Sci. Annals, Fac. Phys. & Mathem., Univ. Thessaloniki, **18**, 57 (1978)

A NEW OCCURRENCE OF GRANODIORITE IN THE NORTH PELAGONIAN ZONE

by

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(Received 5.6.78)

Abstract: *A small lenticular granodiorite in the North Pelagonian zone is examined for first time. X-rays data and optical values of the mineral constituents are presented. Two rocks chemical analyses together with the calculated C.I.P.W. norms, Rittmann-Norms and Niggli values are given. The geological data and the tectonies of the area which suggest a synkinimatic mode of emplaeement of the granodiorite, arc given and discussed. Some petrological evidences combined with field observations suggest a metasomatic (?) origin. The relation of thc granodiorite with the metamorphism and folding of the pelagonian crystalline rocks is discussed in order to determine its probable age.*

A. GEOLOGY AND TECTONICS OF THE AREA

The Ayios Athanasios granodiorite lies on the mountain Voras near the Ayios Athanasios village (Fig. 1) province of Pella (Macedonia).

The area is a part of the North Pelagonian zone which, according to Brunn (1956), Mercier (1968) and Mountrakis & Soulios (1977), consists from the upper horizons to the lower ones, of the following formations:

a) Flysch of Upper Maestrichtian - Final Cretaceous age.
b) Upper Cretaceous limestones (Senonian - Maestrichtian).
c) Overthrust shale-chert-sandstone formation with ophiolites (age Upper Jurassic).
d) Carbonate series (marbles, crystalline limestones, dolomites) of Triassic-Jurassic age.
e) Crystalline basement (gneiss and mica schists).

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Metamorphism of the crystalline basement took place, after Brunn (1956), in the Palaeozoic, but according to Mercier (1968) both the basement and the Triassic-Jurassic carbonate series were subjected to the same metamorphism during the Upper Jurassic - Lower Cretaceous orogenic period.

According to more recent investigations (Mercier et al. 1975, Vergely 1976) during Upper Jurassic - Lower Cretaceous, two foldings took place: A 1st folding in the Upper Jurassic (pre-Tithonian) with direction of folds axis 155° which was symmetamorphic for all the pre-Upper-jurassic formations (basement and carbonate series) and a 2nd one in the Lower Cretaceous (pre-Aptian) with direction of folds axis 0°-30°.

The Tertiary deformations, which followed the deposition of the Upper Cretaceous transgressive formations, accomplished the structure of the Pelagonian zone and the formation of the major anticline of Kaimaktsalan (West Voras). The area where the granodiorite occurs (region of the Ayios Athanasios village) is a part of the SW limb of the Kaimaktsalan major anticline.

Among the previously mentioned Pelagonian formations the following are present in the Ayios Athanasios area:

a) The metamorphic basement with mica schists (biotite, muscovite, quartz, feldspars, chlorite) and

b) The overlying crystalline limestones of Triassic-Jurassic age.

The strike of both the formations is WNW - ESE (100°) and the dip 35°-50° SSW. The contact between the metamorphic basement and the Triassic-Jurassic limestones lies at the Kouforema valley, about 1200 m north of the Ayios Athanasios village.

We mention that after Brunn (1956) there is a marked unconformity between the metamorphic basement and the Triassic-Jurassic carbonate series at the Pelagonian zone. According to the same author there are also, in some places of the zone, conglomerates and phyllites of Upper Paleozoic age between the two horizons. This unconformity, however, has not been observed in the NE Pelagonian zone (region of Mt. Voras). On the contrary there is a normal transition from the basement to the limestones (Mercier, 1968).

In the area of Ayios Athanasios village have only been observed the two-mica schists of the metamorphic basement in contact with the Triassic-Jurassic limestones, but no conglomerates and phyllites between the two horizons. However, near the contact there is a fault several kilometers long with direction NW-SE (120°). The fault has caused an obvious displacement of the Triassic-Jurassic limestones in the SW part of the above mentioned major anticline and probably a displacement and disappearence of an Upper Palaeozoic horizon.

Besides the metamorphic rocks of the basement and the crystalline limestones, a large area between the village of Ayios Athanasios and the torrent Kouforema is occupied by younger calcareous breccias and conglomerates which were ancient talus formed from the erosion of Triassic-Jurassic limestones. Their thickness may be in excess of 50 m and they cover the limestones, interrupting them in the valley of Ayios Athanasios.

The strong compactness of the breccias-conglomerates shows that their age must be pre-alluvium, probably Plio-Pleistocene.

B. OCCURRENCE AND MACROSCOPICAL FEATURES OF THE GRANODIORITE

The Ayios Athanasios granodiorite is situated on the SW side of the Kouforema valley, near the basement-limestones contact and the previously mentioned fault (Fig. 1).

It forms an elongated mass approximately parallel to the fault and the country rocks direction and occupies an area about 250 X 700 m.

The contact of the granodiorite with the country rocks at its north and northeast margins is not visible because it has been covered by the alluvium deposits of Kouforema. At the western boundary, however, there is a well exposed marginal relation of the granodiorite which is overlain by a thin mica schist bed (thickness about 20-50 m). The contact surface dips to the SSW at about 50° beneath the Triassic-Jurassic limestones (Fig. 2). Therefore granodiorite lies inside the metamorphic basement and it has not a visible contact with the limestoues.

Contact or at least relics of a contact metamorphism between the granodiorite and the country rocks have not been observed.

Finaly at the southern margin of the granodiorite the Plio-Pleistocene breccias-conglomerates overlie the granodiorite body, covering part of it.

Structuraly the Ayios Athanasios granodiorite form a uniform pluton. Mineralogically, however, we distinguish two types, namely biotite and hornblende biotite granodiorite. The last one is subordinate. These two types do not show great differences to justify separate discriptions. They are treated therefore together to avoid unnecessary duplication.

Generally in a fresh hand specimen the granodiorite varies from

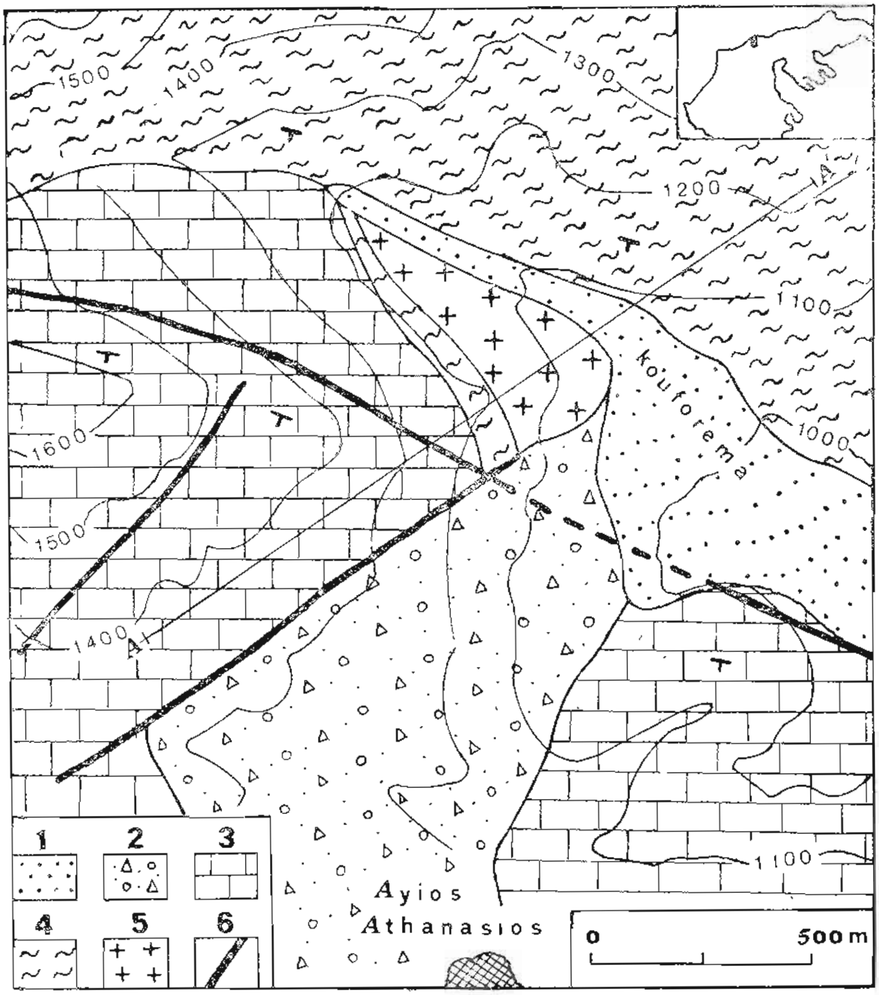

Fig. 1.
Geological map of the Ayios Athanasios area: 1: Alluvium, 2: Plio-Pleistocene breccias-conglomerates, 3: Triassic-Jurassic marbles and crystalline limestones, 4: Palaeozoic crystalline basements, 5: Granodiorite, 6: faults.

light to dark grey depending on the amount of the biotite constituent. Feldspars that constitute the bulk of the granodiorite are subhedral to anhedral and sometimes form larger, than the other constituents, grains. K-feldspars phenocrysts are not infrequently observed. Nests

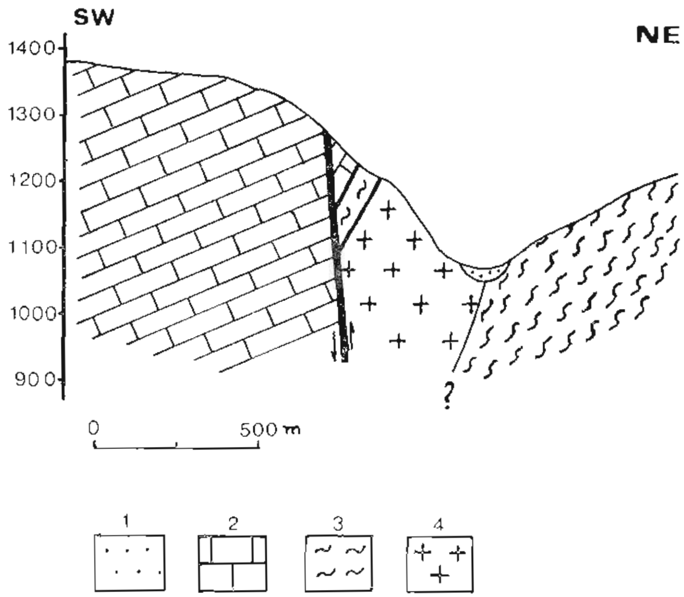

Fig. 2.
Geological section A-A'. 1: Alluvium, 2: Triassic-Jurassic limestones, 3: Crystalline basement, 4: Granodiorite.

of glassy or waxy quartz carry sometimes biotite bouklets.

On the whole, the Ayios Athanasios granodiorite shows a fairly uniform texture and mineral composition. Only in some specimens from the northwest part of the occurrence, biotite is more abundant and the dark green flakes of it give in these specimens their dark grey colour. In the same part there is also an abundance of fine to medium-grained dark coloured enclaves.

C. MICROSCOPICAL FEATURES

The microscopical study of the Ayios Athanasios granodiorite reveals that it consists of subhedral to anhedral plagioclase (Table I), anhedral and rarely subhedral K-feldspars, perthites, the exsolved phase of which forms a variety of textural intergrowths, quartz, biotite, hornblende, sphene, apatite, zircon, allanite, opaque minerals and the alteration products of the feldspars, biotite and hornblende (sericite, calcite,

TABLE I.

Modes of the Ayios Athanasios granodiorite.

	z-11	z-3	1	2	3	4	5
Quartz	28.7	23.6	23.8	22.1	24.1	24.4	26.7
K-feldspar*	16.0	23.3	16.2	20.7	16.8	21.0	18.1
Plagioclase*	40.2	39.0	45.1	43.6	44.2	41.2	40.8
Biotite	13.8	12.7	12.3	7.9	10.4	11.6	12.1
Hornblende			1.2	3.6	2.8		
Others	1.3	1.4	1.4	2.1	1.7	1.8	2.3

* Included sericite.

epidote). In addition it carries very often scattered K-feldspars (microcline) phenocrysts.

The modal composition of some specimens are listed in Table I. For the modal analysis of the rocks a SWIFT point counter was used (2000 counted points, point interval = 0.3 mm).

The Ayios Athanasios granodiorite is generally equigranular, coarse to medium - grained, although in some cases it is inequigranular. The scattered K-feldspars phenocrysts, when present, give to the rock a porphyroid character. A limited chilled facies of feldspars, quartz and minute flakes of biotite has also been observed.

1. Mineral constituents

Plagioclase:

The plagioclase (An_{28}-An_{42}) is the main mineral constituent of the granodiorite (39-45%). It forms stubby subhedral to anhedral crystals as well as rectangular to elongated and lathshaped crystals up to 4 mm.

It is generally unzoned or mildly zoned. Most of the zones are darker than the others due to the alteration products of the plagioclase. The cores appear to be more susceptible to alteration.

Sericite is the main alteration product and it may be accompanied by a member of the epidote group (zoisite?), carbonate, clay minerals and very rarely chlorite. Plagioclase encloses opaque minerals, flaky biotites and rounded quartz especially in the outer part of it.

It is twinned and is characterized by simple laws although these of complex laws are not infrequent.

Structurally according to Bambauer et al. (1967), is «low» plagioclase. The structural index $\Delta(\Theta)_1 = 2\Theta(131) - 2\Theta(1\bar{3}1)$, for two samples is 1.75 and 1.73 correspondingly.

K-feldspars:

K-feldspars are represented mainly by cross-hatched microcline. Their modal percentage ranges between 16% and 23%. The crystals are generally anhedral and range between 0.5 and 2 mm in diameter. The scattered, however, phenocrysts are subhedral and may be 3 cm long.

Replacement of altered plagioclase by the nearby K-feldspars has been observed. It has also been observed quartz, plagioclase and ferromagnesian constituents with their alteration products, enclosed in K-feldspar. In rare cases the K-feldspar is enclosed in quartz.

They are twinned according to Carlshad and Microcline laws. Other laws have been rarely observed. The extinction angle n_α : a varies between 5° and 8°, and the optic axial angle $2V_\alpha$ ranges between 79° and 84°. Dispersion is always r>v. According to the values of $2V_\alpha$ the K-feldspar is characterized as medium — to low — microcline (Marfunin, 1966). Using the spacings (131) and ($1\bar{3}1$) and the triclinicity Δ (Goldsmith & Laves, 1954 a, b) which ranges between 0.33 and 0.86 it is characterized as intermediate microcline. Finaly plot of the examined K-feldspars on the $2\Theta(060)/2\Theta(\bar{2}04)$ diagram (Wright, 1968) shows that they are plotted near the maximum microcline side of the maximum microcline-low albite series.

Nearly all the K-feldspar crystals form microperthites of which the film and the string perthites are the most abundant.

Biotite:

Biotite which is the dominant (8-14%) ferromagnesian mineral constituent of the Ayios Athanasios granodiorite forms subhedral flakes that measure c. 0.5 X 2.5 mm and lathshaped crystals up to 2 mm. The flakes are often embayed because of penecontemporaneous crystallization with the salic minerals. Very often it is in ragged to slivery patches that are pleochroic.

Biotite with its alteration products is often found as inclusions within K-feldspar and quartz and rarely in plagioclase. On the other hand it contains many inclusions particularly of the accessory minerals such as apatite, zircon, sphene and iron ore minerals. Zircon and apatite are very often surrounded by pleochroic halos. In some cases a dark brown to red brown, more or less zoned, mineral is found enclosed in biotite. It appears to be allanite (orthite).

In some way or another biotite is altered. With this alteration is related part of the sphene and a member of the epidote group found as spindleshaped inclusions or as larger grains between the cleavage of more altered biotite. Rutile, magnetite and hematite are aslo products of the alteration. In cases where a chilled facies is present the carried flakes of biotite are mechanically deformed. Hornblende remnants in some biotites indicate that they were originally hornblende.

U-stage measurements on biotite show that it is optically negative with $2V\alpha$ between 8° and 14°. Dispersion is always $r<v$. R.I. was determined by the immersion method and was found to range between 1.631 and 1.642 for $n_\beta \simeq n_\gamma$.

Concerning its colour, biotite in the Ayios Athanasios granodiorite is strongly pleochroic from brown yellow to various shades of olive green and brown green. The colour in biotites generally is correlated with composition and it is controlled by Fe, Ti, Mn and by the Fe^{3+} / Fe^{2+} ratio (Hall 1941, Hayama 1959, Chinner 1960, Gorbatchev 1972, Soldatos et al. 1976, Sapuntzis 1976). According to the above authors, the studied biotite must be poor in titanium as the reddish brown colouration is absent. On the contrary the predominant tint is the green which means high content of ferric iron. The composition of biotite of the Ayios Athanasios granodiorite has been found with the aid of the (060) spacing (Eugster & Wones 1958, Peikert 1963) and it ranges between 51% and 61% in annite. After this it is classified as lepidomelane (Tröger, 1967).

Hornblende:

Hornblende is usually an accessory mineral but in some specimens its presence is obvious. It crystallizes in discrete subhedral crystals up to 1 mm. More commonly it is intergrown in clusters with fine aggregates of biotite, opaque minerals and sphene. It shows perfect prismatic cleavage and sometimes basal parting. Twinning is relatively rare but always parallel to (100). The O.A.P. is parallel to (010) and the $2V\alpha$ is large (78-82°). Dispersion, weak to medium, is $r>v$.

Hornblende is strongly pleochroic from n_α = moderate greenish yellow and n_β = grayish to dark yellowish green to n_γ = brown green to olive green.

Quartz:

Quartz is the most abundant mineral constituent (22-29%) after plagioclase. It forms anhedral grains (c. 0.3-2.5 mm in diameter) and exhibits undulatory extinction. It is relatively free from inclusions but in some instances it encloses microcline, accessories and ferromagnessian minerals. On the other hand it is enclosed as previously was mentioned in feldspars, biotite and hornblende. That means that its crystallization period was long or there are two generations of quartz. In some cases it may be intergrown with K-feldspars and plagioclase in a micropegmatitic and myrmekitic fashion respectively. Myrmekite intergrowths are very rarely developed in lobate, bulbous and fringe myrmekite. Enclosed in K-feldspars were found wholly or partly myrmekitised plagioclases.

Apatite:

Apatite which is enclosed in biotite, hornblende and feldspars forms equidimensional or elongated but slightly rounded grains as well as short prismatic crystals with hexagonal cross sections, and massive grains.

Sphene:

Sphene is sporadically distributed in the Ayios Athanasios granodiorite and occurs as irregularly shaped grains or aggregates. Very rarely it is in wedge-shaped crystals. The irregular grains and aggregates that are associated with the alteration products of biotite and hornblende indicate that the mineral in this case has been formed at a last stage.

Zircon:

It forms subhedral, anhedral or rounded grains and occurs in biotite and feldspars. The characteristic pleochroid halos that surround it in biotite, gradually fade and eventually disappear as the alteration of the host increases.

Epidote:

It occurs with the alteration products of biotite and plagioclase. It also surrounds the orthite grains as a thin rim. The grains are too minute to permit detailed microscopic study thus we suggest that the mineral is a member of the epidote group.

Allanite (orthite):

It has been found as discrete crystals in some specimens ouly. It is enclosed in biotite or is surrounded by a rim of epidote. Orthite appears as a nearly isotropic, brown to red brown mineral and it is more or less zoned and sometimes twinned. It was difficult to measure its optics.

Sparce chlorite, magnetite, haematite, calcite and plenty of sericite occur also as accessories.

2. Discussion:

The optical study of the granodiorite reveals that the rock has been altered after its crystallization. The alteration products are mainly sericite, epidote and calcite.

Because of the alteration it is generally a little difficult to deduce accurately the sequence of the crystallization of the mineral constituents. Concerning plagioclase and biotite the optical study reveals that there was very probably an overlap in tbe crystallization periods of these minerals.

D. GEOCHEMISTRY

Two specimens were analysed by X.R.F. method and together with the C.I.P.W. —norms and the Rittmann— Norms are listed in Table II. In Table III the Niggli values are presented. The analysed rocks were computed and classified using the Rittmann-Norm and then plotted in the Streckeisen diagram (Streckeisen, 1967) (Fig. 3). They cover the granodiorite field which is also covered by the specimens that were modaly analysed (cf. modal composition and Rittmann-Norm).

The Ayios Athanasios granodiorite is a typically oversaturated rock in terms of the Rittman-Norm. ΔQ is positive and quartz is present. The presence of sillimanite in the saturated norm indicates that the rock has suffered an alteration.

Unfortunately it is impossible to find out variations in the major and minor elements with the two rock chemical analyses only. More analyses are needed for this purpose.

Comparison between C.I.P.W. — norm and Rittmann-Norm indicates that the quartz calculated according to Rittmann method is slightly higher than that resulted from the C.I.P.W. method calculation, while orthoclase and plagioclase are lower. The formation of biotite in Rittmann's-Norm affects very probably these relations.

TABLE II.

Chemical analyses, C.I.P.W. and Rittmann norms of the Ayios Athanasios granodiorite.

Chemical analyses (wt. %)			C.I.P.W.-norms (wt. %)			Rittmann-Norms (vol. %)		
	z-3	z-11		z-3	z-11		z-3	z-11
SiO_2	65.64	66.09	Q	23.32	21.24	Q	26.6	25.6
Al_2O_3	15.59	15.39	Co	0.67	0.46	Or	20.8	15.1
Fe_2O_3	2.80	2.50	Or	23.64	20.09	Pl	38.7	44.2
FeO	2.00	2.20	Ab	25.98	32.58	Bi	12.5	13.9
MnO	0.13	0.11	An	15.12	13.42	Mt	0.7	0.7
MgO	1.54	2.09	En } Hy	3.83	5.20	Il	0.2	
CaO	3.39	3.06	Fs } Hy	0.51	1.17	Ap	0.5	0.5
K_2O	4.00	3.40	Mt	4.06	3.62			
Na_2O	3.07	3.85	Il	1.25	1.16			
TiO_2	0.66	0.61	Ap	0.60	0.63			
P_2O_5	0.26	0.27						
L.O.I.	1.37	1.41						
Total	100.35	100.98	Total	98.98	99.57	Total	100.0	100.0

TABLE III.

Niggli values of the Ayios Athanasios granodiorite.

	si	al	alk	fm	c	ti	p	k	mg	qz
z-3	267	37	23	25	15	2.0	0.5	0.46	0.63	+75
z-11	261	36	23	28	13	1.9	0.5	0.37	0.44	+169

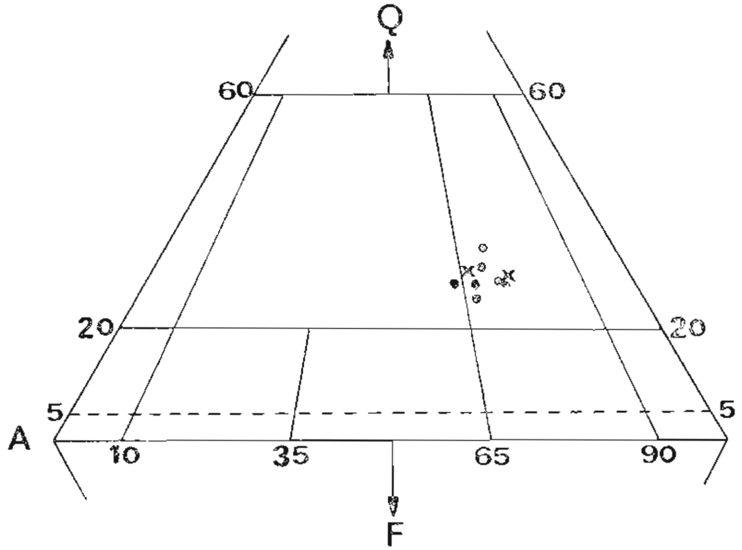

Fig. 3.
Plot of the granodiorite samples in the STRECKEISEN diagram.
● = *point-counted,* x = *Rittmann-Norms.*

E. VIEWS ON THE GRANODIORITE GENESIS AND ITS AGE

It is rather difficult to deduce the granodiorite origin only by the microscopic investigation because granodiorite is more or less altered. There are, however, some petrological evidences, although not sufficient enough, which support a metasomatic (?) origin of it. These are:

a) Two generations of quartz
b) Unzoned or mildly zoned plagioclase
c) Presence of perthite and myrmekite
d) Replacement of plagioclase by microcline
e) Unzoned phenocrysts of K-feldspars
f) Reversal of normal order of crystallization as adduced for rocks crystallizing from magmas.

Field observations give some data concerning the relation of the granodiorite with the tectonics of the area. At first, obvious igneous intrusive contact relations between the granodiorite and the country rocks are absent. There are also no relics of a contact metamorphism of the country crystalline rocks. This must exclude, in our opinion, the posterior intrusion of the granodiorite and hence it must not be considered as postkinematic. On the contrary the mineralogy of the granodiorite (the kind of K-feldspar and its triclinicity, the composition of plagioclase, the kind of the femic constituent and its colour) leads us to the conclusion that it must be considered as synkinematic. Moreover the fact that the direction of the granodiorite outcrop is about the same with the strike of the country rocks suggests that it was probably solidified at the first stage of the folding.

It must be emphasized here that the previously mentioned petrological evidences as well as field observations are only simple data and can not prove alone the granodiorite genesis. More detailed chemical, mineralogical and geological data are needed to find out the mode of granodiorite origin.

The field observations mentioned, however, together with the emplacement of the granodiorite in the crystalline basement, show the relation of its genesis with the metamorphism and folding of the Pelagonian crystalline rocks. Therefore its age must be the same to that of the metamorphism and folding.

According to Mercier (1968) and Vergely (1976), metamorphism and folding in the Pelagonian zone took place during the Upper Jurassic-Lower Cretaceous orogenic period. Thus the granodiorite age must be Upper Jurassic-Lower Cretaceous. After Brunn (1956), however, the age of the metamorphism in the Pelagonian basement is Palaeozoic. In this case the granodiorite age must be considered as Palaeozoic probably in relation to Hercynian orogeny.

It is remarkable that the opinions of the various authors about the age of the different Pelagonian igneous outcrops — even the radiometric determinations — agree for the Upper Palaeozoic age of them (Osswald 1938, Brunn 1956, Marakis 1969, Yarwood & Aftalion 1976).

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ΠΕΡΙΛΗΨΗ

ΝΕΑ ΕΜΦΑΝΙΣΗ ΓΡΑΝΟΔΙΟΡΙΤΟΥ ΣΤΗ ΒΟΡΕΙΑ ΠΕΛΑΓΟΝΙΚΗ ΖΩΝΗ

Ὑπὸ

Γ. ΧΡΙΣΤΟΦΙΔΗ* καὶ Δ. ΜΟΥΝΤΡΑΚΗ**

Στὴ Βόρεια Πελαγονικὴ ζώνη (περιοχὴ τοῦ χωριοῦ Ἅγιος Ἀθανάσιος τοῦ Νομοῦ Πέλλης) ἐπισημάνθηκε μιὰ μικρὴ ἐμφάνιση γρανοδιορίτου ποὺ μελετᾶται γιὰ πρώτη φορά.

Μελετᾶται ἡ σχέση τοῦ γρανοδιορίτου μὲ τὰ περιβάλλοντα πετρώματα, σὲ συνδυασμὸ μὲ τὰ γεωλογικὰ στοιχεῖα καὶ τὴν τεκτονικὴ δομὴ τῆς περιοχῆς ποὺ διαπιστώθηκαν ἀπὸ τὴν ἐργασία ὑπαίθρου, καὶ συμπεραίνεται ὅτι πρόκειται γιὰ συνκινηματικὸ γρανοδιορίτη.

Ἐξετάζονται μικροσκοπικῶς καὶ ἀκτινογραφικῶς τὰ ὀρυκτολογικὰ συστατικὰ τοῦ πετρώματος καὶ ἐπισημαίνονται ὁρισμένες πετρολογικὲς ἐνδείξεις γιὰ μετασωματικὴ (;) προέλευση τοῦ γρανοδιορίτου. Δίνονται ἐπίσης δύο χημικὲς ἀναλύσεις τοῦ πετρώματος μὲ τὶς δυνητικὲς συστάσεις κατὰ C.I.P.W. καὶ Rittmann, καθὼς καὶ οἱ τιμὲς Niggli.

Τέλος συζητεῖται ἡ σύνδεση τοῦ γρανοδιορίτου μὲ τὴν μεταμόρφωση καὶ πτύχωση στὴ Πελαγονικὴ ζώνη, σὲ σχέση μὲ τὰ βιβλιογραφικὰ δεδομένα γιὰ τὴν ἡλικία τῶν φαινομένων αὐτῶν —(Brunn 1956) καὶ (Mercier 1968, Vergely 1976)— καὶ ἐκφράζεται ἡ ἄποψη ὅτι ἡ ἡλικία τοῦ γρανοδιορίτου πρέπει νὰ εἶναι ἀνωπαλαιοζωικὴ ἢ ἀνωϊουρασική - κατωκρητιδικὴ ἀντίστοιχα.

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