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METAMORPHIC GRADE AND PACKING INDEX IN GARNETS

Abstract: The packing index in garnets Φ = 0,7303—0,7483 from different world geological areas shows the systematic change with temperature and pressure of rock recrystallization. The Φ value of garnets can be used at metamorphic grade studies in a certain geological area only.

Резюме: Плотная упаковка атомов (Φ = 0,7303 — 0,7483) химических в гранате из различных геологических месторождений показывает на систематическое изменение в зависимости от температуры и давления перокристализаций пород. Значение Ф для граната можно использовать при измерениях степени метаморфных изменений в конкретной геологической среде.

Introduction

Studying of the metamorphic grade on the basis of physical properties and chemical composition of minerals belongs to the basical objects of metamorphic rock petrology. These aims rise from efforts to define the physical conditions of metamorphosis in different way. Those minerals are actual from the mineralogical point of view which have a wide range of stability in rocks and in which the change of physical recrystallization conditions simultaneuosly determines on changing of their physical properties and chemical composition. Garnet of the metamorphic rocks is very actual for these investigations. It occurs in different rock types and has a wide range of stability.

The systematic change of garnets' properties with metamorphic grade was shown by A. Miashiro (1953), B. Stuart (1962), A. Engel — C. Engel (1960), M. Atherton (1965a), K. Nandi (1967) and R. Binns (1969). This variation in the properties is often commonly accepted and, the garnet on the basis of CaO + MnO content determination or FeO + MgO, occasionally unit cell parameter a_0, determines the metamorphic grade measurement which was reached (K. Nandi). It is issued from presumption that the CaO and MnO contents decrease with metamorphic grade while MgO and FeO contents are increasing.

However, the garnets of higher and lower metamorphic degrees may have the high MnO content (T. Clifford, 1960) and CaO content in the garnet can be also rised with the metamorphic degree (K. Kepezhinskas, 1973).

Garnet's occurence with biotite in different rock types and at wide range of physical conditions of metamorphosis, during which there comes to exchangeable reactions, leads to thermodynamical evaluation of paragenesis on the basis of equilibrium coexistence.

H. Ramberg and D. DeVore (1951) were the first who payed attention to distribution of elements between coexisting phases and they found that the components' distribution distribution between coexisting phases in chemical equilibrium is controlled by thermodynamical laws. The importance of

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this approach to this matter was demonstrated by R. Kretz (1959) and R. Mueller (1960) by the study of the elements' distribution between coexisting minerals in the rocks of amphibolite and granulite facies.

Later on, the element distribution between coexisting minerals was studied by M. Frost (1962), A. Albee (1965), L. Pertchuk (1967), S. Sen — K. Chakraborty (1968), A. Hietanen (1969), J. Lyons — S. Morse (1970), A. Thompson (1976) and J. Ferry — F. Spear (1978) who also determinated the experimental relationships between K_D^{Fe-Mg} distribution coefficient and the physical recrystallization conditions.

This experimental way of studying the mineral relationships and defining the distribution coefficients at known temperature and pressure has lead to obtaining of geological geotermometers and geobarometers. Starting from this thermodynamical approach of evaluating the phycical metamorphosis conditions, there were collected up many dates about temperatures and pressures of rock recrystallization during last decade.

However, the unsolved problem is still the influence of the different factors on the distribution coefficient K_D^{Fe-Mg}; selection of the atomic ratios to K_D calculation, mineral paragenesis, oxygen fugacity, pressure, Ca, Mn variation in the garnet and Al, Fe^{3+}, Ti in biotite.

Stating that K_D^{Fe-Mg} can have a different value also within the framework of the single outcrop and it need not vary with the metamorphic grade (A. Albee, 1965; N. Stevenson, 1979), however, it need not lead to conclusion that the linear relationship between the metamorphic grade and K_D^{Fe-Mg} is rather an exception than the rule (J. Lyons — S. Morse, 1970).

On the other hand, there is caused difficult the numerical, detailed expression of the metamorphic grade also within the isochemical rocks, where the index minerals' occurences and their quantitative changes as for paragenesis sensibly react on change of the physical metamorphic conditions.

So the distribution coefficient persists at one of the appropriate ways of the determination of the thermal and pressure rock evolution. In the cases of the chemical equilibrium it allows a more exact determination of metamorphic conditions, their zonality in the regional scale, evolution of the individual mineral associations and understanding of the physical properties' changing and the chemical composition of minerals. From this point of view the garnet from metapelitic rocks of the Malé Karpaty Mts. was evaluated. The geology of this region is made in details with respects to metamorphic processes in the work by B. Cambel (1976). According to the published dates of the other authors also the garnets from other world regions were investigated.

As the almandines from the Malé Karpaty Mts. could be compared with garnets from other world regions the published dates were compiled for these purposes. Such obtained values of garnets and $T_{calc.}$ — $P_{calc.}$ recrystallization conditions are introduced in tab. 3.

Methodical approach

Two ways of calculation of the atomic packing in garnets were used. The first one comes out of the knowledge about the unit cell volume and of the structural formula of the garnet; the second one — followed from the

Table 1

The measured and calculated values of the unit cell edge (a_o) and the density (ρ) of almandines of the metapelitic rocks from the Malé Karpaty Mts.

№	$a_o^{mer.}$	$a_o^{calc.}$	$\rho^{mer.}$	$\rho^{calc.}$
1Y	11,558	11,553	4,16	4,18
4Y	11,545	11,547	4,17	4,17
6Y	11,549	11,547	4,17	4,20
7Y	11,548	11,550	4,16	4,17
8Y	11,544	11,549	4,19	4,21
9Y	11,554	11,553	4,16	4,19
10Y	11,549	11,547	4,18	4,19
11Y	11,547	11,555	4,18	4,19
12Y	11,539	11,542	4,15	4,16
14Y	11,553	11,552	4,18	4,19
17Y	11,537	11,545	4,17	4,18
18Y	11,563	11,561	4,18	4,19
KB—1Y	11,560	11,550	4,18	4,19
KB—2Y	11,539	11,536	4,17	4,17
KB—3Y	11,549	11,549	4,16	4,18
KB—4Y		11,544	4,19	4,20
KB—5Y	11,551	11,547	4,18	4,17
	± 0,003 — 0,007		± 0,02	

knowledge of the density and of the chemical composition. In both cases it was started from the presuppose that the unit cell edge (a_o) and the density (ρ) are the additive functions of the end members of the garnet group.

Such calculated and measured values a_o (by X-ray diffraction using $CuK\alpha$ radiation) and ς for almandines from metapelites of the Malé Karpaaty Mts. are introduced in Tab. 1. The differences for measured and calculated lattice parameters occur mostly in the accuracy range of measurement by X-ray diffraction. The calculated values of densities are analogically different from the densities obtained micropycnometrically with the reproducibility ± 0.02.

The ionic radii for calculations were used after the work by R. Schannon and C. Prewitt (1969):

Si = 0,26	Mn = 0,93
Ti = 0,60	Ma = 0,89
Al = 0,53	Ca = 1,12
Fe^{3+} = 0,55	Na = 1,02
Fe^{2+} = 0,90*	K = 1,38

* according to person. comm. of doc. F. Hanica (ÚACH SAV)

The packing indices additively obtained from the density have greater dispersion than the atomic packing calculated on the basis of the lattice parameter (Tab. II). Therefore also in graphical presentations of the relationships between Φ, temperature and pressure the priority is given to the packing index obtained on the basis of the unit cell.

Table 2

Comparison of the packing index (Φ) of almandines from metapelitic rocks of the Malé Karpaty Mts., obtained on the basis of a_0 *and* ρ.

№	$a_0^{mer.}$	$a_0^{calc.}$	$\rho^{mer.}$	$\rho^{calc.}$
	Φ	Φ	Φ	Φ
1Y	0,7431	0,7440	0,7339	0,7374
4Y	0,7457	0,7453	0.7380	0,7380
6Y	0,7441	0,7445	0,7354	0,7407
7Y	0,7446	0,7442	0,7385	0,7403
8Y	0,7458	0,7449	0,7356	0,7365
9Y	0,7435	0,7437	0,7335	0,7388
10Y	0,7448	0,7452	0,7356	0,7374
11Y	0,7461	0,7445	0,7332	0,7350
12Y	0,7483	0,7477	0,7293	0,7311
14Y	0,7450	0,7452	0,7334	0,7362
17Y	0,7475	0,7460	0,7340	0,7358
18Y	0,7437	0,7441	0,7313	0.7330
KB—1Y	0,7431	0,7451	0.7352	0,7369
KB—2Y	0.7460	0,7466	0,7378	0,7378
KB—3Y	0,7446	0,7444	0,7365	0,7400
KB—4Y		0,7437		0,7435
KB—5Y	0,7446	0,7353	0,7410	0,7393

Only those chemical analyses of studied garnets were commonly accepted where there was included Fe_2O_3 content and, where the 95 % cations were in corresponding structural positions. That is why the relatively accurate oxygen basis could be obtained for calculation of the structural formula and for the calculation of the individual atoms of garnet in cm^3. The zonal garnet analyses without the determination of Fe_2O_3 content obtained by the electron microprobe (R. Tracy, 1978) were compiled for the comparing reasons. In these, it is quite difficult to determine the quantity of andradite and grossularite components in many cases which have the great tendency to influence the lattice parameter size.

The recrystallization temperature was obtained on the base of K_D^{Fe-Mg} and its dependance on temperature which was determined for garnet — biotite mineral pairs in works by L. Pertchuk (1973) and A. Thompson (1976). The garnet variation XMg — Fe and the change of the distribution coefficient (K_D^{Fe-Mg}) with pressure, stated also in the mentioned works, was used for the pressure recrystallization approximation.

The Pertchuk's approach was preferred as obtained temperatures were more unic and with lesser dispersion. The temperatures according to Thompson have greater variation, so this resulted in lesser correlation between Φ and T — P metamorphic conditions.

Temperature values calculated after works of S. Saxena (1969) and D. Goldman — A. Albee (1977) were not used for their disaccordance with the occurences of the index minerals of the association also at samples, where there occured good accordance between the temperature calculated by Pertchuk and Thompson.

Results and discussion

As the sequence of the changed temperature and pressure conditions, we can understand the changing of the physical properties and the atomic packing according to following model reactions:

$$\underset{\text{garnet}}{(Pyr_{50}Alm_{50})} + \underset{\text{biotite}}{(Flog_{84}Ann_{16})} = \underset{\text{garnet}}{(Pyr_{58}Alm_{42})} + \underset{\text{biotite}}{(Flog_{75}Ann_{25})} \tag{1}$$
$$\sim 600\ °C, \sim 0{,}65\ \text{GPa} \qquad \sim 750\ °C, \sim 0{,}8\ \text{GPa}$$

$$\underset{\text{garnet}}{(Pyr_{41}Alm_{59})} + \underset{\text{biotite}}{(Flog_{91}Ann_{9})} = \underset{\text{garnet}}{(Pyr_{50}Alm_{50})} + \underset{\text{biotite}}{(Flog_{75}Ann_{25})} \tag{2}$$
$$\sim 500\ °C, \sim 0{,}45\ \text{GPa} \qquad \sim 700\ °C, \sim 0{,}7\ \text{GPa}$$

$$\underset{\text{garnet}}{(Pyr_{16}Alm_{84})} + \underset{\text{biotite}}{(Flog_{75}Ann_{25})} = \underset{\text{garnet}}{(Pyr_{33}Alm_{67})} + \underset{\text{biotite}}{(Flog_{58}Ann_{42})} \tag{3}$$
$$\sim 400\ °C, \sim 0{,}2\ \text{GPa} \qquad \sim 650\ °C, \sim 0{,}65\ \text{GPa}$$

That means that if we take into consideration the packing index of the garnet end members.

pyrope	$\Phi = 0{,}7572$
almandine	$\Phi = 0{,}7457$
spessartite	$\Phi = 0{,}7323$
grossularite	$\Phi = 0{,}7268$
andradite	$\Phi = 0{,}6924$

and the idealized additivity of ψ, that means also the change in the packing index for farnet in equations:

(1)	$\triangle\Phi = 0{,}0009$
(2)	$\triangle\Phi = 0{,}0010$
(3)	$\triangle\Phi = 0{,}0019$

It is evident from the positions of these reactions (fig. 1) that the atomic packing of garnets is continuously changed as the effect of exchange reactions at higher temperatures and pressures of rock recrystallization.

Then, the consequence of this is that the packing index (and probably also different physical properties) is given by *i*, the original chemical composition of garnet which follows from the bulk chemical composition of the rock and *ii*, the course of the chemical reaction conditioned by netamorphic grade. Then the garnet packing index cannot be the indicator of metamorphic influence upon the rock. This is effective mainly for the rocks of different chemical composition. Comparing the packing index in garnets with respect to T—P recrystallization conditions has more real signification for rock of similar chemical composition exhibited to different metamorphic grade. Therefore closer connection between Φ and temperature and pressure of recrystallisation within the individual metamorphic fields with similar chemical composition of the original rocks can occurr, as follows from the model approach, than the connection between Φ and recrystallisation temperature generally.

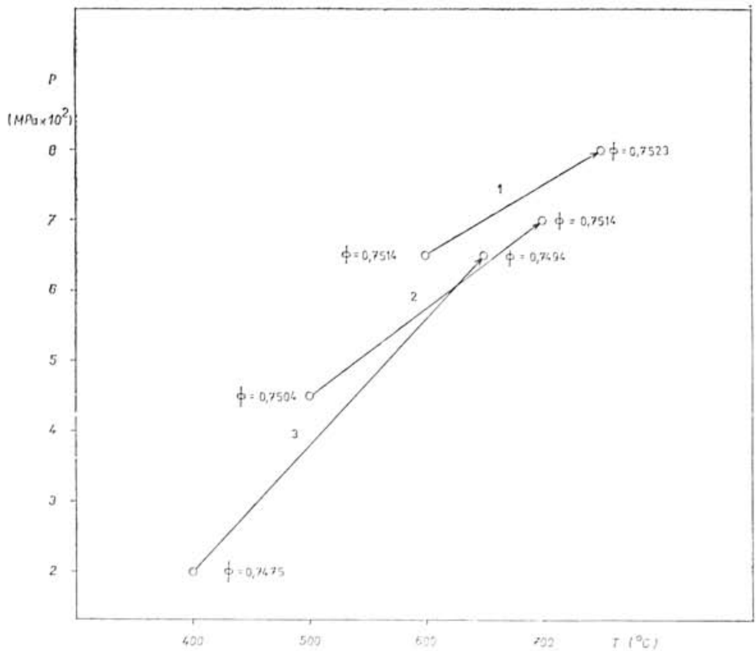


Fig. 1. The packing index change (Φ) calculated from the model aeactions for different temperature and pressure.

As this theoretical approach to the packing index could be followed in the real samples, own and published dates of different authors were compiled up. These results are summarized in tab. 3 and graphically demonstrated in figs. 2 and 3.

Only a week correlation can be seen in generally expressed connection between Φ of the garnet and temperature (fig. 2) and pressure (fig. 3) of recrystallization. However, the general trend is preserved that higher pecking index in garnets goes with higher temperature and pressure.

In consequence of mutual samples' comparison of the individual authors, expressed by different symbols, the equal value of Φ garnet appears in different samples at different $T_{calc.}$ and $P_{calc.}$ conditions. At the same time there occurs a greater connection between Φ and the individual geological areas studied by the individual authors.

In the cases where there was not found a correlation between the temperature obtained on the basis of K_D^{Fe-Mg} and the metamorphic grade (e.g. N. Stephenson, 1979) also correlation between Φ and $T_{calc.}$ and $P_{calc.}$ values was lowered. Although Φ is higher, it can not present the higher metamorphic degree, its expression by calculated temperature and pressure is not sufficient.

Where K_D^{Fe-Mg} connection with metamorphic degree is preserved (B. Butler, 1967, T. Kwak, 1970; W. Phiney, 1963; A. Engel — C. Engel,

Table 3

The packing index [Φ] of garnets and $T_{calc.}$ — $P_{calc.}$ recrystallisation conditions of the rocks from different world areas.*

Sample №	Packing index calculated from		Calculated temperature after [°C]		Presupposed pressure after [GPa]	
	a_0	ρ	Pertchuk	Thompson	Pertchuk	Thompson
R. Lambert [1959]			1*			
646	0,7303	0,7532	425	510	0,25	0,56
684	0,7346	0,7428	515	600	0,43	0,55
992	0,7371	0,7398	445	485	0,27	0,56
982	0,7394	0,7398	505	500	0,42	0,59
1034	0,7378	0,7345	495	530	0,40	0,59
A. Engel — C. Engel [1960]			2			
Qb 226	0,7411	0,7426	605	670	0,75	0,52
Qb 228	0,7417	0,7395	605	695	0,62	0,62
Qb 233	0,7423	0,7519	675	715	0,62	0,55
Qb 100	0,7459	0,7545	765	905	0,71	0,58
Bgn 14	0,7436	0,7575	690	780	0,74	0,53
Bgn 25	0,7440	0,7633	680	705	0,75	0,62
Bgn 18	0,7473	0,7546	705	730	0,79	0,60
Bgn 21	0,7466	0,7574	720	770	0,71	0,64
B. Mason [1962]			3			
143	0,7364	0,7181	440	440	0,27	
G. Chinner [1962]			4			
82 947	0,7454	0,7451	620	710	0,63	0,52
82 888	0,7466	0,7469	670	780	0,72	0,53
G. Chinner [1965]			5			
20—B	0,7431	0,7517	505	480	0,43	
44	0,7423	0,7487	480	460	0,36	
W. Phinney [1963]			6			
SP—9	0,7409	0,7460	515	525	0,45	0,61
SP—12	0,7413	0,7449	495	480	0,38	
SP—13	0,7402	0,7453	445	430	0,28	
SP—106	0,7427	0,7419	510	500	0,44	0,65
SP—107	0,7434	0,7410	530	530	0,48	0,61
SP—109A	0,7440	0,7420	580	580	0,56	0,61
SP—109B	0,7411	0,7450	450	455	0,27	
J. Green [1963]			7			
	0,7431	0,7465	500	535	0,40	0,61
	0,7447	0,7436	525	565	0,45	0,58
V. Lebedev [1964]			8			
225	0,7441	0,7587	655	675	0,75	0,59
32a	0,7471	0,7463	675	690	0,75	0,60
177	0,7457		735	705	0,75	0,58

Continuation tab. 3

Sample №	Packing index calculated from		Calculated temperature after (°C)		Presuposed pressure after (GPa)	
	a_0	ρ	Pertchuk	Thompson	Pertchuk	Thompson
N. Sudovnikov (1965)		9				
113	0,7483	0,7428	695	745	0,75	0,58
2202	0,7423	0,7626	625	665	0,64	0,56
M. Crawford (1966)		10				
37a	0,7416	0,7181	385	390	0,20	
44a	0,7423	0,7395	440	405	0,27	
67a	0,7422	0,7283	420	375	0,24	
B. Butler (1967)		11				
85484	0,7337	0,7429	415	560	0,24	?,53
85476	0,7347	0,7451	455	500	0,30	0,59
85559	0,7419	0,7522	550	605	0,51	0,56
85537	0,7349	0,7297	440	505	0,54	0,54
85610	0,7441	0,7647	645	740	0,68	0,54
S. Korikovskij (1967)		12				
B-72/2	0,7446	0,7452	605	575	0,61	0,65
B-60/4	0,7436	0,7526	580	620	0,57	0,57
S. Sen — K. Chakraborty (1968)		13				
K—231	0,7392	0,7462	685	765	0,74	0,49
K—327	0,7426	0,7418	730	790	0,76	0,53
214	0,7408	0,7419	690	790	0,74	0,48
238	0,7463	0,7359	625	660	0,64	0,59
241	0,7374	0,7430	560	565	0,54	0,59
279	0,7391	0,7337	645	730	0,64	0,52
135	0,7342	0,7359	535	580	0,48	0,59
262	0,7397	0,7419	560	585	0,54	0,58
266	0,7370	0,7444	505	590	0,58	0,61
287	0,7379	0,7402	545	525	0,50	0,61
SP/1	0,7414	0,7394	650	730	0,67	0,53
46/35	0,7455	0,7400	615	660	0,62	0,57
G/1	0,7454	0,7446	640	695	0,66	0,57
12/6	0,7422	0,7387	655	705	0,68	0,58
18/12	0,7420	0,7453	580	600	0,56	0,57
28/21	0,7409	0,7407	575	610	0,56	0,57
33/25	0,7403	0,7417	590	675	0,59	0,53
34/26	0,7393	0,7330	570	650	0,57	0,55
A. Hietanen (1969)		14				
A 23	0,7382	0,7463	400	450	0,20	
B 23	0,7405	0,7479	380	410	0,20	
143	0,7428	0,7466	480	410	0,37	
2083	0,7424	0,7462	520	490	0,44	
2127	0,7428	0,7497	580	615	0,57	0,57
2237	0,7432	0,7438	575	630	0,55	0,55

Continuation tab. 3

Sample №	Packing index calculated from		Calculated temperature after (°C)		Presuposed pressure after (GPa)	
	a_0	ρ	Pertchuk;	Thompson	Pertchuk;	Thompson
J. Lyons — S. Morse (197		15				
L—12	0,7383	0,7475	455	455	0,29	
S—14	0,7432	0,7480	525	615	0,46	0,51
MO—6	0,7429	0,7466	480	510	0,36	0,57
T. Kwak (1970)		16				
78	0,7460	0,7467	565	585	0,55	0,58
79	0,7456	0,7446	600	635	0,59	0,56
120	0,7455	0,7439	580	590	0,57	0,58
290	0,7461	0,7453	600	650	0,60	0,56
150	0,7459	0,7455	580	620	0,57	0,57
156A	0,7455	0,7451	580	610	0,57	0,58
156B	0,7455	0,7446	580	620	0,56	0,56
231	0,7460	0,7445	580	615	0,56	0,57
232B	0,7453	0,7445	590	625	0,59	0,57
249	0,7466	0,7472	660	735	0,67	0,51
292	0,7483	0,7469	700	700		
293	0,7477	0,7460	655	720	0,67	0,53
296	0,7467	0,7429	650	725	0,66	0,51
A. Mukherjee — S. Rege (1972)		17				
1	0,7421	0,7363	625	680	0,64	0,56
2	0,7430	0,7420	500	450	0,42	
3	0,7442	0,7400	650	680	0,68	0,59
4	0,7436	0,7473	705	760	0,76	0,59
5	0,7444	0,7429	625	640	0,64	0,59
6	0,7437	0,7449	690	760	0,75	0,57
7	0,7447	0,7448	620	630	0,63	0,62
8	0,7433	0,7414	620	640	0,63	0,59
R. Sharma — V. Narayan (1975)		18				
B2	0,7450	0,7425	575	635	0,57	0,53
C3i	0,7435	0,7368	490	505	0,38	0,57
C3ii	0,7436	0,7388	520	545	0,45	0,57
D3	0,7447	0,7379	570	625	0,54	0,53
D4	0,7457	0,7370	470	485	0,33	
E3i	0,7439	0,7443	500	500	0,40	0,58
E3ii	0,7469	0,7384	510	540	0,44	0,57
E4	0,7449	0,7441	500	520	0,40	0,58
R. Tracy (1978)		19				
892U	0,7455	0,7352	500	555	0,42	0,60
869	0,7430	0,7487	465	530	0,35	0,61
871	0,7449	0,7406	510	570	0,38	0,57
LiiY	0,7429	0,7467	530	575	0,48	0,62
C26A	0,7456	0,7513	485	550	0,36	0,58
933A	0,7459	0,7455	575	625	0,57	0,58
933B	0,7451	0,7505	560	620	0,53	0,56
595C	0,7449	0,7429	590	670	0,59	0,59

Continuation tab. 3

Sample №	Packing Index calculated from		Calculated temperature after (°C)		Presuposed pressure after (GPa)	
	a_0	ρ	Pertchuk	Thompson	Pertchuk	Thompson
M34	0,7444	0,7343	450	570	0,28	0,59
507 B	0,7456	0,7463	580	620	0,56	0,57
T10B	0,7446	0,7511	525	560	0,45	0,60
T12A	0,7466	0,7411	570	570	0,56	0,59
N. Stephenson (1979)		20				
1	0,7395	0,7439	620	740	0,63	0,51
2	0,7394	0,7420	600	700	0,59	0,52
3	0,7433	0,7424	650	685	0,51	0,46
4	0,7445	0,7440	670	755	0,69	0,53
5	0,7445	0,7427	640	685	0,66	0,58
6	0,7430	0,7455	600	645	0,61	0,59
7	0,7412	0,7460	625	705	0,64	0,54
8	0,7423	0,7456	620	650	0,63	0,61
9	0,7436	0,7456	670	750	0,72	0,57
10	0,7447	0,7454	680	690	0,73	0,64
11	0,7438	0,7462	580	670	0,57	0,53
12	0,7430	0,7415	575	670	0,56	0,51
13	0,7416	0,7448	500	575	0,43	0,52
14	0,7420	0,7436	530	605	0,47	0,54
15	0,7449	0,7437	655	735	0,67	0,52
16	0,7467	0,7418	590	650	0,58	0,56
17	0,7432	0,7456	595	630	0,58	0,58
author**		21				
4Y	0,7457	0,7380	535		0,44	
6Y	0,7441	0,7407	540		0,43	
7Y	0,7446	0,7403	555	350	0,45	
9Y	0,7435	0,7388	460		0,38	
10Y	0,7448	0,7374	485	345	0,42	
12Y	0,7483	0,7311	610	600	0,58	
14Y	0,7450	0,7362	510	435	0,42	
18Y	0,7437	0,7330	420	360	0,35	
KB—1Y	0,7431	0,7369	545	545	0,48	
KB—2Y	0,7460	0,7378	560	475	0,47	
KB—3Y	0,7446	0,7400	555	460	0,46	
KB—5Y	0,7446	0,7393	575	555	0,52	

* Localization and the petrological description of the samples are given in the work D y d a (1977).

** Appropriate graphical symbols are given in Fig 2.

1960; A. H i e t a n e n, 1969), also there occurs a closer correlation between Φ and $T_{calc.}$ nad $P_{calc.}$.

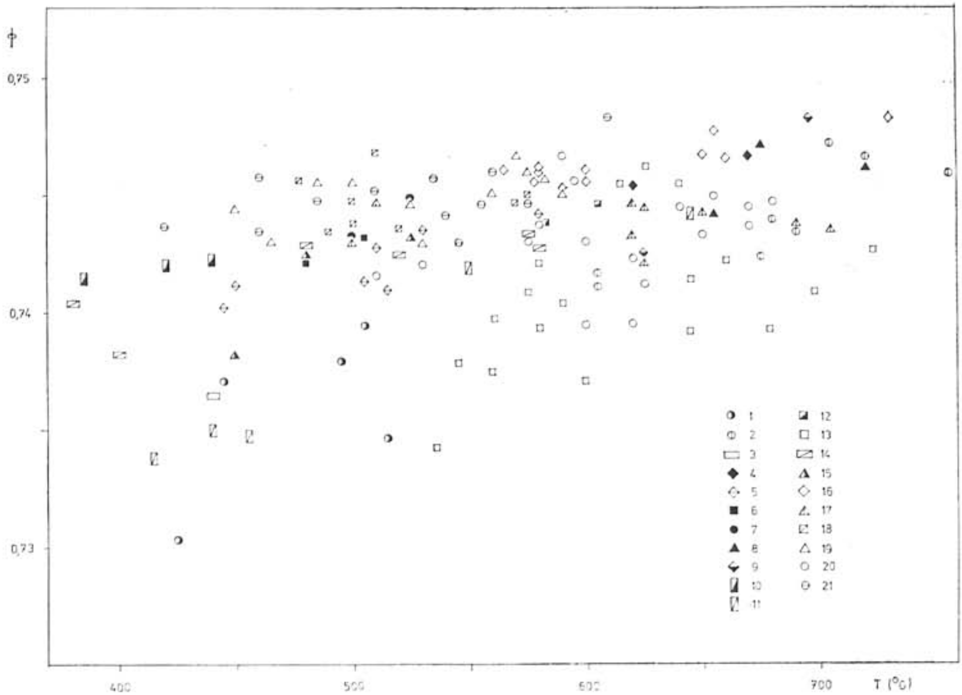
Although there was not tested the linear character of relationship between Φ and $T_{calc.}$ and $P_{calc.}$ values, these relationships are expressed by correlation coefficient. They can by summed up as following:

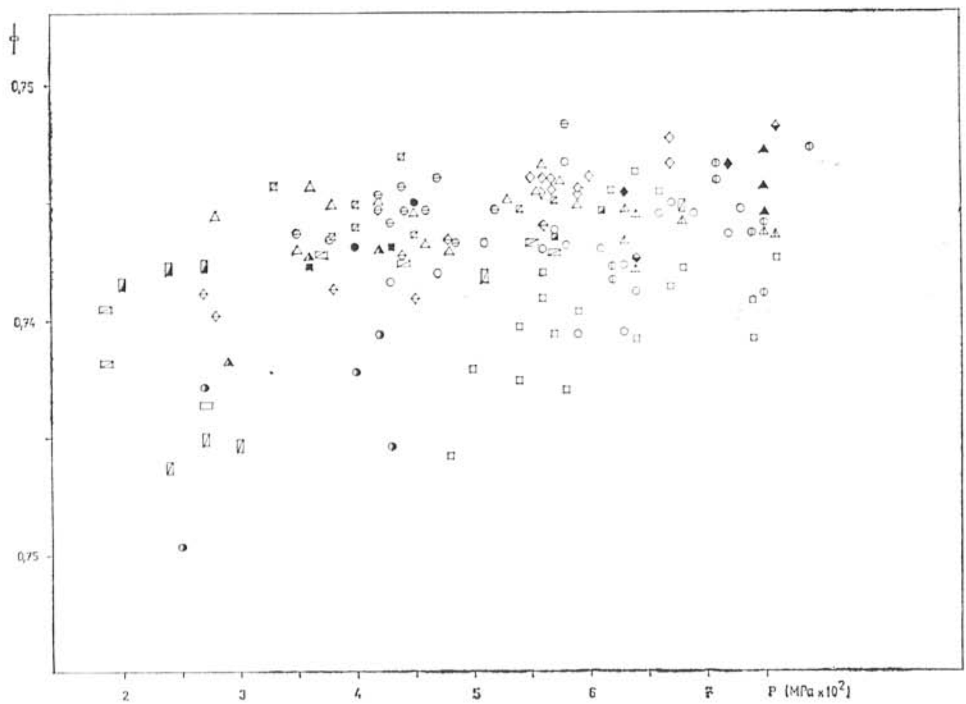
	r Φv.T°C	y = ax + b	r Φv.P	y = ax + b
R. Lambert (1959)				
a)	0,59	$\Phi \approx 0{,}5343\ T + 7103$	0,56	$\Phi \approx 23{,}280P + 7275$
A. Engel — C. Engel (1960)				
a)	0,83	$\Phi \approx 0{,}3564\ T + 7198$	0,49	$\Phi \approx 18{,}562P + 7308$
b)	0,57			
W. Phinney (1963)				
a)	0,85	$\Phi \approx 0{,}2609\ T + 7288$	0,83	$\Phi \approx 11{,}227P + 7373$
b)	0,82	$\Phi \approx 0{,}2327\ T + 7303$		
B. Butler (1967)				
a)	0,97	$\Phi \approx 0{,}4894\ T + 7237$	0,98	$\Phi \approx 24{,}881P + 7279$
b)	0,88	$\Phi \approx 0{,}4290\ T + 7128$		
S. Sen — K. Chakraborty (1968)				
a)	0,47	$\Phi \approx 0{,}1603\ T + 7300$	0,50	$\Phi \approx 19{,}177P + 7288$
b)	0,40			
A. Hietanen (1969)				
a)	0,82	$\Phi \approx 0{,}1870\ T + 7324$	0,84	$\Phi \approx 10{,}095P + 7377$
b)	0,51			
T. Kwak (1970)				
a)	0,89	$\Phi \approx 0{,}1979\ T + 7341$	0,79	$\Phi \approx 12{,}271P + 7387$
b)	0,75	$\Phi \approx 0{,}1292\ T + 7378$		
R. Tracy (1978)				
a)	0,47	$\Phi \approx 0{,}1098\ T + 7391$	0,42	$\Phi \approx 4{,}549P + 7428$
b)	0,29			
N. Stephenson (1979				
a)	0,32		0,29	
the author				
a)	0,59	$\Phi \approx 0{,}1573\ T + 7365$	0,66	$\Phi \approx 15{,}148P + 7380$

a) after Pertchuk b) after Thompson

Lower correlations can be motivated *i,* by incorrect values of Φ and $T_{calc.}$, $P_{calc.}$ added to the individual samples, *ii,* by chemical differences of parent rocks for which *iii,* the recrystallization temperature was determined on the basis of K_D^{Fe-Mg}, which does not be in accordance with the realized metamorphic temperatures, and *iv,* also by closer range of temperatures, pressures and Φ in a certain sample group. From the shown $T_{calc.}$ and $P_{calc.}$ connection of the recrystallization process follows that given value of packing index represents the metamorphic grade only for a certain rock. But the packing index of the certain garnet does not allow to determine the individual metamorphic zone generally.

The difference in the packing index of garnets from the isochemical rocks exhibited to different metamorphic grades need not to determine the differences in T — P conditions of their recrystallization. This relation is in the elaborated samples expressed by the slope of the individual linear regression lines. E. g. $\triangle\ \Phi = 0{,}05$ (fig. 4) after Butler (1976) shows ~ 100 °C diffe-


φ
0,75
0,74
0,73
400
500
600
700
T (°C)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21


φ
0,75
0,74
0,75
2
3
4
5
6
7
8
P (MPa x10²)

rence in the calculated temperature. But the same value, $\triangle \Phi = 0{,}05$, for A. Hietanen (1969) means ~ 200 °C difference.

Accepting of the model system and evaluation of the real samples does not allows using of the garnet packing index on general determination of metamorphic grade for rocks of different chemical compositions from different regions. Taking out any of the rocks series, e.g. metapelites, within this Φ garnets' comparison should be lead to approximation PT conditions of metamorphosis, is also hardly probable. Generalization that on the basis of unit cell edge (a_0) and (FeO + MgO; (CaO + MnO) contents in the garnet (K. Nandi) can be determined the metamorphic degree, need not to be commonly established.

Conclusions

Almandines of the Malé Karpaty Mts. metapelites created during the periplutonic recrystallisation process show systematical change of the packing index (Φ = 0,7431 — 0,7483) dependant on the temperature (T = 460 — —610 °C) and pressure (P = 380 — 580 MPa) of the recrystallisation process.

By model approach of evaluation of garnet and biotite coexistence in metamorphic rocks of different world geological areas the dependence between packing index of garnets and temperature and pressure of metamorphic process was shown.

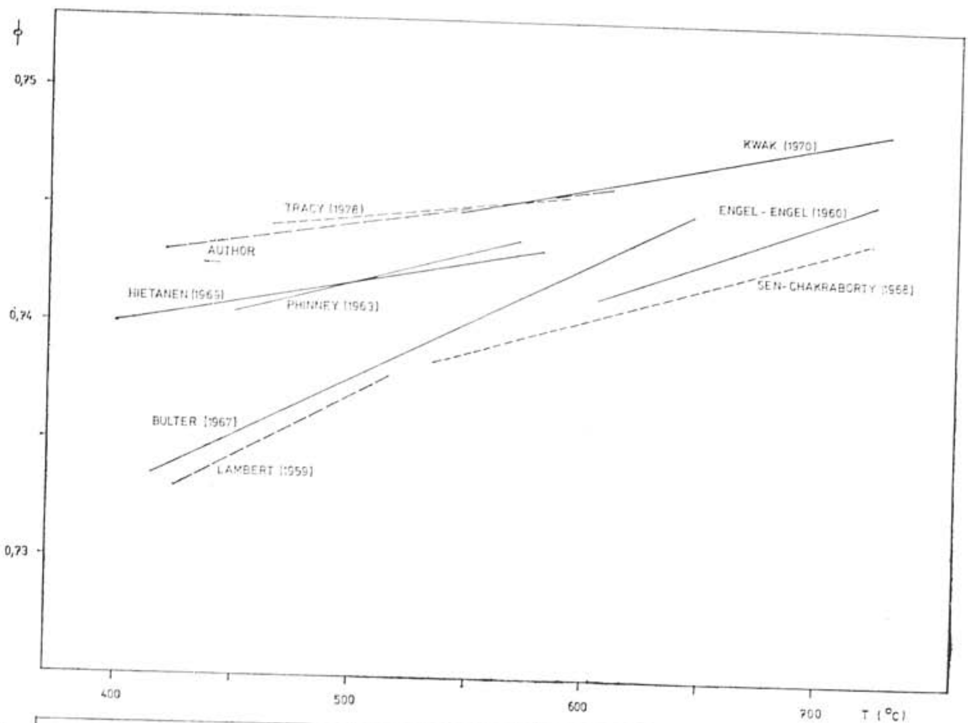
The substitutional reaction in garnets conditioned by the chemical composition of parnet rocks and T—P recrystallisation conditions indicate that the relationship between metamorphic grade and the packing index of garnets is not commonly established for rocks from different regions (figs. 2 and 3). This connection is accepted for given rocks of similar chemical composition exhibited to different metamorphic degrees (figs. 4 and 5).

Being suitable of the packing index for examination of metamorphic grade follows from the mineralogical and chemical composition of the parent rocks and also from the temperature and pressure ranges conditioned by their recrystallisation.

The physical connection of the packing index of garnet with the unit cell edge, density and refractive index, allows to presuppose also the systematical changing of these properties as the result of different P—T—X conditions of recrystallisation process.

Fig. 2. Relations between the packing index (Φ) and the recrystallisation temperature ($T_{calc.}$) of different metamorphic rocks. (The symbols are shown in tab. 3).

Fig. 3. The relations between the packing index (Φ) and the recrystallisation pressure ($P_{calc.}$) of different metamorphic rocks.


ϕ
0,75
0,74
0,73
KWAK (1970)
TRACY (1978)
AUTHOR
ENGEL - ENGEL (1960)
HIETANEN (1969)
PHINNEY (1963)
SEN-CHAKRABORTY (1968)
BULTER (1967)
LAMBERT (1959)
400
500
600
700
T (°C)

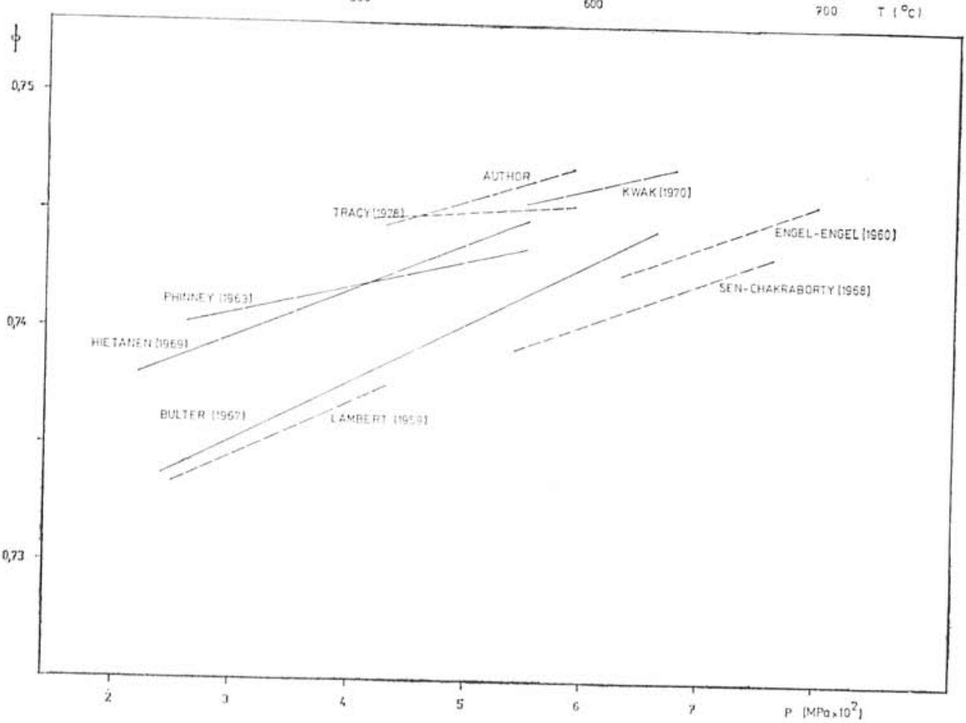

ϕ
0,75
0,74
0,73
AUTHOR
KWAK (1970)
TRACY (1978)
ENGEL-ENGEL (1960)
PHINNEY (1963)
SEN-CHAKRABORTY (1968)
HIETANEN (1969)
BULTER (1967)
LAMBERT (1959)
2
3
4
5
6
7
P (MPa x 10²)

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Fig. 4. The generalized relations between the packing index (Φ) and the recrystallisation temperatures ($T_{calc.}$) of the rocks.

Fig. 5. The generalized relations between the packing index (Φ) and the recrystallisation pressures ($P_{calc.}$) of the rocks.

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