The Canadian Mineralogist
Vol. 33, pp. 585-608 (1995)

RODINGITES OF THE EASTERN PART OF THE JORDANÓW – GOGOŁÓW SERPENTINITE MASSIF, LOWER SILESIA, POLAND

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Abstract

Rodingites from the Jordanów–Gogołów massif (Lower Silesia, southwestern Poland) formed from two types of protolith, mafic rocks and albitites or plagiogranites. The formation of Ca-silicates predates that of the CaMg-silicates. The formation of the Ca-silicates is probably related to low-temperature ocean-floor metamorphism, whereas the CaMg-silicates seem to be products of younger greenschist-facies continental metamorphism (possibly of Variscan age). Calc-silicate rocks from the "leucocratic zone" at Jordanów are unusual metarodingites, since their formation included rodingitization of plagiogranite, thermal metamorphism or metasomatism of an apophysis of Variscan granite, several episodes of brittle deformation involving cementation of older rocks by newly formed minerals, and late Variscan as well as post-Variscan alteration.

Keywords: rodingite, ophiolite, ocean-floor metamorphism, continental metamorphism, eastern Sudetes, Poland.

Sommaire

Les rodingites du massif de Jordanów–Gogołów, en Basse Silésie, dans le sud-ouest de la Pologne, se sont formées aux dépens de deux types de protolithes, roches mafiques et albitite ou plagiogranite. La formation des silicates de Ca, antérieure à celle des silicates de Ca–Mg, serait due à un métamorphisme à faible température, dans un contexte océanique. Les silicates de Ca–Mg, par contre, semblent résulter d'un épisode de métamorphisme continental, peut-être d'âge varisque, à des conditions du faciès schistes verts. Les roches à calc-silicates de la zone "leucocrate" à Jordanów sont des métarodingites exceptionnelles vue leur évolution génétique complexe, comprenant rodingitisation d'un plagiogranite, métamorphisme de contact ou métasomatose près d'une apophyse de granite varisque, plusieurs épisodes de déformation cassante, avec cicatrisation par des minéraux néoformés, et altération d'âge varisque tardif ou nettement postérieure à l'orogenèse varisque.

(Traduit par la Rédaction)

Mots-clés: rodingite, ophiolite, métamorphisme océanique, métamorphisme continental, Sudètes orientales, Pologne.

Introduction

A rodingite is a Ca-rich, SiO_2-undersaturated rock that forms as a by-product of serpentinization. Rodingitic rocks consist of Ca–Al and Ca–Mg silicates such as grossular, epidote, vesuvianite and diopside. The presence of such calc-silicate rocks in the eastern part of the Jordanów–Gogołów serpentinite massif (Lower Silesia, Sudetes, southwestern Poland) has attracted the interest of geologists because of the occurrence of nephrite (*e.g.*, Traube 1885, Gaweł 1957, Heflik 1967). The purpose of this study is to present new data on the origin of the rodingites.

Geology

The Jordanów–Gogołów serpentinite massif is located close to the northern border of the Sowie Góry Mountains Block (Figs. 1A, B). This massif is the largest of three serpentinite massifs adjacent to that block. They are interpreted to be serpentinized mantle tectonites of a highly dismembered ophiolite sequence (Pin *et al.* 1988, Gunia 1992). The serpentinites are considered to be the lower part of the Ślęża ophiolitic sequence (Majerowicz 1979, Narębski *et al.* 1982, Narębski & Majerowicz 1985), of upper Paleozoic age (about 350 Ma, Pin *et al.* 1988).

Mafic members of the ophiolite suite include gabbro, metagabbro, and greenschist (believed to be metamorphosed sheeted dykes), some of which (*e.g.*, metagabbro and metamorphosed sheeted dykes adjacent to Jordanów–Gogołów serpentinites) have an N-MORB geochemical affinity (Pin *et al.* 1988). Other mafic rocks (metamorphosed extrusive rocks) with an affinity to both ocean-floor tholeiites and island-arc tholeiites (Narębski *et al.* 1986) seem to be dis-

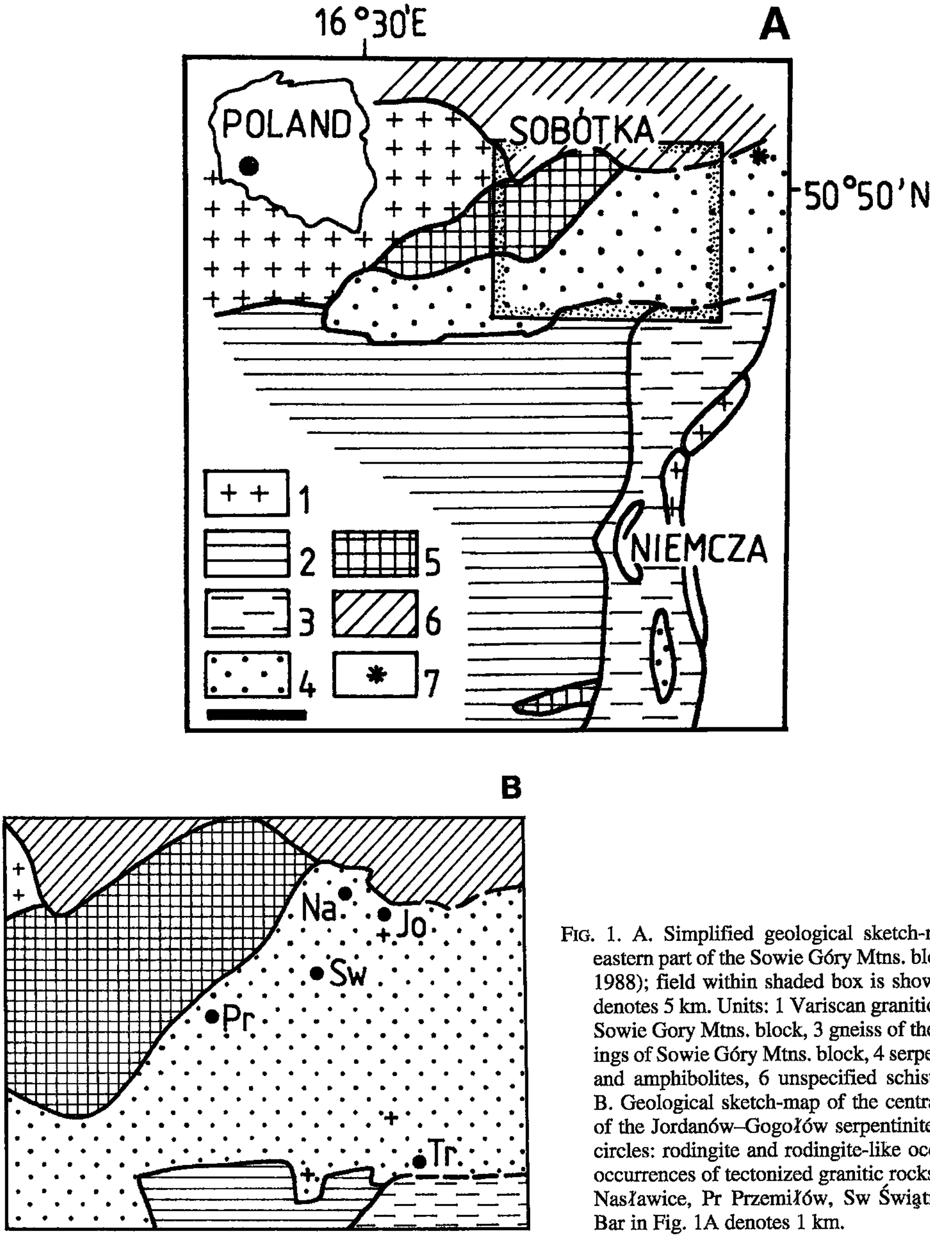


FIG. 1. A. Simplified geological sketch-map of the northeastern part of the Sowie Góry Mtns. block (after Pin *et al.* 1988); field within shaded box is shown as Fig. 1B. Bar denotes 5 km. Units: 1 Variscan granitic rocks, 2 gneiss of Sowie Gory Mtns. block, 3 gneiss of the eastern surroundings of Sowie Góry Mtns. block, 4 serpentinites, 5 gabbros and amphibolites, 6 unspecified schists, 7 Przecławice. B. Geological sketch-map of the central and eastern part of the Jordanów–Gogołów serpentinite massif. Symbols: circles: rodingite and rodingite-like occurrences, crosses: occurrences of tectonized granitic rocks, Jo Jordanów, Na Nasławice, Pr Przemiłów, Sw Świątniki, Tr Trzebnik. Bar in Fig. 1A denotes 1 km.

membered fragments of the same ophiolite sequence. Extensive Hercynian deformation resulted in tectonic dismemberment of the Ślęża ophiolite.

The Sowie Góry Mountains block is one of the largest geological units of the Sudetes and is considered to be the oldest or among the oldest geological structure in Lower Silesia. It is composed of gneiss, migmatitic gneiss, and minor granulite, serpentinite, ultramafic rocks, amphibolite, and marble. The Sowie Góry Mtns. block (Fig. 1A) is believed to be a nappe emplaced in Carboniferous time (Pin *et al.* 1988), *i.e.*, soon after ophiolite formation. Cymerman (1990) suggested that the Sowie Góry Mtns. block is a fragment detached from the Bohemian Massif. Major deformation and metamorphic events recorded in the Sowie Góry Mtns. block took place during the upper Devonian (Żelaźniewicz 1987). Structural development of gneiss in the eastern margin of Sowie Góry Mtns. is attributed to a syntectonic process of progressive low-pressure metamorphism and to the intrusion of Variscan magmas (Dziedzic 1985). The northeastern part of Sowie Góry Mtns. block, adjacent to the Jordanów–Gogołów serpentinites, is mostly covered by Cenozoic sediments.

The Jordanów–Gogołów massif displays tectonic contacts with adjacent geological structures such as the Sowie Góry Mtns. Block and Variscan granitoids (Majerowicz 1979). However, late Variscan leucocratic apophyses penetrated the serpentinites, giving rise to the formation of contact metamorphic zones (at present these zones are altered: Dubińska & Wiewióra 1988, Jelitto *et al.* 1991).

Ultramafic rocks and serpentinites

According to Majerowicz (1963), Maciejewski (1963), and Heflik (1967), the Jordanów–Gogołów massif consists of highly serpentinized peridotite with a wide range of textural varieties: pseudomorphic serpentinite with mesh textures and "bastite", antigorite-bearing serpentinite, chrysotile asbestos, and antigorite veins.

Jędrysek (1989) proposed a model of serpentinization of Jordanów–Gogołów ultramafic rocks based on oxygen and hydrogen isotopic compositions. Antigorite was attributed to the initial and incomplete serpentinization on the ocean floor, whereas lizardite, considered to be younger than antigorite, formed from meteoric water, probably during bulk serpentinization in a continental setting. The origin of chrysotile was not well constrained.

Chromite, present in a small body of podiform chromitite (Spangenberg 1943), and different generations of magnetite and their alteration products (hematite, goethite), are common in the serpentinites. Chalcopyrite, pyrite, as well as rare sphalerite, marcasite, bornite, valleriite, and bravoite also were identified. They may have formed by the penetration of Variscan fluids into the ultrabasic rocks (Niśkiewicz 1989, Sałaciński 1992).

Veins and intergrowths of carbonates (magnesite, dolomite, aragonite and calcite), opal, and chalcedony are common within the Jordanów–Gogołów massif. Observations with a scanning electron microscope (SEM) by Jelitto *et al.* (1991) and Dubińska *et al.* (in press) indicate a post-Variscan formation of carbonate. The isotopic data of Jędrysek & Hałas (1990) suggest a biogenic origin of carbon in the magnesite, dolomite, and aragonite.

Rodingites and leucocratic rocks

Past studies of rodingites in the Jordanów–Gogołów massif identified the following calc-silicate rocks: 1) garnet–vesuvianite rodingites, formed at the expense of gabbro or dolerite bodies (Majerowicz 1984, Dubińska 1989), 2) clinozoisitic rodingites, probably developed from a leucocratic protolith (Dubińska 1989), and 3) a group of calc-silicate rocks from the leucocratic zone at Jordanów, considered as rodingite formed at the expense of gabbro (Heflik 1982).

Several occurrences of blastocataclastic or blastomylonitic leucocratic rocks, composed of quartz, microcline, and oligoclase, were found within the Jordanów–Gogołów serpentinites (including the leucocratic zone at Jordanów, Fig. 1B). Some of these rocks are believed to consist of plagiogranite (Narębski *et al.* 1982), although they contain fractured but unaltered microcline and are rich in K (Dubińska & Szafranek 1990, and unpubl. data). The leucocratic rocks may be associated with vermiculite-bearing schists at their contacts with the serpentinites; vermiculite was formed by transformation of the trioctahedral mica (Dubińska & Wiewióra 1988). Formation of Ca-silicates at the expense of the tectonized leucocratic rocks had not been reported before.

Materials and Methods

The mineral assemblages presented in this paper are based on petrographic examination of about 400 samples representing diverse rock-types (calc-silicate rocks, serpentinites, tectonized leucocratic rocks, granite–serpentinite contact schists from Jordanów and Wiry, carbonate and silica veins, serpentine and amphibole asbestos).

X-ray powder-diffraction patterns (DRON–1 and DRON–2A diffractometers, Co*K*α and Cu*K*α radiation) were obtained for most of the samples; all parts of the macroscopically inhomogeneous samples were checked separately. The serpentines were identified optically (Wicks & O'Hanley 1988) as well as by routine X-ray diffraction (XRD) using the powder method. Chlorites, corrensite, intermediate chlorite–vermiculite, and smectite were identified by XRD (oriented specimens, ethylene glycol and glycerol treatment of samples saturated with Na^+ and Mg^{2+}, respectively, with heating). Polytype determinations of chlorites and intermediate chlorite–vermiculite were made using oblique texture method (Wiewióra & Weiss 1985).

Representative samples were studied by wet-chemical analysis. In most samples, mineral compositions were determined by electron microprobe (JEOL–JXA–840A – AN–1000/855 electron microscope, 15 kV, 35 nA, ZAF correction procedure, using synthetic silicates as well as natural minerals as standards). In other samples, the composition of minerals was deduced from optical and XRD data combined with the bulk chemistry of the rock.

Serpentinite textures were optically identified using the criteria of Wicks & Whittaker (1977), Wicks & Plant (1979), Wicks (1984), and Wicks & O'Hanley (1988).

The nature of the serpentinites

Unaltered ultramafic rocks in the Jordanów–Gogołów massif are rare and randomly distributed, whereas completely serpentinized rocks are very common. The serpentinites are highly fractured and tectonized from a macroscopic to a microscopic scale. Mylonitized zones and highly sheared serpentinites are ubiquitous. The distribution of the different varieties of serpentinites seems to be related to tectonic displacement; huge blocks and boudins of pseudomorphic serpentinite are juxtaposed with a variety completely obliterated by blades of younger antigorite and with mylonitized wedges of serpentinite; all varieties of serpentinite are present within one serpentinite quarry at Nasławice (Fig. 1B).

Pseudomorphic serpentinite, usually without relict minerals, seems to be the earliest textural variety (Fig. 2A). However, the modal composition of the ultramafic protolith (harzburgite and dunite, seldom wehrlite) can easily be identified owing to the pseudomorphic replacement after olivine and orthopyroxene ("bastite"), either uniform or intergrown with small grains of magnetite. Some examples of pseudomorphic serpentinite contain several generations of chrysotile veinlets (<0.5 mm in thickness). The latter include oblique veinlets cross-cutting only "bastite" and veins that cross-cut both hourglass textures and "bastite" (Fig. 2B). Antigorite blades, in some cases showing an interlocking texture, partly obliterate the pseudomorphic serpentinites. However, the distribution of opaque minerals in these rocks commonly preserves the pattern typical of pseudomorphic textures *e.g.*, small grains of magnetite are arranged parallel to the (100) partings of the former pyroxene (Fig. 2C), with perfectly preserved ghosts of their exsolution lamellae, commonly kink-banded, as well as ghosts of the pyroxene cleavages, and of the holly-leaf pattern of former grains of AlCr-rich spinel. Lizardite rosettes (Fig. 2D), which formed at the expense of almost all previously

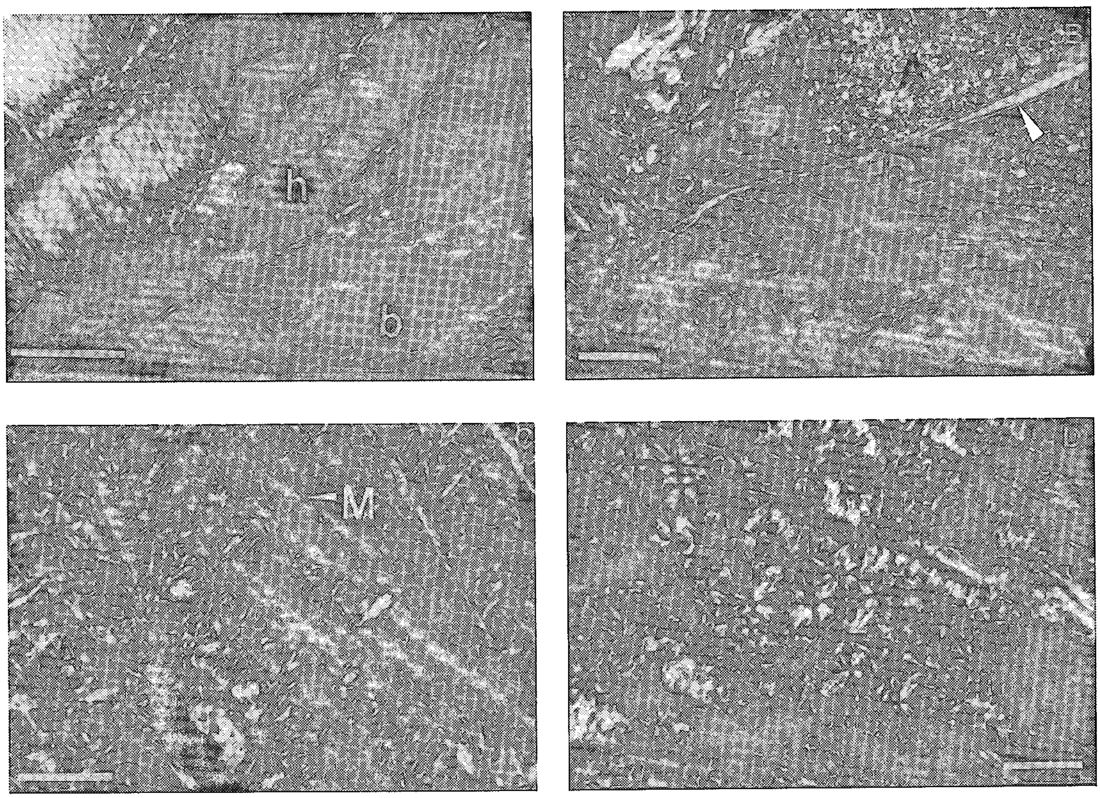


FIG. 2. A. Pseudomorphic lizardite serpentinite with "bastite" (b) and hourglass (h) textures after olivine, opaque minerals (magnetite); sample Na28, crossed polars, scale bar 100 µm. B. Pseudomorphic serpentinite (b: bastite) partly intergrown with blades of antigorite (A) and oblique chrysotile asbestos veinlet (C); sample Na42, crossed polars, scale bar 100 µm. C. Interlocking bastite (B) intergrown with antigorite blades (A) and magnetite grains (M) arranged in parallel to the previous (100) partings of pyroxene; sample Jo24, crossed polars, scale bar 500 µm. D. Lizardite rosettes; serpentinite formed at the expense of the pseudomorphic variety, similar to that in Figure 2A; sample Na3, crossed polars, scale bar 100 µm.

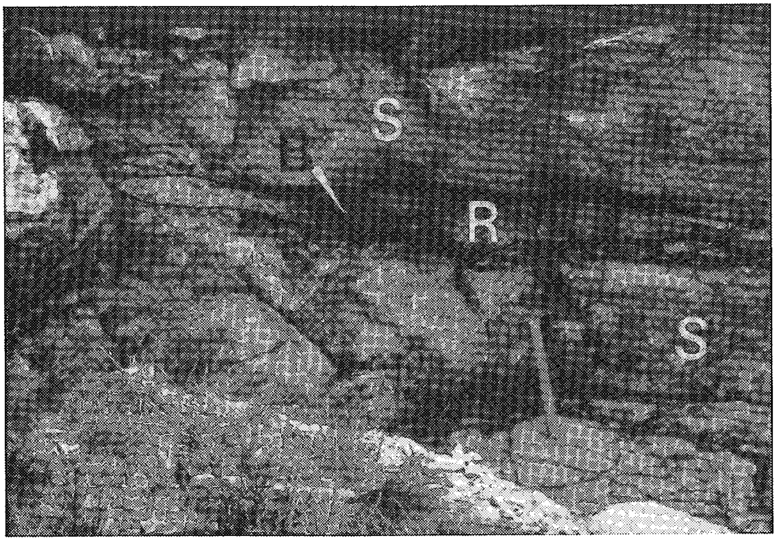


FIG. 3. Rodingitized and tectonized mafic dyke, eastern wall of the Przemiłów quarry. R: boudin of garnet–vesuvianite rodingite, with accessory relict clinopyroxene (sample Pr1; Table 1, 3a). B: chlorite – intermediate chlorite – vermiculite blackwall. S: serpentinite (pseudomorphic variety with bastite and mesh hourglass textures, part of which is obliterated by blades of antigorite, leading to the formation of an interlocking texture, with four or five generations of chrysotile asbestos veins and veinlets).

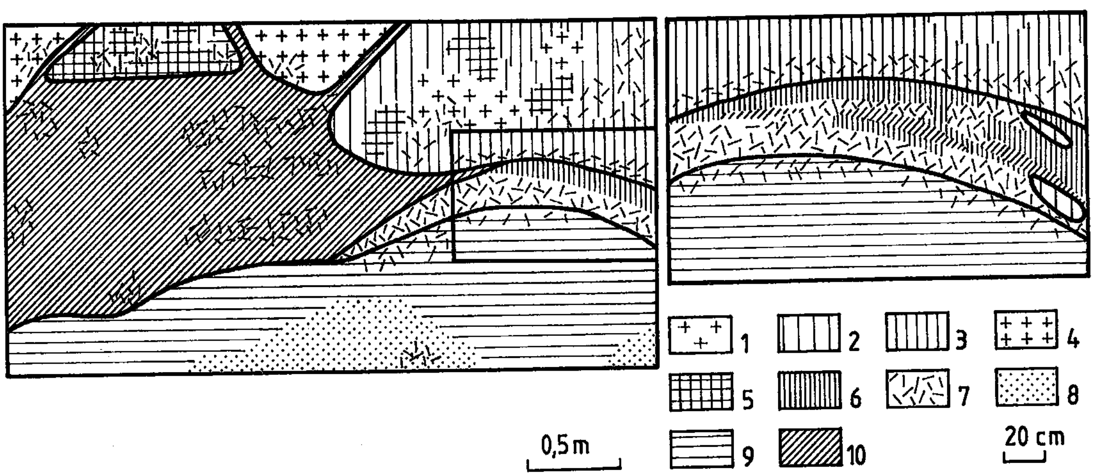


FIG. 4. Schematic sketch of contact between leucocratic zone and serpentinite, along the western wall of the nephrite quarry at Jordanów (Jo in Figure 1B). Right-hand sketch shows details of the framed part in the left-hand sketch; 1 plagiogranite, 2 rodingite composed of zoisite (± garnet), 3 rodingite composed of zoisite (± garnet) and diopside, 4 tectonized leucocratic granite, 5 tectonic breccia composed of rodingite fragments cemented by quartz, 6 clinozoisite-rich rocks intergrown by younger tremolite, 7 nephrite and rocks highly intergrown with tremolite or Mg-rich actinolite, 8 antigorite-bearing (non-pseudomorphic) serpentinite, 9 serpentinite overprinted by talc and tremolite, 10 serpentinite – granite contact schists composed of vermiculite – chlorite – tremolite (± talc).

described rocks, also were identified. Wide (up to 2 m) cross-fiber chrysotile asbestos seems to be the youngest serpentine within the Jordanów–Gogołów serpentinites. The asbestos veins commonly contain fragments of previously formed serpentinites and agglomerates of euhedral grains of magnetite.

Serpentinite adjacent to the leucocratic zone at Jordanów commonly contains talc, chlorite, and acicular tremolite formed at the expense of nonpseudomorphic antigorite serpentinite, with of without relics of a pseudomorphic texture. Al–Cr-rich (>15 wt% Cr_2O_3) primary spinel was pseudomorphically replaced by magnetite preserving the original holly-leaf pattern.

Field relationships of the rodingites

Different textural and compositional varieties of rodingites seem to be randomly distributed within the eastern part of Jordanów–Gogołów massif; almost all types of rodingites are present within one serpentinite quarry at Nasławice (Fig. 1B). The rodingites form small, lenticular, oval or irregularly shaped tectonic inclusions (<0.5 – ~20 m in length) within bodies of serpentinite (Fig. 1B). The serpentinite adjacent to the rodingitic bodies is highly sheared. Hand specimens of rodingite are commonly fine- to medium-grained inhomogeneous rocks, in cases porous, whitish, pinkish, greyish, and greenish in color. Dark grey or green streaks, spots, and irregularly shaped inclusions within the boudins are identified as fragments of tectonized chlorite blackwall or serpentinite. Metasomatic zones, known from other occurrences of rodingite (*e.g.*, Leach & Rodgers 1978) are dismembered, highly fragmented and mylonitized. Only one continuous mafic dyke was found within the Jordanów–Gogołów serpentinites, and it is extensively rodingitized and tectonized (Fig. 3).

The calc-silicate rocks from Jordanów occur in two adjacent zones: one of ~20–25 m (Fig. 4) is locally labeled as the leucocratic zone (Heflik 1967), and the other is ~5 m wide (both together with tectonized granite, nephrite, and altered contact talc – chlorite – mica schists form between granite and serpentinite: Dubińska & Wiewióra 1988, Dubińska & Szafranek 1990).

Petrography of the Rodingites

Petrographic characteristics of the calc-silicate rocks are summarized in Table 1 (rodingites) and Table 2 (rodingites and other calc-silicate rocks from the leucocratic zone).

Rodingites

The rodingites exhibit a variety of textures, some of which are indicative of brittle deformation, and others, ductile deformation (Fig. 5A). Completely mylonitized zones (Fig. 5B) and numerous minerals formed after an episode of granulation (Fig. 5B) also are observed. Highly metasomatized but undeformed rocks (Fig. 5C), as well as rocks with a blastomylonitic or blastocata-

TABLE 1. PETROGRAPHIC FEATURES OF RODINGITES FROM EASTERN PART OF JORDANÓW-GOGOŁÓW SERPENTINITE MASSIF

relict minerals	"rodingitic" minerals			"post-rodingitic" minerals	texture
	CaAl-silicates	Ca(±Al)Mg -silicates	other minerals		
				TYPE-A RODINGITES	
Cpx with (100) partings, Ap acc.), Phl (rare)	Grt (Grs-rich), Ep**, Ttn (acc.)	Ves*	Chl	earlier generation: Di; (?hydro)Adr, sometimes Ti-bearing; K-bearing intermediate mineral younger generation:Dol, Mgs, Ser**	relict minerals: granular "rodingitic" Ca-silicates: granoblastic, usually cataclastic or mylonitic, often porous, blastomylonitic or blastocataclastic, with younger veinlets and pockets in sheared matrix "post-rodingitic" minerals: granoblastic (Ca-silicates), veins & intergrowths: carbonates
				TYPE-B RODINGITES	
Pl (An1-4), Zrn (acc.), Ap (acc.)	Czo, Zo, Grt (Grs or Mn-bearing Grs), Ttn (acc.), An (acc.)	Di	Chl, Cor	Prh, Wai (rare), Ad (frequently Ba-bearing), late Chl, carbonates	relict minerals: hihgly mylonitized "rodingitic" Ca-silicates: Czo and/or Zo - frequently sheared; sheared fragments sometimes inside atolls of Grt or rimmed by Grt; Di - granular aggregates or spherulites "post-rodingitic" minerals: Prh, Ad, late chlorite - veinlets, small pockets, intergrowths, pseudomorphic replacement; carbonates - late intergrowths
				TYPE-C RODINGITES	
	Grt (Grs), Zo		Chl	opal-CT, S, carbonates	Ca-silicates: granoblastic, frequently sheared "post-rodingitic" minerals: pockets, intergrowths, pseudomorphic replacement

Symbols: Ad adularia, Cor corrensite, Pl plagioclase, S smectite, Ser sericite, Wai wairakite; other abbreviations after Kretz (1983). Acc.: accessory. * The distribution of Fe and Ti is commonly found to be inhomogeneous. ** Minerals found in rodingite from drill core, asterisk in Figure 1A.

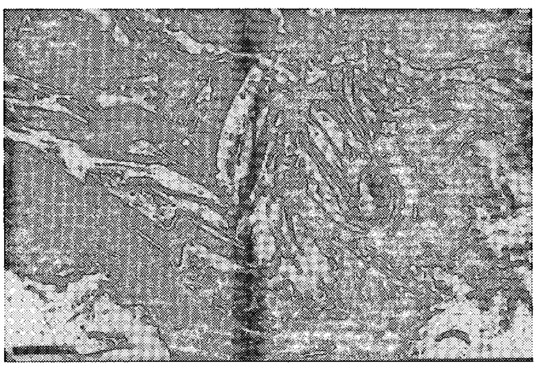
TABLE 2. PETROGRAPHIC FEATURES OF CALC-SILICATE ROCKS FROM LEUCOCRATIC ZONE AND RODINGITES FROM JORDANÓW

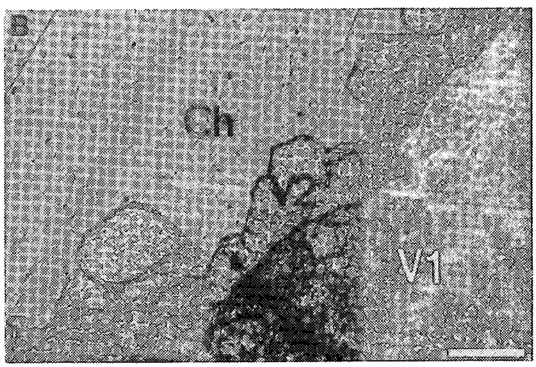
relict minerals	"rodingitic" minerals		"post-rodingitic" minerals	texture
	CaAl-silicates	CaMg-silicates		
			LEUCOCRATIC ZONE	
			samples containing relict feldspar	
chess-board Ab	Zo, Grt (Grs-rich)	Di	fibres or needles of Tr, veinlets of Prh, veinlets and intergrowths of Ad, Ab (newly formed, veinlets), Mor (rare), Vrm (rare, acc.)	relict feldspars - blastomylonitic or blastocataclastic; Zo & Grt - euhedral or mortar; Di - granular or spherulites; Mor - late intergrowths
			tectonic breccias of above rocks cemented by Qtz	
	Zo, Grt (Grs-rich)	Di	Qtz, Oli (scarce), fibers of Tr, Ad (sometimes Ba-bearing) intergrowths and veinlets	fragments of zoisite or garnet (or both) rocks cemented by quartz and overprinted by tremolite; oligoclase - small fragments in quartz matrix
			nephrite and Tr-rich rocks	
	Zo, Grt (Grs-rich)	Di	Qtz, Czo, fibers or needles of Tr, Chl, holly leaf Mag surrounded by Uva, Ttn (acc.), veinlets of Ad, Ab, and Prh	Tr-rich rock with framents of various previously formed rock, usually obliterated by Tr; late Ad, Ab, and Prh veinlets
			tectonized leucocratic granitic rocks	
Qtz, Mc, Oli			fibers of a monoclinic amphibole, Vrm (scarce)	blastocataclastic, intergrown with amphibole formed after granulation
			SEPARATE RODINGITIC BODIES	
	Grt (Grs-rich)	Ves (scarce)	opal-CT	mylonitized Grt with Ves veinlets, Grt breccias cemented by Ves, opal-CT in fissures

Mor - mordenite, Oli - oligoclase, Uva - uvarovite; for other abbreviations see Table 1; * - tremolite-poor fragments; acc. - accessory

clastic texture, may be porous; porosity seems to result from the increasing density of newly formed minerals.

Three distinct groups of rodingites were identified, based on the types of relict minerals present: group-A rodingites contain relict diopsidic clinopyroxene (Table 3), with (100) partings and multiple twinnings, group-B rodingites contain chess-board relict albite (Ab_{99}), and group-C rodingites do not contain relict





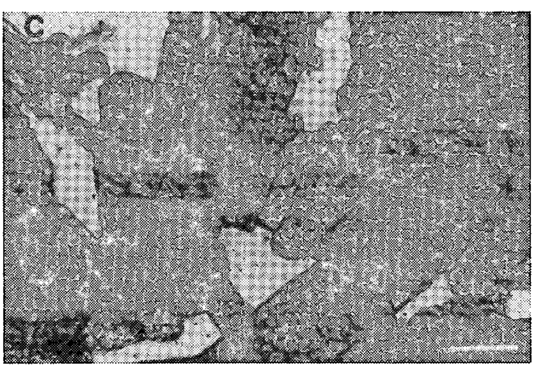


FIG. 5. A. Deformed garnet–vesuvianite (dark fields) in completely sheared rodingite; clear fields: mylonitized chlorite (tectonized blackwall?), sample Na48D, plane light, scale bar 50 µm. B. Fragment of brecciated garnet–vesuvianite (V1) rock; chlorite (Ch, with twin) replaced by newly formed vesuvianite (V2); sample Na53A, partly crossed polars, scale bar 100 µm. C. Vuggy texture of clinozoisite rodingite; porosity reflects an increase in density of newly formed minerals; sample MTNa21, plane light, scale bar 50 µm.

TABLE 3. REPRESENTATIVE COMPOSITION OF CLINOPYROXENE FROM RODINGITES

	relict cpx *with(100) partings*		newly formed				
	type-A rodingites				*type-B rodingites*		
sample weight %	Na621A	Pr8	Na48D	Na621A	Na15C	Na58B	Na69B
SiO_2	53.47	54.33	54.48	54.43	53.68	52.85	54.22
TiO_2	0.26	-	-	0.05	0.06	0.02	-
Al_2O_3	2.16	0.02	0.25	0.12	0.66	3.06	0.89
Cr_2O_3	0.04	0.06	n.d.	0.05	0.01	-	0.02
Fe_2O_3tot.							
FeOtot.	1.44	2.71	0.50	2.04	3.56	0.18	1.99
MnO	0.15	0.06	0.55	0.11	0.09	0.07	0.30
NiO	-	0.10	n.d.	0.03	0.09	n.d.	-
MgO	16.15	16.42	18.11	16.59	15.82	17.13	16.42
CaO	26.04	25.74	26.51	25.62	25.55	26.11	25.72
BaO	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
K_2O	0.09	0.06	-	0.01	0.01	0.45	0.03
Na_2O	-	-	-	-	0.08	0.04	0.18
total	99.80	99.50	100.40	99.05	99.61	99.91	99.77
			on the basis of 6 oxygens				
Si	1.95	2.00	1.97	2.00	1.98	1.93	1.98
Ti	0.01						
Al	0.09		0.01	0.01	0.03	0.12	0.03
Fe^{2+}tot	0.04	0.08	0.02	0.06	0.11	0.01	0.06
Mn			0.02				
Mg	0.88	0.90	0.98	0.91	0.87	0.92	0.89
Ca	1.02	1.01	1.03	1.01	1.01	1.01	1.00
K						0.02	
Na					0.01		0.01

n.d. - not determined

minerals.

Rodingites of group A, whose relics are close to the diopside end-member in composition (Table 3, Fig. 6), are relatively common in the Jordanów–Gogołów massif. Two generations of Ca-silicates are inferred from petrographic observations; the first generation is represented by grossular (Table 4), and the second generation, by vesuvianite (Mg-rich variety, Table 4, Fig. 7A). In many samples, garnet is almost completely sheared or replaced by younger vesuvianite; the shearing may be manifested as inclusions of serpentine in Ca-silicates (Table 5). Granulation and recrystallization of the vesuvianite are common, usually without significant modification of the mineral composition. However, some samples contain zoned vesuvianite with increasing Fe content toward the rim (Table 4, Fig. 6). Several areas consisting of hydroandradite (*e.g.*, in samples Pr2 and Na48D, Table 4) and small prisms of diopside (*e.g.*, in samples Na48D and Na621A, Table 3) replaced the matrix of mylonitized vesuvianite (Fig. 7B). Euhedral fine prisms of diopside, and small grains of hydroandradite, some of them containing more than 2% TiO_2 (Fig. 6, Table 4, sample Sw10C), also were found in highly tectonized fragments of chloritic blackwall included in rodingite bodies.

A K-bearing chlorite–vermiculite intermediate mineral (as defined by Brindley 1980) and minute

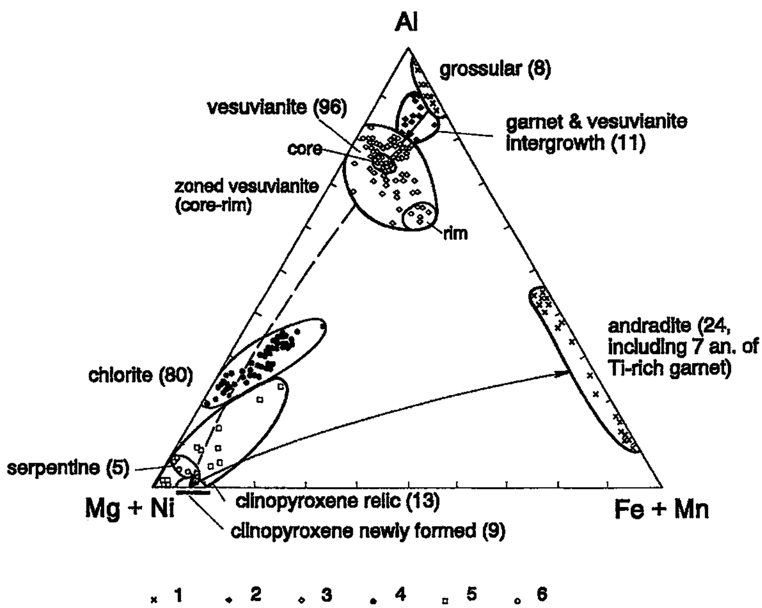


FIG. 6. Chemical composition of major minerals (atomic ratios) from group-A rodingites; 1 garnet, 2 garnet and vesuvianite intergrowths, 3 vesuvianite, 4 chlorite, 5 relict clinopyroxenes [with (100) parting], 6 serpentine (tectonic inclusions in large grains of vesuvianite); bar represents section of newly formed clinopyroxene composition; numbers in parentheses denote number of microprobe analyses. Overlapping analyses are not shown; arrows show directions of the evolution in mineral composition.

TABLE 4. REPRESENTATIVE COMPOSITION OF VESUVIANITE AND GARNET FROM RODINGITES

	VESUVIANITE					GARNET						
	A-TYPE RODINGITES								B-TYPE RODINGITES			
sample	Pr8		Sw10C		Na621A	Sw20	Sw10C	Na48D	Na58B	Na61		Na15D
weight %	core	rim	spotted vesuvianite							Mn-rich	Mn-poor	
SiO_2	37.63	36.86	37.10	37.70	36.85	38.23	36.46	36.18	39.96	38.62	39.34	37.88
TiO_2	0.03	0.07	1.35	0.11	2.56	0.59	2.66	0.01	0.03	0.62	0.18	0.41
Al_2O_3	17.60	13.81	16.91	15.28	13.38	21.75	7.89	3.31	22.50	20.55	21.62	21.48
Cr_2O_3	0.05	-	0.04	0.17	-	n.d.	2.30	0.02	n.d.	0.30	0.07	0.30
FeOtot.	1.56	6.94	3.26	5.49	5.68	1.52	13.96	23.22	0.23	2.41	1.37	2.94
MnO	0.03	0.03	0.04	0.17	0.06	0.18	0.04	0.04	0.13	3.19	0.41	4.03
NiO	0.07	0.06	0.01	0.12	-	n.d.	-	n.d.	n.d.	-	-	n.d.
MgO	3.11	2.87	2.22	2.53	2.78	-	0.29	-	-	-	0.11	0.11
CaO	36.33	35.75	36.35	36.20	35.93	36.99	35.63	32.76	37.25	34.40	36.74	32.83
K_2O	0.04	0.06	-	-	-	-	0.08	0.01	0.03	0.07	0.03	0.01
Na_2O	-	0.04	-	-	-	-	0.08	-	0.01	0.08	0.01	-
total	96.45	96.49	97.28	97.77	97.28	99.26	99.39	95.55	100.14	100.24	99.98	99.72
	on the basis of 50 cations					*on the basis of 12 oxygens*						
Si	18.19	18.11	18.00	18.25	18.09	2.91	2.92	3.05	3.00	2.94	2.97	2.90
Ti	0.01	0.03	0.49	0.04	0.87	0.03	0.16			0.04	0.01	0.02
Al	10.03	7.99	9.67	8.72	7.73	1.95	0.75	0.33	1.99	1.85	1.93	1.94
Cr	0.02		0.02	0.07			0.14			0.02		
Fe^{3+}*		1.99		1.15	1.43	0.10	0.94	1.60	0.01	0.15	0.09	0.14
Fe^{2+}*	0.63	0.86	1.32	1.07	0.94			0.03	0.01			0.04
Mn	0.01	0.01	0.02	0.07	0.02	0.01			0.01	0.21	0.03	0.15
Ni	0.02	0.02		0.04								
Mg	2.24	2.10	1.60	1.82	2.02		0.03				0.01	0.01
Ca	18.81	18.81	18.88	18.79	18.89	3.02	3.06	2.96	2.99	2.81	2.97	2.69

Samples: Pr8: zoned vesuvianite, Sw10C: inhomogeneous spotted vesuvianite, Na621A: vesuvianite adjacent to grain of relict pyroxene.
* In the case of vesuvianite: Fe^{3+} and Fe^{2+} contents were calculated from the formulas: $Fe^{3+} = Mg + Fe_{tot} + Mn - 3/19\ Ca$; $Fe^{2+} = Fe_{tot} - Fe^{3+}$.
In the case of garnet, the proportion of Fe^{2+} and Fe^{3+} was calculated according to the procedure of Evans *et al.* (1979).

inclusions of phlogopite in vesuvianite were commonly found in blackwall from the Przemiłów rodingite dyke (Table 5, Figs. 3, 8). According to an X-ray oblique texture study (Wiewióra & Weiss 1985), the intermediate mineral is present as the Ia polytype, whereas a clinochlore from the same blackwall is present as the IIb modification, like other chlorites from rodingites (Dubińska & Wiewióra, unpubl. data). Thus the intermediate mineral seems to be a product of the alteration of phlogopite (*via* a vermiculitic stage), and its occur-

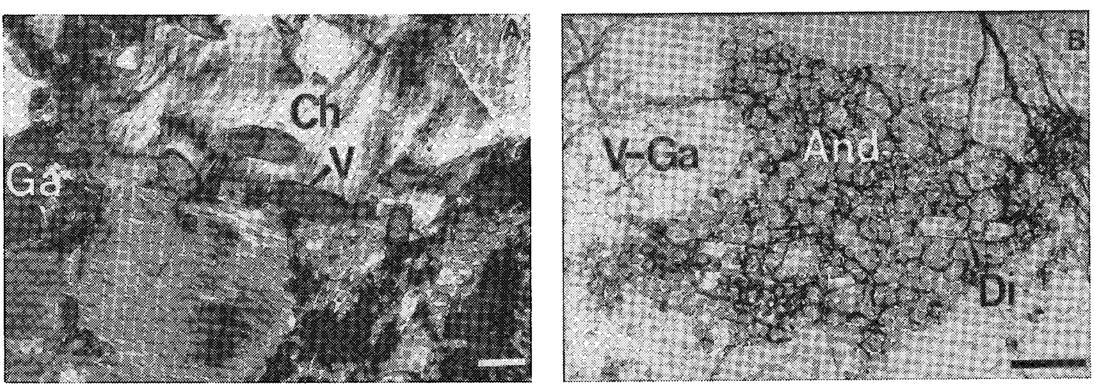


FIG. 7. A. Chloritic (bastite-like, Ch) pseudomorph after pyroxene; anhedral (tectonized) garnet (Ga) and small prisms of vesuvianite (V); sample Sw20, crossed polars, scale bar 100 μm. B. Hydroandradite (anhedral grains, And) – diopside (Di) aggregate within completely mylonitized garnet–vesuvianite matrix (V–Ga); sample Na48A, plane light, scale bar 100 μm.

TABLE 5. REPRESENTATIVE COMPOSITION OF LAYER SILICATES FROM RODINGITES

sample weight %	*TYPE-B RODINGITES*		*TYPE-A RODINGITES*				
	Na16*	Na61*	Sw10C*	Pr1B*	Na48D**	Pr1B***	Pr2****
SiO_2	25.98	28.51	28.95	32.02	41.08	39.96	34.05
TiO_2	0.02	0.02	0.02	-	-	-	0.09
Al_2O_3	24.77	20.23	22.13	16.14	3.21	13.93	15.55
Cr_2O_3	0.18	0.12	0.10	0.06	0.06	0.11	0.33
FeOtot.	8.27	8.48	7.22	7.00	0.94	11.78	6.56
MnO	0.65	0.18	-	0.04	0.05	0.19	0.23
NiO	0.02	-	0.08	0.03	n.d.	0.06	-
MgO	24.05	26.57	27.65	30.37	41.52	18.68	27.89
CaO	0.07	0.05	-	0.08	0.05	-	1.25
K_2O	0.04	0.01	0.02	-	0.04	9.97	1.57
Na_2O	0.01	-	-	-	-	0.02	-
total	84.06	84.17	86.17	85.74	86.95	94.70	87.52
	on the basis of $O_{10}(OH)_8$					*on the basis of $O_{10}(OH)_2$*	*on the basis of 3 Si cations*
Si	2.61	2.85	2.81	3.12	3.82	2.95	3.00
Al^{IV}	1.39	1.15	1.19	0.88	0.18	1.05	1.00
Al^{VI}	1.54	1.24	1.33	0.97	0.18	0.16	0.61
Ti						-	0.01
Cr	0.01	0.01	0.01			0.01	0.02
Fe^{2+}tot.	0.69	0.71	0.58	0.57	0.07	0.73	0.48
Mn	0.06	0.02				0.01	0.02
Ni			0.01				
Mg	3.60	3.96	3.99	4.41	5.75	2.06	3.66
Ca							0.12
K						0.94	0.18
tot.oct. cat.	5.90	5.94	5.92	5.95	6.00	2.96	4.80
layer charge******							26.16

* - chlorite, ** - serpentine or chlorite-serpentine intergrowth, *** - phlogopite, **** - intermediate chlorite-vermiculite (Ca^{2+} and K^+ - interlayer cations); **** - layer charge calculated assuming constant composition of tetrahedral sheet (3 Si 1 Al) and incomplete outer octahedral sheet of intermediate chlorite-vermiculite

rence suggests that K^+ ions were released to form the phlogopite within the blackwall, in analogy to the process reported by Wares & Martin (1980).

A relict grain of pyroxene also was found in an epidote-rich rodingite from a section of core drilled in the eastern part of Jordanów–Gogołów massif covered by a sequence of Tertiary and Quaternary rocks.

Relict albite was identified in clinozoisite–zoisite rodingite (Dubińska 1989) and in garnet–diopside rodingite of group B (Table 1, close to albite end-member in composition).

The clinozoisite–zoisite variety of rodingite, exhibiting little deformation, displays two generations of Ca-silicates (Fig. 9A), separated by an episode of brittle deformation. The older generation of CaAl-silicates consists of clinozoisite, zoisite or both, ± garnet (~80 mol. % of grossular end-member) and accessory titanite. Clinozoisite may have a core containing ~3% and a rim with ~9% of the $Ca_2Fe_3Si_3O_{12}(OH)$ (Ps) end-member (Table 6, Fig. 9B). Garnet, where present, may form atoll-like (Fig. 9A) structures containing Fe-poor (Ps_{3-4}) and tectonized aggregates of clinozoisite inside the atoll, whereas more iron-rich clinozoisite (Ps_{6-7}) forms large crystals outside the garnet atoll (Table 6, sample Na15C). The Mn content of the garnet is variable; it ranges from 0.1 to 5.2% MnO; Mn-free garnet (less than 0.4% MnO) and Mn-rich garnet (more than 4% MnO, Table 4, Fig. 9B) are present in one specimen, without differences in their spatial relation to other

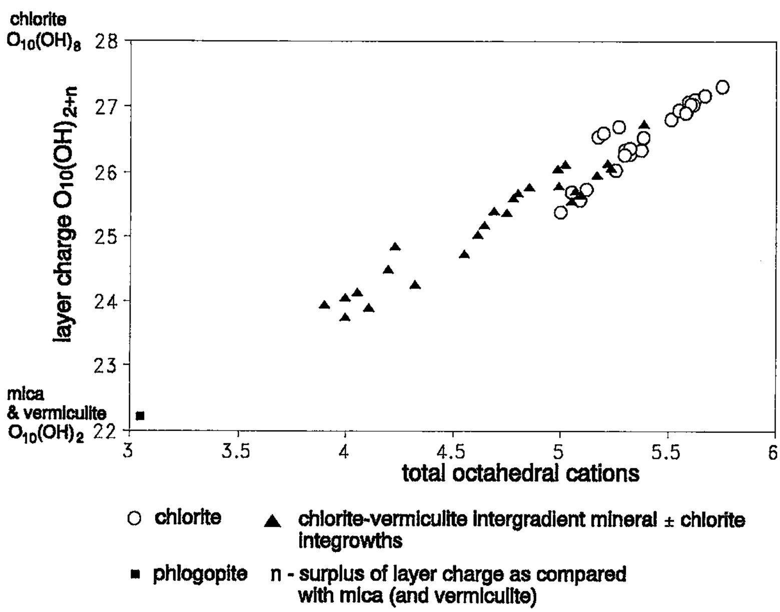


FIG. 8. Total octahedrally coordinated cations *versus* layer charge for intermediate chlorite–vermiculite and chlorite from Przemiłów rodingite blackwall (Fig. 2); compositions of the intermediate chlorite–vermiculite phase were calculated on the basis of three Si cations. The number of octahedrally coordinated cations in the intermediate chlorite–vermiculite phase shows an increase compared to trioctahedral mica; some compositions of the intermediate chlorite–vermiculite phase probably represent intergrowths of chlorite and the intermediate chlorite–vermiculite phase.

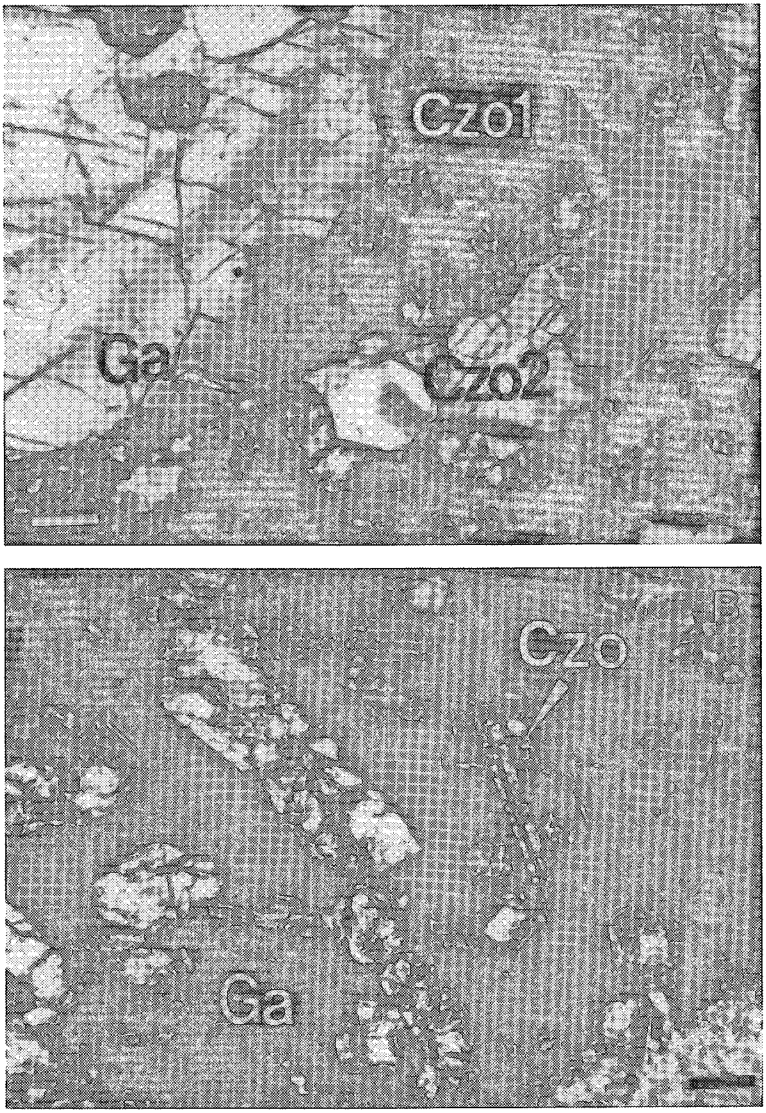


FIG. 9. A. Highly tectonized clinozoisite (Czo1) enclosed inside garnet (Ga) atolls; large prisms of clinozoisite (Czo2) are blastocataclastic, formed owing to the recrystallization of previously granulated material; sample Na15D, crossed polars, scale bar 200 µm. B. Rodingite containing zoned and twinned clinozoisite (Czo) with core containing ~ 3%, and rim, ~ 9%, of the $Ca_2Fe_3Si_3O_{12}(OH)$ end member, and two varieties (Mn-rich and Mn-poor) of grossular garnet (Ga); sample Na61, partly crossed polars, scale bar 200 µm.

minerals (Fig. 9B). The younger generation of Ca-silicates consists of diopside. Clinochlore from these rodingites may be enriched in Mn (up to 1% MnO, Table 5). Late veinlets and monomineralic zones of prehnite are present in many samples (Fig. 10). Some samples contain wairakite.

The garnet–diopside variety of group-B rodingites also consists of two generations of Ca-silicates. An almost stoichiometric grossular represents the first generation, whereas diopside spherulites (Table 3, Fig. 11) represent the second generation.

A chess-board albite (An_{1-4}), apatite and zircon are rare relict minerals in clinozoisite-rich rodingites. Veinlets, intergrowths, and small pockets of K-feldspar

TABLE 6. REPRESENTATIVE COMPOSITION OF EPIDOTE-GROUP MINERALS FROM RODINGITES

	P1-431	Na15C		Na61		Na60	Na69B
mineral	epi	czo*	czo**	czo*	czo**	zo	zo
SiO_2 wt%	37.76	38.95	38.81	39.00	38.71	39.97	38.85
TiO_2	0.08	0.27	0.04	0.03	0.11	0.08	0.05
Al_2O_3	24.96	31.24	30.81	31.25	29.77	33.24	31.78
Cr_2O_3	-	0.09	-	0.07	0.10	0.02	0.11
FeO	9.50	1.39	3.15	1.72	4.13	0.07	1.12
MnO	0.06	0.17	0.27	0.48	0.03	-	0.24
NiO	n.d	0.11	tr.	-	-	-	0.09
MgO	-	0.04	0.13	-	0.04	0.13	0.02
CaO	23.70	24.40	24.86	24.10	24.12	24.88	24.32
K_2O	-	0.05	-	0.05	-	-	0.01
Na_2O	-	-	0.04	tr.	-	-	0.02
total	97.12	96.71	98.11	96.70	97.01	98.39	96.61
on the basis of $O_{10}(OH)$							
Si	3.00	3.01	2.97	3.02	3.00	3.01	3.00
Ti		0.02			0.01		
Al	2.34	2.84	2.78	2.85	2.72	2.95	2.89
Cr		0.01			0.01		0.01
Fe^{3+}tot.	0.63	0.09	0.20	0.11	0.27		0.07
Mn		0.01	0.01	0.02			0.01
Mg			0.02			0.01	0.01
Ni		0.01					
Ca	2.02	2.02	2.04	2.00	2.00	2.01	2.01
% pist.	*21.25*	*3.03*	*6.73*	*3.73*	*8.95*	*0.15*	*2.44*
% pie.	*0.07*	*0.19*	*0.40*	*0.54*	*0.03*	*0*	*0.24*

czo - clinozoisite, epi - epidote, zo -zoisite; Na15C - czo* - outside atoll of garnet; czo** - granulated; inside atoll of garnet: Na61 - clinozoisite zoned, czo* - core, czo** - rim; pist. - pistacite end member, pie. - piemontite end member; sample P1-431 - type-A rodingite, samples Na15C, Na61, Na 60, and Na69B - type-B rodingites

and Ba–K-feldspar (both with the adularia habit; Or_{100} to $Or_{80}Ce_{20}$, where Or and Ce denote K- and Ba-feldspar end members, respectively) also were found in this variety of rodingite (Fig. 10).

A probable protolith for group-B rodingites is plagiogranite (as defined by Nicolas 1989). K- and Ba–K-feldspars are the youngest minerals in the assemblage, as both postdate rodingitization and late development of prehnite (Fig. 10).

Rodingites of group C contain no relict minerals or textures. They are usually rich in garnet (grossular-rich), some samples contain zoisite, minor chlorite (both interstitial and contact), and newly formed clinopyroxene. Younger prehnite, adularia (Fig. 10), carbonates, opal-CT (Fig. 12), and smectite also are present.

Rocks from the leucocratic zone at Jordanów

Calc-silicate rocks from the leucocratic zones at Jordanów display variable textural and compositional features (Table 2). Chess-board albite represents the oldest generation of minerals (Fig. 13A). The feldspathic rock was initially replaced by zoisite (Figs. 13A, 14A, Table 7) or grossular (Table 7), which were later replaced by anhedral fine-grained or acicular spherulitic diopside (Figs. 13A, 14B, Table 8). Granulated calc-silicate rock fragments were successively cemented by younger quartz, producing tectonic breccias commonly consisting of quartz and zoisite (± garnet) or quartz and garnet. Both zoisite and garnet are poor in Fe (Table 7, Fig. 11).

The zoisite and quartz–zoisite-rich rocks may be overprinted by new generations of prismatic clinozoisite with oscillatory zoning (Table 7, Fig. 13B). Fibrous and acicular tremolite (Table 8, sample Jo38B)

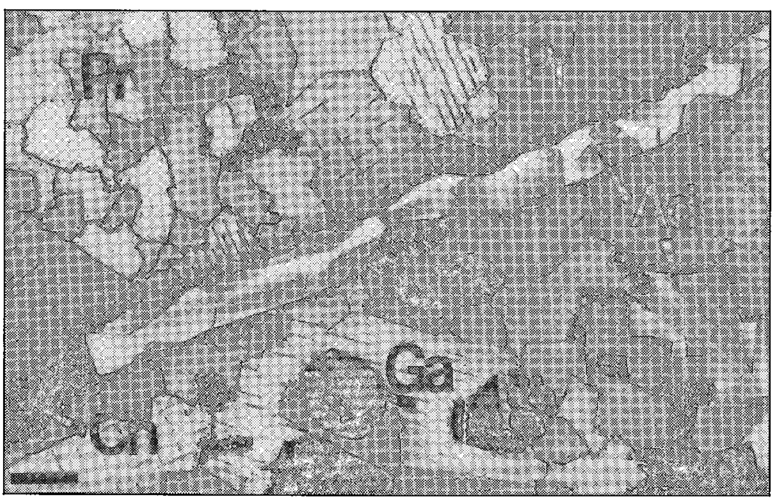


FIG. 10. Zone rich in late prehnite (Pr) in garnet–zoisite rodingite; garnet (Ga) replaced by prehnite and fine-grained chlorite (Ch) aggregates; veinlets and pockets of Ba-bearing adularia (Ad) and chlorite were formed after prehnite; sketch after thin section; sample Na69E, crossed polars, scale bar 100 μm.

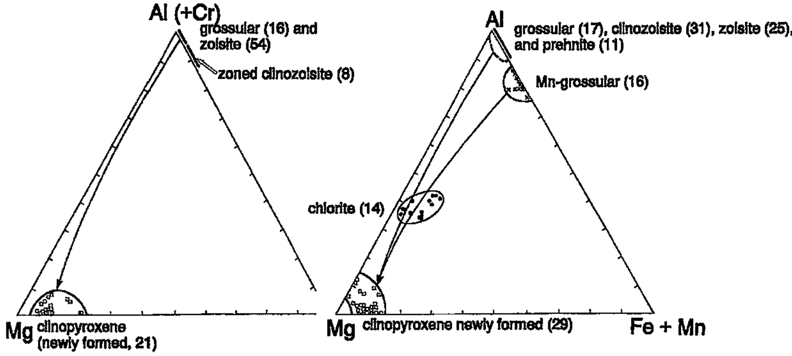


FIG. 11. Chemical composition of major minerals (atomic ratios) from group-B rodingites (left) and rocks from the leucocratic zone at Jordanów (right). The bars represent the composition of Ca–Al-silicates; numbers in parentheses denote number of microprobe analyses. Overlapping compositions are not shown; arrows show directions of the evolution of the mineral compositions.

replaced clinozoisite (Fig. 13B). Small fragments of zoisite, clinozoisite, and diopside-rich rocks, probably of tectonic origin, partly obliterated by the fibrous tremolite, are usually included in nephrite. The tremolite needles and fibers are common in all of the above rocks (*e.g.*, in quartz–zoisite rock, Fig. 14C) and in serpentinites. The monomineralic tremolite felt (nephrite) forms irregularly shaped and lenticular bodies <0.5–2 m in length. Veinlets and intergrowths of prehnite, feldspar grains of adularia habit (most of them Ba-bearing, with the Ba-feldspar end member in the range 0–8 mol.%), albite (usually Ab_{98-100}), mordenite and opal were found in the calc-silicate rocks as well as in the nephrite. Examples of textures that record several episodes of mineral formation are schematically shown at Figures 13A and 13B.

Fragments of ultrabasic rocks tectonically included into the calc-silicate suite were identified owing to the magnetite replacement of primary chromian spinel rimmed with a corona composed of uvarovite-rich garnet and diopside (± tremolite) (Tables 2, 8, Fig. 15).

Fragments of brecciated leucogranite are common

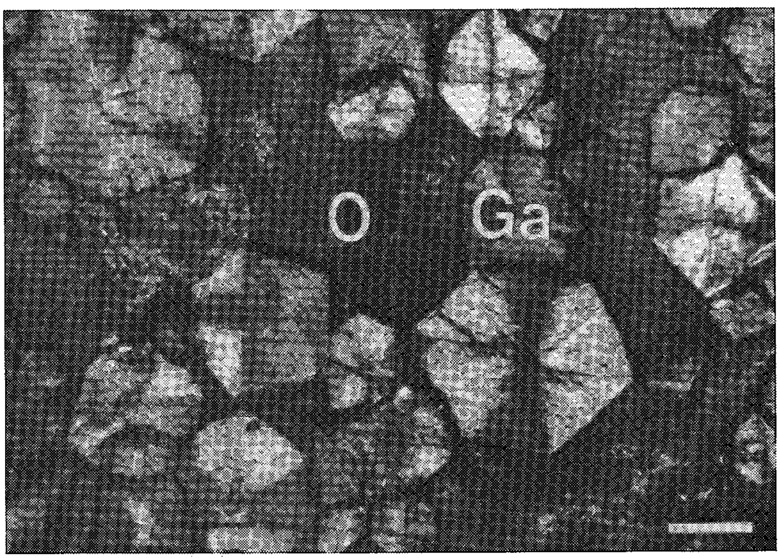


FIG. 12. Anomalously birefrigent garnet (Ga) cemented by opal-CT (O); sample Tr2A, crossed polars, scale bar 200 μm.

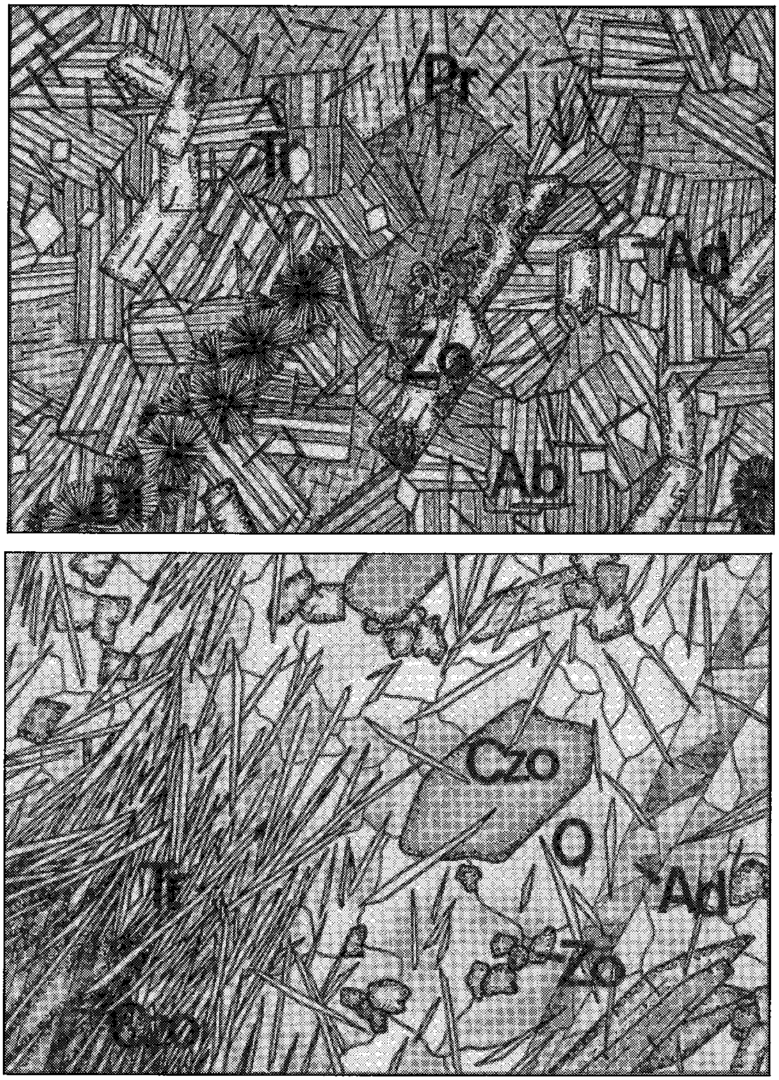


FIG. 13. A. Schematic sketch of the texture of a rock containing relict albite (Ab), subsequently intergrown with zoisite (Zo, the largest crystals about 1 mm in length), spherulites of diopside (Di), and tremolite (Tr) needles; intergrowths of prehnite (Pr) and adularia (Ad) represent a late, low-temperature generation of minerals; sample Jo44 from leucocratic zone of Jordanów.

within the leucocratic zone. The granite, although highly tectonized, contains fresh grains of feldspar, and is not altered. No example was found of granite overprinted by Ca-silicates typical of "rodingitic" assemblage. However, small sheafs of Mg-rich actinolite formed after the granite's granulation.

COMPOSITION OF THE SUITE

Major-element compositions of some rodingites from the study area have already been published (Majerowicz 1984, Dubińska 1989). The data presented here (Tables 9, 10, 11) are used to document the relationship between mineral parageneses and chemical evolution.

Bulk compositions of rodingites plotted on the ACF diagram (Fig. 16) are consistent with petrographic observations; evolution of rodingite composition from early CaAl-silicates (epidote, grossular) toward diopside was observed in the zoned boudins of rodingite (Table 10, samples Na58B, Na58C, Na58D) as well as in calc-silicate rocks from Jordanów. Since early-

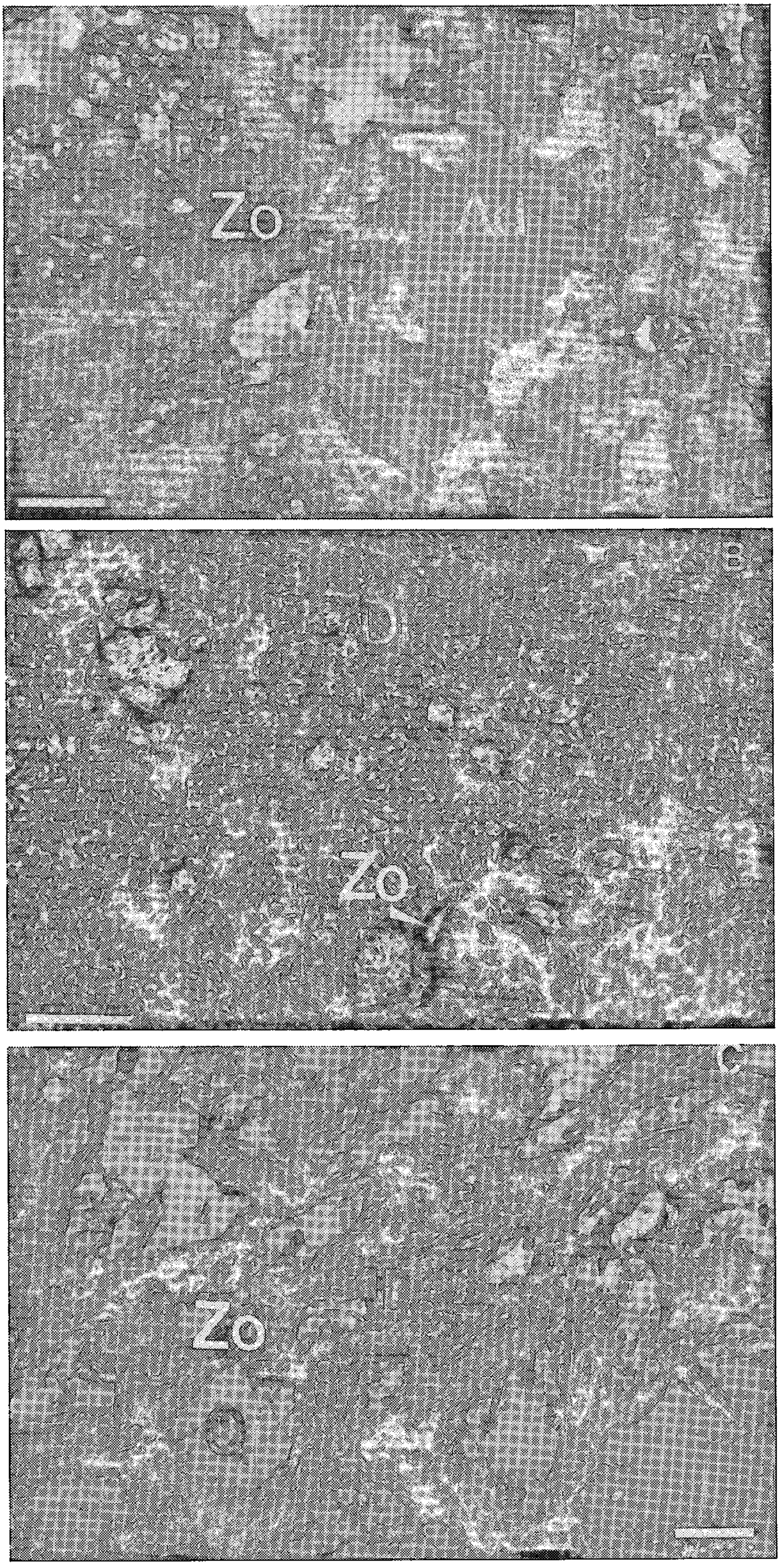


FIG. 14. A. Relict chess-board albite (Ab) and K-feldspar (adularia habit, Ad) surrounded by zoisite (Zo); sample Jo31, crossed polars, scale bar 200 μm. B. Zoisite (Zo) replaced by fine-grained diopside (Di) groundmass; sample Jo40, plane light, scale bar 100 μm. C. Quartz (Q) – zoisite (Zo) rock overprinted by tremolite fibers (Tr); sample Jo1, plane light, scale bar 200 μm.

TABLE 7. REPRESENTATIVE COMPOSITION OF EPIDOTE AND GARNET FROM LEUCOCRATIC ZONE AT JORDANÓW

	ZOISITE		CLINOZOISITE			GARNET		
sample	Jo1	Jo38B	Jo38B* rim	Jo38B* core	Jo56**	Jo48	Jo56***	Na43****
SiO_2 wt%	39.54	39.16	38.88	38.44	38.56	39.84	37.30	39.66
TiO_2	0.07	-	0.04	0.01	0.04	-	0.01	0.04
Al_2O_3	32.75	32.44	31.20	28.37	29.32	22.05	8.22	22.04
Cr_2O_3	-	-	-	0.02	-	0.05	15.96	0.03
Fe_2O_3tot.	0.89	0.93	2.68	6.24	4.98	0.47	3.10	0.45
Mn_2O_3	-	0.37	0.04	0.14	0.09	0.02	0.11	-
NiO	-	0.02	-	0.04	-	0.02	0.06	-
MgO	-	0.02	0.06	-	-	-	-	-
CaO	24.56	24.39	24.34	23.95	23.99	37.27	34.68	36.98
K_2O	0.08	0.08	0.04	0.04	0.01	0.01	0.02	0.02
Na_2O	-	0.04	0.05	-	0.03	0.06	0.02	0.02
total	97.89	97.45	97.33	97.25	97.02	99.78	99.48	99.24
	on the basis of $O_{10}(OH)$					*on the basis of 12 oxygens*		
Si	3.01	3.00	3.00	3.00	3.01	3.00	3.01	3.00
Al	2.93	2.93	2.83	2.61	2.69	1.96	0.78	1.97
Cr							1.02	
Fe^{3+}tot.	0.05	0.05	0.16	0.37	0.29	0.03	0.19	0.03
Mn^{3+}tot.		0.01					0.01	
Ca	2.00	2.00	2.01	2.01	2.00	3.01	2.99	3.00
% pist.	*1.71*	*1.78*	*5.19*	*12.29*	*9.78*			
% pie.		*0.36*	*0.04*	*0.14*	*0.09*			

* - zoned clinozoisite; ** - clinozoisite from nephrite; *** - small grains of garnet adjacent to magnetite grain with holly leaf habit; **** - sample from Nasławice, probably tectonically displaced fragment of leucocratic zone from Jordanów; pist. - pistacite end member, pie. - piemontite end member

TABLE 8. REPRESENTATIVE COMPOSITION OF CLINOPYROXENE (NEWLY FORMED) AND AMPHIBOLE FROM LEUCOCRATIC ZONE AND SERPENTINITE FROM JORDANOW

	CLINOPYROXENE		MONOCLINIC AMPHIBOLE			
sample	Jo40	Jo44	Jo1	Jo1	Jo38B	Jo41*
SiO_2 wt%	54.83	53.23	57.03	58.37	57.19	58.62
TiO_2	-	0.08	0.08	0.08	0.04	0.03
Al_2O_3	0.19	-	0.79	2.36	2.11	-
Cr_2O_3	-	-	0.09	-	0.05	0.11
FeOtot.	2.31	7.39	7.99	3.03	4.91	4.33
MnO	0.30	0.21	0.33	0.13	0.20	0.03
NiO	0.02	-	-	-	0.12	0.04
MgO	16.32	13.68	19.28	21.10	20.67	22.31
CaO	25.72	24.79	13.17	13.84	13.49	13.71
K_2O	0.01	0.04	0.04	0.08	0.10	0.05
Na_2O	0.02	-	0.18	0.14	tr.	tr.
total	99.72	99.42	98.98	99.14	98.88	99.23
	on the basis of 6 oxygens		*on the basis of 23 oxygens*			
Si	2.00	2.00	7.92	7.89	7.83	7.98
Ti	0.01		0.01	0.01		
Al	0.01		0.13	0.38	0.34	
Cr			0.01			0.01
Fe^{2+}tot.	0.07	0.23	0.93	0.34	0.56	0.49
Mn	0.01	0.01	0.04	0.01	0.02	
Ni					0.01	
Mg	0.89	0.77	3.99	4.25	4.22	4.52
Ca	1.01	1.00	1.96	2.00	1.98	2.00
K			0.01	0.01	0.02	0.01
Na			0.05	0.03		

* - antigoritic serpentinite from Jordanów intergrown with tremolite and talc

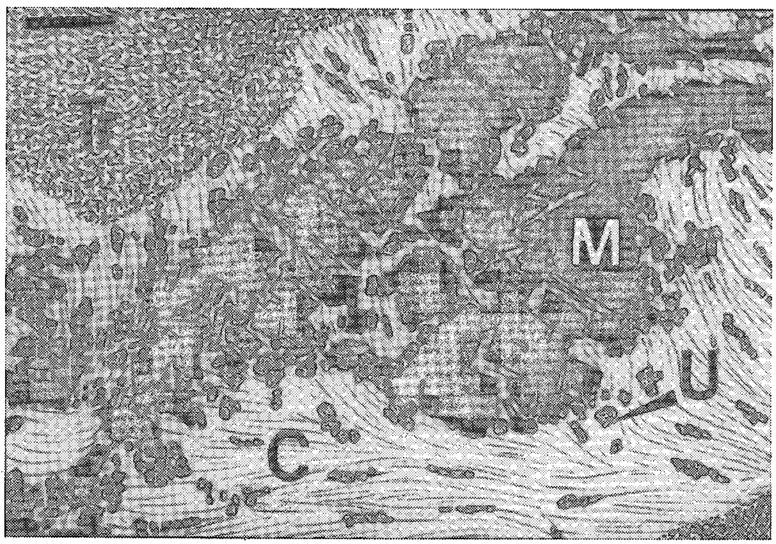


FIG. 15. Sketch of fragment of ultramafic rock tectonically included in rodingitized body. Symbols: M: magnetite replacement after primary holly-leaf Cr-rich spinel, U: uvarovite, C: corona-like diopside ± tremolite intergrowths, Tr: tremolite (± minor diopside) fine-grained felt (nephrite), sample Jo56. Scale bar: 100 μm.

TABLE 9. WHOLE-ROCK COMPOSITIONS OF TYPE-A RODINGITES FROM EASTERN PART OF JORDANÓW-GOGOŁÓW SERPENTINITE MASSIF

sample weight %	*VESUVIANITE-RICH RODINGITES*									*CLINOZOISITE-RICH RODINGITES*	
	Na35	Na48D	Na53B*	Na57K*	Sw6A	Sw9B	Sw20*	Pr2	Pr8	P1-431	739*
SiO_2	42.95	37.88	37.5	41.6	36.98	36.92	39.72	36.14	39.27	36.6	40.1
TiO_2	0.48	0.27	0.01	0.02	0.03	0.12	0.04	0.04	0.05	0.21	0.05
Al_2O_3	14.20	14.76	16.8	11.2	18.46	17.99	17.99	16.86	14.23	16.7	16.2
Cr_2O_3	0.03	0.01	tr.	0.03	0.01	0.05	tr.	tr.	tr.	0.12	0.10
Fe_2O_3	3.63	3.26	2.29	4.01	2.06	5.52	5.52	3.09	6.71	6.52	4.13
FeO	0.24	tr.			0.57			1.55			
MnO	0.07	0.10	0.09	0.11	0.28	0.09	tr.	0.15	0.07	0.14	0.08
MgO	4.43	8.52	3.92	9.75	2.60	4.68	13.55	10.55	5.59	18.80	13.2
NiO	0.04	0.02	0.06	0.06	0.01	0.01	0.03	0.01	0.07	0.01	0.07
CaO	31.76	30.59	35.2	29.7	36.30	34.37	22.51	27.04	33.65	13.50	22.6
Na_2O	tr.	0.22	0.01	0.01	0.01	0.01	tr.	0.06	tr.	0.13	0.10
K_2O	-	0.20	<0.01	<0.01	-	-	tr.	-	tr.	0.32	0.03
P_2O_5	0.27	0.01	0.02	-	0.01	0.01	n.d.	0.03	n.d.	tr.	tr.
CO_2	0.18	0.37	n.d.	0.01	0.29	0.22	n.d.	0.22	n.d.	n.d.	n.d.
H_2O^+	1.24	3.44	n.d.	n.d.	1.96	1.40	n.d.	3.58	n.d.	n.d.	n.d.
ign. loss			3.58	2.70						6.18	3.01
total	99.52	99.90	99.41	99.20	99.57	99.14	99.36	99.32	99.64	99.23	99.67
Ti (ppm)			54	119		177	720	270	241	1235	280
Cr (ppm)			21	5		5	346	12	15	820	650
Ni (ppm)			95	511		57	232	55	56	409	530
V (ppm)			4	14		9	119	8	8	134	27
Zr (ppm)			35	26		94	70	160	276	5	3

* total iron as Fe_2O_3; P1-431 - epidote-garnet rodingite from drill core: 739 - rodingite from Szklary (separate small ultrabasic massif adjacent to Sowie Góry Mts. block) containing garnet (grossular), epidote, newly formed diopside, clintonite, and chlorite

TABLE 10. CHEMICAL COMPOSITION OF TYPE-B AND TYPE-C RODINGITES FROM EASTERN PART OF JORDANÓW-GOGOŁÓW SERPENTINITE MASSIF

sample weight %	*TYPE B-RODINGITES*								*TYPE C-RODINGITES*	
	Na58B*	Na58C*	Na58D*	Na60*	Na15A	Na16	Na26	MTNa21*	Tr9	Jo51
SiO_2	44.3	50.4	52.1	39.4	39.84	45.39	36.30	39.4	39.30	42.1
TiO_2	0.03	0.01	0.01	0.02	0.26	0.36	0.49	tr.	0.23	<0.02
Al_2O_3	19.2	8.25	4.06	25.3	23.82	13.38	24.38	31.1	22.56	20.7
Cr_2O_3	tr.	tr.	tr.	tr.	0.01	0.02	0.01	tr.	0.02	1.57
Fe_2O_3	0.74	0.81	0.39	0.91	2.00	1.87	2.28	1.11	0.44	0.10
FeO					1.34	1.23	1.86		0.07	
MnO	0.23	0.17	0.16	0.14	1.69	0.43	0.06	0.21	0.29	0.15
MgO	2.75	14.2	16.3	7.91	6.42	11.71	0.17	1.79	0.37	0.30
NiO	tr.	tr.	tr.	tr.	0.02	0.01	0.02	0.01	tr.	0.02
CaO	29.7	25.5	25.3	20.9	22.78	22.78	24.10	21.9	37.01	34.9
Na_2O	0.96	0.15	0.31	0.01	0.06	0.17	0.01	0.01	0.01	0.01
K_2O	0.03	0.05	0.07	0.01	0.15	-	-	0.29	-	0.01
P_2O_5	0.03	0.02	0.01	0.02	0.06	1.10	0.02	0.10	tr.	<0.01
CO_2					0.20	0.26	0.22	n.d.	0.11	
H_2O^+					0.48	1.40	2.48	n.d.	0.08	
ign. loss.	0.75	1.32	1.02	5.22				3.40	0.04	
total	99.41	100.88	99.73	99.84	100.13	99.92	100.40	99.32	100.53	100.21
Ti (ppm)	170	60	36	138				24		
Cr (ppm)	7	7	<7	14				14		
Ni (ppm)	20	8	<8	71				71		
V (ppm)	4	2	<1	4				3		
Zr (ppm)	285	56	40	104				25		

* - total iron as Fe_2O_3, Na58B, Na58C, and Na58D - samples from one zoned boudin (Na58B - fragment composed of grossular, newly formed diopside, and relict feldspars: Na58C - fragment composed of grossular, newly formed diopside, and clinochlore; Na58D - fragment composed of newly formed diopside, chlorite, and minor grossular); Jo51 - rodingite from small separate body at Jordanów quarry

TABLE 11. CHEMICAL COMPOSITION CALC-SILICATE ROCKS FROM THE LEUCOCRATIC ZONE AT JORDANÓW QUARRY

sample weight %	*RODINGITE-LIKE ROCKS***						*OTHER CALC-SILICATE ROCKS*			
	Jo31	Jo40*	Jo44	Jo51***	Jo58	Jo59	Jo1	Jo38B	Jo48*	Na43****
SiO_2	54.21	55.5	61.48	42.1	53.3	73.0	70.08	61.78	63.3	62.82
TiO_2	0.30	<0.02	0.03	<0.02	0.02	0.02	-	0.10	<0.02	0.02
Al_2O_3	12.79	12.3	21.26	20.7	17.8	11.0	15.41	14.95	13.7	13.95
Cr_2O_3	0.96	0.03	tr.	0.10	<0.02	0.06	0.01	0.05	<0.02	0.01
Fe_2O_3	0.01	1.96	0.74	1.57	0.60	0.38	0.18	1.31	0.31	0.01
FeO	1.05						0.35	1.20		0.42
MnO	0.14	0.11	0.15	0.15	0.03	0.01	0.03	0.11	0.01	0.05
MgO	8.76	8.48	0.57	0.30	3.67	0.29	0.72	4.90	0.27	0.69
NiO	0.05	0.03	tr.	0.02	0.07	0.01	tr.	0.04	0.01	0.01
CaO	17.44	17.0	5.80	34.2	18.8	9.53	11.52	12.76	22.5	20.74
Na_2O	2.18	2.31	7.68	0.01	2.37	2.98	0.08	0.20	0.16	0.09
K_2O	1.37	1.86	0.50	<0.01	1.85	0.09	0.65	0.65	0.21	0.87
P_2O_5	0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.01	0.01	<0.01	
ign. loss		1.15		0.91	2.03	1.92			0.28	0.01
CO_2	0.22		0.27				0.22	0.22		0.15
H_2O^+	0.84		0.92				0.64	1.28		0.08
total	100.33	100.83	99.57	100.21	100.54	99.29	99.86	99.56	100.47	99.93

* - total iron as Fe_2O_3, ** for description see Table 2 and text, *** rodingite from separate small body at Jordanów quarry, **** sample from Nasławice, probably tectonically displaced from leucocratic zone at Jordanów

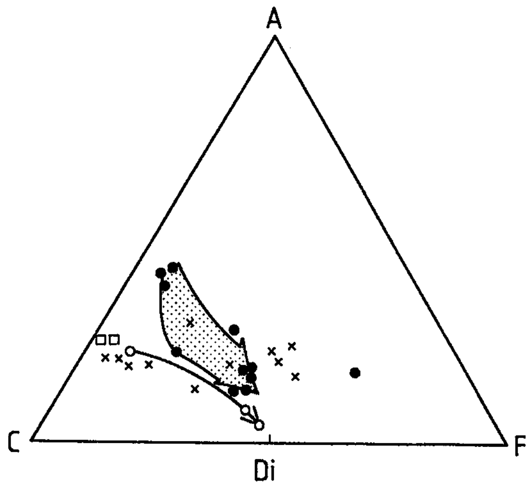


FIG. 16. ACF diagram. Symbols: crosses: vesuvianite rodingites (group A), full circles: rocks bearing clinozoisite or zoisite (or both) (group-B rodingites and some rocks from the leucocratic zone at Jordanów; samples from Jordanów rich in chlorite or amphibole have not been included), squares: other rodingites, circles: samples from one zoned boudin of rodingite (Na58B, Na58C, Na58D); dotted area: compositional evolution of an epidote-bearing calc-silicate rock.

formed CaAl-silicates are both Mg- and Fe-poor (Fig. 6), the Mg content of the vesuvianite is low, and newly formed diopside is not abundant in these samples; the apparently "horizontal" position of the group-A rodingites on the ACF diagram reflects the content of relict pyroxene and the chlorite admixture in the samples.

Compositions of the completely metasomatized (*e.g.*, monomineralic) grossular or clinozoisite samples do not fit into the "rodingite field" of Coleman (1977), indicating that term *rodingite* should be used only in a descriptive and genetic sense, without chemical connotation, as suggested by Schandl *et al.* (1989).

DISCUSSION

Two main generations of Ca-silicate minerals, separated by an episode of brittle deformation, are identified in the rodingitic rocks from the eastern part of Jordanów–Gogołów serpentinite massif. Grossular and clinozoisite or zoisite represent the first generation. This episode is probably concomitant with the early serpentinization of the ultramafic rocks and the simultaneous activity of Ca^{2+}-rich fluids (Barnes & O'Neil 1969, Barnes *et al.* 1972, 1978, Neal & Stanger 1985). Thus it is probable that early serpentinization and early rodingitization both are products of the ocean-floor stage of ophiolite evolution (Wicks & O'Hanley 1988, Nicolas 1989, Bougault *et al.* 1993). Vesuvianite and diopside formed during the next stages of rodingite evolution.

There are at least two possible geological interpretations of these stages: 1) CaMg-silicates postdate

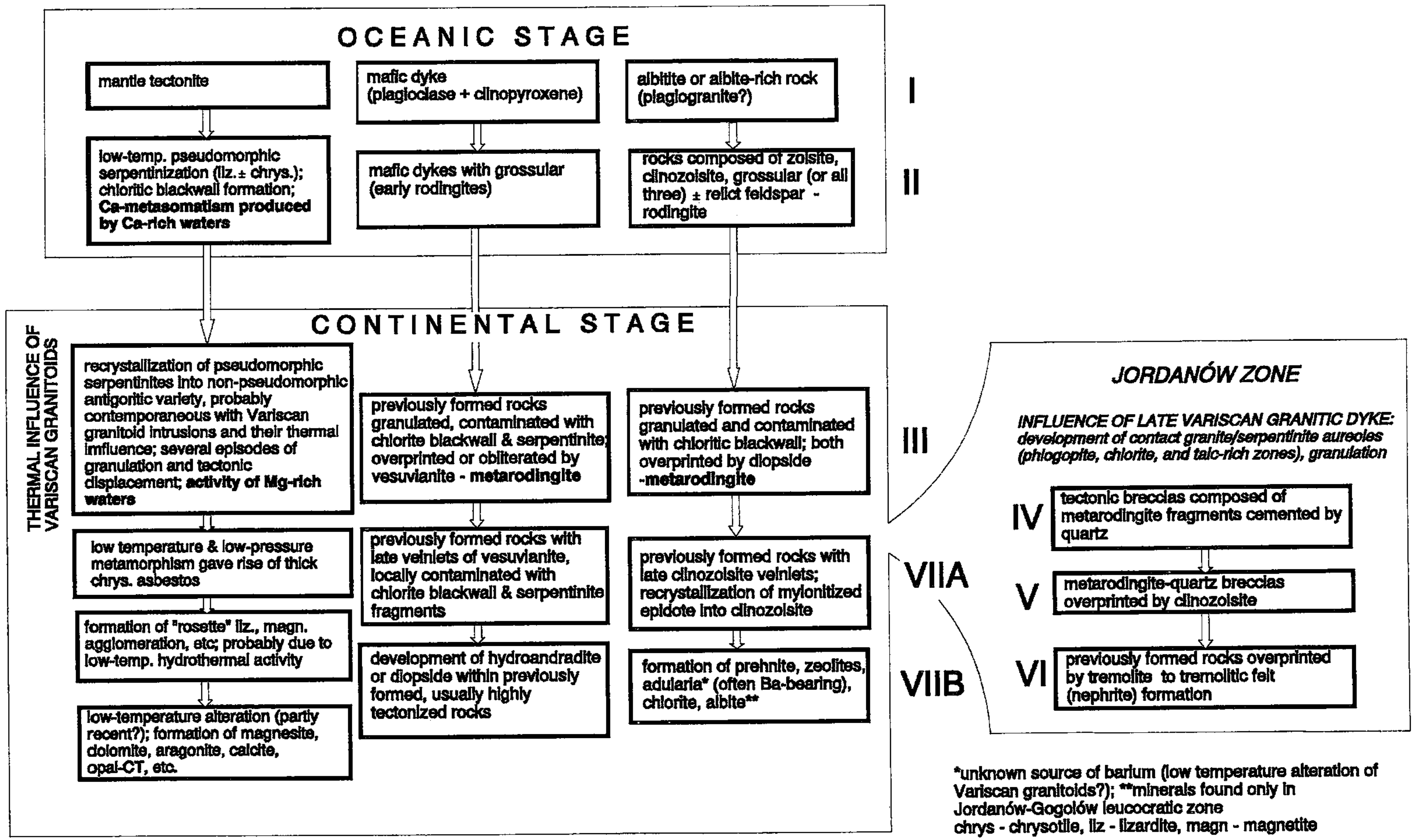
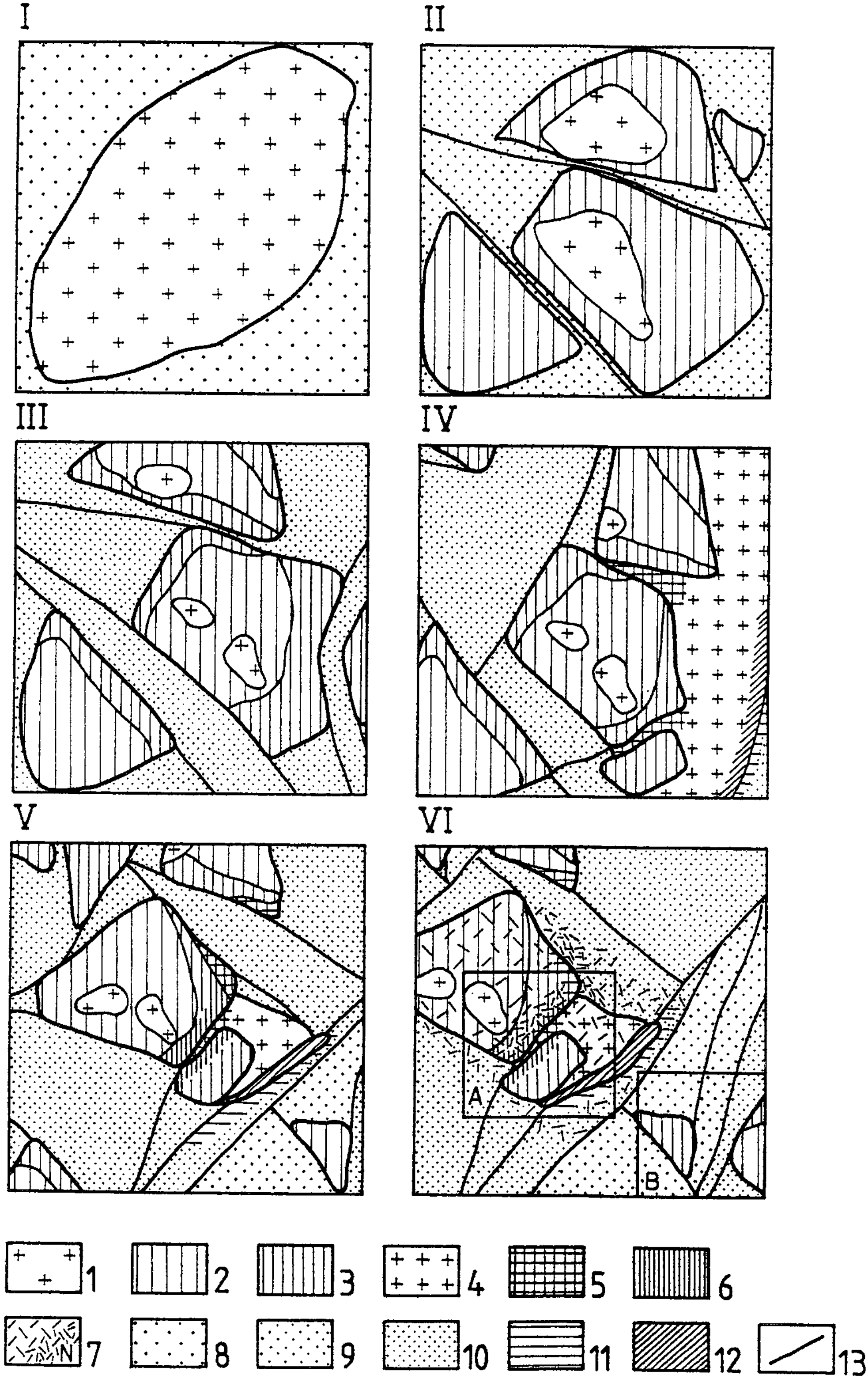


FIG. 17. Petrogenesis of rodingites and calc-silicate rocks from the leucocratic zone at Jordanów as related to serpentinite formation and metamorphism; I to VI correspond to the relevant diagrams in Figure 18.


I
II
III
IV
V
VI
A
B
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N
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13

rodingitization, and are products of interaction with a Mg-rich fluid. The formation of vesuvianite and diopside is probably associated with the formation of antigorite in serpentinites, *i.e.*, their thermal metamorphism (Evans 1977), which may be related to the emplacement of the adjacent Variscan granites; 2) the formation of CaMg-silicates was related to a local increase in the activity of Mg^{2+} close to small fragments of serpentinite and chloritic blackwall incorporated into the rodingite body during an episode of brecciation that accompanied rodingitization.

Both possibilities are supported by textures in the samples studied; however, evidence for the first one seems to be more widespread than for the second. This is consistent with the paragenetic sequences of minerals in other occurrences of rodingite (Leach & Rodgers 1978, Schandl *et al.* 1989). The similar trend reflects the evolution of water composition, starting with high pH and Ca-rich solutions in fresh ultramafic rocks. These solutions may converge to a slightly alkaline pH and high concentration of Mg when serpentinization of ultramafic rock is complete and subsequent recrystallization occurs, *i.e.*, as early lizardite-bearing serpentinite is transformed into antigorite-bearing serpentine with concomitant release of magnesium (Barnes & O'Neil 1969, Barnes *et al.* 1972, Moody 1976, Barnes *et al.* 1978, Neal & Stanger 1985, O'Hanley *et al.* 1992). The evolution of rodingites is tentatively correlated with serpentinite metamorphism in Figure 17.

This variability of rodingites and serpentinites and their random distribution can be explained as a result of brittle deformation and rock displacement to form the mosaic structure (from a microscopic to a macroscopic scale) of the Jordanów–Gogołów serpentinite massif. The fractures probably were in contact with oceanic waters rich in manganese (oceanic hydrothermal system? intersection of the rift valley and transform fracture zone? Bougault *et al.* 1993), which resulted in the local formation of Mn–rich minerals, whereas late Variscan hydrothermal activity could be responsible for the Ba-containing minerals.

Metarodingites from Jordanów

A possible model for the development and evolution of calc-silicate rocks from the leucocratic zone at Jordanów is shown in Figures 17 and 18. The zoisite- or garnet-rich rocks with relict grains of feldspar probably are partially rodingitized albitite or plagiogranite. The diopside in group-B rodingites can be roughly correlated with vesuvianite in the group-A rodingites.

The next episodes of calc-silicate rock evolution seem to be highly influenced by emplacement of granitic veins, producing a contact zone between serpentinite (containing a rodingite body) and granite; the very common quartz–zoisite rocks at Jordanów are presumably products of shearing of the rodingite and subsequent cementation of zoisite fragments by quartz. The vermiculitization of trioctahedral mica from the contact zones probably released K to form K-feldspar veinlets and intergrowths.

The presence of a *mélange* of the calc-silicate rocks in a small leucocratic zone at Jordanów resulted from tectonic disruption of the rocks that were transported from different metamorphic zones. An occurrence of quartz–zoisite and quartz–garnet rocks in other localities (*e.g.*, samples Na36 and Na43 from Nasławice, about 3 km west of Jordanów) supports this possibility.

Late Variscan and younger geological episodes are well recorded from the calc-silicate rocks (this study) and from rocks in the contact zone between granite and serpentinite (Dubińska & Wiewióra 1988, Dubińska & Szafranek 1990).

The leucocratic zone at Jordanów seems to contain an unusual suite of metarodingites compared to other metarodingites reported from different ophiolites up to the present. The metamorphism of rodingites has been considered to be: (1) an isochemical process with changes in mineral assemblages due to changes in temperature and pressure, possibly related to younger contact or regional metamorphism (Frost 1975, Cimmino *et al.* 1979, Evans *et al.* 1979, Koller & Richter 1984, Rösli *et al.* 1991); (2) closed-system metasomatic process related to changes in fluid composition accompanying replacement of lizardite by

←

FIG. 18. Schematic representation of hypothetical formation of leucocratic zone at Jordanów (not in scale); 1: plagiogranite, 2: rodingite containing zoisite (± garnet), 3: rodingite containing zoisite (± garnet) and diopside, 4: apophysis of Variscan granite, 5: quartz veins related to the apophysis of Variscan granite, 6: rocks containing clinozoisite, 7: rocks containing intergrown tremolite (up to nephrite – N), 8: ultramafic rock, 9: pseudomorphic serpentinite, 10: antigoritic serpentinite, 11: serpentinite overprinted by talc and tremolite, 12: serpentinite–granite contact rocks (suite of schists composed of trioctahedral mica – chlorite – talc – tremolite altered to vermiculite – chlorite – talc – tremolite schists), 13: tectonic fractures; I...VI correspond to I...VI in Figure 3; field A: leucocratic zone at Jordanów, field B: rocks tectonically displaced from the leucocratic zone at Jordanów into other fragments of the Jordanów–Gogołów serpentinite massif.

antigorite (± chrysotile) (O'Hanley 1991, O'Hanley *et al.* 1992).

The lack of Ca-silicates typical of a rodingitic assemblage (epidote, grossular, *etc.*) in the Jordanów tectonized leucogranite suggests its emplacement into the ophiolite suite when serpentinization was complete, whereas actinolite in granite was formed after an episode of granulation. Most of the Ca-silicates (*e.g.*, zoisite, diopside, and late clinozoisite) and phyllosilicates from the serpentinite – Variscan granite contact predate the formation of nephrite (Dubińska & Wiewióra 1988, Dubińska & Szafranek 1990). Thus the Jordanów nephrite is very likely connected to a post-Variscan or very late-Variscan episode.

Conclusions

According to the present study, the initial serpentinization of the peridotite and the partial rodingitization of dykes and lithic inclusions occurred in an oceanic environment. Subsequent alteration, however, took place in a continental environment, typical of ophiolitic suites. An analogous sequence of serpentinite formation, processes of recrystallization and serpentinization–rodingitization relationships were found in numerous ophiolite suites ranging in age from Archean to Pleistocene (*e.g.*, Frost 1975, Laurent 1980, O'Hanley & Offler 1992, O'Hanley *et al.* 1992, Rössli *et al.* 1991, Schandl *et al.* 1989, 1990, Yui *et al.* 1990).

In the Jordanów–Gogołów massif, early serpentinization was more extensive, and its temperature was lower, than previously suggested by Jędrysek (1989). The serpentinite textures support the conclusion that early low-temperature serpentinization was widespread in the ultramafic rocks of Jordanów–Gogołów massif. The ultramafic rocks were highly fractured, as is evident from numerous early veinlets of chrysotile, and oceanic water probably penetrated through these small fractures.

The ubiquity of pseudomorphic serpentinites and zones enriched in antigorite without evident foliation, and the porous structure of many rodingites, suggest that textures of these rocks are typical of low-pressure metamorphism, and that the rocks did not undergo high-pressure metamorphism, which would be expected in the subduction zone or beneath the overlying Sowie Góry Mtns. Block, as proposed Cymerman (1990). The relationships of the Sowie Góry Mtns. to the Jordanów–Gogołów massif (and the Ślęża ophiolite) probably should be revised.

Acknowledgements

The author expresses her sincere thanks to Zbigniew Jońca for most of the wet-chemical analyses. Prof. Alfred Majerowicz and Dr. Jacek Siemiątkowski kindly provided some of the samples. I am greatly indebted to Ewa Starnawska, Dr. Andrzej Kozłowski, Dr. Paweł Zawidzki and Dr. Maria Kozłowska-Koch for their help with electron-microprobe analyses. Oblique texture diffractograms were kindly made by Prof. A. Wiewióra. Many of the ideas presented in this paper were developed through discussion with Dr. Andrzej Kozłowski and Paweł Bylina. Constructive comments and improvements to the English text by Dr. David O'Hanley are deeply appreciated. Critical reading of the manuscript by two anonymous reviewers and by Prof. Robert Martin is acknowledged. Financial support was provided by Warsaw University (grant BW–153) and Committee of Scientific Research (grant 6 6188 92 03).

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Received June 2, 1994, revised manuscript accepted September 21, 1994.