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ORIGIN OF THE ULTRAMAFIC COMPLEX AT DUKE ISLAND, SOUTHEASTERN ALASKA

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ABSTRACT

The Duke Island ultramafic complex crops out in two areas that total 9 square miles. Rocks within the complex are comprised of olivine, clinopyroxene, hornblende and ferriferous oxides and are classified as dunite, peridotite, olivine pyroxenite and hornblende pyroxenite; all are devoid of plagioclase and orthopyroxene. A pegmatite of hornblende and anorthite is closely associated and probably comagmatic, but abundant gabbro surrounding the complex has been altered near its margin and is apparently older. Remarkable gravitational layering, showing grain-size grading, occurs intermittently in the olivine-bearing ultramafic rocks through a possible thickness of 2 miles. Although the Fe/Mg ratios of olivine and clinopyroxene increase slightly in the ultramafic units in the order listed above, cryptic layering is slight or absent. Counterparts in the layering of cross-bedding, slide conglomerates and slump structures suggest accumulation under the influence of magmatic currents, and a marked structural break, locally analogous to an angular unconformity with basal conglomerate, marks the contact of olivine pyroxenite and the dunite-peridotite zone and indicates at least two major intrusions of magma into the complex. A variety of structural, mineralogic and petrologic evidence suggests that the ultramafic rocks crystallized from a magma of ultrabasic composition. Hornblende pyroxenite generally forms a border zone around the olivine-bearing rocks, and together with the alteration aureole, seems to represent peripheral reactions that tended to produce a succession of zones in local equilibrium along thermal and chemical gradients between the ultrabasic magma and its country rock. The possible composition and temperature of the ultrabasic magma are discussed.

INTRODUCTION AND ACKNOWLEDGMENTS

Duke Island is at the southern end of southeastern Alaska (55°55′N, 131°20′W) and has an area of 59 square miles. The ultramafic complex exposed on the island is a member of a belt of 35 or more ultramafic bodies that occur along the 350-mile length of the Alaskan panhandle. A brief description of the belt is available in Taylor and Noble (1960). The present paper is a summary of the petrology of the Duke Island complex; a more comprehensive report is in preparation.

The information presented here was largely collected while the author was attending the California Institute of Technology, and the contributions of many people there by way of discussion, assistance, and criticism are gratefully acknowledged. Particular thanks go to Dr. James A. Noble for sponsoring the field work and supervising the study. During the academic year 1958–1959, support was provided by the Foster Hewitt Fellowship in Field Geology. Grants from the Geological Survey of Canada have covered reproduction of some of the diagrams. G. V. Middleton and D. M. Shaw have made several helpful suggestions with regard to exposition.

GEOLOGICAL DESCRIPTION OF DUKE ISLAND

Metamorphic rocks. The geology of part of Duke Island is shown in Fig. 1. The oldest rocks are metamorphosed volcanic and clastic sedimentary formations. These generally fringe the igneous core of the island, which is comprised of gabbroic, ultramafic and granitic plutons that apparently were emplaced in that order. The metamorphic rocks are not in contact with the ultramafic complex, but where they are closer than ¼-mile to the main gabbro mass, they have mineral assemblages indicative of the hornblende hornfels facies and, locally, the pyroxene hornfels facies (Fyfe *et al.*, 1958). Elsewhere, they belong to the albite-epidote hornfels or green schist facies.

Primary (pyroxene) gabbro. The primary gabbro is comprised of 40–50 per cent plagioclase and 45–55 per cent pyroxene and hornblende combined. Olivine and biotite are present locally; ilmenomagnetite and apatite are common accessories. Plagioclase ranges from An_{40} to An_{95}, An_{50-75} predominating (Fig. 2). Orthopyroxene and clinopyroxene are generally both present, but rocks having only one or the other do exist. By optical properties (Figs. 3, 4), orthopyroxene ranges from En_{47} to En_{76}, and clinopyroxene from about $Ca_{37}Mg_{53}Fe_{10}$ to $Ca_{38}Mg_{29}Fe_{33}$. As shown in Fig. 3, the Fe/Mg ratio of each pyroxene increases as plagioclase becomes more sodic. Olivine changes in the same way, its range of variation being Fo_{27} to Fo_{82}.

The pyroxene gabbro underlies most of the eastern half of Duke Island and thus, is abundant. Unfortunately, little is known about its structure: the rock is largely massive; topographic relief is low;

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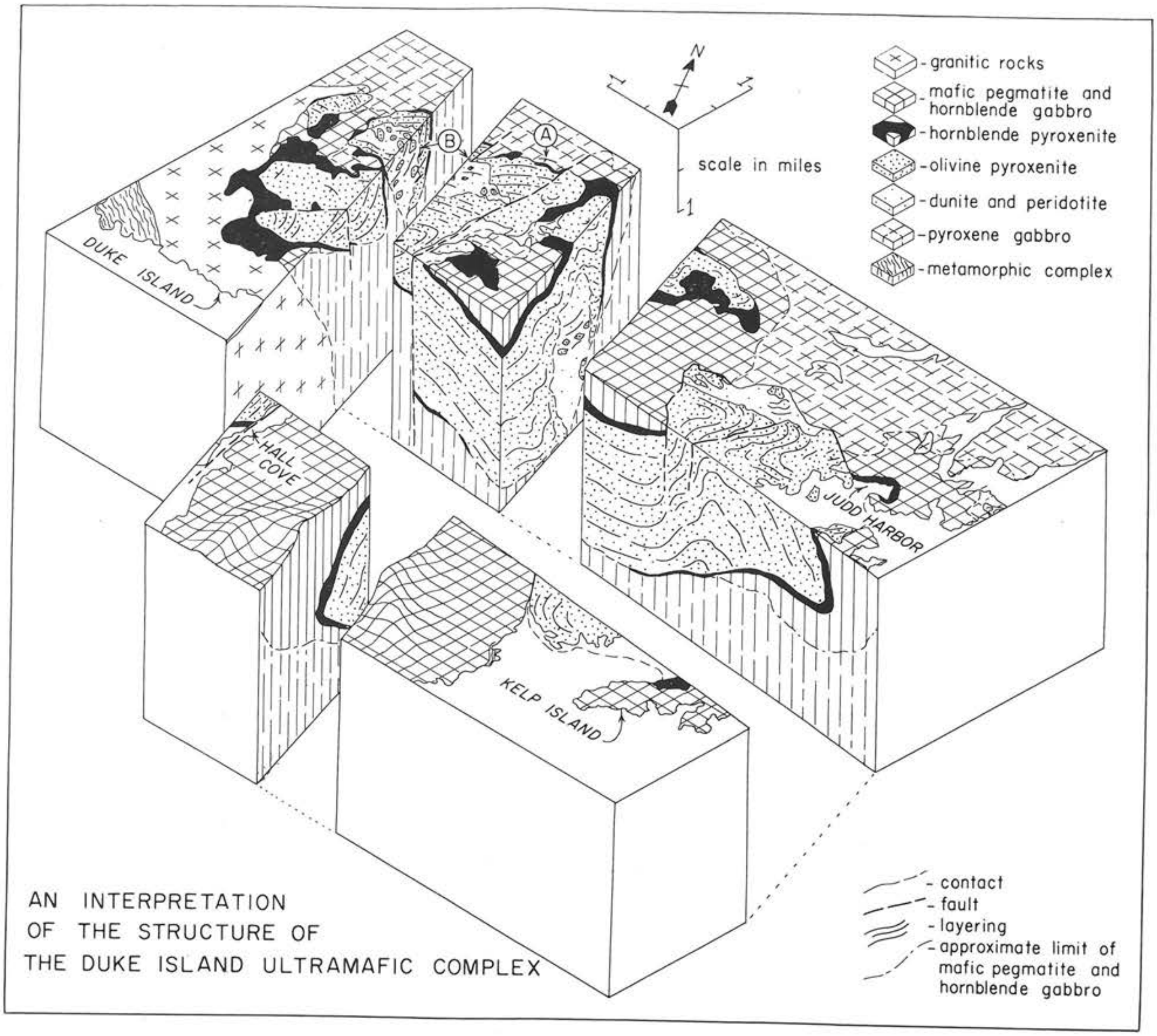

Fig. 1

contacts are poorly exposed; and the pattern of mineral variation is not obviously systematic. Rhythmic layering does, however, occur at two localities, and one, denoted "A" in Fig. 1, is notable. The layering there is continuous and regular for several tens of feet, and individual layers have thicknesses up to one foot. Each layer has its base clearly defined by a marked concentration of pyroxene: proceeding upward, the proportion of mafic minerals decreases in a sharp gradation, and the rock becomes normal or slightly feldspathic and shows marked igneous lamination. The layering is approximately parallel to the nearby contact of the gabbro against the ultramafic complex, and the direction of tops of layers, as indicated by grading, suggests that the gabbro underlies the ultramafic rocks. The same relation is indicated for this locality and others by the graded rhythmic layering that occurs in the ultramafic complex as described below.

Description of the ultramafic complex

(a) Petrography and mineralogy

Most of the ultramafic rocks crop out in two areas that total 9 square miles, but the areas are believed to be the exposure of one large body at depth (Fig. 1). This interpretation is based partly on an aeromagnetic map and partly on geological inference, some of which is mentioned below. If it is correct, then it is imprecise to refer to each exposure as a "body." The word "outcrop" is therefore used in its broader sense, and the exposures are called the Hall Cove and Judd Harbor ultramafic outcrops.

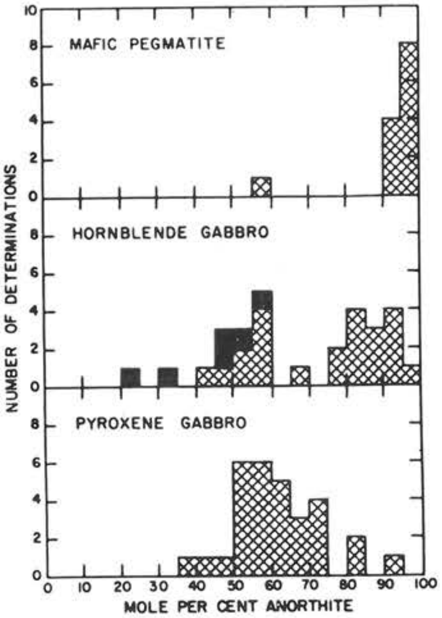

FIG. 2. Histograms of the composition of plagioclase in the different types of mafic rocks occurring at Duke Island, Alaska. In the hornblende gabbro histogram, the dark part represents plagioclase from hornblende gabbro near the granitic intrusions; the rest represents plagioclase in hornblende gabbro near the ultramafic rocks.

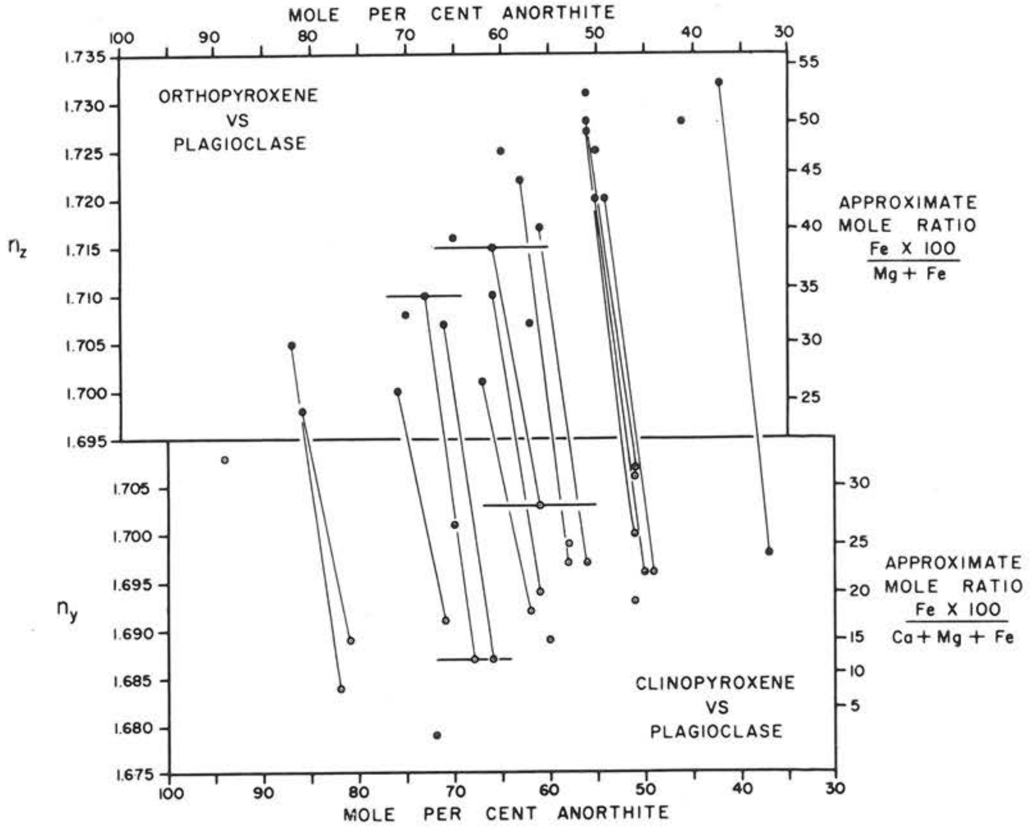

FIG. 3. Relation of the chemical variations in the pyroxenes and plagioclase of the primary gabbro at Duke Islands as determined by optical properties. The plots of coexisting pyroxenes are joined by "tie lines." In the clinopyroxene, the proportion of Ca is roughly constant near 40 per cent.

The ultramafic rocks are essentially comprised of three minerals: olivine; clinopyroxene (diopsidic augite); and hornblende. The results of modal analyses are given in Figs. 5A and B, and the rock classification scheme is apparent in Fig. 5A. The principal units are dunite, peridotite, olivine pyroxenite, and hornblende pyroxenite. Much of the hornblende pyroxenite contains 13–17 per cent magnetite, 2–3 per cent ilmenite, and minor hercynitic spinel. Chromite or chromiferous magnetite is a sparse accessory in dunite and peridotite. Olivine is generally partly altered to serpentine and secondary magnetite, but otherwise, the rocks are fresh. Orthopyroxene and plagioclase are notable by their absence.

Figure 5C shows the approximate areal abundances of the different rocks. The histograms were prepared by weighting each modal analysis by the map area the specimen is believed to represent. Although perhaps not statistically elegant, this procedure does give proper weighting to specimens that come from small occurrences of a particular rock type, and the result graphically portrays distribution features that are very obvious in the field. Olivine pyroxenite containing 15–30 per cent olivine (plus serpentine alteration) is an extremely abundant rock type and has a histogram mode distinct from that of olivine-free hornblende pyroxenite. Peridotite is rare by comparison, but a slight mode is present for dunitic rocks in the Judd Harbor outcrop. Several of the other ultramafic bodies in southeastern Alaska have comparable distributions in that their principal modes correspond to dunite, olivine pyroxenite, and olivine-free pyroxenite.

The refractive indices of clinopyroxene and olivine increase slightly through the rock sequence from dunite to hornblende pyroxenite (Fig. 6). Higher index is due primarily to a larger Fe/Mg ratio, and the indicated compositional range for olivine is Fo_{78} to Fo_{85}. Optics and chemical analyses show clinopyroxene to range from about $Ca_{45}Mg_{48}Fe_7$ to $Ca_{50}Mg_{38}Fe_{12}$ (Fig. 7). The larger 2V of clinopyroxene in the ultramafic rocks as compared to that in gabbro (Fig. 4) indicates a larger Ca/Mg+Fe ratio or, in other words, less Ca-poor pyroxene in solid solution. This suggests that Ca-poor pyroxene did not reach its saturation limit in the ultramafic rocks during their crystallization and, thus, is compatible with the absence of orthopyroxene.

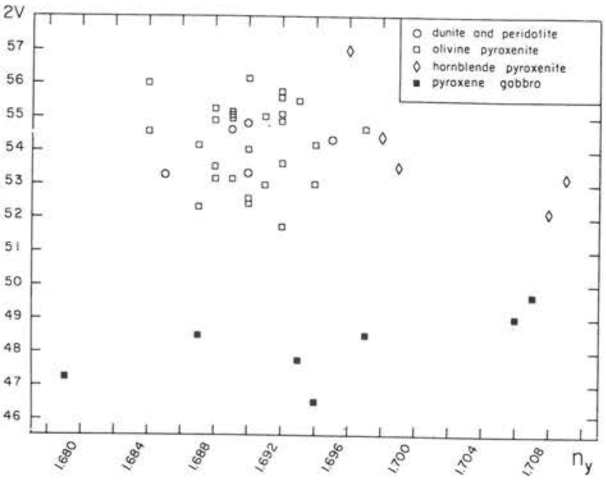

FIG. 4. Plot of 2V against n_y for clinopyroxene from Duke Island rocks. This is roughly equivalent to a plot of Ca content against Fe/mg ratio.

(b) Layering

The outstanding feature of the Duke Island ultramafic complex is an abundance of stratification that has many of the features of the rhythmic layering in the Skaergaard, Stillwater, and other intrusions, but which is distinct in that it is graded by grain size rather than mineral density (Fig. 8). The distribution and attitude of the layering is shown in Fig. 1 by trend lines. It is almost exclusive to olivine-bearing rocks and involves only two primary-precipitate minerals, clinopyroxene and olivine. (Hornblende pyroxenite exposed on Kelp Island just south of Duke Island shows magnetite layers, a few of which are graded.) Most layers are 2–10 inches thick; the greatest thickness observed for a continuously graded layer is 25 feet; the common maximum thickness is 2–4 feet. Many layers can be traced laterally for 300 feet, and possibly, some extend 900 feet. Thicker layers are generally coarser, but in an average example, grain size is 4–10 mm at the base, decreasing to 0.2–2 mm at the top. The bottom of each graded layer is sharp; the top may be sharp but commonly is transitional into finely laminated rock. Both pyroxene and olivine show grain size sorting, and olivine tends to concentrate near the tops of layers because it is generally finer (the two minerals have about the same density.) Layers lacking distinct grading commonly alternate with graded ones, but direction of grading is rarely reversed and, thus, is a reliable indicator of tops where structures are complicated.

Figure 9 shows a variant of graded layer that is comparable to a conglomerate bed. It is comprised of fragments of olivine pyroxenite in a matrix of peridotite. This type of layer occurs only in the peridotite zone of the Hall Cove outcrop. Associ-

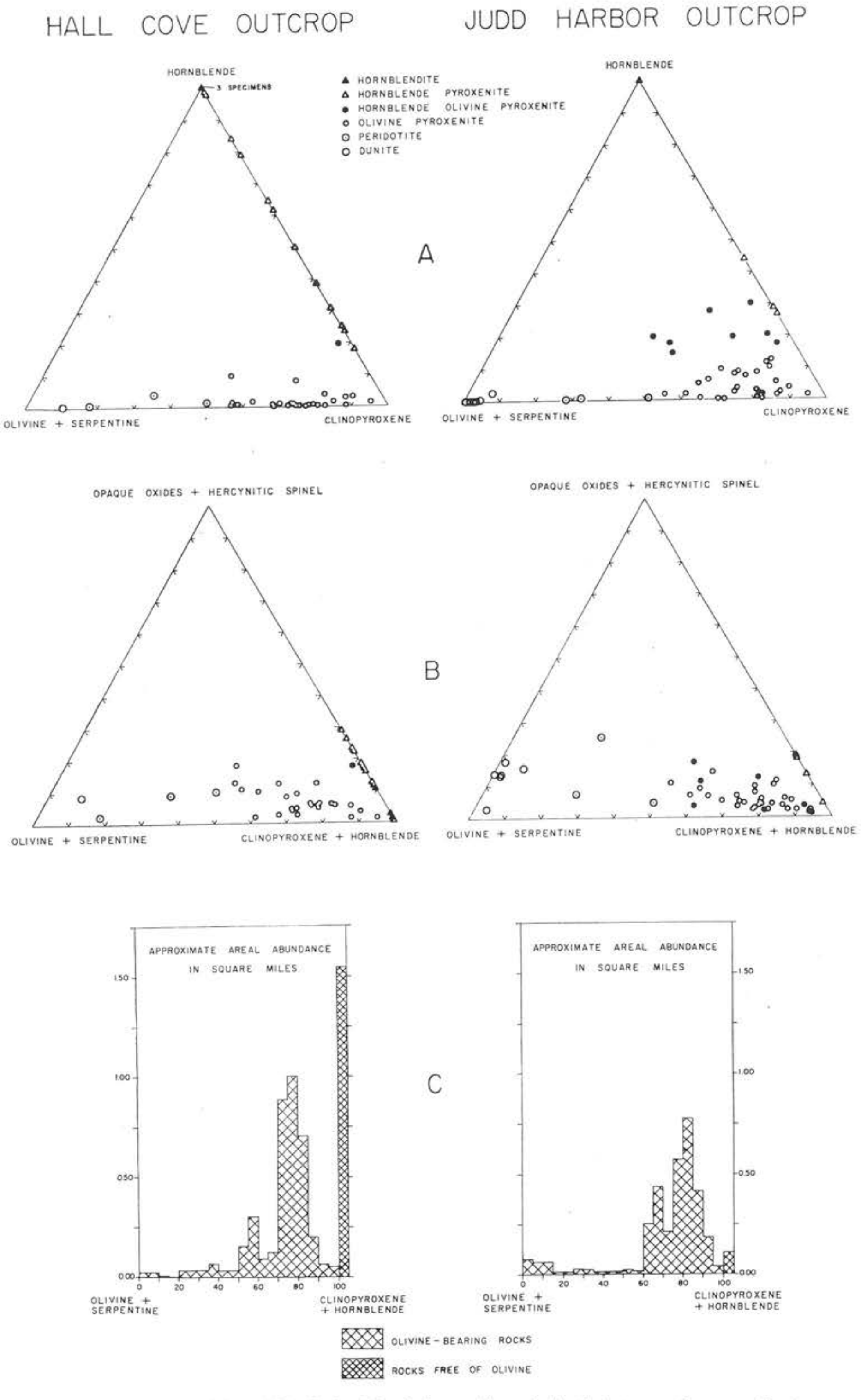

FIG. 5. Modal composition of the Duke Island ultramafic rocks in their two main areas of outcrop.

ated with it are other structures characteristic of clastic sediments, including slump structures and cross-layering. It seems clear that the graded layers have formed by gravity accumulation of crystals under the influence of currents. A mechanism of irregular magmatic convection comparable to those proposed by Wager and Deer (1939) and Hess (1960) is probable. However, at Duke Island, mechanical disruption in the magma chamber and slumping have apparently played an important role in generating and perpetuating currents.

Another type of layering occurring in olivine pyroxenite at Duke Island is marked by a poorly defined alternation of pyroxene and olivine and by thin, discontinuous bands of dunite. In appearance, it is not unlike the "inch-scale layering" of the Stillwater Complex (Hess, 1960, p. 133). The pyroxene crystals commonly show preferred orientation normal to the lamination, possibly because of growth in situ or recrystallization, or both. Most of the layering in the Judd Harbor olivine pyroxenite zone is this type.

Cryptic layering is weakly developed in the Hall Cove peridotite zone but has not been detected in the other parts of the complex by optical methods.

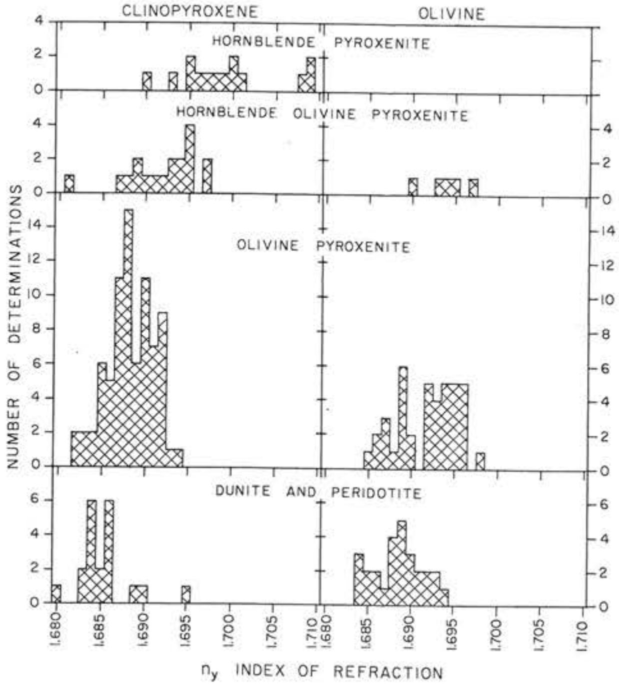

FIG. 6. Histograms of the refractive indices of clinopyroxene and olivine in the major ultramafic rock units.

(c) Structure of the complex

The distribution of rock types in several of the ultramafic bodies in southeastern Alaska is roughly concentric and, in idealized development, features a dunite core surrounded by successive rings of peridotite, olivine pyroxenite, pyroxenite, and hornblendite (Taylor and Noble, 1960). The Union Bay complex has the most extensive sequence of zones, and the Blashke Islands complex, the most symmetric zoning. At Duke Island, the rock-type distribution in the Hall Cove ultramafic outcrop is vaguely concentric in approximately the above sequence but primarily because of a remarkably continuous border zone of hornblende pyroxenite. In the Judd Harbor outcrop, rock units are arranged side by side, although here too, the main bodies of hornblende pyroxenite are peripherally located.

In the Hall Cove outcrop, abundant evidence shows that at least two intrusions are involved in the formation of the olivine-bearing rocks. The peridotite zone is part of the younger intrusion. It cuts sharply across olivine pyroxenite layering, and itself has layering that dips about 20 degrees flatter, giving a relation not unlike an angular unconformity (Fig. 1, locality B). Fragments and blocks of olivine pyroxenite, some of them layered, are included in the peridotite and are concentrated in the lower half of the exposed section like a basal conglomerate. Many of the smaller fragments occur in fragmental layers (Fig. 9). Larger blocks, commonly having dimensions of tens to hundreds of feet, occur individually or in jumbled clusters. Generally their weight and impact has caused intense deformation of peridotite layers on which they have fallen, and cross-layering is associated and apparently was produced by irregular currents accompanying influx of the blocks. It is clear that both intrusions were largely liquid, although the younger may have contained an appreciable proportion of olivine crystals. Emplacement of the younger intrusion seems to have caused folding and faulting in earlier olivine pyroxenite and, thus, was probably forcible.

In the Judd Harbor outcrop, layered structures in the dunite-peridotite zone are discordant with those in olivine pyroxenite, and here too, relations suggest that the former was forcibly emplaced into the latter.

Thickness estimates for the layered rocks are tenuous because of the complicated structure. Intermittently layered olivine pyroxenite totals about 10,500 feet in the Hall Cove outcrop and 5300 feet in the Judd Harbor outcrop. About 1500 feet of continuously layered peridotite are exposed in the Hall Cove outcrop.

The interpretation given in Fig. 1 shows dunite and peridotite as part of a younger intrusion and assumes that the complex is one large body with a highly continuous peripheral zone of hornblende pyroxenite. The vertical dimension shown for the body is the minimum required to accommodate the exposed layered rock.

Mafic pegmatite. A remarkable pegmatite of hornblende and anorthite (Fig. 2) occurs in abundance in the southwest part of Duke Island. Most of it froms veins and dikes in gabbro, but some occurs in a swarm of dikes trending N. 50° W. through the olivine pyroxenite in the Judd Harbor ultramafic outcrop. The dikes range in width from half an inch to 200 feet, and a few extend 1200 feet along strike. Grain size is commonly 1–6 inches and locally reaches 4 feet. A more detailed description and pictures of the rock have been published by Koschmann (1935).

The very calcic plagioclase in the pegmatite precludes derivation of the rock from normal gabbroic magma. The ultramafic complex is the probable source because it is rich in calcium and contains hornblende that is optically and chemically similar to the pegmatite hornblende. The pegmatite is more common near the better developed parts of the hornblende pyroxenite zone, and comparable pegmatite is associated with several of the other ultramafic bodies in Alaska. The abundance of the pegmatite at Duke Island, especially between the two areas of ultramafic outcrop, suggests the presence of more ultramafic rock at depth.

Altered (hornblende) gabbro. An appreciable part of the primary gabbro has been altered to hornblende and plagioclase. Some of the alteration fringes

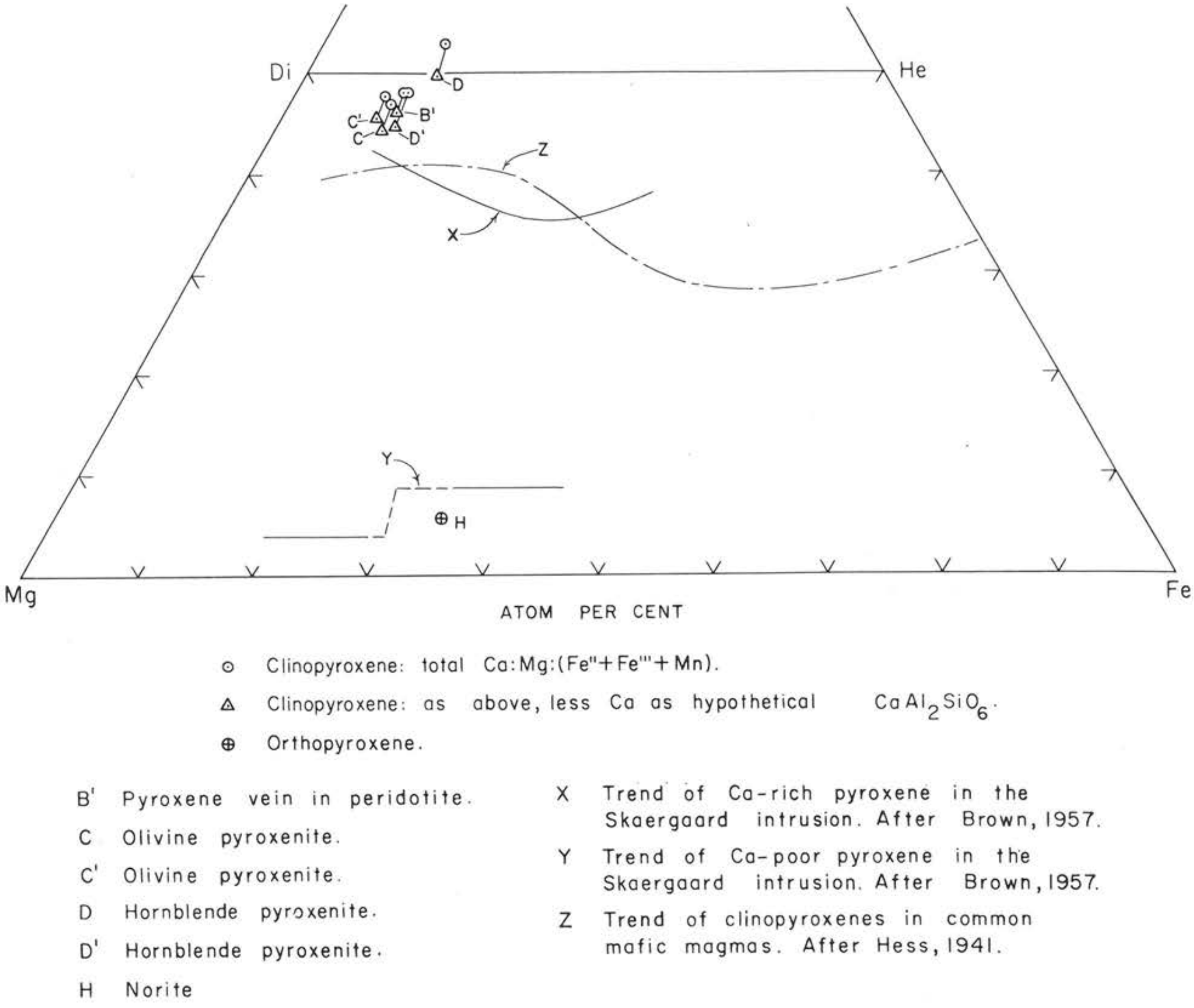

FIG. 7. Plot of Duke Island pyroxenes on a Di-He-Mg-Fe diagram.

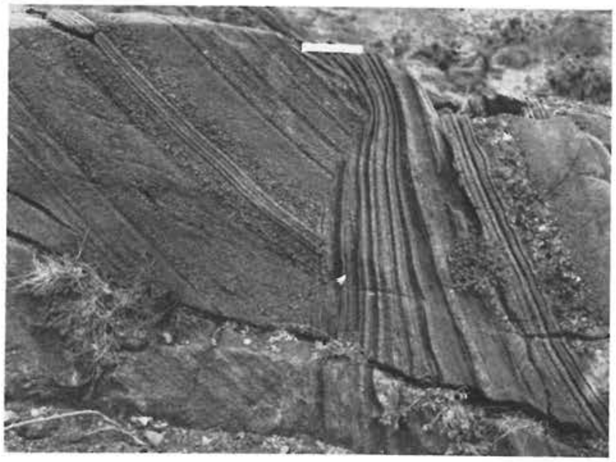

FIG. 8. Two generations of graded layering in the olivine pyroxenite zone of the Hall Cove ultramafic outcrop. The angular block on the left has been broken from a well-solidified accumulate and, then, covered by the layers on the right. Subsequently, the entire structure has been tilted to the right. The scale is six inches.

FIG. 9. Fragmental layers in the peridotite zone of the Hall Cove ultramafic outcrop. Small fragments of olivine pyroxenite have been sorted by size. They are surrounded by a peridotitic matrix. The scale is six inches.

granite plutons and probably has been caused by these younger intrusions; its plagiocalse ranges from An_{20} to An_{57}.

Most of the altered or hornblende gabbro occurs around the ultramafic rocks, particularly between their two main areas of outcrop. It has uneven porphyroblastic to pegmatitic texture and is intimately intermixed with and veined or intruded by mafic pegmatite. Its plagioclase ranges from An_{40} to An_{98} and, as shown in Fig. 2, is to a considerable extent intermediate between the feldspars of pyroxene gabbro and mafic pegmatite. Evidently, this hornblende gabbro is an alteration of pyroxene gabbro caused by the highly calcic water-rich pegmatite from the ultramafic complex.

GENESIS OF THE ULTRAMAFIC COMPLEX

Evidence of an ultrabasic magma. In the structural interpretation presented in Fig. 1, it is implicit that the ultramafic rocks represent at least two intrusions of magma of ultrabasic composition.[1] Such an interpretation is, of course, subject to serious question, particularly in view of the abundance of gabbro exposed on the island. However, attempts to interpret the ultramafic and gabbroic rocks as parts of a stratiform body like the Stillwater complex have not given reasonable results, and certain features are in direct conflict (notably, the relations at locality A). The idea of two ultrabasic intrusions provides a relatively consistent picture, and a variety of chemical and mineralogical evidence summarized below seems in agreement.

The ultramafic and gabbroic rocks contrast markedly in their mineralogy and chemistry. The primary gabbro generally contains orthopyroxene and locally is noritic. Ca-poor pyroxene does not occur in the ultramafic rocks and is absent from their norms (except in rock appreciably oxidized during serpentinization of olivine). Ultramafic clinopyroxene is undersaturated in Ca-poor pyroxene and, if anything, becomes more so in the lower-temperature differentiates (Fig. 7). It overlaps gabbro clinopyroxene in refractive index but has a different trend of optical and, probably, chemical variation (Fig. 4). Overall, the ultramafic rocks are extremely undersaturated in silica. Their norms contain not only olivine, but nepheline, leucite and larnite. The chemical trend in going from dunite to mafic pegmatite is not one of appreciable silica enrichment, and mineral analyses indicate extensive substitution of Al for Si in the tetrahedral sites of clinopyroxene and hornblende from the lower temperature rocks, due probably, to some extent, to a deficiency of silica.

Some of the mineralogical features that contribute to the contrast in degree of silica saturation shown by ultramafic and gabbroic rocks might be rationalized with formation of the rocks from one magma if it is assumed that, after accumulation of

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[1] The adjective *ultramafic* should probably only be used in reference to mafic-rich *rocks* that are essentially free of feldspar. The magma's composition is described as *ultrabasic*, implying low silica content, because the feldspar-bearing mafic pegmatite is probably one of its differentiates, and because chemical analyses show the Duke Island ultramafic rocks to contain appreciable normative anorthite.

the olivine-bearing ultramafic units, the main body of residual magma underwent a brief period of extensive oxidation. The change of iron from the ferrous to the ferric state could have caused precipitation of the abundant magnetite in the hornblende pyroxenite zone and, in addition, would reduce the Fe^{2+}/Mg ratio of the residual magma and effectively increase its silica content. As a result, the Fe/Mg ratios of the mafic silicates crystallizing from the magma would drop abruptly and then progressively increase again with differentiation after oxidation ceased, and orthopyroxene might take the place of olivine in the crystallization sequence, appearing both as a distinct phase and in increased amounts in solid solution in clinopyroxene. This would account for some of the pyroxene variations shown in Figs. 3 and 4. The effective production of silica by oxidation could have led to the precipitation of gabbro plagioclase in that it would produce albite in place of the normative nepheline common to the ultramafic rocks. The principal feature that seems to contradict the above interpretation, in addition to the structural relations, is that clinopyroxene in the rock richest in magnetite, hornblende pyroxenite, has a higher Fe/Mg ratio than that in the olivine-bearing ultramafic units and, possibly, less Ca-poor pyroxene in solid solution (Figs. 6, 7). Furthermore, the envisaged period of oxidation would probably require a rather special event in the history of the complex, which seems unlikely inasmuch as similar magnetite-rich pyroxenites occur in several other ultramafic bodies in Alaska and British Columbia (Taylor and Noble, 1960). Clinopyroxene variations in the ultramafic rocks at Union Bay are comparable to those shown in Figs. 6 and 7 (Ruckmick and Noble, 1959).

If the ultramafic rocks were differentiated from gabbroic magma, they might be expected to contain interstitial plagioclase as a product of interprecipitate magma. Also, one might expect the ultramafic and gabbroic rocks to have gradational contacts. The complex is, however, devoid of plagioclase, and its contact with gabbro is everywhere sharp and apparently intrusive. Filter pressing might locally remove pore magma but probably could not cause a complete absence. It might be argued (in fact, in parts of the complex, it is probable) that the pore magma was water rich and that the components of plagioclase crystallized in hornblende; the ultramafic rocks have normative anorthite that, in some, is due to Al_2O_3 in hornblende, and data obtained by Yoder and Tilley (1956) indicate that, in basic rocks at moderate to high water pressures, plagioclase is incompatible with pyroxene and olivine, their reaction producing hornblende. Nonetheless, unless two distinct magmas are involved, it seems fortuitous that interstitial plagioclase should be absent everywhere in the Duke Island ultramafic complex (and in the other ultramafic bodies in S. E. Alaska; *cf.* Taylor and Noble, 1960), especially when olivine, pyroxene, and plagioclase coexist in the primary gabbro. On the other hand, a high activity of water might well have been one of the characteristics of the ultrabasic magma that distinguished it from the gabbro magma.

The mafic pegmatite is the only feldspathic rock considered to be directly related to the ultramafic complex. Although abundantly exposed it probably is a proportionately minor unit, and in terms of normative mineralogy, it too is very much undersaturated in silica. The mineralogic and textural relations of hornblende gabbro and mafic pegmatite are not typical of comagmatic rocks and would seem to preclude their formation by differentiation of one liquid. More likely, the hornblende gabbro is the alteration aureole of an ultrabasic magma emplaced in a country rock of pyroxene gabbro.

Composition and crystallization of the magma. Fine-grained rocks that might represent chilled ultrabasic magma have not been recognized at Duke Island. Rough estimates of the chemical composition of the average rock exposed in each of the ultramafic outcrops are given in Table 1. They were obtained by weighting chemical and modal analyses by the abundances shown in Fig. 5 and are, therefore, close to the composition of olivine pyroxenite. The extent to which the estimates may represent the liquid part of the initial intrusions depends, of course, on many factors: *e.g.* the assumptions made in the computations; the extent to which the exposed rocks represent the complex as a whole; the proportion of crystals in the initial intrusions; the composition and amount of mafic pegmatite and other materials lost to the country rock; and the extent to which the analyzed rocks represent contamination by country rock. Olivine pyroxenite is probably a gravitationally accumulated differentiate of the magma; it constitutes most of the layered rock and apparently represents the product of cotectic precipitation of olivine and clinopyroxene inasmuch as the proportions of these minerals are roughly those of the eutectic product in the system $CaMgSi_2O_6$-Mg_2SiO_4 (Bowen, 1914). However, the absence of cryptic layering may indicate that the rock is close in composition to its parent magma. Dunite and peridotite probably formed by fractionation of an excess of olivine over the cotectic proportion and/or by accumulation of olivine crystals suspended in the initial intrusions. The estimates in Table 1 include normative anorthite, hence the anorthite-bearing mafic pegmatite is a conceivable late differentiate.

The hornblende pyroxenite zone, as exposed, is considerably more extensive in the Hall Cove ultramafic outcrop than in the Judd Harbor outcrop. However, as shown in Fig. 5A, the olivine-bearing rocks in the Judd Harbor outcrop contain a larger proportion of hornblende, and this may indicate that hornblende pyroxenite has formed by some process of differentiation *in situ* that was more effective in the northwest part of the complex. Hornblende pyroxenite at the top of the complex may be the result of gravity-controlled fractional crystallization, olivine having ceased to crystallize because of a peritectic reaction giving hornblende or magnetite, or both. The magnetite layering at Kelp Island could be supporting field evidence, and perhaps notable is that much of the hornblende pyroxenite has about the same proportion of magnetite as the liquidus minimum of the join $CaMgSi_2O_6$-Fe_3O_4 in air atmosphere (D. Presnall, personal communication, 1962). However, the marginal (and basal?) border zone requires a different explanation. The continuity of the border zone suggests that it is a reaction rim. In fact, the physical and mineralogic relations of the hornblende pyroxenite zone and the alteration aureole of hornblende gabbro could be interpreted to represent an approach to local equilibrium along thermal and chemical gradients between a water-rich ultrabasic magma and a pyroxene gabbro country rock. The mechanics of the reactions are problematical but are probably related to the escape of mafic pegmatite from the ultramafic complex. Notable in this respect is that an appreciable amount of hornblende and magnetite occurs as alteration associated with the swarm of mafic pegmatite dikes in the Judd Harbor olivine pyroxenite.

TABLE 1. ESTIMATES OF THE COMPOSITION OF THE AVERAGE ULTRAMAFIC ROCK EXPOSED IN EACH OF THE TWO MAIN AREAS OF ULTRAMAFIC OUTCROP AT DUKE ISLAND. H_2O IS NOT INCLUDED

	I Hall Cove	II Judd Harbor	C.I.P.W. Norms					
					I		II	
SiO_2	43.9	45.5	Ol	Fo	19.9	24.2	25.5	30.9
Al_2O_3	6.0	4.8		Fa	4.3		5.4	
Fe_2O_3	5.3	2.9	Clpx	Di	40.4	47.4	40.9	47.8
FeO	8.1	7.5		He	7.0		6.9	
MgO	18.9	22.2	Larnite			2.0		2.3
CaO	15.9	15.7	An			12.5		10.1
Na_2O	0.6	0.4	Ne			2.8		1.8
K_2O	0.4	0.4	Lc			1.9		1.9
TiO_2	0.8	0.5	Mt			7.7		4.2
MnO	0.1	0.1	Il			1.5		1.0
	100.0	100.0				100.0		100.0

Areas Represented: Hall Cove outcrop 5.4 sq. miles
Judd Harbor outcrop 3.6 sq. miles

Much of the period of solidification of the ultrabasic magma must have been marked by cotectic crystallization of diopsidic pyroxene and forsteritic olivine. A maximum temperature during this time would be that of the eutectic in the system $CaMgSi_2O_6$-Mg_2SiO_4 (1387° C. at 1 atmosphere; Bowen, 1914). Possible excess olivine in solution during the formation of dunite could require higher temperatures, but the other constitutents evident in the ultramafic rocks (*e.g.* FeO, Fe_2O_3, Al_2O_3 and H_2O) would lower the liquidus. Thus the magma may initially have been at 1250° C. or less and was probably appreciably cooler by the pegmatitic stage.

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