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Descriptions and analyses of New Zealand nephrite and tangiwaite jade (pounamu) by Ferdinand von Hochstetter (1864) and Friedrich Berwerth (1880): a scholarly annotated English translation

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18 Text-Figures, 1 Table

Ferdinand von Hochstetter
Friedrich Berwerth
Nephrite
Tangiwaite
New Zealand

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Abstract

Ferdinand von Hochstetter arrived in New Zealand as a member of the scientific contingent on the Austrian Novara expedition in 1858 and spent nine months exploring and surveying in both the North and South islands. During his sojourn, he developed a special interest in the New Zealand varieties of nephrite (pounamu), so highly prized by the indigenous Maori people who utilised it as a material for the manufacture of weapons, tools, and ornaments. On his return to Vienna Hochstetter had two samples analysed and published a paper describing the varieties of nephrite with special reference to the indigenous language terminology and their meaning, along with the results of the analyses. In 1880, Friedrich Berwerth, at the behest of Hochstetter, published a paper in two parts on nephrite and bowenite correcting key errors in the analyses of the earlier publication. This paper presents annotated scholarly English translations of, and commentary on both publications, discusses the origin of pounamu, and proposes the reinstatement of the name *tangiwaite* in place of *bowenite* for the tangiwai variety of New Zealand pounamu.

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Beschreibungen und Analysen von neuseeländischem Nephrit und Tangiwait-Jade (Pounamu) von Ferdinand von Hochstetter (1864) und Friedrich Berwerth (1880): eine kommentierte englische Übersetzung mit Anmerkungen

Zusammenfassung

Ferdinand von Hochstetter kam 1858 als Mitglied des wissenschaftlichen Kontingents der österreichischen Novara-Expedition nach Neuseeland und verbrachte neun Monate damit, die Nord- und Südinseln zu erkunden und zu vermessen. Während seines Aufenthaltes entwickelte er ein besonderes Interesse an den neuseeländischen Nephritarten (Pounamu), die von den einheimischen Maori, die es als Material für die Herstellung von Waffen, Werkzeugen und Ornamenten verwendeten, so hoch geschätzt wurden. Bei seiner Rückkehr nach Wien ließ Hochstetter zwei Proben analysieren und veröffentlichte einen Beitrag, in dem die Nephritarten unter besonderer Berücksichtigung der Terminologie der indigenen Sprache und ihrer Bedeutung sowie die Ergebnisse der Analysen beschrieben wurden. Im Jahr 1880 publizierte Friedrich Berwerth auf Geheiß von Hochstetter einen zweiteiligen Beitrag über Nephrit und Bowenit, in dem gravierende Fehler in den Analysen der früheren Veröffentlichung korrigiert wurden. Der hier gebrachte Beitrag besteht aus kommentierten englischen Übersetzungen beider Beiträge, erörtert die Herkunft von Pounamu und schließt mit dem Vorschlag zur Wiedereinsetzung des Namens *Tangiwait* anstelle von *Bowenit* für die Tangiwaiart des neuseeländischen Nephrits (Pounamu).

Introduction

During the round-the-world voyage of exploration and scientific discovery of the Austrian frigate *Novara*, the expedition geologist Ferdinand von Hochstetter (1829–1884) (Text-Fig. 1) spent nine months in New Zealand from 22 December 1858 to 2 October 1859. The results of his geological investigations published in *Geologie von Neu-Seeland* in May 1864 were of fundamental importance in the subsequent development of geological sciences in New Zealand and later earned him the accolade of "*Father of New Zealand geology*". In this work the occurrence of nephrite jade in New Zealand is only briefly mentioned: "*…[T]he occurrence of nephrite (p[o]unamu of the natives) on the west coast of the South Island, which owes its Maori name Te Wahi pounamu (i.e., land of greenstone) to this feature, belongs to the zone of crystalline schists*" (Fleming, 1959: 213, translated from Hochstetter, 1864a: 199), and in an appendix Hochstetter provides a list of the Maori words describing the different colour varieties of nephrite utilised in the manufacture of tools, weapons, and adornments (Fleming, 1959: 269–274; Hochstetter, 1864a: 269–274).

Hochstetter was unable to visit the area of the West Coast of the South Island of New Zealand, which was the main source of nephrite but did collect a beach pebble of a "*nodular piece of nephrite*" from the Nelson area, northern South Island. Most of his information on pounamu and its utilisation by the Maori was provided by Julius von Haast (1822–1887) who assisted Hochstetter with his scientific surveys and probably obtained the samples that he described in his paper, and possibly also from David Monro (1813–1877) at Nelson with whom Hochstetter formed a firm friendship and who assisted in translating his public addresses (Johnston & Nolden, 2011). It is also likely that information on pounamu came from Charles Heaphy (1820–1881) who was one of the first Europeans to explore the West Coast of the South Island and observe the technique of manufacturing pounamu tools by the Maori, and who informed Hochstetter of the "*primitive, plutonic and metamorphic formations*" that he had found in the South Island, and their likelihood in hosting "*metalliferous veins*" (Hochstetter, 1859).

The importance of Hochstetter's paper on New Zealand nephrite published in 1864 in the *Sitzungsberichte der kaiserlichen Akademie der Wissenschaften in Wien: mathematisch-naturwissenschaftliche Classe* is, that it provides the first detailed account of the occurrence, varieties and chemical composition of New Zealand pounamu. Unfortunately, the paper was marred by the inclusion of flawed analyses of two varieties provided by the laboratory of Hermann von Fehling (1812–1885) in Stuttgart, and as a consequence, Hochstetter's unproductive discussion to explain the significance of their compositions. As a result, it was generally accepted that New Zealand "*pounamu jade"* had a composition different from that used by stone tool cultures in other parts of the world. The analytical errors were only rectified at the behest of Hochstetter with new analyses of the same material by Friedrich (Fritz) Berwerth (1850–1918), assistant at the k. k. Hof-Mineraliencabinet (Imperial Royal Mineralogical Court Museum) in Vienna, in 1880. Berwerth's contributions also add important additional data on the occurrence and descriptive mineralogy of pounamu, so that the publications of both scientists provide the most complete detailed information on pounamu that were not referenced in New Zealand until the publication of Alexander Finlayson's seminal paper on nephrite and magnesian rocks in 1909.

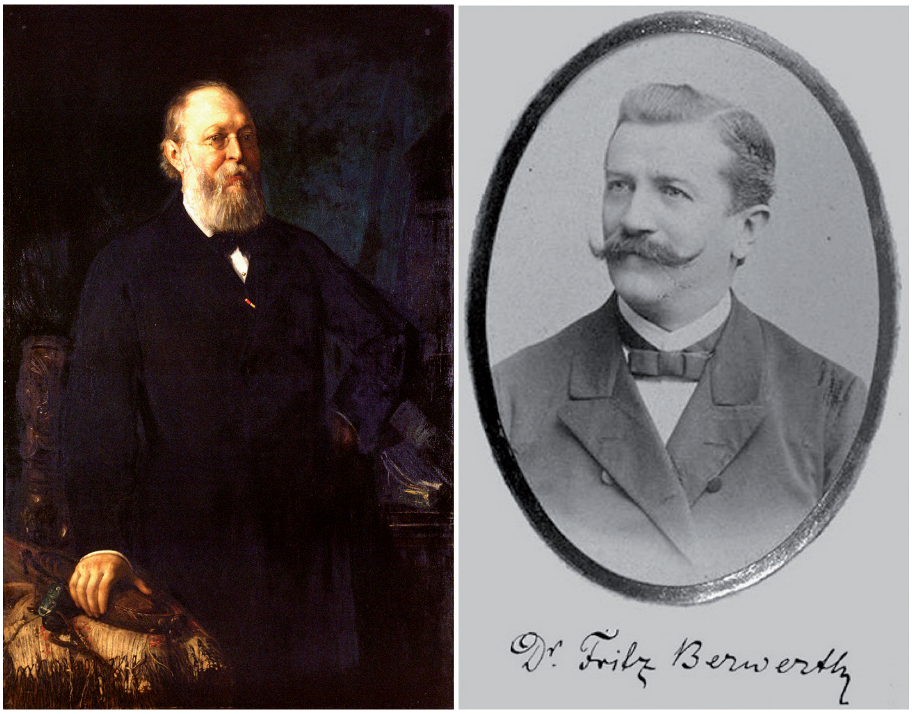
Hochstetter's paper presented to the Viennese Academy of Sciences at the meeting on 12 May 1864 and published in Sitzungsberichte der kaiserlichen Akademie der Wissenschaften in Wien, mathematisch-naturwissenschaftliche Classe, Vol. XLIX, 1864: 466–480

On the occurrence and the different varieties of New Zealand nephrite (pounamu of the Maori)

by Prof. Dr Ferdinand von Hochstetter

The New Zealand nephrite or axe stone [1] – pounamu [2] of the Maori, "greenstone" of the English colonists – distinguishes itself in purer varieties by a beautiful, green colour, and translucence, especially in comparison with the mostly cloudy and dull coloured, oriental occurrences – jade oriental of the lapidarist. It adopts a fine polish and is highly valued by the Maori. Various objects are made from the stone.

Above all, the pounamu is sought as a material for the mere, the battle axe of the Maori chief [3]. Such a nephrite battle axe (called *mere-pounamu*), especially when it was wielded by the hand of a brave ancestor in bloody conflict



Text-Fig. 1.
Left: Ferdinand von Hochstetter (1829–1884). Portrait painting by Franz Rumpler (1848–1922) in 1882, as director of the natural history museum in Vienna, showing him with several Maori objects, a carved wooden box (*wakahuia*), a woven flax cloak (*korowai*), a pounamu *tiki*, and the hand grip of a pounamu *mere* or club with its plaited flax cord just visible beneath (Natural History Museum Vienna).
Right: Friedrich Martin Berwerth (1850–1918), portrait photograph, 1882 (original in the Mineralogical-Petrographic Department of the Natural History Museum in Vienna).

is regarded as a treasure, and is kept with the greatest of care in the family of the chief and passed on from generation to generation. Only a few years ago a mere-pounamu was found that had been lost in war and was repurchased from the fortunate finder by a tribe near Auckland for the sum of 1,200 pounds sterling; and the most precious gift which the Maori presented to the Queen of England was also a mere-pounamu [1]) [4]. Ear ornaments and amulets are also almost exclusively made of pounamu. The ear pendants have the shape of perforated rods, 3–4 inches long and about half an inch thick. The amulets, *tiki* of the Maori, 2–2½ inches long and 2 inches wide, have the form only vaguely reminiscent of a crouching human figure with a large head and even larger eyes, which are now commonly highlighted by rings of red sealing wax [5]. They are worn by men and women hung on a string necklace on the chest. In former times hatchets and axe blades, small chisels and planes, were also made of pounamu.

The way in which the Maori work the nephrite is a very simple one. They use other hard rocks for the cutting and polishing, chiefly various varieties of siliceous slate or a hard quartz sandstone, such as occurs in the Grey River on the west coast of the South Island. For example, if an ear pendant is to be made, a straight piece of wood is tied to a suitable piece of nephrite using flax. Then a piece of siliceous slate is rubbed along the wood with great patience, while continuously wetting it with water. It takes a period of several days, often a week, until the cutting is completed and a piece has been shaped. The hole or eye is made with a piece of flint or chalcedony tied to a round stick, by twisting the stick back and forth as quickly as possible between the hands, in exactly the same way I saw the indigenous people of the Nicobar Islands and the Carolines use wood of various degrees of hardness to light fires [6].

1) See the image of a mere-pounamu in: Dr. Hochstetter, Neu-Seeland. p. 224 [Hochstetter, 1864a: 224]

All New Zealand nephrite comes from the West Coast of the South Island, where it is found at various locations, but mainly in the form of pebbles and cobbles in riverbeds and on the seashore [7]. On the eastern side of the South Island and in the North Island, there is no nephrite. The Maori of the North Island organize expeditions to the South Island for the express purpose of obtaining nephrite, and therefore this island is also called **Te Wahi Pounamu** [2]), the place of the greenstone or greenstone land [8]. Even now almost every year parties come from the northern island to the Buller, Grey and Arahura, with money, blankets, clothes, etc., in order to barter for nephrite, partly processed, partly raw, from the Maori settled at the mouth of these rivers [9], and the prices paid are astonishing. My friend Dr **Haast** [10] informed me that he saw a hand-sized piece about 2–3 inches thick, which was purchased for 5 pounds Sterling, and that in 1860 Tamate Freeman, a chief from the Aorere (Province of Nelson) with four of his people were at the Arahura River and bought a piece weighing 70 pounds for 60 pounds Sterling. With mortal danger and all kinds of privations, the Maori dragged this burden along the West Coast, and the chief reckoned that at least four beautiful mere could be made from it.

Little is known with certainty about its in-situ occurrence. According to the Maori and others, pounamu is mainly found in three places. The first is about 15 miles from the mouth of the Arahura or Brunner rivers. The Maori say that there is an outcrop of nephrite several feet thick in the form of an overturned, upright canoe exposed in the river bed that is called Te Waka (the canoe); but it is so hard and solid that it could not be broken because of the lack of appropriate tools and they have to content themselves with pieces that they find in the river and on the beach. It was not until 1860 that explosives were used and the above mentioned piece, which Tamate Freeman bought, could be

2) It is usually misspelled **Te Wai Pounamu**, which would mean **pounamu-water**.

obtained. The contact rocks are described by the Maori as a green slate, perhaps talc, chlorite slate, or serpentine.

A second locality where it is found lies south of Mount Cook near Jacksons Bay or Milford Sound. Several years ago a whaler apparently came to Nelson with a whole cargo of nephrite from there. However, he kept the details of the location a secret. He brought the load to China where he purportedly achieved a high price. The following year he again stopped by at Nelson, as several of his crew had suffered injuries from the explosives. He also took the second cargo to China, but this time he did not do so well as the Chinese had found the material too hard [11].

Dr **Hector**, geologist of the province of Otago, who explored Milford Sound on an expedition to the west coast, writes in his report on the occurrence at Milford Sound [3]: "*We anchored for a short time in Anita Bay (at Milford Sound), to examine the beach from which the Maori procured the jade or greenstone for the manufacture of their ornaments and weapons. It is from among the shingle that this stone is obtained, occurring as rounded pebbles along with fragments of hornblendic gneiss and felstone. Although I found many of these greenstone pebbles, I did not discover the source from whence they are derived, but a large felstone dyke crops out behind the beach, in contact with a green hornblendic rock and serpentine; and as the felstone near the sides of the dyke contain small green specks, which are of the nature of this mineral, it is probable that it has been formed along the line of junction as nodules and irregular masses.*" [12]

As a third locality, the lake Pounamu (also written Ponamu) in the province of Otago, identical with the one on the map written as Lake Wakatip (actually Whaka tapu), is given. [13]

Individual pieces and pebbles of nephrite can be found all along the west coast districts from Cape Foulwind in the north to Milford Sound in the south, and a small rounded piece of 3 inch diameter I myself found at Current Basin, north of Nelson, among the beach pebbles in an area where a great serpentine belt (the serpentine dyke of Dun Mountain), is associated with numerous different metamorphosed layers of slate, that it is under similar geological circumstances, as Dr **Hector** describes at Milford Sound, where serpentine also occurs nearby [14].

The Maori know very well the considerable differences in hardness, colour, and transparency characteristic of the different types of pounamu, and it is extraordinary how many varieties of pounamu they distinguish and have assigned special names [15]. I have gone to great lengths to collect and research these names and the varieties they relate to, and am able to provide the following information:

1. Tangiwai, also koko-tangiwai, is the noblest kind of vibrant green colour, a beautiful celadon green, and approaching emerald green; sometimes flamed; very transparent, even pieces of one inch thickness are still translucent; hardness is lower than for the other varieties; the structure is peculiarly scaly. Tangiwai literally means, a stone which looks like flowing water. The word may refer to the transparency and the internal flame colour patterns.

3) Geological expedition to the west coast of Otago, New Zealand, Report by J. Hector M.D. Otago, Provincial Government Gazette 1863. Nov. 5, p. 460.

This variety is mainly found in places on the coast south of Mount Cook, for example, **Pipiotahi** (*piopio*, a thrush species *Turnagra crassirostris*, tahi or tai salt water), a word, which is also used to describe the transparent variety of the stone [16].

2. Kawakawa, a dark green variety, less transparent and of greater hardness; therefore, mostly used for weapons (mere). The location of this variety is mainly given as the Arahura River. The name kawakawa also designates a shrub (*Piper excelsus*) [17].

Reverend **Taylor** [4]) [18] lists several composite names, such as:

Kawakawa – aumoana,

Kawakawa – rewa,

Kawakawa – tongarewa (esteemed type),

Kawakawa – watumu (inferior type),

by which the Maori distinguish the individual modifications of kawakawa; names, which in their composition are reminiscent of our systematic nomenclature in natural history.

3. **Kahurangi**, dark green and cloudy, with spotted or flamed colour, only slightly translucent, mainly for ornamental items, (hardness circa 6). An amulet (tiki), which I brought back is made from this variety. Also found in the Arahura River.

4. **Inanga** or **hinanga**, a light grey-green, milky, and often cloudy-coloured variety, reminiscent of chalcedony or agate, of considerable hardness (6–7); is mainly worked as ear pendants. The name *inanga* is also a small freshwater fish of 3–6 inches in length, *Elaeotris basalis,* which are found in Lake Taupo and commonly in other lakes of the North Island [19]. Perhaps this name was given to the stone because of the similar shape of the fish to that of the ear pendants. Locality is the Arahura River and especially in the gravels at the coast near its mouth.

Reverend **Taylor** introduces the names for other subspecies:

Hinanga – kore,

hinanga – rewa,

hinanga – tuti.

5. **Aotea** or **kaotea**, light green, milky, with black specks and nodules; is collected on the West Coast near the mouth of the Taramakau River [20].

In addition to the names given, **Taylor** mentions, but without further explanation, a series of other names for nephrite, such as *hopapa* [21], *kurutongarerewa*, *parataua* (inferior variety), *totoeka*, *tungaherehere* (inferior variety). So we have nearly a dozen names for different varieties of pounamu.

With regard to the most important properties, two groups of New Zealand nephrites may be distinguished.

A. Intensively green coloured varieties: *tangiwai*, *kawakawa* and *kahurangi*, more or less translucent, of lesser hardness (5–6) and of a foliated structure.

4) *A leaf from the Nat. Hist. of New Z.* p. 36 [Taylor, 1848: 36]

B. Pale green colored, milky cloudy, only slightly translucent varieties: *inanga*, *aotea*, which are reminiscent of agate, chalcedony and other siliceous rocks, and also similar in their greater hardness of 6–7; dense, without foliated structure.

The second Group B includes the less valuable varieties, which are most frequently represented in our collections and are very similar to oriental nephrites (*jade oriental*) or those from which art objects are made in China under the name Yo. Although the word "jade" originally has no definite mineralogical definition [5]), **Damour** [22] has defined two varieties of *jade néphrétique* or *jade oriental*:

1. *Jade blanc* with a specific gravity of 2.97. The chemical composition corresponds to the general formula $RO.SiO_2$. This variety is therefore included by **Damour** in the amphibole family, namely with tremolite [6]).

2. *Jade vert* or *jadéite* from apple green to emerald green colour, translucent, with splintered, fine lamellar and sometimes somewhat fibrous fracture; specific weight 3.34, hardness 6.5 (higher than those of *jade blanc*). The analysis revealed a composition similar to that of Dipyre in the Wernerite-group [23] of the formula:

$$3\ (NaO, CaO, MgO, FeO) + 2A1_2O_3 + 9SiO_2$$ [7])

This distinction of the two varieties of *jade oriental* appears to align with the two groups of New Zealand nephrites defined above and **Scheerer**'s analysis of a New Zealand nephrite ("Punamustein" [8]), which actually agrees with the formula of **Damour**'s *jade blanc*: $RO.SiO_2$ [25].

A piece of inanga from my collection in the form of an ear ornament has a specific gravity close to 3.009, and a hardness = 6.5. So it seems that Group B of the New Zealand nephrite varieties corresponds to **Damour**'s jade blanc.

It was interesting to now also consider the vibrant green and translucent varieties of New Zealand nephrite, which are so rare in our collections, and investigate these more closely to see if they matched Damour's *jade vert*. This assumption was based on the similarity of certain physical properties, especially transparency and fissile slaty fracture, and the possibility that the piece examined by Damour, although sourced from China, may originally have come from New Zealand, as repeatedly New Zealand nephrite had been exported to China to be processed there. The investigation however came up with very different results.

I chose from my collection two pieces of the most beautiful green-coloured varieties of **tangiwai** and **kawakawa**; both pieces have a perfectly homogeneous appearance, especially attractive and pure, as is usually only found with crystallized minerals, but differ very much in transparency, hardness, specific gravity and chemical composition.

a) Tangiwai. The examined piece was an ear ornament in the shape of a 4½ inch long and ½ inch thick rounded and smoothly polished rod, which at the upper thinner end features an eye. The colour is a beautiful celadon green, approaching emerald green, with a hint of yellow in places. The material is so translucent, almost transparent that you can see printed writing clearly through a thickness of 3 lines. The discontinuous surfaces running through in a parallel direction have a foliated structure, and small plates can be split off easily in this direction. The schistose structure, however, is not as perfect as in the otherwise so similar **antigorite**; the fracture surfaces are therefore not so parallel as with this mineral, but uneven with a splintery slaty foliation or scales. Perpendicular to the imbricated fracture there remains a fibrous cleavage, though indistinct. The hardness shows very striking differences. On the split surface it is the least hard at 4–5, without appreciable difference, whether one attempts to scratch vertically to the fibre fracture or parallel to it. On an area corresponding to the fibrous fracture, the hardness is a little greater, namely in the direction of the oblique fracture 5, perpendicular to it 5.5. On a polished transverse surface perpendicular to the slaty and fibrous fracture, the hardness is greatest and reaches 6.

A second smaller piece of tangiwai, also in the form of an ear ornament revealed quite similar **differences** of hardness, but by a step lower, that is 3.5 to 5.

The specific gravity was found to be the same for both pieces = 2.61.

Under the blowpipe, the thinnest splinters of the tangiwai variety are infusible, but it burns white and becomes opaque.

b) Kawakawa. Examined was an oblong piece of 5 inches in length, ¾ inches in width and ½ inch in thickness, whose sides were polished. Colour dark leek green. Dull, only translucent on the edges or in thin slivers. The structure as in tangiwai; the differences in hardness are analogous; however the hardness in general is greater: on the flaky fracture 5.5, on the fibrous fracture 6–6.5 and on a polished transverse surface almost 7. The specific gravity is notably higher = 3.02. Melts under the blowpipe, although very difficult, becomes discoloured and opaque.

It is clear that a mineral with such peculiar structural properties, although it cannot be regarded as a crystallised body, has optical properties that are similar to the structural dichroism and optical axes of antigorite demonstrated by **Haidinger** [9]) [26].

One might have expected dichroism [27] in the tangiwai when observed with a diachroscopic lens in the direction of the schistose fracture in a translucent piece: but the two images appear completely alike in this direction, as in the direction perpendicular to the oblique fracture. Examina-

5) The word jade is used by the Chinese in the same sense as the Chinese word Yo, and similarly originally has no mineralogical meaning, but denotes only the more precious harder stone types, from which the Chinese with wonderful craftsmanship cut the most varied luxury objects, figures, vases, plates, etcetera, stone varieties which are harder than soapstone and limestone and of general hardness of quartz. Yo is therefore used to describe everything made of clear quartz crystals, milky-white opal, red carnelian and jasper, coloured and banded agate, translucent chalcedony, of reddish and greenish feldspar, and hard, green translucent nephrite and serpentine varieties. Namely, among the green Yo varieties are the various minerals, such as amazonite, prase, chrysoprase, serpentine, nephrite.

6) *Ann. de Chimie et de Physique* 3. Serie, t. XVI, p. 469. [Damour, 1846: 469]

7) *Compt. rendus* 1863. LVI, p. 861 [Damour, 1863: 864] [24]

SiO_2	59.17
Al_2O_3	22.58
Na_2O	12.93
CaO	2.68
MgO	1.15
FeO	1.56
K_2O	Traces

8) *Poggendorff's Annalen 84.* [Scheerer, 1851: 379–381, 399]

9) *Sitzungsb. d. mathem.-naturw. Classe der k. Akad. d. Wissensch. in Wien* 1848. Bd. 1, S. 278 [Haidinger, 1848: 278].

tion of thin and thick sections cut in different directions with regard to the optical axes also led to a positive result.

If the difference in hardness of the green New Zealand nephrite already gave rise to the assumption that this mineral is essentially different from Damour's *jadeite*, then this was proved beyond doubt by chemical investigation.

Chemical investigation.

The analyses were carried out in the laboratory of Prof. Dr. v. **Fehling** in Stuttgart by Messrs **Melchior** and **Meyer**, and gave the following results:

a. Variant **tangiwai**, translucent. Specific gravity = 2.61.

b. Variant **kawakawa**, only translucent at the edges. Specific gravity = 3.02.

	a.	***b.***
SiO_2	53.01	55.01
Al_2O_3	10.83	13.66
FeO	7.18	3.52
MnO	trace	trace
CaO	12.40	–
MgO	14.50	21.62
K_2O	0.97	1.42
H_2O + LOI	1.11	5.04
	100.00	100.27

The values determined in these analyses deviate so significantly from the composition of the *jadeite* given above that it is hardly possible to compare them. Closer agreement is found with the older analyses of oriental nephrite and **Scheerer**'s analysis of pounamu, if one compares the two new nephrite analyses with each other and the older nephrite analyses: [28]

1. **Nephrite from the Orient**. [29]

I. Kastner, Gehlen's Journal II. 459. [Saussure de, 1806]
II. Schafhäutl, Annal. d. Chem. et Pharm. 46, 33 (an amulet, specific gravity = 2.96). [Schafhäutl, 1843]
III. Schafhäutl, as above (as a ringstone).
IV. Rammelsberg, Pogg. Ann. 62. 148. [Rammelsberg, 1844]
V. Damour, Ann. Chimie et Phys. III series. 16. 469. [Damour, 1846: 469]
(*jade blanc*. specific gravity = 2.97).
VI. Scheerer, Pogg. Ann. 84, 379. [Scheerer, 1851: 379]

2. **From New Zealand.**

VII. Scheerer, as above. (Pounamu).

	I	**II**	**III**	**IV**	**V**	**VI**	**VII**
SiO_2	50.50	58.91	58.88	54.68	58.24	57.28	57.10
Al_2O_3	10.00	1.32	1.56	–	–	0.68	0.72
FeO	5.50*	2.43	2.53	2.15	1.14	1.37	3.39
MnO	–	0.82	0.80	1.39	–	–	–
MgO	31.00	22.42	22.39	26.01	27.14	25.91	23.29
CaO	–	12.28	12.51	16.06	11.94	12.39	13.48
K_2O	–	0.80	0.80	–	–	–	–
H_2O	27426	0.25	0.27	0.68		2.55	2.50
Cr_2O_3	0.05	–	–	–	–	–	–
*Total***	*99.80*	*99.23*	*99.74*	*100.97*	*98.46*	*100.18*	*100.48*

*Fe_2O_3
***added*

so in the case in analyses ***a*** and ***b***, the high alumina content stands out above all except that in **Kastner**'s analysis I. **Rammelsberg** and **Scheerer** therefore believed that the latter does not refer to any nephrite substance. Analysis ***b*** only has a complete lack of lime in common with **Kastner**'s. Also noteworthy is the low magnesia content in ***a*** and the large water content and Loss on Ignition in ***b***.

Rammelsberg did not attempt to give **nephrite IV**, which he analyzed, a special chemical expression. The following might be the closest formula:

$$2\ (MgO.SiO_2) + CaO.SiO_2$$

which calls for:

SiO_2	57.7
MgO	24.8
CaO	17.4

Nephrite Analysis V from **Damour** results, according to **Naumann**, in values very close to the formula:

$$3\ (MgO.SiO_2) + CaO.SiO_2,$$

which requires:

SiO_2	58.5
MgO	28.3
CaO	13.2

Therefore it appears that the composition of these nephrites can be represented as $RO.SiO_2$ with the oxygen ratio 1:2.

Analyses **V** and **VII** correspond very precisely to the formula $RO.SiO_2$, which **Scheerer** calculated according to the theory of polymeric isomorphism. On the presumption that there are 3 atoms of water, 1 atom of magnesia and 3 atoms of alumina, 2 atoms of silica, one finds in Analysis **VI** the oxygen ratio:

$$SiO_2 : RO = 29.95 : 14.96.$$

The formula $RO.SiO_2$, however, requires 29.93:14.98, so there is only a difference of 0.02.

In Analysis VII, we have

$$SiO_2 : RO = 29.87:14.66,$$

the formula is 29.87: 14.94, that is a difference of 0.28.

Scheerer also shows how the old **Kastner** analysis with the aid of the theory of polymeric isomorphism, almost equals the formula $RO.SiO_2$. If one takes the iron oxide as FeO in this analysis the result is the oxygen ratio,

$$SiO_2 : RO = 29.35:14.32$$

which comes very close to 2:1.

The new nephrite analyses ***a*** and ***b*** give the following oxygen numbers:

	a.	***b.***
SiO_2	27.54	28.57
Al_2O_3	5.06	6.38
FeO	2.15	1.05
CaO	3.54	–
MgO	5.80	8.64
K_2O	0.16	0.24
H_2O	0.99	4.88

If one ignores the water content, then the oxygen ratios without reduction of the individual components to 100 are:

		SiO_2	:	R_2O_3	:	RO
in	***a.***	27.54	:	7.21	:	9.50
”	***b.***	28.57	:	7.43	:	8.88

Or

		SiO_2	:	$(R_2O_3 + RO)$
in	***a.***	27.54	:	16.71
”	***b.***	28.57	:	16.31

Despite the considerable differences between the individual components this shows that the oxygen ratios of both analyses strangely align.

If one converts the iron oxide to ferrous iron, which is more natural, the results are:

in	***a.***	6.46	FeO	with	1.43	oxygens,
”	***b.***	3.17	FeO	”	0.70	”

then the following oxygen ratios result:

		SiO_2	:	R_2O_3	**:**	RO
in	***a.***	27.54	:	5.06	**:**	10.93
”	***b.***	28.57	:	6.38	**:**	9.58

Or

		SiO_2	:	$(R_2O_3 + RO)$
in	***a.***	27.54	:	15.93
”	***b.***	28.57	:	15.96

and a close correspondence is again shown.

If, after subtracting the water, assuming iron oxide in the two analyses is a mixture calculated to 100, the following oxygen ratios are obtained:

	SiO_2	:	R_2O_3	:	RO	or	SiO_2	:	$(R_2O_3 + RO)$
a.	27.84	:	5.11	:	11.06		27.84	:	16.17
b.	28.89	:	6.70	:	9.63		28.89	:	16.33

Here, too, the close correspondence of the oxygen ratios of the two substances, which appear to be of different compositions, is noticeable, without a suitable formula resulting from the oxygen numbers.

Taking into account the water and assuming FeO, the resulting oxygen ratios are:

For ***a.*** **tangiwai**.

SiO_2	27.6	=	13.8	SiO_2	14
Al_2O_3	5.1	=	1.7	Al_2O_3	2
RO	11.0	=	11	RO (Mg,Ca,Fe,K)O	14
HO	1.0	=	1	HO	1

from which the derived formula is:

$$2R_2O_3 .3SiO_2 + 11 (RO.SiO_2) + HO$$

For ***b.*** **kawakawa**:

SiO_2	28.6	=	14.3	SiO_2	7
Al_2O_3	6.4	=	2.1	Al_2O_3	1
RO	9.6	=	10	RO (Mg,Ca, Fe,K)O	5
HO	4.5	=	4	HO	2,

from which the formula is:

$$R_2O_3 .2SiO_2 + 5 (RO.SiO_2) + 2 HO$$

However, these complex formulas are not very satisfactory.

One arrives at simpler ratios when the analyses are calculated on the basis of the theory of polymer isomorphism, i.e. a third part of the amount of oxygen in water to the monoxides and two thirds of the amount of oxygen in alumina to the acids; assuming iron oxide as FeO we then get:

		SiO_2 (+ Al_2O_3)	:	RO (+ HO)
in	***a.***	31.09	:	11.26
”	***b.***	32.82	:	11.07

This ratio, especially that of ***b***, is close to 3 : 1:

a.	Observed	31.09	:	11.26	Diff. + 0.90
	observed after 3 : 1	31.09	:	10.36	
b.	Observed	32.82	:	11.07	Diff. only + 0.13
	observed after 3 : 1	32.82	:	10.94	

The formula for the oxygen ratio 3:1 corresponds to:

$$2RO.2SiO_2$$

None of the previous nephrite analyses indicate this 3 : 1 oxygen ratio. Most of them, even calculated according to the theory of polymeric isomorphism, do not result in a simple relationship. If RO = 1, $SiO_2 + Al_2O_3$ yield values of 1.8 - 2.5. Analysis **II**, for example, has the relationship:

$$(SiO_2 + Al_2O_3) : RO = 30.91:13.16 = 2.35:1$$

The majority of analyses, however, fluctuate around the ratio of 2 : 1, and as shown above, agree very closely with the analyses by **Scheerer** and **Kastner**.

The New Zealand nephrite varieties tangiwai and kawakawa with the oxygen ratio:

$$RO (+ HO): SiO_2 (+ A1_2O_3) = 1 : 3$$

thus differ from the nephrite formula $RO.SiO_2$ where RO: SiO_2 = 1 : 2 established by **Scheerer** and **Damour**. According to the latter relationship, the nephrites would equate with the augites and hornblendes which have the same oxygen ratio; and among the nephrites, which, according to Scheerer, have this proportion, there is also a New Zealand variety.

In the newly analysed varieties, the high proportion of the acid is evidently due to the considerable amount of alumina present according to the theory of polymeric isomorphism. Taking the alumina content into account elsewhere has proven to be unsatisfactory, and if one may admit at all that the formation of such non-crystallized minerals took place according to fixed chemical proportions, then this must be exact and pure. The resulting ratio should be 1:3, which corresponds specifically to the two analyses.

If one looks for a magnesia silicate with the same or a similar composition in the mineral kingdom one finds such acidic compounds to be rare. **Rammelsberg** gives the meerschaum formula as $2MgO.3SiO_2$, also the 1:3 ratio; the amounts of silica and magnesia in both minerals are nearly identical, but the water content of meerschaum significantly exceeds that of nephrite. Soapstones have a very similar composition, to which **Rammelsberg** gives the formula:

$$3\ (4MgO.\ SiO_2) + 4aq.\ \text{where}\ RO: SiO_2 = 4:10.$$

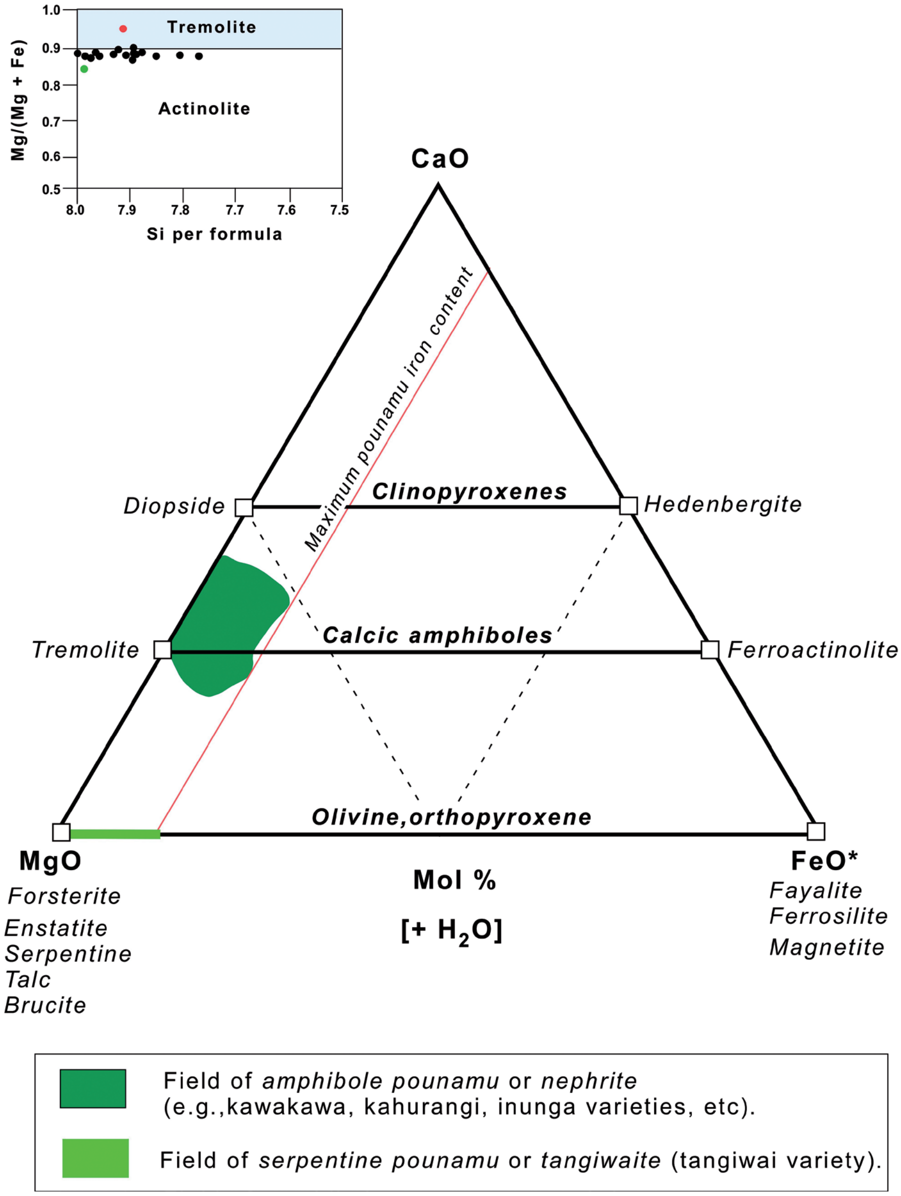
The water content corresponds to that of nephrites. Silicic acid and magnesia occur in somewhat larger amounts. [30]

Notes on Hochstetter's paper

1 "*Axe-stone*" is defined by HUMBLE (1843) as a "*mineral from New Zealand. Inhabitants make axes and other cutting instruments – hence the name. Subspecies of jade – resembles nephrite or nephritic stone*". The name *nephrite* is derived from the Greek *nephos*, a kidney: it was supposed to be a cure for disease of the kidney.

2 *Pounamu* is the Maori word for two types of jade rock that are essentially composed of (1) tremolite-actinolite (actinolite being the dominant amphibole species)[1] and (2) serpentine (antigorite variety)[2]. *Nephrite* (*sensu stricto*) refers to the former (following DAMOUR's 1846 original classification of jade into nephrite and jadeite types). In New Zealand, the latter type of pounamu has been variously described as *noble serpentine* (HECTOR & SKEY, 1866); *marmolite* (HUTTON & ULRICH, 1875); *bowenite* (BERWERTH, 1880b; FINLAYSON, 1909, and all references to this pounamu composition after this date); and *tangiwaite* (EG-

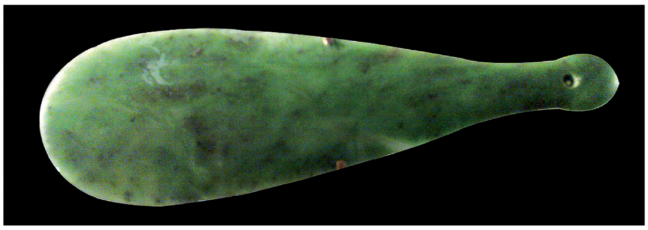
1 Ideal formula $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$.
2 Ideal formula $Mg_3Si_2O_5(OH)_4$.



Text-Fig. 2.
Mol.% CaO – MgO – FeO* (as total iron) + H_2O diagram showing composition fields of New Zealand pounamu, i.e., *nephrite* and *tangiwaite* (see comment 2 and Discussion), and relevant end-member minerals. Pounamu composition fields determined from available published and unpublished analyses of the two varieties (SCHEERER, 1851; HOCHSTETTER, 1864 (corrected; see text); HECTOR & SKEY, 1866; DAMOUR, 1865; FELLENBERG, 1869; BERWERTH, 1880a, b; ALLEN, 1882; CLARKE & MERRILL, 1888), KINNICUTT, 1889; DUPARC & MRAZEC, 1892; DIESELDORFF, 1901; BISHOP, 1906; FINLAYSON, 1909; HENDERSON et al., 1959; COLEMAN, 1966; WILKINS et al., 2003; TENNANT et al., 2005; GRAPES & YUN, 2010; GRAPES, unpublished data).
Inset shows a plot of amphibole compositions in terms of Mg/(Mg + Fe) ratio verses Si atoms per formula unit. Black circles: Actinolite compositions in a *kawakawa* variety of nephrite pounamu (data from GRAPES & YUN, 2010); Green circle: Actinolite composition from pounamu nephrite (BERWERTH, 1880a); Red circle: Tremolite composition from a fibrous (non-nephritic) white segregation in serpentine-dunite, Mount Bowen, Southern Alps (MORGAN, 1908: 127).

LESTON, 1887; CHESTER, 1896; KOECHLIN, 1911; SPENCER, 1919) (Text-Fig. 2). **In this paper, we use the term *tangiwaite* to replace *bowenite* in describing the serpentine variety of pounamu**. The microcrystalline interwoven or felted texture (*nephritic texture*) of both the tremolite-actinolite and antigorite pounamu compositions results in their respective hardness of 6–6.5 (nephrite) and 4.5–6 (tangiwaite) on the Mohs hardness scale of 1 to 10, and density of 2.95–3.05 and ~2.61.

It should be noted that pounamu, that is nephrite and tangiwaite, are rarely monomineralic rocks of tremolite-actinolite and antigorite serpentine respectively, but typically contain small amounts of other minerals (impurities). These accessory phases are:



Text-Fig. 3.
Upper: Portrait of a Maori chief, Wiremu Kingi of the Te Ati Awa tribe, holding a pounamu mere. Painted by Gottfried Lindauer (1839–1926) (Auckland Art Gallery: Ac.No.1915/2/71, public domain, Wikimedia Commons). **Centre:** The nephrite mere ("He meremere pounamu") presented to Queen Victoria mentioned by Hochstetter (from TAYLOR, 1855: 244; no scale given); **Bottom:** Pounamu mere (42 cm x 12 cm) presented to Sir George Grey (1812–1898) in 1851, and named kataore after a chief killed in the 1830s (Auckland War Memorial Museum, CC BY-SA 3.0 Sladew, Wikimedia Commons).

In *nephrite*: chlorite, serpentine, talc, diopside, Cr-bearing Ca-garnet, Cr-muscovite, titanite, magnesite, chromite, pyrite, chalcopyrite, + rare green-brown hornblende, margarite, quartz.

In *tangiwaite*: chlorite, talc, olivine, tremolite-actinolite, epidote, magnesite, magnetite, chromite, + rare awaruite ($FeNi_3$; ULRICH, 1890: 629).

(TURNER, 1935; GRAPES, unpublished data).

3 See Text-Figure 3 upper.

4 See Text-Figure 3 centre.

5 See Text-Figure 4: a.

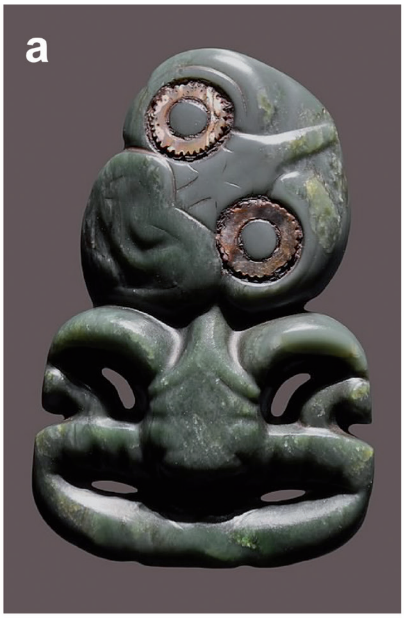
6 Charles Heaphy[3] observed the process of drilling a hole through a pounamu mere at the "*greenstone village*", Taramakau River on the West Coast, in May 1846 (Text-Fig. 5). He writes: **"***The most difficult part of the work is to drill the hole for the thong in the handle* [of the mere]*. For this pieces of sharp flint are obtained from the Pahutani cliff, forty miles to the north* [of Taramakau River]*, and are set in the end of a split stick, being lashed in very neatly. The stick is about fifteen or eighteen inches long* [38–46 cm]*, and is to become the spindle of a large teetotum*[4] *drill. For the circular plate of this implement the hardened intervertebral cartilage of a whale is taken; a hole is made through, and the stick firmly and accurately fixed in it. Two strings are then attached to the upper end of the stick, and by pulling them, a rapid rotatory motion is given to the drill. When an indentation is once made in the poenamu the work is easy; as each flint becomes blunted it is replaced by another in the stick, until the work is done."* (HEAPHY, 1862: 18–19).

7 See Text-Figure 5. The main sources of pounamu are the Arahura and Taramakau rivers, north Westland. In the Southern Alps drained by these two rivers, BELL & FRASER (1906: 69–70) observed that nephrite occurs as "*rounded segregations in talc rock or talc-serpentine rocks. The segregations vary in size from 1 in. (25 mm) or less in diameter to 2 ft. (0.6 m), or even more, in lateral dimension. As a rule, they average less than 1 ft. (0.3 m) in width. With the wearing away by abrasion or by decomposition of the enclosing talcose or serpentiferous matrix, the segregations are freed as rounded masses generally covered by a coating of serpentinuous material derived from their own decay. It is these segregations which were transported by the Arahura and other glaciers in the period of maximum ice-advance, and which appear in the glacial debris along the lower Arahura and other streams as the famous 'greenstone' boulders of the West Coast"*. They also noted "some large nephrite boulders of particularly good quality" in Olderog Creek and in the Arahura River just below its conjunction with this creek (Text-Fig. 6). Subsequent investigation discovered a nephrite source in prominent outcrops of the *Pounamu Ultramafic Belt*[5] on either side of a tributary of *Olderog Creek*

3 Charles Heaphy (1820–1881), artist and draughtsman of the New Zealand Company, explorer and soldier, who with Thomas Buller and a Maori guide, Keru, were the first to explore the West Coast of the South Island reaching the Arahura River in May 1846 (Text-Fig. 5). Hochstetter became acquainted with Heaphy while he was in Auckland. At that time, Heaphy was the principal surveyor in Auckland and had produced a map of the Auckland volcanoes.

4 A small spinning top spun with the fingers.

5 Consists of numerous lenses, typically < 60 m wide and 200 m long, seldom > 90 m wide and 1.4 km long, of a dismembered ophiolite association metamorphosed to transitional greenschist-amphibolite facies conditions (e.g. REAY & COOPER, 1984).



Text-Fig. 4.
(a). Pounamu tiki (*kawakawa* variety) with red sealing wax eyes (in the exhibition 'Maori, their treasures have a soul') (Musee des Arts Premiers, Paris, 2011–2012, [Wikimedia Commons]); **(b).** Portrait of Hinepare of the Ngati Kahungunu tribe, c.1890, by Gottried Lindauer (1839–1926). She is wearing a pounamu tiki and earring (Alexander Turnbull Library, Wellington, New Zealand: Reference No. G-516, [Wikimedia Commons]).

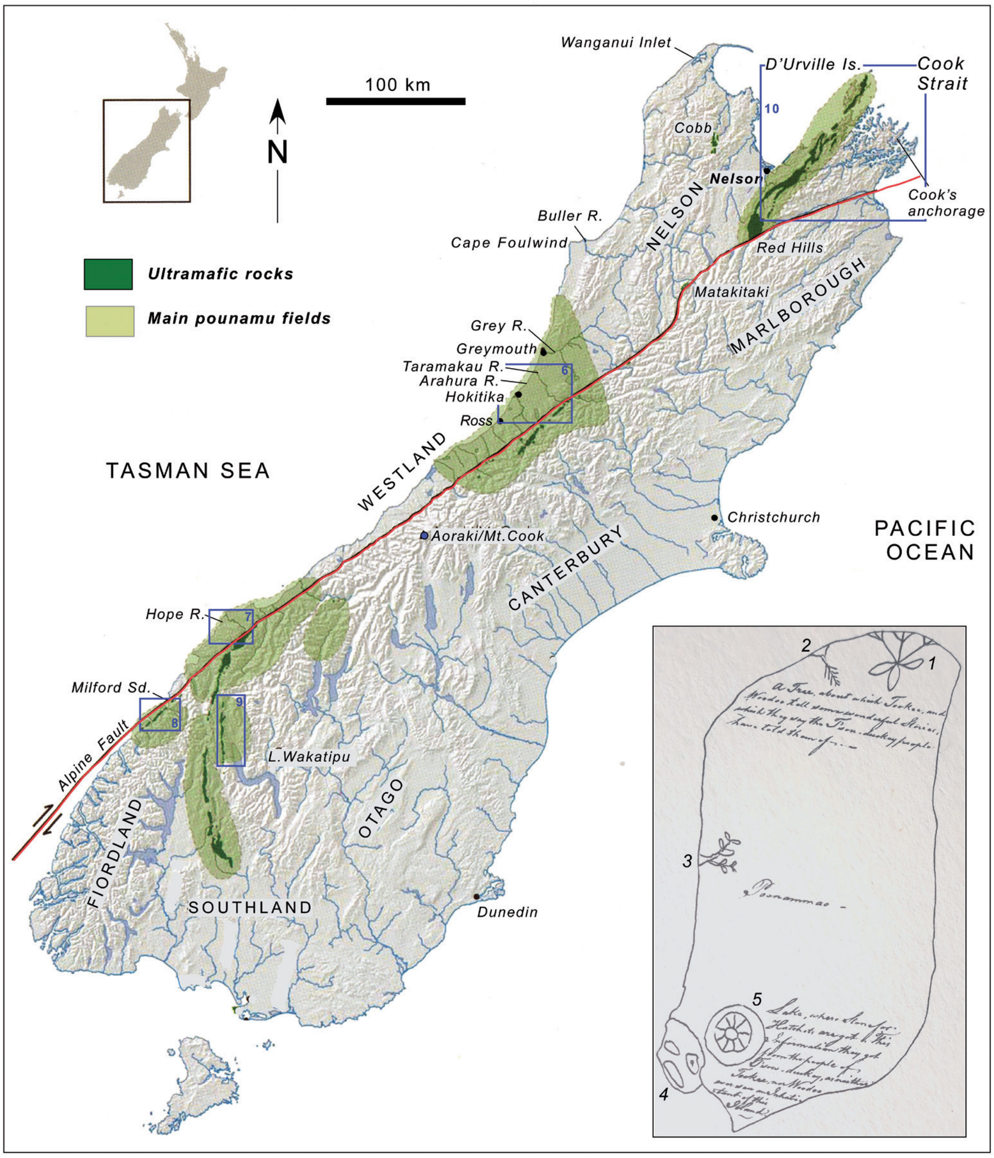
that has been named *Jade Creek* (Text-Fig. 6). According to JOHNSTON (1983), this occurrence has provided the only known large concentration of nephrite and semi-nephrite boulders, weighing up to 25 tons, in Westland, and most have been removed by helicopter. The locality is ~30 km from the mouth of the Arahura River. Hochstetter quotes 15 miles (24 km) for the location of the "Te Waka" pounamu outcrop of the Maori which implies that it must have been a very large boulder protruding from the river bed like an upturned canoe situated west of the Alpine Fault and derived from the adjacent fluvial gravels (Text-Fig. 6). Supporting evidence for this conjecture is given by MCKAY (1893): "*olivine and serpentine rocks are abundant in the shingle of the river-bed below Humphrey's Gully* [Arahura River, see Text-Fig. 6 for location], *and, higher up, boulders of this class increase in number and in size greatly.* […] *Many of the boulders of olivine rock resemble a dark form of jade or greenstone; thin splinters of the rock being translucent, and of a darker or paler green, according to thickness of the specimen, and in the manner in which it is viewed"* (MCKAY, 1893: 150), and, "*the second gorge of the Arahura* [see Text-Fig. 6 for location] […] *has been excavated across the rocks in-situ of the Mica-schist range. The banks and rapids of the river are studded with large boulders of olivine rock"* (1893: 151).

8 In response to a question put to the New Zealand lawyer and ethnologist Frederick Chapman of Dunedin by Professor Heinrich Fischer, Freiburg[6]: "Is the true name of the South Island 'Te Wai Pounamu,', The Water of Greenstone, or 'Te Wahi Pounamu,' The Place of Greenstone?" (CHAPMAN, 1891: 510), the later phrase used by Hochstetter is the incorrect one and it should be *Te Wai Pounamu* (*the water of pounamu)* (CHAPMAN, 1891: 522–523). This is the name given to the South Island of New Zealand by Captain James Cook as printed on his map from the first voyage, 1768–1771, to New Zealand: "… *as they* [the Maori] *all agree, that* [pounamu] *is fished out of a large lake or collection of waters, the most probable conjecture is that it is brought from the mountains and deposited in the water by the torrents. This lake is called by the natives Tavai Poenammoo–that is 'The water of Green Talc;' and it is only the adjoining part of the country, not the whole southern island of New Zealand, that is known to them by the name which hath been given to it on my chart*" (CHAPMAN, 1891: 523). Chapman considered that if Cook had heard "*Te Waihi*" he would have written "*Vahee*" or "*Wahee*" instead of "*Tavai*" for "*Te Wai*". Skinner however, has pointed out that "*the pronunciation of 'wai' and 'wahi' by the southern Maori are often so alike as to be indistinguishable save to an acute or trained ear"* (SKINNER, 1935: 216).

Johann Reinhold Forster (1729–1798), who together with his son Georg Forster (1754–1794) accompanied Cook on his second voyage to New Zealand, 1772–1775, writes: "*This stone* [pounamu] *is commonly brought by the natives from the interior parts of Queen Charlotte's Sound* [in the now-called Marlborough Sounds, north-eastern part of the South Island, where Cook temporarily anchored; Text-Fig. 6] *to the South West, in which direction they pointed. We asked for this native place, and they called it Poënamo, from whence probably the abovementioned part of the country obtained the denomination of Tavai Poënamoo*" (FORSTER, 1778: 18).

In this respect a sketch map of New Zealand drawn by a Maori, Tuki-Tahua (the oldest known Maori map), originally on the floor of Lieutenant-Governor Phillip Gidley King's house on Norfolk Island, and later transferred by Tuki on paper, in 1793, is instructive. Part of this map showing the South Island is reproduced in Text-Figure 5 and on it re-

6 Heinrich Fischer (1817–1886), University of Freiburg, Baden. Distinguished by his investigations on the origin and character of jade published in FISCHER (1875).



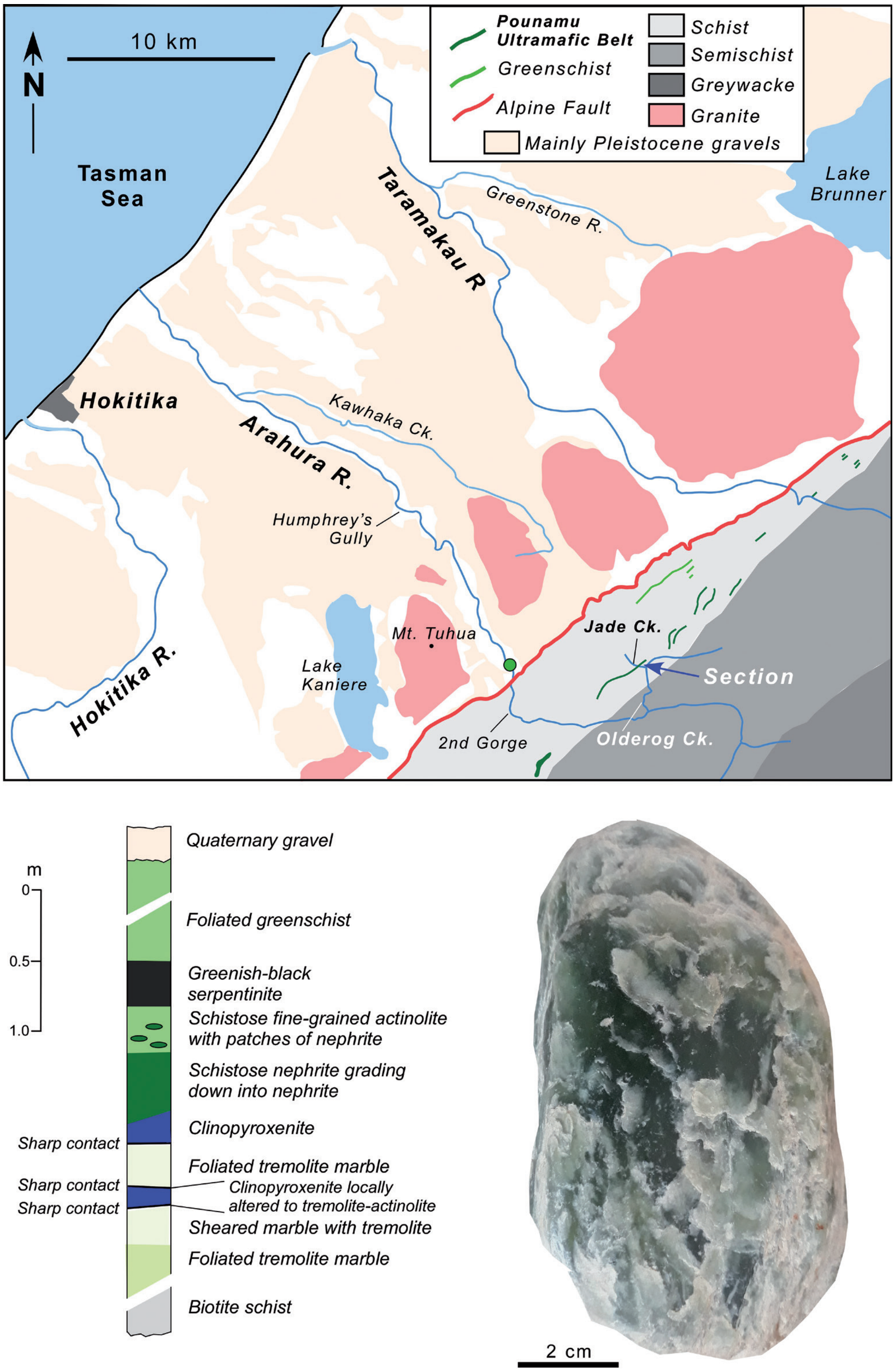
Text-Fig. 5.
Map of the South Island of New Zealand showing distribution of ultramafic rocks and areas of pounamu finds (modified from Christie et al., 2010: 188), together with places mentioned in the text, and locations of separate maps (Text-Figs. 6–10) denoted as *blue squares*.
Inset: The South Island part of a sketch map of New Zealand by Tuki-Tahua in 1793 (see comment 8 in text). *Numbered locations*: **1** = Marlborough Sounds; **2** = Wanganui Inlet (NW Nelson); **3** = Taramakau and Arahura rivers (Westland); **4** = Fiordland; **5** = Lake Wakatipu. The text was added to the map by Lieutenant-Governor Phillip Gidley King in Norfolk Island (Barton, 1998: 507).

marks were written by King from Tuki's information (extracted from Maling, 1969). The word "*Poonammao*" is written near what appears to be the tree-like symbol presumably depicting two rivers on the West Coast. These rivers are probably the Taramakau and Arahura, from which the Maori obtained nephrite. In the south-western part of the map is a circular spoked wheel-like structure adjacent to which is written "*Lake where stones for hatchets are got…*" that most likely represents Lake Wakatipu – another general source area of pounamu known to the Maori. The sketch map was sent to the Home Office, London, on 8 November 1793 and is now in the Public Record Office. Tuki had only heard of the South Island from others but his map supports the information about pounamu given by Maori in Queen Charlotte Sound (Marlborough Sounds; Text-Fig. 5) to Captain James Cook and Johann Reinhold Forster.

Chapman (1891: 481) was of the opinion that the Taramakau and Arahura rivers are "*…in all probability the Wai-pounamu (Water of Pounamu) of the Maoris*". Conversely, Edward Shortland (1851: 205) considered that Lake Wakatipu was "*probably the 'Wai-pounamu', of which the natives spoke in reply to the enquiries of Captain Cook and Mr. Banks, who supposed it to be the name of the whole island*" when informed by Maori in 1844 that the lake was "*celebrated for the 'pounamu,' found on its shores, and in the mountain torrents which supply it*". In reporting information from an "*old Maori*", Beattie (1920: 45) records that the "*general name of the whole district north of Lake Wakatipu was Te-wahi-pounamu*", but whether this also included the Arahura and Taramakau river sources is a moot point.

As a final comment, William Anderson (1777: in Beaglehole, 1967), surgeon and keen naturalist aboard Cook's ship, *Resolution*, during his third and last voyage to New Zealand between 1776–1779, writes that "*wherever it* [pounamu] *may be found, which they* [the Maori] *say is in the channel of a large river far to the southward* [of Queen Charlotte Sound]. *It is dispos'd in the earth in thin layers or perhaps detatch'd pieces like our Flints*". The "*large river*" (rather than a "large lake or collection of waters" interpreted by Cook) could be the Arahura, the Taramakau, or perhaps the Dart River that runs into Lake Wakatipu (Text-Fig. 5).

9 According to Heaphy (1846: 127) "*The Arahura river descends from this range* [the Southern Alps]. *In its bed, after freshes, is found the poenamu, in shingles and slabs; and*

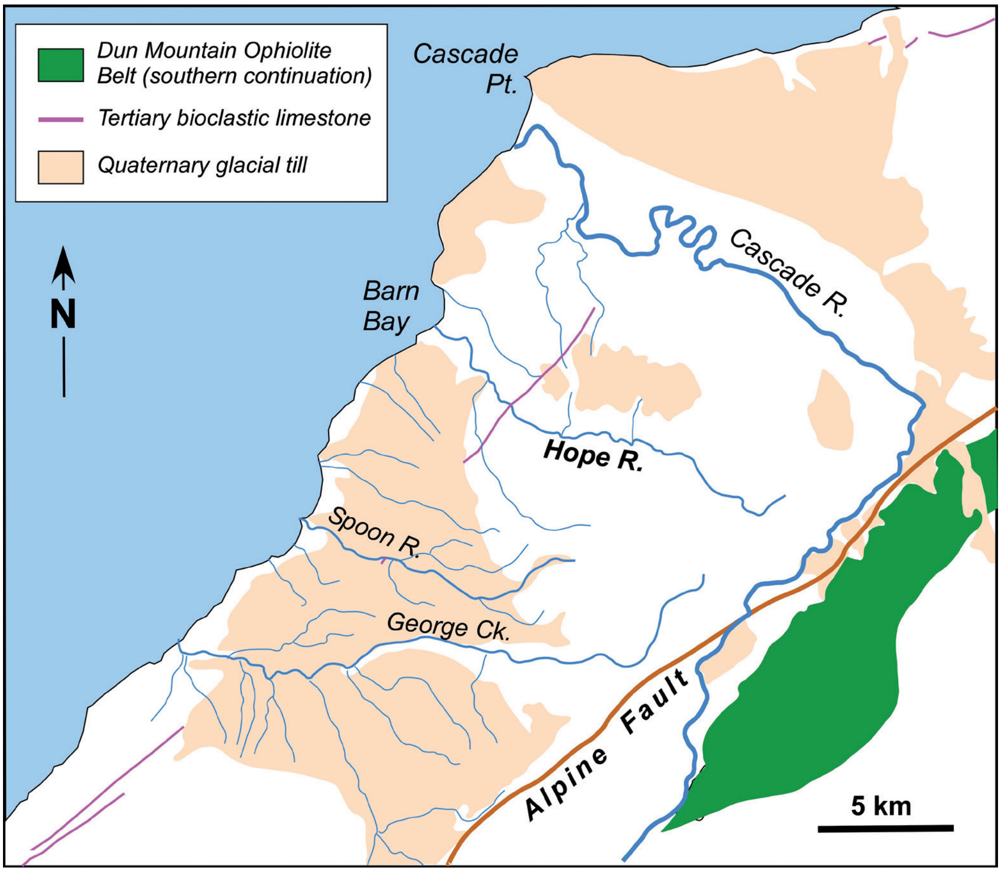


Text-Fig. 6.
Map showing location and extent of the nephrite-bearing *Pounamu Ultramafic Belt* in the Alpine Schist (biotite and garnet zone schist), Southern Alps, north Westland (simplified after Nathan et al., 2002), and Pleistocene glacial outwash that is the main source of nephrite pounamu in the Taramakau and Arahura rivers. Green circle supposed position of *Te Waka* (the canoe), a large pounamu 'outcrop' (boulder?) in the Arahura River 15 miles (24 km) inland from the river mouth according to Hochstetter. **Below:** Section through an in-situ nephrite-bearing ultramafic-mafic-marble sequence exposed in a tributary (Jade Creek) of Olderog Creek that debouches into the Arahura River (after Johnston, 1983), and water-smoothed cobble of nephrite pounamu from this outcrop. The section dips north at 60° (see Text-Fig. 5 for location and text comment 7 for details).

the material of the meris [sic] *which we saw making at the village* [near the mouth of the Taramakau River; see comment 6] *was from this place."*

10 Julius Haast (1822–1887), a German-born New Zealand explorer, geologist, and founder of the Canterbury Museum in Christchurch.

11 A report in the *Nelson Examiner and New Zealand Chronicle*, 21 January 1843 (page 183), states that "*Captain Anglin* [sic; William Andrew Anglem (1804–1846)], *with part of his crew, had ascended a large river in a boat, somewhere on the west coast of this island, to collect green stone, or some other valuable mineral; and while blasting, an explosion of gunpowder took place, which dreadfully injured the captain's hands and face, and more or less wounded two of the men. The captain immediately bound up both his eyes, and was conveyed on board the vessel, then at a distance of twelve hours' sail; and, on reaching the ship, started for Nelson, and arrived here in ten days. By taking every possible precaution, mortification was kept down until the schooner got here, and on the following day, the captain had one of his fingers taken off. Although both*



Text-Fig. 7.
Map of the Hope River–Barn Bay area, south Westland, showing distribution of ultramafic rocks of the southern continuation of the Dun Mountain Ophiolite Belt, Pleistocene glacial till and Tertiary limestone band (see Text-Fig. 5 for location and text comment 11 for details). Pounamu is found in all streams draining glacial till.

his hands are dreadfully shattered, it is hoped that no further amputation will be necessary. The sight of one eye is entirely lost; and one of the crew, it is feared, will lose the sight of an eye. Captain Anglin reports that there is very fine white marble in the neighbourhood of the spot where the accident occurred, but, for some reason, is unwilling to give any precise information whereabouts it was". The river referred to was most certainly the Hope River that debouches into Barn Bay, ~90 km north of Milford Sound, and this agrees with Anglem's report of very fine white marble in the area (Text-Figs. 5, 7), which equates with a 0.5–30 m thick layer of distinctive creamy-white bioclastic limestone, the *Awarua Limestone* (Rattenbury et al., 2010).

According to Beattie (1920: 50), "*pounamu*" was being collected from Milford Sound by Maori with Captain William Anglem and others in 1841, resulting in the first successful shipment of pounamu to China, mentioned by Hochstetter. Shortland (1851: 36) records the result of the second shipment of pounamu after the accident in 1843; "*the specimens carried to China were found to be of a quality not esteemed there, being disfigured by the presence of small black specks, like the mica grains in granite. So the speculation failed*". The "*small black specks*" are chromite and a characteristic feature of pounamu found in the Hope River (Beck & Mason, 2010: 93), that is derived from glacial till (Text-Fig. 7).

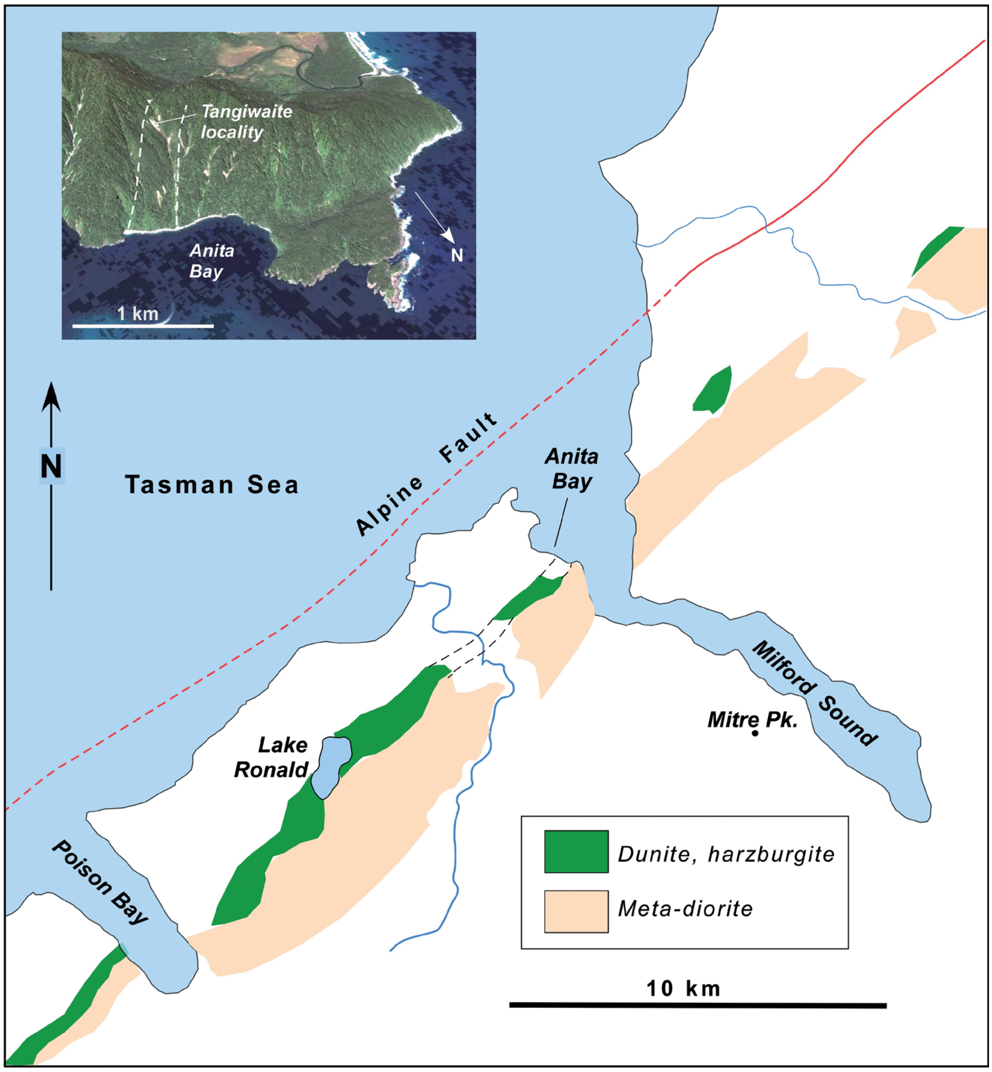
12 See Text-Figure 8 (Map of Milford Sound geology and tangiwaite occurrence).

The first description of pounamu from Milford Sound is given as early as 1844 by David Monro who befriended and assisted Hochstetter by translating his public addresses during his stay in Nelson during August to October 1859.

"*The greenstone, so much prized by the Maories, and also it was hoped by the Chinese, is found in various places on the west coast. It has principally hitherto been worked in a place called Barn Bay* [Text-Figs. 5, 8]*. A block of it, weighing several tons, lay on the beach here, in breaking up which Captain Anglin* [sic] *and some of his crew were so much injured* [see comment 11]*. But the mineral must be abundant, for I was shown several rounded pebbles of it picked up on the beach, where they are sufficiently common. There are two kinds of greenstone, that which is commonly seen, and which is named the ponamoo* [sic]*, and another sort more glassy and transparent named tuggewai* [sic]*. The ponamoo is exceedingly hard, and has an irregular fracture. The tuggewai is much softer, of a more transparent green, and divides easily into plates. It can be scratched with a penknife, and thin plates can thus be raised.*

The greenstone prized by the Chinese is undoubtedly the same mineral, slightly different in colour. It has a transparency and brilliancy which I have never yet seen in the New Zealand stone. Ornaments made of the Chinese greenstone look almost like a stained glass, or some parts of them are nearly colourless, while others are clouded with beautiful transparent grass-greens and whites. The mineral of these shades of colour is exceedingly valuable in China – worth its weight in gold. It is by no means unlikely that the mineral having the requisite shade may yet be found in New Zealand. Where there is a large extent of greenstone, it is rather indeed probable that very considerable varieties in its tint will be met with." (Monro, 1844: 123–124).

Heaphy (1862: 17) states that the "*tangi wai is the least esteemed by the Maoris, but by far the most beautiful of all.*



Text-Fig. 8.
Map showing the distribution of ultramafic rocks (*mylonitised dunite, harzburgite*) and eastern contact *metadiorite* across Milford Sound to Poison Bay in the south. There is a 40 m thick band of *hornblendite* along the ultramafic-metadiorite contact.
Inset: The nature of the steep bush-covered terrane fronting Anita Bay where *tangiwai* was first found as beach pebbles derived from an in-situ source on the hill slope (probably where the slip is visible) at a height of ~420 m. Dashed white lines define the width and strike of the steeply inclined ultramafic rocks (Photo: Google Earth Image, 2009).

It is of clear pale green, and is very translucent. […] *It is the only kind of poenamu that would be esteemed for purposes of ornament by Europeans*", and therefore the reason why Hochstetter chose to analyse it.

The first analyses of tangiwai were given by Hector & Skey (1866: 412)[7] in the *Report of the New Zealand Exhibition of 1865* held in Dunedin, under the heading "*Serpentine.*"

"*This mineral occurs in New Zealand in two forms,—Common Serpentine, that forms extensive rock masses characteristic of the mineral found in various parts of the Middle Island, both in the Province of Nelson and Otago, and noble Serpentine, which occurs in thin veins associated with the Jade, or greenstone of the Maoris, by whom it is distinguished by the name of Tangiwai. Large masses of this beautiful mineral were exhibited in the Geological Department (Otago), having been brought from Milford Sound, where they occur as boulders of various sizes, and generally much water worn. Some of the smaller pieces, when cut and polished, were very attractive, on account of their beautiful deep sea green colour, their translucency, their purity, and remarkable closeness of grain. This mineral is somewhat soft, and, breaking readily, is capable of being worked into any shape with the greatest ease, and for ornamental work generally is well adapted. It's general characters are as follows:—Colour dull green and mottled black, lustre slightly resinous, fracture splintery, streak dirty white, hardness 4.5, sp. gr. 2.592. Is completely decomposed by hydrochloric acid. In blow-pipe flame infusible, turns faint buff colour, no distinct soda reaction, but slight reaction of manganese with the proper fluxes*".

This description is comparable with that of Hochstetter's tangiwai. Three analyses of the Anita Bay tangiwai are given in Table 1 (Analyses 11, 12, 13).

Ten years later Hutton & Ulrich (1875) referred to the Anita Bay tangiwai occurrence as *marmolite*[8]:

"*The Serpentine which occurs plentifully at Anita Bay, is pale green, translucent and with a more or less schistose structure. It is tolerably hard, but can be scratched with a knife. It is the inferior greenstone, or Tangiwai, of the Maoris, and the Marmolite of mineralogists. The true green-*

7 James Hector (1834–1907), geologist, explorer, administrator. Appointed director of the Geological Survey and Colonial Museum of New Zealand, Wellington, in 1865.
William Skey (1835–1900), Colonial Laboratory analyst attached to the Colonial Museum and Geological Survey of New Zealand.

8 *Marmolite* (Nuttall, 1822) is a pale green foliated or laminated type of serpentine with a pearly lustre. However, the serpentine mineral is either chrysolite or lizardite (Nagy & Faust, 1956; Whittaker & Zussman, 1956), not antigorite as is tangiwai.

	Nephrite										Tangiwaite			
wt.%	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
SiO_2	57.10	55.01	51.08	56.00	51.70	52.25	57.75	57.38	57.35	56.55	40.20	41.20	45.91	44.77
Al_2O_3	0.72		1.42			0.58	0.90	0.22	0.22	0.21	Tr.	Tr.	5.63	
Cr_2O_3			Tr	Tr	0.30	0.26					Tr.	Tr.	Tr.	
Fe_2O_3		3.52			0.65		0.38							
FeO	3.39		12.43	11.13	7.62	6.80	4.79	3.50	5.94	6.21	12.10	12.10	1.69	3.35
MnO			Tr	Tr	Tr		0.46				Tr.	Tr.	Tr.	
MgO	23.29	21.62	21.35	21.95	23.50	18.07	19.86	22.32	20.70	19.78	33.20	34.02	35.07	39.17
NiO							0.22							
CaO	13.48	13.66	9.00	9.94	13.09	19.27	14.89	13.68	13.47	13.6				
Na_2O			tr	tr		0.68								
K_2O		1.42						0.69						
H_2O (T)*	2.50	5.04	0.97	0.97	2.42	1.50	0.68	2.78	3.13	2.81				12.94
H_2O+											12.70	12.74	12.67	
Total	**100.48**	**100.27**	**96.25**	**99.99**	**99.28**	**99.41**	**99.93**	**100.57**	**100.81**	**99.16**	**98.20**	**100.06**	**100.97**	**100.23**
Hardness			5.5-7					5.0-6.0				4.5		3.5-5
Density			3.02			3.015	3.18	3.03		3.0895		2.592		2.61

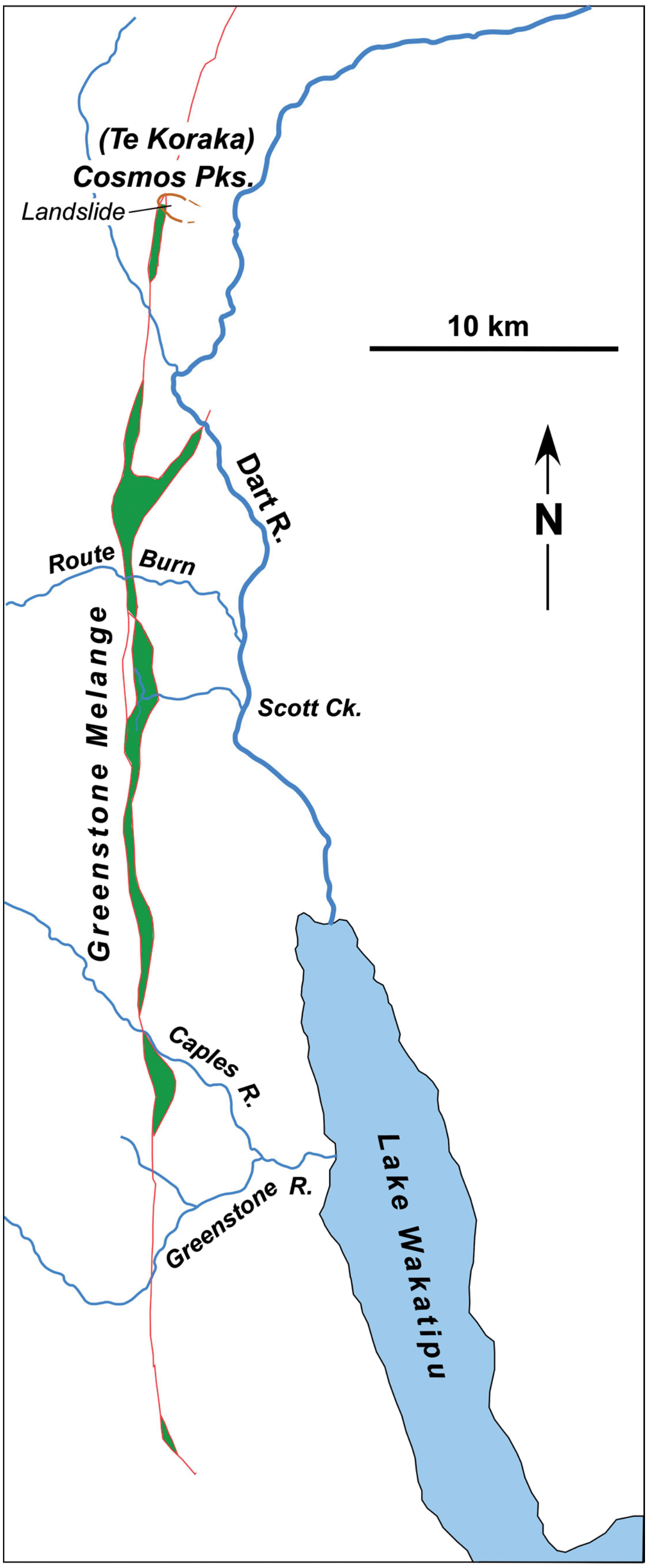
Tab. 1.
Analyses of pounamu between 1851 and 1880.
***H_2O(T)** =Total H_2O, i.e., H_2O^+ and H_2O^-. Tr = trace.
1. SCHEERER (1851); **2**. HOCHSTETTER (1864) (corrected Al_2O_3 and CaO values after BERWERTH, 1880a); **3**, **4**. HECTOR & SKEY (1866); **5**, **6**. DAMOUR (1865). Fragment of an axe (5); dark green jade axe (6); **7**. FELLENBERG (1869); **8, 9**, **10**. BERWERTH (1880a). Analysis 8 is a reanalysis of Hochstetter's "kawakawa"; **11**, **12**, **13**. HECTOR & SKEY (1866); **14**. BERWERTH (1880b).

stone, or Pounamou of the Maoris, — the Nephrite or Jade of mineralogists—appears to occur only in veins through the marmolite, and does not exist in large separate dykes. Nephrite may be distinguished from Marmolite by its hardness, it being impossible to scratch the former with a knife. Chemically, nephrite differs from marmolite only by the absence of water in its composition (nephrite, as tremolite-actinolite, contains ~2.2 % H_2O), and any number of different varieties may be found differing much in hardness, even in the same block of marmolite" (HUTTON & ULRICH, 1875: 28–29).

From HECTOR's 1863 description of the pounamu occurrence at Milford Sound quoted by Hochstetter, the location is inscribed as "*Hornblende schists with large veins of Jade*" on his 1873 geological sketch map of New Zealand. This new map was especially prepared for the International Vienna Exhibition in 1873, where New Zealand had a large display created by Hector assisted by Julius von Haast with the help of Hochstetter who was a member of the organising committee. It was drafted by Augustus Koch, a cartographer and artist in Wellington, New Zealand, who had accompanied Hochstetter as artist on his North Island expedition in 1859 (NATHAN, 2014). In addition to Monro's 1844 information, DIESELDORFF (1901) lists Barn Bay as a source of pounamu, and BEATTIE (1920) records that Maori informants had told him that good pounamu could be obtained there. These occurrences were not in-situ "*nodules or irregular masses*" as suggested by Hector at Anita Bay, but boulders derived from glacial till and in turn derived from the ultramafic rocks further inland (the southern continuation of the *Dun Mountain Ophiolite Belt* dextrally offset by the Alpine Fault (Text-Figs. 5, 7).

Under the heading "*Serpentine*" in the *Juror's Report of the New Zealand Exhibition 1865*, Hector draws attention to the presence of *noble serpentine (tangiwai* variety of pounamu, and distinguished from *common serpentine*) occurring as thin veins associated with "*the Jade, or greenstone* [nephrite] *of the Maoris*" at Milford Sound (Anita Bay) (HECTOR & SKEY, 1866: 412). Under the heading "*Jade*" in the same report is recorded that "*One kind of the jade (ordinarily known as Maori greenstone, or 'Poenamu') from Milford Sound is speckled with chromic iron. It occurs in-situ on several parts of the West coast of Otago, as veins traversing serpentine and hornblende schist*" (HECTOR & SKEY (1866: 413), However, COX (1882: 394–395) states that "*the only locality where it* [nephrite] *has been found in situ is at Milford Sound, where it occurs as veins traversing serpentine and hornblende schist, one variety being speckled with chromic iron"*. This is probably the analysed sample containing 12.10 % FeO (Table 1) but as Cr_2O_3 is present in trace amounts, the black inclusions are more likely magnetite. Again, the Milford Sound locality is generalised and includes Anita Bay and the coastal area to the north.

13 Lake Wakatipu (Text-Fig. 5), incorrectly equated as the location of "Te Wai Pounamu", is not a source of nephrite, but "float" has been found in rivers entering the northern and western part of the lake, that drain fault-bounded septa of ultramafic rocks that form part of what is called, the *Greenstone Melange Belt* (Text-Fig. 9). The story of the rediscovery of an important in-situ source of the *inanga* variety of pounamu (largely semi-nephrite) in a mountainous area north of Lake Wakatipu known to the Maori as *Te Koroka (*now called *Cosmos Peaks)* (Text-Fig. 9) (BEATTIE, 1920; SKINNER, 1935), is detailed in BECK & MASON (2010: 72–74).



Text-Fig. 9.
Map of the area north of Lake Wakatipu, western Otago, showing the fault-bounded Greenstone Melange belt (sheared/schistose serpentinite, gabbro, greyschist), *Te Koroka* (a South Island chief) the source of *inanga* pounamu, and pounamu-bearing streams (see Text-Fig. 5 for location and text comment 12 for details). Maori sources mention that the pounamu source occurred in a great cliff or landslide called *Te Horo* (the Maori word for "to fall off" or "crumble down") (Beck & Mason, 2010: 74), and possibly the area marked "landslide" on the map. Greenstone River was the route followed by Maori from the east coast of the South Island to the pounamu source rather than being a collection site.

14 With respect to this find, Hochstetter writes: "*[I]n Current Basin, […] slaty limestone is exposed […] at Okure* [sic] *Bay. Here it stands vertical, or is in part even somewhat overturned to the east, and below the calcareous slates (apparently above them) are thick beds of a semi-crystalline serpentinous rock, partly reddish, partly grey, which gradually passes into real serpentine.* […] *At the foot of these cliffs I also found a nodular piece of nephrite, which probably belongs to these altered rocks*" (Fleming, 1959: 242; Hochstetter, 1864a: 226) (Text-Fig. 10).

In 1901, Arthur Dieseldorff[9] (University of Marburg) wrote a letter to Hochstetter's widow, Georgiana von Hochstetter (1842–1905), requesting permission to examine this nephrite specimen. The following is an English translation of the original German holograph letter:

Letter from Arthur Dieseldorff to Georgiana von Hochstetter

(Dr Albert Schedl Collection, Vienna)

"Marburg in Hessen
Elisabeth Strasse 10
13 April 1901

Esteemed Mrs Hofrat!

During his famous circumnavigation of the earth your husband found, namely to the north of Nelson in the South Island of New Zealand, a nephrite cobble at Okuri Bay. From collections placed as my disposal I also picked out nephrite from the neighboring D'Urville Island and as you can see from the enclosed small publication, these were described by me as a mineralogist.

This shall be examined in more detail in my doctoral thesis [Dieseldorff, 1901]. For this purpose, I would very much like to have the nephrite cobble found by your husband for comparison. In this regard I wrote to Hofrat Tschermak, who had Dr Berwerth inform me that the sample was still in your custody.

While I now most politely ask you to lend it to me for a few days, I would also like to ask if you would allow a small splinter to be chipped off for the purpose of making a thin section.

With the greatest of thanks in advance, I have the honour to be,

Your very devoted

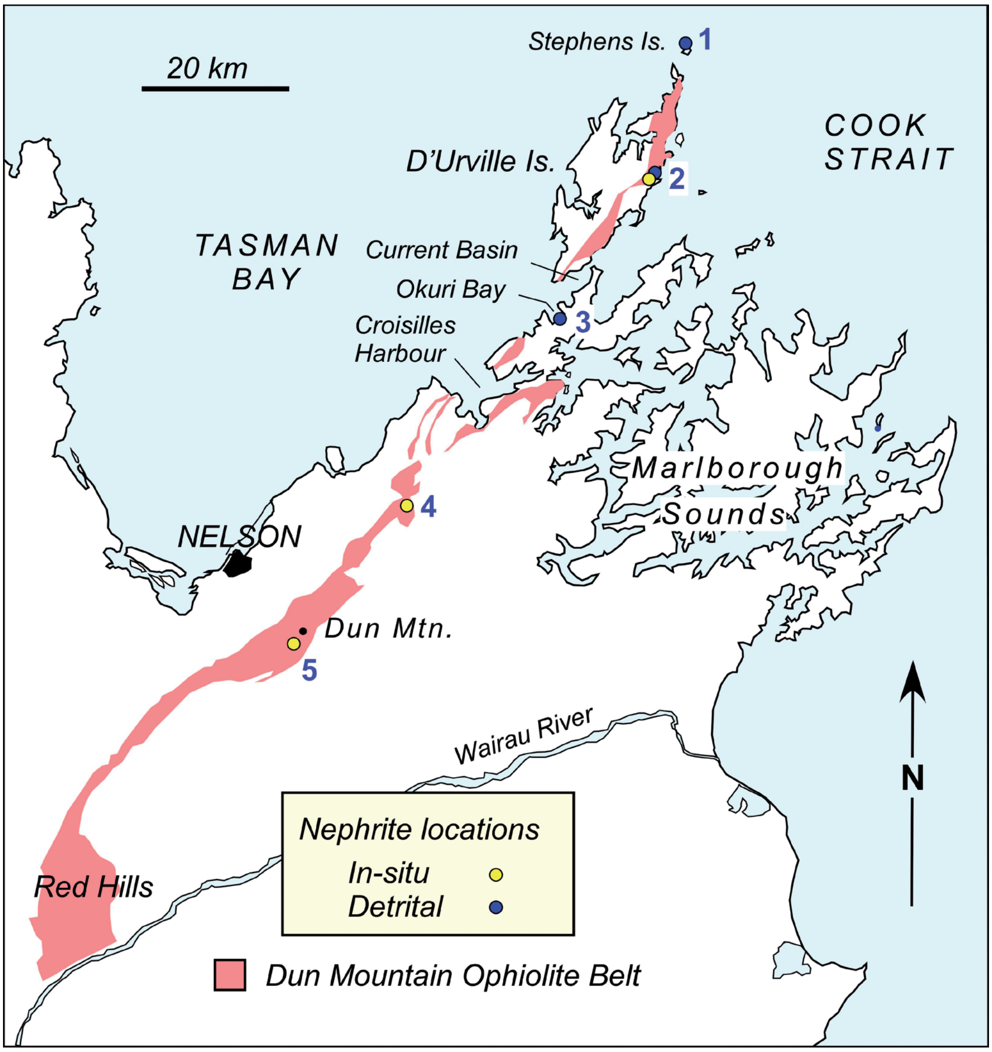
Arthur Dieseldorff

cand. rer. Nat

Marburg in Hessen, (not in Austria)"

However, there is no description of Hochstetter's sample in Dieseldorff's 1901 doctoral thesis paper, because the sample was neither in Hochstetter's collection nor in the Natural History Museum, Vienna. However, four additional nephrite samples, three detrital and one in-situ, from D'Urville and Stephens islands collected by Hugo Schauinsland[10] of Bremen, on a zoological expedi-

9 Arthur Daniel Dieseldorff (1866–1928), German mining engineer.
10 Hugo Hermann Schauinsland (1857–1937), German herpetologist, Übersee-Museum, Bremen.



Text-Fig. 10.
Map showing numbered localities (1–5) of in-situ and detrital nephrite – semi-nephrite associated with the Dun Mountain Ophiolite Belt, Nelson Province. 1, 2. DIESELDORFF (1901); 3. HOCHSTETTER (1864a); 4, 5. COLEMAN (1966) (see Text-Fig. 5 for location and text comment 14 for details).

tion that visited New Zealand in 1896–1897, are described and analysed by Dieseldorff, and these were certainly derived from the same rocks as Hochstetter's pebble (Text-Fig. 10), i.e. melange of the *Dun Mountain Ophiolite Belt*.

15 See Text-Figure 11. Types of pounamu, the *tangiwai* and *kawakawa* varieties described by Hochstetter.

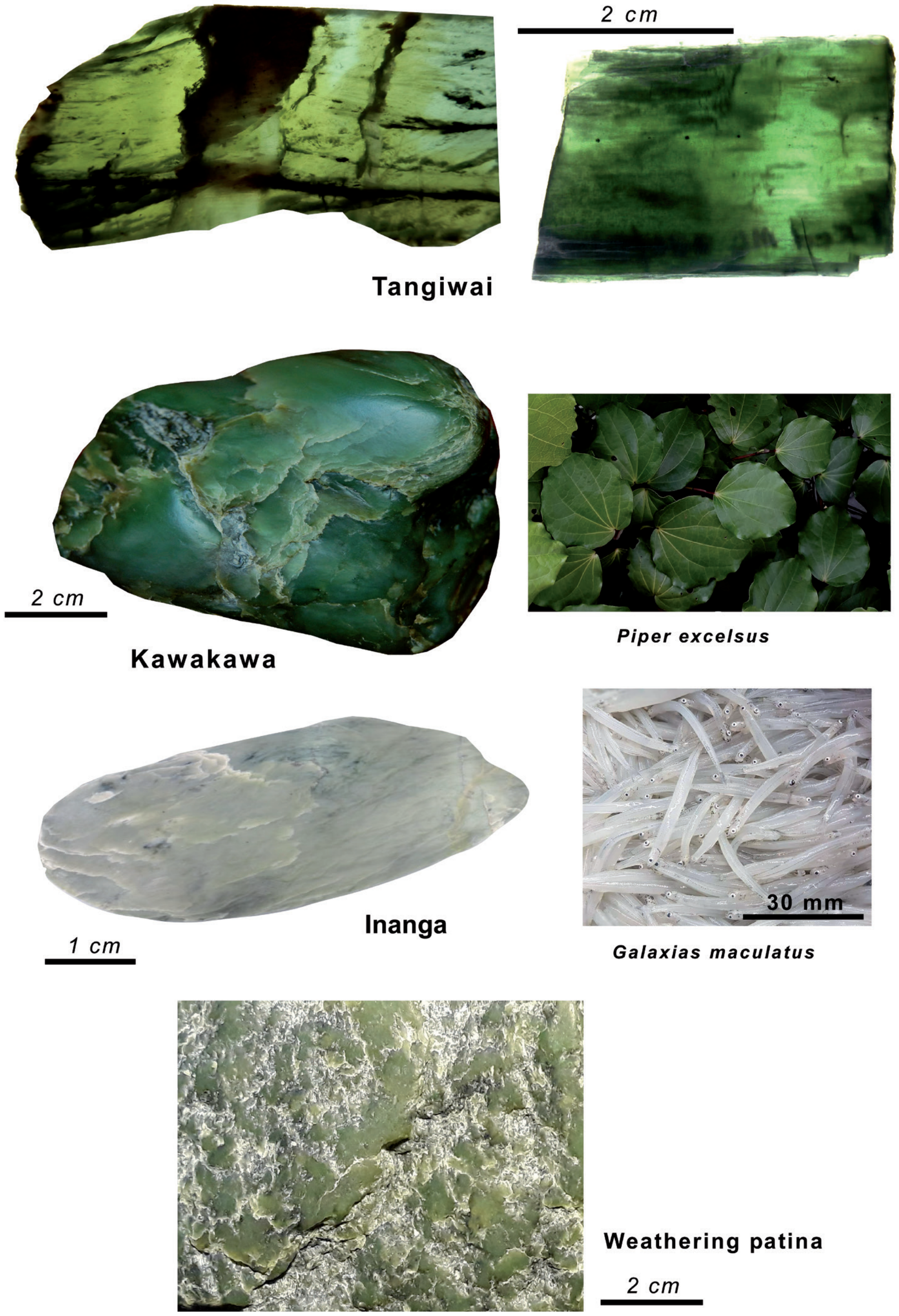
16 *Tangiwai* takes its name from the tears that come from great sorrow. Tangi means "to cry" and wai means "water", or "tears". *Koko-tangiwai*, the longer name for this stone, refers to a deep sorrow that is never completely healed. *Pipiotahi* is the Maori name for Milford Sound and means *one piopio – (tahi* meaning one), the South Island thrush (*Turnagra Crassirostris*), and the Sound is known as the "*place of the singing thrush*".

17 See Text-Figure 11. Types of pounamu, the *tangiwai* and *kawakawa* varieties described by Hochstetter.

18 Reverend Richard Taylor (1805–1873), missionary of the Church Mission Society in New Zealand, who wrote numerous articles and books about the natural and cultural environment in New Zealand.

19 The Latin name *eleotris basalis* is quoted in TAYLOR (1855: 414), but the *inanga* is now known as *Galaxias maculatus*, and commonly as *whitebait*, as shown in Text-Figure 11.

20 There is some confusion regarding this variety of pounamu. *Aotea,* perhaps more correctly spelt *Kahotea* in this case, is a variety of nephrite streaked or flecked with white. *Kahotea* is an abbreviation of *kakaho*, the white flowing seedhead of the toetoe (*Cortaderia richardii*) and the name commemorates the first discovery of a "white" pounamu boulder in the Arahura River (BECK & MASON, 2010). WILLIAM ANDERSON (1777) refers to such examples of uncut pounamu traded aboard Cook's ship in Queen Charlotte Sound in February 1777 as being "*cover'd with a whitish crust"* like that on flint nodules. The white patina rind on nephrite is the result of weathering when buried in an alkali environment that results in a "*loosening"* of the fibrous tremolite-actinolite nephritic texture to produce an increased intergranular porosity, that, in turn, causes light refraction, dispersion and total reflection, producing a white appearance (e.g. TSIEN, 1996) (see Text-Fig. 12). On the other hand, Reverend James Stack (letter in CHAPMAN, 1891: 515) refers to *aotea* as "*a counterfeit greenstone, opaque; often mistaken when in the river beds by the unskilful*"; ELSDON BEST (1974: 207) clarifies "*opaque*" to mean the outside weathered portion of large boulders. Regarding *kahotea,* Stack refers to this variety as "*dark green with spots of black through it, rather more opaque than the other varieties"* (in CHAPMAN, 1891: 513), thus contributing to the confusion of the correct definition of the nephrite term.



Text-Fig. 11.
Three varieties of pounamu. *Tangiwai*, two backlit slices; ***Kawakawa,*** stream cobble and *Piper excelsus*; ***Inanga,*** river pebble and *Galaxias maculatus* ***(Inanga or whitebait);*** irregular surface of pounamu river cobble (possibly *Kahurangi* variety) with white weathering patina preserved in hollows. See text comments 17 and 19 for details (Photos: Rodney Grapes).

21 *Hohapa*; it is unclear whether Taylor means nephrite, or some other green stone. *Kuru tongarerewa*: *Kuru* is applied to a pendant and not to a variety of nephrite. *Totoeka*, also spelt *Totoweka:* a very rare rusty, yellow or yellowish-brown-coloured nephrite variety, with red inclusions that are likened to the blood (*toto*) of the *weka* (*Gallirallus australis*).

22 Augustin Alexis Damour (1808–1902), French mineralogist with an interest in prehistory.

23 *Dipyre* is a varietal name of *scapolite* with a composition generally expressed in terms of two end members, *marialite* (Ma) ($Na_4Al_3Si_9O_{24}Cl$) and *meionite* (Me) ($Ca_4Al_6Si_6O_{24}CO_3$). Intermediate compositions between Ma_8Me_2 and Ma_5Me_5 are referred to as dipyre. At the time of Hochstetter's writing, *wernerite* (as a mineral group name) was used synonymously with scapolite, but is now discarded (Bayliss, 1987).

24 Damour's *jade vert* analysis if treated as a monomineralic substance computes on the basis of 6 oxygens to jadeite pyroxene ($NaAl[Si_2O_6]$) with the structural formula:

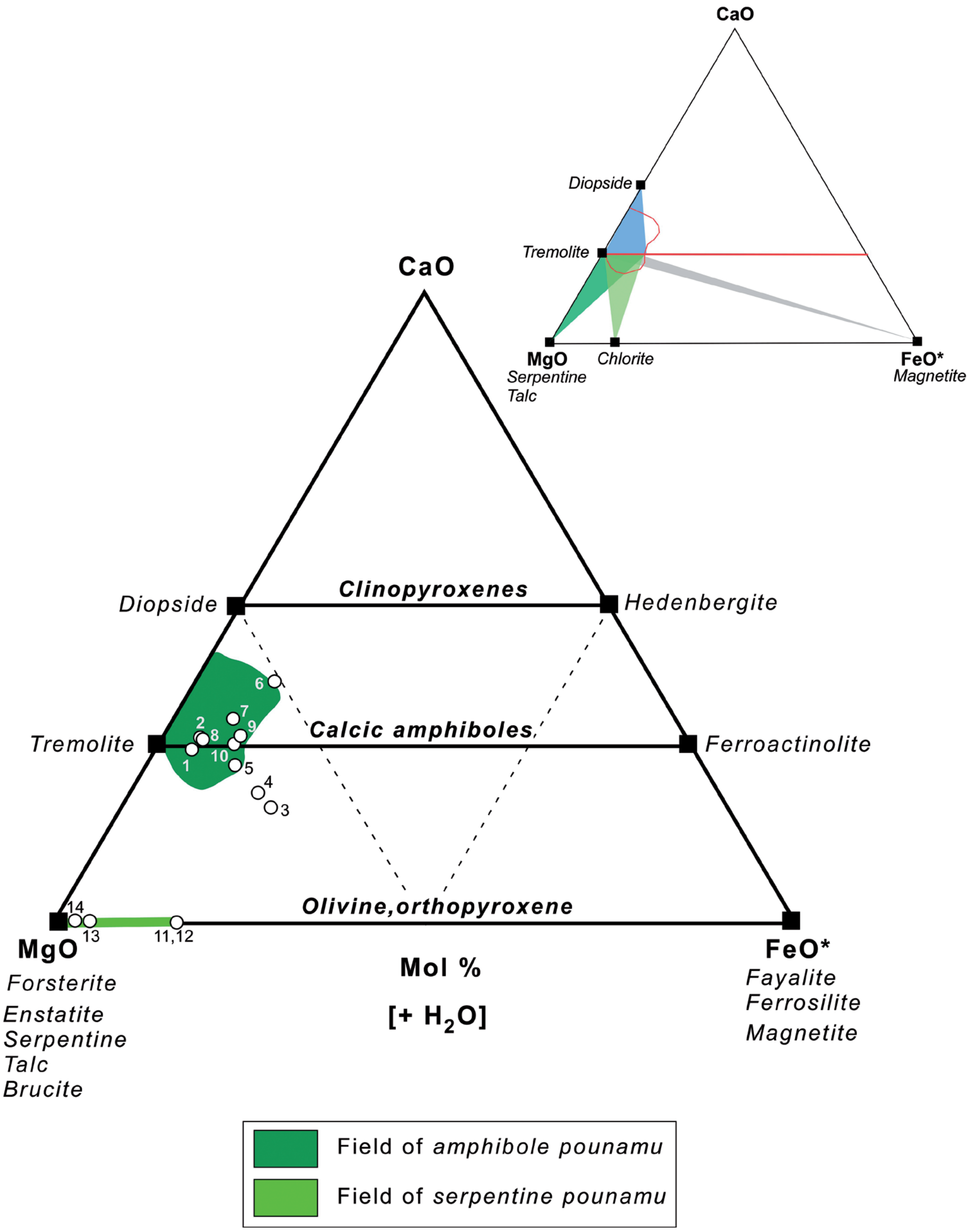
$$(Na_{0.851}Ca_{0.098})_{0.949}\,(Mg_{0.058}Fe_{0.044}\,Al_{0.904})_{1.006}\,Si_{2.009}O_6$$

25 On the assumption that the pounamu analysed by Scheerer[11] is monomineralic, his analysis recalculated on an anhydrous basis of 23 oxygens yields a structural formula of:

$$Ca_{1.90}(Mg_{4.56}Fe_{0.37})_{4.93}\,(Si_{7.51}\,Al_{0.112})_{7.62}O_{22}(OH)_2$$

The importance of Scheerer's analysis is that it was the first to clarify the nephrite variety composition of pounamu. At the time of Hochstetter's publication, Scheerer's analysis was the only one available. Damour's two pou-

11 Karl Johann Scheerer (1813–1875), German metallurgist and chemist.



Text-Fig. 12.
Mol.% CaO – MgO – FeO* + H_2O chemographic diagram, with FeO* = all iron, showing compositions of nephrite and tangiwaite pounamu determined between 1851 and 1880: Numbers refer to analyses listed in Table 1.
Inset: Diagram showing typical accessory minerals in nephrite pounamu and their relationship to the pounamu composition field as vector cones; *blue* = diopside; *dark green* = serpentine, talc; *light green* = chlorite; *grey* = magnetite/chromite. Chlorite composition is from GRAPES (unpublished analyses). The accessory mineral(s) will only affect the nephrite composition where individual oxide values exceed those in tremolite-actinolite. Nephrite compositions with CaO *above* tremolite-ferroactinolite tie-line may contain *diopside* (e.g. 6). Compositions with CaO *below* tie-line may contain non-Ca-bearing hydrous Mg-Fe minerals *serpentine, talc, chlorite*, and Fe-rich compositions (e.g. 3, 4) may also contain *magnetite* and/or *chromite-picotite* if indicated from the Cr_2O_3 content. The only variation in tangiwaite compositions is along the MgO-FeO* base of the triangle.

namu analyses were published in 1865, and those of HECTOR & SKEY in 1866.

26 Wilhelm Karl Ritter von Haidinger (1795–1871), Austrian mineralogist and founding director of the Geological Survey of Austria.

27 The property by crystals of exhibiting two different colours when viewed along different axes.

28 As provided to Hochstetter (Fehling to Hochstetter, February 1861) both analyses by Melchior and Meyer are spurious. Despite a density of 2.61, **analysis 1** is not the "*tangiwai*" variety of pounamu (see translation of BERWERTH, 1880b), nor is it of the nephrite variety. Berwerth concluded that it was "*a mistake for an analysis by someone else*" and therefore certainly not the composition of the sample supplied by Hochstetter. Except for the presence of 0.94 % K_2O and the low H_2O content of 1.11 %, the analysis approximates that of *magnesio-hornblende,* and of unknown origin, in which case the measured density is also too low for this amphibole composition (i.e. ~3.0–3.1). In **analysis 2** of the *kawakawa* variety, the Al_2O_3 value is mistakenly exchanged for that of CaO (see translation of BERWERTH, 1880a) and the corrected analysis indicates a composition approaching that of the *nephrite* and with the right density of 3.02. However, the high K_2O of 1.43 % and H_2O of 5.40 % are anomalous*. All subsequent New Zealand nephrite analyses have K_2O contents of < 0.5 % and H_2O contents of 1.8-2.7 %. Also, Na_2O is present in amounts ranging from < 0.01-0.70 % despite Fehling's communication to Hochstetter stating that both "*minerals only contain potash and no soda*". Nevertheless, if some is present in Hochstetter's kawakawa (0.69 % according to Berwerth's re-analysis), it indicates that muscovite ($KAl_2(Si_3Al)O_{10}(OH,F)_2$) must be present; emerald-green chromian muscovite has been found with chlorite intergrown with tremolite-actinolite in nephrite selvages surrounding metagabbro in quartzo-feldspathic schist (the source of K) in northwest Otago (COOPER, 1995) (see Text-Fig. 17B). If Hochstetter had received the correct analyses of "*kawakawa*" and "*tangiwai*" pounamu from Fehling's

laboratory, his paper would have been the first to characterise the two mineralogical varieties of New Zealand pounamu, i.e. nephrite and tangiwaite.

Extract of letter from Hermann Christian Fehling to Ferdinand von Hochstetter dated February 1861 relating to a 'chemical study of various minerals from New Zealand'

(Dr Albert Schedl Collection, Vienna)

"No 1. Kawakawa pounamu variety of the Maori. Specific gravity 3.02, hardness 6.50

No.2. Tangiwai pounamu variety of the Maori. Specific gravity 2.61, hardness 5.0

	No. 1 (Melchior) [see HOCHSTETTER, 1864b: 475, *b.*]	No. 2 (Melchior & Meyer) [see HOCHSTETTER, 1864b: 475, *a.*]
Silica	55.01	53.01
Alumina	13.66	10.83
Iron oxide	3.52	7.18
Mangenese oxide	0.00	0.00
Lime	--	12.40
Magnesia	21.62	14.50
Potash	1.42	0.97
Water and Loss on Ignition	5.04	1.11

Nephrite No. 1 does not contain lime, both minerals only contain potash and no soda.

Stuttgart Feb 1861, Dr. Fehling".

Analyses of the two pounamu varieties, nephrite and tangiwai, produced between 1851 and 1880 are listed in Table 1, and their compositions are plotted in terms of mol.% CaO-MgO-FeO*, where Fe* = all iron as FeO (Text-Fig. 12). All nephrite analyses except 3 and 4 plot within the nephrite field defined in Text-Figure 2. Analyses 3, 4, 5, 6 and 7 show notable deviations from the tremolite-ferroactinolite tie-line, and with reference to the vector diagram (inset in Text-Fig. 12), indicating the presence of diopside (6, 7), and analyses plotting below the tie-line indicating the presence of hydrous Mg-Fe silicates and magnetite (3, 4, 5). The only compositional variation of tangiwai is along the MgO-FeO base of the triangle. The high Fe in analyses 11 and 12 implies the presence of magnetite (Fe_3O_4) rather than Cr-spinel ($[Fe,Mg][CrAl]_2O_4$) as only trace amounts of Cr_2O_3 and Al_2O_3 are recorded. The high Al is analysis 13 could suggest the presence of Al-serpentine, rather than Mg-chlorite which would tend to reduce the silica and water content. Analyses of serpentine in a tangiwai sample indicated between 2.2–4.5 % Al_2O_3 (GRAPES, unpublished analyses).

29 Except for the analyses of Schafhäutl[12] (**II** and **III**), the nephrite analyses listed and discussed by Hochstetter are not pure minerals of the tremolite-actinolite series with the ideal Ca-amphibole site occupancies, $\mathbf{A}_{0\text{-}1}\mathbf{M4}_2(\mathbf{M3,M2,M1})_5\mathbf{T}_8O_{22}(OH)_2$, and the following comments can be made on these compositions when recalculated on an anhydrous basis of 23 oxygens with all iron as FeO.

I. With high Al_2O_3 and no CaO, the analyses of Kastner[13] approximates an *orthoamphibole* composition $\mathbf{A}_{0\text{-}1}(\mathbf{M4,M3,M2,M1})_7\mathbf{T}_8O_{22}(OH)_2$ (all M-sites combined) of the *anthophyllite-gedrite* series:

$$(Mg_{6.22}Fe_{0.56}Cr_{0.005}Al_{0.39})_{7.17}(Si_{6.87}Al_{1.13})_{8.00}O_{22}(OH)_2$$

Kastner's analysis (in DE SAUSSURE[14], 1806) is often quoted in the old literature as the composition of nephrite (e.g. MITCHELL, 1823; SHORTLAND, 1851). He described the sample as a "*greasy nephrite*", but there are no details as to where it came from, although probably Germany, and no physical properties are recorded. According to FISCHER (1875: 165) the analysis closely approximates the poitin or Hochstetter's incorrectly analysed "*kawakawa*" mineral from New Zealand with the formula:

$$(Ca,Na)_{0.3}(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2\cdot 4H_2O$$

II and **III**. The two analyses from Schafhäutl closely approach the basic Ca-amphibole formula, being, respectively,

$$K_{0.14}Ca_{1.78}(Mg_{4.52}Mn_{0.09}Fe_{0.28}Al_{0.83})_{5.07}(Si_{7.97}Al_{0.03})_{8.00}O_{22}(OH)_2$$

$$K_{0.14}Ca_{1.81}(Mg_{4.50}Mn_{0.09}Fe_{0.29}Al_{0.18})_{5.06}(Si_{7.94}Al_{0.06})_{8.00}O_{22}(OH)_2$$

However, the presence of K_2O and no Na_2O, and the very low H_2O in both analyses is questionable.

IV, **V**, **VI.** These three analyses from Rammelsberg, Damour and Scheerer, respectively, are the least monomineralic nephrites. Their structural formulae are as follows:

$$Ca_{2.35}(Mg_{5.30}Mn_{0.16}Fe_{0.25})_{5.71}Si_{7.47}O_{22}(OH)_2$$

$$Ca_{1.80}(Mg_{5.45}Fe_{0.13})_{5.58}Si_{7.85}O_{22}(OH)_2$$

$$Ca_{1.81}(Mg_{5.26}Fe_{0.16})_{5.42}Si_{7.81}Al_{0.11})_{7.92}O_{22}(OH)_2$$

All show cation deficiencies in T-sites, excess in M1, 2, 3 sites, excess (IV) and deficiency (V, VI) in the M4 site. In analysis IV, the low H_2O of 0.68 % is questionable and the high MnO of 1.39 % is unusual.

VII. See text comment 25.

30 *Meerschaum* (*sea-foam* in German) is now known as *sepiolite* with the ideal formula $Mg_4Si_6O_{15}(OH)_2\cdot 6H_2O$, i.e., wt.% SiO_2 = 55.65; MgO = 24.89; H_2O = 19.26. *Soapstone*[15], also known as *steatite*, is an ultramafic rock essentially composed of talc with various amounts of chlorite, amphiboles, (e.g. tremolite-actinolite, anthophyllite, cummingtonite), trace chromite, and is formed by metamorphism of protoliths such as dunite, serpentinite, or dolomite. The soapstone composition quoted from Rammelsberg by Hochstetter is that of *talc* ($Mg_3Si_4O_{10}(OH)_2$), and if alumina is accounted for possibly *saponite* ($Ca_{0.3}(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2\cdot 4H_2O$).

12 Karl Franz Emil von Schafhäutl (1803–1890), German physicist, geologist, librarian and musicologist.

13 Karl Wilhelm Gottlob Kastner (1783–1857), professor of physics and chemistry at the University of Heidelberg between 1805 and 1812.

14 Nicolas-Theodore de Saussure (1767–1845), professor of mineralogy and geology at the University of Geneva.

15 An old name for *saponite* (from the Latin for *soap*, and therefore *soapstone* alluded to by Hochstetter at the end of his paper).

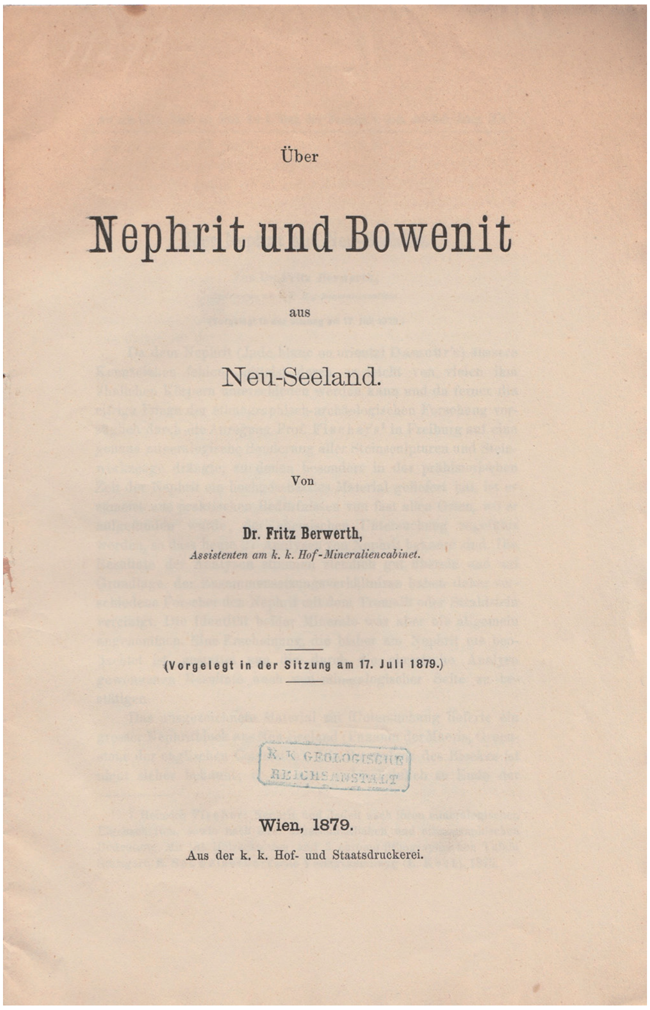
Berwerth's paper in Sitzungsberichte der kaiserlichen Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Classe, Vol. LXXX, 1880: 102–115 (Text-Fig. 13)

On nephrite from New Zealand by Dr Fritz Berwerth

Assistant at the Imperial Royal Mineralogical Court Museum

Since nephrite (**Damour**'s *jade blanc ou oriental*) lacks external characteristics by means of which it can easily be distinguished from many similar bodies, and furthermore since the suggestion of Prof. **Fischer**[1] in Freiburg urging that diligent care be undertaken, a precise mineralogical distinction of all stone sculptures and stone tools, for which nephrite provides a highly valued material, especially in prehistoric times, where it was mostly used for practical reasons in almost all places where it was found, so that today 27 analyses of nephrite are known. The results of the analyses agree fairly well and on the basis of the composition, various researchers have therefore equated nephrite with tremolite or actinolite. Previously the identity of these minerals in nephrite had not been observed, but now the results obtained from chemical analysis allows them to also be confirmed from the mineralogical point of view.

The excellent material for this investigation was provided from a large block of nephrite from New Zealand (*pounamu* of the Maori, *greenstone* of the English colonists). The provenance of the block is not known for certain; but according to a letter from Dr Julius Ritter von **Haast** [1] to Hofrat F. v. **Hochstetter** relating information from Gerhard **Müller** in Westland (New Zealand), it was probably found at the end of the 1850s in Greenstone Creek [2], a tributary of the Taramakau River in the area of Hokitika on the West Coast of the South Island and purchased in Auckland by an English captain[2]. He brought the block to London, where in the autumn of 1877, Dr Carl **Fischer** from Sydney happened to find it in an antique dealer's store. At the behest of Hofrat F. v. **Hochstetter**, Dr **Fischer** took the block to Vienna, and by the generosity of Heinrich Ritter von **Drasche-Wartinberg** it was purchased and presented as an outstanding display piece to the Imperial Royal Mineralogical Court Museum [3].


Über

Nephrit und Bowenit

aus

Neu-Seeland.

Von

Dr. Fritz Berwerth,

Assistenten am k. k. Hof-Mineraliencabinet.

(Vorgelegt in der Sitzung am 17. Juli 1879.)

K. K. Geologische Reichsanstalt

Wien, 1879.

Aus der k. k. Hof- und Staatsdruckerei.

Text-Fig. 13.
Title page of Friedrich Berwerth's papers on New Zealand "*nephrite and bowenite*" (S Nolden Collection). Note that the date is 1879 rather than 1880. At the (18th) meeting of the mathematical and natural sciences section of the Viennese Academy of Science on 17 July 1879 Hochstetter presented the two papers on behalf of the author, Friedrich Berwerth, with the request that they might be published in the proceedings of the Imperial Viennese Academy of Sciences, which they were in 1880.

The block represents the larger half of a huge rolled boulder in which the smaller half has a 23 centimetre deep borehole drilled into it. Its shape was approximately that of an ellipsoid bulging on one side. The friction surfaces are smoothly polished, only in the places protected against impact and abrasion is a light grey decomposition product developed up to a thickness of several lines (steatitic?) thick. Traces of such a change can only be seen on the surface. The original weight of the block was 123.32 kilos. The block now has two cut surfaces and the weight of the main piece has been reduced to 109.85 kilos. The section, which is a mirror image of the main piece, weighs 7.90 kilos. The cut surfaces have been polished. Both are characterized by a deep green, intense colour and highly mirrored surface measuring 47 cm, the short 22 cm. The nephrite mass turns out to be relatively pure on these surfaces. As an admixture, there are some black grains that have been exposed under the surface due to the grind-

1 Heinrich **Fischer**: *Nephrite and jadeite according to their mineralogical properties, as well as their prehistoric and ethnographic importance.* With 131 woodcuts and 3 chromo-lithographic plates, Stuttgart, E. Schweizerbart'sche Verlagshandlung (E. Koch). 1875. [Fischer, 1875]

2 In this letter, Julius v. **Haast** relates the following valuable remarks by Gerhard **Müller** on the purchase price of nephrite in New Zealand: "*In this stream, as well as in the upper course of the Arahura River, blocks of nephrite were often collected, which are 6" to 5' in diameter. In 1869 I myself collected between 300 to 400 pounds of greenstone from the Arahura River between the mouth of the Kawhaka and Mt. Tuhua* [4]*, consisting of float up to 1½ in. diameter. As for the rivers between Ross and Greymouth, I have never heard that a piece of greenstone has been found in any of them. To the south of Hokitika, nephrite is found in three places, namely 1. in the Hope River. 2. in Barn Bay, and 3. in Clinton* [sic; Anita] *Bay, Milford Sound* [5]*. In the first two places it was only found as scree, while in Clinton [Anita] Bay, where it is also found in large cobbles on the beach, it is said to occur in a layer 6' to 8' thick striking in a south direction into the mountain. I could not get reliable news of which type of rock the layer is bounded by on either side. As for the value of nephrite, it can only be approximately determined. It is more a matter of wasting time and the trouble of carrying the stone to the harbour than of any real value; but I think that if I put the value at £ 100 a ton (20 hundred weight), I am not far wrong. Finally I want to say that the nephrite from the Hope River is considered the best quality that can be procured on this coast.*"

ing and that are consistently clustered into several larger or smaller groups. The hardness on the smooth surfaces is close to that of quartz. The fresh fracture surfaces appear as a result of the excellent splintery fracture. The colour nuances range from deep green through grass green to mountain green and leek green, depending on the degree of transparency, which is noticeable in splinters up to several centimetres thick. Close attention was paid to the appearance of crystalline parts on the fracture surface created by impact which had a stronger refraction and which glistened from the nephrite matrix in sharply defined contours. A proper examination of these crystals was therefore justified, since their genesis must be related to the dense mass of the nephrite. All these crystalline areas are composed of clusters of small, up to 5 mm long columns, which appear confused and are randomly imbedded in the dense nephrite matrix. Isolated crystals are seldom separated. With the aid of a magnifying glass, it was possible to establish that several small crystals are split into columnar surfaces which show an excellent glassy lustre. Most of the crystals can be removed individually from the matrix, leaving an impression of their crystal form in the dense mass. In several examples, the shape of these impressions resembles a hornblende prism, narrowly truncated on the sharp edge of the prism. The exact proof that actinolite is present is provided by crystal particles, which I succeeded in extracting from the mass, which was stubborn against the hardest steel instruments, in that sufficient material was required for an analysis. The separated crystals were all fractured pieces. A complete crystal could not be obtained. Although the habit, cleavage, lustre, and colour characterise these small crystals as actinolite, I undertook measurements of the obtuse prism angles of the cleavage of two fragments at Hofrat **Tschermak**'s mineralogical petrological institute at the University [6]. In both cases, the results are the mean of several measurements. I obtained:

1., $1\bar{1}0$: 110 = 54° 38′, resp. 125° 22′

2., $1\bar{1}0$: 110 = 54° 35′ " 125° 25′.

The habit of these crystals, which occur within the dense mass of nephrite, corresponds to a variety of hornblende.

Under the microscope in a thin section made from a piece of the crystal-like part, all cross-sections of the tiny prisms appear almost colourless. Their inclusion in the dense nephrite is porphyry-like. Dichroism is weakly recognizable. The characteristic parting of the straight cleavage of the hornblende cannot be seen even under strong magnification. In some cases, the inclusion of lamellae can be clearly identified according to the well-known law of trillings. Microscopically, the same phenomenon can be seen in these small crystals as can be observed especially in the large dark crystals enclosed in talc and chlorite schist. The formation of these segregation surfaces, according to which the separation into many short columns on large crystals in slates is common, is due to the great pressure to which these slates have been subjected. A further analogy with the large actinolites of the slate could be seen in a defect kink in one of the tiny crystals. As an unusual inclusion, I was able to see a flake of a brownish colour when it was very much enlarged.

Before the blowpipe splinters of the crystals become white and melt into a shiny dark bead. Pure transparent crystal particles were used for the analysis. With the exception of the water determination, which was carried out according to the instructions given by [Ludwig] **Sipöcz**, the usual methods were used. The amount of dried material at 105 °C was 0.3493 g, alumina 0.0069 g, iron oxide 0.0241 g (Iron oxide was calculated from the oxide), lime 0.0475 g, magnesium pyrophosphoric acid 0.1015 g, corresponding to magnesia 0.0891 g, water 0.0098 g.

In percentage:

SiO_2	56.55
Al_2O_3	0.21
FeO	6.21
CaO	13.60
MgO	19.78
H_2O	2.81
	99.16

The specific gravity of splinters in the pycnometer at 16 °C, determined from two experiments, is 0.4866 g = 3.095 and 0.4768 g = 3.094; on average 3.0895. Other components have not been tested. Given the integrity of the crystals, the water content of 2.81 % must be taken as bonded water. A discussion of the role of water with respect to actinolite is not possible based of this single analysis. This must be postponed until new investigations into known types of hornblende are available, and in which the presence of water has been checked with appropriate accuracy. (The results of the following nephrite [actinolite] analyses can be used to confirm an analysis, but not as starting points for dealing with theoretical questions.)

In order to compare my analysis, I use an analysis carried out by **Rammelsberg** of the radiating fibrous (actinolite) from Arendal [7]:

I. Actinolite crystals from nephrite.

II. Arendal actinolite. Specific weight = 3.026 **Rammelsberg**.

	I.	**II.**
SiO_2	56.55	56.77
Al_2O3	0.21	0.97
FeO	6.21	5.88
CaO	13.60	13.56
MgO	19.78	21.48
H_2O	2.81	2.20.

In both cases the following relative proportion of the constituent parts corresponds to the results of the analysis:

$$Si_{20}\ Fe_2\ Ca_5\ Mg_{11}\ H_6\ O_{61}.$$

The numbers determined and calculated show the following agreement:

I.		Found	Calculated	± Difference
	SiO_2	56.55	56.66	- 0.11
	FeO	6.21	6.80	- 0.59
	CaO	13.60	13.22	+ 0.38
	MgO	19.78	20.77	- 0.99
	H_2O	2.81	2.55	+ 0.26

II.	Found	Calculated	± Difference
SiO_2	56.77	56.66	0.11
FeO	5.88	6.80	-0.92
CaO	13.56	13.22	0.34
MgO	21.48	20.55	-0.61
H_2O	2.20	2.77	0.35

From the formula $Si_{20}\ Fe_2\ Ca_5\ Mg_{11}\ H_6\ O_{61}$ it can be seen that compared to the normal silicate $Si\ R''O_3$ there is an excess of silica and a water content that is in the ratio of 2 : 3 to the excess of silica.

As the examination indicated that small crystals enclosed in the nephrite were actinolite, it was also important to examine the dense nephrite matrix.

A very thinly prepared section of the stone appears colourless in transmitted light. The fibrous-crystalline composition is obvious between crossed nicols. The arrangement of the fibres is random. Only in individual tufts of fibres, from which the whole mass appears to be braided and compressed, are the fibres evenly arranged. One thus observes a kaleidoscopic effect between crossed nicols from which identifiable elements rarely emerge when enlarged. I noted cross-sections of hornblende prisms, and here and there oblong cross-sections in unpredictable fissures of microscopic actinolite crystals. **Kenngott** [8] made similar observations on pounamu nephrite. He writes: "It is extremely rare to observe individuals marked by an elongated oblong section. Interference of blue and yellow colours that merge into each other and alternate when rotated. The rare oblong sections show no noticeable difference but quite the same colours." The material for **Kenngott**'s investigation was obtained from Edmund von **Fellenberg** [9], who had obtained it from a sample weighing 180 pounds that had been brought to Idar-Oberstein. It is not unlikely that the Idar-Oberstein stone was the smaller missing half of the Vienna nephrite specimen.

The nephrite has very few foreign inclusions and must be regarded as extremely pure. Under very high magnification I found one black, indeterminable grain. Apart from a thin film of substance infiltrated into the mass, there was only once found a foreign component, enclosed in black flakes, within the nephrite. This foreign substance is not compact, it appears powdery. Under high magnification, one can observe yellowish light shining through it. According to this behaviour, the inclusion does not seem to belong to an ore compound.

Before the blowpipe splinters melt with a weak blistering, forming a pale light green-coloured bead. The material of the analysis consisted of light green, pure translucent fragments selected using a hand lens. The composition was found from the following provisions.

1. 0.6508 g sample dried at 110 °C, contained: silica 0.3721 g (iron oxide digested), lime 0.0886 g, magnesium pyrophosphoric acid 0.3723 g.
2. 5229 g sample dried at 110 °C gave: silica 0.3009 g, iron oxide 0.0345 g, alumina 0.0012 g, lime 0.0698 g, magnesium pyrophosphoric acid 0.3021 g corresponding to magnesia 0.1088 g.
3. 4847 g sample dried at 120 °C, gave 0.0152 g water.
4. In 0.7980 g a trace of potassium was detected.

These determinations correspond to the following percentage ratios in Analysis **III**.

	1.	**2.**	**3.**	**III.** Average
SiO_2	57.17	57.54	–	57.35
Al_2O_3	–	0.22	–	0.22
FeO	–	5.95	–	5.94
CaO	13.61	13.34	–	13.47
MgO	20.60	20.80	–	20.70
H_2O	–	–	3.13	3.12
				100.81

The following formula are calculated from these numbers:

$$Si_{20}\ Fe_2\ Ca_5\ Mg_{11}\ H_8\ O_{61}$$

Observation and calculation are in the following satisfactory agreement:

	Found	Calculated	± Difference
SiO_2	57.35	57.03	+ 0.32
FeO	5.94	5.32	+ 0.62
CaO	13.47	13.31	+ 0.16
MgO	20.70	20.86	- 0.16
H_2O	3.13	3.42	- 0.29.

The above formula also shows an excess of silicic acid and a water content that is in a ratio of 1 : 2 to the excess of silicic acid.

The mixture of the dense mass of nephrite would then contain one more molecule of water than that of the crystals.

Following the examination of the dense and crystallized part of the nephrite block, I undertook at the request of Hofrat F. v. **Hochstetter** a new analysis of the New Zealand nephrite variety that he called "kawakawa". An analysis of the "kawakawa" nephrite was carried out by **Melchior** and **Meyer** in the laboratory of Prof. von **Fehling** in Stuttgart. The result of this analysis did not correspond to any known compound. Various doubts concerning the correctness of this analysis appear to be justified by the new investigation. The material for analysis was taken from the same piece from which Hofrat von **Hochstetter** had provided Prof. von **Fehling** a sample specimen. Hofrat von **Hochstetter** described this as follows:[3] For examination I had before me an elongated piece of five inches long, three quarters of an inch wide, and half an inch thick, the sides of which were polished. Colour dark leek green. Cloudy, only translucent at the edges. The structure is like the tangiwai variety; the differences in hardness are also similar: In general the hardness values are greater: on the scaly-slate fracture 5.5, on the fibrous fracture 6–6.5, and on a polished transverse surface almost 7. The specific gravity is notably higher = 3.02. Melts before the blowpipe, although only with difficulty, becomes discoloured and opaque."[sic]

The composition was determined on the basis of the following results:

1. 0.8242 g sample dried at 105 °C gave: silica 0.4730 g, alumina 0.0018 g, iron oxide 0.0324 g, lime 0.1128 g,

3 Sitzb. d. Ak. d. Wissensch. Wien 1864. XLIX. Bd., 1. Abth., p. 474 [Hochstetter, 1864b: 474]

magnesium pyrophosphoric acid 0.5108 g, corresponding to magnesia 0.1840 g.

2. 0.3751 g of sample dried at 105 °C, digested in a glass tube with purified hydrofluoric acid and sulphuric acid in a carbon dioxide atmosphere, titrated with a chamalcon solution, of which 1 CC. 0.0056827 g iron equivalent, – 0.315 g equal to 0.01315 g iron oxide.

3. 0.5630 g of sample dried at 120 °C gave 0.0147 g water.

4. 0.5528 g of sample dried at 120 °C gave 0.0164 g water.

5. 0.6358 g dried sample gave 0.0230 g potassium platinum chloride, corresponding to 0.0044 g potash.

This results in the following proportional ratios of the components in Analysis **IV**.

	1	2	3	4	5	**IV**. Average		**Melchior** & **Meyer** [4]
SiO_2	57.38	–	–	–	–	57.38		55.01
Al_2O_3	0.22	–	–	–	–	0.22		13.66
FeO	3.51	3.50	–	–	–	3.50	Fe_2O_3	3.52
CaO	13.68	–	–	–	–	13.68		–
MgO	22.31	–	–	–	–	22.32		21.62
K_2O	–	–	-	–	0.69	0.69		1.42
H_2O	–	–	2.61	2.96	–	2.78		5.04
						100.57		100.27.

The specific gravity was measured using fragments in pycnometers at 16 °C from 0.7838 g found to be 3.031. Using the hydrostatic balance I obtained from a 16.2688 g fragment 2.996.

The following formula results for kawakawa:

$$Si_{20}\ Fe\ Ca_5\ Mg_{12}\ H6\ O_{61}$$

have the same molecular ratio as that of pure actinolite. The correspondence between the determined and calculated values is shown in the following table:

	Found	Calculated	± Difference
SiO_2	57.38	57.52	- 0.14
FeO	3.50	3.45	+ 0.05
CaO	13.68	13.42	+ 0.26
MgO	22.32	23.01	- 0.69
H_2O	2.78	2.58	+ 0.20.

Only those nephrite analyses in which a sufficient water content is indicated can be used to compare the analyses carried out recently. Since, however, in these analyses Loss on Ignition was usually measured as water, new investigations should be carried out on a somewhat different water content. The fact that almost all analyses show only a trace of water Loss on Ignition can be attributed to the fact that previously, attainment of intense heating levels was not possible.

The following analyses are used for comparison:

V. Punamustein (pounamu) from New Zealand. **Scheerer**. [SCHEERER, 1851: 379, LIII.]

VI. Nephrite adze from Meilen, specific weight 2.98 L.R. von **Fellenberg** [10]. [FELLENBERG, 1866: 121, No. 3]

VII. Nephrite fragment from Meilen. L.R. von **Fellenberg**. [FELLENBERG, 1866: 121, No. 1]

VIII. Nephrite fragment from Meilen, specific gravity 3.03. L.R. von **Fellenberg**. [FELLENBERG, 1866: 121, No. 2]

IX. Nephrite from Concise, specific gravity 2.874. L.R. von **Fellenberg**. [FELLENBERG, 1866: 121, No. 5]

	V.	**VI.**	**VII.**	**VIII.**	**IX.**
SiO_2	57.10	56.90	57.10	56.50	56.14
Al_2O_3	0.72	–	–	–	0.48
FeO	3.39	7.06	6.30	6.75	4.66
MnO	–	0.67	0.65	0.42	1.13
CaO	13.48	12.94	12.76	13.27	11.12
MgO	23.29	20.37	20.60	20.09	22.68
H_2O	2.50	2.80	3.25	3.50	3.72.

The relative proportion of the components in these analyses [11], compared with analyses **I–IV**, shows the following juxtaposition:

I. $Si_{20}\ Fe_2\ Ca_5\ Mg_{11}\ H_6\ O_{61}$
II. $Si_{20}\ Fe_2\ Ca_5\ Mg_{11}\ H_6\ O_{61}$
IV. $Si_{20}\ Fe\ Ca_5\ Mg_{12}\ H_6\ O_{61}$
V. $Si_{20}\ Fe\ Ca_5\ Mg_{12}\ H_6\ O_{61}$
VI. $Si_{20}\ Fe_2\ Ca_5\ Mg_{11}\ H_6\ O_{61}$
III. $Si_{20}\ Fe_2\ Ca_5\ Mg_{11}\ H_8\ O_{62}$
VII. $Si_{20}\ Fe_2\ Ca_5\ Mg_{11}\ H_8\ O_{62}$
VIII. $Si_{20}\ Fe_2\ Ca_5\ Mg_{11}\ H_8\ O_{62}$
IX. $Si_{20}\ Fe_5\ Ca_4\ Mg_{12}\ H_8\ O_{62}$

Analyses **V–IX** show the following correspondence between observation and calculation. The manganese oxide is combined with iron oxide.

	V.	**VI.**	**VII.**	**VIII.**	**IX.**
SiO_2	- 0.87	+ 0.24	+ 0.07	- 0.53	- 0.46
FeO	+ 0.68	+ 0.93	+ 1.63	+ 1.86	- 1.01
CaO	+ 0.04	- 0.28	- 0.55	- 0.04	+ 0.56
MgO	+ 0.10	- 0.37	- 0.26	- 0.07	+ 0.04
H_2O	- 0.11	+ 0.25	- 0.17	+ 0.08	+ 0.32

The attempt to calculate the appropriate amount of serpentine for the water content does not give any result.

The foregoing chemical results may serve as preliminary work for a later investigation of the more important members of the hornblende group, but the observations made so far on the large block of nephrite have shown the complete identity of the nephrite with actinolite.

Since nephrite is by its very nature a "dense actinolite slate", the answer to the question of geognostic occurrence can now be given more decisively than before. Especially for the nephrite tools found in Europe, at least in Switzerland, the assertion of many researchers that the introduction of even a small piece of nephrite on trade routes from the Orient to Switzerland occurred at the time of the Pfahlbau [Neolithic stilt-house/lake dwellings] period, or the assumption that the lake dwellers brought their stone tools with them from the Orient is doubtful from the geognostic point of view. News of the discovery of nephrite in

4 The main mistake in this analysis can be attributed to a typographical error by the analysts in exchanging the lime content for alumina.

the Alps, which one would more correctly call "nephritic actinolite slate", has not yet become known. The discovery of the same in the Alps, especially in the mountains of the cantons Wallis and Bunden composed of "green rocks", can still be expected, given the fact that the Alps have not yet been completely explored in recent extensive geological investigations. Information from **Schlagintweit** and **Stoliczka** concerning the occurrence of the high quality nephrite in Khotan [12] and the report by **Hochstetter** from Dr **Hector** concerning the occurrence of nephrite in Milford Sound in the South Island of New Zealand is unfortunately incomplete. However, this observation that the greenstone (diorite) hornblende gneiss or hornblende slate are associated with nephrite, agrees with the geological reports of the greenstone regions of the Alps.

If the Swiss lake dwellers ever made nephrite tools from "nephritic actinolite outcrops" from the Alps, this was very seldom as large quantities of nephrite are unknown in the prehistoric period, and the finds of nephrite tools relatively rare. The assertion that nephrite, if it was once present in the Alps, can still be found there, is doubtful, but not totally refuted, as before the historical period there was a need to find the precious stone. In the Wiser collection in Zürich there is a nephrite that was found in the moraine of the Grindelwald Glacier, Canton Bern. When describing two worked nephrites, **Fischer** expressly emphasizes their strong similarity with actinolite from Zermatt.

If these observations are considered together with many comparable studies, the assumption of an importation of nephrite to Europe exclusively from the Orient can no longer be supported from the geognostic point of view [13].

Berwerth's paper in Sitzungsberichte der kaiserlichen Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Classe, Vol. LXXX, 1880: 116–118

On bowenite from New Zealand by Dr Fritz Berwerth

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Dana gave the name bowenite to the noble, hard serpentine from Smithfield Rhode Island, North America, which **Bowen** had described as nephrite, but was recognized as serpentine by **Smith** and **Brush**. According to a new investigation requested by Ferdinand von **Hochstetter** and carried out by me, the mineral called "tangiwai" in the Maori language, is also bowenite. According to Ferdinand von **Hochstetter**[5] the term "*tangiwai*" is used by the Maori of New Zealand to describe the noblest type of the many varieties of greenstone (nephrite) that can be found there. A vibrant green colour and high transparency characterise tangiwai. Because of its lesser hardness, it is used more for ornamental objects than for weapons or tools. Some pieces of the "variety of pounamu" known as "tangiwai" were personally acquired in New Zealand by Ferdinand von **Hochstetter** and described as follows: The piece examined was an ear ornament in the form of a 4.5 inch long and 0.5 inch thick, rounded and a smoothly polished rod, with a hole piercing the upper thinner end. The colour is a beautiful celadon green, close to an emerald green, with a hint of yellow in some parts. The stone is extremely translucent, almost transparent, so much so that one can clearly see printed text through a section of 3 lines thickness. Cracks running through in a parallel direction indicate the peculiar, scaly or irregular-slaty structure, and platelets can be split off in this direction with considerable ease. The scaly structure, however, is not so perfect as that of antigorite, which is very similar in many respects; the displacement surfaces are therefore not as smooth as with this mineral, but rather uneven with scaly-slaty fractures. Perpendicular to the scaly-slaty fracture, although not very clearly, a fibrous fracture may be recognized. The hardness shows very striking differences. On the parting surface of the undulating, slaty fracture, it is the least 4–5, without noticeable variation, whether one tries to cut perpendicularly to the direction of fracture or parallel to it. On a surface that corresponds to the fibre break, the hardness is somewhat greater, namely, in the direction of the oblique break it is 5; perpendicular to the oblique and fibrous break, the hardness is greatest and reaches 6.

A second, smaller piece of tangiwai, also in the form of an ear ornament, resulted in similar **differences** in hardness, but the hardness itself was consistently one level lower, that is from 3.5–5.

The specific gravity of both pieces was found to be equal to 2.61.

Before the blowpipe the tangiwai variety is infusible, even in the thinnest splinters, but it burns white and becomes opaque.

Ferdinand von **Hochstetter** gave a sample from the larger, more fully described piece to Professor von **Fehling** in Stuttgart for analysis, in whose laboratory the investigation was carried out by Messrs **Melchior** and **Meyer**. The composition determined, however, is in contradiction with the newly observed physical properties, according to which "tangiwai" was characterized as a harder serpentine. There was also no similarity in composition with nephrite and jadeite. According to this analysis, "tangiwai", like "kawakawa", should have been a new composition. The differences between the analysis by **Melchior** and **Meyer** and the new one suggest that on the part of Messrs **Meyer** and **Melchior** only a confusion with another analysis can have occurred. [6] The result of the new tangiwai analysis using material from the same pieces which **Meyer** and **Melchior** had at their disposal, is found from the following determinations.

5 Sitzb. d. Akad. d. Wiss. XLIX. 1864. Mai. Über das Vorkommen und die verschiedenen Abarten von neuseeländischem Nephrit (Punamu der Maoris). [HOCHSTETTER, 1864b]

6 Taugiwai [sic; Tangiwai] analysis from Melchior and Meyer

SiO_2	53.01
Al_2O_3	10.83
FeO	7.18
MnO	Trace
CaO	12.40
MgO	14.50
K_2O	0.97
H_2O + LOI	1.11
	100.00

At 105 °C dried substance contained 0.6455 g: silica 0.2890 g, iron oxide 0.0241 g, magnesium pyrophosphoric acid 0.7019 g, corresponding 0.2529 g, magnesia, water 0.835 g. (Water was determined according to **Sipöcz**'s method).

Composition according to the percentages:

SiO_2	44.77
FeO	3.35
MgO	39.17
H_2O	12.94
	100.23

For "tangiwai", if the iron oxide is combined with magnesia, the formula is:

$$Si_2\,Mg_3\,H_4\,O_9 \text{ or } 2\,SiO_2.3\,MgO.2\,H_2O,$$

which is that of serpentine. The specific gravity with splinters in the pycnometer at 16° C. from 0.8154 g. was determined = 2.6067.

The variety of their pounamu called "tangiwai" by the Maori is therefore a "false-nephrite" and belongs to the serpentine variety called "bowenite" [14].

Notes on Berwerth's papers

1 See text comment 10 in section "Notes on Hochstetter's paper".

2 See Text-Fig. 6 for locations.

3 See Text-Fig. 14.

4 See Text-Fig. 6 for locations.

5 See Text-Figs. 5, 7, 8 for locations.

6 Gustav Tschermak von Seysenegg (1836–1927), professor of mineralogy and petrography at the University of Vienna.

7 Actinolite in granite from the Arendal district, Norway (Rammelsberg, 1860). The structural formula based on 23(O) is: $Ca_{2.01}(Mg_{4.42}Fe_{0.68})_{5.10}\,(Si_{7.83}Al_{0.16})_{7.99}O_{22}(OH)_2$. Rammelsberg refers to actinolite by the old name *stralstein* (Rammelsberg, 1860: 461).

8 Gustav Adolph Kenngott (1818–1897), professor of mineralogy at ETH Zurich and at the University of Zurich. The quotation in Berwerth (1880a) is from Kenngott (1870).

9 Edmund von Fellenberg (1838–1902), Swiss alpinist and geologist. Son of Ludwig Rudolf von Fellenberg.

10 Ludwig Rudolf von Fellenberg (1809–1878), Swiss chemist and mineralogist in Bern.

11 Structural formulae of the comparative analyses are:

I: $Ca_{2.06}(Mg_{4.17}Fe_{0.73}Al_{0.03})_{4.93}(Si_{7.99}Al_{0.01})_{8.00}O_{22}(OH)_2$
II: $Ca_{2.00}(Mg_{4.42}Fe_{0.68})_{5.10}\,(Si_{7.83}Al_{0.16})_{7.99}O_{22}(OH)_2$
VI: $Ca_{1.94}(Mg_{4.25}Mn_{0.08}Fe_{0.83})_{5.16}Si_{7.96}O_{22}(OH)_2$
VII: $Ca_{1.91}(Mg_{4.30}Mn_{0.08}Fe_{0.74})_{5.12}Si_{7.99}O_{22}(OH)_2$
VIII: $Ca_{2.00}(Mg_{4.22}Mn_{0.05}Fe_{0.80})_{5.07}Si_{7.97}O_{22}(OH)_2$
IX: $Ca_{1.67}(Mg_{4.75}Mn_{0.13}Fe_{0.55})_{5.43}(Si_{7.89}Al_{0.08})_{7.97}O_{22}(OH)_2$

12 In the area near Khotan (Heitan), southern Xinjiang Province in western China, dolomite-hosted nephrite from the Khunlun Mountains, was, and still is, collected from the Yurdungkash and Karakash rivers flowing from them (translated as the rivers of white jade and black jade, respectively). Nephrite was formerly obtained from quarries in the Khunlun Mountains where it occurs as veins and nodules. These ancient workings were visited by Herman von Schlagintweit, a German explorer of Central Asia, in 1856 (described and published in Schlagintweit, 1873), and the Moravian palaeontologist, Ferdinand Stoliczka, in 1874.

13 In his initial presentation on the Khotan nephrite deposits to the Royal Bavarian Academy of Sciences on 5 July 1873, Schlagintweit refers to the then current scientific discussion, "Die Nephritfrage" (the nephrite question). This scientific controversy concerned the nephrite source of Neolithic stone axes discovered in large numbers in European lake-dweller sites. Some argued that as nephrite deposits were unknown in Europe, it could have come from the Khunlun Mountains area, although this was disproved in 1907 by Ernst Kalkowski, Jena.

14 Berwerth's paper introduced the term *bowenite* for the variety of jade-like serpentine known to the Maori as tangiwai. His reference to tangiwai as "false-nephrite" is because although serpentine, it has a felted, nephritic texture (the "remarkable closeness of grain" referred to by Hector & Skey, 1866), and the observation of George T. Bowen who originally described the rock from Rhode Island as being akin to nephrite (possessing a dense, felt-like aggregate of fine fibers of serpentine) and its jade-like colours, i.e., "bright apple green – sometimes tinged with blue" (Bowen, 1822: 346). On the basis of Bowen's analysis which included 4.25 % CaO (due to the presence of tremolite contamination), James Dwight Dana (1850: 265) coined the term *bowenite*. Subsequent analysis of the Rhode Island occurrence by Smith & Brush (1853) found "bowenite" to have the same composition as serpentine (trace to 0.63 % CaO), as Berwerth found for tangiwai, and in Dana's *System of Mineralogy* (E.S. Dana, 1892), *bowenite* was relegated to a varietal status.

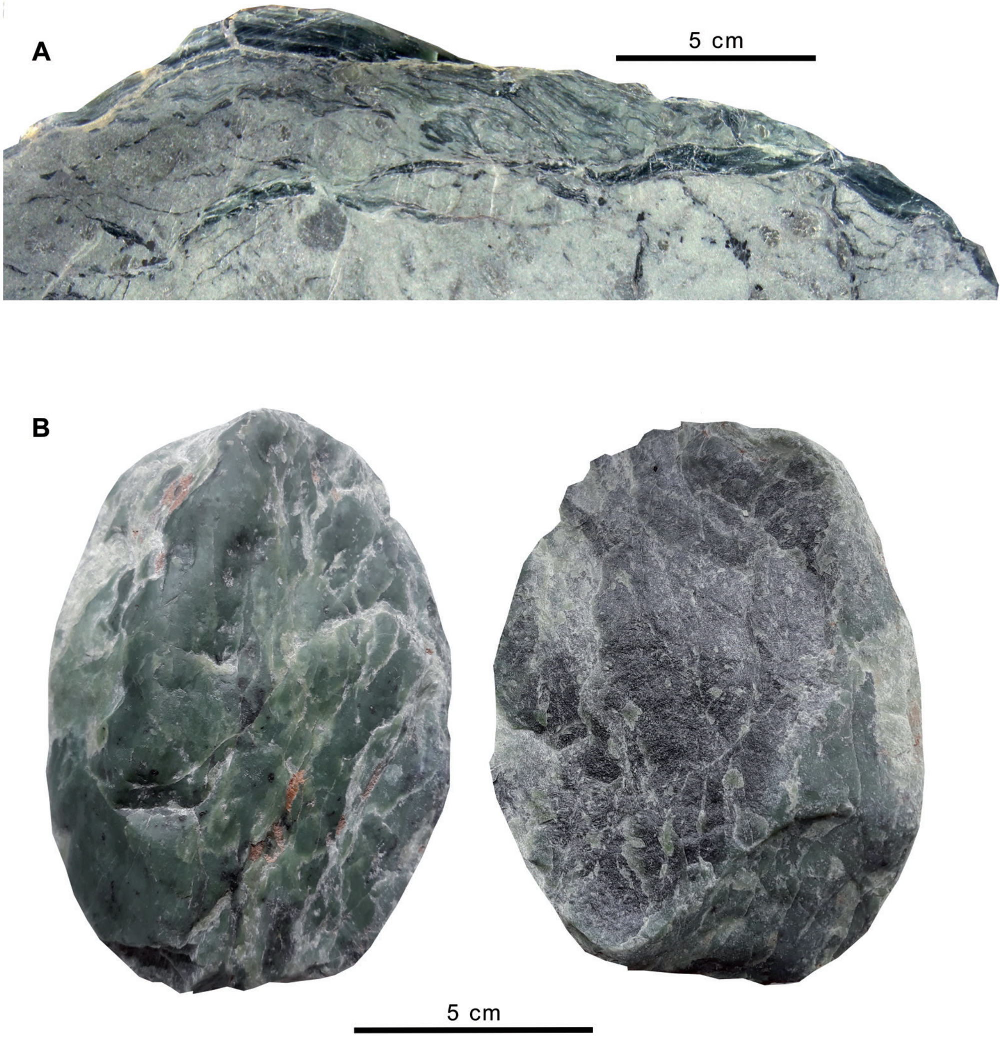
The term *bowenite* was first used (tentatively) in New Zealand in 1890 by Georg Heinrich Friedrich Ulrich (1830–1900): "*Among the specimens from the Cascade River at the foot of the Olivine Range* [South Westland; Text-Fig. 8] *are pieces of a hard nephrite-like serpentine (bowenite ?), containing small specks of Awaruite embedded in it. The specimens are evidently portions of rolled pebbles*" (Ulrich, 1890: 629). For the well-known Maori tangiwai collecting site at Anita Bay, Milford Sound, originally mentioned by Hector (1863) as "*jade*", Marshall (1904: 482) provides the first petrographic observation of a hand-specimen of what he termed "*bowenite*" as "*clear transparent green, with a splintery fracture and small opaque inclusions. Microscopically a dense mesh of minute needles of colourless transparent serpentine, occasional small unaltered cores of olivine, and some grains of chromite*". In the Southern Alps, Bell & Fraser (1906) seem to have confused the properties of tangiwai and regarded it as being different from bowenite: "*There are several distinct varieties of nephrite which are known to the Maoris as 'pounamu,' 'tangiwai,' 'kawakawa,' etc. Pounamu is the most common variety […] Tangiwai is of a greenish-grey or dull*

Text-Fig. 14.
Sawn block of kawakawa variety of pounamu on display in the Natural History Museum, Vienna. The history of the stone is described in BERWERTH (1880a) (Photo: Alice Schumacher).

green colour, is harder than pounamu and most frequently occurs fissiliform. Not infrequently bowenite is associated with it, which makes it much softer" (BELL & FRASER, 1906: 70). On the other hand, MORGAN (1908) records a talc-serpentine in the Southern Alps, as "*a dark-green semi-transparent rock, containing a brown weathering carbonate, which does not effervesce with cold dilute hydrochloric acid, and is probably ferriferous magnesite. The rock has a uniform hardness of about 2.5 to 3, and therefore the talc present must be harder than typical talc. On the joint surfaces, which are also movement planes, there are thin flakes of a fairly hard, transparent, green substance, which may be called bowenite (tangiwai of the Maoris)"* (compare with Text-Fig. 15B). None of the above authors refer to Berwerth's publication, which is first referenced in the New Zealand context by FINLAYSON (1909).

In addition to the term bowenite, the earliest record of the name *tangiwaite* appears in the Dictionary of Chemistry (WATTS, 1869: 659) and described as "*a variety of nephrite from Tangiwai in New Zealand.* In the *Catalogue of Minerals and Synonyms* (EGLESTON, 1887: 86), tangiwaite is erroneously regarded as synonymous with "*jadeite"* (sodic pyroxene) as is "*poenamu"* [sic] and "*tanginwaite"* [sic]; bowenite is listed as a variety of serpentine synonymous with nephrite (EGLESTON, 1887: 156). In DANA (1892: 686), under "*bowenite*" it is regarded as a "*similar kind from New Zealand called tangiwaite or tangawaite*", and in CHESTER's *Dictionary of the Names of Minerals* (1896: 265), it is referenced to BERWERTH's 1880a paper on Hochstetter's tangiwai. The name is also recorded by Rudolf KOECHLIN (1862–1939), the brother-in-law of Friedrich Berwerth, in the *Mineralogisches Taschenbuch* (2nd edition, 1911: 55) which presented tables sorted by mineral names with appendant chemical formula, crystal system and all important physical properties, and was a benchmark for students and mineral collectors of that time; it is listed in SPENCER (1919: 388), who references Koechlin as the source. In the 1928 edition of the *Mineralogisches Taschenbuch* under the section "*Directory of Names*" "*tangawait (tangiwai)*" is stated as "*like bowenite. New Zealand*" (page 61), and on page 13 bowenite is listed separately as "*bowenite, variety serpentine, like nephrite*". Smithfield R.I. Bowenite was designated as the official state mineral of Rhode Island in 1966.

Thus, although the nephritic texture of *bowenite* and *tangiwaite* varieties of antigorite serpentine have similar physical properties (texture, hardness, density), and their composition is the same, their lithological association and mode of origin is entirely different as detailed below. Furthermore, bowenite and tangiwaite have a different appearance in terms of their colour as seen in Text-Figure 16. *The Encyclopedia of Igneous and Metamorphic Petrology* (BOWES, 1989: 548) describes bowenite along with tangiwaite in the New Zealand context in terms that are distinctly different from the Rhode Island occurrence: "*Bowenite (tangiwaite, tangawaite, tangiwai – Maori) is the name given in New Zealand to a particular type of serpentine composed of a dense felt-like aggregate of serpentine fibers with flakes of talc, grains of chromite, and associated patches of magnesite: occurrence is as veins in a foliated rock containing the same minerals but having talc as the major constituent*". Therefore, it is on the basis of origin and visual appearance that reinstatement of the more culturally appropriate petrographic name *tangiwaite* in place of *bowenite* is proposed for the *tangiwai* variety of pounamu exclusive to New Zealand.

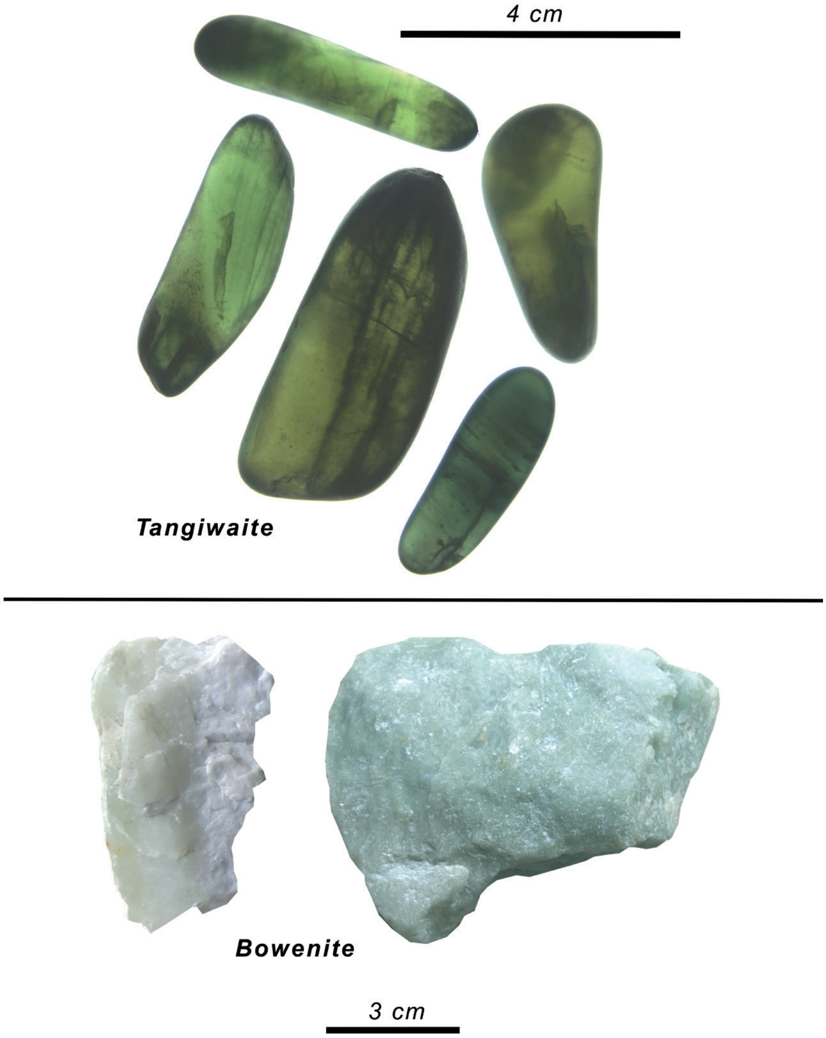


Text-Fig. 15.
Origin of tangiwai pounamu. **A**. Sectioned slab of pale yellowish-green mylonitised talcose dunite with dark-green segregations (shear zones) of tangiwaite, Anita Bay, Milford Sound. **B**. **Left:** Surface appearance of river cobble of tangwaite with red-brown streaks of Fe-magnesite; any talc has been eroded. **Right:** Cleaved surface exposing centre of cobble showing a core of fine-grained black serpentine, Arahura River, north Westland (Photos: Rodney Grapes).

Discussion

Nomenclature and correction

Five years after the publication of Hochstetter's paper on pounamu, Ludwig von Fellenberg in Bern published an analysis of New Zealand nephrite obtained from the stone-cutters of Idar-Oberstein in Germany. The sample was described as "*blackish-green in colour, beautiful celadon green when viewed against the light*" (translated from Fellenberg, 1869: 97), and therefore analogous to Hochstetter's kawakawa. Based on this and analyses of nephrite samples from elsewhere, Fellenberg proposed that because of the confusing nomenclature applied to the naming of nephrite, such as "*jade, jade nephritique, nephrit, punamu, beilstein*", etc., that nephrite should be retained for all compositions equating to a tremolite-actinolite formula, and all the others discarded. However, he accepted that the names of "*those variants Tangiwai and Kawakawa, made famous by Hochstetter and differing greatly in their composition*" should be adopted (translated from Fellenberg, 1870: 104). In Heinrich Fischer's monumental work of nephrite and jadeite of 1875, and reprinted in 1880, the problem with the analyses published by Hochstetter was still not known; "*In the paper by F. v. Hochstetter, published in 1865* [sic], *the latter, thanks to the analyses he had carried out by Melchior and Meyer, provided important evidence that the nephrite-like grass-green stones of New Zealand, called by the natives Tangiwai and Kawakawa, have a completely different composition, compared to nephrite, so that great caution is required in the mineralogical diagnosis of the objects coming from there; for example, according to Hochstetter's letter to me, the tiki he acquired in New Zealand, which corresponds perfectly to the one shown in Fig. 7 (sketch of tiki), is not made of nephrite, but from the Kawakawa mineral*" (translated after Fischer, 1875: 20). Even as late as 1882, Dana refers to Hochstetter's "*aluminous nephrite*" analyses as "*probably mere mixtures, as well be true of such massive substances*" (Dana, 1882: 802). It was only when both pounamu variants were re-analysed by Berwerth in 1879 at Hochstetter's behest, and published in 1880, that the errors in the original compositions, that had been accepted by Fellenberg, Fischer, and presumably everyone else, were discovered.



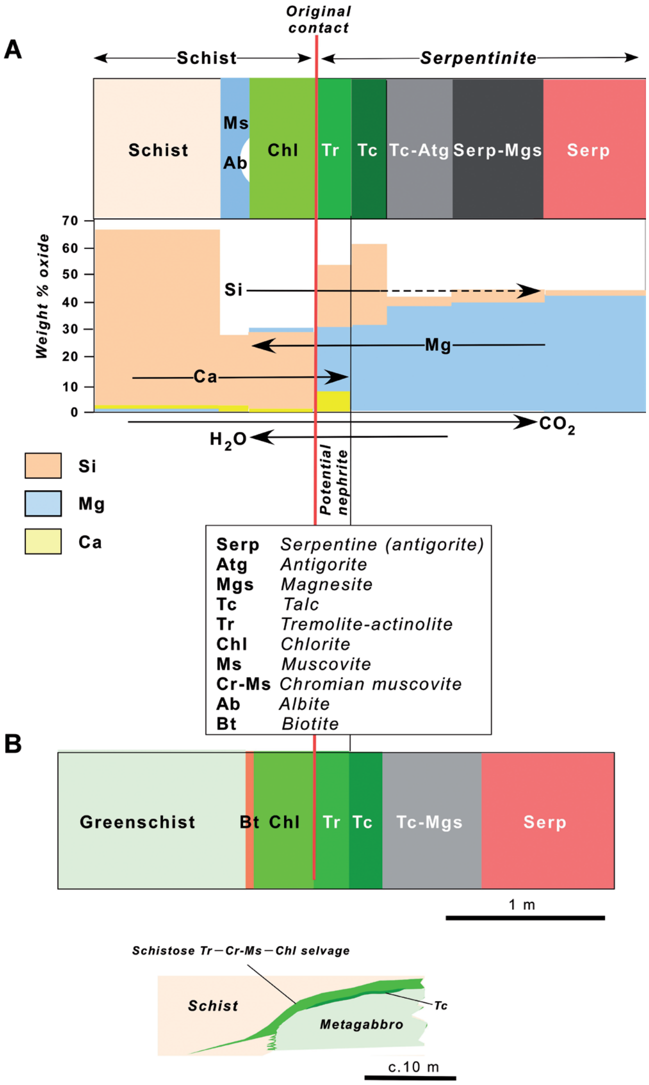
Text-Fig. 16.
Examples of tangiwaite and bowenite. **Upper:** Backlit beach pebbles of tangiwaite, Anita Bay, Milford Sound. Note the elongate, flattened habit that reflects their occurrence in shear zones within mylonitised talcose dunite as shown in Text-Figure 15 (Photo: Rodney Grapes). **Below:** Samples of Rhode Island bowenite, Conklin Limestone Quarry, Lime Rock, Lincoln, Providence County, USA (Photo: Rodney Grapes).

Origin of pounamu

In New Zealand, *nephrite* pounamu is a metasomatic rock[1] *exclusively* associated with (and derived from) serpentinised ultramafic-mafic rocks (e.g., Hector, 1863; McKay, 1893; Dieseldorff, 1901; Bell & Fraser, 1906; Morgan, 1908; Finlayson, 1909; Turner, 1935; Coleman, 1966; Wood, 1972; Cooper, 1976, 1995; Koons, 1981; Cooper & Reay, 1983; Ireland et al., 1984). In the Southern Alps, these intensely deformed rocks are known as the Pounamu Ultramafic Belt (Reay & Cooper, 1983). Hochstetter's 1864 paper was the first to recognise this close relationship between the occurrence of pounamu and ultramafic-mafic rocks. Where he fortuitously found a nephrite pebble on the beach fronting the Current Basin between Rangitoto ki te Tonga/D'Urville Island and Croisilles Harbour, Nelson Province (Text-Fig. 10), he noted the nearby presence of serpentine (his great serpentine dyke of the Dun Mountain mineral belt; Grapes & Nolden, 2020) associated with "*numerous different metamorphosed layers of slate*", and he mentions that the contact rocks of pounamu in Westland, are "*green slate, perhaps talc, chlorite slate, or serpentine*". At that time, the only known in-situ locality of pounamu was at Anita Bay, Milford Sound (Hector, 1863, quoted by Hochstetter), and where the associated rocks were described as hornblende schist and felsite, now recognised as hornblendite and meta-diorite, respectively (Czertowicz et al., 2016).

An ideal metasomatic zonal sequence and the chemical changes involved developed between quartzo-feldspathic schist (metagreywacke) and serpentinite in the Southern Alps (Arahura Valley area) is shown in Text-Figure 17A, with the development of a near monomineralic tremolite-actinolite zone formed at the contact of the two lithologies (Cooper, 1976; Koons, 1981; Cooper & Reay, 1983). Two-way diffusion of the main tremolite-actinolite-forming oxides occurs, with Mg and H_2O from serpentinite decreasing towards the schist; Si, Ca and CO_2 from schist increasing towards the serpentinite. It is likely that Ca necessary for growth of the tremolite-actinolite zone in the serpentinite is mainly provided by dissociation of calcite in the schist according to the reaction $CaCO_3 = CaO + CO_2$, with CO_2 diffusing further into the serpentinite (the most rapidly moving metasomatic front) to form magnesite ($MgCO_3$). Metamorphic conditions under which this metasomatic sequence formed are estimated as 450 °C ± 50 °/6 ± 1 kb/~20 km depth (transitional between greenschist-amphibolite facies) (e.g. Grapes & Watanabe, 1992). A similar metasomatic zonal sequence may also develop between metabasaltic greenschist and serpentinite (Text-Fig. 17B).

1 Replacement by a process of simultaneous solution and deposition of minerals in rocks by others of different mineralogical and chemical composition through the infiltration of an externally-derived hydrothermal fluid (the metasomatising agent).



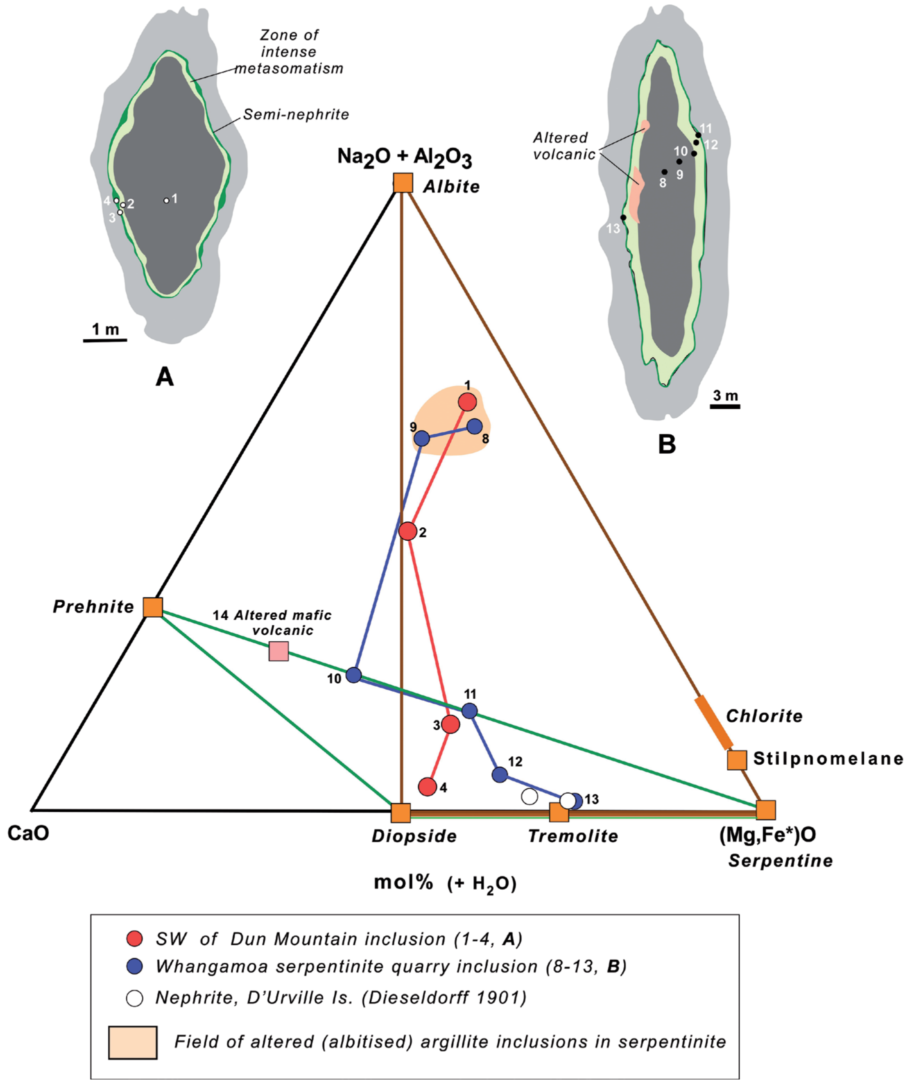
Text-Fig. 17.
Origin of nephrite pounamu. **A:** Schematic diagram to illustrate a metasomatic zoning profile developed at the contact between quartzo-feldspathic schist and serpentinite, northern Southern Alps (adapted from Koons, 1981). The width of the tremolite-actinolite zone at the margin of the serpentinite is between 0.5–1.5 m and composed of 95–98 % tremolite-actinolite, < 2 % chlorite + talc, < 2 % chromite + magnetite. Wt.% concentrations of SiO_2, MgO and CaO in the different zones are shown below together with arrowed directions of element + volatile movement between schist and serpentinite (see text for details). **B:** Schematic diagram to illustrate metasomatic zoning developed at the contact of metabasaltic greenschist and serpentinite (adapted from Fig. 4. of Cooper, 1976); sketch showing part of a schistose nephrite selvage developed along the margin of a metagabbro pod within quartzo-feldspathic schist (modified from Figure 2 of Cooper, 1995).

The mode of formation of semi-nephrite at the margins of inclusions of altered (sodic) argillite (slate) inclusions in serpentinite from the Dun Mountain Ophiolite Belt, Nelson Province, such as that collected by Hochstetter, is analogous with that described above from the Southern Alps, except that a semi-nephrite zone forming irregular lenses along the sheared/cataclastic contact between argillite-serpentinite is less well-developed and typically only 2.5–10 cm wide, with veins extending into the serpentinite (Coleman, 1966). Talc and chlorite zones developed in the Southern Alps example are lacking. The altered argillite is characterised by a matrix of albite crowded with a felted network of tremolite-actinolite fibres to produce a particularly hard rock called *pakohe* by the Maori and used for the manufacture of stone tools (Reed, 1959; Johnston, 2011). Hochstetter (1859) refers to these rocks as altered slates that are "*grey, hard, cherty, and fractured into small pieces*", and considered that they had been included and altered by the ultramafic rocks. Metamorphic conditions for recrystallisation of these rocks are those of prehnite-pumpellyite to greenschist facies; ~2–3kb/~250 ± 50 °C. Bulk chemical changes within two argillite inclusions leading to the formation of semi-nephrite at their margins are shown in a mol.% (Al_2O_3, Na_2O) – CaO – (Mg,Fe*)O + H_2O diagram with Fe* = all iron as FeO (Text-Fig. 18). The composition trends can be explained by diffusion of Mg from the serpentinite into the inclusions, migration of Ca towards the serpentinite contact to form tremolite-actinolite ± diopside, and Na enrichment in the internal part of the inclusion to form albite. Because the argillite inclusions may contain macroscopic to microscopic mafic volcanic fragments (e.g. inclusion **B** in Text-Fig. 18), additional Ca is provided from the breakdown of Ca-plagioclase in this lithology to form diopside and prehnite (e.g., compositions 2, 4 in **A**, 10, 11, 12 in **B** in Text-Fig. 18). Thus, the nephritic selvages plot within compositional triangles delineating both mafic volcanic-serpentinite and Ca-poor argillite-serpentinite rocks as shown in Text-Figure 18. It can be noted that the nephrite compositions determined by Dieseldorff (1901) from D'Urville Island (and almost certainly the same as Hochstetter's sample), equates with the non-diopside-bearing part of the nephrite selvage developed around inclusion **B** in Text-Fig. 18, a true nephrite with a composition on the basis of 23(O) of:

$$Na_{0.01}(Ca_{1.79}Fe^{2+}{}_{0.20})_{1.99}(Mg_{4.61}Mn_{0.02}Fe^{2+}{}_{0.25}Fe^{3+}{}_{0.12})_{5.00}$$
$$(Si_{7.80}Al_{0.15}Fe^{3+}{}_{0.05})_{8.00}O_{22}(OH)_2$$

Petrographic investigations by Finlayson (1909) and Turner (1935) suggest that the formation of nephrite pounamu involves two stages, a chemical (metasomatic) change to produce a tremolite-actinolite rock, such as that shown in Text-Figure 17, followed by the mechanical formation (during shearing stress) of a nephritic microstructure. This microstructure is characterised by a felted, asbestos-like mass fibre habit of tremolite-actinolite that seems to have involved recrystallisation and growth of new submicroscopic short lath-like fibres, even though macroscopically nephrite appears glassy and massive. It might also be expected that in some instances the metasomatic sequences in Text-Figure 17 will be tectonically disrupted or even partly excised during second stage deformation. This would explain the observation by Bell & Fraser (1906) of nephrite occurring as "*rounded segregations in talc rock or talc-serpentine rocks*". Given the "*lubricating*" effect of "*soft*" chlorite, talc and serpentine rocks, it can be concluded that recrystallisation of tremolite-actinolite zones/selvages occurred during post-metamorphic/metasomatic deformation (shearing) (Text-Fig. 17B).

The earliest known tangiwai pounamu is associated with mylonitic dunite-harzburgite of the *Anita Ultramafites* (Wood, 1972), now known as the *Anita Peridotite* – a component of the 3–4 km wide, 30 km long *Anita Shear zone* (Hill, 1995; Klepeis et al., 1999) (Text-Fig. 8). Tangiwai pounamu was later recognised in association with other bodies of serpentinised ultramafic rocks such as those in the Southern Alps (Bell & Fraser, 1906; Morgan, 1908), South Westland (Ulrich, 1890; Finlayson, 1909; Turner, 1935), and in the Cobb ultramafics of northwest Nelson (Henderson et al., 1959) (Text-Fig. 5). *Tangiwaite* is initially



Text-Fig. 18.
Origin of nephrite pounamu. Plot of semi-nephrite and associated compositions from tectonic inclusions in serpentinite of the *Dun Mountain Ophiolite Belt* in terms of mol.% (Al_2O_3 + Na_2O) – CaO – (Mg,Fe*)O (a modified ACF diagram) where Fe* = all iron as FeO. Sample numbers refer to analyses listed in Table 12 of Coleman (1966); sketches of tectonic altered argillite inclusions (*dark grey*), their metasomatised rims (*light green*), and semi-nephrite selvages (*dark green*). **A:** Dun Mountain. **B:** Whangamoa serpentine quarry, are redrawn from Text-Figures 7 and 18, respectively, of Coleman (1966). *Brown* composition triangle = altered argillite; *green* composition triangle = altered volcanic (see text for details).
Main mineral compositions:

A.	**B.**
Qz-Ab-Stp-(Tr-Act) (**1**)	*Qz-Ab-Chl-(Tr-Act)* (**8, 9**)
Higher (*Tr-Act*) content (**2**)	*(Tr-act)-Diop-Prh* (**10**)
(Tr-Act)-Diop (**3**)	*(Tr-Act)-Diop* (**11**)
(Tr-Act)-Diop (**4**)	*(Tr-Act)* (**12**)
(***semi-nephrite***)	(***semi-nephrite***)
	(Tr-Act) (**13**)
	(***semi-nephrite***)

(*Qz* = quartz; *Ab* = albite; *Stp* = stilpnomelane; *(Tr-Act)* = tremolite-actinolite; *Diop* = diopside; *Chl* = chlorite; *Prh* = prehnite).

formed by serpentinisation of ultramafic rocks such as dunite or harzburgite according to the reactions,

$3Mg_2SiO_4 + 2SiO_2 + 4H_2O = 2Mg_3Si_2O_5(OH)_4$ (In *dunite*)
Olivine   fluid   serpentine

$Mg_2SiO_4 + MgSiO_2 + 2H_2O = Mg_3Si_2O_5(OH)_4$ (*In harzburgite*)
Olivine   enstatite   serpentine

followed by recrystallisation with the growth of bundles of short fibres of serpentine that produces the same compact texture as nephrite pounamu, but without having the same hardness, during a late deformation (shearing) event as shown in Text-Figure 15.

In contrast the dominantly apple or yellow green bowenite (the name applied to tangiwai pounamu by Berwerth), which occurs as veins and nodules in dolomitic marble of northeastern Rhode Island, Massachusetts, USA, can be explained by the introduction of silica, or perhaps the presence of chert nodules, and water into dolomite to form serpentine according to the following reaction,

$3CaMg(CO_3)_2 + 2SiO_2 + H_2O = Mg_3Si_2O_5(OH)_4 + 4CaCO_3 + 3CO_2$
Dolomite   serpentine   calcite

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References

ALLEN, C.L. (1882): On the composition of two specimens of jade. – Chemical News and Journal of Physical Science, **46**, 216–217, London.

ANDERSON, W. (1777): Journal. – In: BEAGLEHOLE, J.C. (1967): The journals of Captain James Cook on his voyages of discovery, Volume 3: The voyage of the 'Resolution' and 'Discovery' 1776–1780. – Hakluyt Society Extra Series, No. **36**, Cambridge (Hakluyt Society).

BARTON, P.L. (1998): Maori Cartography and the European Encounter. – In: WOODWARD, D. & LEWIS, G.M. (Eds.): The History of Cartography, Volume 2, Book 3, Cartography in Prehistoric, Ancient, and Medieval Europe and the Mediterranean, 493–523, Chicago – London (The University of Chicago Press).

BAYLISS, P. (1987): Mineral nomenclature: scapolite. – Mineralogical Magazine, **51**, 176, London.

BEAGLEHOLE, J.C. (1967): The journals of Captain James Cook on his voyages of discovery, Volume 3: The voyage of the 'Resolution' and 'Discovery' 1776–1780. – Hakluyt Society Extra Series, No. **36**, Cambridge (Hakluyt Society).

BEATTIE, J.H. (1920): The southern Maori and greenstone. – Transactions of the New Zealand Institute, **52**, 45–52, Wellington.

BECK, R. & MASON, M. (2010): The jade of New Zealand – Pounamu. – 237 pp., North Shore/Auckland Region (Penguin Group).

BELL, J.M. & FRASER, C. (1906): The geology of the Hokitika sheet, North Westland Quadrangle. – New Zealand Geological Survey Bulletin, **1**, 101 pp., Wellington.

BERWERTH, F. (1880a): Über Nephrit aus Neu-Seeland. – Sitzungsberichte der mathematisch-naturwissenschaftlichen Classe der kaiserlichen Akademie der Wissenschaften, **80**, 102–115, Wien.

BERWERTH, F. (1880b): Über Bowenit aus Neu-Seeland. – Sitzungsberichte der mathematisch-naturwissenschaftlichen Classe der kaiserlichen Akademie der Wissenschaften, **80**, 116–118, Wien.

BEST, E. (1974): The stone implements of the Maori. – Dominion Museum Bulletin, **4**, 445 pp., Wellington, New Zealand. [Reprint of 1912 first edition].

BISHOP, H.R. (1906): Investigations and studies in Jade. – 2 volumes, New York (Privately printed).

BOWEN, G.T. (1822): Analysis of a variety of nephrite from Smithfield, R.I. – American Journal of Science, **5**, 346–348, New Haven.

BOWES, D.R. (Ed.) (1989): The encyclopedia of igneous and metamorphic petrology. – 666 pp., New York (Van Nostrand Reinhold).

CHAPMAN, F.R. (1891): On the working of greenstone or nephrite by the Maoris. – Transactions of the New Zealand Institute, **24**, 479–539, Wellington.

CHESTER, A.H. (1896): A dictionary of the names of minerals, including their history and etymology. – XV + 320 pp., New York (John Wiley & Sons).

CHRISTIE, A.B, BAKER, R.G. & BRAITHWAITE, R.I. (2010): Mineral resources of the West Coast region, New Zealand. – GNS Science Report **2010**/61, 235 pp., Lower Hutt.

CLARKE, F.W. & MERRILL, G.P. (1888): On Nephrite and Jadeite. – Proceedings of the United States National Museum, **11**, 115–130, Washington, D.C.

COLEMAN, R.G. (1966): New Zealand serpentinites and associated metasomatic rocks. – New Zealand Geological Survey Bulletin, **70**, 102 pp., Wellington.

COOPER, A.F. (1976): Concentrically zoned ultramafic pods from the Haast Schist zone, South Island, New Zealand. – New Zealand Journal of Geology and Geophysics, **19**, 603–623, Wellington.

COOPER, A.F. (1995): Nephrite and metagabbro in the Haast Schist at Muddy Creek, northwest Otago, New Zealand. – New Zealand Journal of Geology and Geophysics, **38**, 325–332, Wellington.

COOPER, A.F. & REAY, A. (1983): Lithology, field relations, and structure of the Pounamu Ultramafics from the Whitcombe and Hokitika rivers, Westland, New Zealand. – New Zealand Journal of Geology and Geophysics, **26**, 359–379, Wellington.

COX, S.H. (1882): Notes on the mineralogy of New Zealand. – Transactions of the New Zealand Institute, **15**, 361–409, Wellington.

CZERTOWICZ, T.A., SCOTT, J.M., WAIGHT, T.E., PALIN, J.M., VAN DER MEER, Q.H.A., LE ROUX, P., MÜNKER, C. & PIAZOLO, S. (2016): The Anita Peridotite, New Zealand: ultra-depletion and subtle enrichment in sub-arc mantle. – Journal of Petrology, **57**, 717–750, Oxford.

DAMOUR, A. (1846): Analyse dur jade Oriental réunion de cette substance à la tremolite. – Annales de Chimie et de Physique, Ser. 3, **16**, 469–474, Paris.

DAMOUR, M.A. (1863): Notice et analyse sur le jade vert. Réunion de cette matière minérale à la famille des Wernerites. – Comptes rendus hebdomadaires des séances de l'Académie des sciences, **LVI**, 861–865, Paris.

DAMOUR, A. (1865): Sur la composition des haches en pierre trouvées dans monuments celtiques et chez les sauvages. – Comptes Rendus de l'Académie des Sciences, **61**, 357–368, Paris.

DANA, E.S. (1892): The system of mineralogy of James Dwight Dana (6th edition) – 1134 pp., New York (John Wiley & Sons).

DANA, J.D. (1850): A system of mineralogy (3rd edition). – 876 pp., New York (G.P. Putnam).

DIESELDORFF, A. (1901): Beträge zur Kenntniss der Gesteine und Fossilen der Chathaminseln sowie einiger Gesteine und neuer Nephritfundort Neu-Seelands. – Dissertation, Philosophische Fakultät der Universität Marburg, 57 pp., Marburg.

DUPARC, L. & MRAZEC, L. (1892): Notice sur la composition chimique de la néphrite de la Nouvelle-Zélande. – Archives des Sciences, Société de Physique et d'Histoire Naturelle de Genève, ser. 3, **27**, 115–121, Genève.

EGLESTON, T. (1887): Catalogue of minerals and synonyms. – Bulletin of the United States National Museum, **33**, 197 pp., Department of the Interior, Government Printing Office, Washington.

FELLENBERG, L.R. VON (1866): Analysen einiger Nephrite aus den schweizerischen Pfahlbauten. – Mitteilungen der Naturforschenden Gesellschaft Bern, **1865**/580–602, 112–125, Bern (H.P. Haller). http://doi.org/10.5169/seals-318774

FELLENBERG, L.R. (1869): Analysen einiger Nephrite und Jadéite. – Verhandlungen der Schweizerischen Naturforschenden Gesellschaft in Solothurn, **53**, 88–104, Bern.

FINLAYSON, A.M. (1909): The nephrite and magnesian rocks of the South Island of New Zealand. – Quarterly Journal of the Geological Society, **65**, 351–381, London.

FISCHER, H. (1875): Nephrit und Jadeit nach ihren mineralogischen Eigenschaften sowie nach ihrer urgeschichtlichen und ethnographischen Bedeutung. [Translated in English: Nephrite and jadeite according to their mineralogical properties as well as their prehistoric and ethnographic importance] – 2 volumes, 427 pp., Stuttgart (E. Schweizerbart'sche Verlagshandlung).

FLEMING, C.A. (1959): Ferdinand von Hochstetter: Geology of New Zealand. – 320 pp., Wellington (R.E. Owen, Government Printer).

FORSTER, J.R. (1778): Observations made during a voyage round the world, on physical geography, natural history, and ethnic philosophy. – 649 pp., London.

GRAPES, R. & NOLDEN, S. (2020): Ferdinand von Hochstetter's 1864 description of Dunite – a scholarly annotated English translation. – Jahrbuch der Geologischen Bundesanstalt, **160**, 409–422, Wien.

GRAPES, R. & WATANABE, T. (1992): Metamorphism and uplift of Alpine Schist in the Franz Josef-Fox Glacier area of the Southern Alps, New Zealand. – New Zealand Journal of Geology and Geophysics, **10**, 171–180, Wellington.

GRAPES, R.H. & YUN, S-T. (2010): Geochemistry of a nephrite weathering rind. – New Zealand Journal of Geology and Geophysics, **53**, 413–426, Wellington.

HAIDINGER, W.K. V. (1848): Ueber den Zusammenhang der Körperfarben, oder des farbig durchgelassenen, und der Oberflächenfarben, oder des farbig zurückgeworfenen Lichtes gewisser Körper. – Sitzungsberichte der mathematisch-naturwissenschaftlichen Classe der kaiserlichen Akademie der Wissenschaften in Wien, **8**, 97–133, Wien.

HEAPHY, C. (1846): Notes of an expedition to Karatiri and Arahura, on the western coast of the Middle Island, performed by Messers. Heaphy and Brunner. – Nelson Examiner and New Zealand Chronicle, vol. **5**, October 10.

HEAPHY, C. (1862): A visit to the greenstone country. – Chapman's New Zealand Magazine, October 1862: 107–111; November 1862: 166–171, Auckland.

HECTOR, J. (1863): Geological expedition to the West Coast of Otago, New Zealand. – Otago Provincial Government Gazette, **6**/ 274, 435–438 + map, Dunedin.

HECTOR, J. & SKEY, W. (1866): Supplementary report on Class I: Coals, building stones, basaltic rocks, limestones, freestones, metals and metallic ores, magnesian rocks, graphite, clays, cements, economic minerals, bitumen, resins. – Appendix A in N.Z. Exhibition, 1865: Reports and Awards of the Jurors, 371–452, Dunedin (Mills, Dick & Co.).

HENDERSON, J., MACPHERSON, E.O. & GRANGE, L.I. (1959): The geology of the Motueka subdivision. – New Zealand Geological Survey Bulletin, **35**, 26 pp., Wellington.

HILL, E.J. (1995): The Anita Shear Zone: A major, middle Cretaceous tectonic boundary in northwestern Fiordland. – New Zealand Journal of Geology and Geophysics, **38**/1, 93–103, Wellington. http://doi.org/10.1080/00288306.1995.9514641

HOCHSTETTER, F. (1859): Lecture on the geology of the Province of Auckland, New Zealand. – Auckland Provincial Government Gazette, **8**/14, 88–100, 8. July.

HOCHSTETTER, F. (1864a): Reise der Österreichischen Fregatte Novara um die Erde in den Jahren 1857, 1858, 1859 unter den Befehlen des Commodore B. von Wüllerstorf-Urbair: Geologischer Theil. Erster Band, Erste Abtheilung: Geologie von Neu-Seeland: Beiträge zur Geologie der Provinzen Auckland und Nelson. – 274 pp., Wien (Verlag k. k. Hof- und Staatsdruckerei).

HOCHSTETTER, F. (1864b): Über das Vorkommen und die verschiedenen Abarten von neuseeländischem Nephrit (Punamu der Maoris). – Sitzungsberichte der mathematisch-naturwissenschaftlichen Classe der kaiserlichen Akademie der Wissenschaften, **49**, 466–480, Wien.

HUMBLE, W. (1843): Dictionary of geology and mineralogy. – 294 pp., London.

HUTTON, F.W. & ULRICH, H.F. (1875): Report on the geology and goldfields of Otago. – 244 pp., Dunedin (Mills, Dick & Co.).

IRELAND, T.R., REAY, A. & COOPER, A.F. (1984): The Pounamu Ultramafic Belt in the Diedrich Range, Westland, New Zealand. – New Zealand Journal of Geology and Geophysics, **27**, 247–256, Wellington.

JOHNSTON, M.R. (1983): Nephrite in the Pounamu Formation, McArthur Crags, Olderog Creek, Arahura Valley, Westland. – Industrial Rocks and Minerals, **8**, 5–8, New Zealand Geological Survey, Department of Industrial and Scientific Research, Lower Hutt.

JOHNSTON, M.R. (2011): Pakohe – a rock that sustained early Maori society in New Zealand. – In: ORTIZ, J., PUCHE, O., RÁBANO, I. & MAZADIEGO, L.F. (Eds.): History of research in mineral resources. – Cuadernos del Museo Geominero, **13**, 61–74, Instituto Geológico y Minero de España, Madrid.

JOHNSTON, M.R. & NOLDEN, S. (2011): Travels of Hochstetter and Haast in New Zealand 1858–1860. – 336 pp., Nelson (Nikau Press).

KALKOWSKI, E. (1907): Geologische Deutung des Nephrites von Gulbashen. – Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, **1907.F**, 159–168, Stuttgart.

KENNGOTT, A. (1870): Nephrit (punamu) aus Neuseeland. – Vierteljahrsschrift der Naturforschenden Gesellschaft in Zürich, **15**/4, 372–377, Zürich.

KINNICUTT, L.P. (1889): Nephrite and jadeite. – Proceedings of the American Antiquarian Society, **6** (New Series), 84–90, Worcester.

KLEPEIS, K.A., DACZKO, N.R. & CLARKE, G.L. (1999): Kinematic vorticity and tectonic significance of superposed mylonites in a major lower crustal shear zone, northern Fiordland, New Zealand. – Journal of Structural Geology, **21**, 1385–1405, Amsterdam. https://doi.org/10.1016/S0191-8141(99)00091-7

KOECHLIN, R. (1911): Tabellarische Übersicht und Namenverzeichnis der Mineralian. – In: LOEHR, A.R. VON, BECKE, F., KOECHLIN, R. & ROTKY, O. (Eds.): Mineralogisches Taschenbuch der Wiener Mineralogischen Gesellschaft, 7–121, Wien.

KOECHLIN, R. (1928): Namenverseichnis und Tabellarische Übersicht der Minerale. – In: HIBSCH, J.E., HIMMELBAUER, A., KOECHLIN, R., MARCHET, A., MICHEL, H. & ROTKY, O. (Eds.): Mineralogisches Taschenbuch der Wiener Mineralogischen Gesellschaft, 1–126, Wien.

KOONS, P.O. (1981): A study of natural and experimental metasomatic assemblages in an ultramafic-quartzofeldspathic metasomatic system from the Haast schist, South Island, New Zealand. – Contributions to Mineralogy and Petrology, **78**, 189–195, Berlin. https://doi.org/10.1007/BF00373780

MALING, P.B. (1969): Early charts of New Zealand, 1542–1851. – 134 pp., Wellington (Reed).

MARSHALL, P. (1904): Magnesian rocks at Milford Sound. – Transactions of the New Zealand Institute, **37**, 481–484, Wellington.

MCKAY, A. (1893): Geological explorations of the northern part of Westland. – Appendix to the Journals of the House of Representatives of New Zealand, **C-3**, 132–186, Wellington.

MITCHELL, J. (1823): Dictionary of chemistry, mineralogy and geology. – 630 pp., London.

MONRO, D. (1844): Notes of a journey through a part of middle island of New Zealand. – The Nelson Examiner, and New Zealand Chronicle, 5 October 1844, 123–124.

MORGAN, P.G. (1908): The geology of the Mikonui subdivision, south Westland, New Zealand. – Geological Survey Bulletin, **6** (New Series), X + 175 pp., Wellington.

NAGY, B. & FAUST, G.T. (1956): Serpentines: natural mixtures of chrysotile and antigorite. – American Mineralogist, **41**, 817–838, Washington, D.C.

NATHAN, S. (2014): James Hector and the first geological maps of New Zealand. – Journal of the Royal Society of New Zealand, **44**, 88–100, Wellington.

Nathan, S., Rattenbury, M.S. & Suggate, R.P. (Compilers) (2002): Geology of the Greymouth area. – Institute of Geological & Nuclear Sciences 1:250 000 geological map 12, 1 sheet + 58 pp., Lower Hutt.

Nuttall, T. (1822): Observations on the serpentine rocks of Hoboken, in New Jersey, and on the minerals which they contain. – American Journal of Science (1st Series), **4**, 15–23, New Haven.

Rammelsberg, C.F. (1844): Beiträge zur Mineralchemie. – Annalen der Physik und Chemie, **62**, 137–158, Leipzig.

Rammelsberg, C.F. (1860): Handbuch der Mineralchemie. – 1st edition, 1038 pp., Leipzig (W. Engelmann).

Rattenbury, M.S., Jongens, R. & Cox, S.C. (Compilers) (2010): Geology of the Haast area. – Institute of Geological & Nuclear Sciences 1:250 000 geological map 14, 1 sheet + 58 pp., Lower Hutt, New Zealand.

Reay, A. & Cooper, A.F. (1984): The Pounamu Ultramafic Belt, and ophiolite within the Torlesse Terrane, New Zealand. – Ofioliti, **9**, 135–144, Bologna.

Reed, J.J. (1959): Soda-metasomatised argillite associated with the Nelson ultramafic belt. – New Zealand Journal of Geology and Geophysics, **2**, 905–915, Wellington.

Saussure, N.T. de (1806): Analyse des Jade. – Journal für die Chemie und Physik und Mineralogie, **2**, 450–462, Berlin.

Schafhäutl, C. (1843): Chemisch-mineralogische Untersuchungen. – Annalen der Chemie und Pharmazie, **46**, 325–347, Leipzig.

Scheerer, T. (1851): Beiträge zur näheren Kenntniss des polymeren Isomorphismus. – Annalen der Physik und Chemie, **3**, 321–410, Halle.

Schlagintweit, H. (1873): Über Nephrit nebst Jadeit und Saussurit im Künlün-Gebirge. – Sitzungsberichte der mathematisch-physikalischen Klasse der k. b. Akademie der Wissenschaften zu München, **3**, 227–267, München.

Shortland, E. (1851): The southern districts of New Zealand. A journal with passing notices of the customs of the Aborigines. – XIV + 315 pp., London (Longman, Brown, Green and Longmans).

Skinner, H.D. (1935): New Zealand greenstone. – Transactions of the Royal Society of New Zealand, **65**, 211–220, Wellington.

Smith, J.L. & Brush, G.J. (1853): Reexamination of American minerals: Part I. Emerylite; euphyllite; Litchfield mica; unionite; kerolite; bowenite; williamsite; lancasterite; hydromagnesite; magnesite. – American Journal of Science, **15**, 207–215, New Haven.

Spencer, L.J. (1919): Eighth list of new mineral names. – Mineralogical Magazine and journal of the Mineralogical Society, **18**, 373–390, London.

Stoliczka, F. (1874): Note regarding the occurrence of jade in the Karakash Valley on the southern borders of Turkestan. – Quarterly Journal of the Geological Society of London, **30**, 568–570, London.

Taylor, R. (1848): A leaf from the natural history of New Zealand: or a vocabulary of its different productions, etc., etc., and their native names. – J. Williamson, “New Zealander Office”, 102 pp., Auckland.

Taylor, R. (1855): Te Ika-a-Maui or New Zealand and its inhabitants. – 530 pp., London (Wertheim & MacIntosh).

Tennant, W.C., Claridge, R.F.C., McCammon, C.A., Smirnov, A.L. & Beck, R.J. (2005): Structural studies of New Zealand pounamu using Mossbauer spectroscopy and paramagnetic resonance. – Journal of the Royal Society of New Zealand, **35**, 385–398, Wellington.

Tsien, H.H. (1996): Crystal growth and whitening of archaic tremolite yu. – Acta Geologica Taiwanica, **32**, 131–147, Taipei.

Turner, F.J. (1935): Geological investigations of nephrites, serpentinites and related “greenstones” used by the Maori of Otago and South Canterbury. – Transactions of the Royal Society of New Zealand, **65**, 187–210, Wellington.

Ulrich, G.H.F. (1890): On the discovery, mode of occurrence, and distribution of the nickel-iron alloy awaruite, on the West Coast of the South Island of New Zealand. – Quarterly Journal of the Geological Society of London, **46**, 619–632, London.

Watts, H. (1869): A dictionary of chemistry and the allied branches of other sciences. Volume **5**. – 1118 pp., London (Longmans, Green).

Whittaker, E.J.W. & Zussman, J. (1956): The characterisation of serpentine minerals by X-ray diffraction. – Mineralogical Magazine, **31**, 107–126, London.

Wilkins, C.J., Tennant, W.C., Williamson, B.E. & McCammon, C.A. (2003): Spectroscopic and related evidence on the coloring and constitution of New Zealand jade. – American Mineralogist, **88**, 1336–1344, Washington, D.C.

Wood, B.L. (1972): Metamorphosed ultramafites and associated formations near Milford Sound, New Zealand. – New Zealand Journal of Geology and Geophysics, **15**, 88–128, Wellington.

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