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Ferdinand von Hochstetter's 1864 description of Dunite – a scholarly annotated English translation

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10 Text-Figures, 1 Table

Ferdinand von Hochstetter
Dunite
Olivine
Chromite
Dun Mountain
New Zealand

Contents

Abstract

Ferdinand von Hochstetter (1829–1884) named Dunite at a public lecture in Nelson, New Zealand, on 29th September 1859, shortly after his visit to Dun Mountain where specimens were collected and mineral deposits investigated. On his return to Vienna, the dunite specimens were independently analysed at the laboratories of the Polytechnic Institute and Imperial Geological Survey of Austria. Hochstetter published his description of dunite in the journal of the German Geological Society in 1864 (HOCHSTETTER, 1864a). This article comprises a scholarly annotated English language translation of Hochstetter's paper and a translation of a related published letter in which Hochstetter outlines the place and relationship of dunite, lherzolite and chassignite. Presented with historical and biographical notes, the paper looks at the history and current status of the term dunite, its petrogenesis and relevance in regional tectonics.

Ferdinand von Hochstetters Beschreibung von Dunit 1864 – eine englische Übersetzung mit Anmerkungen

Zusammenfassung

Anlässlich seines öffentlichen Vortrages am 29. September 1859 in Nelson, Neuseeland, benannte Ferdinand von Hochstetter (1829–1884) erstmals einen Dunit, kurz nach seinem Besuch des Dun Mountain, wo Handstücke gesammelt und Mineralvorkommen untersucht wurden. Nach seiner Rückkehr nach Wien wurden die Proben von Dunit in den Laboratorien des k. k. Polytechnischen Instituts und der k. k. Geologischen Reichsanstalt unabhängig voneinander untersucht. Hochstetter publizierte diese Analysen zusammen mit seiner Beschreibung in der Zeitschrift der Deutschen Geologischen Gesellschaft im Jahr 1864 (HOCHSTETTER, 1864a). Die vorliegende englische Übersetzung mit historischen und biografischen Anmerkungen wird noch durch die Übersetzung eines Briefes ergänzt, in dem sich Hochstetter mit dem Namen Dunit im Vergleich zu dem verwandten Lherzolith und Chassignit auseinandersetzt. Die Benennung und der Status des Namens Dunit sowie verwandte Minerale werden zusammen mit Betrachtungen zur Petrogenese und Relevanz in der regionalen Tektonik vorgestellt.

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Introduction

The first mention of the rock term dunite was by Ferdinand von Hochstetter (Text-Fig. 1) during a public lecture in Nelson, New Zealand, on 29 September 1859 in which he outlined the geology of the Nelson Province, northern South Island of New Zealand, based on his explorations with Julius von Haast (see JOHNSTON & NOLDEN, 2011 for details). The part of Hochstetter's lecture relevant to a prominent NE–SW striking belt of serpentine through the province, its component rocks and Dun Mountain, is as follows:

"*An immense serpentine dyke, of a thickness of several miles, stretches from the northern extremity of D'Urville's Island, across the French Pass, through the Croixelles, by the Dun Mountain, Upper Wairoa, and is met with again, on a continuation of the same straight line, on the red hills, near the Tophouse, on the northern side of the Wairau Valley. This dyke can thus be traced from north-east to south-west for a distance of eighty miles. The strike of the serpentine dyke is perfectly parallel to that of the slates, but its eruptive origin is proved by the occurrence of a breccia of friction (Reibungsbreccia) at the line of contact; and the fact of beds of slate enclosed in it being converted into hard and semi-vitrified cherts. The serpentine, in its turn, has been broken through by eruptive dykes of hypersthenite and gabbro. The rock of the Dun Mountain proper is a variety of serpentine, of so novel and peculiar a character, that I am obliged to apply to it a new term, and call it 'Dunnite'* [sic]." (Text-Fig. 2).

Hochstetter's lecture was printed in full in the Nelson Examiner (1 October 1859) (HOCHSTETTER, 1859a) and later in the New Zealand Government Gazette (Province of Nelson) No. 39 (HOCHSTETTER, 1859b) of the same year. The lecture was prepared with the help of Dr. David Monro, a Scot, member of the Nelson Provincial Council, and Chairman of the local committee of the Dun Mountain Copper Mining Company, which may account for the double 'n' spelling of dunite in the printed versions – this spelling derived from the old Gaelic donn, meaning "brown", although on one of Hochstetter's draft geological maps now in the Nelson Provincial Museum (M1671; detail reproduced in JOHNSTON & NOLDEN, 2011: 188) is written as "Dunit". During an excursion to the hills east of Nelson (locally known as "The Mineral") between 29th August and 1st September 1859, to examine chromite workings, Hochstetter with Monro and others ascended Dun Mountain on the evening of Wednesday 31st where "*…from the summit…we had a very fine view over the mountain range bounding the Wairau Valley on the west*" (diary of Sir David Monro for 1859, transcribed by FLEMING, 1959: 959) (Text-Fig. 3), and when he presumably discovered and collected in-situ dunite (Text-Fig. 4). Five years later, in 1864, Hochstetter published a formal account of the rock and its component minerals, olivine and chromite, in the Journal of the German Geological Society, a translation of which follows HOCHSTETTER (1864a).

Text-Fig. 1.
1857 lithographic portrait of Ferdinand von Hochstetter by Adolf Dauthage (1825–1883) (Hochstetter Collection Basel).

Hochstetter's paper in Zeitschrift der Deutschen Geologischen Gesellschaft, Vol. XVI, 1864: 341–344

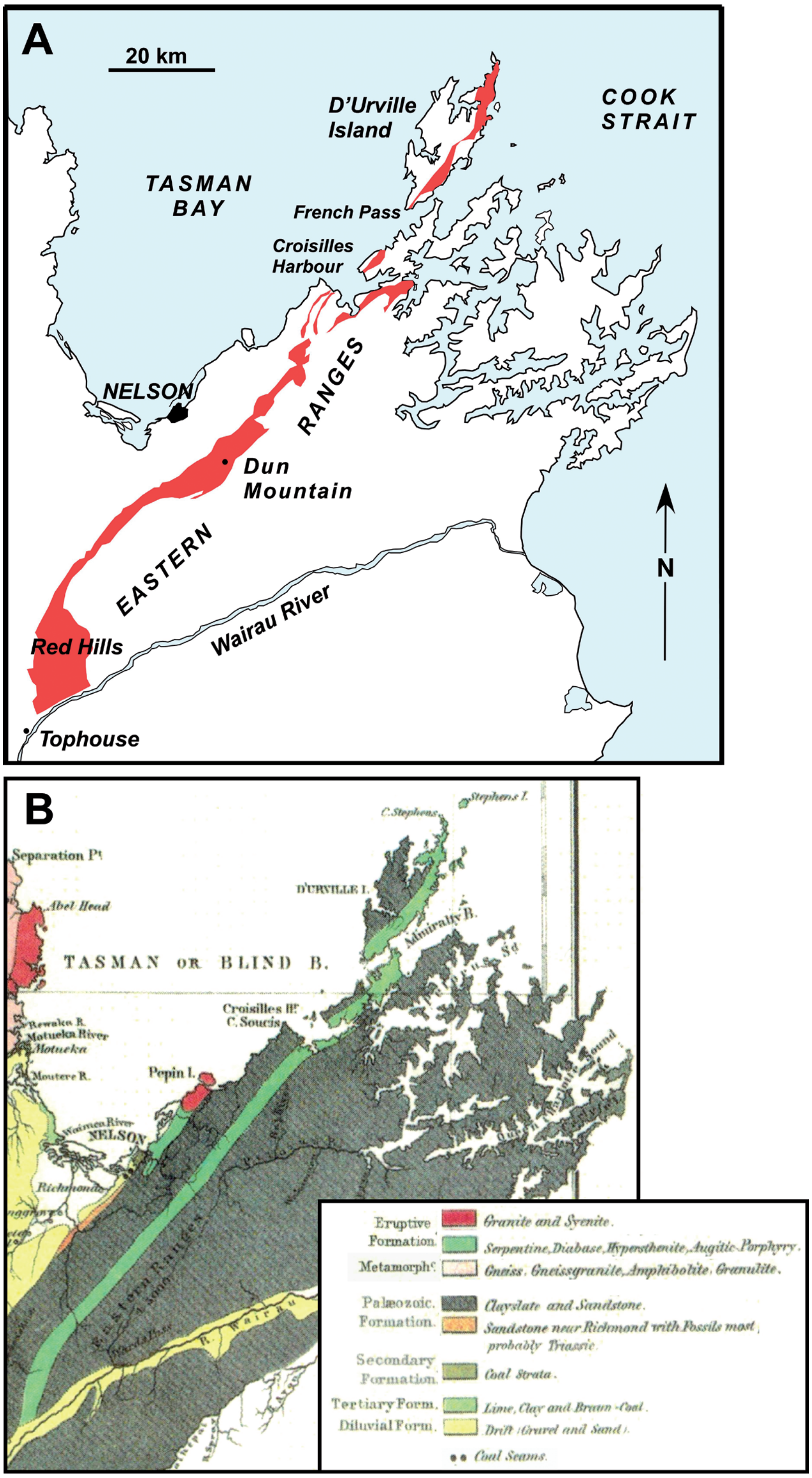
Dunite, granular olivine-rock from Dun Mountain, Nelson, New Zealand

Ferdinand von Hochstetter, Vienna

During my visit to New Zealand* I came across a peculiar rock that I called Dunite which occurs in association with serpentinite and forms the huge 4,000 feet-high Dun Mountain, six English miles south-east of Nelson. Amongst the thickly forested mountains in this area, Dun Mountain is conspicuously barren and owes its name to the dun colour of the yellow rusty-brown rocks. Countless boulders cover the mountain slopes; their weathered and corroded surfaces are a dirty, rusty colour. Sometimes more yellowish, at other times more reddish-brown; only low shrub and alpine plants grow between the boulders, hence the rock colours are little concealed by vegetation.

Dunite on a freshly broken surface is of light yellow-green to grey-greenish colour and exhibits a greasy to glassy lustre. The texture is granular crystalline. The fractured surface is uneven, angular-granular and coarsely splintery; single grains show a preferred cleavage, recognizable as small reflecting surfaces with a glassy sheen. This cleavage can also be seen as striations in thin rock flakes when viewed under the microscope in certain conditions. Hardness 5.5 (slightly less than feldspar). Specific gravity 3.295. Streak white. Under the blow pipe small splinters of the rock show a rust-yellow colour, but do not melt. The rock almost completely dissolves in hydrochloric acid.

* See Dr. F. Hochstetter, lecture on the Geology of the Province of Nelson. New Zealand Government Gazette No. 39, 1859. [HOCHSTETTER, 1859b]

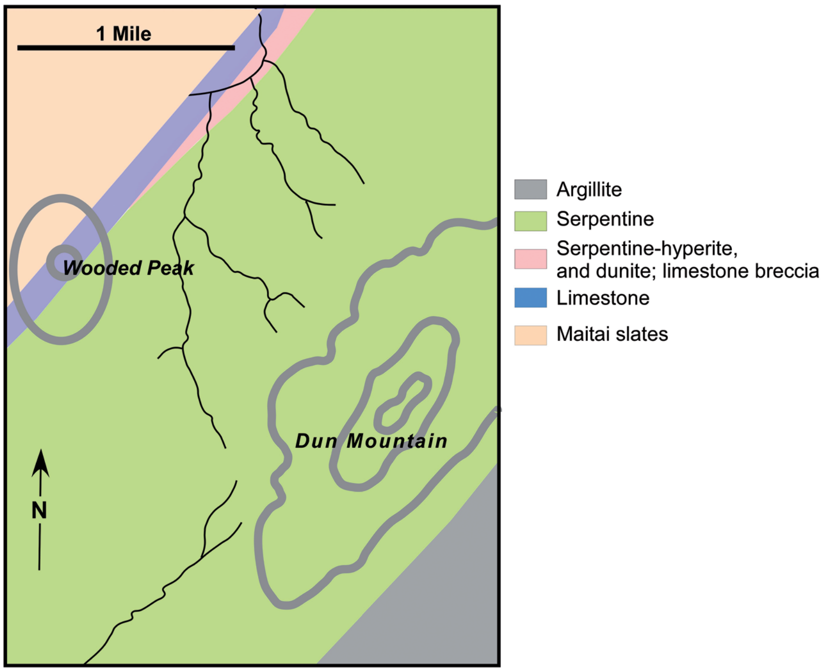


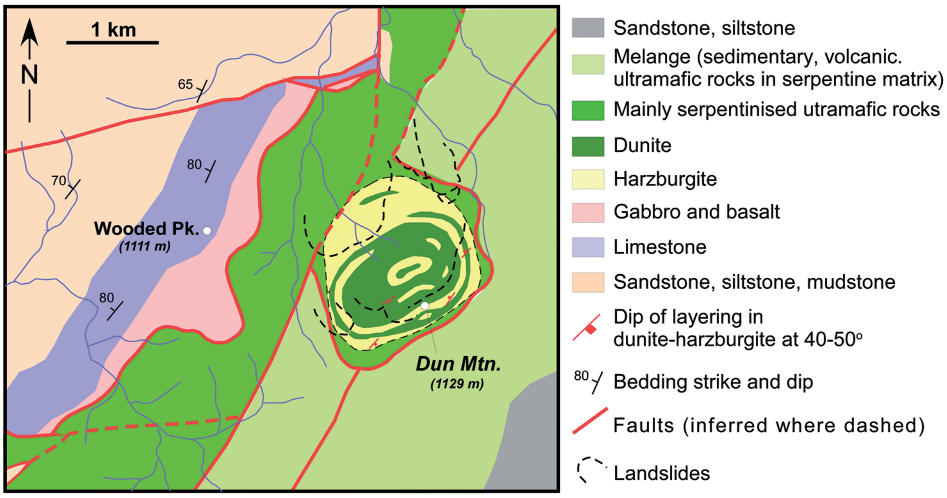
Text-Fig. 2.
A: Map of the north-eastern part of the South Island of New Zealand showing locations mentioned in Hochstetter's public lecture, Nelson, on 29 September 1859, and the copper- and chromite-bearing rocks of the 'mineral belt' (in red) extending from D'Urville Island in the north to Tophouse in the south (see text). **B:** Part of the Geological map of the Nelson Province by Dr. Ferdinand von Hochstetter 1859 and Julius von Haast 1860 showing the 'mineral belt' referred to by Hochstetter as an 'immense serpentine dyke' (HOCHSTETTER & HAAST, 1864).

Chromite occurs as needle-head sized black grains which when viewed under the hand lens form octahedrons with rounded edges disseminated through the rock as the characteristic accessory mineral.

Dun Mountain forms part of a magnificent serpentinite mountain range which extends in length for 80 English miles and in width varies between 1 and 2 English miles. I have documented its eruptive character [1] elsewhere**. It is continuous with Wooded Peak which consists of common serpentinite. Here chromite locally occurs in such abundance that it is mined. Therefore, we can assume that the chromite-rich rocks on Dun Mountain are also composed essentially of a magnesia silicate. All characteristics listed above indicate olivine; however, who would presume to suggest without proof of a chemical analysis that olivine could occur in such large eruptive masses as to form Mesozoic mountain ranges similar to serpentinite. Two analyses commissioned by me give results in good agreement with each other.

** See Novara Expedition, Geological part. Volume 1: Geologie von Neu-Seeland, p. 217. [HOCHSTETTER, 1864b: 217]





Text-Fig. 3.
Upper: Map of the Dun Mountain area (redrawn and re-orientated to true north from Hochstetter's 1864 map of copper and chromite mineralisation (here omitted) between Dun Mountain and Wooded Peak (HOCHSTETTER, 1864b). **Lower:** Map of the same area simplified after JOHNSTON (1981) and also showing the distribution of essentially unserpentinised dunite and harzburgite (but not all in-situ) centred on Dun Mountain according to LAUDER (1965a: Fig. 4). Dun Mountain forms a SE-directed nappe-like structure.

Analyses of Dunite

a. The analysis was carried out in the K.K. Polytechnic Institute by E. Reuter under the guidance of Prof. Dr. A. Schrötter.

b. Carried out in the K.K. Geological Survey by Dr. A. Madelung.

The samples selected for analysis contained as little chromite as possible.

	a.		b.
SiO_2	42.80		42.69
MgO	47.38		46.90
FeO	9.40		10.09
Na_2O, NiO, CoO	traces	NiO	trace
Water (from heating to 160° C)	0.57		0.49
	100.15		100.17

Ignoring water, the following oxygen numbers can be calculated.

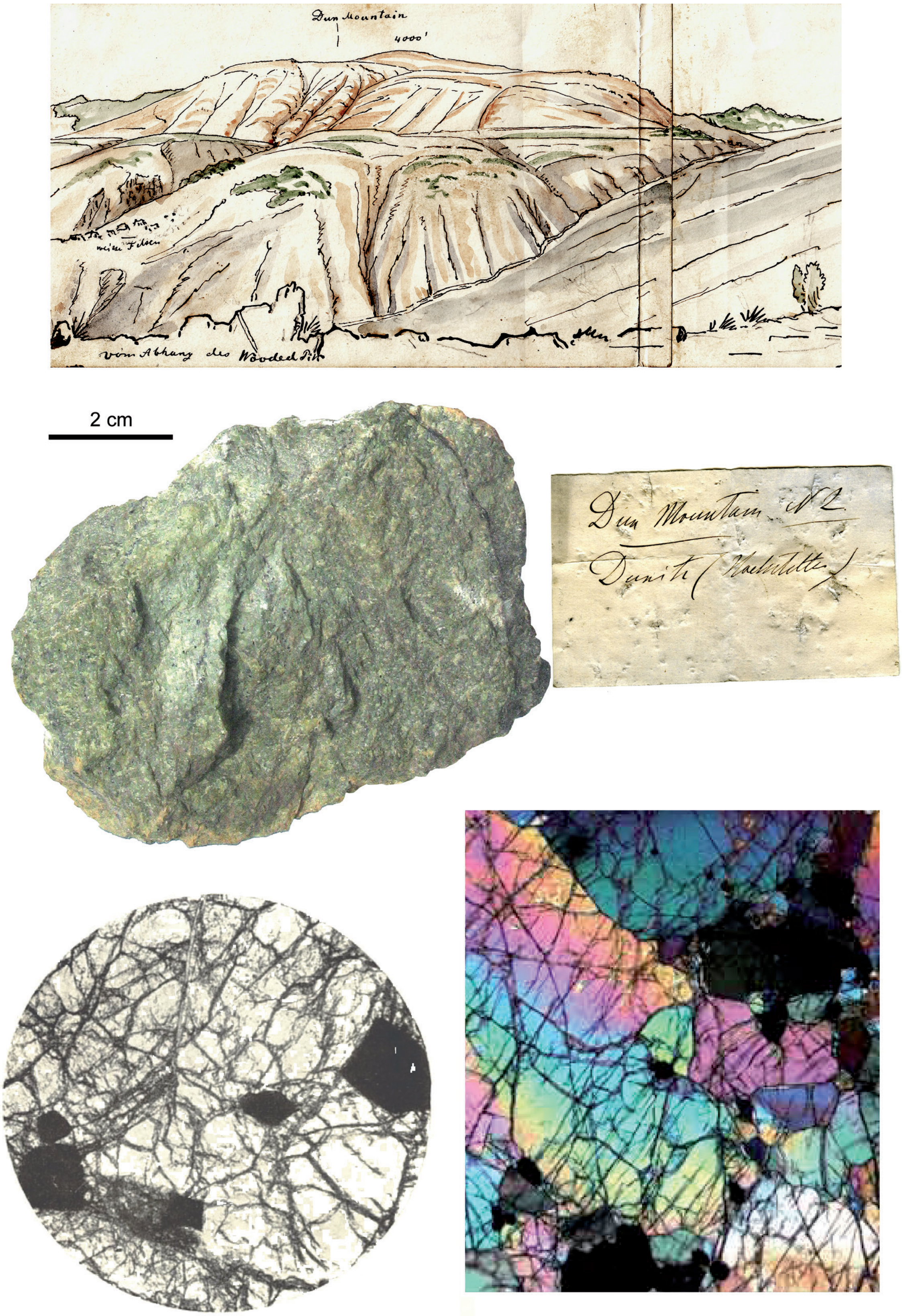
	a.	b.		a.	b.
SiO_2	22.3	22.1	SiO_2	22.3	22.1
MgO	19.0	18.8	RO	21.1	21.0
FeO	2.1	2.2			

From both analyses the olivine formula can be derived:

$$\dot{Fe}^2 \ddot{Si} + 9\dot{Mg}^2 \ddot{Si}$$

or expressed as 2RO . SiO_2 with an oxygen ratio of 1:1. [2]

Characteristic is the presence of trace amounts of nickel in the dunite which is considered by Stromeyer to be an integral part of olivine [3]. It is likely that chromite in the dunite is also nickel-bearing, similar to chrome-iron ore of Texas and Pennsylvania [4]. Traces of cobalt detected in analysis **a** have also been found in other olivine rocks, such as by Genth in olivine of the Thjorsa lava from Hekla [5]. Regarding the chrome content, which Walchner considers a component of olivine [6], it forms a separate mineral in the dunite.



Text-Fig. 4.
Top: Hochstetter's sketch of Dun Mountain at '4,000' ft. viewed towards the north-east from the dray road on Wooded Peak (Hochstetter Collection Basel). **Centre:** Original dunite sample collected by Hochstetter together with original label written by Julius Haast who accompanied Hochstetter on his visit to Dun Mountain in August–September 1859 and who may have trimmed the sample that was used for reference, research and teaching purposes. Note the thin zone of brown 'dun-coloured' weathering along part of the lower edge of the sample; the disseminated black spots of chrome spinel; the lighter yellowish-green areas (top and centre) which represent areas of fresh olivine in comparison to the slightly darker green colour of most of the specimen where olivine is associated with minor serpentine and brucite alteration as evidenced by the small amount of water (0.49–0.57 %) in Hochstetter's analyses of a duplicate sample of the dunite (1864a: 342) (photos kindly supplied by Dr. Albert Schedl, Geological Survey of Austria). **Bottom:** Microscopic views of dunite from Dun Mountain. **Left:** View under plane-polarized light showing extensive cracking of clear olivine and black euhedral chrome spinel (Marshall, 1925: Fig. 1); **right:** View under crossed nicols showing 2nd–3rd order interference colours of olivine and opaque chrome spinel (Grapes, unpublished data). Scale for both images x 35.

Olivine in older non-volcanic rocks is well known from other localities, the hypersthene rocks from Elfdalen [7], also in the Urals olivine crystals occur in talc schist on Itkul mountain near Sysserk [8], as coarse olivine (*glinkite*) in talc schist from Kyschtimsk [9], and as pseudomorphs in serpentinite from Snarum in Norway [10]. However, up to now it has not been known that olivine can form whole mountain ranges [11]. Dunite is mineralogically related to olivine xenocrysts [*dunite*] in volcanic rocks, like old fresh feldspar to glassy volcanic feldspar, but from a mineralogical point of view, dunite is different from fresh, coarse olivine. Geologically it is diagnostic as rock-forming and as part of an eruptive rock suite of Mesozoic age [12], which in future should be listed together with hyperite [13], gabbro and serpentinite.

Now that what I have named dunite in New Zealand turns out to be olivine-rock, I expect that there will be other dunites also in the northern hemisphere associated with gabbros and serpentinites, or with augite-porphyries and diabase-like rocks. In particular, hard crystalline parts of serpentinite bodies should be investigated with greater care. It is likely that a number of such localities have been missed.

Finally, I want to remark that the dunite as well as the closely associated serpentinite are cut by hyperite veins from which one can obtain superb examples of coarse-grained hypersthene [14]; furthermore that the copper mine of the Dun Mountain Company [15] is not associated with the dunite but related to the adjacent serpentinite of Wooded Peak. On the surface the copper manifests itself as greenish and bluish chrysocolla, which forms thin layers, crusts and films on crumbling serpentinite boulders; these indications were followed in shafts and along tunnels and some smaller and larger ore bodies were found containing cuprite with nests of native copper, and also copper sulphates. However, a continuous economic ore body has not yet been discovered.

Notes on Hochstetter's paper

1 Hochstetter is using the term 'eruptive' in the general sense of igneous rocks.

2 Two years after Hochstetter, William Skey, analyst of the Colonial Laboratory, Wellington, provided two analyses of 'dunite' (Nos. I and II in HECTOR & SKEY, 1866). No. I and an additional 'dunite' analysis (No. 8) were listed by SKEY in 1871 (Tab. 1). The analyses were made in response to the application of magnesium to the production of artificial light of intense brilliancy prompting the analyses of various magnesian rocks at the 1865 New Zealand Exhibition in Dunedin to be made, but without indicating any economic value.

The descriptions of the Dun Mountain rocks are as follows:

"No. I and II. Dunite or Massive Olivine. Colour light green, dotted with black specks of chrome ore, non-lustrous, feebly translucent, structure massive, also flaky in parts, fracture irregular, sometimes conchoidal. Alone fusible in blow-pipe flame, siliceous part is entirely decomposed by hydrochloric acid, silica separating in gelatinous form, hardness 6 specific gravity 3.462*."

	I	II	8
SiO_2	40.85	40.14	51.01
Al_2O_3	0.80		tr.
Cr_2O_3	1.30	1.20	0.40
Fe_2O_3	tr.		
FeO	7.65	8.34*	9.68
MnO	nd.		
MgO	47.31	48.20	38.51
CaO	tr.		tr.
H_2O	1.93	1.93	0.40
Total	**99.84**	**99.81**	**100.00**

* Combined Al_2O3, Fe_2O_3, FeO
tr. = trace; nd. = not detected

Tab. 1.
Analyses of dunite and harzburgite (I and II from HECTOR & SKEY, 1866: 411; 8 from SKEY, 1871: Tab. 3).

"No. 8. Dunite (Massive Olivine). Has nearly the composition of No. I, but its mineralogical characters being slightly different to that of ordinary Dunite, an analysis was rendered necessary. It is blackish coloured of a lustre almost attaining to vitreous, and it exhibits a massive crystalline structure. The analysis shows it to contain half an equivalent of silica more than true Dunite does**." (HECTOR & SKEY, 1866: 411; SKEY, 1871: 18) (Tab. 1).

Nos. I and II are dunite. No. 8 is harzburgite (Tab. 1); Skey mistakenly calls it dunite although he recognized that the rock contained enstatite together with olivine and chromite.

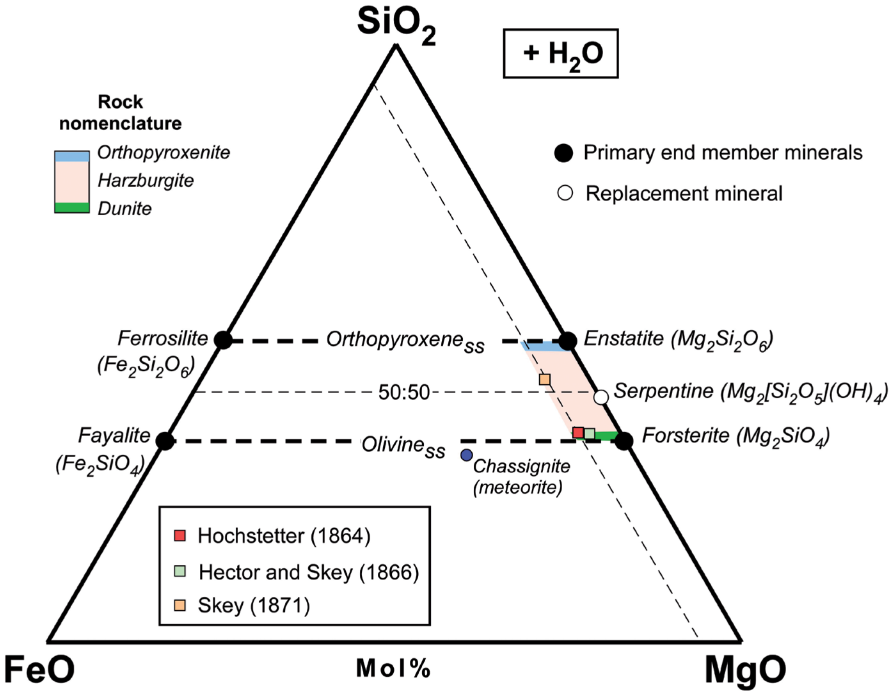
The presence of H_2O in the analyses of Hochstetter and Skey indicates that some of the olivine is replaced by serpentine and brucite. The dunite and harzburgite compositions are plotted on a mol% SiO_2-FeO-MgO diagram in Text-Figure 5.

3 Friedrich Stromeyer (1776–1835; German chemist), gives 0.32 and 0.37 % NiO in olivines separated from basalt in Germany (quoted in WALMSTEDT, 1825) and was the first to report of nickel in olivine. ROSS et al. (1954) record 0.25 % NiO in olivine from Dun Mountain and electron microprobe analyses yield 0.30–0.42 % (GRAPES, unpublished analyses). In the dunite itself, NiO ranges from 0.25–0.32 % (REED, 1959; GRAPES, unpublished data). In the chromite, NiO ranges from 0.15–0.77 % (GRAPES, unpublished data).

4 GARRETT (1852) reported 2.282 % NiO in chromite from one of the Pennsylvania chromite mines (Wood Mine, Chester Country), and 0.10 % in chrome sand washings. The typical nickel content of most commercial chrome ores in Pennsylvania is between 0.1 and 0.24 % NiO (THAYER, 1956: 25). Hochstetter's reference to chrome-iron ore in Texas may refer to the Texas Mine that was worked by the Texas Mining and Manufacturing Company of New York, close to the Wood Mine in Pennsylvania, not the state of Texas which has no chromite deposits (KNOPF, 1921).

5 Frederick Augustus Genth (1829–1893; German-American chemist specializing in analytical chemistry and mineralogy) records a trace of CoO in olivine from the Thjorsa lava (GENTH, 1848: 20). ROSS et al. (1954) give 0.017 % in

* Hochstetter gives a specific gravity of 3.295.
** Because of the presence of enstatite.



Text-Fig. 5.
Compositions of dunite and harzburgite from Dun Mountain, the Chassigny iron-dunite meteorite, and component minerals plotted in terms of mol% SiO_2-FeO-MgO (+ H_2O). The ultramafic rock fields apply to terrestrial compositions.

Dun Mountain olivine. In the dunite, Co ranges from 133–152 ppm, or 0.017–0.019 % CoO (Reed, 1959; Grapes, unpublished analyses).

6 Frederick August Walchner (1799–1865; German geologist, chemist and mineralogist). According to his experiments, chrome (Cr_2O_3) occurs in different varieties of olivine (Bischof, 1855). Analyses of Dun Mountain olivine gives 0.01–0.20 % Cr_2O_3 (Grapes, unpublished electron microprobe analyses); Ross et al. (1954) record 0.015 %. In the dunite Cr_2O_3 ranges from 0.17–1.01 % and depends on the amount of chromite present. One dunite analysis given by Davis et al. (1980; analysis in Tab. 3) yields 10.27 % Cr_2O_3 which reflects its high chromite content so that it could be classified as a chromite-dunite (Vogt, 1894; Turner, 1930: 189).

7 Olive-green olivine occurs as large crystals at Elfdalen, Sweden, associated with hypersthene rocks composed essentially of hypersthene and labradorite (Rose, 1835). Such rocks were subsequently classified as olivine norite characterized by plagioclase + hypersthene + olivine.

8 At Itkul mountain, olivine occurs in greenish imbedded nodules in talc schist of Sysserk, Urals. Gustav Rose (1798–1873; German mineralogist and crystallographer) mentions irregular-shaped olivine crystals at this locality which are sometimes as large as a man's fist (Bischof, 1855: 363). Chemical analysis of the olivine rock is given by Heindl & Pendergast (1934) who record the presence of accessory serpentine and an opaque mineral (probably Ti-magnetite as their analysis contains 1.82 % TiO_2).

9 Glinkite is an outdated synonym for an amorphous variety of olivine (named after General V.A. Glinka, Governor of the Urals) from the District of Perm where it forms small veins in talc. It was chemically analysed by Beck (1848) with the forsterite end-member composition of Fo_{82}.

10 Serpentine pseudomorphs of olivine from Snarum, Norway, are well-known to mineral collectors. One such crystal pseudomorph collected in the 19th century has dimensions of 4.3 x 2.8 x 1.7 cm.

11 In a letter to Julius von Haast dated 12 and 16 June 1864, Hochstetter wrote, "Just think – my dunite is just plain olivine. Pure olivine as a mountain form, as an igneous mass rock type; that is unheard of and is a completely new confirmed result." (Nolden, 2013: 105). Fridolin Sandberger (1826–1898; geologist, mineralogist and palaeontologist at the University of Würzburg) also notes from evidence of the transformation of olivine rock into talc schist in the Urals (an example alluded to by Hochstetter), that olivine rocks must have existed as large masses, supporting Hochstetter's statement "that olivine could occur in such large eruptive masses as to form Mesozoic mountain ranges similar to serpentinite." However, the idea that a large mass of dunite was formed as a result of crystallization from magma of the same composition remained a problem. Actually, in-situ outcrops of dunite on Dun Mountain only extend over a relatively small area, perhaps no more than 1.3 km^2, and are confined almost entirely to the plateau summit; overall, most outcrops are harzburgite (Text-Fig. 3), a rock term not coined until 1887 from its occurrence at Baste, near Harzburg, Germany (Rosenbusch, 1887). Edward Heydelbach Davis (1845–1871), the second geologist to investigate the Dun Mountain area in October 1870, writes "at first sight it (dunite) appears to be much more extensive, but this is due to the peculiar nature of the slope deposit, large blocks, of many tons weight, lying here and there, apparently in situ, and requiring a close scrutiny to prove that they are loose. The whole of the north-west and north sides of the mountain are covered with this deposit, which has a general tendency to cement itself together into a conglomerate" (Davis, 1871; Johnston, 2007) (Text-Fig. 3).

12 Hochstetter is following Carl Friederich Naumann (1862), a German mineralogist and geologist, who defines an eruptive formation as an assemblage of rocks characterized by their petrographical and palaeontological features and formed at a definite period of time – in this case the Mesozoic.

13 Hyperite is described by HOCHSTETTER (1864b: 226) as a "fine grained mixture of saussurite (i.e., of a dense feldspathic substance) and hypersthene, sometimes only saussurite or only hypersthene, [that] resist weathering more than the serpentine, and thus project like groins on the weathered serpentine rocks." Saussurite was subsequently identified as grossular garnet (hydrogarnet) and the hypersthene as diallage (diopside-augite with closely-spaced {100} partings lined with Fe-oxide) (MARSHALL, 1908), and subsequently called rodingite (MARSHALL in BELL at al., 1911).

14 Hochstetter is referring to an 18 m-wide band of very coarse-grained hyperite in serpentinite that was intersected in an adit (Deep Adit Tunnel of the Duppa [chromite] Lode) on Wooded Peak, and characterized by "coarse laminated specimens of greenish hypersthene" with "glossy cleavage faces a square foot in area" (HOCHSTETTER, 1864b: 225).

15 See JOHNSTON (1983, 1987).

The name 'dunite' and a letter

In his 1871 report on the geology of the Nelson area, Edward Hydelbach Davis acknowledged Hochstetter's 'dunite' but pointed out that "…*Olivine rocks, although rare, are not peculiar to New Zealand, much less to the Dun Mountain, and as the term does not carry any meaning beyond locality, I think that either Olivine rock, or one of the Northern Hemisphere names, is preferable*." (DAVIS, 1871: 110, footnote).

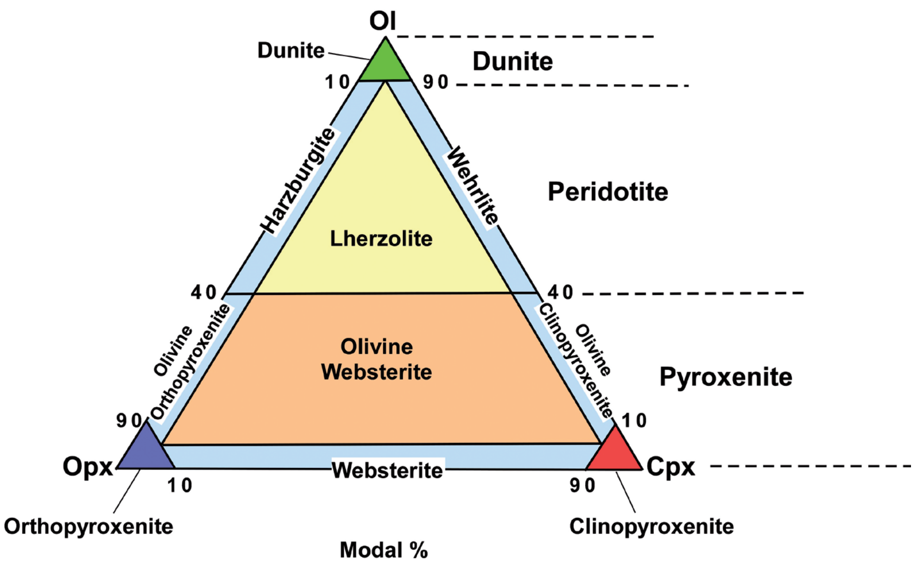
In Europe the olivine rock referred to by Davis was termed olivinfels. SANDBERGER (1866), had noted that, "*credit goes to Hochstetter who discovered a granular olivine rock in 1859 in New Zealand. Although he describes it under the name dunite, without reference to European occurrences, nevertheless, made very interesting observations about the relationship of the rock to serpentine*" (SANDBERGER, 1866: 386, translated from German). He examined fragments of dunite given to him by Hochstetter and was able to separate chromite, enstatite with chrome diopside inclusions from the olivine indicating that the Dun Mountain dunite he examined also contained small amounts of orthopyroxene (enstatite) and clinopyroxene (diopside) – these minerals, together with olivine being characteristic of lherzolite (named after the type locality of *Étang de Lers* [Lake of Lers], derived from the old spelling Étang de Lherz, in the French Pyrenees). From this association Sandberger concluded that he saw no reason to separate dunite from lherzolite and considered that the name olivine rock (olivinfels) be applied to both, and that "*the very rare occurrence of chromium diopside and enstatite has now convinced Hochstetter with respect to my communication, and accordingly his statement about this* [letter transcribed below (HOCHSTETTER, 1866: 77)] *is to be corrected*" (SANDBERGER, 1866: 391, footnote, translated from German).

The recommendation of Sandberger and Davis that the term 'dunite' be abandoned for 'olivine rock' was not taken up in Europe, New Zealand or elsewhere and today 'dunite' is entrenched as a valid term in plutonic igneous rock nomenclature as shown below in the current ultramafic rock classification scheme based on the modal proportions of olivine (Ol), orthopyroxene (Opx) and clinopyroxene (Cpx). From this it is evident that dunite can contain up to 10 modal % ortho- and clinopyroxene and that lherzolite, in contrast, spans a large composition field and can contain between 40 and 90 % olivine (Text-Fig. 6).

Hochstetter's letter (HOCHSTETTER, 1866)

"Vienna, 19 November, 1865.

I was very interested in the remarks of Dr. F. Sandberger on Olivinfels in this issue of the Neues Jahrbuch p. 449 [SANDBERGER, 1866: sic; should be p. 385]. After the frequently misunderstood rock in the Pyrenees, Tyrol and New Zealand has now been correctly identified, and now also appears in Nassau and may yet be found at many other localities [1], it may in fact play a more prominent role than previously believed. The names lherzolite and dunite, from Lake Lherz at Col d'Aneon in the Pyrenees and Dun Mountain in New Zealand, are not synonymous and as Dr. Sandberger notes, lherzolite has priority over dunite [2].



Text-Fig. 6.
Classification and nomenclature of ultramafic rocks based on modal proportions of olivine (Ol), orthopyroxene (Opx) and clinopyroxene (Cpx) (after LE MAITRE, 2002).

At the time I named the New Zealand rock dunite (1859, Lecture on the Geology of the Provence of Nelson, New Zealand Government Gazette, No. 39) [HOCHSTETTER, 1859b]; and recognized the same as olivinfels (1863) [3], I had however, no idea that the rock generally described as augitefels lherzolite [4], consists essentially of olivine; even after Descloizeaux [DESCLOIZEAUX, 1862] and Damour [DAMOUR, 1862] have again drawn attention to this rock type, confirming LELIEVRE's original observation (1787) that it is composed of chrysolite [5], contrary to the later misconceptions, I consider the name dunite fully justified. Dunite and lherzolite fall under the general term olivine rock and are closely related, but still just as different as orthoclastic granite, granitite and syenite [6].

I have hand specimens of lherzolite collected by my friend, Prof. Dr. Zirkel in Lemberg [7], from his trip to the Pyrenees last summer. The rock of Lherz, the type lherzolite, is a dark grey-green mixture of olivine, diopside, enstatite and picotite [8], [9]. The much lighter, yellowish-green dunite consists of fresh, granular olivine without any trace of diopside and enstatite, and instead of picotite contains accessory chromite disseminated as individual small grains. Both rocks are therefore essentially the same composition and in their appearance. This is different for the lherzolite from Serre de Sem near Vicdessos (Ariege-Department). From its outer appearance the hand specimen from this locality closely resembles my dunite. It likewise consists almost entirely of fresh, granular olivine, and I would certainly describe it as dunite, if it were not for the sporadic inclusion of isolated grains of emerald green diopside and black picotite. So here we have lherzolite with a different, and perhaps quite localised proportion of mineral constituents. The dunite composition (olivine and chromite) has, as far as I know, only been found in a meteoric rock, in G. Rose's *chassignite*. The chassigny meteorite (found in 1815), according to G. Rose, consists of iron-rich olivine with accessory chromium ore [10].

Therefore, so far we have three special varieties of olivine rock named after their localities – two terrestrial and one meteoric:

lherzolite, dunite, chassignite,

and these names may at least coexist.

Dr. Ferdinand v. Hochstetter."

Notes on Hochstetter's letter
(HOCHSTETTER, 1866)

1 Hochstetter is referring to olivine-rich basalt (picrite) at Nassau. Another European occurrence is the subject of a letter from Dr. Theodor Kjerulf (1825–1888; a Norwegian geologist and first director of the Norwegian Geological Survey) entitled "Olivinefels in Norway" (KJERULF, 1867) which was found in 1864 and equated with Hochstetter's dunite: "*I see from the German Geological Society Volume XVI, Issue February, March, April – which only arrived in Christiania in December 1864 –Ferdinand von Hochstetter precisely recognised this new mountain type (of olivinfels) as Danil* [sic. Dunit] *from New Zealand as early as 1859. All that remains for me to do is to confirm Herr von Hochstetter's assumption that there are many olivine rocks on this half of the earth, associated with gabbro and serpentine intrusions*" (KJERULF, 1867: 72, translated).

2 The name lherzolite was coined by Jean-Claude DELAMÉTHERIE (1743–1817; French mineralogist, geologist and paleontologist) in 1795 and was regarded by him as an augite-fels (rock) composed of ortho- and clinopyroxene. In 1862 Augustin-Alexis Damour (1808–1902; French mineralogist) described the rock as a granular aggregate of olivine, enstatite, diopside, and picotite. Listed in Text-Figure 7 is an average analysis (selected oxides) of lherzolite from the type locality taken from LE ROUX et al. (2007). The chemical composition is significantly different from Hochstetter's dunite as also shown on the modal mineral classification diagram of ultramafic rocks (two black circles with values 97 % olivine for Dun Mountain dunite [REED, 1959] and 57.9 % olivine, 26.1 % orthopyroxene, 15.9 % clinpyroxene for Lherz lherzolite [LE ROUX et al., 2007]; Text-Fig. 7).

3 HOCHSTETTER (1863).

4 See comment 2.

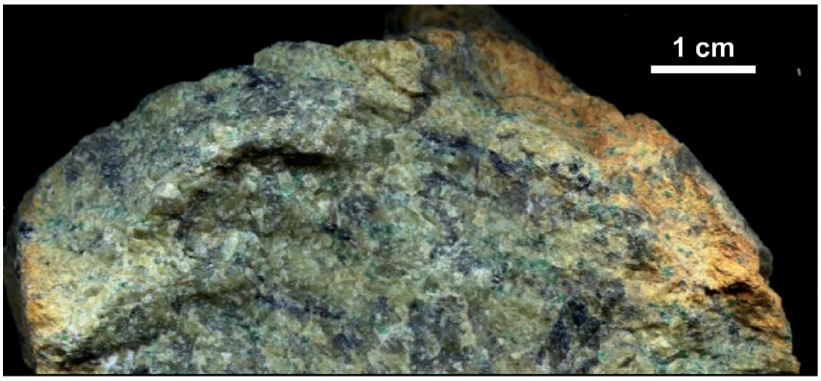
5 Claude-Hugues Lelievre (1752–1835; French mineralogist). Chrysolite is an outdated synonym for transparent, green to yellow-green olivine, analogous to peridot the gem quality variety of olivine. The name is from the Greek "golden stone' in reference to its golden lustre.

6 Hochstetter's terms Orthoklasiten der Granit and Granitit are translated as orthoclase (or alkali-feldspar) granite and biotite granite, respectively. The outdated term granitit (granitite) was used by ROSE (1849) for granite containing biotite as the only dark constituent; it was later called biotite granite (BENECKE & COHEN, 1879), and this name was adopted by ZIRKEL (1894). Rose also included syenite in the granite group in which biotite is accompanied by hornblende. In comparison with the modal variation in olivine-orthopyroxene-clinopyroxene that distinguishes dunite from lherzolite, etc., modal variation of quartz, alkali feldspar (orthoclase) and plagioclase differentiates between the current classification of alkali feldspar granite, (biotite) granite and syenites cited by Hochstetter as shown in Text-Figure 8.

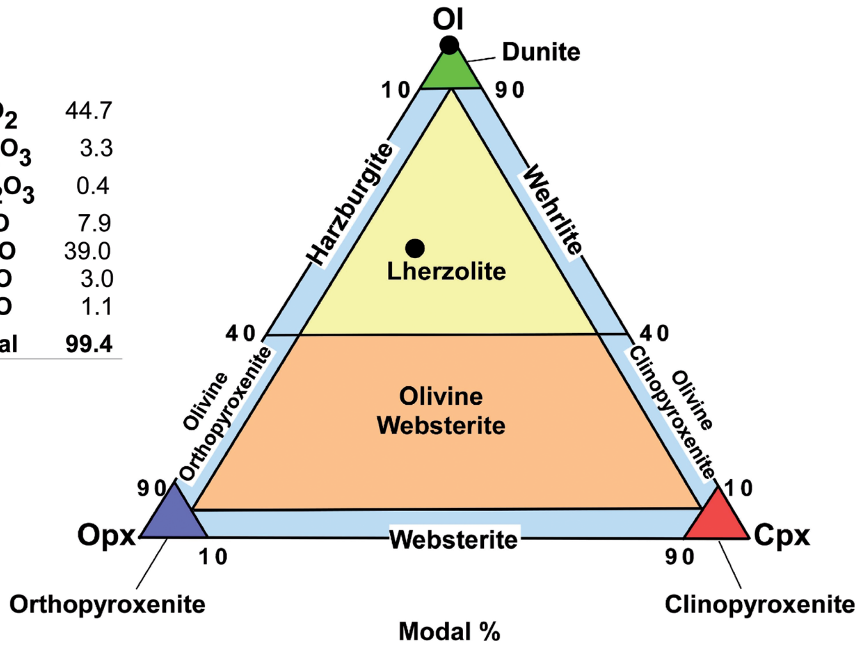
7 Ferdinand Zirkel (1838–1912; German geologist and Professor at Lemberg, now Lviv in the Ukraine). He provided petrographic descriptions of the rocks Hochstetter had collected in New Zealand (HOCHSTETTER, 1864b: 109–123).

8 See comment 2.

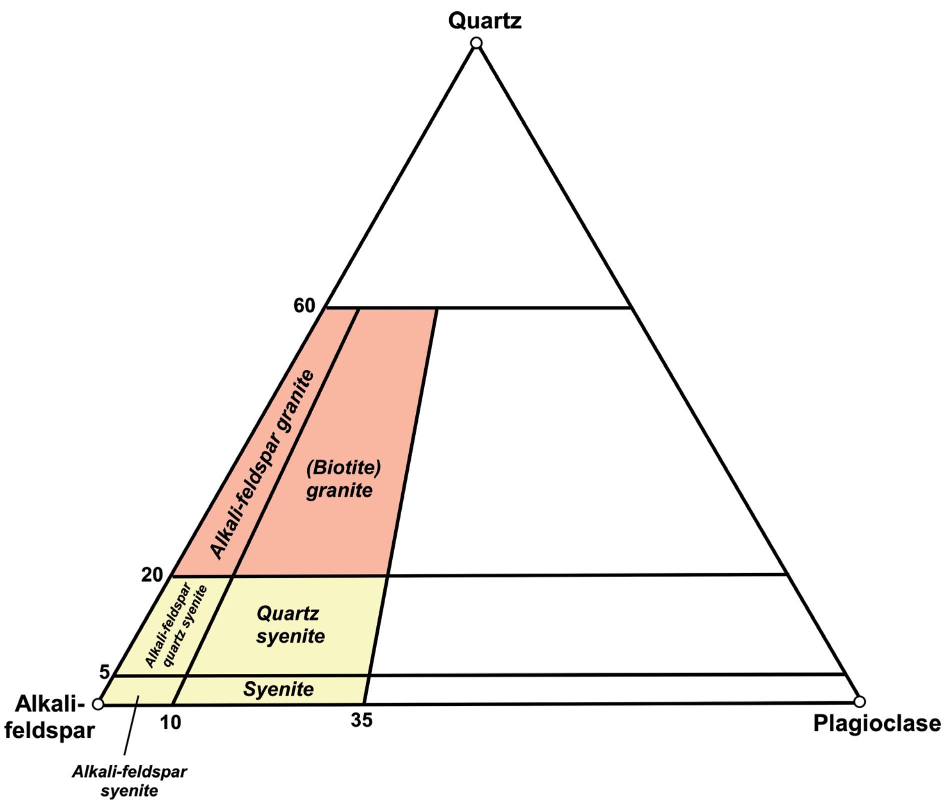
9 The term picotite is used for a variety of hercynite spinel ($Fe^{2+}Al_2O_4$) with appreciable chromium. In his 1864 paper on dunite, Hochstetter described the opaque oxide as chromite ($Fe^{2+}Cr_2O_4$). Electron microprobe analyses indicates that the Cr-rich spinel in the Dun Mountain dunite contains appreciable Al and Mg, as well as Fe^{3+} and in a plot of 100 Fe^{2+}/(Mg + Fe^{2+}) verses 100 Al/(Cr + Al) (recalculated on the basis of four oxygens and three cations) (Text-Fig. 9), show considerable solid solution of four spinel series end-member compositions (chromite-hercynite-spinel (sensu stricto)-magnesiochromite), (GRAPES, unpublished data). Alteration of the Cr-rich spinel indicates the formation of "ferritchromit" (it contains 50.4 % Fe_2O_3, 25.8 % FeO, 1.9 % Al_2O_3, 16.4 % Cr_2O_3; 4.2 % MgO; GRAPES unpublished data) as indicated by the arrowed trend in Text-Figure 9. An analysis of an opaque mineral separate from the dunite by ROSS et al. (1954) indicates that in comparison with the electron microprobe compositions, the sample is contaminated with magnetite (69.6 % Fe_2O_3;



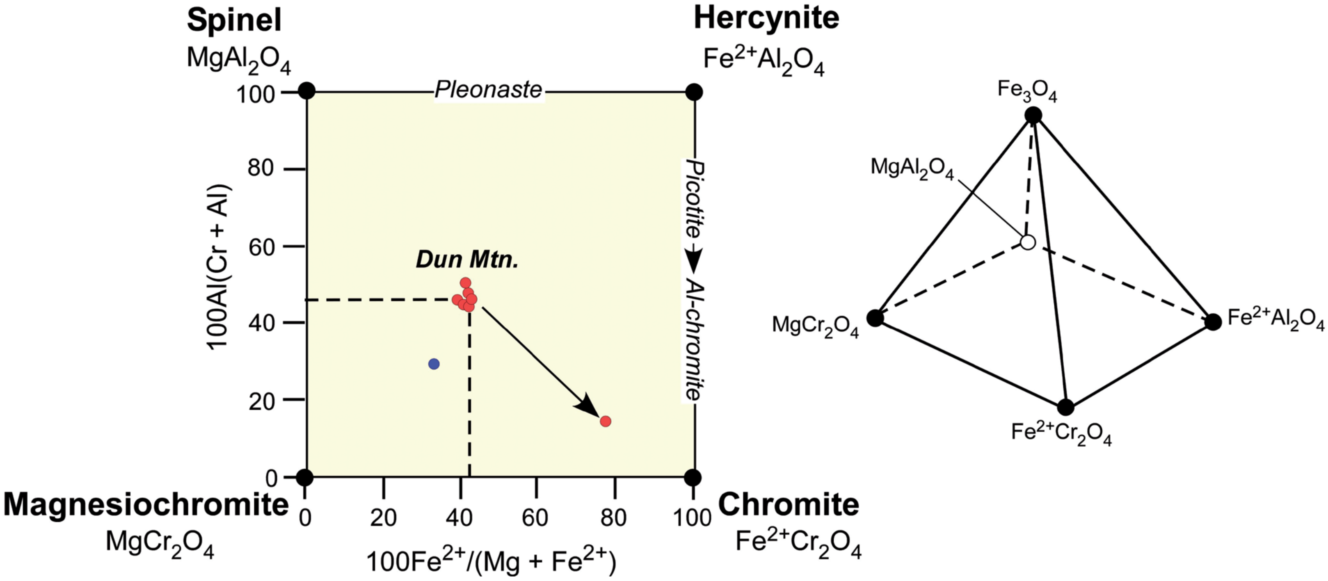
SiO_2	44.7
Al_2O_3	3.3
Cr_2O_3	0.4
FeO	7.9
MgO	39.0
CaO	3.0
H_2O	1.1
Total	**99.4**



Text-Fig. 7.
Top: Lherzolite with oxidized yellow-brown weathering rind from the vicinity of Étang de Lers, French Pyrenees. *Grass-green* = olivine; chrome-green = chrome diopside; *bluish-grey* = orthopyroxene; *black specks* = chrome spinel (picotite). **Below:** Average analysis (n = 12; selected oxides) of Lherz lherzolite with 57.9 % olivine, 26.1 % orthopyroxene, 15.9 % clinopyroxene (Le Roux et al., 2007) plotted on the ultramafic classification diagram together with Dun Mountain dunite containing 97 % olivine (Reed, 1959) (*black circles*).



Text-Fig. 8.
Classification and nomenclature of acid igneous rocks based on modal proportions of quartz (Q), alkali-feldspar (A) and plagioclase feldspar (P) (*see text*) (modified after Streckeisen, 1967).

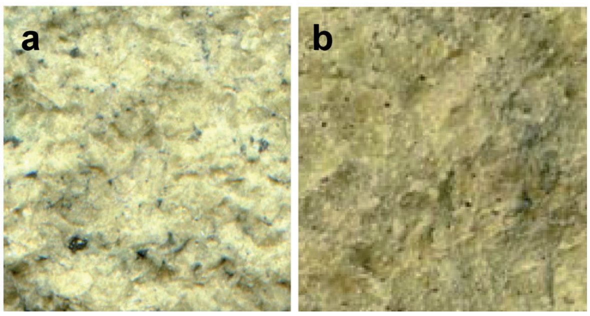


Text-Fig. 9.
Composition of Dun Mountain dunite chrome spinels (*red circles*) plotted in terms of spinel end-members, *spinel*, *hercynite*, *chromite*, *magnesiochromite* (or *picrochromite*). *Arrow* indicates alteration to '*ferrichromit*'. Note that the *ferrochromit* alteration composition actually plots above the 2D spinel composition plane because of its high Fe_2O_3 content; *Blue circle* = bulk composition of spinel separate from dunite (Ross et al., 1954). The plot is a projection from magnetite (Fe_3O_4) as shown (*see text*).

30.25 % FeO; no Cr_2O_3 and Al_2O_3), which occurs as a minor secondary alteration phase associated with serpentine in the dunite (Lauder, 1965b). The 2D spinel nomenclature diagram can therefore be envisaged as the basal plane of a tetrahedron projected from the fifth spinel end-member, magnetite (Fe_3O_4), which accounts for the Fe^{3+} component in the Dun Mountain chrome spinel (Text-Fig. 9).

10 Chassigny is a Mars meteorite, which fell on October 3, 1815, in Chassigny, Haute-Marne, France (Pistollet, 1816). It is essentially an iron-rich dunite (Vauquelin, 1816; see mol% MgO-FeO-SiO_2 plot in Text-Figure 5, and analysis in Text-Figure 10) with 91.6 % olivine (Prinz et al., 1974) of the composition Fo_{68} compared to Fo_{92} in Hochstetter's Dun Mountain dunite, and with minor amounts of ortho- and clinopyroxene, chromite, alkali feldspar and melt inclusions in olivine. Vauquelin's analysis of the Chassigny iron-rich dunite meteorite is compared with that of the Dun Mountain dunite (average analysis) quoted in Hochstetter in Text-Figure 10. Because Hochstetter chose dunite with no visible chromite for analysis, chrome was not determined. As the high metallic chrome (Cr) in the meteoric dunite is in chromite as Cr_2O_3 the value should be 2.92 % which would raise Vauquelin's oxide total to 99.82 %. In contrast, subsequent analyses of the meteorite listed in Mason et al. (1975) show Cr_2O_3 contents ranging from only 0.66 to 0.98 %. The yellow-green colour of the iron-rich Chassigny dunite compared with that of Dun Mountain reflects its more Fe-rich olivine composition of Fo_{68} (Text-Fig. 5). Gustav Rose proposed the name Chassignite in his 1864 classification of meteorites formulated on the basis of the meteorite collection in the Museum für Naturkunde, Berlin.

	a	b
SiO_2	33.90	42.75
FeO	31.00	9.74
MgO	32.00	47.14
Cr	2.00	nd
Total	**98.90**	**99.63**



Text-Fig. 10.
Vauquelin's (1816: 53) analysis of the Chassigny iron-rich dunite meteorite (**a**) compared with Hochstetter's (1864b: 342) average analysis of Dun Mountain dunite (**b**), together with the respective colour difference of both dunites; nd = not determined (*see text*).

Postscript

Dunite and other ultramafic rocks (peridotites) defined in Text-Figure 6 are now known to form the major constituents of the Earth's upper mantle (i.e., to a depth of ~410 km) as evidenced by fragments (xenoliths) that have become entrained in basalt erupted on the Earth's surface. Xenoliths of dunite, referred to by Hochstetter, are considered to represent the refractory residue after extraction of basalt magma from lherzolite and harzburgite. Dunite may also form by gravitation accumulation of olivine crystals on the floors of magma chambers within the ocean crust (termed ophiolite – a section of the ocean crust and underlying mantle) below mid-oceanic ridges, or layered intrusions of basaltic magma within continental crust. Mountain or 'Alpine-type' dunite bodies, such as recognised by Hochstetter at Dun Mountain, are portions of upthrusted and deformed ophiolite or deeper mantle (e.g., such as the Pyrenees lherzolite). The association of dunite (and interlayered harzburgite) with gabbro and basalt at Dun Mountain (Text-Fig. 3) is now interpreted as a tectonically disrupted ophiolite sequence (Blake & Landis, 1973; Coombs et al., 1976; Davis et al., 1980). The entire 80 mile-long 'immense serpentinite dyke' recognised by Hochstetter is now referred to as the steeply-dipping and dismembered part of a Permian oceanic-continental collision zone, the eastern portion of which has been reduced to a melange (Text-Fig. 3). Since Hochstetter coined the term 'dunite' from Dun Mountain in 1859, both names have been linked as the Dun Mountain Ophiolite Belt.

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Our thanks to Albert Schedl and Manfred Linner of the Geological Survey of Austria for helpful comments and editorial suggestions.

Appendix

English translation of holograph draft of letter from Ferdinand von Hochstetter to Fridolin von Sandberger, dated Vienna, 28 February 1866 (Dr. Albert Schedl Collection, Vienna).

Vienna, February 28, 1866

Dear Colleague!

I received your kind consignment a few days ago and thank you very much for the beautiful olivinite from Bavaria. As for your remarks about the New Zealand rocks, I am sorry not to be able to agree with you on everything. If I had known of Damour's treatise on lherzolite before my communication on dunite, I would certainly have emphasized the very close relationship between dunite and lherzolite, but I would still have thought it justified to keep the name dunite, since I myself as well could not be convinced today of the identity of both occurrences, even if both fall under the term olivine rock as syenite and granite are both orthoclase-bearing. The first is geological. The occurrence, as I have described it, is essentially different from that of the Pyrenees, i.e., the typical varieties of the two rocks are so different that a distinction seems justified. I maintain that dunite is a mixture of olivine and chromite, and lherzolite is a mixture of olivine and enstatite, diopside. However, I have subsequently convinced myself of the occurrence of diopside in dunite. I met Dr Roth[1] from Berlin two years ago when he was here [page 2] and we compared dunite with diopside in picotite-bearing olivine xenoliths from Kapfenstein in Styria[2], I carefully searched for diopside in my dunite specimens. At that time we could not find any in a large number of samples. It was not until I broke open a large handspecimen to send you a piece that I found individual grains of diopside and also enstatite. So diopside occurs in dunite, and I agree with you on this, even though it does not appear as an essential mineral, as in lherzolite, which one might term augitefels. As for the picotite, even today I have not been able to convince myself that what I said was chromite[3] is actually a chrome spinel. I cannot determine a hardness of 8 or 7.5 anywhere in my samples; all grains in dunite, especially since the larger grains you mention yield a brown powder with the knife, have a decidedly semi-metallic lustre. If the black grains in the dunite are picotite, then all the chrome ore on Dun Mountain that has been mined for years and sold to England as chromite, is picotite, because all chrome iron levels that I have from there have a slightly greater hardness than about 6, as, for example, Baltimore chrome ore. However, this may be due to a slightly higher content of Al_2O_3; and that is why I do not want to conclude that the Dun Mountain chrome ore [page 3] is picotite. Incidentally, I will have the larger grains, which you also consider picotite, examined quantitatively, then we will know for certain.

I enclose a rock sample from Brook Street valley near Nelson, which contains black, rounded grains of a hardness above 7, which may perhaps be picotite; but this occurrence is unrelated to Dun Mountain. I was even more surprised than the picotite by your view that the coarsely-laminated hypersthene from Dun Mountain is chromium diopside. However, I am not entirely sure about the samples I sent to you, so I am enclosing a fragment of what I thought to be hypersthene, with the question of whether this is the mineral which you determined as chromium diopside. I have specimens of this mineral up to 1 foot long and ½ foot wide, and was of the opinion that unless there is something typical of hypersthene or diallage that I frankly cannot clearly distinguish, it is this mineral.

Finally, as far as my view of the eruptive character of the Dun Mountain-serpentine belt is concerned, I still hold this view. I gave my reasons for this in the geology of New Zealand. All phenomena are such that if this serpentine belt is not eruptive in nature, then there are also no eruptive diorites, diabase, augite-porphyries, etc., accompanied by parallel [page 4] veins of augitophyre[4], diabases, etc., even feldspar-rich syenite-like rocks. I also cannot share the view that the serpentine originated from the olivine rock, like anhydrite from gypsum in hydrous deposits, or as original formations occurring next to each other, as well as olivine rocks and the like from serpentine, as the eruptive formations formed at the same time adjacent to each other.

I am sorry that our views diverge so widely here; but I am convinced that if I could develop the matter further here on the basis of the whole series of events, we would come closer in many respects; in any case, our differing view will lead to further investigation which will clarify the questions. Because I don't want to argue just for the sake of the matter, I take the liberty to develop my views again.

Thank you also for the niobite. I am following your Triassic studies with great interest, and they are producing such interesting results.

With friendly greetings
Your most devoted
F. Hochstetter

1 Justus Roth (1818–1892).

2 Mantle xenoliths in host basaltic tuff from Kapfenstein, Styria, Austria, consist of a suite of spinel-lherzolite, harzburgite, dunite, with the former being the most abundant rock type (e.g., Kurat et al., 1980).

3 The mineral term 'chromit' was first proposed by Wilhelm von Haidinger (1795–1871) in 1845 for its chrome content.

4 An outdated term for lava with phenocrysts of augite.

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