SYNCRYSTALLIZATION AND SUBSOLIDUS DEFORMATION IN OPHIOLITIC PERidotITE AND GABBRo*

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ABSTRACT. The Vourinos (Greece), Troodos (Cyprus), and Canyon Mountain (Oregon, U.S.A.) Complexes illustrate the effects of penetrative deformation at various stages in the accumulation and crystallization of peridotite and gabbro in ophiolite complexes. In the Vourinos, only harzburgite has a tectonic fabric. In the Troodos, deformation increases downward from wehrlite through dunite into harzburgite. At Canyon Mountain, the earliest identifiable deformation affected gabbro and obscured many petrologic relations between it and the earlier units; involvement of the gabbro, however, reveals large folds and faults. The presence of both deformed and undeformed ultramafic dikes and pegmatites and the absence of the early phases of deformation in gabbro in much of the complex are interpreted as effects of intense deformation during deposition and crystallization of the lower part of a thick cumulate pile. Gabbroic augen gneiss in the Bay of Islands Complex (Newfoundland, Canada) and widespread tight folding and foliation of gabbroic and ultramafic rocks together in the Zambales Complex (Philippines) are cited as additional evidence that tectonic fabrics related to hypersolidus and subsolidus deformation in ophiolitic rocks other than harzburgite are widespread and have been overlooked.

Amphibolite-facies regional metamorphism of gneissic gabbro obscures, and may obliterate, evidence of hypersolidus and subsolidus deformation. Mimetic hornblendization of gneissic gabbro, which is well shown in the Baltimore (Maryland-Pennsylvania, U.S.A.) and Tilaquillo (Venezuela) Complexes, may be misinterpreted as foliation formed during regional metamorphism. Intense hypersolidus or subsolidus deformation, followed by hornblendization related to regional metamorphism, probably contributed substantially to misidentification of gabbro as metavolcanic rocks in the Tilaquillo Complex and at the Lizard (Cornwall, England).

INTRODUCTION

During the last 10 to 15 yrs, increasingly careful mapping has shown that some ophiolites are exceedingly complex, but it also has led to general agreement on some broad characteristics of the ophiolite assemblage. Some reasons for the complexities have been summarized very well by George (1978, p. 845):

If syntectonic and posttectonic magmatic sedimentation, crystal-mush flow, partial fusion of metamorphic peridotite, and multiple intrusion of magma act simultaneously during the formation of ophiolites, then the resulting field relations, structures, textures, and fabrics will be exceedingly complex, particularly if subsequent transport and emplacement impose strong metamorphic and tectonic overprints. One should expect that differences in the relative chronology and intensity of the processes of the formation of ophiolites make every ophiolite unique.

The intent of this discussion is to call attention to some effects of variations in the timing of deformation during accumulation and crystallization of peridotite and gabbro in ophiolite complexes. Ambiguities in critical relations that result from intense deformation of successive rock units before complete crystallization of some cumulate piles may lead to petrogenetic interpretations that are questioned or contradicted by definitive relations in other complexes; some examples are cited.

This discussion may disappoint some readers, because it is based mostly on features seen in outcrop, in hand specimen, and under the

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petrographic microscope. No new petrofabric data are presented; for data on the Canyon Mountain Complex the reader is referred to Avé Lallemant (1976). No correlations are suggested between structural and petrologic features of the complexes mentioned and possible oceanic plate tectonic settings because of the tenuous nature of available evidence or outright disagreements in the literature. My purpose is to call attention to rock relations that have been overlooked, not recognized, or ignored to varying degrees, and that have not been considered adequately in the construction of oceanic crustal models.

**PLUTONIC ROCKS OF THE OPHIOLITE ASSEMBLAGE**

The igneous rocks of the ophiolite assemblage may be divided into two groups, one made up of plutonic ultramafic and gabbroic rocks and one of volcanic and subvolcanic or hypabyssal rocks that include sheeted dikes, pillowed flows, and associated silicic rocks. In most complexes, rocks of the second group clearly intrude or lie unconformably on the plutonic rocks (Kidd, Dewey and Bird, 1978; Thayer, 1977). The plutonic rocks generally may be divided into three main lithologic units: harzburgite and dunite at the bottom; a wehrlitic zone, mainly of olivine and clinopyroxene rocks that range from dunite to clinopyroxenite but which may include troctolite; and gabbroic rocks at the top. The harzburgite generally is distinguished from wehrlite and clinopyroxenite by a tectonic fabric, lack of cumulus textures, predominance of orthopyroxene over clinopyroxene, and the absence of feldspar. Podiform chromite deposits, many of which show cumulus or metacumulus features, occur in the harzburgite and in the lower part of the wehrlitic zone (Greenbaum, 1978; Jackson, Green, and Moores, 1975; Thayer, 1969a). The wehrlitic rocks grade upward into cumulate gabbro, which in turn grades upward into massive noncumulate gabbro, and in some complexes appears to grade into plagiogranite (Coleman, 1977; Jackson, Green, and Moores, 1975).

Generally accepted petrogenetic theory sets the harzburgite apart from the clearly magmatic cumulate rocks, because it is considered to be a metamorphic refractory residue left from partial melting of mantle material and removal of liquid basaltic magma (Coleman, 1977, p. 90). Although the mineralogy and geochemistry of harzburgite are its most diagnostic features, tectonic fabrics are also cited as a genetic characteristic related to partial melting. In contrast, preservation of cumulus textures in wehrlitic rocks and gabbro clearly shows that these rocks crystallized from fluid magma. The association of tectonite fabrics with harzburgite apparently has become so ingrained in the literature that equally prominent tectonite fabrics in wehrlite and gabbro have been overlooked (Kidd, Dewey, and Bird, 1978, p. 790, 801; personal observations of the author).

The differences between the relations of dunite to harzburgite in the Vourinos and the Troodos Complexes illustrate ambiguity introduced by deformation. In the Vourinos, chromitites of two distinct ages are present: (1) thin cumulate chromitite layers in the stratified sequence, and
(2) chromite tectonites in which cumulus textures have been all but obliterated (personal observations) within dunite in the harzburgite (Jackson, Green, and Moores, 1975). In the Troodos and Canyon Mountain Complexes, however, tight infolding of harzburgite with overlying rocks and conflicting evidence on the stratigraphic distribution of chromite deposits have led to serious ambiguities in the rock succession.

In the Troodos Complex, as in the Vourinos, chromite deposits occur in the lower part of the dunite and in dunite lenses within harzburgite no more than 2.2 km horizontally from the dunite–harzburgite contact (Greenbaum, 1978, fig. 1). The chromite in harzburgite forms pods that are enclosed in dunite lenses or envelopes and that decrease in number away from the dunite–harzburgite contact. All structures are aligned with the regional foliation in the harzburgite. Similar textures, structures, and chemical compositions indicate that the deposits in the harzburgite are genetically equivalent to those in the dunite (Greenbaum, p. 1186).

SYNTECTONIC CRYSTALLIZATION IN THE VOURINOS, TROODOS, AND CANYON MOUNTAIN COMPLEXES

The recent descriptions of the Vourinos ophiolite in Greece and the Troodos Complex in Cyprus have shown significant differences in relations of harzburgite and cumulate rocks that result from hypsosolidus deformation (deformation during crystallization) of peridotite and gabbro. In the Vourinos, an apparently undeformed stratified sequence of cumulate rocks 1500 m thick is cleanly deposited across harzburgite that has been folded three or four times. The layered sequence ranges from dunite and chromitite to cumulate diorite and is characterized by cyclic units (Jackson, Green, and Moores, 1975). In the Troodos Complex, a cumulate sequence of gabbro, pyroxenite, wehlite, dunite and chromitite lies on highly deformed harzburgite (George, 1978; Greenbaum, 1978). Wehlite and dunite in the lower part of the cumulate sequence show a gradual downward increase in penetrative deformation, and the basal dunite is intricately interfolded with harzburgite. The transition from undeformed wehlite down to dunite that shows the same fabric as harzburgite “probably occurs over a stratigraphic interval of approximately 500 m” (George, 1978, p. 855) Strong tectonism during magmatic sedimentation would result in just such a transition. Completely crystallized units in the lower part of the section would show penetrative subsolidus deformation, which would grade upward into crystal-mush flow (grain boundary sliding) and fluid flow as the ratio of liquid to crystals increased.

Both Greenbaum and George interpret the chromite deposits and dunite lenses in harzburgite as infolded from the overlying dunite zone, despite the distance of many from the main dunite contact. Occurrence of major chromite deposits within harzburgite in other complexes, especially the Skoumtsa, Voidolakkos, and Xerolivado deposits in the Vourinos complex, are not explicable by this hypothesis (Zachos, 1969). From
the available evidence, one cannot say how many of the chromite deposits and dunite lenses in the Troodos harzburgite were infolded and how many were indigenous. George's (1978, p. 862) descriptions and suggested alternative explanations are ample evidence that the relations between harzburgite and obviously cumulate rocks in the Troodos are much more complex than the simple "unconformity" described in the Vourinos.

The Canyon Mountain Complex displays structural and petrologic features that have not been described in the Vourinos or Troodos Complexes, because gabbro apparently was affected by the earliest identifiable penetrative deformation. Some of the features have been illustrated and described briefly (Avé Lallemant, 1976; Thayer, 1963, 1977), but some broader implications have not been considered. By providing a prominent "stratigraphic" marker, gabbro reveals large structures that would be obscure or would not be identifiable at all within harzburgite and wehlrite only.

The features to which I wish to refer are exposed in the southeastern part of the Canyon Mountain Complex, south and west of Baldy Mountain, between the main mass of peridotite (harzburgite) and the sheeted dike unit (Thayer, 1977). There, in an area about 3 by 6.5 km, ultramafic rocks are exposed as a complex series of east- and northeast-trending lenses within gabbro. The largest individual lens appears to be about 1800 m long and 650 m wide and extends over a vertical range of 275 m. The smaller masses are only a few meters or tens of meters in size. Rocks consisting of various proportions of olivine, orthopyroxene, clinopyroxene, and plagioclase show banding or layering, which may be cut at any angle by prominent foliation and lineation (Thayer, 1963; Avé Lallemant, 1976, p. 17). In many places, isoclinal folds are preserved in gabbro, and dikes of gabbroic pegmatite range in texture from completely undeformed to gneissic (Thayer, 1963, figs. 3, 9, 10).

The lenses of peridotite are interpreted as a series of isoclinal folds with amplitudes of several hundred meters or as related fault slices in the gabbro-peridotite transition zone. Steep crossfolding is believed to have caused the lateral discontinuity of the peridotite masses. The limbs of these structures form the lithologic boundaries that are crossed by the F₁ foliation, which according to Avé Lallemant (1976, p. 17) also characterizes the harzburgite. The intense deformation in this area has disrupted and largely obscured the original "stratigraphic" sequence from harzburgite to gabbro that is well shown in the western part of the complex (Thayer, 1977, p. 95). Over a distance of 4.5 to 5 km eastward from Pine Creek, wehlritic rocks and pyroxenite are missing or scarce, and gabbro adjoins the harzburgite. The southwestern slope of Baldy Mountain is riddled with dikes of gabbro generally normal to the contact. In the ridge that extends southward from Baldy Mountain, folding and recrystallization have obscured or obliterated distinctions between infolded remnants and primary and transposed layering.

A succession of gabbroic dikes and pegmatites and ultramafic dikes in gabbro show that the gabbro, at least, was deformed tectonically be-
Folding of gabbro at high temperature in the Canyon Mountain Complex.

A. Exposure of isoclinal fold in banded gabbro in vertical face of outcrop, 20 cm scale.

B. Upper surface of same outcrop showing mineral-graded layers and stringer of undeformed leucogabbro derived from a leucocratic layer.

Before it had crystallized completely. The vertical face of the outcrop shown in Plate 1 shows a tight synform in planar-layered gabbro, but the top face shows a stringer of undeformed gabbro that apparently originated in a leucocratic layer and cut across more mafic layers. In another outcrop, dikes of olivine- and plagioclase-bearing websterite and gabbro evidently were intruded during folding of a new-foliated olivine gabbro (Thayer, 1963, fig. 8; Avé Lallemant, 1976, figs. 3e, 4c): the websterite dike 3 to 5 cm wide cuts across both the foliation ($S_1$) and the folded layers ($S_0$) of the host olivine gabbro, and yet itself has a foliation parallel to $S_1$ and is folded, albeit not as strongly as the host, about a fold axis subparallel to the fold axis of the folded $S_0$ layers. One of the gabbro dikes, 15 cm wide, follows the $S_1$ foliation and is itself foliated; the other gabbro dike, 1 cm wide, follows the $S_1$ foliation and is gently warped, but it is not foliated. None of the dikes has chilled margins. South of Baldy Mountain, undeformed dikes and irregular patches of gabbro pegmatite that contain crystals 15 cm or more in length transect
foliated peridotite (Thayer, 1963, fig. 10), in stark contrast to equally coarse gneissic gabbro pegmatite interlayered with ultramafic rocks (Thayer, 1963, fig. 3). The presence of dikes showing all textural gradations between these extremes indicates that they were formed comagmatically during the entire episode of deformation.

At the very least, the relationships described above indicate that, in some places, gabbroic components were mobile after the $S_3$-producing deformation ($F_1$ event of Avé Lallemant, 1976), either in late-stage magma or in post-crystallization, volatile-rich fluids; whereas in other places, a sufficiently high percentage of the gabbroic magma had crystallized for the gabbro to acquire typical solid-state deformation textures during $F_1$. Moreover, I suggest that these relationships are consistent with syncrystallization deformation of the eastern part of the cumulate gabbro-wehrlite sequence, since dikes that cut $S_3$ layers that were folded during $F_1$ were themselves folded during $F_2$. All the gabbro in the complex was involved in the $F_2$ folding, which produced foliation only in places. Both the $F_1$ and $F_2$ events are interpreted as preemplacement, because they preceded intrusion of rocks related to the sheeted dike unit.

NOTES ON THE BAY OF ISLANDS AND ZAMBALES COMPLEXES

High-temperature penetrative deformation probably is more common in ophiolitic gabbro than most geologists realize. Correct interpretation of petrogenetic relations between sheeted dike swarms and spatially associated gabbro is not possible without adequate knowledge of the tectonic history of the gabbro.

With regard to deformation in gabbro and rocks of the "critical zone," the Bay of Islands Complex may be much more like the Canyon Mountain Complex than the literature indicates. Cooper (1936, p. 23) was well aware of "gravity banding" processes, but he also recognized folding with development of "secondary foliation and linear structure" in gabbro before complete solidification. Smith (1958, p. 86) found that deformation of "unsolidified magma" had modified cumulate layering in gabbro, although its general relations to underlying ultramafites were maintained. Smith indicated also that relations of gabbro to ultramafites might appear closer in some places than in others.

The more recent publications imply that the gabbroic and related ultramafic rocks are dominated by cumulus textures in contrast to tektontite fabrics in harzburgite. Malpas' (1977) summary of the stratigraphy of the complex indicated structural relations between rock units very much like those in the Troodos. The basal unit, as much as 4 km thick, consists predominantly of harzburgite in which tektontite fabrics are present throughout. The harzburgite grades upward through a transition zone of several meters into about 350 m of pure dunite in which cumulate features are discernable everywhere. The upper part of the dunite is feldspathic and is interbanded with norite, troctolite, and anorthosite in the critical zone of Smith (1958). Some post-accumulation deformation is attributed to slumping of a crystal mush. The gabbros are all layered.
and sedimentary features such as graded bedding and cross bedding have been seen.

Observations during a recent visit of the Table Mountain massif revealed intensity of penetrative deformation in gabbro and "transition zone" rocks which far exceeds any that has been described there. All the rocks seen, in outcrop or in locally derived float, are strongly foliated or lineated, and some gabbro has been reduced to augen gneiss (pl. 2). Very few dikes were seen, but they include two pegmatitic gabbro dikes like those in the Canyon Mountain Complex: one is isoclinaly folded and foliated, the other undeformed; neither shows chilled margins. The foliation has been folded on both large and small scales. No cumulus textures were recognized, although all the rocks are regarded as metacumulates.

The presence of deformed and undeformed gabbro dikes shows that, as in the Canyon Mountain Complex, penetrative deformation preceded final crystallization of gabbro. The relation of this deformation to that in harzburgite obviously cannot have been determined, because it has not been recognized previously. The existence of the foliation would seem to confirm the conclusion of Williams and Malpas (1972) that the sheeted dikes and pillow lavas in Blow-Me-Down Mountain are younger than the gabbro so cannot have been intruded by it as Smith (1958)
believed. Hypersolidus folding of the intensity indicated might explain at least some of the interfingering of gabbro and peridotite that Smith (1958, p. 70, fig. 12) attributed to flowage of partly crystalline magma.

Geologic mapping of more than 1000 km² in the Zambales Ophiolite Complex, Luzon, Philippines, has revealed intricate structural relations between harzburgite, cumulate chromite, dunite, and gabbro. Layering crosses lithologic contacts (Rossman and others, 1959; Thayer, 1967, fig. 7.6) between major units of harzburgite, dunite–wehlrite, and gabbro in many places and at various angles over distances of as much as 5 km along the strike (Rossman, 1970). Some 3 to 5 km south of the Acoje mine, interlayered gabbric and ultramafic rocks strike east-west across a north-trending boundary zone between harzburgite on the west and norite on the east. The zone of prominent layering extends at least 500 m from north to south. The layers range from about a decimeter to 10 m in thickness, lack any obvious order, and merge endwise with the peridotite and norite. The layering is parallel to foliation in wehlite and pyroxenite in the border zone of the harzburgite and to prominent lineation that crosses elongate chromite deposits at angles of 45° to 60° to their long axes (Rossman, 1970, pls. 6-8). Isoclinal folding and shearing of ultramafic and feldspathic rocks together, as in the Canyon Mountain Complex, would seem to explain best many rock relations within the Zambales Complex.

Complex igneous relationships of a very different kind between gabbric and ultramafic rocks are exposed along the South Lawis River 1 to 2 km east of the Coto Mine (Thayer, 1967, fig. 7.6). There, slabs of peridotite and leucogabbro lie side by side in a matrix of mafic gabbro to form breccia that resembles slabby turbidite conglomerate. Xenoliths of banded gabbro that are recrystallized along their borders are enclosed in peridotite (Thayer, 1967, fig. 7.7). All contacts appear to be intrusive or igneous, and the only reasonable explanation of the relations requires coexistence of solid or mushy gabbro with a mobile ultramafic fraction. Detailed studies of these areas by petrologic skeptics should be very instructive.

**EFFECTS OF AMPHIBOLITE-FACIES METAMORPHISM IN THE BALTIMORE AND TINAQUILLO COMPLEXES**

Recognition of hypersolidus penetrative deformation in gabbric rocks introduces a corollary need to distinguish it from later deformation in rocks that have been regionally metamorphosed. Some amphibolites formed from basalt and gabbro that are very similar and may even appear to be identical—on more careful examination may be shown to have had quite different histories. Mimetic replacement of pyroxene in gneissic gabbro by hornblende may be much more common than is generally realized (Thayer, 1972; Elthon and Stern, 1978).

The importance of distinguishing between foliation in amphibolite formed during regional metamorphism and that in gneissic hornblende–pyroxene gabbro is well illustrated in the Baltimore Complex (Maryland-
Pennsylvania–Virginia, U.S.A.). “Throughout much of the Baltimore Complex, gabbro is altered to amphibolite that has a well developed foliation... However, relict igneous textures survive in many places” (Morgan, 1977, p. 44). He did not point out that relict metamorphic textures and structures that predated tectonic emplacement of the complex might also be preserved. The specimen in plate 3-A, from a quarry near Hollofield, Md. (Hopson, 1964, p. 141), shows axial plane foliation across a fold in coarse- and fine-grained banded metagabbro. The foliation is shown by elongate aggregates of hornblende in a matrix of white feldspar. In thin section, however, the hornblendes within the aggregates are oriented at random, and the aggregates have ragged borders (pl. 3-B). The texture clearly is mimetic after pyroxene gabbro (Williams, 1886, pl. 1-3). Foliation of this kind and prominent lineation cross the layering in gabbroic and ultramafic rocks in the quarry at angles of about 20° (Hopson, 1964, p. 141). The original gneissic foliation and lineation are interpreted as preemplacement in age.

Geologic mapping in the vicinity of Baltimore by Crowley (1976) and others (Morgan, 1977, p. 47) has shown that the Baltimore Complex most probably was emplaced as a thick thrust sheet that shed debris into the Wissahickon Formation on which it now rests. Crowley found that internal contacts in gabbro are cut off at the basal thrust. The Wissahickon and the Baltimore Complex have been regionally metamorphosed together to facies that range locally from greenschist to upper amphibolite (Morgan, 1977, p. 44). Along the contact against schistose Wissahickon Formation near the Hollofield quarry, the gabbro has been transformed to amphibole schist in which no relict features remain. The alteration of the gabbro, therefore, cannot be related to “ocean-floor metamorphism” of the kind Elthon and Stern (1978) described in the Sarmiento complex in Chile.

In the Tinaquillo Ultramafic Complex in Venezuela and probably also in the Lizard (Cornwall, England), tectonite fabric and regional amphibolite facies metamorphism contributed to misidentification of gabbro as volcanic rocks that had been recrystallized by “high-temperature” peridotite (MacKenzie, 1960; Green, 1964a,b; Thayer, 1969b). Recent investigations leave little doubt that the feldspatic rocks (pseudogabbro of MacKenzie) in the Tinaquillo originated as gabbro comagmatic with the peridotite (Bellizzia and Lopez Eyzaguirre, 1972; Lopez Eyzaguirre, 1972). As argued previously, (Thayer, 1969b, 1972; Thayer and Brown, 1961), the field relations between peridotite and the rocks in question are typical of those between gabbro and peridotite in ophiolite complexes, except for the pervasive foliation and destruction of original magmatic textures.

The metagabbro ranges in texture from fine-grained gneiss to coarse augen gneiss. Coarse-grained gabbroic gneiss south of El Tigre mine (MacKenzie, 1960, pl. 4) consists of scattered pyroxene augen that range up to 3 cm in a streaky matrix of granulated, kink-banded pyroxene and plagioclase and some brown hornblende (pl. 4). In outcrop, the gneiss
A. Foliated hornblende gabbro of the Baltimore Complex cut by folded band of coarse-grained facies. Axial-plane foliation shown by aggregates of green hornblende that replaced pyroxene and calcic plagioclase. From quarry near Hollophield, Md.

B. Photomicrograph of foliated hornblende metagabbro like that in (A) showing relict foliation preserved by distribution of randomly oriented hornblende and granular calcic plagioclase. Specimen from same quarry as the specimen in (A). Length of field 1 cm.
Augen gneiss derived from pegmatitic hypersthene gabbro, showing augen and schlieren of fresh pyroxene in matrix of granulated calcic plagioclase. From "pseudo-gabbro" mass south of El Tigre mine, Tinaquillo complex, Venezuela (MacKenzie, 1960, pl. 4).

resembles gneissic gabbro pegmatite in the Canyon Mountain Complex (Thayer, 1963, fig. 3). In hand specimen, fine-grained hornblende metagabbro shows a distinct granular texture, as well as prominent foliation and lineation. In thin section, brown hornblende is randomly oriented and undeformed. Where hornblende is subordinate, the rock is distinctly granoblastic (MacKenzie, 1960, pl. 3, fig. 1), and the hornblende forms irregular grains and rims on pyroxene. Where hornblende has completely replaced pyroxene, however, the rock has a marked poikilitic texture, with rounded feldspar or feldspar pseudomorphs enclosed in a matrix of randomly oriented hornblende grains. MacKenzie's statement (p. 306) that minor fold axes in gabbro parallel elongation of fantastically stretched enstatites in dunite shows that the gabbro and dunite were deformed together at high temperature as solid rocks. The problem of distinguishing between hypersolidus and subsolidus creep in many amphibolitized metagabbros may not be resolvable. The Tinaco complex that forms the country rock of the Tinaquillo Complex, like the Wissahickon Formation, has been metamorphosed regionally up to the amphibolite facies.

The petrologic relations between gabbro and peridotite at Tinaquillo raise some interesting questions. The peridotite is the "high-temperature"
or lherzolite type (Jackson and Thayer, 1973), in which high-alumina diopside shows reequilibration by exsolution of Al₂O₃ to form low-alumina diopside and plagioclase during emplacement (Green, 1963). Gradations from dunite (or harzburgite) to gabbro suggest a normal ophiolite succession from dunite through pyroxenite to gabbro, in which pyroxenite has been amphibolitized. If this is true, pyroxene augen in the gabbro should be zoned like those in the peridotite. Any feldspar formed by reequilibration of diopside would be “lost” in gabbro. The proportion of gabbro in the complex has been underestimated, because any gabbro between peridotite and true country rock was mapped as part of a hypothetical thermal metamorphic aureole around the peridotite. Banded gabbro in the western end of the map, near Las Tetas along the road to Vallecito, in fact, is included in the country rock.

All things considered, I would like to suggest that the gabbroic rocks in the Tinaquillo Complex and similar rocks in the Lizard (Flett, 1946; Green, 1964b) originally may have had the same relation to peridotite as the lower gabbros in Canyon Mountain. They differ, however, by having been formed in a moderately high-pressure deep-seated environment. The Giles Complex in Central Australia, if transferred to an oceanic environment, might serve as a tentative model. In the Giles Complex, stratiform mafic and ultramafic masses that were intruded at various levels into a granulite-facies terrane show evidence of crystallization at corresponding pressures (Nesbitt and others, 1969, p. 547):

The evidence for the high-pressure development of some intrusions of the central zone can be summarized as follows:
1) sub-solidus reaction relationships between olivine + plagioclase → orthopyroxene + clinopyroxene + spinel, and orthopyroxene + plagioclase → garnet.
2) spinel and rutile exsolution in pyroxenes
3) high R₂O₃ contents in the pyroxenes
4) unusually high K₂O (Mg/Fe) values for coexisting pyroxenes (requiring high liquidus temperatures and hence high pressures)
5) dominance of orthopyroxene rather than olivine in the early crystallization sequence
6) when observed, chill-zones are very thin (e.g. South Mount Davies is 4,200 metres thick and has a chilled zone of a few centimetres) ...

High-temperature deformation of the sheets, particularly in the central zone, resulted in the formation of localized gabbro-gneiss zones approximately parallel to the main igneous layering. In many respects this resembles the flow-layering, described by Thayer (1963) as being characteristic of Alpine ultramafic bodies. This feature, together with rotation of the intrusions into a near vertical position by later deformations, illustrates the possible relationship between flat-lying stratiform intrusions and those of the Alpine ultramafic association.

Identification of the “pseudogabbro” in the Tinaquillo Complex and Traboe Schist in the Lizard Complex as gabbro that was comagmatic with peridotite would eliminate the strongest argument for contact metamorphism by “high temperature” peridotite. Crystallization of gabbro at pressures postulated by Green (1970) for peridotite in the Lizard (10-14 kb) would be possible if it were free of olivine. In both complexes, most olivine formed by reequilibration of pyroxene in gabbro during emplacement would have been replaced by pargasite during metamorphism. Is
it possible that the gabbro in the Tinaquillo complex crystallized in a magma chamber within the upper mantle, at a depth of 30 to 40 km under a roof of peridotite? A microprobe study of pyroxene augen in the gabbro should shed some light on the question.

CONCLUSIONS

The gabbroic rocks and related ultramafic cumulates in ophiolite complexes deserve much closer study in many complexes than they have had so far. The few examples cited emphasize the pertinence of George's comment about the individuality of ophiolite complexes. The igneous "unconformity" between harzburgite and dunite may indicate a magmatic hiatus related to local deformation during development of the Vourinos Complex that did not occur in either the Troodos or Canyon Mountain Complexes. Even the most intense tectonic fabrics can no longer be regarded as unique to harzburgite, and textures in podiform chromite deposits show that cumulate features are not restricted to gabbro, wehlrite, and dunite in harzburgite-type complexes (Jackson and Thayer, 1972). More critical examination of harzburgite-dunite--wehlrite--gabbro relations in ophiolites like the Canyon Mountain, Zambales, and Bay of Islands Complexes would seem to be needed.

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