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THE RELATIONSHIP BETWEEN PREFERRED ORIENTATION OF OLIVINE IN DUNITE AND THE TECTONIC ENVIRONMENT

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ABSTRACT. It is now well known that the olivine crystals of peridotites often have a strong tendency to a common orientation. Information on olivine fabrics was summarized by Turner (1942) with the addition of much new data, and Ladurner (1956) has recently surveyed the literature again and provided further examples of preferred orientation. Most of the studies of olivine orientation recorded in these papers have, however, been made without reference to the geographical orientation of the rock specimens in the field, so that the relationship of the axes of the oriented crystals to the boundary of the parent peridotite body, or to local tectonic directions, are not known (except in so far as fissility planes or chromite layers in the hand specimen are assumed to lie in particular tectonic orientation). The present contribution attempts to relate the orientation of olivine crystals in the type dunite, from Dun Mountain, Nelson, New Zealand, already made known by Turner (1942), to the tectonic setting of the Nelson peridotite belt.

GEOLOGICAL SETTING

The general geology of the region was described by Bell, Clarke, and Marshall (1911) for the New Zealand Geological Survey. Features of present interest are summarized below, and a modified version of the official map is given as figure 1.

Dun Mountain (3703 ft) is a hill, about 1¼ miles across, of olivine-rock, chromite-bearing in parts, lying within the complex belt of serpentinite and other rocks mapped as the "Mineral Belt" by Bell, Clarke, and Marshall. The "Mineral Belt" as a whole reaches a width of nearly 4 miles in the neighborhood of Dun Mountain, and strikes N55°E. Beyond the immediate area of Dun Mountain it extends some 50 miles NE to D'Urville Island in Cook Strait, and 30 miles SW where it is cut off by a major fault. Throughout its 80-mile length it is generally conformable with the strike of the enclosing sedimentary rocks (see Geological Map of New Zealand, 1:1,013,760, New Zealand Geological Survey, 1947).

The surrounding sediments were all grouped as the Maitai Series by Bell, Clarke. and Marshall (1911). Later work by the Geological Survey has, however, re-established an earlier subdivision into two groups, the Te Anau Series and the Maitai Series of Carboniferous-Permian age, as shown below (after Wellman, 1948, 1953):

Maitai group	7000 ft	Conglomerate, sandstone, and limestone.
	2000 "	Green and purple banded mudstone.
	7000 "	Gray banded mudstone and sandstone.
	2000 "	Limestone and calcareous sandstone (Maitai Limestone).

Te Anau group	5000 "	Pillow lava, conglomerate, and breccia.
	7000 "	Red and green sandstone, mudstone with plant impressions.
	20,000 "	Coarse sandstone, sandstone with fragments of black argillite, conglomerate, tuff and lava.

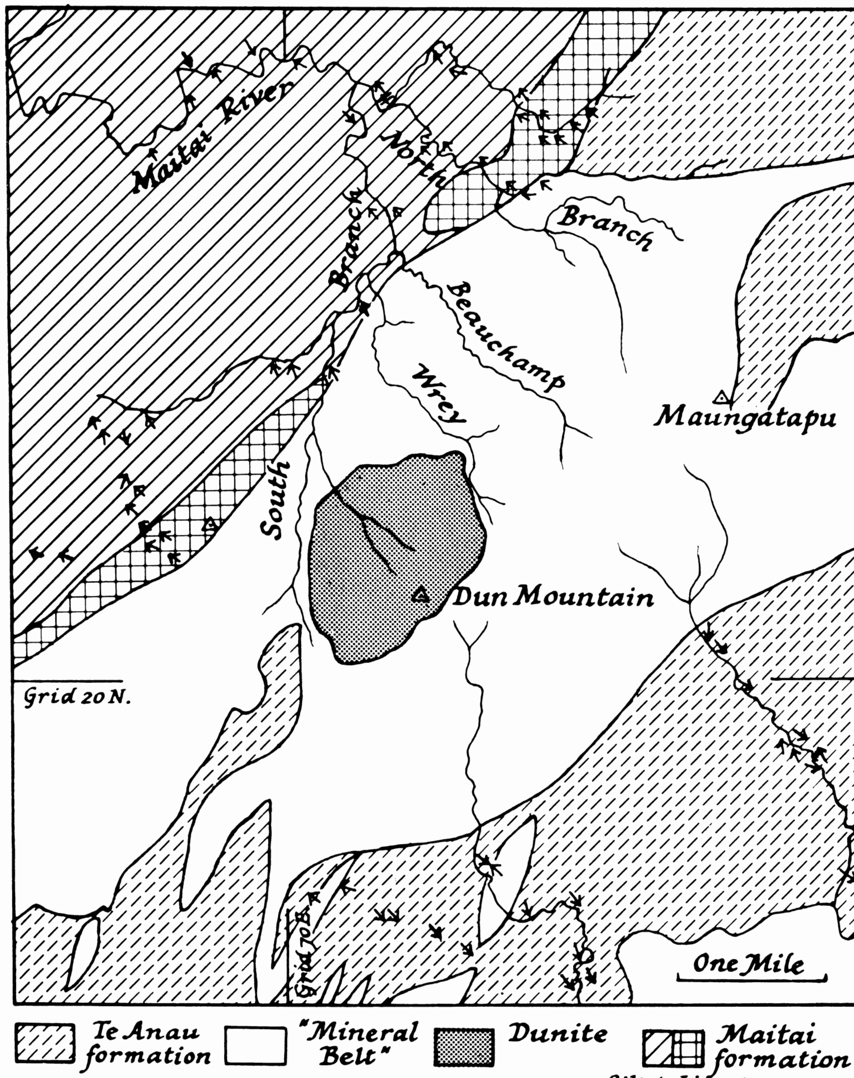


Fig. 1. Geological map of Dun Mountain area, Nelson, New Zealand, after New Zealand Geological Survey, with additions.

The rocks of the "Mineral Belt" are emplaced immediately below the horizon of the Maitai Limestone.

Passing south-eastwards, transverse to the regional strike, in the vicinity of Dun Mountain, the formations met with are:

(1) Siltstone, argillites, and sandstones of the middle part of the Maitai Series. These rocks are closely folded, individual minor anticlines and synclines being of the order of 50 to 100 feet across. Associated with this is a coarse fracture-cleavage parallel to the axial lines of the folds. Quartz "saddle-reefs" have sometimes segregated in the arches of the folds.

(2) A partly recrystallized limestone, the Maitai Limestone.

(3) Serpentinite, in generally concordant contact with the limestone, though showing much internal shearing and some involvement of limestone blocks. This junction is the boundary of the undifferentiated "Mineral Belt" of Bell, Clarke, and Marshall. Although these workers did not subdivide the "Mineral Belt", they recognized its heterogeneous character and the occurrence within it of many inclusions of Maitai rocks (as defined by them), now probably to be classed as of the Te Anau group. Their map indicates broadly this state of affairs.

Within this belt occur serpentinites in great variety, with cognate gabbros, saussuritized gabbros, rodingite, and veins of prehnite. Allocthonous inclusions comprise fine-grained flinty sediment—the so-called "baked argillite"—and reddish and greenish fine-grained lavas, sometimes with pillow structure, or in the form of what seems to have been glass-cemented breccia, or as masses of ordinary breccia. Blocks of these rock types, sometimes many yards across, are surrounded by serpentinite and appear to be isolated in it, forming a dismembered stratigraphy within the tectonically mobile serpentinite. All the inclusions seen belong to rocks of Te Anau type.

This complex extends to the crest of the Dun Mountain Range to the NE and SW of Dun Mountain itself.

(4) At Dun Mountain, however, the serpentinite gives place by a sharp junction or rapid transition to a core of unserpentinized dunite (cf. cross section by Finlayson, 1909, p. 356). The approximate outline of this dunite core is shown on figures 1 and 2. As far as is known, this dunite body does not enclose masses of country rock. Some 500 yards SE of Dun Mountain summit dunite gives place again to the serpentinite complex.

ORIENTATION OF OLIVINE

Oriented specimens were collected from the core dunite at the points shown on figure 2. Because of the distribution of good exposures, most of the samples come from toward the margin of the body, but the central part was sampled near the summit. Petrofabric diagrams, plotted in the lower hemisphere of a Schmidt net, and rotated so that the primitive circle is horizontal, were prepared for each specimen (figs. 3-6). Three diagrams are presented for each rock, based on the location of X, Y, and Z optical vibration-directions in 50 olivine grains, except in specimen 8207a where 100 grains were measured. As Turner (1942) points out, 50 grains is an adequate number to show the orientation pattern.

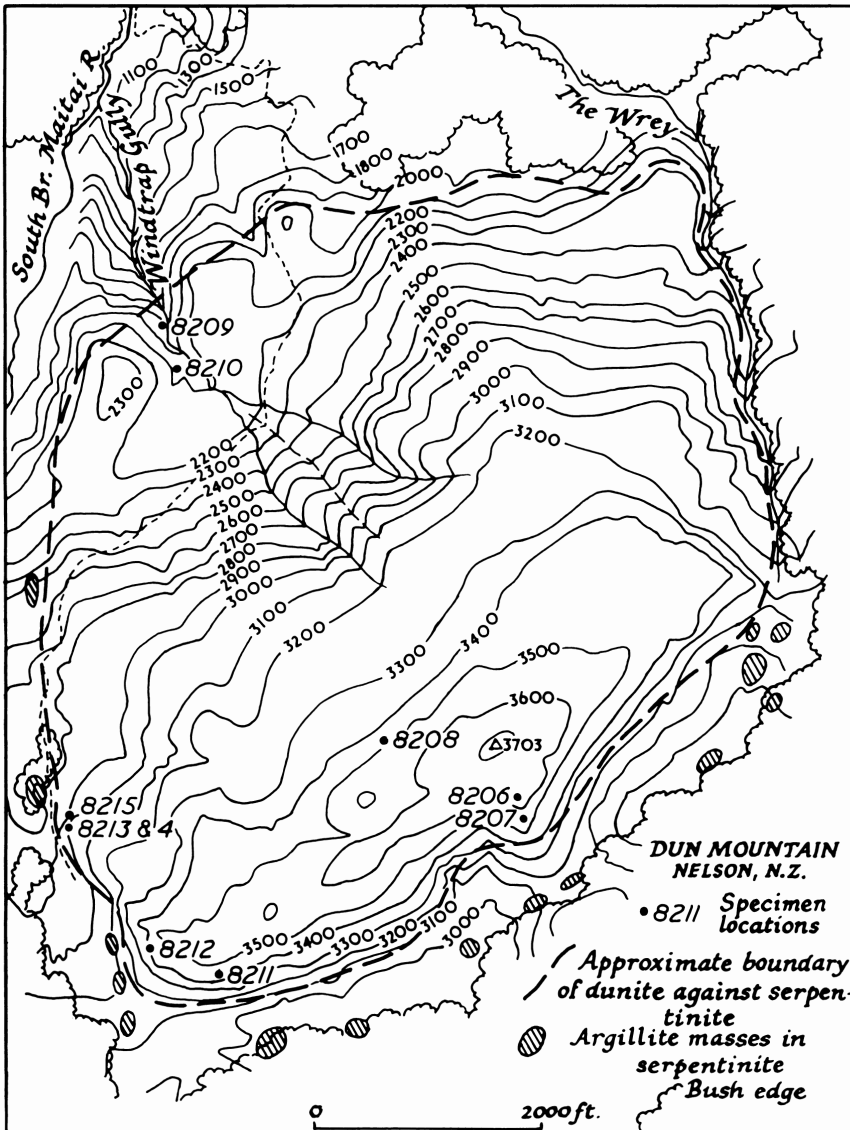


Fig. 2

The rocks have no visible schistosity, or fissility, and the grains are on the whole equidimensional. Dimensional orientation is recorded for olivine (Turner, 1942; Ladurner, 1956) and in particular for olivine in one specimen of dunite from Dun Mountain (Turner, 1942, p. 286); but in the rocks used for the present study sections cut at right angles to each other showed no obvious dimensional regularity, and the interlocking habit of the grains makes the value of statistical measurement doubtful.

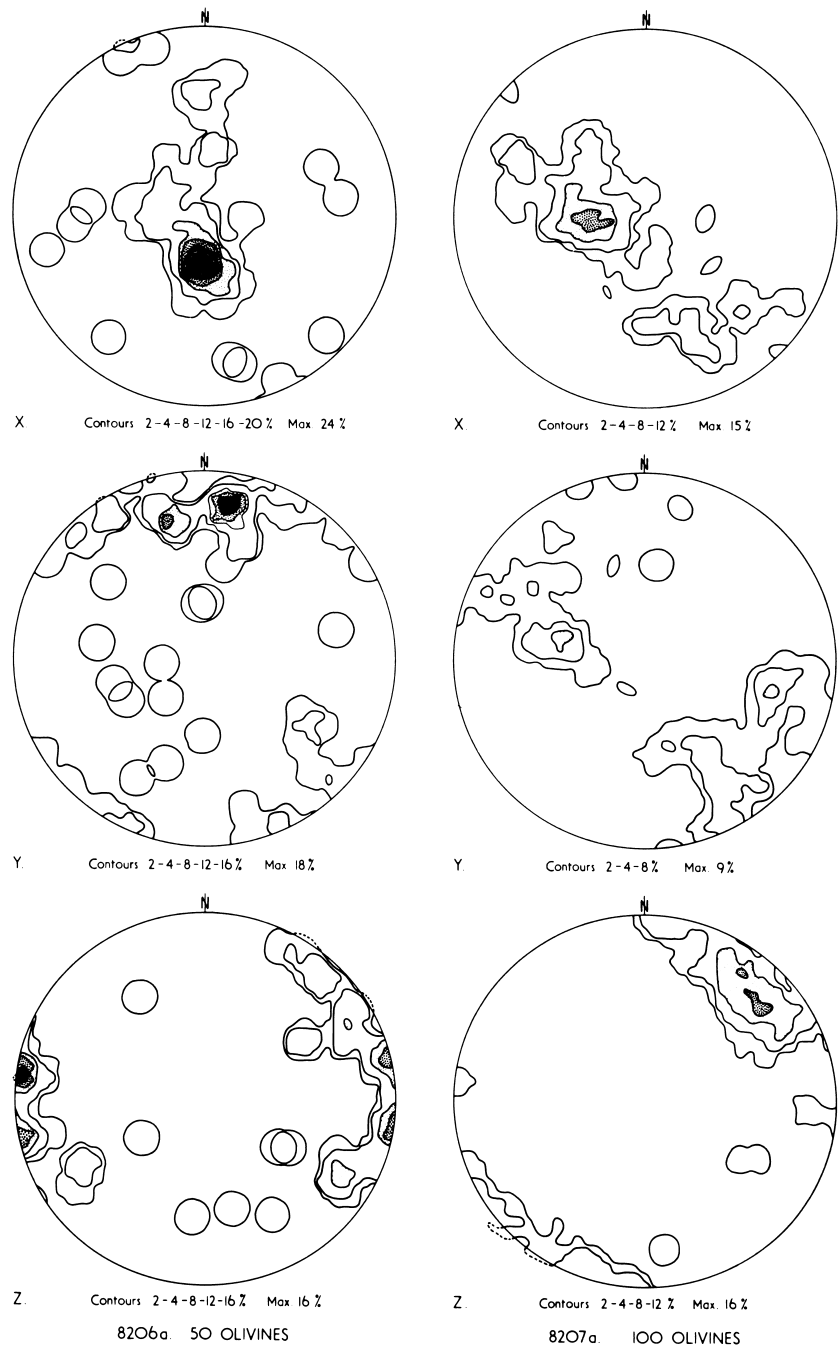

N
N
X
Contours 2-4-8-12-16-20% Max 24%
X
Contours 2-4-8-12% Max 15%
N
N
Y
Contours 2-4-8-12-16% Max 18%
Y
Contours 2-4-8% Max 9%
N
N
Z
Contours 2-4-8-12-16% Max 16%
Z
Contours 2-4-8-12% Max. 16%
8206a. 50 OLIVINES
8207a. 100 OLIVINES

Fig. 3

The orientation diagrams all show a marked similarity, suggesting that the fabric is homogeneous throughout the mass. The symmetry of the pattern is orthorhombic. All the rocks examined have the X vibration-direction (= crystallographic *b*-axis) of the olivine concentrated in the central region of the stereogram, with maxima of from 12 to 24 percent per 1 percent area. There is a tendency for the spread of poles of individual diagrams to form a girdle toward NNW-SSE in the direction of the concentration of Y ellipsoid axis. Taken together, the X-maxima of all the diagrams lie in such a zone.

In every case, also, there is a concentration of poles of Z vibration-direction toward the margin of the stereogram. In five cases this concentration lies geographically NE-SW and more or less horizontal, or with a plunge which does not exceed 20°. Specimen 8206a (fig. 3) differs from the majority in having its Z-maxima E-W, while 8212b (fig. 5) has the maximum directed to S77°W, though a subsidiary concentration has the more usual direction. Maximum concentrations of Z range from 14 to 20 percent.

The concentration of Y is generally less than that of X and Z, except in the case of 8206 (fig. 3), a rock with a very strong preferred orientation altogether, where the Y maximum is as strong as the other two. Y tends to lie NNW-SSE with concentrations nearer the edge rather than the center of the stereogram. Except in 8207a and 8212b the horizontal disposition of the maxima is quite plain. The value of Y-maxima varies from 8 to 18 percent.

From these data it may be said that, in general, the olivine crystals of the Dun Mountain mass lie with optical Z (crystallographic *a*) directed between N40°E and N68°E. The average direction from five specimens, excluding 8206a and 8212b, is N55°E; from all specimens it is N66°E. X (=*b*) is more or less vertical, or steeply inclined, and Y (=*c*) roughly horizontal and directed NNW, though with some rolling of the crystal position about Z.

ORIENTATION OF JOINTS

The attitudes of the principal joints were measured at the locations of the oriented specimens and elsewhere in the dunite. Poles to 74 joints are plotted in figure 7, with great circles representing the planes to which the concentrations of poles correspond.

The concentration representing a plane striking N34°E and dipping 30°NW is the strongest. This may perhaps be correlated with the effect of the (010) cleavage of olivine normal to X vibration-direction in the crystal orientation diagrams. Thin sections show this parallelism of cleavage well when cut approximately normal to the statistical position of the (010) crystal plane.

The exact interpretation of the controlling factors in the formation of joints represented by the other four peripheral maxima is less certain. The maxima all lie in the NE quadrant and appear to form two pairs with average directions of N15°E and N85°E. However, two features which are certainly significant stand out. The pattern is symmetrically disposed about a line directed at N50°E and the symmetry, like that of the rock fabric, is orthorhombic.

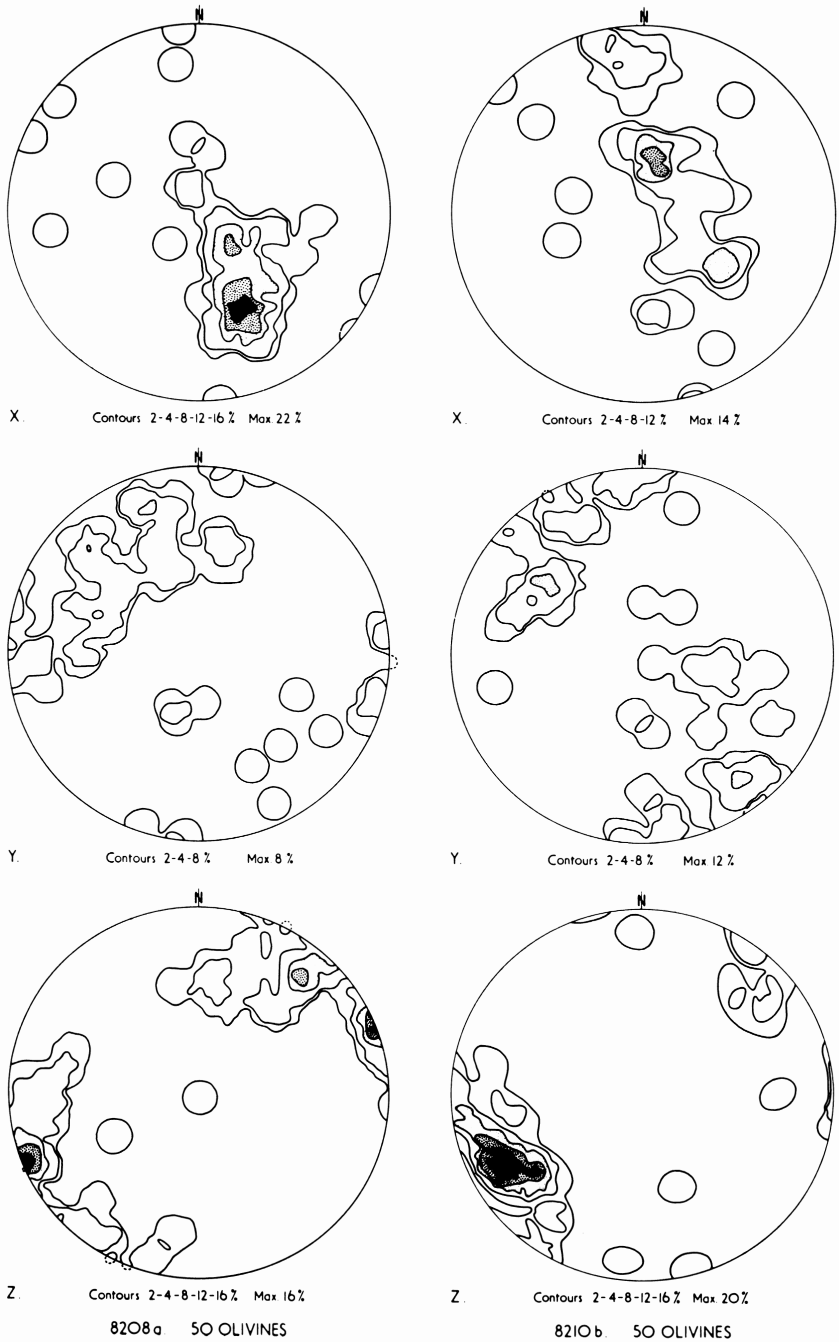

N
X.
Contours 2-4-8-12-16 % Max 22 %
X.
Contours 2-4-8-12 % Max 14 %
Y.
Contours 2-4-8 % Max 8 %
Y.
Contours 2-4-8 % Max 12 %
Z.
Contours 2-4-8-12-16 % Max 16 %
Z.
Contours 2-4-8-12-16 % Max 20 %
8208 a 50 OLIVINES
8210 b. 50 OLIVINES

Fig. 4

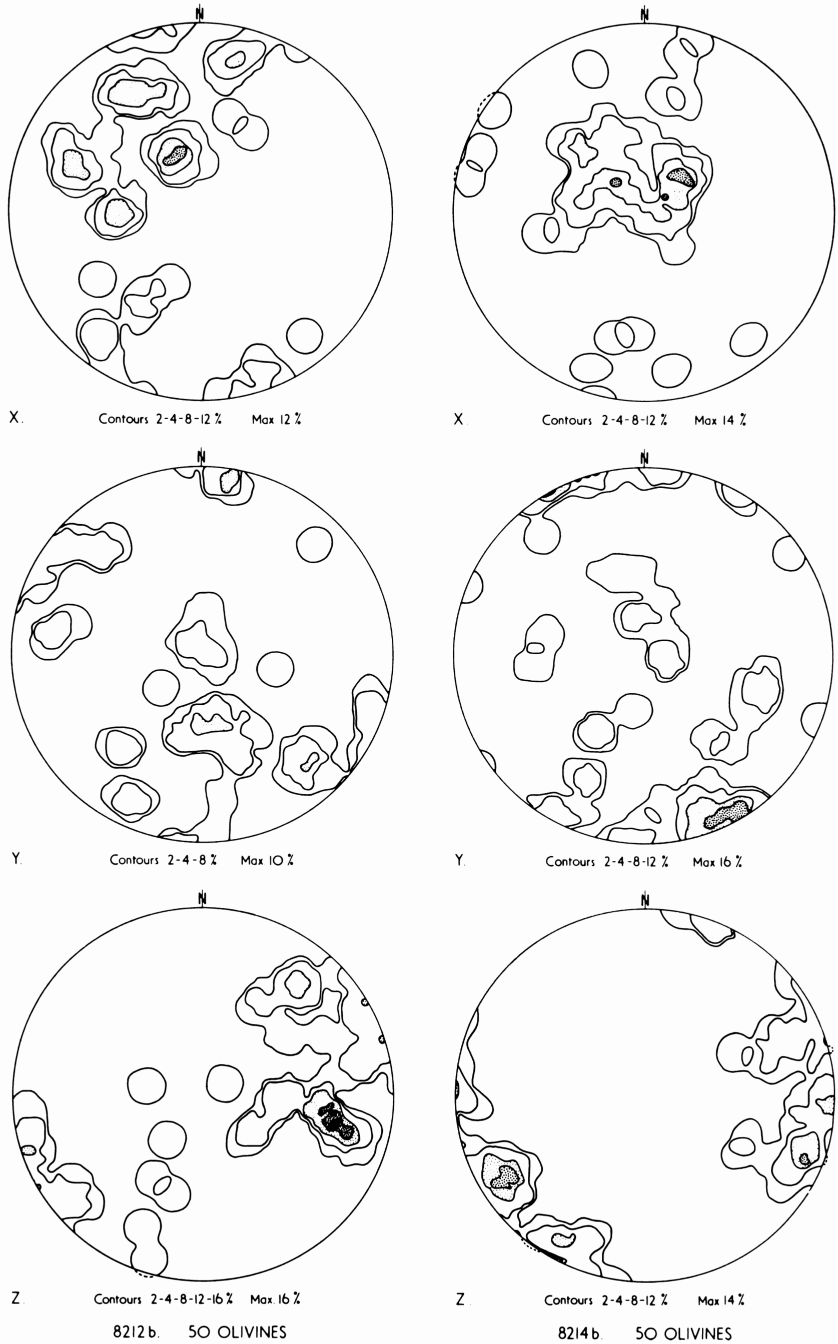

N
X. Contours 2-4-8-12 % Max 12 %
X. Contours 2-4-8-12 % Max 14 %
Y. Contours 2-4-8 % Max 10 %
Y. Contours 2-4-8-12 % Max 16 %
Z. Contours 2-4-8-12-16 % Max. 16 %
Z. Contours 2-4-8-12 % Max 14 %
8212 b. 50 OLIVINES
8214 b. 50 OLIVINES

Fig. 5

FOLD-AXES IN ADJACENT SEDIMENTS

The mapping by the Geological Survey shows clearly the regional strike of major rock units at N55°E. Measurements of bedding planes and intersections between bedding and cleavage in the Maitai River (fig. 7) indicate that the sharp, upright, minor folds there plunge at 15° to N56°E in conformity with the regional trend of the major stratigraphic groups. R. N. Brothers (personal communication), using independent observations analyzed by the "beta-method", deduces an axial plunge of 12° to N50°E.

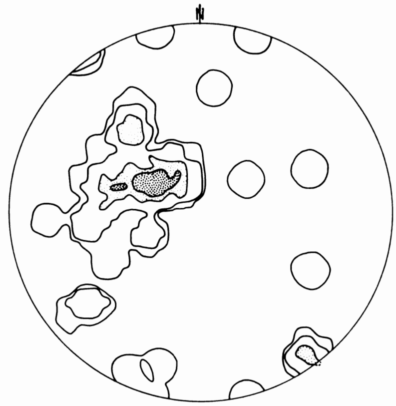
DISCUSSION

From the foregoing data it would seem that there is a definite relationship between the fold-axes, the olivine orientation, and the joint pattern of the peridotite in the Dun Mountain area. The correspondence in strike and in order of magnitude of plunge of the fold-axes and of optical Z of the olivines can hardly be fortuitous. The generally steep plunge of X in the olivines is also a striking feature. It would, of course, be of great interest to multiply the number of oriented specimens, both to confirm the apparent trends and especially to see whether the X-maxima of a larger sample align themselves along a NW-SE girdle, as seems possible from the present diagrams. Were this so, it would indicate that the (010) plane in the olivine was behaving like the bedding planes in the Maitai formation. A comparable tendency to girdling of the normal to (010) in individual rock specimens has been noted already (see Ladurner's summary, 1956, p. 34-35). Incidentally, in specimen 8206a (fig. 3), with a strong X-maxima (24%), undulose extinction bands (translation lamellae) parallel to (100) are strongly developed, as they are in all the rocks here studied. The correlation between strong development of (100) translation lamellae and a change from an X-maximum to an X-girdle mentioned by Phillips (1938, p. 134) does not seem to apply to the present case.

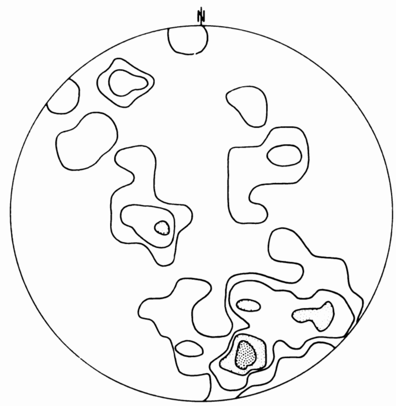
The two outstanding geological questions on which enlightenment might be sought from petrofabric study are the date and the mechanism of emplacement of the dunite. Bell, Clarke and Marshall (1911, p. 39) state that "there is in the 'Mineral Belt' rocks no sign of mineral change resulting from stress, nor is there any development of cataclastic or schistose structure." They conclude that the rocks are intrusive and were intruded later than the folding of the Maitai formation.

The present work shows that there is a definite relation between the fold-axes and the olivine orientation. Evidence of strain is found in the presence of undulose extinction lamellae and actual rupture of grains on (100) planes. This would be equally consistent with prekinematic or synkinematic emplacement of the dunite. While postkinematic emplacement along a privileged path parallel with the regional strike cannot be absolutely excluded, the orientation pattern is not easily explained on this assumption, and on general grounds of association of peridotites with orogeny it seems very much less probable.

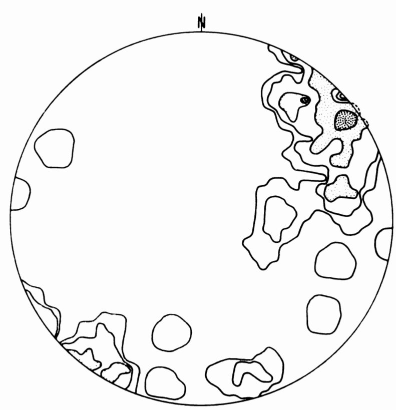
Although Brown (1957, p. 16) is inclined to ascribe the orientation found by Phillips (1938) in peridotite from Rhum to sedimentary processes, to do so in the present case would be to ignore the (100) undulose extinction bands (also found in Rhum (Phillips, p. 133)), which are certainly due to strain.



X. Contours 2-4-8-12 % Max. 16 %



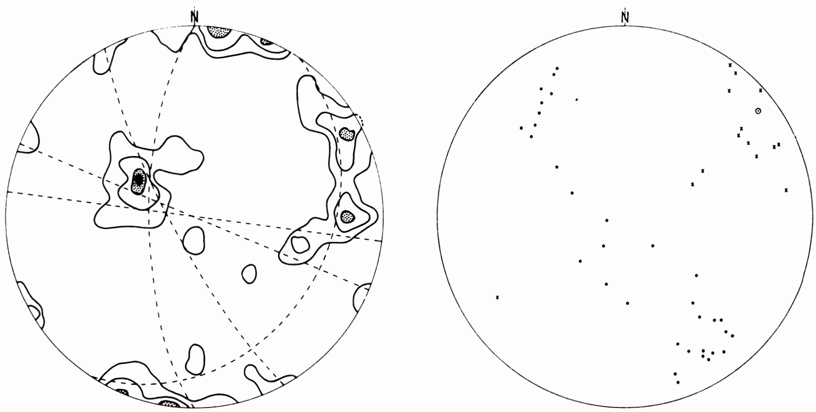
Y. Contours 2-4-8-12 % Max 16 %



Z. Contours 2-4-8-12 % Max. 14 %

8215 a. 50 OLIVINES

Fig. 6



JOINTS IN DUNITE
Contours 2·7-4-5·4-6·8-8 %
(74 observations)

FOLDING IN MAITAI FORMATION
• Poles to bedding planes ⊙ Mean fold axis
▪ Intersections of bedding and cleavage

Fig. 7

At Dun Mountain the olivine orientation is undoubtedly due to pressure and most probably to the tectonic folding forces. The work so far done does not, however, permit the separation of any crystal-orientation effect due to forces of emplacement from that due to folding and thus does not serve to confirm or deny the possibility of quasisolid injection of dunite. It might have been expected that the envelope of serpentinite around the Dun Mountain core would, by its incompetence, have shielded the dunite from the effects of tectonic compression. It does not seem to have done so. Of course much, or all, of the serpentinization may have been later than the imposition of the orientation pattern. On the other hand, the penetration of the serpentinite into the Te Anau sedimentary and volcanic sequence, leading to the incorporation of so many inclusions of those rocks, suggests tectonic mobility of the serpentinite and thus its development before the end of the folding movements.

CONCLUSIONS

The discussion tends to the conclusion that olivine orientation at Dun Mountain is related to the axes of regional folding and is very probably produced by the folding forces. We are thus able provisionally to relate one commonly recorded scheme of olivine orientation to the local tectonic axes. It is found that optical Z (= crystallographic *c*-axis) of olivine may be oriented parallel to tectonic *b*-axis (the axis of folding) while X (= crystallographic *b*) may lie in the axial plane of upright folds, though it may also tend to form, with Y, a girdle in the *ac* tectonic plane. This represents an advance upon previous relating of crystal orientation to various types of s-planes.

Further petrofabric work on the Dun Mountain dunite, in conjunction with field studies on the dates of emplacement and, serpentinization would seem likely to clarify the mechanism of orientation further.

ACKNOWLEDGMENTS

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Much of the work was done while the writer was on the staff of Auckland War Memorial Museum, where the specimens studied are housed.

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