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THE EXAMILI FORMATION AND ITS RELATION TO THE VERTISKOS SUBZONE OF THE SERBO-MACEDONIAN MASSIF

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A B S T R A C T

The Examili formation is composed of clastic meta-sediments, acid mainly meta-volcanics and small intercalations of intermediate to basic meta-tuffs. The acid meta-volcanics correspond to the geotectonic environment of active continental margins or island arc while the basic ones show relationships to ocean floor basalts. The Lipsidri meta-volcanics bear a baryte ore mineralization and show high values in base metals. The geochemistry of the Vertiskos gneiss shows a probable para-origin and displays an interest for searching for massive base metal sulfides and gold in epigenetic quartz veins.

Σ Υ Ν Ο Ψ Η

Ο σχηματισμός Εξαμίλι αποτελείται από κλαστικά μετα-ιζήματα, όξινα κυρίως μετα-ηφαιστειακά πετρώματα και μικρές παρεμβολές μετα-τόφφων ενδιάμεσης έως βασικής σύστασης. Τα όξινα μετα-ηφαιστειακά τοποθετούνται στο νεωτεκτονικό περιβάλλον των ενεργών ηπειρωτικών περιθωρίων ή νησιωτικού τόξου ενώ τα βασικά δείχνουν συγγένεια προς βασάλτες ωκεάνιου πυθμένα. Τα μετα-ηφαιστειακά στην περιοχή Λειψύδρι φέρουν μεταλλοφορία βαρύτη και παρουσιάζουν υψηλές τιμές σε βασικά μέταλλα. Ο γνεύσιος του Βερτίσκου με βάση τη γεωχημεία του παρουσιάζει παρα-προέλευση και μεταλλοφορία σουλφιδίων και χρυσού μέσα σε επιγενετικές χαλαζιακές φλέβες.

INTRODUCTION

The Examili formation belongs to the Circum-Rhodope Belt and is a linear NW-SE trending sequence, bound by the Vertiskos formation (of Paleozoic age) to the east and the volcano-sedimentary sequence of Akrita-Metalliko-Doubia to the west (Kockel et al., 1977) (Fig. 1). According to Kockel et al. (1977)

Ν. ΒΕΡΑΝΗΣ-ΧΡ. ΚΟΥΓΚΟΥΛΗΣ και Α. ΚΑΣΩΛΗ-ΦΟΥΡΝΑΡΑΚΗ. Ο σχηματισμός Εξαμίλι και η σχέση του με την υποζώνη Βερτίσκος της Σερβομακεδονικής ζώνης.

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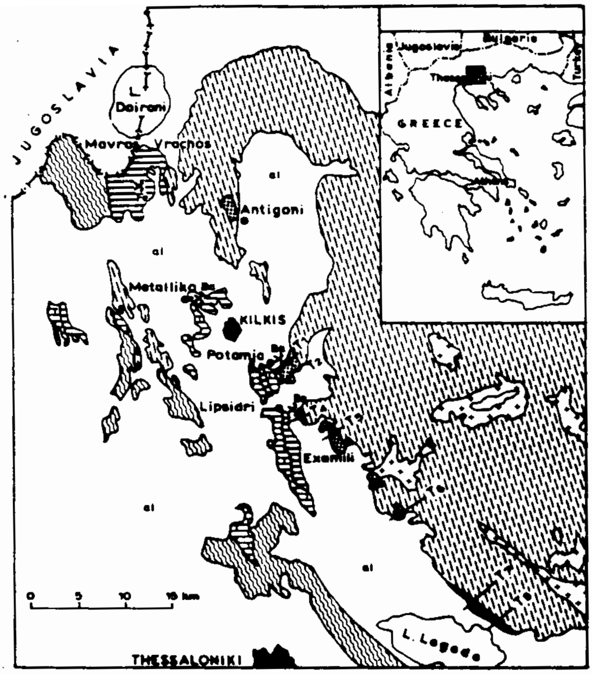
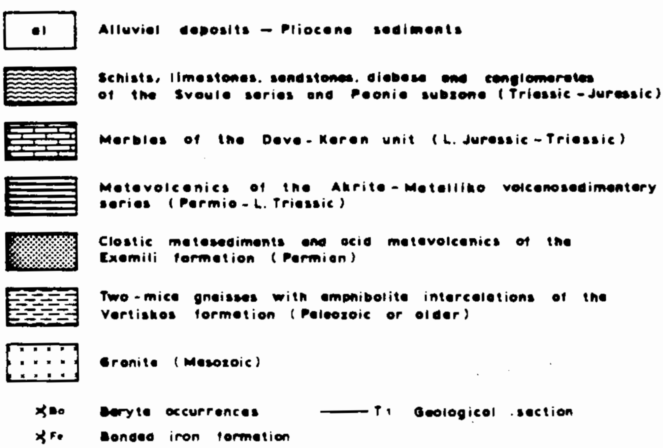


Fig. 1. Geological sketch map illustrating the area studied.

Σχ. 1. Γεωλογικός χάρτης που δείχνει την περιοχή μελέτης.



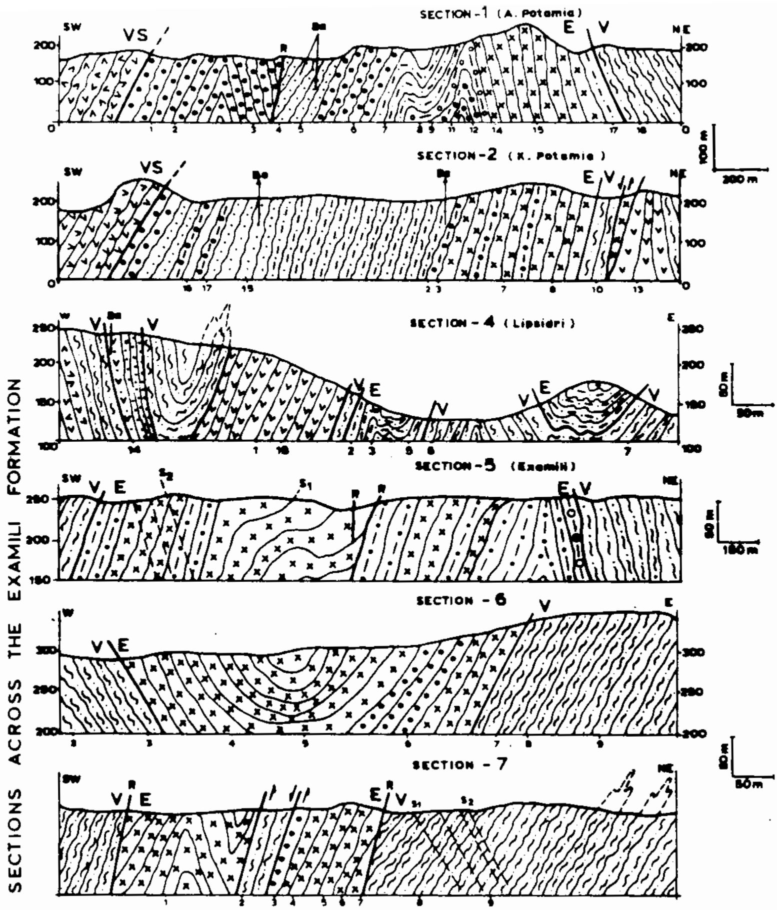
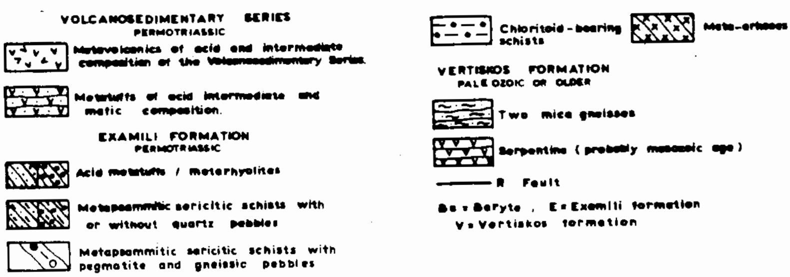


Fig. 2. Geological profiles of positions T-1, T-2, T-4, T-5, T-6, T-7.

Σχ. 2. Γεωλογικές τομές στις θέσεις T-1, T-2, T-4, T-5, T-6, T-7.



the age of Examili formation is determined to be after the regional metamorphism, which condensed the body of the so-called Serbo-Macedonian massif, and before the volcano-sedimentary sequence on its western border. That is, it is attributed somewhere to Permian up to Lower Triassic. The Examili-Vertiskos contact is tectonic with a stratigraphical break, while the transition from the Examili formation to the neighbouring volcano-sedimentary sequence is normal (Fig. 2).

The area in study covers an extent of 40Km (total length) between Ano Potamia-Kilkis and Analipsi - St.Basel Lake. The Examili formation, according to Kockel et al. (1977), consists only of clastic meta-sediments. However, our recent studies in the area indicate the presence of submarine meta-volcanic occurrences.

This work is a mineralogical and a chemical study of the Examili formation and the neighbouring Vertiskos gneiss. In addition, the tectonic setting, the ore mineralization and the paleogeographical development of the district are also considered.

META-VOLCANIC ROCKS

The Examili meta-volcanics seem to comprise a separate zone with a NW-SE direction. As it can be seen from the geological sections T-1, T-2, T-4 (Fig.2) the intercalations with the meta-sediments are rare. Only in the geological section T-6 an intercalation of small thickness (30m) in meta-sediments is present.

The Examili meta-volcanics are mainly acid (lavas, tuffs) with a small participation of intermediate and basic meta-tuffs. The submarine type of volcanism is proved by the absence of continental sediments and by the presence of stratiform syngenetic baryte ore mineralization (unpublished data) in the meta-volcanics. Furthermore the presence of magnetite and albite is attributed to the reaction of seawater with the rock in a submarine volcanosedimentary environment (Lagerblad and Gorbatscher, 1985).

The acid meta-volcanics consist fo albite or/and quartz phenocrysts in a fine-grained salic groundmass. The sericite participation ranges from 7-25%. The intermediate meta-tuffs consist of sericite, quartz, albite and chlorite, while the basic ones consist of biotite, chlorite, quartz, albite, calcite, epidote and magnetite.

Chemical features

Major and trace element (Zn, Cr, Ni, Cu, Pb) chemical determination was performed by atomic absorption at the Kozani's chemical laboratories of I.G.M.E. while the rest trace elements (Zr, Nb, Y, Ba, Sr, Rb as well as Ti) were deremined by XRF at the chemical laboratories of I.G.M.E. in Athens.

Table 1. Chemical composition of the Examili meta-volcanic rocks.
A=ore-free acid meta-volcanics, B=acid meta-volcanics near ore mineralization, C=intermediate meta-volcanics near ore mineralization, D=basic meta-tuffs near ore mineralization.

Πίνακας 1. Χημική σύσταση των μετα-ηφαιστειακών Εξαμιλίου.
Α=όξινα μετα-ηφαιστειακά χωρίς μεταλλοφορία, Β=όξινα μετα-ηφαιστειακά κοντά στη μεταλλοφορία, C=ενδιάμεσης σύστασης μετα-ηφαιστειακά κοντά στη μεταλλοφορία, D=βασικοί μετατόφφοι κοντά στη μεταλλοφία.

	A n = 5		B n = 9		C n = 6		D n = 5	
	mean value	standard deviation	mean value	standard deviation	mean value	standard deviation	mean value	standard deviation
SiO_2	74.89	3.14	77.12	1.23	65.00	3.32	49.00	0.89
TiO_2	0.07	0.03	0.07	0.02	1.38	0.18	1.37	0.37
Al_2O_3	11.36	1.42	11.38	1.22	14.41	1.83	15.42	0.74
Fe_2O_3	0.33	0.22	0.68	0.46	3.91	3.30	6.37	2.89
FeO	0.68	0.20	0.40	0.39	1.15	0.90	6.86	2.85
MnO	0.12	0.16	0.03	0.01	0.09	0.05	0.24	0.08
MgO	0.30	0.26	0.36	0.20	1.55	0.71	6.47	0.64
CaO	0.16	0.07	0.42	0.25	0.67	0.16	1.34	0.25
Na_2O	1.08	0.37	2.20	1.32	2.17	1.25	2.25	1.08
K_2O	8.06	2.79	5.10	1.93	4.17	1.32	1.72	1.48
P_2O_5	n.d.		0.16	0.01	0.30	0.17	0.36	0.09
H_2O^-	0.24	0.05	0.12	0.07	0.22	0.04	0.69	0.51
L.O.I.	1.53	0.41	1.35	0.56	3.34	1.08	6.36	1.41
			Trace elements in p.p.m.					
Zn	17	19	33	34	1753	1726	2376	637
Cr	14	21	6	3	25	22	148	83
Ni	32	41	3	2	38	35	107	43
Cu	7	7	40	30	110	57	64	15
Pb	6	5	42	42	5337	3025	62	32
Zr	33	8	77	52	162	45	110	31
Nb	5	2	11	8	12	4	8	1
Y	34	13	31	12	40	13	40	6
Ba	274	187	3144	2527	3705	1770	739	349
Sr	23	6	142	176	157	115	64	33
Rb	276	119	187	84	97	35	47	37

The chemical composition (mean values) of the meta-volcanics is given in Table 1. The rocks have been divided in four groups according to their distance from the baryte ore mineralization. Group A includes acid members away from baryte ore mineralization, group B includes acid members which contain baryte ore mineralization, group C represents the intermediate meta-volcanics near the baryte exploitation and finally group D includes the basic meta-tuffs near baryte ore-mineralization.

The most outstanding lithochemical features of group A are their high content of silica (~75% SiO_2) and potassium (~8.0% K_2O) and low content of sodium (~1.0% Na_2O) and magnesium (~0.3% MgO). The acid meta-volcanics of group B exhibit high silica (~77% SiO_2), increase of sodium (~2.2% Na_2O) and decrease of potassium (~5.0% K_2O) and a small increase of magnesium (~0.4% MgO) compared to the mean values of group A. Besides, they show geochemical anomalies as regards the Ba content (3,144 ppm). The intermediate meta-tuffs (group C) are characterized by high concentrations in titanium (~1.4% TiO_2), magnesium (~1.5% MgO), calcium (~0.7% CaO), iron (3.9% Fe_2O_3, 1.2% FeO), barium (3,700 ppm) and base metals, Zn (1,750 ppm), Pb (5,340 ppm). The basic members of group D display high iron content (6.4% Fe_2O_3, 6.9 FeO), titanium (~1.4% TiO_2), alkalies (~2.3% Na_2O, 1.7% K_2O) and Zn (2.376 ppm).

The meta-volcanics, due to their submarine origin, have undergone hydrothermal alteration, such as silification, potassium or sodium metasomatism as well as magnesium alteration. Hughes (1973) uses the K_2O+Na_2O vs K_2O/K_2O+Na_2O diagram to determine the degree of alteration. From Fig. 3 it is obvious that the Examili meta-volcanics are mostly altered in the potassium metasomatic field.

The elements Zr, Y, Nb and Ti are considered to be the most immobile ones (Winchester and Floyd, 1977). From the pertinent diagram shown in Fig. 4 it results that the acidic meta-volcanics are mostly rhyodacitic-dacitic in composition, the intermediate tuffs mainly andesitic and the basic members sub-alkaline basalts.

In the diagrams Ni, Cr vs FeO*/MgO (after Miyashiro and Shido, 1975) the meta-volcanics (especially the more acidic members) plot in the field of active continental margins or of island arc (Fig. 5).

The above suggestion is further strengthened by the fact that the Examili meta-sediments (arkoses, psammites, conglomerates) which are contemporary with the meta-volcanics show a para-continental environment.

In the Ti-Cr (after Pearce, 1979), Ti-Zr-Y, Ti-Zr (after Pearce and Cann, 1973) and Zr/Y vs Zr (after Pearce and Norry, 1979) diagrams of Fig. 6 the basic metatuffs plot in the fields of ocean floor, or middle ocean ridge basalts.

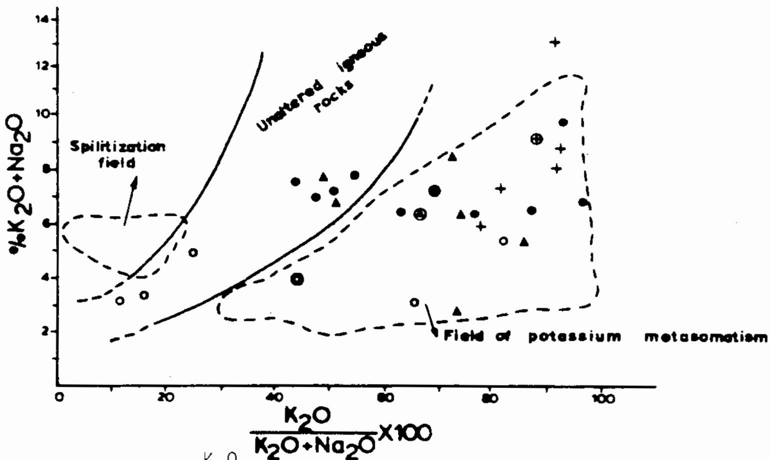


Fig. 3. $(K_2O + Na_2O)$ vs $\frac{K_2O}{K_2O + Na_2O}$ X 100 of the meta-volcanics according to Hughes (1973) diagram.

Σχ. 3. Σχέση $(K_2O + Na_2O)$ ως προς $\frac{K_2O}{K_2O + Na_2O}$ X 100 των μετα-ηφαιστειακών σύμφωνα με το διάγραμμα του Hughes (1973).

+= Group A ⊕= mean value •= Group B ◉= mean value

▲= Group C ⊛= mean value ○= Group D ◎= mean value

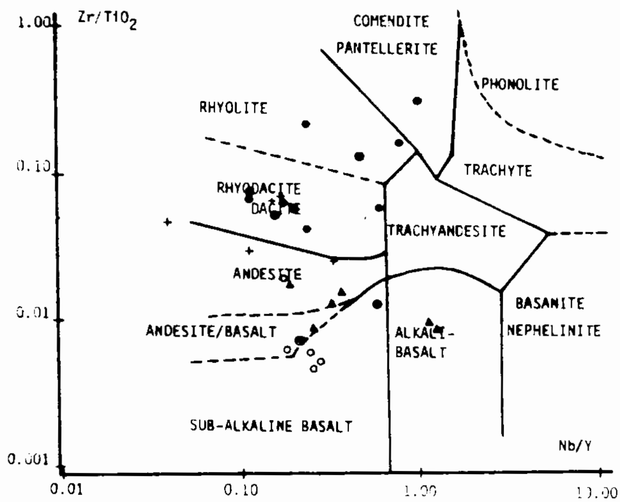


Fig. 4. Zr/TiO_2 vs Nb/Y of the Examili meta-volcanics according to Winchester and Floyd (1977). Key as Fig. 3.

Σχ. 4. Σχέση Zr/TiO_2 ως προς Nb/Y των μετα-ηφαιστειακών Εξαμιλίου σύμφωνα με το διάγραμμα των Winchester and Floyd (1977). Οι συμβολισμοί όπως στο Σχ. 3.

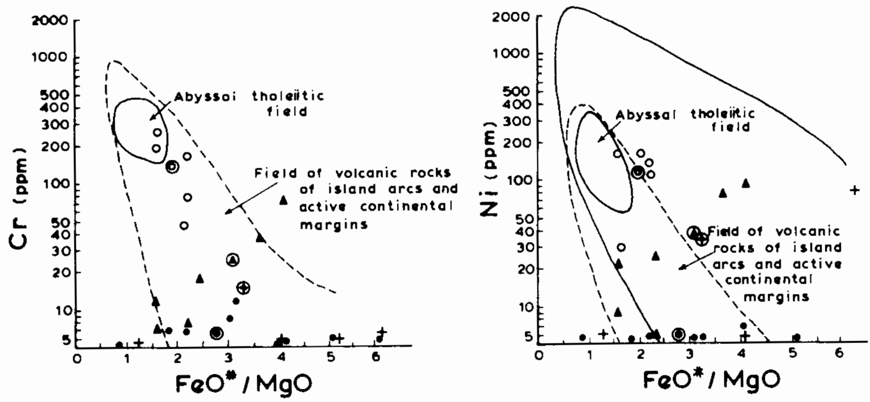


Fig. 5. Ni, Cr vs FeO*/MgO (after Miyashiro and Shido, 1975) discrimination of the Examili meta-volcanics. Key as Fig. 3.

Σχ. 5. Σχέση Ni και Cr ως προς FeO*/MgO (κατά τους Miyashiro και Shido, 1975) των μετα-ηφαιστειακών Εξαμιλίου. Οι συμβολισμοί όπως στο Σχ. 3.

CLASTIC META-SEDIMENTS

The clastic meta-sediments constitute the larger part of the Examili formation and can be distinguished in three categories;

compact meta-arkoses and meta-sandstones
schistose sericitic meta-sandstones
chloritoid-bearing schists

The meta-arkoses and meta-sandstones are white-gray, compact, medium grained rocks. They consist mainly of quartz and albite with sericite, apatite, zircon, garnet, epidote, calcite and tourmaline traces as minor accessories. The texture is mortar with larger quartz grains (0.2-1.2 mm) surrounded by finer quartz material (0.02-0.05mm).

The sericitic meta-sandstones are white-gray strongly schistosed, fine, clastic meta-sediments which form separate zones 20-300 m in thickness or interlay with the compact meta-sandstones, meta-arkoses. They consist of quartz, sericite, feldspar, plus minor chlorite, epidote and apatite.

Chemical features

The chemical composition of the clastic meta-sediments is presented in Table 2.

The Examili meta-arkoses, meta-sandstones, compared with the mean values of sandstones free of volcanic material (Pettijohn, 1963), display higher values

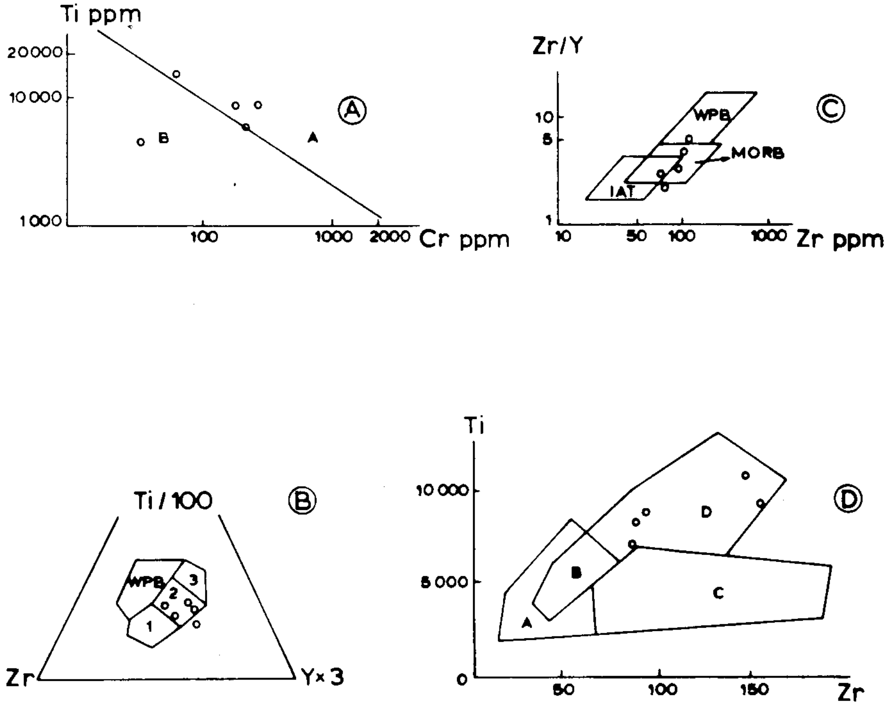


Fig. 6. A. Ti-Cr diagram discriminating between ocean floor basalts (A) and low K-tholeiites (B) (after Pearce, 1979).
B. Ti-Zr-Y discrimination diagram after Pearce and Cann (1973). Ocean-floor basalts plot in field 2, island-arc basalts in fields 2 and 3, calc-alkali basalts in fields 1 and 2.
WPB = within-plate basalts
C. Zr/Y vs Zr diagram after Pearce and Norry (1979)
IAT = island-arc tholeiites, MORB = middle ocean ridge basalts
D. Ti vs Zr diagram after Pearce and Cann (1973)
B + C = calc-alkali basalts A + B = island-arc basalts D + B = ocean floor basalts.

Σχ. 6. A. Διάγραμμα Ti-Cr που διαχωρίζει τους βασάλτες ωκεάνιου πυθμένα (A) από τους θολεΐτες χαμηλού K (B) (κατά τον Pearce, 1979).
B. Διάγραμμα Ti-Zr-Y κατά τους Pearce and Cann (1973).
C. Διάγραμμα Zr/Y ως προς Zr κατά τους Pearce and Norry (1979).
D. Διάγραμμα Ti-Zr κατά τους Pearce and Cann (1973).

Table 2. Chemical analyses of the Examili clastic meta-sediments and the Vertiskos gneiss.

Πίν. 2. Χημικές αναλύσεις των κλαστικών μετα-ιζημάτων Εξαμιλίου και του γνευσίου του Βερτίσκου.

	Examili clastic meta-sediments: meta-sandstones, meta-arkoses schistose sericitic meta-sandstones n = 10		Examili clastic meta-sediments: chloritoid bearing schist n = 1	Vertiskos gneiss n = 20	
	mean value	standard deviation		mean value	standard deviation
SiO_2	84.09	2.88	66.31	68.00	3.60
TiO_2	0.20	0.07	0.98	0.64	0.20
Al_2O_3	6.89	1.83	16.24	13.50	1.51
Fe_2O_3	0.38	0.30	5.96	0.97	0.58
FeO	0.87	0.90	1.72	2.82	1.34
MnO	0.07	0.07	0.03	0.06	0.02
MgO	0.51	0.90	0.30	1.14	0.74
CaO	0.14	0.06	0.10	1.16	0.84
Na_2O	0.95	0.75	0.27	1.86	0.91
K_2O	3.06	1.17	5.45	4.50	1.55
P_2O_5	n.d.		n.d.	n.d.	
H_2O^-	0.23	0.07	0.20	0.29	0.11
L.O.I.	1.47	0.67	1.11	2.96	0.82
			Trace elements in p.p.m.		
Zn	21	30	18	66	33
Cr	13	11	28	92	36
Ni	13	15	5	18	18
Cu	5	4	2	15	12
Pb	20	27	-	12	17
Zr	129	82	256	172	71
Nb	3	3	19	11	5
Y	13	4	41	25	11
Ba	600	367	721	856	717
Sr	31	19	309	128	78
Rb	84	38	110	113	45

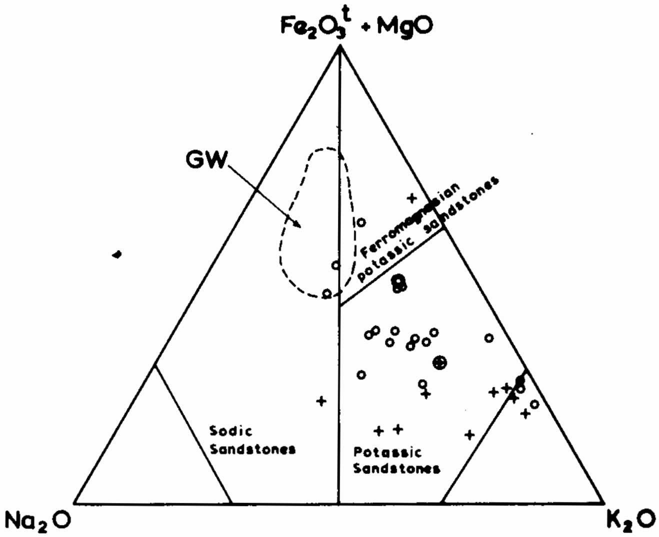


Fig. 7. Classification of the Examili meta-sediments and Vertiskos gneiss (after Blatt et al., 1972). GW = greywacke field.

Σχ. 7. Ταξινόμηση των μετα-ιζημάτων Εξαμιλίου και του γνευσίου του Βερτίσκου (κατά τους Blatt et al., 1972). GW = πεδίο γραουβάκη. +=meta-sandstones, meta-arkoses, ⊕=mean value, o=Vertiskos gneiss, ⊙=mean value.

in potassium and lower ones in calcium, iron, magnesium, strontium. The relatively high concentration in potassium (3.0% K_2O) may be attributed either to the contact of the clastic meta-sediments with the potassium-rich metavolcanics (Frietsch, 1982) or to the mechanical and chemical corrosion of the Vertiskos gneiss which is the rock "source" for the Examili sediment deposition.

According to the Fe_2O_3+MgO/Na_2O/K_2O diagram (Fig. 7) (after Blatt et al. 1972) the Examili meta-arkoses, meta-sandstones, belong to the geological environment of taphrogeosyncline.

VERTISKOS GNEISS

The Vertiskos gneiss has been studied to a distance up to one km from its contact with the Examili formation. It is a relatively monotonous two-mica gneiss with rare lithological differences and with muscovite, biotite, chlorite, quartz and albite as main constituents and garnet, epidote, zoisite, tourmaline and apatite as minor ones.

Chemical features.

The chemical composition of the gneiss is presented in Table 2. Using different discriminatory techniques we tried to determine the protolith of the gneiss. In the diagram Fe_2O_3+MgO/Na_2O/K_2O (Fig. 7) it plots in the field of K-rich arkoses (potassic sandstones) which type Blatt et al. (1972 p. 318) have named as taphro-geosynclinal sandstones. In the diagrams Al/3-K vs Al/3-Na (after Moine and de la Roche, 1968) and log (SiO_2/Al_2O_3) vs log [(CaO+Na_2O/K_2O] (after Prabhu and Webber, 1984) (not shown in figures) it plots also in the sedimentary field. Application of DF criterion (after Shaw, 1972) gives both negative and positive values which is characteristic of greywackes relfecting their mixed igneous and sedimentary parentage.

In the Vertiskos gneiss there occur intercalations of chlorite-amphibolitic schist (0.20-20 m in thickness) and in some positions of its contact with the gneiss a baryte ore mineralization was noticed.

EXAMILI-VERTISKOS CONTACT

A strong shearing is observed in some positions along the contact. The dipping of the contact is generally eastern (30-80^{o}) becoming rarely western. According to Mercier (1966) the Vertiskos overthrust over the Mesozoic cover is Eocene in age. Inversion of the layers is also observed in the nearby formation (volcano-sedimentary sequence Akrita-Metalliko-Doubia, Deve Koran etc).

The tectonic parameters between the two formations are parallel. The Alpidic folds probably covered previous Paléozoic features of the Vertiskos gneiss. The stratigraphic break between the two formations is supported only by the pebbles of pegmatite (rarely of gneiss) which are found in the Examili schistose meta-sandstones (profile No 5 of Fig. 2).

METAMORPHISM

In the muscovite-chlorite gneisses which are found in the west margin of the Vertiskos formation (Fig. 1) the paragenesis chlorite+muscovite+albite+quartz dominates characterizing low grade metamorphic conditions. This metamorphism is retrograde of a higher subfacies or medium grade with the paragenesis biotite+muscovite+almandine+plagioclase. Retrogression phenomena in Serbo-Macedonian massif and especially in the Vertiskos series have been mentioned by Kockel and Walther (1967), Boskos (1983), Papadopoulos (1982), Kassoli et al. (1986), Kalogeropoulos et al. (1986).

Age determination by K/Ar and Rb/Sr at the eastern part of the Vertiskos series, gave for the medium grade metamorphism an older than Cretaceous age, contemporal with the isoclinal folds, while the retrograde one is of Cretaceous and related to the open folds (Papadopoulos and Kilias, 1985).

The Examili formation is characterized by the paragenesis iron-chloritoid+mica+albite indicative of low grade metamorphism. Age determination with Pb isotopes on the metamorphic Examili baryte ore mineralization gave an age of 200-300 m.y. (unpublished data).

ORE MINERALIZATION

In the Vertiskos gneiss of the studied area we meet two main types of ore mineralization;

a) A massive stratiform, syngenetic ore mineralization of base metal sulfides±baryte±gold, which is found in the contact between the muscovitic gneiss and the chlorite-amphibolitic schsit.

b) A massive to disperse ore mineralization of pyrite-arsenopyrite-chalcopyrite±gold in epigenetic quartz veins which intrude along tectonized zones and are accompanied by veins of basic compositions.

The second type of ore-mineralization is emplaced before the D_2 deformation and after the D_1 one regarding the time.

In the Examili formation a massive stratiform, syngenetic baryte ore-mineralization is included in the meta-volcanics as was previously mentioned. The meta-tuffs in Lipsidri area show geochemical anomalous values in base metals and may be connected with an ore mineralization of base metal sulfides.

In the neighbouring volcano-sedimentary sequence of Akrita-Metalliko-Doubia which presents significant similarites with the Examili formation as regards the meta-volcanics, there were localized occurrences of baryte, iron formations and base metal sulfides in certain stratigraphic horizons.

STRATIGRAPHY AND PALEOGEOGRAPHICAL DEVELOPMENT OF THE EXAMILI FORMATION

The Examili sediments were deposited into a narrow elongated basin which was formed possibly after the end of Paleozoic (upper Carboniferous). Similar basins are referred in bibliography as "furrows" (Holub, 1976) and in some cases they are accompanied by magma emergence.

The Examili basin has acted as a collector of the clastic sediments which were mechanically transported from the neighbouging Vertiskos. In the firts stages we had the deposition mainly of clastic sediments and some acid pyroclastics. Later the acid calc-alkaline lavas and pyroclastics follow with a reduction or absence of clastics.

The basin's depth is not uniform as the changing thickness of the sediments reveals. The limits and orientation of the basin were changed by the later Alpidic folds. The clastic meta-sediments are relatively uniform as regards their chemical composition, a fact due to the rock "source" (Vertiskos gneiss) and to the arid, semi-arid climate conditions which dominated during Permian in the Europian space (Falke, 1976).

The differentiation in schists and compact meta-sandstones, meta-arkoses is due to tectonic activity along the basin and the seasonal climate conditions (Rau and Tongiorgi, 1976). The cyclicity of the meta-sediments may be due to alternations of land emergence and simultaneous activity of the relief with following sinking of the sedimentation basin. The later Alpidic folds obviously have covered the initial cyclicity of the meta-sediments.

The succession of the meta-sediments along the basin from the exterior to the interior is not constant. In the southern part of the formation included between Examili village and Lagada Lake (Fig. 1) the compact meta-arkoses dominate with few intercalations of acid meta-tuffs of small thickness (20-50 m).

The schistose sericitic meta-sandstones including pebbles of quartz and pegmatite (more rarely of gneiss) occur near the contact with the Vertiskos gneiss.

In the nothern part of the formation the quantitative participation of the meta-volcanics is greater (Figs 1, 2). The meta-volcanics interlay between the clastic meta-sediments to the east and the volcanosedimentary meta-volcanics to the west.

The chemical sediments (evaporites, carbonates, black schists) are absent because of the sedimentation's great speed and the relatively small width of the basin.

CONCLUSIONS

From this study it resulted that:

The Examili formation is composed of clastic meta-sediments (meta-sandstones, meta-arkoses, schistose sericitic meta-sandstones, chloritoid bearing schists) acid mainly meta-volcanics and small intercalations of intermediate-basic meta-tuffs. The meta-volcanics belong to the geotectonic environment of active continental margins or island arc over a thick continental crust. The Lipsidri meta-volcanics show a separate interest because they bear baryte ore mineralization and show high values in base metals (Zn+Pb=0.8%). The meta-sandstones as well as the acid Examili meta-volcanics display an interest for industrial minerals (quartz, K-feldspars).

The Vertiskos gneiss from the metamorphism of sediments, contains chlorite-amphibolitic schist intercalations of small thickness and displays an interest for searching for massive base metal sulfides and gold.

The Examili-Vertiskos contact is tectonic with a stratigraphical break which is proved by the presence of pegmatite and gneiss pebbles (conglomerate of the base) in the Examili formation schists.

An initial medium grade metamorphism and a later low grade retrograssion was determined for the Vertiskos gneiss. The Examili formation has undergone only a low grade metamorphism.

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