Limburgite from Nevis Bluff, Kawarau Gorge, Central Otago.

By C. OSBORNE HUTTON, Petrologist New Zealand Geological Survey.

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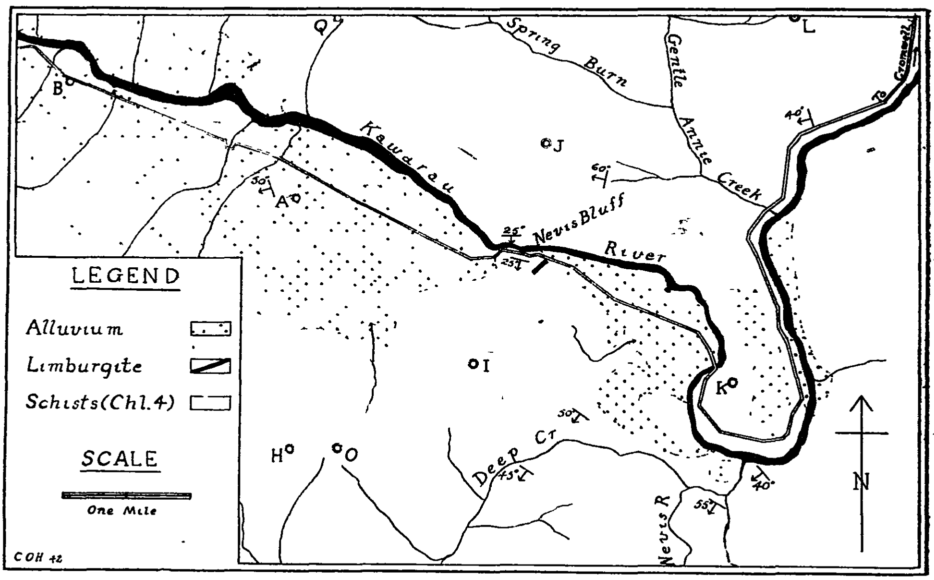
DURING a recent examination of the metamorphic rocks of the Kawarau Gorge area, Western Otago, the writer mapped the outcrop of a dyke of limburgite that had been uncovered by a recent slip (20/2/40) of considerable size (Text Fig. 1). The dyke strikes



TEXT FIGURE 1.
Part of Kawarau Survey District, Otago Land District, showing position of limburgite dyke at Nevis Bluff, Kawarau River.

at 40° and dips west at a high angle, approximately 80°–85°, whilst the adjoining schists strike nearly 90° (east-west) with a low dip to the south of 25°. The dyke has a fairly constant width of 24 inches, and it has been injected along a plane parallel to the major jointing in the adjacent schists. In the lamprophyre itself, jointing is strongly developed, and this follows two planes, one parallel to the plane of the dyke and one normal to that direction. The dyke outcrops in the face of a cliff 150 feet above the Queenstown-Cromwell road, and ascends the cliff for 150 feet to a terrace above, but it does not appear again in a second line of bluff at the back of the terrace. Owing to the close spacing of the joints in the limburgite, blocks have readily fallen out, and as a result a cleft, or "chimney," remains in the cliff-face, at least 5 feet deep.

A large slip had occurred just before the writer's visit, so that the only portion of the dyke examined was the 150 feet exposed above this slip. About half-way up the cliff face the dyke is laterally displaced by about 5 feet, along a plane parallel with the schistosity. This feature has the appearance of a small slip-plane developed by the creep of the schists on the Nevis Bluff itself.

The margins of the dyke against the schists have been chilled along a narrow zone about 2–3 inches wide; the selvage is a very dense, close-grained rock with a sub-conchoidal fracture.

PETROGRAPHY.

A study of the several specimens collected makes it clear that the dyke rock is a typical limburgite, with a finer-grained, chilled marginal phase.

Central Zone.

(P. 2275, 2277A, 2277B.) Macroscopically these rocks are dense, black and fine-grained, with a fairly regular fracture. In thin section they are observed to be hypocrystalline and have a tendency towards a porphyritic texture.

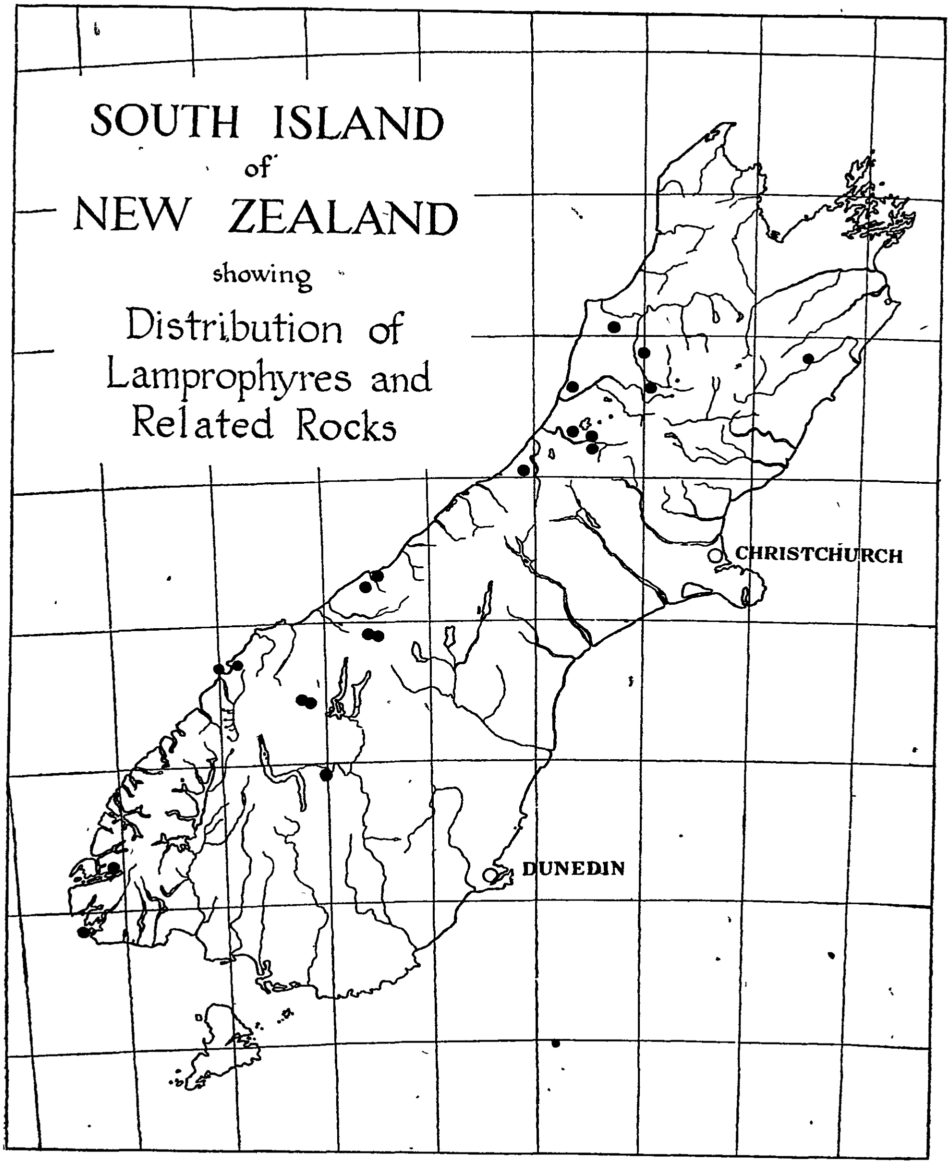
Subidiomorphic to idiomorphic crystals of olivine are commonly very much altered to a ferruginous yellowish-brown or golden serpentine. Crystals up to 1·5 mm. are usual, but they average approximately 0·3 mm. Glomeroporphyritic aggregates were noted occasionally. Serpentine has penetrated the cleavage planes and cracks and has replaced much of the olivine (Pl. 7, Figs. 1 and 2). The unaltered mineral is colourless and no zoning was apparent, although the optic axial angle varied somewhat from grain to grain, the following values for 2 V were obtained by Federov stage methods: 88° (+), 88° (—), 86° (—), 85° (—). These values correspond with compositions ranging from Fa_8–Fa_{25} (Winchell, 1933, p. 191). In the transformation olivine → serpentine, the usual strings of iron-ore grains are not present; presumably the iron has been used up in the development of ferruginous serpentine.

Clinopyroxene is more abundant than the olivine, but it usually occurs in smaller crystals averaging 0·2 mm.; phenocrysts do not occur. The mineral is very pale brown, or colourless in minute crystals, and is completely unaltered. The optic axial angle is fairly constant at 56° (± 2°), while the angle* $Z \wedge c = 44–45°$; thus the composition is approximately $CaSiO_3$ 40, $MgSiO_3$ 26, $FeSiO_3$ 34, according to the diagram of Wager and Deer (1939, p. 80). When plotted on Hess's diagram (1941, p. 518, Fig. 1) a pyroxene of this composition would fall into the field of ferroaugite. Zoning appeared to be absent and twinning was uncommon. Parallelism of crystals due to flow is noteworthy in some rocks, particularly where olivine

* Nemoto's method (1938) was employed.

phenocrysts have offered resistance to the movement of the nearly solidified liquid.

Serpentine occurs replacing olivine to varying degrees; the mineral is fibrous, uniaxial and negative, with positive elongation of the fibres, and has a moderately high birefringence. Pleochroism is weak but distinct, with X = pale yellow and Z = golden yellow,



TEXT FIGURE 2.

Distribution of lamprophyres and related rocks in the South Island of New Zealand. Solid circles indicate areas where dykes, etc., are to be found and not necessarily the number of occurrences in any particular locality.

or in some cases greenish-yellow. Carbonate, with $\gamma=1\cdot668$ is often closely associated with the serpentine. Refractive index and microchemical tests indicate that an important amount of $MgCO_3$ is present in solid solution in the carbonate.

Very pale brown glass is an important constituent of these rocks. In parts of the thin sections " ocelli " of glass or patches clear from olivine, pyroxene and iron-ore occur (Pl. 7; Fig. 3); in these ocellar patches numerous tiny platelets of biotite and long acicular crystals of augite and barkevicitic hornblende occur. Most of these " ocellar " areas of glass are irregularly bounded, although in some cases the glass-filled vesicles are sharply defined. This " ocellar " structure is better developed in some rocks than in others, e.g., P. 2277B, and in the lamprophyre group as a whole it is a common enough feature (cf. Flett, 1911, p. 90; Turner, 1932, p. 227; Hutton, 1936c, p. 27). The refractive index of the glass is 1·522 (± 0·001), a value which, according to George's table (1924, p. 365), corresponds to about 62–63 per cent. of silica. Hence this glass is very much more acid than that in a limburgite from the Milburn district described by Benson (1942, p. 111), and it is clear that the early and voluminous separation of iron-ore, olivine and pyroxene has led to the production of a feldspathic glass.

In places the glass in the vesicular areas and mesostasis is golden-yellow and may be very poorly birefringent. The refractive index of the yellow variety is not constant but about 1·56. In the writer's opinion this birefringent material is simply glass in the process of incipient crystallization, and cannot be termed palagonite, for as defined by Peacock (1928, p. 375) the R.I. should be about 1·47 for that material. Again ocellar patches and vesicles are occupied by a golden brown material, that may be isotropic or occasionally microspherulitic; the fibres have negative elongation and the refractive index varies from about 1·52–1·55. In places the golden-brown material grades into an olive-green gel or mineraloid. At least the golden-brown material could be compared with chlorophaeite as defined by Peacock (1928, p. 369), while the isotropic olive-green mineraloid may, again following Peacock (*loc. cit.* pp. 363 and 369) be referred to the same mineral.

The origin of these ocellar areas and vesicles occupied by glass with minor ferromagnesian constituents on the one hand and chlorophaeite on the other seems to be clearly the result of the oozing or sweating of the residual liquid magma into vesicular cavities (e.g. Harker, 1909, p. 324, Fig. 98A). In most cases it would appear that these residual liquids are richer in iron and alkalies than the solidified part of the magma, thus resulting in crystallization of minerals such as chlorophaeite, biotite and barkevicitic hornblende.

Biotite in reddish-brown platelets is an important accessory mineral. Iron-ore is most plentiful in irregularly shaped grains, and bars not exceeding 0·2 mm. in length. It is probably all ilmenite as the analysis (Table I) shows nearly 6 per cent. for TiO_2. Apatite was noted occurring in very slender needles.

In one specimen (P. 2275) rare patches of analcime were noted surrounded by the glass and chlorophaeite of the vesicles; this rock thus shows affinities with the monchiquites. Also in this rock minute needles of a colourless mineral were observed enclosed in areas of sub-crystalline glass, and these appear to have crystallized from the glass itself. The refractive index is approximately 1·48 (± 0·01) and the elongation of the needles is positive; therefore, the mineral is tentatively referred to as natrolite.

Marginal Zone.

Mineralogically the chilled margin is similar to the rocks described above. However, in thin section the rock is strongly porphyritic with phenocrysts of olivine pseudomorphs, and minor pyroxene, often in glomeroporphyritic patches, set in a very fine-grained base of pyroxene, iron-ore, biotite and glass.

In this rock no olivine remains, for it is replaced entirely by a pale green bowlingitic serpentine, and carbonate ($\gamma = 1{\cdot}70$), with or without talc. Yellowish ferruginous serpentine and yellow patches of crystallized glass are rarely developed. Vesicles are occupied by pale green serpentinous material.

The chemical analysis of the Kawarau limburgite may be compared with similar rocks from Riquewihr (Vosges), the Kerguelen Archipelago, and Milburn (South Otago) by reference to Table I. The Kawarau rock differs from the Vosges limburgite chiefly in the lower percentages of MgO and CaO in the latter and from the Milburn rock by reason of the lower Al_2O_3 and higher MgO. On the other hand, it is very similar to the Kerguelen rock, where the only slight differences lie in the percentages of SiO_2 and Al_2O_3. The slightly higher figures for these constituents in analysis 4 (Table I) possibly indicate a higher percentage of the feldspar molecule in the glassy base of the Kerguelen limburgite than in the glass of the Nevis Bluff rock. One striking feature of the latter rock is the important amount of SrO, viz., 0·36 per cent. Except for a single occurrence of a vein of strontium-aragonite near Alexandra, some 24 miles away to the south-east (Hutton, 1936A) strontium-rich rocks are, as yet, unknown in this region.

The norm classification of the Nevis Bluff limburgite shows nearly 37 per cent. of feldspar, and although none was recognised in any of the thin sections, this clearly substantiates the evidence suggested by the refractive index work that the glass is feldspathic.

The Nevis Bluff rock is mineralogically comparable to a limburgite from a conglomerate three-quarters of a mile south-west of Pukenamu (Whangarei Survey District) mentioned by Ferrar and Bartrum (1925, p. 62). In thin section (P. 9150) the rock consists of phenocrystic olivine set in a fine base of augite, iron-ore and glass (Pl. 7, Fig. 4); the latter has a refractive index equal to approximately 1·52. Unfortunately a hand-specimen was not available so that accurate refractive index determinations were not possible without destroying the only thin section available.

TABLE I.—ANALYSES OF LIMBURGITES.

	I	II	III	IV
SiO_2	40.70	40.86	40.23	43.74
Al_2O_3	8.99	13.20	8.60	13.57
Fe_2O_3	4.51	6.24	3.24	4.14
FeO	8.37	9.18	7.25	8.98
MgO	9.69	5.80	12.45	10.85
CaO	9.94	7.69	12.82	9.09
Na_2O	1.58	2.77	2.94	2.35
K_2O	1.97	2.00	1.65	2.47
H_2O+	4.16	4.34	3.13	1.22
H_2O-	1.42	1.92	0.59	0.77
CO_2	0.64	tr.	3.13	0.05
TiO_2	5.81	3.96	2.83	1.61
P_2O_5	1.65	1.56	0.74	0.50
S	0.09	0.04	—	0.01
MnO	0.17	0.19	0.21	0.45
NiO	0.02	0.01	—	—
Cr_2O_3	0.05	tr.	—	—
V_2O_3	0.02	0.025	—	—
ZrO_2	nt. fd.	—	—	—
BaO	nt. fd.	0.08	—	0.02
SrO	0.36	0.07	—	—
Cl.	0.015	0.12	—	nil.
F.	0.15	—	—	—
	100.31	100.06	99.81	99.82
Less	0.06	.03	—	—
	100.25	100.03	99.81	99.82

Norms of Analyses I and II.

	I	II
or.	11.64	11.80
ab.	13.37	22.55
an.	11.62	18.26
hl.	—	0.20
di.	18.76	7.86
hy.	11.88	4.09
ol.	4.11	8.72
mt.	6.50	0.05
il.	11.04	7.53
ap.	3.90	3.70
pr.	0.17	—
(cc.)	(1.46)	—

I. Limburgite (P. 2277) south side of road, Nevis Bluff, Kawarau Gorge. Analyst, F. T. Seelye.

II. Limburgite (P. 4139), quarry half mile east of Milburn, Otago. Analyst, F. T. Seelye.

III. Limburgite, Riquewihr, Vosges. Analyst, S. Parker (Friedlander and Niggli, 1931, p. 399).

IV. Limburgite, Suhm Island, Royal Sound, Kerguelen Archipelago. Analyst, A. B. Edwards. (Edwards, 1938, p. 86, Table 21, analysis 1.)

Correlation and Age of the Lamprophyres and Related Hypabyssal Rocks.

Igneous rocks are rare in the area between Alexandra and Lake Wakatipu, and as far as the writer is aware, the Nevis Bluff limburgite, together with serpentinites in Springburn Valley (Hutton, 1936B.), only three miles to the north of Nevis Bluff, are the only known outcrops of igneous rocks, except for the possible occurrence of a dyke of porphyrite in the Carrick Ranges (Hutton, 1875, p. 31). However, from the eastern slopes of Mount Niger, 38 miles to the north-north-west of Nevis Bluff, Park found a hornblende camptonite dyke, and this specimen, which represents the first lamprophyre to be recorded as such in situ in Western Otago, has been described by Turner (1933). On the other hand, McKay (1882) reported the existence of numerous dykes of basic rocks invading schists in the region between the Palnoon Burn, Shotover and Matukituki rivers in north-western Otago (Text Fig. 2). Examination of many boulders from these rivers (Park, 1909; Turner, 1933; Hutton, 1936C) has shown them to be lamprophyres. From the Haast and Makarora Valleys in the Haast Pass area, Turner (1932) has recorded boulders of alkaline rocks, viz., tinguaites and camptonites. In every case these dykes appear to cut through the schists of the Otago Complex. However, in the Big Bay district, in the extreme north-west corner of Otago, Healy (1938) has recorded lamprophyre dykes intruding the Tertiary sequence there, and he suggests that these igneous rocks were injected during the deposition of the Tertiary sediments in early mid-Tertiary times. To the south, Benson (1935, pp. 147 and 148) records a dolerite and a lamprophyre cutting Lower Ordovician quartzites and greywackes in the Preservation Inlet region. Park (1924, p. 755) mentions the presence of boulders of diabase porphyry in the bed of a stream draining the mountain range between Mount Hodge and Mount Pinder. However, these rocks could not be traced to their source, but it would seem that they had been derived from a dyke or dykes penetrating the schists and gneisses of the Dusky Sound district.

In Westland and western Nelson numerous examples of lamprophyres and basic igneous dykes have been recorded, sometimes penetrating granitic rocks (Bell and Fraser, 1906; Smith, 1908; Morgan, 1908, 1911; Morgan and Bartrum, 1915; Henderson, 1917).

Recent work by Gage in the Greymouth area has shown the existence of two dykes, identified by the writer as augite-olivine basalts or ankaramites, one in the Roa Mine and the other in Blackwater Creek. Both of these dykes cut through Brunner Beds but their relationship with upper horizons is not known. In these northern occurrences the best evidence bearing on the age of the dykes is seen within the Blackwater River watershed, where lamprophyres cut the granites and pass up into the basal Hawk's Crag Series (Morgan and Bartrum, 1915, p. 104). The Hawk's Crag breccias were considered to be of Eocene age, but as the Island Sandstone of Bortonian age is stratigraphically several horizons higher, then a Cretaceous age for the breccias is possible.

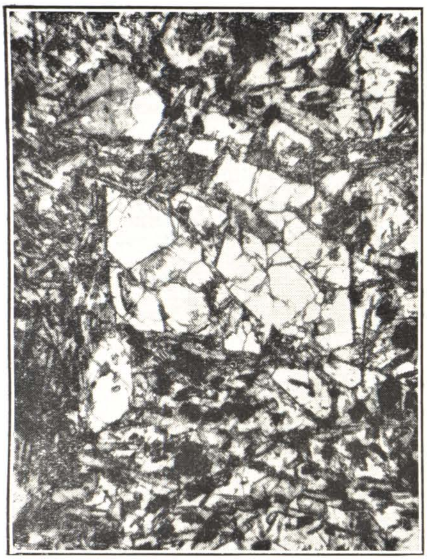


FIG. 1—Limburgite (P. 2277A) from Nevis Bluff showing olivine phenocrysts altering to serpentine. × 43.

FIG. 2—Limburgite (P. 2277A) showing clear areas of glass, and olivine completely pseudomorphed by serpentine. × 43.

FIG. 3—Ocellar patch in P. 2277B composed of glass, biotite, augite, and hornblende. × 43.

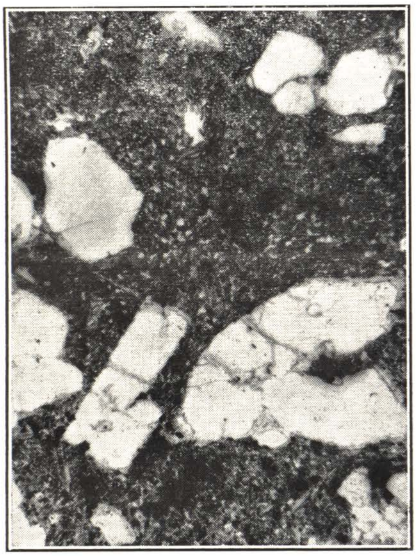


FIG. 4—Olivine phenocrysts set in a base of augite, iron-ore, and glass. P. 9150. × 43.

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In southern Westland, in the region of Abbey Rocks, Cox (1877, p. 81) has described brecciated volcanic rocks and tuffs overlain by marls and fine-grained lithographic limestone. Again, south of Abbey Rocks, Cox reported the existence of volcanics somewhat higher in the sequence, immediately underlying greensands. In an unpublished report, Bolitho mentions basic volcanic material considered by him to be sills, intruding westerly dipping limestones in a small creek entering the sea about ten chains from Otitia Rock, just north of the mouth of the Paringa River. Collections have not been made of these south Westland occurrences so that the exact rock types are not known.

Turner (1932, pp. 227–228) has drawn attention to the petrographic similarity that exists between important groups of dyke rocks in Westland and north-west Otago, this being particularly the case with the rocks described by Smith (1908) from New River and those investigated by Turner (*loc. cit.*) from Haast Pass. In addition to what Turner has said, the writer suggests that all the lamprophyres and related hypabyssal rocks of Westland, Nelson and north-west Otago are related genetically and belong to the same period of intrusion. Previously, however, Bell and Fraser (1906, p. 82) considered that the lamprophyres of the Hokitika district could be correlated with the Koiterangi basalts which overlay limestones.

The date of intrusion of the dykes is dependent entirely on what information is available regarding the age of the Tertiary rocks they intrude. Except for the Omoeroa River and Jackson Bay mudstones (Wellman and Willett, 1942, pp. 300–301), the exact ages of the Tertiary sediments of Southern Westland are not known. However, the fine-grained limestone of the Paringa area is so similar to the Cobden limestone (Whaingaroan Stage) in the Greymouth district that correlation of these formations is tentatively suggested. If this assumption is a correct one, then on the basis of the evidence obtained from near Abbey Rocks, the date of intrusion of the basic igneous dykes of Western Otago and Westland, is at least as recent as Whaingaroan or Mid-Oligocene.

However, the exact nature of many of the known dykes in the Westland area is as yet unknown and their relationship to the intruded rocks remains obscure. Therefore, before a complete picture of the history of the hypabyssal intrusion can be deduced, every effort should be made to collect material from these dykes and from the sediments they intrude.

The only other area in New Zealand where lamprophyres are known to occur at present is on the northern end of the Inward Kaikoura Range, in the vicinity of Mount Tapuaenuku (Thomson, 1913). The age of these igneous rocks is indefinite, but some of the types are so similar to those occurring in the Westland region that it does appear probable that the Kaikoura rocks should be correlated with the other South Island occurrences.

The rather limited distribution of lamprophyre dykes and related igneous rocks in New Zealand invites explanation. Up to the present time no true lamprophyre dykes have been recorded from the North

Island. In the South Island, occurrences appear to be limited to a narrow zone that stretches from southern Nelson, through to southern Westland; one zone then appears to swing round into western Otago parallel with older lines of folding and dislocation, while a second zone continues southwards to Preservation Inlet. Finally, there are the basic dykes in the Inward Kaikoura Range, about which little is known. Unfortunately, little information is available concerning the attitude of the dykes in the zone west of the Southern Alps, but the close parallelism of this zone with the mountain chain seems to be in some way closely related to the alpine structure itself.

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