GEOLOGY AND GEOHERITAGE OF MOTU KAIKOURA, AOTEA/GREAT BARRIER

Mitre Peak, Motu Kaikoura, is an exfoliation dome composed of stratified volcanic breccias.

Bruce W Hayward
March 2023

Unpublished Report BWH 220/23

SUMMARY

Motu Kaikoura is an uplifted and eastward tilted (by 10-20°) remnant of the middle Miocene West Great Barrier andesite stratovolcano that erupted between 15 and 12 million years ago as part of the Northland-Coromandel Volcanic Arc. The majority of the volcanic rocks consist of thick massive beds of volcanic breccias and stratified volcanic breccias. The former were probably deposited by debris flows (dryer lahars) coming down the steeper sides of the volcano and the latter by more water-rich (40-90% water) lahars (hyperconcentrated flows), both of which were probably generated by rainstorms and/or earthquakes between eruptions. These breccias are interbedded with andesite lava flows, mostly 2-20 m thick and some contained within small paleovalleys. A few thin flows interfinger with red-oxidised breccias that were created by fragmentation of the flows as they were flowing along and cooling. A 200 m-wide andesite intrusion with beautifully-developed columnar jointing intrudes the sequence and forms the West Point of the island.

Since eruption ceased, the volcano has been substantially eroded away and more recently (last few million years) the west side of Great Barrier (including Motu Kaikoura) has been uplifted several hundred metres along the east side of the Hauraki Fault and gently tilted down to the east. Continued erosion, particularly during the lower sea levels of the long colder periods of the Ice Ages (last 2.6 myrs), developed the anastomosing stream pattern around and to the east of Motu Kaikoura. Rising sea level after the peak of the Last Ice Age gradually flooded the Fitzroy River and its lower tributaries between 10,500 and 7,500 yrs ago. The drowned river valley forms Abercrombie Passage and Port Fitzroy, but further sea level rise overtopped a low saddle forming Man of War Passage. Coastal erosion processes have formed deep guts, sea caves and a sea arch around the more exposed parts of the island with excellent examples of high tide platforms, high tide notches and cavernous weathering also present.

This report identifies one landform (Man of War Passage) and one geological feature (West Point intrusion) as geoheritage features of regional significance and lists and maps a further 14 landform features and 6 geological features of local geoheritage status.

INTRODUCTION

In 2022, I was asked by Mike Lee, on behalf of the Trustees of Motu Kaikoura, to undertake a survey of the geology and landforms of the island and prepare a schedule of Geoheritage features. I agreed to do this at my own cost so long as the trust could provide me with accommodation at the lodge and boat transport around the whole island for me to survey the rocks in the sea cliffs.

I stayed at the lodge, February 27th - March 2nd, courtesy of the rangers Clint and Jacinda Stannard and their family. On the morning of Feb 28th Clint took me slowly on a circumnavigation of the whole island (clockwise) in a small motorized boat. During this 3.5 hr trip I made measurements on the dip of the strata, faults and joints and made notes on the geology and any unusual or outstanding landform features. I later walked several of the tracks to and around the top of the island to make notes on any useful rock exposures or interesting landforms.

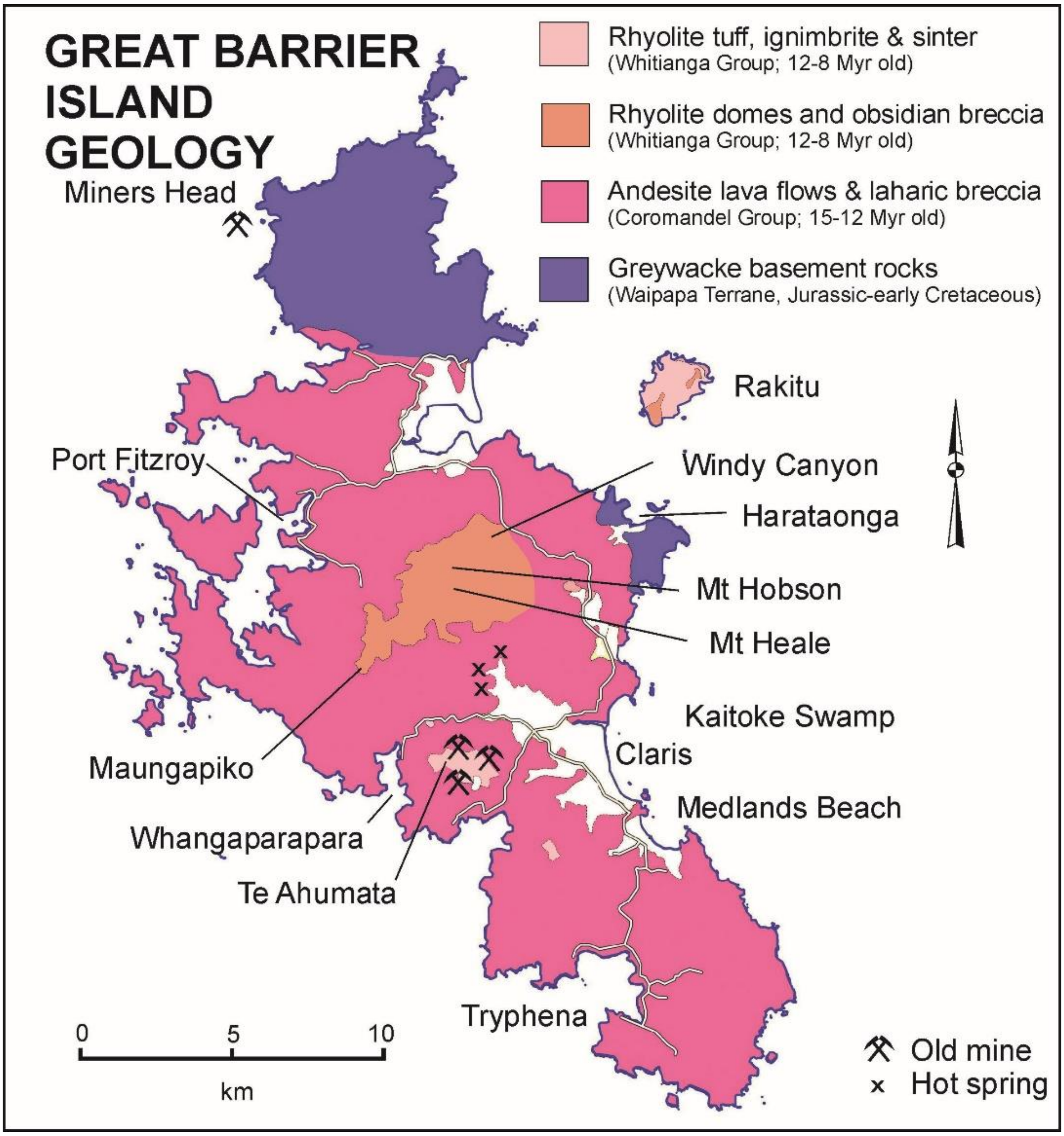
GEOLOGY OF SURROUNDING AREA

Great Barrier and surrounding islands are geologically an extension of Coromandel Peninsula (Hayward, 2017). They consist of three main groups of rocks:

a. Basement greywackes (Waipapa Terrane) of Triassic-early Cretaceous age (250-110 myrs). These occur in two areas on Great Barrier – the northern block (Moore and Kenny, 1985) and the Harataonga area. Both areas are presumably uplifted fault blocks that have all the younger volcanic rocks eroded off them.

b. Andesite volcanic, volcaniclastic and intrusive rocks (Coromandel Group) form the bulk of Great Barrier (e.g., Hayter, 1954; Hayward, 1973, Moore, 2001). They were erupted by andesite stratovolcanoes – the one in the north during the early Miocene period (18-17 myrs ago) (e.g., Hayward, 2017) and the remainder in the mid Miocene period (15-12 myrs ago).

c. Rhyolite volcanic domes, ignimbrites and ash (Whitianga Group) occur in three main areas – Rakitu Island (Hayward and Moore, 1985), Mt Hobson area, and Te Ahumata (Ramsay, 1971; Ramsay and Kobe, 1974). These were erupted and deposited during the late Miocene (12-8 myrs ago).



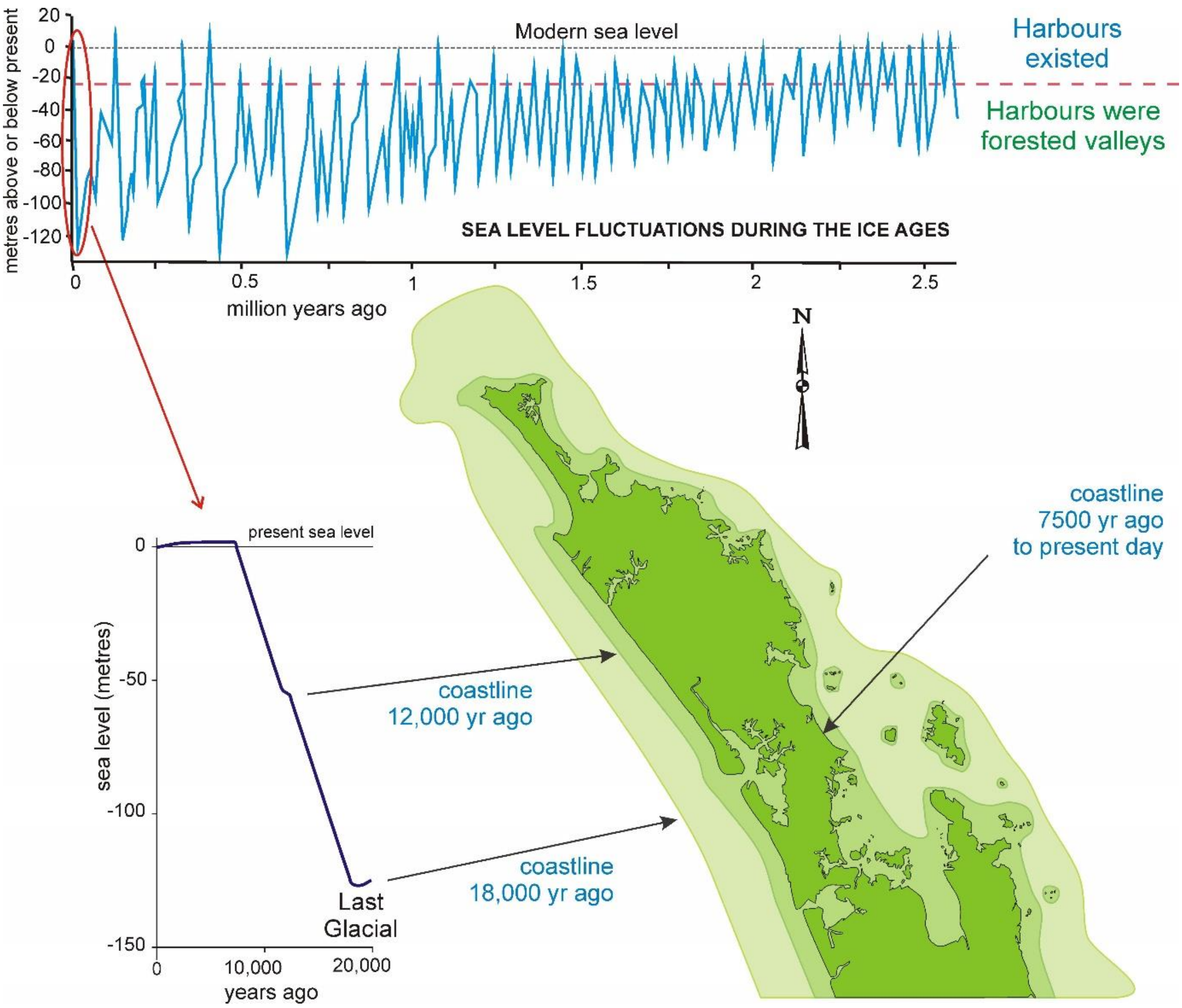
Generalised geology of Aotea/Great Barrier Island (from Hayward, 2017).

The whole of Port Fitzroy coastline and that of the islands around its mouth is composed of rocks of the middle group – andesite breccias, flows and intrusions (Coromandel Group). The breccia and lava flow sequence is bedded and dips in a general easterly direction at 10-30˚. Moore (2001) postulated that these dips were essentially the original east-dipping slopes of a volcano centred out to the west – a West Great Barrier Volcano. Another possible explanation, that needs more testing is that most of the island dips east, like much of Coromandel Peninsula, and that the whole area was uplifted more on the Hauraki Fault to the west of the island and tilted down to the east.

LANDFORMS OF MOTU KAIKOURA

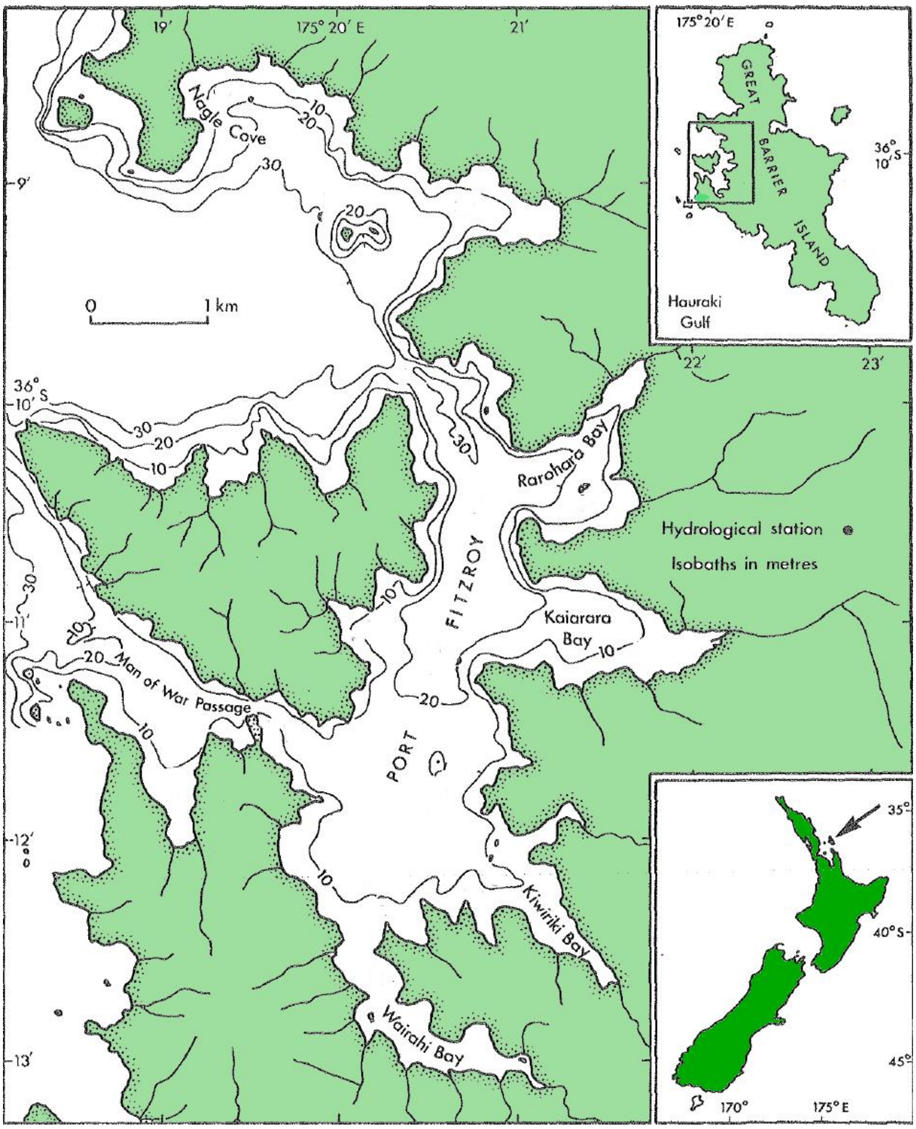
Motu Kaikoura is the largest island off the coast of Aotea/Great Barrier sitting across the entrance to Port Fitzroy. The island is 185 m high, 4 km east-west and 3 km north-south with a triangular outline on the map. It owes its existence, as does Coromandel Peninsula and Great Barrier itself, to a period of uplift over the last 3-5 myrs on the east side of the Hauraki Fault, which runs NNW along the east side of the Hauraki Plains, Firth of Thames and Hauraki Gulf. There was also downthrow on the west side of the fault over the last 3 myrs creating the Hauraki Graben.

Following and during this period of uplift, weathering and erosion of the rocks started developing the valley and ridge systems we have today. The stream erosion was amplified during the Ice Ages of the last 2.6 myrs, when sea level was lower than present for 60-90% of the time, during glacial periods. In the last 1 myrs there have been ten main glacial periods with sea level as 100-130 m below present during the peak colds. The last glacial peak was just 18-20,000 yrs ago. During the short, warm interglacial periods, between the cold glacials, sea level rose to the present level or slightly higher.



Top: Sea level cycles of the Ice Ages (last 2.6 myrs) showing the times when sea level was higher than 20 m below present and Port Fitzroy would have existed as a sheltered harbour. Bottom: The changing land area of northern New Zealand as sea level rose from its peak low 18-20,000 yrs ago to present level 7,500 yrs ago. Note that Great Barrier would have been joined to the mainland up until about 13,000 yrs ago. (From Hayward, 2017)

During the periods of lower sea level, the streams eroded down deeper and flowed at grade to the lower tide level. It was at these times that the stream valleys were eroded that now form Port Fitzroy and its various arms. During the last 1 myrs there have been ten Port Fitzroys each created by drowning of the Fitzroy valley network by sea level rise in the warm interglacials. The most recent drowning occurred after the peak of the Last Ice Age, 18,000 yrs ago. As the polar ice cap on land in the northern hemisphere melted with climate warming, sea level rose progressively, separating Great Barrier from the rest of the North Island by about 12,000 yrs ago. Between 10,500 and 7500 yrs ago the sea gradually rose and drowned the lower parts of the Fitzroy stream network which drained out through Port Abercrombie valley. The shallowest part of Abercrombie Passage today is about 30 m deep. The sea would have advanced up through there before later overtopping the low saddle that is now Man of War Passage. The shallowest part of Man of War Passage today is about 13 m below low tide indicating that it started to be submerged as sea level rose about 9000 yrs ago.



Bathymetry of Port Fitzroy showing how the ancient Fitzroy River would have flowed northwards out through Abercrombie Passage and Port Abercrombie when sea level was lower during cold glacial periods of the Ice Ages. Modified from Hickman (1979).

Abercrombie Passage was a deep gorge on the Fitzroy River during the Last Ice Age and was progressively drowned by rising sea level between 10,500 and 7,500 years ago.

During the Last Ice Age, between the present and the Last Interglacial (100-130,000 yrs ago) high sea levels, Port Fitzroy was a forested river valley network. Most of the coast of Motu Kaikoura had inland bluffs with weathered rock and scree forming fans around their base. When sea level rose, the soft scree and weathered rock was quickly eroded away by the waves and the sea cliffs exhumed. They continue to actively erode today. At sea level, the zone of most rapid erosion today is in the base of the cliffs, just above high tide level, where alternating wetting and drying by sea splash and sun during the tidal cycles gradually eats away at the rock creating high tide platforms, notches and cliff overhangs.

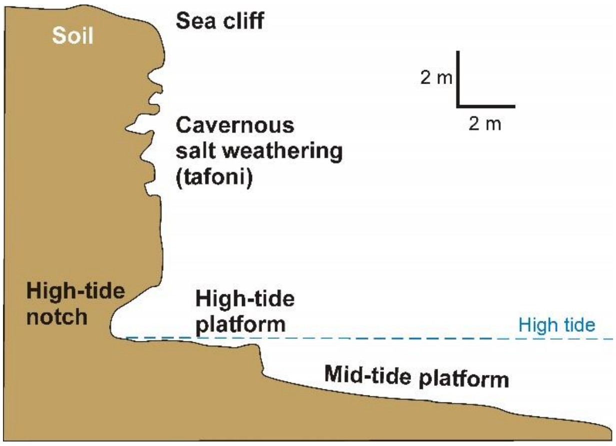


Diagram illustration erosion along the base of the sea cliffs that has formed a variety of coastal landforms, many seen on Motu Kaikoura. (From Hayward, 2017)

The cliffs are intersected by sets of near vertical fractures or joints and sometimes lower angle ones as well. The steep cliff faces, especially those that have been undercut, periodically fail along one of these fractures and large blocks slide and fall down. In a few places there are scallops eroding out of the cliffs higher up, sometimes with a smaller honeycomb pattern (tafoni). This cavernous weathering often occurs in slightly weaker rocks and is caused by the growth of salt crystals between grains in the rock which pushes them apart and erodes them out. The salt crystals grow as salt spray on the cliff dries out and evaporates.

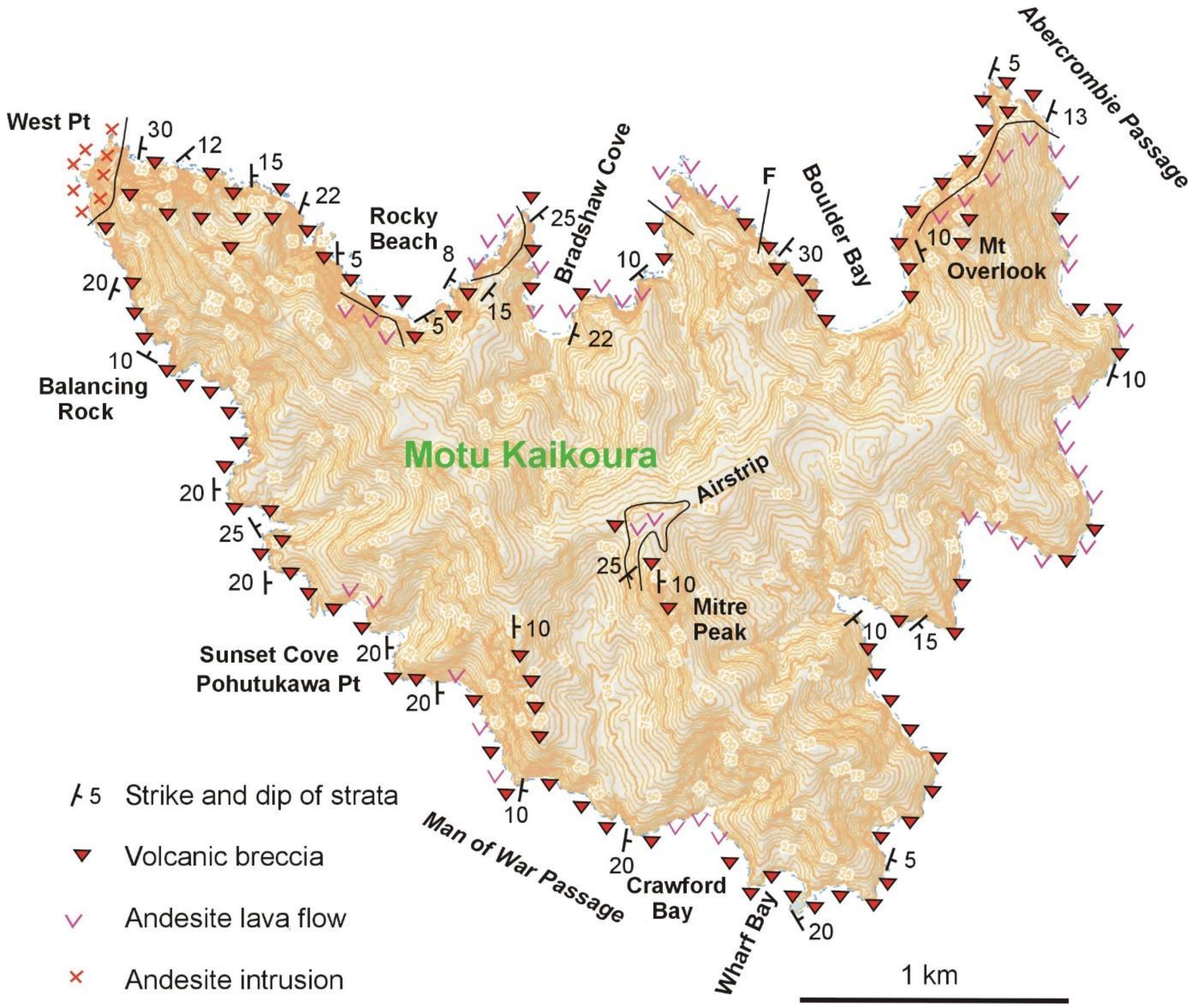
Wave erosion is often concentrated along the fractures or sheared fault zones and in places has created sea caves in the cliffs, or a combination of rainwater runoff from the top and marine erosion at the base has carved out deep chasms or guts that extend most of the way up the cliffs. The four points along the northern side of Motu Kaikoura each is tipped by andesite lava, which is a harder rock and generally more erosion-resistant than the volcanic breccias, although the cooling joints in the lava often assist erosion and negate the hardness.

The three major points on the north side of Motu Kaikoura all have more erosion-resistant andesite lava forming their ends at and above sea level. View from Mt Overlook. Also visible in the distance are the north sides of Nelson and Motuhaku islands.

Not only are most of the steep sea cliff faces produced by large blocks or slabs of rock breaking away along vertical fracture planes of weakness, but a similar process occurs on the rocky inland peaks. Here the fractures are quite widely spaced and so the rocks in between the fractures become rounded knolls with onion-skin-like exfoliation of the outer parts of the rock as they weather.

In the landform schedule, I have chosen the best examples on Motu Kaikoura of the results of many of these land-forming and modifying processes. The drowned saddle of Man of War Passage is considered to be of regional importance, of lower value than nationally important similar features at the mouths of Whangape and Whangaroa Harbours in Northland, on Rakaunui Inlet, Kawhia Harbour and Tory Strait, Marlborough Sounds. All the other listed landforms are considered to be of local significance and do not, in my opinion, reach the criteria for regional significance.

GEOLOGY OF MOTU KAIKOURA



Simplified geology map of Motu Kaikoura showing the distribution of lava flows, volcanic breccia and the West Pt intrusion, and the attitude of the bedding in the stratified breccias. Data is mostly based on my field work by boat on the morning of Feb 28 2023 with Clint Stannard steering amnd pointing out features.

Motu Kaikoura is made of rocks of the Coromandel Group, all of which erupted in the middle Miocene between 15 and 12 million years ago. On Motu Kaikoura these comprise andesitic tuff breccias (volcanic breccias), andesite lava flows and an andesite intrusion.

West Point intrusion

The west point of Motu Kaikoura is composed of a 200 m wide, 80-m-high body of andesite lava cut by numerous, spectacular, mostly columnar cooling joints. The intrusive contact with the volcanic breccias is well exposed in the cliffs on the northeastern side where the contact strikes near north-south and is subvertical. The stratified breccia has been dragged up to a tilt at 30° away from this contact. On the southern side of the intrusion, the contact is less clear and partly obscured by scree and vegetation but appears to slope at 40° to the southeast.

Within the intrusion there are a number of zones parallel to the intrusive contacts, each comprised of parallel sets of subhorizontal to gently dipping columnar joints. These zones are interpreted as multiple periods of intrusion and cooling within and along the edge of the intrusion. One of the contacts between two of these zones on the southern side has a highly unusual texture of subvertical ridges and gauges, that may have been produced as semi-solid lava was intruded alongside earlier solidified andesite.

There is no sign that this intrusion extends far in a northwest direction as it is not present on nearby Nelson Island. The West Point intrusion is the only intrusion recognised on Motu Kaikoura and indicates that this was close to one of the conduits up which magma moved to erupt and form the volcano. There is another possible andesite intrusion forming the southeast portion of nearby Motuhaku Island. It contains a 5 m-wide raft of highly folded and cooked (cemented) thin-bedded mudstone that must have been ripped from the side of the conduit passing through soft, relatively unconsolidated sediment and carried along within the "intrusion".

West Point is composed of the partially eroded remnants of an andesite intrusion which was a small shallow magma chamber at one time during the eruption of West Great Barrier Stratovolcano.

Lava flows

These comprise about 20% of the rocks on the island and can be seen in the sea cliffs and shore platforms in various places right around the island. These rocks are medium grey when fresh but weather to shades of red and purple. Although no geochemical analyses have been undertaken on Motu Kaikoura samples, their appearance is that of andesite. Andesite is usually erupted from subduction-related volcanoes in a volcanic arc that parallels the collisional boundary between tectonic plates. In this case the Great Barrier stratovolcano erupted as part of the eastern belt of the Northland-Coromandel Volcanic Arc above the zone of subduction of the edge of the Pacific Plate beneath the Australian Plate.

Many of the lava flows are 3-20 m thick and rather massive, often with steep columnar cooling joints oriented perpendicular to the flow's top and bottom. A few of these flows have zones where close-spaced (5-20 cm thick) planar cooling joints are present. All flows appear to be conformable within the sequence of volcanic breccias, although in several places along the northern coast of the island their shape suggests they flowed down paleovalleys on the slopes of the volcano and cooled and solidified as thick lenses within these valleys. In many places the exact geometry of the flows cannot be determined by the limited amount of exposure, especially on the more sheltered eastern shore of the island.

In a few places on the northern side of the island (especially in the cliffs on the eastern side of Bradshaw Cove) there are thin tongues and lenses of lava flow within red-oxidised angular breccias. The clasts in these breccias are all of the one composition and texture and the same as the interlensing flows and are interpreted to be autobreccias formed by the lava flows shattering and breaking up as they flowed along and solidified.

Thin, grey lava flows interfingering with red-oxidised autobreccias that were erupted very close to this location and emplaced while hot. The overlying cream- and buff-coloured volcanic breccias were deposited by cold flows of debris coming down the volcano's slopes.

Volcanic breccias

Approximately 80% of the rocks forming Motu Kaikoura (and much of nearby Great Barrier Island) are volcanic breccias of andesitic composition. Most of these breccias contain angular to subangular cobbles and pebbles of a limited variety of colours and textures "floating" within a matrix of sand-sized ash. Boulder-sized clasts are also sometimes present. Technically most units could be called tuff breccias. Some of the beds have a lighter-coloured matrix and contain pebbles of cream devitrified pumice (erupted andesite froth). In several places there is a distinct thin bed (0.2-0.5 m thick) of dark coloured tuff lacking larger clasts that was probably deposited as an airfall deposit of volcanic ash.

There are two kinds of bedding or stratification within the volcanic breccias, each of about equal volume. One kind consists of thick beds of massive breccia with no obvious stratification or sorting, with clasts of all sizes distributed randomly throughout. Several of these thick beds contain subrounded rafts of andesite lava flow that have been picked up by the passing lahar and rafted along within it. The second kind of unit is well stratified breccia with distinct bedding visible within it, usually expressed as layers of different sized clasts that were deposited sequentially on the volcano's slopes by the passing lahars.

Well-bedded volcanic breccia forming the lower half of the cliff at the east end of Rocky Beach. Several dark beds may be airfall volcanic ash deposits. The upper half of the cliff is composed of a thick bed of massive breccia, lacking bedding.

Volcanic breccia containing a 4 m raft of andesite lava that has been carried down in the cold debris flow.

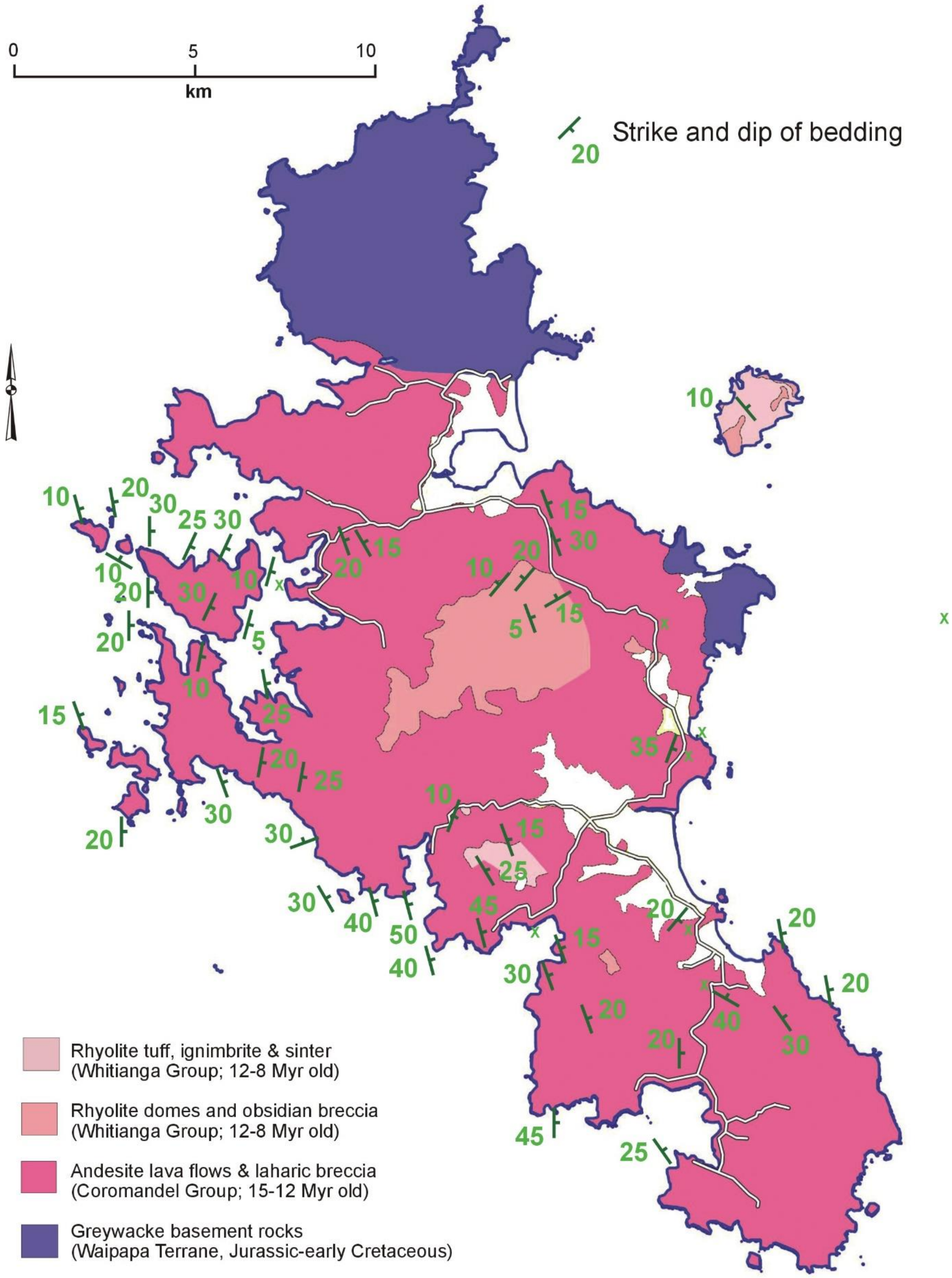
The term lahar is used here for any mass flow, other than normal stream flow (which would usually result in more rounded clasts) on the slopes of a volcano. Other definitions include: “A lahar is a violent type of mudflow or debris flow composed of a slurry of pyroclastic material, rocky debris and water” (Wikipedia). Both kinds of volcanic breccia described above can be deposited by a passing lahar. These lahars may occur during eruptions or at any other time by the collapse of unstable lava, breccia and ash on the volcano’s steeper slopes. It often involves water (rainfall during storms, crater lake break out) but not always. In technical terms the more stratified deposits are often deposited from hyperconcentrated flows (containing 5-60% sediment mixed with water) whereas the more massive deposits were more likely deposited by debris flows or debris avalanches (less water).

Most of these lahars would have originated on the steeper slopes (10-25°) of the stratovolcano cone and would have deposited the volcanic breccias on gentler slopes further down, on either the lower slopes of the cone or on the gently sloping ring plain (both sloping at 0-10°).

Structure

The strike and dip (attitude) of the bedding within the breccias (and occasionally at the base or top of the flows) is shown on the geological map. With one exception (within an inferred paleovalley) all strata slope in a general easterly direction (mostly with a strike of between 160 and 040° and a dip of 5-30° to the northeast, east or southeast. As noted above, dips of up to 10° are possibly from the original slope on which the breccias were deposited but dips of >15° are likely to include a component of later tectonic tilting. There are no obviously water-laid sediments on Motu Kaikoura, which would have originally been deposited horizontally. Thus, we cannot be sure how much and what direction a component of later tectonic tilting might have been. It seems probable that the original volcano slope was to the east and the main cone was located out to the west, as inferred by Moore (2001). If the original slopes were in the range 0-10° then the rocks of Motu Kaikoura have probably been uplifted and tilted an average 10-15° east in the western and central parts of the island and maybe none at all in the east part.

The map below shows new and archival measurements of dip on the Coromandel Group andesitic breccias and younger rhyolitic sediments of the Whitianga Group on Great Barrier. Two measurements are on water-laid lake/pond sediments and these dip 30 east in Medlands Stream and 10° east in a Whangaparapara Rd cutting. These clearly record later post-depositional tectonic tilting of a similar amount and direction to that inferred on Motu Kaikoura. With a notable exception around Windy Canyon, the majority of the dips on Great Barrier Island are 10-30° east in the northern and central parts of Great Barrier and 20-40° in the southern part, and I infer these are clear proof of significant uplift of the western side of Great Barrier, along the Hauraki Fault, and tilting down to the east. The northern Great Barrier block has obviously been uplifted even more and the younger rocks stripped off it to expose the basement rocks. The outcrop of basement greywacke basement around Harataonga, in the east, is contrary to the uplift in the west with down tilt to the east, and is best explained as a separate uplifted block.



Structural geology map of Great Barrier Island showing strike and dip on bedded volcanic sedimentary rocks. From observations of the author (2023), Hayward (1973), Ramsay and Kobe (1974), Hayward and Moore (1985) and Edbrooke (2001).

ACKNOWLEDGEMENTS

I am grateful to Mike lee and the Trustees of Motu Kaikoura for the invitation to undertake this study. I am particularly grateful to the two rangers Clint and Jacinda Stannard and their family for their hospitality and help while on Motu Kaikoura and especially for transporting me to and from and around the island to study the rocks and coastal landforms.

REFERENCES

EDBROOKE, S. W., 2001. *Geology of the Auckland Area. 1: 250 000 geological map 3.,* Institute of Geological and Nuclear Sciences.

HAYTER, I. B. 1954. *The geology of the southern, and part of the central portion of Great Barrier Island.* Unpublished MSc thesis, University of Auckland.

HAYWARD, B. W. 1973. A note on the geology of the coastline west of Whangaparapara, Great Barrier Island. *Tane*, 19:175-178.

HAYWARD, B. W. 2017. Out of the Ocean into the Fire. History in the rocks, fossils and landforms of Auckland, Northland and Coromandel. *Geoscience Society of New Zealand Miscellaneous Publication*, 146, 336 p.

HAYWARD, B. W. and MOORE, P. R. 1985. Geology and volcanic history of Arid Island (Rakitu), north-eastern New Zealand. *Journal of the Royal Society of New Zealand,* 15:169-185.

HICKMAN, R.W. 1979.Seasonal hydrology of Port Fitzroy, Great Barrier Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 13: 231-240.

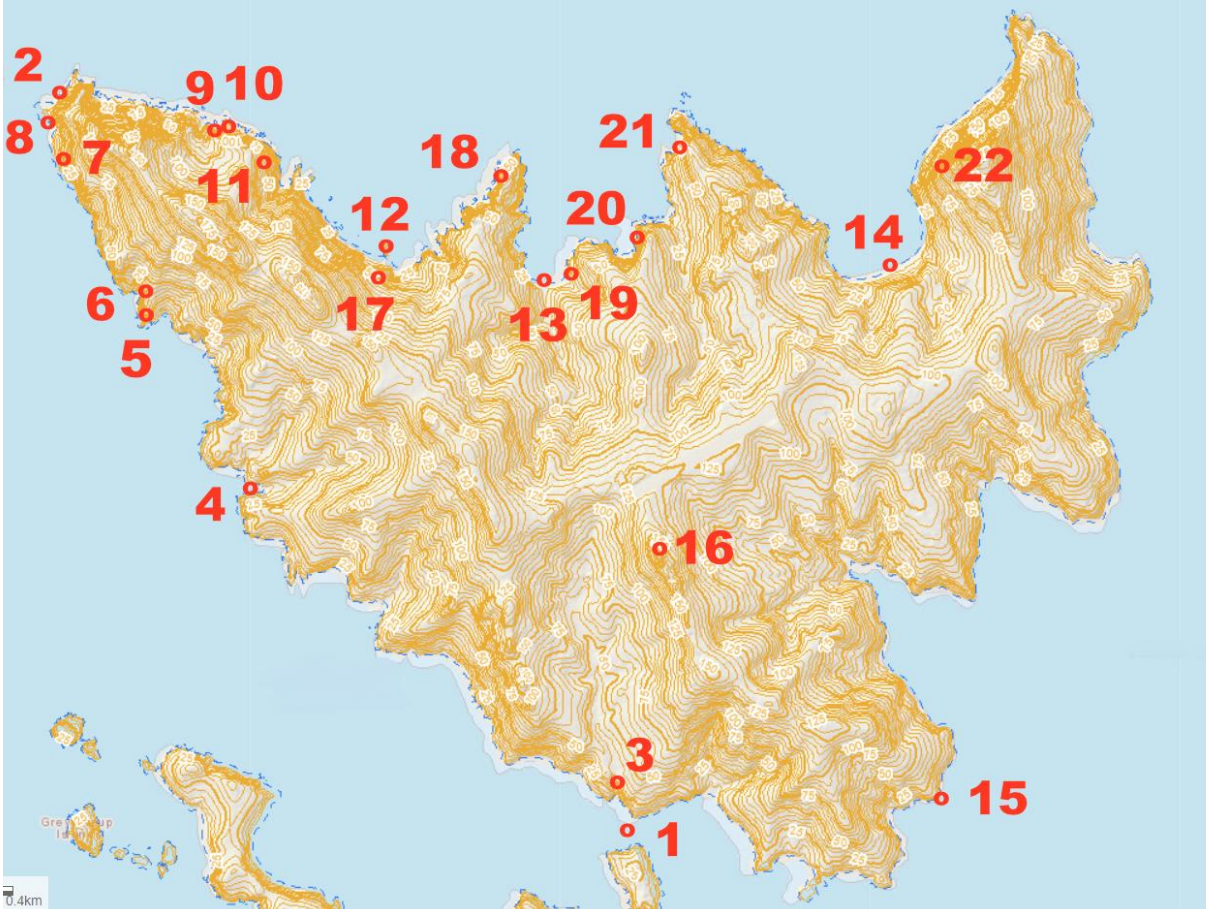
MOORE, P. R. 2001. Geology in Armitage, D. "Great Barrier Island.:40-51.

MOORE, P. R. and KENNY, J. A. 1985. Geology of northeastern Great Barrier Island (Needles Point to Rangiwhakaea Bay), New Zealand. *Journal of the Royal Society of New Zealand,* 15:235-250.

RAMSAY, W. R. H. 1971. *Geology of the south-central Great Barrier Island.* Unpublished MSc thesis, University of Auckland.

RAMSAY, W. R. H. and KOBE, H. W. 1974. Great Barrier Island silver-gold deposits, Hauraki Province, New Zealand. *Mineralium Deposita,* 9: 143-153.

Motu Kaikoura schedule of geoheritage features and sites



Location of identified geoheritage sites on Motu Kaikoura Island.

International and national significance – nil

Regional significance

1. **Man of War Passage** – drowned saddle. Most recently this would have been a low saddle between the Fitzroy River valley and the headwaters of a stream draining west along the south side of Motu Kaikoura. The last time it was a saddle was during the Last Ice Age period up until about 10,000 yrs ago, after which it was progressively flooded by rising sea level. [36°11'16.8"S 175°19'31.6"E]


Man of War Passage from the west

Man of War Passage from the east.

2. West Point – **large intrusion and columnar cooling joints**, reminiscent of Giant's Causeway. Columns are perpendicular to steep intrusive contact with breccias, which is best seen on the northern boundary in the cliff. Unusual face within the intrusion with subvertical and close-spaced gauges over it. These are of unknown origin but probably relate to intrusive movement of part of the body when the magma was still plastic and not quite solid. Only definite intrusion on Motu Kaikoura. [36°10'00.1"S 175°18'12.7"E]

View from north of West Point intrusion.


Eastern intrusive contact of West Point intrusion with horizontal columnar joints.


Southwest intrusive contact (upper right, 30° slope) of West Point intrusion.

Unusual vertical ropey texture, or gauges, within West Point intrusion.

Local significance

<u>Landforms</u>

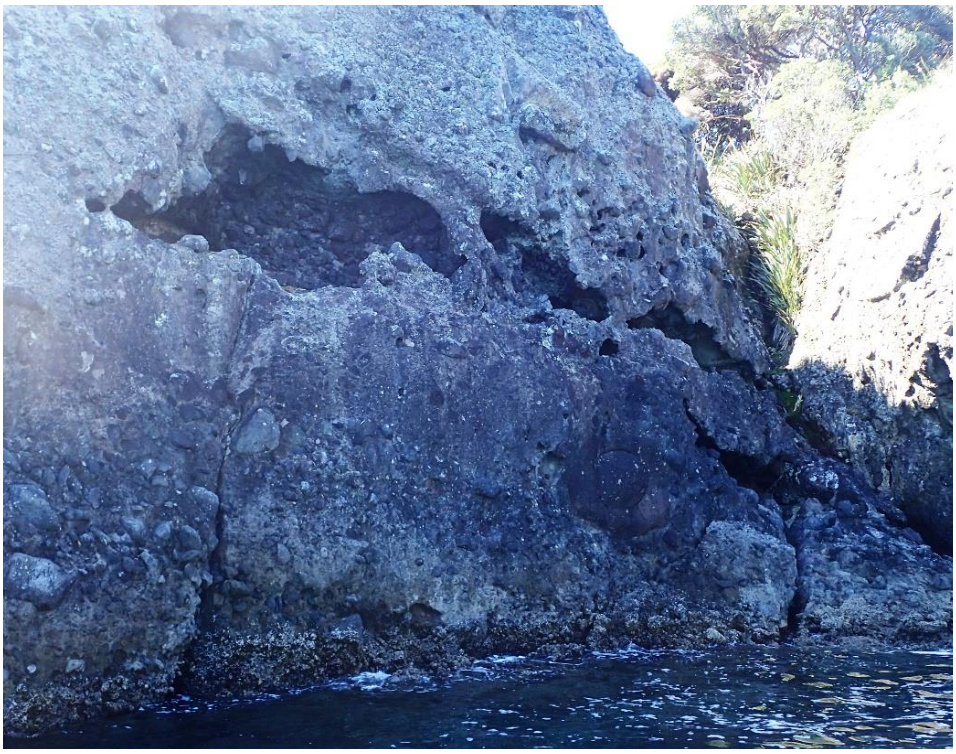
3. **Pond Stream waterfall** – an unusual tilted waterfall flowing down a fracture, which strikes 170˚ dips 50˚W, cuts through stratified tuff breccia. [36°11'13.1"S 175°19'28.0"E]

Pond Stream waterfall follows a sloping fracture down to the sea.

4. **Sunset Cove** high tide notch erosion and overhang in tuff breccia on the east side of the cove and deep **cavernous weathering** along softer bands within the breccia on the west side. [36°10'41.8"S 175°18'39.5"E]

High tide notch, cavernous weathering and overhang, east side Sunset Cove.

High tide notch, cavernous weathering and overhang, east side Sunset Cove.



Cavernous weathering, west side Sunset Cove.

5. **Balancing Rock**. 3 m diameter loose boulder of tuff breccia balancing at top of high vertical sea cliff. [36°10'24.5"S 175°18'24.2"E]

Balancing Rock from the east.

Balancing Rock.

Balancing Rock from the west.

6. Deeply **eroded gut** at sea level, extending vertically most of the way up through the cliffs. Erosion has occurred along a weak joint plane [36°10'20.6"S 175°18'23.3"E]


Deep incised gut along weak joint.

7. Forested **rock fall area**. Best and largest example of an area of large boulders that have fallen from the bluffs above and now form a sloping area of vegetated large and small rocks (up to 10 m diameter) that extends well up the cliffs [36°10'07.2"S 175°18'12.7"E]


Large rock fall from the west.

Large rock fall extends most of way up slope.

Some of the largest blocks in the rock fall.

8. **Sea arch** through columnar-jointed andesite intrusion. Blocks of the andesite lava have fallen out along the cooling joints creating an unusual sea arch that leads through to asmall beach. The arch is 4 m high and 4 m wide and is the only one on Motu Kaikoura. [36°10'03.4"S 175°18'12.2"E]

West Pt sea arch eroded through columnar-jointed part of intrusion.

West Pt sea arch eroded through columnar-jointed part of intrusion.

9. Largest **sea cave** on Motu Kaikoura, eroded along major vertical fracture striking 010˚ with fallen boulders blocking view of entrance from sea. [36°10'03.4"S 175°18'33.9"E]

Entrance to sea cave behind boulders in middle of photo.

10. Deep **eroded gut** along joint plane striking 010˚, and located 10 m east of and parallel to the large sea cave. [36°10'03.4"S 175°18'35.0"E]


Deep gut eroded along fracture.

11. West Rocky Beach **dip slope** striking 020˚ dipping 22˚E forming steep hill side that merges with sea cliffs. [36°10'06.9"S 175°18'40.8"E]

West Rocky Beach dip slope (centre of photo) from Mt Overlook.

12. **Rocky Beach** - best example of an **islet** and excellent example of a **high tide platform**. The islet is just off the beach and is about 30 x 20 m in dimensions and 15 m high. It is composed of laharic tuff breccia. On the exposed northern side there is a typical high tide platform that has not eroded back as fast as the cliff because of the platform rock’s greater resistance to erosion as it is water-logged all the time. The rocks directly above high tide level however, have eroded back by the alternating wetting and drying of tides and sea splash, thereby creating the platform. [36°10'15.7"S 175°18'56.1"E]

Rocky Beach islet and high tide platform on north (right) side.

13. **Bradshaw Cove** - only sand beach on Motu Kaikoura. [36°10'19.1"S 175°19'17.1"E]

Bradshaw Cove.

14. **Boulder Bay** - largest boulder beach on Motu Kaikoura. [36°10'16.7"S 175°20'02.8"E]

Boulder Beach

15. Excellent example of small **high tide notch** erosion on sheltered side of Motu Kaikoura, eroded into laharic tuff breccia by alternate wetting and drying of tides and splash. [36°11'12.7"S 175°20'10.5"E]

High tide notch, northeast of Wharf Bay.

High tide notch, northeast of Wharf Bay.

16. **Mitre Peak** – excellent example of a small, steep, exfoliation dome on a ridge crest. Made of bedded laharic andesite breccia, 185 m above MSL. When viewed from the north it has the profile of a bishop’s mitre, but when viewed from the east or west it is seen to be elongate in a north-south orientation. [36°10'46.6"S 175°19'32.1"E]

Mitre Peak from north.

Mitre Peak from east.

Geology

17. Rocky Beach - **paleovalley filled with lava flow**, in cliffs behind much of western half of the bay. [36°10'17.5"S 175°18'56.0"E]

Columnar jointed flow over baked breccia in west side of paleovalley, behind Rocky Beach.

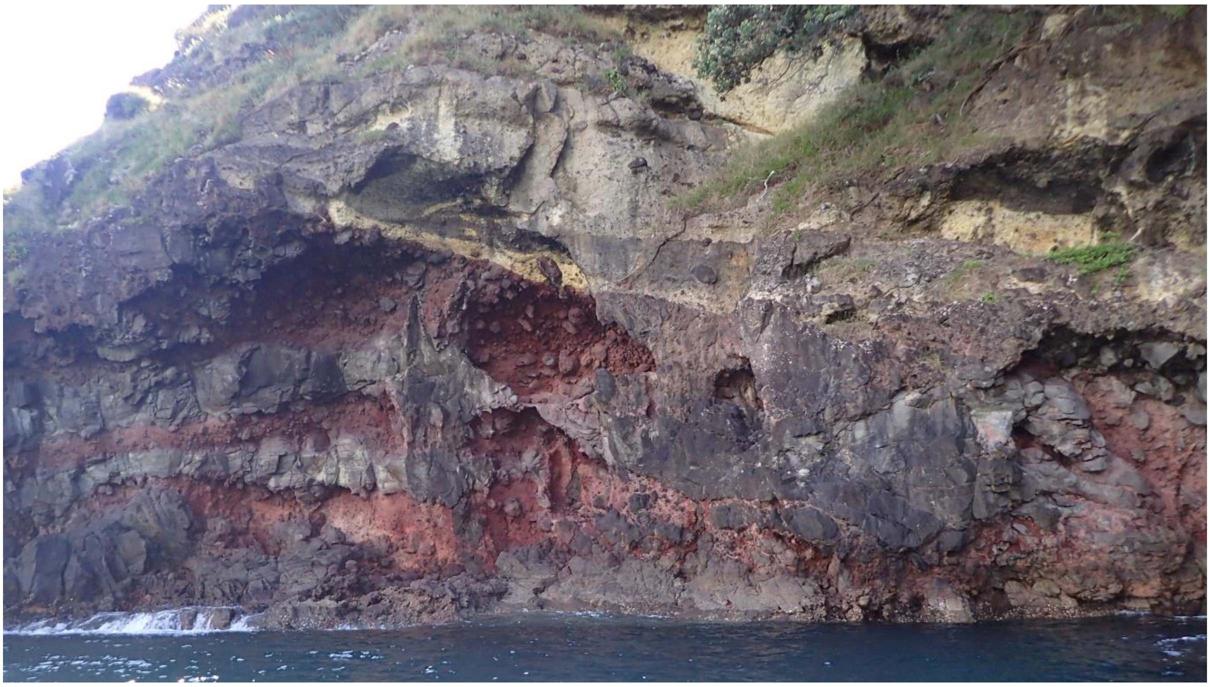
18. **Faulted edge to thick lava flow-breccia sequence** forming point between Bradshaw Cove and Rocky Beach. Up to 30 m thick, massive andesite lava (probable flow) overlain by well-bedded tuff breccia dipping 8-15˚ ESE. Right on the point the sequence stops against a steep fault with displaced breccia on the east side. [36°10'10.9"S 175°19'08.1"E]

19. Thin lava flows and red-autobreccia possibly filling a small paleovalley in the cliff just east of Bradshaw Cove beach. [36°10'17.5"S 175°19'20.4"E]

Sequence of thin lava flows and red autobreccia beneath laharic breccia and thicker flow, east side Bradshaw Cove.

Platy-jointed andesite flow beneath stratified laharic breccia in cliffs on east side of Bradshaw Cove.

20. A sequence of **thin, lensing flows separated by red autobreccia** overlain with a sharp contact by bedded cream tuff breccia. [36°10'13.3"S 175°19'29.5"E]



Sequence of flows and baked breccia overlain by cream and grey breccias.

Thin flows and red autobreccia.

21. **Paleovalley wall,** at least 30 m deep, eroded into tuff breccia and with a strike of 130˚ dipping 30˚NE and filled with thick andesite lava with vertical joints which suggest the presence of two thick lava flows. Forms end of point between Bradshaw and Boulder bays. [36°10'04.4"S 175°19'34.4"E]

22. **Mt Overlook western cliffs sequence** of thick flows overlying ~15-20 m of bedded tuff breccias extending all way to island's northeast point. Mt Overlook itself is underlain at the top by more breccias. [36°10'04.2"S 175°20'08.6"E]

The northwest cliffs of Mt Overlook expose a significant thickness of the Motu Kaikoura volcanic sequence.

Mt Overlook cliffs showing sequence of two volcanic breccia units overlain high in the cliff by vertical-jointed lava flow.