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High-pressure metamorphism between the Pelagonian Massif and Vardar Ophiolite Belt, Yugoslavia

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ABSTRACT. A reported occurrence of metamorphic rocks containing sodic pyroxenes, in the transition zone between the Pelagonian Crystalline Massif and the Vardar Ophiolite Belt, in Macedonia, Yugoslavia, has been re-investigated, and pyroxenes, micas, plagioclase, and clinozoisite analysed by microprobe. The presence of the high-pressure metamorphic assemblage quartz + omphacite + albite is confirmed, giving the first definite indication of blueschist-facies metamorphic conditions in Yugoslavia.

THE first, and as yet the only recorded occurrence of 'jadeitite' in Yugoslavia was recorded by Tućan (1936*a*). The jadeitite, a pyroxene schist, is found as loose blocks in the Aljagica district, between the mountains Solunska glava and Karadžica, about 25 km south of Skopje, Macedonia. This district lies in the Dinaride fold belt, on the northeastern border of the Pelagonian Crystalline Massif, adjacent to the western part of the Vardar Ophiolite Belt (fig. 1). The pyroxene schist is a dense, tough, very fine-grained rock, greenish grey in colour, with a massive but inhomogeneous structure, showing granoblastic texture in thin section. Tućan listed the minerals in the rock as jadeite, clinozoisite, epidote, white mica, biotite, quartz, acid plagioclase, amphibole, graphite, sphene, and zircon. Our investigations confirm this list, except that two pyroxenes are present, omphacite and sodic augite, the acid plagioclase is albite and the white mica is phengitic muscovite (Tables I and II). Tućan (1936*a*) gave the analysis of the rock as SiO_2 52.32, TiO_2 1.62, Al_2O_3 14.83, Fe_2O_3 0.93, FeO 5.28, MnO 0.06, MgO 4.42, CaO 14.02, Na_2O 4.66, K_2O 0.17, H_2O^+ 1.44, H_2O^- 0.14, total 99.89%.

The locality where the blocks of pyroxene schist are found consists mainly of a series of gneisses and mica schists, usually containing amphibole, epidote, clinozoisite, chlorite, staurolite, and brucite. There are also rarer quartzites and quartzitic schists. Further south the predominant rocks are marbles. Between the marbles and the schists and the gneisses there is a transitional sequence of amphibolites and amphibole schists, sometimes containing garnet, zoisite, and calcite. Several different types of amphibole occur in the amphibolites, and have been determined optically as barroisitic hornblende, crossite, and glaucophane. Tućan (1936*b*) described an occurrence of glaucophanitic amphibole in a gneiss, and concluded that the loose blocks of pyroxene schist were derived from the transitional sequence of amphibolites.

Metamorphic rocks with sodic pyroxenes and amphiboles have been recorded from a number of places in Yugoslavia (fig. 1) but have been little studied (Majer, 1978; Nikitin and Klemen, 1938; Simić and Simić, 1963; Petkovič, 1952). They lie near contacts between metamorphic complexes and ophiolite belts in Serbia and Macedonia, in a comparable tectonic setting to blueschists in the Alps, Greece, and Turkey (Ackermand and Raase, 1973; Okrusch *et al.*, 1978; Okay, 1978).

Tućan decided that the pyroxene was derived from volcanic rocks, and his chemical analysis resembles a rock of spilite to keratophyre composition. The present investigation of several rock samples from the Aljagica region has revealed several with relict ophitic texture, and others with relict heteroblastic texture.

The results of microprobe analyses of plagioclase, micas and epidote-group minerals from the pyroxene schist are given in Table I. The plagioclase is virtually pure albite, and the white mica

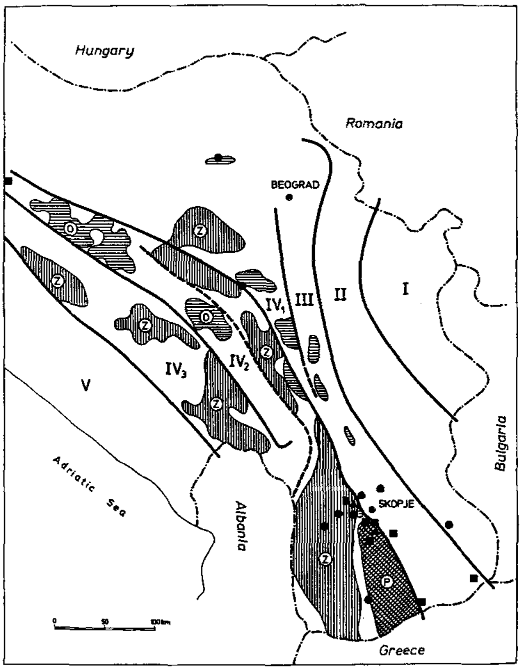

FIG. 1. Geological sketch-map of eastern Yugoslavia. Legend: I. Carpatho-Balkanide tectonic zone. II. Serbian-Macedonian Massifs. III. Vardar Ophiolite Belt. IV. Inner Dinarides (including western ophiolite belt): [IV_1 subzone of Upper Palaeozoic massifs and eastern part of ophiolite zone (harzburgite); IV_2 central ophiolite zone (lherzolite); IV_3 subzone of Upper Palaeozoic and Triassic Massifs]; V. Outer Dinarides. ▲ rocks with sodic pyroxenes ± sodic amphiboles. ● rocks with sodic amphiboles. ■ rocks with barroisitic amphiboles. P Pelagonian Crystalline Massif. Z Upper Palaeozoic Massifs. O Larger ultramafic massifs of western ophiolite belt.

TABLE I. *Microprobe analyses of plagioclase, micas, and clinozoisites from pyroxene schist*

	A	B	C	D	E
SiO_2	67.88	50.35	40.00	39.30	38.63
TiO_2	0.02	0.28	0.65	0.03	0.09
Al_2O_3	19.76	27.24	16.00	31.53	28.23
FeO*	0.34	4.26	17.90	1.87	6.77
MnO	—	0.06	0.17	0.0	0.05
MgO	—	2.27	11.38	0.10	0.19
CaO	0.59	0.02	0.13	22.85	24.04
Na_2O	10.52	0.16	0.82	0.20	0.0
K_2O	0.0	10.62	8.40	0.0	0.03
Total	99.11	95.26	95.45	95.88	98.02
Molecular proportions on the basis of 32 O (A), 22 O (B and C) and 12.5 O (D and E)					
Si	11.941	6.786	5.960	3.057	3.036
Al^{IV}	4.103	1.214	2.040	—	—
Al^{VI}	—	3.114	0.770	2.889	2.616
Ti	0.003	0.029	0.073	0.0	0.009
Fe	0.050	0.481	2.231	0.122	0.449
Mn	—	0.007	0.022	—	—
Mg	—	0.456	2.527	0.009	0.024
Ca	0.111	0.003	0.021	1.907	2.021
Na	3.588	0.040	0.238	0.028	—
K	0.0	1.825	1.596	—	—
Ab	97.0				
An	3.0				
Or	0.0				

* Total iron calculated as FeO.
— Not determined or not calculated.
0.0 Element analysed but not detected by microprobe.
A. Plagioclase, mean of six analyses.
B. White mica, mean of two analyses.
C. Biotite.
D and E. Clinozoisite.

Analyses performed by I. C. Young using the Cambridge Microscan Mark V Microprobe at University College, with Link EDS system.

contains about 4% FeO, and is thus phengitic muscovite. The proportion of Al^{IV} in the white mica indicates a celadonite content of about 40%, comparable with micas from other blueschists. The clinozoisite has a variable Fe content, due to zoning which can be recognized optically. The analyses of pyroxene (Table II) reveal two chemical types, one omphacite, the other sodic augite. The composition of the omphacite is similar to that from metabasites on the island of Siphnos in the Aegean, from the Tauern Window in the Alps, and from Turkey, all areas of blueschist-facies metamorphism. The paragenesis in the pyroxene schist, omphacite + albite + clinozoisite + phengitic muscovite + quartz, is analogous to the assemblage jadeite + albite + quartz in the pure Na_2O-Al_2O_3-SiO_2 system, and suggests that metamorphism took place under low-temperature, high-pressure conditions, characteristic of the blueschist facies. The two varieties of sodic pyroxene occur together in the fine-grained granoblastic pyroxene schist, although individual grains of the two varieties have not been seen in contact. It seems possible that the two pyroxenes may coexist in equilibrium, with a solvus gap between them.

Equilibrium stability relationships between omphacite, quartz, and albite have been reviewed by Turner, 1980 (177–9). There has been a considerable revision of Turner's assumptions and the experimental data upon which he based them (Essene and Fyfe, 1967), but this work has not yet progressed to the point where pyroxene compositions can be converted into temperatures and pressures under the relatively low temperature conditions we are discussing here. For a review

TABLE II. *Microprobe analyses of sodic pyroxenes from pyroxene schist*

	A		B	
SiO_2	54.91		51.22	
TiO_2	0.09		0.08	
Al_2O_3	10.44		3.12	
FeO*	9.05		14.45	
MnO	0.03		0.14	
MgO	5.35		7.90	
CaO	13.53		21.33	
Na_2O	6.44		1.63	
K_2O	0.01		0.02	
Total	99.85		99.89	
Molecular proportions on the basis of 6 O				
Si	2.000	2.000	1.963	2.000
Al^{IV}	0.0		0.037	
Al^{VI}	0.448	1.017	0.073	0.995
Ti	0.002		0.003	
Fe	0.276		0.463	
Mn	0.001		0.005	
Mg	0.290		0.451	
Ca	0.528	0.983	0.876	0.998
Na	0.455		0.120	
K	0.0		0.002	
End members, calculated after Cawthorne and Collerson, 1974				
Jadeite	28.8		5.6	
Wollastonite	34.2		47.3	
Enstatite	18.8		24.5	
Ferrosilite	17.3		21.4	
Ca–Ti tschermakite	0.1		0.2	
Acmite	0.7		1.0	

A. Omphacite, mean of four analyses.
B. Sodic augite, mean of two analyses.
Other notes as for Table I.

of the present state of the experimental and theoretical work, see Holland (1979, 1980). Here, we give the pressures estimated by Turner's method purely as an indication of the order of pressures under discussion. Omphacite A of Table II would coexist with albite + quartz at 7.1 kbar at 200 °C and 8.5 kbar at 300 °C. The presence of phengite rather than muscovite as the white mica suggests this low temperature range, and if temperature were higher the pressure would also be higher. Okrusch *et al.* (1978) have also considered temperature and pressure in an assemblage quartz + omphacite + phengite + epidote . . . . + paragonite + glaucophane + garnet. K_D between garnet and omphacite suggested a temperature in the range 450–500 °C and omphacite + albite + quartz stability a pressure of 14 kbar. However, the omphacite in their sample had a higher jadeite content (Jd_{88}) than ours, so their pressure is likely to be higher.

We conclude that the 'jadeitite' described by Tućan is an omphacite fels, formed by low-temperature, high-pressure metamorphism of a rock which was originally of the spilite–keratophyre suite. The metamorphic conditions fall into the blueschist facies. The presence of blueschists at the boundary between the Pelagonian Massif and the Vardar Ophiolite Belt may indicate that the boundary is the site of an ancient subduction zone (Ernst, 1973). Further investigations are needed to confirm this conclusion, and also to date the metamorphic event.

REFERENCES

Ackermand, D., and Raase, P. (1973) *Contrib. Mineral. Petrol.* **42**, 333–41.
Ernst, W. G. (1973) *Tectonophysics*, **17**, 255–72.
Essene, E. J., and Fyfe, W. S. (1967) *Contrib. Mineral. Petrol.* **15**, 1–15.
Holland, T. J. (1979) *Am. Mineral.* **65**, 129–34.
——(1980) *Eos*, **60**, 405 (abstract).
Majer, V. (1978) *Geol. vjesnik*, **30/2**, 477–80.
Nikitin, W., and Klemen, R. (1938) *Neues Jahrb. Mineral. Abh.* **74**, 36–49.
Okay, A. I. (1978) *Contrib. Mineral. Petrol.* **68**, 7–11.
Okrusch, M., Seidel, E., and Davis, E. N. (1978) *Neues Jahrb. Mineral. Abh.* **132**, 284–308.
Petkovič, M. (1952) *Geol. anali Balk. pol.* **20**, 137–45.
Simić, M., and Simić, V. (1963) *Trudovi*, **10**, 125–36.
Tućan, F. (1936*a*) *Glasnik Hrv. Prir. Dr.* **41–48**, 91–100.
——(1936*b*) *Rad JAZU*, **256**, 141–94.
Turner, F. J. (1980) *Metamorphic Petrology.* McGraw-Hill, New York.

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