

EXSOLUTION LAMELLAE IN THE PYROXENES OF THE THESSALONIKI GABBROS

by

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Abstract: *Exsolution lamellae in the pyroxenes of the Thessaloniki gabbros have been studied optically and analysed by electron micro-probe.*

Microscopic observation indicates that the lamellae included in orthopyroxene are very fine (commonly 5μ thick) and usually oriented so that on the (010) plane they are at an angle of about 6° upto 12° on either side to the c-crystallographic axis of the host pyroxene. The lamellae included in clinopyroxene are broader and oriented with their (100) crystal plane parallel to the (100) plane of the host pyroxene.

The microprobe chemical analyses of the unmixed phases show that clinopyroxene contains hypersthene lamellae with a composition $Ca_{1.4}Mg_{7.8-9}Fe_{10.7}$ and the orthopyroxene contains diopsidic augite lamellae $Ca_{39.7}Mg_{50.5}Fe_{9.8}$; these results are in agreement with the optical identification of the phases.

The coexistence of both clino- and orthopyroxene with the mentioned unmixed phases as exsolution lamellae indicates that the cooling of the magma was slow and its temperature at the time of intrusion was approximately $1100^\circ C$.

INTRODUCTION

Since the early work of Hess (1941) it has been accepted that the most important pyroxenes in igneous rocks belong to the quadrilateral composition area of the $CaMgSi_2O_6 - CaFeSi_2O_6 - MgSiO_3 - FeSiO_3$ system. Pyroxenes of this system are divided into the Ca-poor and Ca-rich groups of pyroxenes. In many plutonic igneous rocks both of the cited above pyroxenes may show various types of exsolution of one from the other, developed at subsolidus temperatures.

The exsolution phenomena in pyroxenes in different magmatic associations received much attention and have been the subject of many investigations, because they provide a great potential for storing in-

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formation on the phase relations and the genetic relations of the rocks containing them.

Hess & Phillips (1938), *Hess* (1941), *Edwards* (1942), *Walker & Poldervaart* (1949) and *Poldervaart & Hess* (1951) studied the exsolution phenomena in pyroxenes from igneous rocks by means of the optical method and interpreted them on the basis of the phase relations of the CaSiO_3 - MgSiO_3 - FeSiO_3 system.

Bown & Gay (1959, 1960) and *Morimoto & Tokonami* (1969) examined the exsolution phenomena in pyroxenes by the X-ray techniques. Most of their results confirmed those obtained by the optical method. Since then, the phase relation between the Ca-rich and Ca-poor pyroxenes and their lamellation have been widely studied by means of electron microprobe analyser (*Boyd & Brown* 1969, *Binns et al* 1973, *Cawthorn and Collerson*, 1974) and recently have been published several studies based on (TEM) Transmission Electron Microscopy (*Chambers & Lorimer*, 1973; *Boland*, 1972, 1974; *Buseck & Iijima*, 1974 e.t.c.).

The present investigation was undertaken in order to obtain more detailed information on the exsolution lamellae occurring in both clino- and ortho-pyroxen of the Thessaloniki gabbros in the hope of throwing some light on their genesis, identification and orientation and in finding their relation to the cooling history of the Thessaloniki intrusion.

It must be emphasized that in a work of this type on the pyroxenes, the combination of microprobe and optical studies is more valuable than either alone.

GENERAL DESCRIPTION OF THE PYROXENES BEARING ROCKS.

The pyroxenes with the exsolution textures described in this paper come from different rock types of the Thessaloniki gabbros.

A general description of the above rocks is given by *Sapountzis* (1969), but more recently a detailed account of their mineralogy, petrology and geochemistry has been presented by *Sapountzis* (1973).

The latter indicated that these rocks are medium-grained gabbros which extended over an area of 30 km² and are essentially composed of gabbronorite, olivine gabbronorite and normal gabbro: Chemical data for major and trace elements C.I.P.W. norms, modes and many other indexes and relationships of the cited above petrographic types and their constituent minerals are also given in that paper; it is sufficient to state here that they consist essentially of four cumulus mineral phases, i.e plagioclase (An_{90} to An_{95}), olivine (Fo_{74} to Fo_{82}), cli-

nopyroxene as a persist mafic phase throughout most of the petrographic types and orthopyroxene which commonly coexists with clinopyroxene.

DESCRIPTION AND OPTICAL DATA.

Clino- and orthopyroxenes are the most abundant minerals in the Thessaloniki gabbros and they have a tholeiitic character (*Sapountzis* 1973).

Clinopyroxene is an important constituent in all rock types but especially in normal gabbro it may reach up to 47%. In hand specimens and separated grains the examined clinopyroxenes are brown-green to black-green in colour whereas in thin sections the grains are colourless. They belong to the diopside-augite field with a narrow composition ranging from $\text{Ca}_{47}\text{Mg}_{40}\text{Fe}_7$ to $\text{Ca}_{46}\text{Mg}_{42}\text{Fe}_{12}$ and contain low amounts of Al, Fe^{3+} and Ti, as it is shown in Table 1. The β -refractive indices of the analysed clinopyroxenes ranging from 1.692 to 1.700 increase with their iron content.

Orthopyroxene is present in only small amounts in the normal gabbro but it becomes abundant locally, especially in gabbronorite where it comes up to 25%.

In hand specimens and mineral crushes orthopyroxenes are brownish to bronze in colour, whereas in thin sections they show faint pleochroism from pale pink to pale green but sometimes are colourless. They belong to the bronzite-hypersthene group with a composition ranging from $\text{Ca}_3\text{Mg}_{70}\text{Fe}_{19}$ to $\text{Ca}_2\text{Mg}_{66}\text{Fe}_{33}$. Their analyses and cation contents are also presented in Table 1.

The cited above clino- and orthopyroxenes occur commonly as closely intergrown independent subhedral crystals and both contain numerous fine, closely spaced lamellae, that are visible best under crossed nicols and a relatively high magnification. In a few large clinopyroxene crystals the lamellae can be distinguished from the host in parallel nicols by their pale pleochroic colour and sometimes by the cracks which are perpendicular to the lamellae elongation (Fig. 1B).

The lamellae vary in thickness and generally they are more thick within the clinopyroxene than the orthopyroxene.

Lamellae and certain patches of one pyroxene within another, once thought to be inclusions or replacement textures. Since the work of *Hess & Phillips* (1938), *Hess* (1944), and *Poldervaard* and *Hess* (1951) these textures have been attributed to exsolution phenomena in the

solid state. However, there are some disagreement by *Guimaraes & Brajnikov (1948)*, *Guimaraes (1952)*.

Exsolution textures in Ca-rich may be lamellae of orthopyroxene or pigeonite and in Ca-poor pyroxene lamellae of clinopyroxene.

TABLE 1

Electron microprobe analyses of pyroxene from the Thessaloniki gabbros.

	1 (P ₂)	2 (344)	3 (301)	4 (P ₂)	5 (344)	6 (301)
	Clinopyroxenes			Orthopyroxenes		
Oxide weight percentage						
SiO ₂	52.71	51.97	52.69	55.34	54.93	55.89
TiO ₂	0.48	0.42	0.14	0.23	0.23	0.06
Al ₂ O ₃	2.22	2.49	1.97	1.17	1.42	1.58
Fe ₂ O ₃	—	—	—	—	—	—
FeO	4.90	5.22	4.62	12.28	13.12	11.50
MnO	—	0.24	0.18	0.47	0.51	0.28
MgO	17.56	16.68	16.52	30.22	29.80	30.54
CaO	23.49	22.57	21.67	0.75	0.72	1.01
Na ₂ O	0.12	—	0.13	—	—	—
Cr ₂ O ₃	—	0.23	0.21	0.11	0.08	0.14
Total	101.18	99.82	98.13	100.87	100.81	101.00
Atomic proportions on the basis of 6 oxygens						
Si	1.914	1.914	1.960	1.950	1.945	1.957
Al	0.086	0.086	0.040	0.050	0.055	0.043
Al	0.009	0.022	0.046	0.011	0.004	0.022
Ti	0.005	0.012	0.004	0.006	0.006	0.002
Cr	—	0.007	0.006	0.003	0.002	0.004
Fe ³⁺	—	—	—	—	—	—
Fe ²⁺	0.149	0.161	0.144	0.362	0.389	0.337
Mn	—	0.007	0.006	0.014	0.015	0.008
Mg	0.901	0.916	0.916	1.587	1.573	1.594
Ca	0.915	0.891	0.864	0.028	0.027	0.038
Na	0.008	—	0.009	—	—	—
Total	3.987	4.016	3.995	4.011	4.014	4.005
Z	2.000	2.000	2.000	2.000	2.000	2.000
(WX ₂ Y)	1.987	2.016	1.995	2.011	2.014	2.005
Ca	47.17	45.11	44.78	1.42	1.36	1.92
Mg	45.85	46.37	47.47	79.70	78.49	80.62
Fe	6.98	8.52	7.75	18.88	20.15	17.46

Owing to their thinness it is not always possible to identify them optically, however, some workers suggested that the distinction bet-

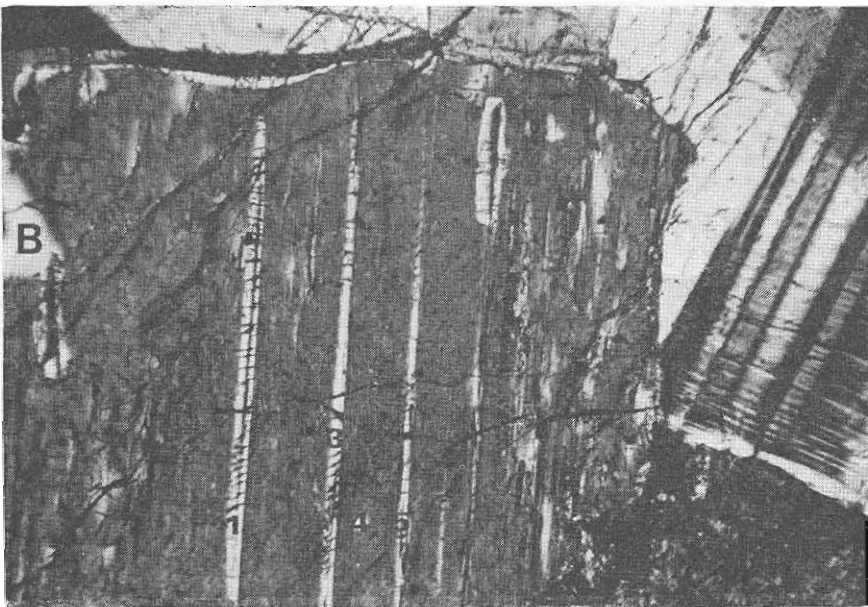
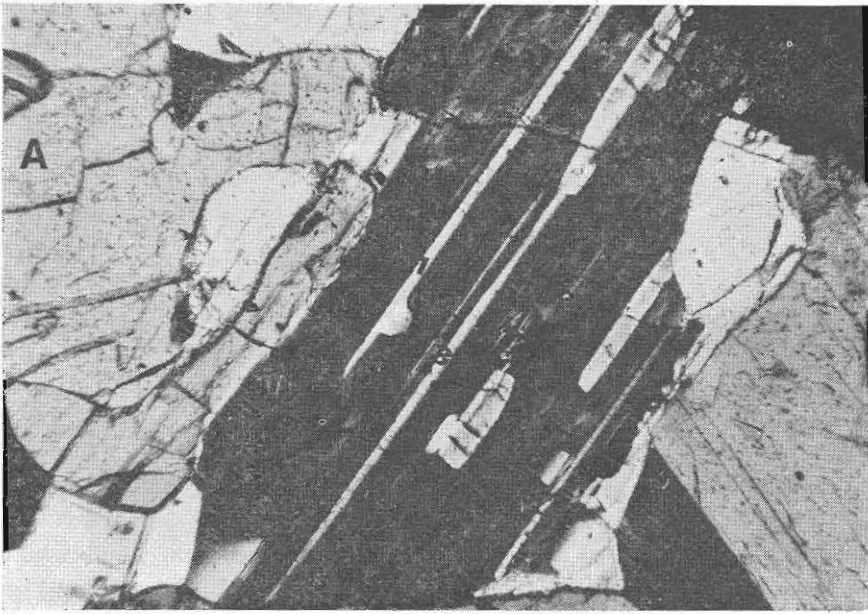


Fig. 1. A) *Hypersthene lamellae (light) in augite (dark)*. B) *Hypersthene lamellae in augite; note the cracks perpendicular to the lamellae elongation*. The numbers on both figures are referred to the analysed spots. Crossed nicols X 120.

ween pigeonite and orthopyroxene lamellae would be possible on the basis of their orientation; orthopyroxene lamellae are exsolved parallel to (100) plane and pigeonite lamellae parallel to (001) plane of the augite host (*Poldervaart & Hess, 1951; Brown, 1957; Deer et al., 1963*).

Microscopic examination of the Thessaloniki clinopyroxenes shows that the enclosed exsolution lamellae are usually beautifully developed and consist of relatively evenly spaced broad sheets up to 10 μ thick (Fig. 1A+B). They show, as the hypersthene in the matrix, pale-pink to pale-green pleochroic colour, have straight extinction, and higher refractive indices and lower birefringence than the host clinopyroxenes. They are oriented with their (100) lattice plane parallel to the (100) lattice plane of the host augite. Thus, according to the cited above optical characters and to their orientation we believe that the occurring in the form of lamellae exsolved phase is orthopyroxene.

The Thessaloniki orthopyroxene, coexisting with clinopyroxene contain very fine (up to 5 μ thick) exsolution lamellae or blebs which are always visible under crossed nicols especially in (010) sections (Fig. 2A+B).

Although they are too thin to allow accurate measurement, in suitably oriented sections-parallel to (010) plane-and when the host crystal is in extinction they are best observed because their extinction angle is clearly different from that of the host. The lamellae are colourless, not pleochroic, and are approximately parallel to (100) plane; they exist with two optic orientations extinguishing symmetrically at angles between 6° and 12° on either side of the (100) symmetry plane of the host as determined from a (010) section.

These optical characters suggest that the exsolution lamellae observed in the orthopyroxenes are of a clinopyroxene phase of the augite type.

ANALYTICAL METHOD AND CHEMISTRY.

The analyses of the Thessaloniki pyroxene lamellae presented here were carried out in the Department of Geology, Manchester University, England, using a Cambridge Gioscan II model electron microprobe. Operating conditions were; accelerating voltage of 15 KV; beam spot size less than 2 μ and specimen current of 5×10^{-8} amps. Standard used were pure metal for Fe, Cr and Mn. Other standards were as follows, Si, Ca, Mg-diopside; Al-anorthite and Ti-rutile. Corrections for

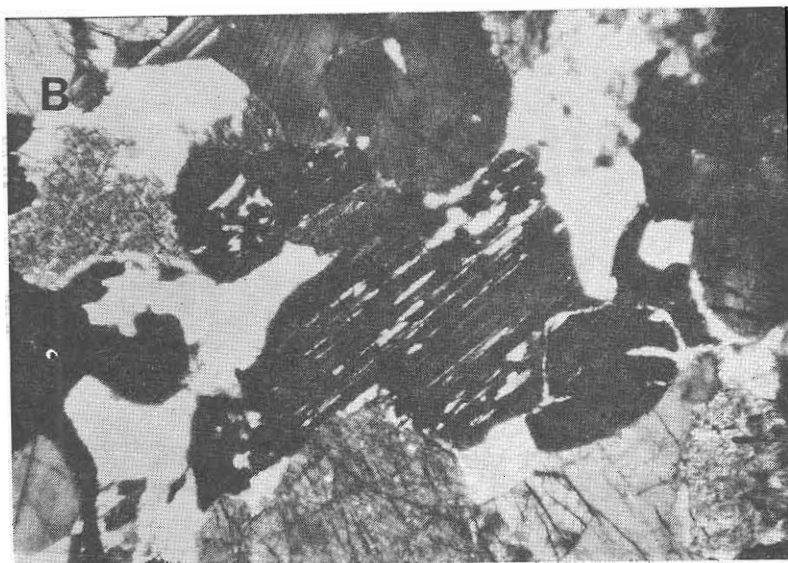
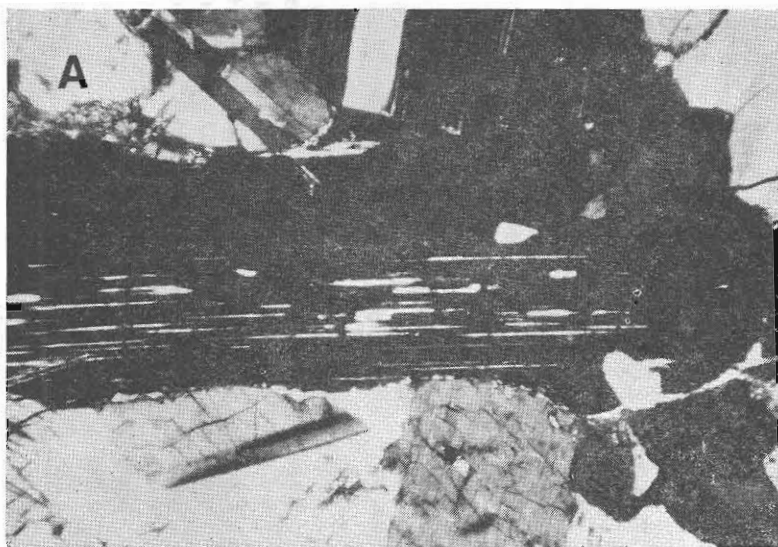


Fig. 2. A) A typical orthopyroxene of the Thessaloniki gabbros; note the fine exsolution lamellae of the Ca - rich pyroxene phase. B) Bronzite - Hypersthene with fine scale exsolution lamellae and blebs of clinopyroxene parallel to (100) of the host. Crossed nicols X 50.

TABLE 2

Electron microprobe analyses of lamellae included in clinopyroxenes.

Oxide weight percentage	P ₂						3
	1	2	3	4	5	2	
SiO ₂	53.82	52.40	54.24	52.65	53.90	51.96	54.18
Al ₂ O ₃	1.36	2.11	1.42	2.18	1.67	2.39	1.51
MgO	30.44	16.77	29.92	17.12	31.04	16.71	30.24
MnO	0.46	0.23	0.52	0.24	0.48	0.22	0.51
CaO	0.83	22.81	0.74	22.93	0.71	22.67	0.76
FeO*	13.04	4.81	12.68	4.68	12.76	5.36	13.21
TiO ₂	0.19	0.42	0.22	0.45	0.20	0.44	0.20
Cr ₂ O ₃	0.11	0.14	0.11	0.12	0.09	0.16	0.10
Total	100.25	99.69	99.85	100.37	100.85	99.91	100.71
Atomic proportions on the basis of 6 oxygens							
Si	1.921	1.929	1.938	1.924	1.910	1.914	1.925
Al	0.057	0.092	0.060	0.094	0.070	0.059	0.063
Mg	1.620	0.920	1.593	0.932	1.639	1.574	1.601
Mn	0.014	0.007	0.016	0.007	0.014	0.016	0.015
Ca	0.032	0.900	0.028	0.898	0.027	0.027	0.029
Fe ²⁺	0.389	0.148	0.379	0.143	0.378	0.387	0.393
Ti	0.005	0.012	0.006	0.012	0.005	0.006	0.005
Cr	0.003	0.004	0.003	0.003	0.003	0.002	0.003
W _o	1.55	45.56	1.41	45.33	1.31	4.35	45.10
En	78.83	46.58	79.02	47.07	79.62	78.54	78.57
Fs	19.63	7.86	19.58	7.60	19.07	20.11	20.01

l = lamellae

h = host mineral

* Total iron as FeO

TABLE 3

Electron microprobe analyses of lamellae included in orthopyroxenes.

Oxide weight percentage	P ₂			344**			301**				
	1	2	3	1	2	3	1	2	3	4	5
SiO ₄	52.27	53.82	52.42	54.34	55.43	54.98	52.71	51.97	52.55	52.10	51.79
Al ₂ O ₃	1.98	1.53	2.06	1.93	1.76	1.53	2.09	1.43	1.59	2.01	2.25
MgO	18.42	30.72	18.14	17.82	17.73	16.94	17.59	32.08	17.62	31.95	17.64
MnO	0.27	0.43	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	20.14	0.68	19.85	19.43	19.12	20.41	22.51	1.40	23.33	0.72	23.22
FeO*	6.27	12.87	5.88	6.48	5.96	6.14	5.10	13.12	4.91	13.22	5.10
TiO ₂	0.41	0.21	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr ₂ O ₃	0.10	0.08	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.85	100.34	99.13	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Atomic proportions on the basis of 6 oxygens

Si	1.920	1.917	1.933	1.977	2.005	2.000	1.931	1.869	1.931	1.869	1.906
Al	0.086	0.064	0.090	0.083	0.075	0.066	0.090	0.061	0.069	0.085	0.098
Mg	1.008	1.631	0.997	0.966	0.956	0.918	0.960	1.720	0.967	1.708	0.967
Mn	0.008	0.013	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ca	0.793	0.026	0.784	0.757	0.741	0.796	0.884	0.054	0.919	0.028	0.916
Fe ²⁺	0.193	0.383	0.181	0.197	0.180	0.187	0.156	0.395	0.151	0.397	0.157
Ti	0.011	0.006	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cr	0.003	0.002	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
W ₀	39.60	4.26	39.81	39.44	39.48	41.86	44.18	2.49	45.16	1.30	44.88
En	50.36	79.43	50.60	50.30	50.91	48.31	48.01	79.31	47.43	80.10	47.42
Fs	10.04	19.31	9.59	10.27	9.61	9.83	7.81	18.20	7.42	18.60	7.69

l = lamellae

h = host mineral

* Total iron as FeO. ** Partial analyses where values of SiO₂ are calculated to a 100.

absorption, atomic number effects, counter dead time and instruments drift were made.

Individual grains with Ca-rich or Ca-poor lamellae which are easily detectable optically on polished thin sections and their host pyroxenes from each of the (P₂), (344) and (301) samples were analysed in this manner. Complete analyses for 11 spots and partial analyses for 8 spots, as well as their cation contents are presented in Tables 2 and 3. The analysed spots on the lamellae and the host pyroxene are shown in Fig. 1 (A+B).

All the analysed lamellae enclosed in clinopyroxenes are rich in magnesium and iron, and poor in calcium (less than 0.83 wt % CaO). The SiO₂ is relatively high, compared with that contained in clinopyroxene, and fairly constant, whereas no significant differences in the minor constituents (Al₂O₃, MnO, TiO₂, Cr₂O₃) has been noticed (Table 2). The lamellae contain slightly less aluminium than the host clinopyroxene; the manganese content is low, tending to increase with the amount of SiO₂ in host mineral and coexisting lamellae, whereas titanium exhibits a reverse trend. Chromium is invariable in both minerals. The same relationships between the minor constituents in coexisting separate orthopyroxene-clinopyroxene pairs have been found by *Sapountzis* (1973).

Although quantitative analyses of all the lamellae enclosed in orthopyroxene have not been possible due to their small size, analyses of some thicker lamellae and blebs give valuable information about their chemical composition (Table 3).

The high amount of calcium and the relatively low magnesium and iron contents make them members of clinopyroxene (Ca-rich series).

The variation in the principal cations Ca, Mg, Fe, is best seen by reference to Table 3. The lamellae always contain more aluminium and titanium and less manganese than does the Ca-poor host. This relations has also been found in co-existing separate clino- and orthopyroxene pairs (*Sapountzis*, 1973). These data suggest that the lamellae in hypersthene are clinopyroxene of the diopsidic-augite field.

Generally the composition of the orthopyroxene lamellae enclosed in clinopyroxene is almost identical to that of separate hypersthene host and the composition of the clinopyroxene lamellae in hypersthene is very close to that of the separate clinopyroxene host. This relationship shows that subsolidus equilibrium was maintained over a substantial period during cooling.

DISCUSSION.

The formation of exsolution lamellae in pyroxenes is a sub-solidus phenomenon related to the PT conditions and composition of the magma.

The lamellation has been considered by *Hess and Phillips* (1938) as due to an inversion of pigeonite to orthopyroxene, with the segregation of diopside in the form of an intergrowth, orthopyroxene being able to hold CaSiO_3 in solution to the extent of about 9 per cent, but unmixed on further cooling.

Edwards (1942) observed similar intergrowths of diopside and hypersthene and considered it as due to exsolution of clinopyroxene attending an inversion of pigeonite to hypersthene.

The lamellation has been also attributed by *Hess* (1941), *Walker and Poldervaart* (1949), and *Poldervaart and Hess* (1951) to exsolution in the solid state. However, the origin of lamellar intergrowths in orthopyroxenes, pigeonites and monoclinic pyroxenes has been considered by *Guimaraes and Brajnikov* (1948) and *Guimaraes* (1952) as a result of alteration which was called by them «Enstentization».

Dunham et al. (1972) reported that simple diffusion theory can explain the magnitude of exsolution lamellae observed in natural rocks from the earth and the moon. The dominant diffusion process must have been the movement of calcium. After the experimental work on the solvus within the system MgSiO_3 - $\text{CaMgSi}_2\text{O}_6$ by *Boyd and Scheirer* (1964) it is assumed that no diffusion takes place below 800°C. (*Dunham et al* 1972).

The Thessaloniki pyroxenes have been formed from a cooled body of magma and show, as a result, evidence of having exsolved lamellae of Ca-rich and Ca-poor pyroxenes at subsolidus temperatures. Textural relationships in the Thessaloniki gabbros show that the clinopyroxenes from which hypersthene lamellae have been exsolved, originally crystallized in equilibrium with orthopyroxene rather than pigeonite. Hypersthene evidently separated from Ca-rich clinopyroxene below the temperature where orthopyroxene-bronzite, hypersthene- is the stable calcium poor pyroxene phase. Similar situations in igneous rocks pyroxenes, from the more common usually tholeiitic magma types, were described by *Hess* (1949), *Brown* (1957), *Bown and Gay* (1960), *Best* (1963) *Brown and Vincent* (1963) e.t.c. In such intrusive magmas a Ca-rich clinopyroxene and a Ca-poor phase, both exhibiting exsolution lamellae crystallize together in the early and middle stages of differentiation. However, the difference in the Thessaloniki pyroxenes is that

whereas in most cases the accompanying independently crystallized Ca-poor pyroxene is pigeonite-which may subsequently invert to orthopyroxene- the coexisting pyroxene is an orthopyroxene with no evidence that it was at any time a pigeonitic pyroxene. The same relationship has been observed in Guadalupe igneous complex by *Best*, and *Mercy* (1967).

The intergrowth of diopsidic lamellae in hypersthene found in co-existence with Ca-rich pyroxene in the Thessaloniki gabbros gives a valuable geologic thermometer. The inversion temperatures of pyroxenes of this composition (En_{75}) has been determined experimentally by *Hess* (1941) as been about 1100° C. Furthermore, the diffusion theory-as has been reported by *Dunham* et al. (1972)-when applied to the relatively thick lamellae observed in the Thessaloniki pyroxenes, implies that these lamellae could be formed only if the diffusion of Ca had taken place at a temperature of approximately 1000° C.

Therefore, the coexistence of Ca-rich and Ca-poor pyroxenes in the Thessaloniki gabbro both containing subsolidus exsolution textures, indicate that they crystallized in the early stage of differentiation. The chemistry and thickness of their lamellae suggest that the magma has been cooled slowly and had a temperature of about 1100° C at the time of intrusion.

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ΠΕΡΙΛΗΨΙΣ

ΠΛΑΚΙΔΙΑ ΔΙΑΜΕΙΞΕΩΣ ΤΩΝ ΠΥΡΟΞΕΝΩΝ ΕΚ ΤΩΝ ΓΑΒΒΡΩΝ ΤΗΣ ΘΕΣΣΑΛΟΝΙΚΗΣ

ὑπό

ΗΛΙΑ Σ. ΣΑΠΗΟΥΝΤΖΗ* καὶ ΧΡΗΣΤΟΥ ΚΑΤΑΓΛ**

Λεπτὰ πλακίδια (lamellae) ἐκ διαμείξεως ἐντὸς τῶν πυροξένων ἐκ τῶν γάββρων τῆς Θεσ/νίκης, μελετῶνται ὀπτικῶς καὶ χημικῶς διὰ τοῦ ἠλεκτρονικοῦ μικροαναλυτοῦ.

Οἱ μικροσκοπικὲς παρατηρήσεις δεικνύουν ὅτι τὰ ἐγκεκλεισμένα, ἐντὸς τῶν ὀρθοπυροξένων πλακίδια, εἶναι πολὺ λεπτὰ (συνήθως πάχους 5 μ.) καὶ προσανατολισμένα κατὰ τοιοῦτον τρόπον ὥστε ἐπὶ ἐπιπέδου (010) νὰ σχηματίζοντα ἄνω γωνίαν περίπου 6° ἕως 12° μὲ τὸν κρυσταλλογραφικὸν ἄξονα -c τοῦ ξενίζοντος πυροξένου. Τὰ ἐντὸς τῶν κλινοπυροξένων ἐγκεκλεισμένα πλακίδια ἔχουν σχετικῶς μεγαλύτερον πάχος καὶ τὸ (100) ἐπίπεδον αὐτῶν εἶναι παράλληλον πρὸς τὸ (100) ἐπίπεδον τοῦ ξενίζοντος πυροξένου.

Οἱ ἀναλύσεις διὰ τοῦ ἠλεκτρονικοῦ μικροαναλυτοῦ τῶν διαμειχθέντων φάσεων δεικνύουν ὅτι οἱ κλινοπυροξένοι περιέχουν ὑπερσθενικά πλακίδια συστάσεως $Ca_{1.4}Mg_{7.8}Fe_{1.7}$ καὶ οἱ ὀρθοπυροξένοι πλακίδια διοσιδικοῦ αὐγίτου συστάσεως $Ca_{3.9}Mg_{5.5}Fe_{.8}$. Τὰ ἀποτελέσματα αὐτὰ εὐρίσκονται ἐν συμφωνίᾳ μὲ τὸν προσδιορισμὸν τῶν πλακιδίων τούτων διὰ τῆς ὀπτικῆς μεθόδου.

Ἡ συνύπαρξις ἀμφοτέρων κλινο-καὶ ὀρθοπυροξένων μὲ τὰς προαναφερθείσας ὑπὸ μορφὴν λεπτῶν πλακιδίων φάσεις διαμείξεως, δεικνύουν ὅτι τὸ μᾶγμα ἐκ τοῦ ὁποίου προέκυψαν ἐψύχθη βραδέως καὶ ὅτι τοῦτο εὐρίσκετο κατὰ τὸν χρόνον τῆς διεισδύσεως εἰς θερμοκρασίαν περίπου 1100° C.

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