellis reading: "*At Tangiwai on the night of 24 December 1953 Arthur Cyril Ellis was witness to a railway disaster he had endeavoured to avert by waving his torch ahead of the approaching express. After the engine and five carriages had crashed into the flooded Wangaehu River, Arthur Ellis entered the train and, with the Guard, went forward to the sixth carriage, which was balancing on the brink of the torrent. As he was beginning the movement of the passengers from the carriage it toppled forward into the river and was swept downstream. When it came to rest on its side, Arthur Ellis, who throughout displayed much calm and continued to allay panic, broke a window by means of his torch and, with the aid of another passenger, John Warren Holman, assisted to safety all surviving passengers from the partially submerged carriage. Through his presence of mind and his courageous actions, in circumstances of extreme danger, Arthur Ellis assisted in the saving of twenty-one lives.*"

A total of 151 people died as a result of the disaster, with 60 bodies being recovered 24km downstream and 20 never having been found, presumably washed out to sea 120km away. One entire train carriage was found over 2km down the river. The tragedy led to the establishment of a lahar monitoring and early warning system, and bridges were strengthened. Another crater lake lahar at the same locality occurred in March 2007 but, even though it was larger than the 1953 event, caused no casualties. The railway authorities were absolved of any blame in the 1954 enquiry, although a dissenting voice was raised by a mountaineer named Jim Mason who claimed that he had recognised the geological threat posed by rising lake levels in the crater and had written to warn the Railways Department before the event: http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11175376



*The Auckland-Wellington train crossing the rebuilt and now geological hazard-monitored Tangiwai Bridge in 2018.*

Compared to Taranaki volcano, lahars emanating from Ruapehu tend to be relatively small, but even "small" lahars pose a serious threat to life, as demonstrated by those who died at Tangiwai as a result of a combination of poor geological hazard awareness and incredibly bad luck.

**Desert Highway to Turangi.** Continue east for 10km on the H49 and turn left into H1 at Waiouru to cross the remote, high and inhospitable "Rangipo Desert", with views of the three volcanoes Ruapeho, Ngauruhoe ("Mount Doom" in the film Lord of the Rings), and Tongariro on the left. This "Desert Road", the highest part of Highway 1, is used as a training ground by the New Zealand army and is commonly closed by snowfalls during winter. The desert-like aspect of the area is due less to a lack of water but more to the combined drying effects of frequent strong winds, summer sun, and the porosity of the volcanic debris covering the area. The volcanic wastelands of the Rangipo Desert provided the Black Gate of Mordor scenic background locations for the Lord of the Rings.

The Rangipo Desert is essentially a coalescence of ring plain lahars and airfall deposits of the adjacent andesitic volcanoes, including in places Taupo ignimbrite (TI: a pyroclastic flow or "fiery rock dust cloud"). Roadside exposures of brown-weathered TI become more numerous as the H1 nears the Taupo Lake area. For example just after the H1 crosses the Waihohonu Stream where TI deposits (left) rest on andesitic debris thought to have been generated during the growth of the Ngauruhoe cone. Stopping on this busy highway is not recommended, but the many exposures of TI, lahar breccias and ash fall deposits in road cuts (for example after crossing the Oturere Stream) can be enjoyed from the car as HI descends to pass the junction with H46 and finally arrive in Turangi, 63km from Waiouru.

Turangi lies at the southern end of Lake Taupo on the Tongariro River, claimed to be one of the best trout fishing areas in the world. The Tongariro River Trail offers good walking opportunities, as does the circular walk around the volcanic crater Lake Rotopounamu, 15 minutes' drive SW of Turangi on H47, on the NW side of the andesitic Pihanga Volcano. Another pleasant way to spend part of the afternoon is to visit the Tokaanu thermal area, a 10 minute drive NW from Turangi on H41. In addition to the private thermal pools, there is a (free) short walk through the steaming thermal area with boiling mudpools, providing a low key but enjoyable foretaste of the more spectacular thermal locations to come. For the evening, the authentic Turangi Tavern provides pub food and drink. Cheers.



*Steaming pool on the thermal walk at Tokaanu at the southeastern end of Lake Taupo. The Taupo Volcanic Zone has one of the highest heat flows in the world due to the presence of magma at shallow depths, and this promotes the convective movement of heated meteoric water.*

## Day 9: Tongariro, Ngauruhoe and Ruapeho volcanoes then on to Taupo.

This trip initially southwest from Turangi explores the other (northwest) side of the three volcanic peaks passed the previous day, climbing the ski slopes of Ruapeho and offering excellent opportunities for walking in high volcanic terrain. Drive back south on H1 and turn right into H46 which runs west past Lake Rotoaira (right) and the steaming, sulphurous slopes of Tongariro (left) to turn left into H47 and then left again into H48, 45kms from Turangi.

Just over 1km down H48 park (left) on the roadside where on the right the Mounds Walk path leads southwest to a lookout. The path crosses hummocky terrain caused by a volcanic debris avalanche from Mount Ruapeho around 10,500 years ago. This massive debris avalanche has been mapped on the ground as the "Murimotu Formation" and occurred when an estimated 200 million cubic metres of loosely consolidated fresh volcanic materials suddenly slid rapidly downslope then spread out over the lower ground to form an apron of rubble in places up to 12 metres thick. This wholesale collapse of the northern flank of the mountain has been explained in various ways, with a recent discussion having been provided by Conway (2016). The most likely scenario is that of a dangerously unstable, steep sided volcano built from hydrothermally altered volcanic debris partly held together by buttresses of glacial ice weakened by many years of deglaciation under a warming climate. The sudden failure of the northern slopes was perhaps triggered by an earthquake and/or eruption event after a long history of gradual destabilisation.

*Mounds Walk on the ring plain of Ruapehu volcano. The vegetated hillock in the foreground marks one of many large blocks of volcanic material that slid down from the slopes of Mount Ruapeho in a volcanic debris avalanche around 10,500 years ago. The symmetric peak of Ngauruhoe volcano ("Mount Doom") rises in the background.*

Drive southeast on H48 to park by the Whakapapa Visitor Centre, worth a visit especially for the video coverage of recent eruptions from Mount Ruapeho. It can get very busy here: if parking is full then it is best to continue driving on up the ski area (see description below) and come back later.

There are several walks from Whakapapa: we recommend that to Taranaki Falls (allow 1.5-2 hours), starting one block north of the visitor centre by walking east along the road leading to the Tongariro Crossing. The walk is circular and can be done in either direction. We suggest the clockwise route: although this does involve climbing steps at the falls, the overall experience is probably more enjoyable,

initially descending to the river which you follow to Taranaki Falls with its prominent andesitic lava flow, then returning via the higher ground with splendid views over the surrounding volcanoes.

*The Taranaki Falls andesite lava flow (Whakapapa Formation) erupted around 9,000 years ago from a cone currently hidden beneath the Ruapehu summit area ice field. Lavas emanating from this cone flowed NNW down the volcanic slopes for up to around 10 kilometres: https://core.ac.uk/download/pdf/45830512.pdf*

Return to Whakapapa Tourist centre car park and continue the drive up H48 (Bruce Road), climbing through spectacular volcanic landscapes to the car park in the skiing area at the end of the road (toilets and café available). Walk east past the ski lift area towards the linear rock ridge of Mead's Wall ahead, locating the line of sticks with yellow paint that leads north up the side of the Wall to a viewpoint looking south towards the snowy volcanic summit. The "Wall" here was named after William Perrett Mead, the story of whom can be found at:

https://teara.govt.nz/en/biographies/4m49/mead-william-perrett.

"I impressed on all parties asking for particulars of the route that the rock wall was their important landmark both going up and coming down, and after a while I found them calling it Mead's Wall." W M Mead, *Memories of a Mountain and a River*.

*Happy Valley/Whakapapa ski area in summer, with Mead's Wall (background left) and Pinnacle Ridge (background right: mostly brecciated lavas) both belonging to the Te Herenga Formation (200-150,000 years old: the oldest dated eruptions of the volcano). In the foreground are young (c. 6,000 year old) lavas of the Whakapapa Formation (Iwikau unit).*

*Close-up of vertical andesite dyke forming Mead's Wall (1650m asl) on the northern slopes of Ruapehu volcano, looking south with views to Pinnacle Ridge and the Te Herenga Formation (left) and the snowy summit area beyond. Such dykes acted as vertical feeder channels for the andesitic magma on the way to eruption. Deep erosion of the Pleistocene volcano exposed the dyke cutting Te Herenga lavas and breccias before the eruption of the young Whakapapa lavas (right) in Holocene times.*

*View from Mead's Wall dyke across to the lower slopes of Pinnacle Ridge which are draped by a distinctive andesitic air fall deposit erupted from a nearby vent around 10,000 years ago.*

Ruapehu has erupted on repeated occasions since it first emerged in late Middle Pleistocene times around 200,000 years ago, frequently through a cover of glacial ice and snow. The chemical composition of the lavas has ranged from basaltic andesite through andesite to dacite: it is a classic example of a plate subduction-generated stratovolcano. The adjacent symmetric cone of Ngauruhoe ("Mount Doom"), 10km NE of Whakapapa, is a young (and highly active) eruptive centre of the andesitic Tongariro Volcanic Complex, appearing only around 2,500 years ago. Mount Tongariro volcano *sensu stricto* first erupted in Pleistocene times around 275,000 years ago, but since then around a dozen volcanic cones have been produced in the volcanic centre. The most recent eruption from Tongariro occurred in 2012 and caused considerable disruption but no injuries.



The porphyritic andesites erupted from these volcanoes have a long and complex history that begins with melting in the deep mantle (c. 100km depth) above the subducting plate slab to produce basalt magma which rises to the base of the crust at a depth of around 30-40km. Here the basaltic magma cools and partially crystallises to produce dark solid rock full of minerals rich in iron and magnesium, leaving a residual liquid richer in silica and of andesitic composition, some of which rises to erupt at the surface. This is a simplification of a complex process, but the idea is that magma compositions can change on their journey from the mantle and through the crust before they eventually erupt as lava. So in this case the original parent magma was basaltic in chemistry but this changed as crystals were left behind, producing a residual liquid richer in $SiO_2$. This process is called fractional crystallisation (or crystal fractionation) and is of fundamental importance to explain how magmas can change from basaltic through andesitic, dacitic and rhyolitic compositions. Thus, whereas the basalts of Auckland and Northland had a relatively simple journey from their source to the surface, the much more voluminous magmas associated with plate subduction in the TVZ have had a more complicated journey, becoming affected by crystal fractionation (and various degrees of mixing and contamination by the rocks they encountered) as they stopped off in the lower crust along the way.

*Porphyritic andesite erupted from Ruapehu volcano.*



**Whakapapa to Taupo.** Return to Turangi via H47 and H41, passing the path (right) leading to the volcanic crater lake of Rotopounamu and stop at the scenic lookout (left) over Taupo Lake. Here, the line of andesitic volcanoes running over 50 km from SW to NE between Ohakune and Turangi gives way dramatically to "inverted" volcanoes in the central part of the Taupo Volcanic Zone. These central volcanoes are characterised by large, lake-filled craters, much more explosive eruptions, and rhyolites rather than andesites. There is a wide view from here across the volcanic hill of Maunganamu ("Mosquito Hill": a rhyolite dome) and the Tongariro River delta to the lake itself, the largest lake in New Zealand and the site of a dormant supervolcano.

Drive north from Turangi on H1 for 9km, passing the South Taupo wetlands of the Tongariro Delta (the main river feeding the lake) to reach the village of Motuoapa. Take the first turning on the left and park, then return on foot to the H1, follow the pavement one block north, and cross the road to locate the Motuopapa Cliff Lookout walking track. Climb the track, turning right near the top to reach the lookout. The view from here over Lake Taupo is a good place to think about supervolcanoes and their eruptive products.

The surface expression of Taupo volcano is a giant hole in the ground filled with lakewater, unlike the obviously volcanic andesitic mountains of Ruapehu, Ngauruhoe, and Tongariro. The tranquil, lacustrine scene enjoyed from the Motuoapa Cliff lookout however disguises the fact that Taupo is an explosive

monster of a volcano, capable of producing among the largest eruptions on Earth. Such eruptions eject so much magma that the roof of the emptying magma chamber collapses, leaving a depression rather than a volcanic cone.

The blueprint for the lake as we see it today was formed after a massive expulsion of pumice and ash as the magma chamber collapsed around 26,500 years ago, an event known as the Oruanui eruption. In places close to Taupo the ignimbrite deposits left from this eruption can be 200 metres thick, and much of New Zealand was covered in volcanic ash which drifted over 1,000km southeast across the ocean to deposit a layer nearly 20cms thick in the Chatham Islands

https://teara.govt.nz/en/photograph/8715/ash-layer-chatham-islands

Overall, the Oruanui event erupted more than 1,000 cubic kilometres of volcanic material, blasted out of the volcano as fast-moving pyroclastic flows and Plinian ash and pumice plumes rising high into the stratosphere. The enormity of such "Ultra-Plinian" eruptions is such that they measure 8 on the Volcanic Explosivity Index (VEI: a relative scale that increases logarithmically to a maximum, open-ended value of 8) and are described as "mega-colossal" events from "supervolcanoes". The Late Pleistocene Oruanui eruption at Lake Taupo is the youngest of the world's supervolcano eruptions, meaning that no such events have occurred so far in Holocene time. There will of course be another supervolcano eruption somewhere around the world: it is just a question of time.

*View northward over Lake Taupo from Motuoapa Cliff lookout. The northern half of the lake covers a huge volcanic crater. Some idea of the scale of this volcano is given by the fact that the far northern shore is over 25km away from Motuoapa village. The present day magma chamber lies around 7 kilometres below the lake but, for the moment at least, the volcano records only relatively low level seismic activity: earthquakes at depths of around 5-10km are frequent but usually of Magnitude 3 or less. On the left side of the photo rises the hill of Motuoapa which marks one of several lava domes found around this volcano. Such domes occur where the magma has degassed sufficiently to inhibit explosive eruption.*

Continue north on H1 to Taupo. The most recent large eruption from Lake Taupo occurred around 1,800 years ago and is variously referred to as the "Hatepe" or "Taupo" eruption and, whilst not "super" (it had a VEI = 7) it was nevertheless one of the most violent volcanic events occurring worldwide over the last 5,000 years. The volcanic vent has been identified offshore in the east side of the lake, the shape of which was modified as ash drifted eastward to rain down on the surrounding countryside so that on the journey north to Taupo you cross the area where the resulting ash deposits are thickest. The eruption also produced a massive hot pyroclastic flow which overwhelmed the topography for tens of kilometres around the volcanic vent, surpassing even the summit of Tongariro volcano (but not Ruapehu, which divided the flow) and left behind the distinctive Taupo ignimbrite deposit seen in many places while driving through the area.

## Day 10: Taupo to Orakei Korako

The plan for today is to start locally by looking at Taupo rhyolitic volcanic deposits in the town and alongside the scenic Waikato River, then visit the famous Huka Falls, the steaming uplands of the Craters of the Moon (paid entry), and finally the outstanding geothermal area at Orakei Korako (also paid entry). From here either backtrack for another night in Taupo or move on to a hotel in Rotorua. If staying for two nights in Taupo, then Orakei Korako can be left to the following morning before moving up to the Rotorua area an hour's drive away.

Taupo township is built mostly on 1,800-year old volcanic deposits left after the last major eruption from the lake area. These rocks partly cover Oruanui deposits which occur extensively for many kilometres around Taupo Lake. On the west side of Lake Taupo the Oruanui volcanic deposits themselves overlie even older eruptive rocks produced by another episode of supervolcano eruption (this one known as the Whakamaru event) which took place around 320,000-340,000 years ago during a tremendous flare-up of volcanic activity. The whole area around and to the northeast of Taupo Lake has been active for around 2 million years during which time eight large, oval-shaped volcanic centres (or "calderas") have produced many eruptions, some of which have been supersized. It is one of the most active volcanic zones in the world.

The origin of such huge amounts of rhyolitic magma has been the subject of much scientific debate. Volcanism in the central TVZ was originally andesitic but became more rhyolitic around 700,000 years ago before the gigantic flare-up started around 340,000 years ago, around the same time as the andesitic volcanism began in the southern TVZ. Since the beginning of this volcanic flare-up until the present day, an incredible amount (estimated as 4,000 cubic kilometres) of rhyolitic pyroclastic rocks has been erupted, at times covering much of North Island in pumice and ash. This exceptional volcanic activity has taken place as subduction-generated basaltic magmas have intruded a crust which has been stretching and thinning as the TVZ splits apart at speeds in places greater than ten millimetres a year (which may not sound much, but on geological timescales that is ten kilometres every million years).



But the question remains: how exactly was such a huge amount of rhyolitic magma produced? One idea, attractive in its simplicity, is that the crust beneath Taupo has got so hot that it has begun to melt on a grand scale. Crust is more siliceous than the mantle and so melting it can produce rhyolitic magma. The author will admit to initially subscribing to this idea, but has since seen the likely error of his ways. As more chemical data have become available from the TVZ (and there is by now an enormous amount) a strong argument has emerged that any melting of crustal rocks at depth may influence but not be the main cause of the "rhyolite machine" responsible for the TVZ flare-up. Instead the answer appears to lie in changes in crystal fractionation: see, for example, the paper by Deering and coworkers available online: https://academic.oup.com/petrology/article/52/11/2243/1538846. This publication argues that with time the magmas beneath the TVZ have become wetter, with fluid focussing in the rapidly extending crust, and with magmas rising more rapidly and losing $CO_2$ gas preferentially to $H_20$ (leaving the magmas relatively richer in water). Wetter basaltic magmas have different crystal fractionation behaviours than dry ones, and they produce a residual magma richer in silica (dacitic rather than andesitic). The argument continues that this dacitic magma rises in the crust, becomes more viscous, and undergoes further crystal fractionation to produce even more silica-rich magma: rhyolite. Whatever the details, the origin of the Taupo rhyolites seems most likely to lie in the unusual mix of subduction magmatism and rapid crustal extension that is going on in central North Island.

**The Taupo (Horeke) Eruption.** A major eruption from a rhyolitic caldera such as Taupo takes place as a series of events over hours or days that typically involve some combination of (1) vertical gas-blast-driven "Plinian" ash clouds, (2) explosive interactions between magma and water (phreatomagmatic), and (3) destructively ground-hugging pyroclastic flows. These varying eruptive styles can occur repeatedly with changing volcanic behaviour as the overpressured magma chamber beneath is emptied. The most recent event of around 1,800 years ago at Taupo Lake, for example, started with minor ash expulsion followed by the emergence of a Plinian eruption cloud of gas, liquid and pumiceous rock particles rushing skywards to heights of tens of kilometres. The collapse of such columns can drive fast-moving clouds of fragmented materials horizontally over the area surrounding the vent, and the prevailing breeze will drift large quantities of ash downwind.

The eruption style at Taupo then changed as lake water entered the vent, producing explosive phreatomagmatic outbursts that showered the area with fine ashy materials. Condensation of water in volcanic ash clouds often generates heavy rainstorms that will wash over and redistribute the soft, ashy, pumiceous volcanic fall deposits, locally producing mudflows, so that the local landscape is under constant change from erosion and deposition as the eruption proceeds. In the continuing Taupo event, a renewed pumiceous Plinian eruption column again rose and collapsed, heralding the climactic phase of the eruption, when a massive, hot pyroclastic flow burst from the volcano at speeds of hundreds of km/hour and charged out turbulently in all directions for up to 80kms. The destructive power of such events is great enough to transform the landscape, eroding exposed higher areas and filling valleys that become choked with metres of unsorted mixtures of pumice and other rocks embedded in a fine ashy matrix. This sculpting and smothering of the topography is a key reason why the landscapes around Taupo are commonly softer and less obviously "volcanic" than those around the andesitic mountains immediately to the southwest. It is a softness that belies extreme violence.



As the 1,800 year-old Taupo eruption declined and the vent area subsided, domes of degassed rhyolite magma rose slowly into the volcanic centre, and freshly deposited volcanic materials blocked the escape of any water, causing the caldera lake to rise over 30 metres during an estimated 15 years or so before the dam burst (see *New Zealand Landscape: Behind the Scene* by Paul Williams). The resulting flood sent water charging down the Waitomo River in quantities estimated as 200 times the present-day discharge, further altering and eroding the newly transformed volcanic landscape. The amount of floodwater released by this catastrophic event has been estimated as 20km$^3$, which is about a third of the amount of water currently held in Lake Taupo (a similar dam outburst after the Oruanui eruption was three times greater, with a water volume equivalent to the that of the entire present-day Taupo Lake pouring out in a matter of weeks).

**Taupo suburbs and Waikato River.** A convenient way to start looking at Taupo geology is simply to drive from the town centre up Spa Road for 1km, turn left into Motutahae Road and take the first left (Motutere Ave) to park immediately on the left. Walk back to the Motutahae/Motutere junction to examine the road cut in the photo below (note: this road cut is likely to degrade with time).

*Road cut in Motutahae Road, Taupo, revealing layers of soft, pale ash and pumice. Pumice is a peculiarly vesicular (full of holes) volcanic rock formed as hot, pressurised magma is ejected violently from the vent. Rapid depressurisation causes gases dissolved in the magma to exsolve, forming a bubbly foam that is frozen as the material cools on exit from the volcano. The pale pumice has a very low density (it can float on water) so that fragments can concentrate in the upper part of deposited layers, as seen in the photo above. Pumice is very common in Plinian eruption columns and pyroclastic flows, and can be extensively redistributed over the landscape in alluvial deposits after an eruption.*



*Road cut in Motutahae Road, Taupo, exposing the sharp base of the white pumiceous deposit (seen in the photo above) which rests upon brown sandy sediments interpreted to have been deposited as valley side alluvium and soils before the Taupo eruption. These sediments are likely to be equivalent to the Pleistocene Hinuera Formation that is found widely along the Waikato river valley and out into the lower ground around the city of Hamilton, and some of them at least would have been deposited during and after the great dam-burst floods that resulted from caldera lake outlets temporarily blocked by volcanic eruption deposits.*

Drive back into Motutahae Road and continue downhill to take the first turning on the right (Waikato St) that leads down to a car park by the Waikato River. Follow the river footpath southeast (downstream) on the west side of a large meander to admire the white cliffs of Taupo volcaniclastic valley-fill materials shown in the photos below.

*The Waikato River is the longest in New Zealand (425km), draining through lakes Taupo, Ohakuri and Atiamuri before escaping from the Taupo Volcanic Zone via the Ongaroto Gorge into the Waikato alluvial plains, and eventually out to the Tasman Sea near Port Waikato.*



*The white pyroclastic rocks below the Taupo bungy jump are around 25km northeast from the vent in Lake Taupo which erupted 1,800 years ago. Note how the lower part of the white cliff succession is more massive whereas in the more central area distinct layers can be detected, presumably reflecting variations in eruptive behaviour as the*

*eruption proceeded. On the lower left of the photos above and below the white volcanic rocks can be seen resting on older rocks close to the river surface. These older rocks comprise a thin layer of pale brown sandy sediment (Hinuera Formation?) beneath which is a basement of harder rocks belonging to the Huka Group of lake sediments that were present before the Oruanui and Taupo eruptions 26,500 and 1,800 years ago respectively. Note how the promontory of this harder basement (pale grey rocks on lower left) juts out into and narrows the river.*

*Close up of basement promontory of Huka Group rocks (left) against which the younger rocks have been banked as they infilled the local topography. Huka Falls lies 4km downstream and offers a more dramatic example of river constriction by the hard Huka Group sediments.*

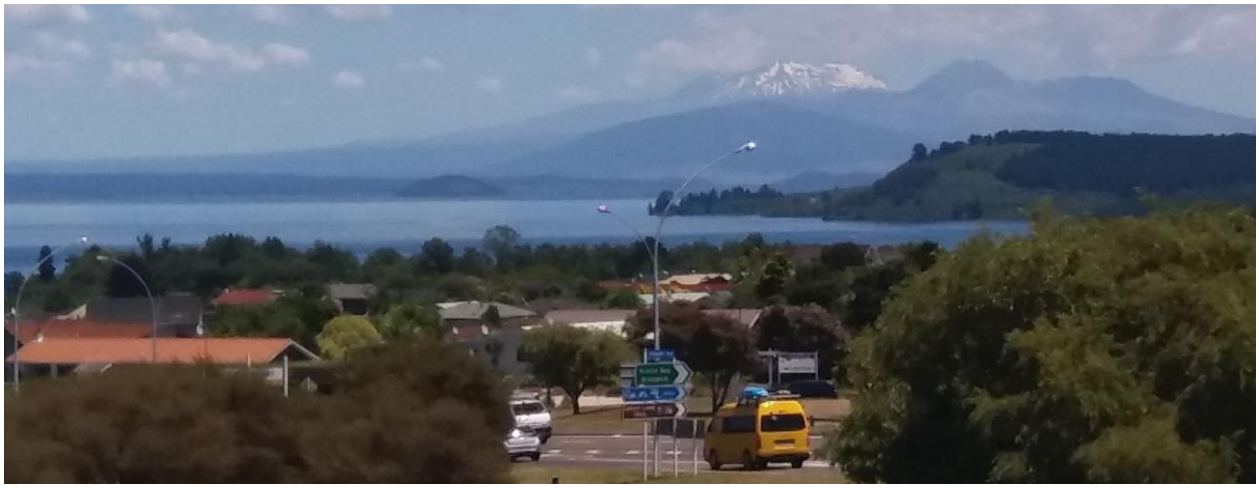


The lower part of the white pyroclastic sequence here can be examined at the cliff-base below the bungy jump, although hard hats should be worn.

*The lower part of the pyroclastic volcanic valley-fill succession comprises thick fragmental deposits containing unsorted, angular fragments of pumice and other rocks set in a fine ashy matrix.*

For those staying at least two nights in Taupo and looking for exercise, consider walking rather than driving to Huka Falls by following the 3km Huka Falls Walkway for an hour downstream from the car park in Spa Park north of the riverside Taupo bungy jump. This avoids getting involved in the busy Huka Falls car park area on the other side of the river. Alternatively, drive to Huka Falls as described below.

**Huka Falls.** Drive back to Taupo town centre and turn right (north) to cross the river and climb the valley side on the Thermal Explorer Highway. Just over 1km from the river turn right into Huka Falls Road and immediately right again to the scenic lookout over Lake Taupo. The town of Taupo lies at the head of a small inlet (Tapuaeharuru Bay) where the lake is drained by the Waikato River. To the east (left) rises Mount Tauhara (1088m) which marks the position of a cluster of dacite dome intrusions. This is the largest dacite outcrop in the Taupo Volcanic Zone (TVZ), which makes it interesting because such rocks are rare in the TVZ, forming less than 0.1% of eruptive products. Dacite is intermediate in composition between rhyolite and andesite, and a detailed study of the Tauhara dacite has concluded that it formed by mixing of siliceous (rhyolitic) and more mafic (andesitic and/or basaltic) magmas (https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1002/2013GC005016): "Mixing took place in well-stirred magma chambers located at mid-crustal depths (8–13 km) at temperatures from 840° to 900°C" over timescales of a few months to at most a couple of years."



*View across Taupo Lake to the andesitic volcanoes of snow-covered Ruapehu and the adjacent symmetric cone of Ngauruhoe which is a satellite cone of the main Tongariro Volcanic Centre (right). A fast-moving, hot pyroclastic flow erupted from a vent on the left side of Taupo Lake 1,800 years ago and was powerful enough to travel over Tongariro summit. The forested island of Motutaiko (centre left) is a rhyolite dome dated as 7,000 years old https://academic.oup.com/petrology/article/55/8/1511/1485339*

Continue driving along Huka Falls Road to park at the falls, if there is room (if not, try the upper car park or visit the Craters of the Moon first). Walk to the falls which can be enjoyed from a pedestrian bridge which spans the narrow gorge carved by the Waikato River down into the hardened lake sediments of the Huka Group. The sediments of the Huka Group are Middle to Late Pleistocene in age and were deposited on the floor of a precursor lake to Lake Taupo that existed for over 300,000 years before the Oruanui supereruption 24,600 years ago. This older "Lake Huka" is estimated to have once run northeast for up to 100km from what are now the southern shores of modern Lake Taupo:

https://ir.canterbury.ac.nz/handle/10092/10850

*The Waikato River has become constricted by cutting down into hardened lake sediments of the Huka Group. As the river (seen in the background) enters the gorge the flow rate increases and foam (Huka is the Maori word for foam) is produced as the water bursts out over the Huka Falls where the river widens once again (foreground left).*

## Craters of the Moon



The sediments in the Huka Group are of additional interest because they form a hard, impermeable capping to the aquifer of the Wairakei-Tauhara geothermal field which centres on this area. This "caprock" is cut by faults which allow hot water to escape towards the surface to feed the geothermal field (and in places cold water to percolate downwards). Extraction of hot water and steam from this field has gone on since 1958, making it the world's second oldest steam power plant and leading to local ground subsidence which in places can exceed 10 metres.

An excellent place to enjoy the surface manifestation of the Wairakei-Tauhara geothermal field is at the Craters of the Moon (Karapiti) fumerole field. Continue driving along the Huka Falls Road north to cross the main road (signs to Craters of the Moon) to the car park 1.7km further on. Payment of the modest entrance fee allows a signposted walk through the area, characterised by steaming ground and craters produce by shallow steam explosions, with localised steam vents and hot mud pools. There are five areas that are most active, all surrounded by heat-stressed vegetation. Most of the active craters appeared after the 1955 opening of the nearby geothermal power plant due to exploitation-induced boiling. There are extensive views over Lake Taupo and surrounding regions, especially from the lookout near the end of the walk.

*Steam rising from one of the shallow explosion-induced "Craters of the Moon" at Karapiti. Geothermal waters boil beneath ground level, releasing steam mixed with volcanic gases. These gases are mostly carbon dioxide and smelly hydrogen sulphide, the latter oxidising to sulphuric acid to produce an "acid sulphate geothermal system". The unusual "geothermal vegetation" at this site includes prostrate kānuka and thermal clubmoss, both of which can withstand unusually high temperatures (more than 50°C) and acid soils with high metal concentrations: https://www.waikatoregion.govt.nz/assets/PageFiles/39733/TR201532.pdf*

Now drive north to Orakei Korako (see below), unless your schedule allows two days in the Taupo area, in which case consider making the scenic backroad drive from Craters of the Moon to Maraetei Dam. To do this, start by driving back towards Taupo but then turn right northwards up Poihipi Road to turn right into Kaahu Road which runs towards Whakamaru Dam, passing white exposures of Whakamaru rhyolitic pyroclastic flow. This road runs along the western edge of the huge Whakamaru Caldera from which emerged one of New Zealand's largest known supervolcano eruptions around 349,000 years ago. At Whakamaru Dam turn left into Whakamura Road which becomes Waipapa road from which an access road runs down to Maraetei Dam, where there are impressive cliff exposures of the Whakamuru pyroclastic flow.



**Orakei Korako Geothermal Park.** The drive to Orakei Korako from Craters of the Moon takes 30 minutes: north on Highway 1 then right into Tutukau Road and left into Orakei Korako road. Allow a minimum of two hours to visit this site which closes at 16.30 in summer. Toilets and food are available. Buy tickets, take a small boat across the flooded River Waikato as it enters the artificial Lake Ohakuri, and follow the enjoyable self-guided walking trail on the opposite shore. Of the three main geothermal sites between Taupo and Rotorua (Orakei Korako, Waiotapo, and Waimangu Volcanic Valley) this is the most remote and therefore normally the quietest of the three.

The flooding of the Waikato valley here in 1961 for hydrothermal energy raised the water level by 18 metres and submerged many thermal springs and geysers. Despite this loss, Orakei Korako remains a world class geothermal site with an excellent array of geothermal features including sinter deposits, boiling water and mudpools, a range of unpredictable geysers, and a rare example of an acid sulphate geothermal cave, all accessible from a guided walk (with many steps) through attractive rainforest:

https://www.orakeikorako.co.nz/geothermal-formations-orakei-korako



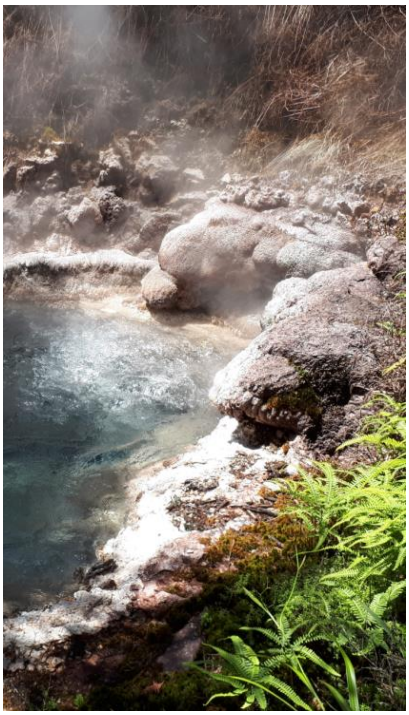
*The lowest terrace at Orakei Korako, crossed immediately on leaving the boat, is the Emerald Terrace, which is covered in colourful microbial mats and continues for another 35 metres out beneath the lake surface. The unreal colours are due to various oxides and sulphides of iron, antimony and other metals.*

The Orakei Korako geothermal field lies on the northeastern side of the Whakamaru Caldera and at the southwestern end of a prominent zone of crustal fracture known as the Paeroa Fault. The massive eruptions from the Whakamaru Caldera 349,000 years ago were followed some ten thousand years later by further rhyolitic eruptions, this time centred on the Paeroa Fault as a more localised linear rather than giant circular eruption source. Such events highlight the importance of young tectonic ("neotectonic") activity in the Taupo Volcanic Zone (in this case in the influence of NE-SW oriented fault zones) and the commonly close link between volcanicity and faulting. The Paeroa Fault will be visited tomorrow, on the excursion south from Rotorua (see below).

*The terraces above the Emerald Terrace are fault scarps reported as having formed by an earthquake in 131 AD. The combination of neotectonics and geothermal features makes the Orakei Korako site geologically special.*



*The highly active "Artist's Palette" at Orakei Korako provides a splendid variety of geothermal features, notably several unpredictable geysers and clear blue chloride pools. Geothermal waters are commonly enriched in hydrogen chloride, producing alkaline chloride waters from which the siliceous sinters precipitate. The sintery areas at the Orakei Korako geothermal site are especially outstanding, formed as the hot spring waters cool and precipitate films of opaline silica which coat the ground surface and are coloured by trace elements and microorganisms.*



*Rounded masses of pale siliceous sinter (geyserite: a type of opal) in Orakai Korako Geothermal Park.*

Geyserites around boiling springs and geysers form in an extreme terrestrial environment that harbours the highest temperature forms of life known on Earth (hyperthermophilic microbes). It has been reported that evidence for life on land goes back at least 3.5-billion years ago, according to an ancient geyserite find in the Pilbara Craton of Western Australia:

https://phys.org/news/2017-05-oldest-evidence-life-billion-year-old-australian.html

## Day 11: Rotorua to Te Kopia

**Rotorua** lies at the southern end of a major caldera produced by a supervolcano ("Mamuku") eruption around 240,000 years ago and, like Taupo, now infilled by a crater lake. The Mamaku gravity-controlled pyroclastic flows erupted from this caldera smothered the ground north and west of the lake in a giant plateau-like fan (>400 $km^2$) of pumiceous deposits now dissected by rivers.

Rotorua is the geothermal tourism capital of the Taupo Volcanic Zone and its commercialism can come as a shock after travelling through smaller towns in New Zealand. The success of the tourist industry here is due to the fact that hot water lies beneath much of the town, rising in the south at Whakarewarewa, probably up faults on the southern rim of the caldera. It has been estimated that around one third of these superheated waters emerge at Whakarewarewa as hot springs and geysers. The remaining hot water moves northwards under the town through fractures, trapped under pressure beneath an impermeable capping of hardened lake sediments and volcanic rocks, to emerge in the north. The main hot spring activity at the surface is therefore confined to the southern (Whakarewarewa), northwestern (Kuirau Park/Ohinemutu) and northeastern (Government Gardens) parts of the town.

In the north, a walk around Kuirau Park (free entry, including footbaths) is recommended, especially at its far northern end. In the south, the Whakarewarewa area is famous for the Pōhutu geyser which erupts frequently daily and can reach a height of 10m, although to get close to this you need to pay for entry to the Te Puia Maori Village tourist attraction site. Pōhutu geyser and the other geothermal features were initially threatened by overexploitation: by the late 1970´s over 1,000 boreholes had been drilled, some as deep as 200m. One result of this was a decline in surface geothermal activity, forcing the government in the mid-1980's to reduce the number of wells to below 200, which successfully led to increased sub-surface water pressure and has allowed a partial recovery to take place. A complete drilling ban is imposed for a distance of 1.5km from Pōhutu geyser.



*Steaming lakewater in Kuirau public park, Rotorua.*

**Waimangu Volcanic Valley**. From the Whakarewarewa thermal area south of Rotorua, drive 20 minutes south on H5 and turn left towards Waimangu Volcanic Valley where there is a car park and ticket office. As at Orakei Korako the tickets are quite expensive, but there is no choice and this is again a very special geothermal site. The visit involves a 3.5-4km walk from the ticket office to Lake Rotomahana, with an optional bus back (included in price) and an optional boat tour of the lake (extra charge).

Waimangu lies at the southwestern end of a 17km-long volcanic rift fracture created during the eruption of Mount Tarawera on 10 June 1886. This was one of the largest historic volcanic eruptions in New Zealand and it killed over 100 (mostly Maori) people. The area still remains very active, with fatalities resulting from geyser outbursts and hydrothermal explosions produced by superheated subsurface water flashing to steam continuing into the 20th century:

http://www.waimangu.co.nz/waimangu-volcanic-valley/eruption-chronicles_idl=1_idt=3999_id=22960_.html

The continuing high geothermal activity at this site is probably due to the intersection of the Tarawera rift fault with the fault zone bounding the Okataina Volcanic Centre (OKC), another major eruptive zone that defines a huge, irregular caldera lying to the east of Rotorua. The OKC has been a centre of volcanic activity since at least 325,000 years ago: here at Waimangu we are on its southern margin. Over the last 21,000 years alone there have been over 40 active vents within the OKC, the most recent eruption being that at Talavera in 1886.

A detailed guide to the specific sites visited during the walk is supplied with the entrance tickets and so will not be repeated here. Starting with a panoramic view northeast along the rift valley to Mount Tarawera, the route runs downhill past the southernmost crater, now filled with Emerald Pool, to a view over Echo Crater and Frying Pan Lake, which last erupted in 1973.



*View northeast over Echo Crater partially infilled by Frying Pan Lake, with the steaming Inferno Crater Lake behind. This is currently the most active part of the Waimangu geothermal system.*

*View northeast across Frying Pan Lake, with steaming Cathedral Rocks on the right. Further to the right, at the northern end of the lake, is the site of the extinct Waimangu Geyser, once the world's largest geyser on record (reaching heights of 450m) and responsible for the deaths of four tourists in 1903.*

The path then runs northeast, following the hot overflow channel (Hot Water Creek) draining Frying Pan Lake and then climbs to a view over Inferno Crater Lake, one of the largest hot springs in New Zealand. This sub-circular crater is excavated in the side of a small rhyolitic dome known as Mount Haszard, named after members of the Haszard Family who died during the 1886 eruption. The lake shows a distinctive cyclic behaviour, rising and falling 9m or so over a period of around 6 weeks. The lake is hottest when rising and overflowing (>75$^{o}$C), reducing in temperature by at least half when at minimum levels. This area between Frying Pan and Inferno lakes is the hottest, most active part of the geothermal system today.

*Boiling spring producing a mini-geyser close to Inferno Crater in the hot centre of the Waimangu Volcanic Valley.*

From here there is a choice of route, either following the low ground along the hydrothermally active valley floor, or taking the longer and more strenuous route over Mount Haszard, following a series of craters produced by the 1886 eruption and with views out towards Mount Tarawera.

The widened valley path continues northeast, following the Haumi stream and passing more examples of hot springs, steam vents, silica terraces and, finally, views over Lake Rotomahana and Mount Tarawera. The lake is a consequence of the flooding of several 1886 explosion craters and is still geothermally active, with geyser eruptions and steam explosions occurring into the 1950´s.

**Wai-o-tapu.** Drive south to turn left into the H5 and head south a short distance to the Wai-o-tapu Tavern junction for Waikite Valley Road (right) and Wai-o-tapu (left). Turn left into the Wai-o-tapu Loop Road and after 400m left again to park at an excellent (and free) example of a boiling mud pool.

*Boiling mud pool on the Wai-o-tapu Loop Road, the site of a former 3-metre-high mud volcano called Te Huinga that was washed away by heavy rain in 1925. In these geothermal mud pools hot acidic volcanic gases attack the underlying rocks to produce clays that mix with hot water and steam to form a boiling slurry.*

The mud pools lie within one of the largest geothermal areas in New Zealand. Driving 1.5km south from the mud pools leads past the turnoff (left) to the Lady Knox geyser, artificially induced at 10.15 every morning, to the large carpark at the Wai-o-Tapu “geothermal wonderland” tourist attraction. This scenically attractive site is best known for its colourful pools, springs and sinters and was once much more active than at present. It is of additional geological interest because of the chemistry of its waters, some of which can be unusually enriched in unusual metals such as mercury, gold and antimony. The series of collapse and explosion pits and craters give some idea of the kind of hot plumbing systems that lie beneath these geothermal areas. However, the site is expensive to visit and can be overrun with visitors (especially in the morning after the Lady Knox geyser has erupted). We arrived at one such congested moment and decided not to visit.

Return to the Wai-o-tapu Tavern crossroads and drive 6km west along the Waikite Valley Road, initially gently climbing before descending more steeply over the Paeroa Fault escarpment to reach the Waikite Valley Thermal Pools, an excellent stop for geothermal relaxation. Then continue driving 3km west on the Waikite Valley Road to turn left into the Te Kopia Raod which you follow for 9km to reach the inconspicuous Te Kopia Scenic Reserve (park on the left). This attractively remote and little-visited site offers a short boardwalk to several geothermal features and a splendid view of the Paeroa F ault scarp.

*The abrupt escarpment marking the trace of the Paeroa fault at the Te Kopia Scenic Reserve, 14km northeast from the Orakei Korako geothermal field. View looking northeast: the fault dips around 45$^{o}$ to the northwest (left) and has dropped down the Te Weta fault block (left: low ground) against the Paeroa fault block (right: high ground). Violent eruptions of rhyolitic pyroclastic rocks occurred here around 340 thousand years ago, following the faultline to create a linear vent zone very different from the curved shapes associated with most major eruptive centres in the Taupo Volcanic Zone.*

Return to Rotorua (40km) for an overnight stay or continue north for 86km to the coastal town of Whakatane in preparation for a day boat trip to White Island volcano.

## Day 12: White Island (Whakaari).

A visit to White island is something of an adventure and is not cheap, but it is an experience of a lifetime. We did it in January 1998 (see above) but decided it was a one-off experience and did not repeat in 2018 when visiting NZ to prepare this guide. Boats leave in the morning if weather and volcanic activity allow. The trip into the Bay of Plenty involves a journey that crosses 49km of ocean to arrive for a 1-1.5hour tour of the active volcano before the return journey with packed lunch and possibility of marine life viewing. To learn more, visit the website:

https://movin2newzealand.wordpress.com/2015/12/29/a-journey-to-an-active-andesite-stratovolcano-white-island/

The geotraverse described in this Holiday Geology Guide has taken us through the Taupo Volcanic Zone (TVZ) from the andesitic volcanoes of Ruapehu, Ngauruhoe and Tongariro in the southwest through the rhyolitic eruptive centres clustered between Taupo and Rotorua in the central area. Now we have moved to the northeastern part of the TVZ where andesitic volcanism once again becomes dominant over rhyolite, and volcanoes begin to look like volcanoes again, instead of giant depressions in a countryside smothered by pyroclastic rocks.

The total distance from Ruapehu to White Island is around 240km. Whereas Ruapehu stands proud as a classic stratovolcano rising nearly 2800m above sea level, White Island volcano only manages a height of 321m and an exposed width of just 2km. Below water however is hidden a huge stratovolcano measuring 16 by 18 kilometres in size and currently the most active volcano in New Zealand. Most of the recent activity is the result of magma-water interaction (phreatomagmatic) and strombolian eruptions. The volcano comprises cones and craters in various stages of erosion and build-up, with present activity focused on "Central Crater", the floor of which lies just 30m above sea level and is mostly covered by a debris avalanche that killed 11 sulphur miners in 1914. This crater floor displays active fumeroles and hot springs emerging from the geothermal system beneath.

Lavas erupted from the White Island volcano vary in their silica ($SiO_2$) content, typically from 55-64%, which means they range from basaltic andesite (53-57%$SiO_2$) through andesite (57-63% $SiO_2$) to dacite (63-69% $SiO_2$). These lavas typically contain many crystals ("phenocrysts") of pale feldspar and dark pyroxene brought up from depth during the rise of the magma towards the surface. A detailed consideration of how these lavas originate, mix and move upwards to the volcanic vent is provided in a paper published by Cole et al., in 2000:

https://academic.oup.com/petrology/article/41/6/867/1587273

Essentially the model involves fluids rising from the dehydrating subducting plate and causing melting in the mantle above. The melts rise to magma chambers lying 2-7km beneath White Island where they undergo various mixing and separation processes that ultimately determine their silica content upon eruption.

From White Island the Circum-Pacific Ocean "Ring of Fire" stretches for 40,000km through Indonesia, Japan and down the west coast of the Americas. This zone of oceanic plate subduction produces most of the volcanic eruptions and earthquakes on the planet. There are many countries around the Pacific where the geological phenomena resulting from plate subduction can be viewed, but none of them are in a setting as relaxed and accessible as New Zealand. We hope you have enjoyed the show.



*This Holiday Geology Guide is dedicated to my sister Jo. Her enthusiasm for life is an example to us all.*

# Background to Holiday Geology Guides

The author and geologist Wes Gibbons has always had an interest in writing short geoguides aimed at inquisitive tourists, offering them the opportunity to learn about the landscapes and rocks of scenically attractive places. His argument is that there is so much more to know about rocks and Earth history than the superficial descriptions offered by tourist guidebooks, which rarely even scratch the surface of Deep Time.

His first attempt in the geoguide direction produced *The Rocks of Sark* (1975), published jointly with John Renouf of Manche Technical Supplies in Jersey, a venture that taught a youthful Wes to always be the one responsible for the final proof reading. In 1976 Wes moved from Sark to begin a PhD supervised by Greg Power (Portsmouth University) and Tony Reedman (British Geological Survey). Living in a former Post Office in the village of Greatham on the Hampshire-West Sussex border, Wes decided to pass his spare time preparing a guide to the geology of the Weald in southeast England. He sold the idea to the publishers Allen and Unwin who commissioned other authors to develop a mini-series: *The Weald* (1981), *Snowdonia* (1981), *Lake District* (1982), and *Peak District* (1982).

His next field-based guidebook surfaced in 1985, fruit of several years research work in Corsica (*Corsican Geology: a field guidebook* by Gibbons and Horák). Two years later Wes launched the Holiday Geology series, using a simple, inexpensive format later described as "a single A3 laminated sheet …. folded into three and (with).. six portrait panels … filled with a lively mix of colour photos, maps, sections and text" (review by Nigel Woodcock in Geological Magazine, 2000). The first two Holiday Geology guides were *Scenery and Geology around Beer and Seaton* (Gibbons 1987) and *Rocks and Fossils around Lyme Regis* (Gibbons 1988). The Holiday Geology concept attracted the attention of the British Geological Survey who went on to expand the series to over 20 titles.

Following his retirement in 2004 to live in Barcelona with Teresa Moreno, Wes maintained his interest in publishing field guides by writing the text to *Field Excursion from Central Chile to the Atacama Desert* (Gibbons and Moreno 2007), *The Geology of Barcelona: an Urban Excursion Guide* (Gibbons and Moreno 2012), and *Field Geotraverse, Geoparks and Geomuseums* (in central and southwest Japan: Gibbons, Moreno and Kojima 2016). His most recent publishing project, the most ambitious so far aimed at a general readership, has produced the book *Barcelona Time Traveller: Twelve Tales* (2016, Spanish translation 2017: Bimón Press Barcelona) and the resurgence of the Holiday Geology concept, although this time in virtual format linked to the *Barcelona Time Traveller* webpage.



Wes Gibbons, May 2018

http://barcelonatimetraveller.com/