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SIMPLE MODEL OF PARAGNEISS AND AMPHIBOLE ROCK PROTOLITHS OF THE NÍZKE TATRY MTS. CRYSTALLINE COMPLEX

(Figs. 3, Tabs. 3)

Abstract: Protoliths of amphibolites, amphibole gneisses and paragneisses from the Nízke Tatry Mts. crystalline complex can be considered a mixture of basic volcanic and terrigenous sedimentary material. Simple two- and three-component mixing models show that these amphibolite may contain up to 25 % of admixture of terrigenous sedimentary material, and typical paragneisses on the contrary, up to 25 % of basic volcanic material.

Резюме: Протолиты амфиболитов, амфиболовых гнейсов и парагнейсов кристаллиникума Низких Татр можно считать смесью основного вулканического и терригенного осадочного материала. Простые двух- и трехкомпонентные модели смешивания показывают, что эти амфиболиты могут содержат до 25 % примеси теригенного осадочного материала и типичные парагнейсы, на другой стороне, до 25 % основного вулканического материала.

The Tatride crystalline complex lies in the western part of the Nízke Tatry Mts. Metamorphites of the Nízke Tatry Mts. crystalline complex are formed mainly by migmatites of various structural types and less by intercalations of paragneisses, amphibole rocks, and, to a very low degree, by intercalations of graphite, pyroxene, ultramafite and other rock types. These metamorphites were intruded by Variscan granitoid pluton. Geochronological data suggest Palaeozoic origin of metamorphism. The basic region, where most examined samples come from, is that of Jasenie — Kyslá, its geological structure having been described by Bezák — Klinec (1980; 1983).

Paragneisses occuring in migmatites form intercalations in meter-even dekameter- sizes. They are mostly grey oriented rocks. Biotite garnet-biotite and muscovite-biotite gneisses are the most frequent. Plagioclase of these rocks corresponds to oligoclase—andesine, together with biotite, quartz and garnet it is their basic rock-forming mineral. Muscovite content depends on rock type. There are only scarcely occuring gneisses with high contents of clinozoisite, those with pyroxene and basic plagioclases, which are supposed to contain an admixture marl material in protolith.

Amphibole gneisses and amphibolites like paragneisses represent a characteristic ingredient of the Nízke Tatry Mts. crystalline complex where they occur in the form intercalations of centimeter- even dekameter- thickness. Their main rock-forming minerals are represented by green magnesian hornblende and plagioclase corresponding to andesine. Biotite, quartz, garnet, epidote-group minerals and opaque minerals represent other characteristic minerals of these rocks.

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Fig. 1. Alternation of bands with amphibole (dark) and without it in amphibole gneiss. Characteristic thickness of bands 1—3 cm. Špíglová dolina valley, the Nízke Tatry Mts.

During field and petrographic investigation it can be seen that amphibole rocks are of volcanoclastic character, which is supported by low and constant thickness of amphibole rock intercalations, stratification of rocks depleted in amphibole with amphibolites and amphibole gneisses within the outcrop (Fig. 1), samples and thin sections. On the other hand, paragneisses contain intercalations rich in mafic minerals (biotite, hornblende, opaque minerals and those of epidote group), that should be considered relics from basic volcanoclastic material (Fig. 2).

The main object of our paper is to determine relative abundances of basic volcanic and terrigenous material in paragneisses and amphibolites.

Methodology

Because of impossibility to determine abundance ratios of particular end members — basic volcanic and sedimentary ones by direct methods in particular types of metamorphites, and/or samples, we chose mathematic methods for modelling — factor analysis and adapted GENMIX program (Le Maitre, 1981). We used 24 original analyses that, together with some comparative ones, are given in Tab. 1. Beside these we took 13 analyses from the paper by

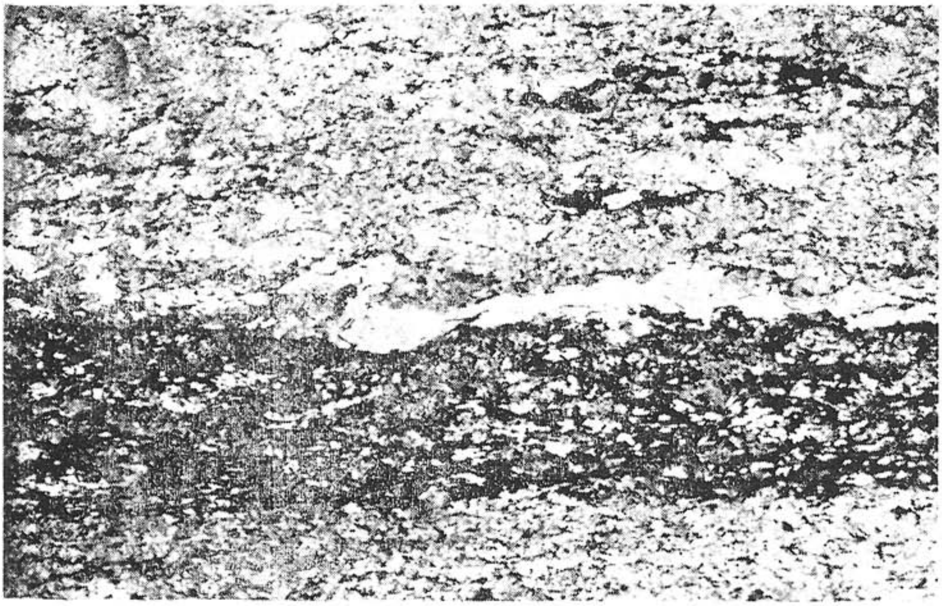

Fig. 2. Basic volcanoclastic material relic in biotite gneiss. Sample J-37, magnification 10 ×, without nicols. Jasenie—Kyslá, the Nízke Tatry Mts.

Miko (Pecho et al. 1980; 1983): JP1/32, JP1/10, JP1/13, JP2/13B, JP1/12, JP1/14, JP1/20, JP1/33, JP1/1, JP1/18, JP1/23, JP1/17, JP1/43 and 7 from the catalogue by Cambel and L. Kamenický (1982): 37/1, 37/2, 37/3, 37/4, 38/1, 38/2 and 38/3. Only major elements (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O) were taken into consideration, while water, P_2O_5 and SO_3 were eliminated. All iron was calculated on FeO and the analysis was calculated on 100 %. We tried to eliminate strongly altered samples, alteration signs, however, at least plagioclase sericitization, biotite chloritization are present in each sample. We kept original names of the samples. We classified original analyses according to these criteria: gneiss — amphibole gneiss boundary: 10 % of amphibole; amphibole gneiss — amphibole boundary: 10 % of quartz.

GENMIX program (Le Maitre, 1981) solves petrological mixing model by least squares method — in our case, e. g. that of basic volcanite + sediment = amphibole gneiss type. The program calculates optimum ratios of starting end members (volcanite + sediment) and gained composition of a product and compares it to desired product.

The used Q-mode factor analysis in general calculates the same problem. Compared to GENMIX it has, however, several advantages:

1. It operates with the whole set of primary data at once.

2. It does not require to state a priori the necessary number of end members. In our case selection of two end members appeared sufficient, they explained

Table 1

Chemical composition of rocks

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^+	H_2O^-	SO_3	Total	anal.
J-119	70.63	0.78	13.79	0.56	3.75	0.07	1.17	1.96	3.72	1.93	—	1.28	0.02	—	99.66	GÚ
J-66	70.30	0.57	12.69	1.45	2.21	0.05	0.94	1.76	2.65	2.15	0.07	2.79	0.32	tr.	97.95	GP
J-128	69.27	0.47	15.78	0.29	3.19	0.06	0.78	3.17	4.00	1.77	—	0.74	0.03	—	99.56	GÚ
J-89	66.89	0.75	14.20	1.40	3.26	0.14	1.85	4.82	0.90	2.31	0.19	2.37	—	0.19	99.27	GP
J-91	66.58	0.80	15.35	1.04	4.18	0.12	2.23	4.02	2.31	1.79	0.17	1.27	—	0.19	100.05	GP
J-115	66.65	0.79	15.66	1.37	3.45	0.06	1.28	1.94	3.44	2.93	—	2.08	0.04	—	99.69	GÚ
J-37	62.81	1.89	14.29	0.90	6.14	0.11	2.61	2.81	2.21	3.22	0.24	1.61	0.50	0.16	99.50	GP
J-35	62.70	0.48	15.39	0.60	2.54	0.07	3.31	3.06	0.31	3.66	0.15	6.62	0.35	0.14	99.38	GP
J-44	57.50	1.05	18.89	2.07	4.23	0.13	2.63	5.53	2.34	2.32	0.30	2.60	—	0.21	99.80	GP
J-129	69.18	0.57	14.92	0.79	3.56	0.05	0.96	2.95	4.20	1.25	—	1.27	0.03	—	99.73	GÚ
J-71	59.63	0.37	15.06	1.38	4.36	0.07	4.83	4.97	2.85	1.75	0.04	2.96	0.27	0.02	98.56	GP
J-72	59.28	0.42	15.24	0.75	5.09	0.09	5.21	4.91	3.00	1.23	0.07	1.99	0.31	tr.	97.59	GP
J-111	54.72	3.36	14.27	2.47	8.39	0.18	3.62	4.85	1.45	2.86	—	2.71	0.08	—	98.96	GÚ
J-60	52.98	2.76	14.75	1.38	9.83	0.18	4.42	5.82	0.76	3.29	0.31	2.75	0.36	0.19	99.78	GP
J-118	53.96	1.81	13.29	2.18	6.80	0.17	6.95	7.45	2.17	1.58	—	2.87	0.04	—	99.27	GÚ
J-112	53.57	2.03	14.80	2.11	7.01	0.16	5.62	8.22	1.18	1.94	—	2.03	0.06	—	98.73	GÚ
J-42	52.83	3.24	13.98	1.18	10.18	0.17	4.01	6.94	2.16	1.87	0.34	1.57	0.63	0.59	99.69	GP
J-38	52.09	2.12	14.80	1.53	8.87	0.16	5.35	8.81	1.35	1.81	0.33	1.71	0.61	0.26	99.80	GP
J-2	48.92	2.19	15.41	1.44	9.33	0.22	6.54	7.64	1.18	3.42	0.35	2.71	0.60	0.53	100.48	GP
J-58	52.69	2.08	15.67	1.67	8.19	0.14	5.07	8.39	1.83	1.74	0.33	2.03	0.65	0.31	100.79	GP
J-83	49.97	1.40	15.76	1.99	7.61	0.13	7.78	6.10	1.28	2.70	0.19	3.01	0.33	0.67	97.92	GP
J-63	47.20	1.71	13.63	2.65	7.03	0.11	7.33	6.79	2.08	0.55	0.22	6.43	0.47	0.02	96.22	GP
J-121	44.47	3.99	14.48	1.76	11.07	0.27	7.20	9.40	3.20	1.42	—	1.36	0.08	—	99.93	GÚ
SP-20	49.43	1.41	15.09	4.23	6.80	0.21	7.41	9.75	2.14	1.61	—	1.31	0.18	—	100.15	GÚ
Tholeiite	49.30	1.80	15.20	2.40	8.00	0.17	8.30	10.80	2.60	0.24	—	—	—	—	98.81	
Al-gneiss	51.66	1.06	23.44	2.61	6.91	0.20	3.52	3.48	1.96	3.28	0.27	1.65	0.17	—	100.21	
Q-gneiss	73.97	0.51	11.95	1.32	2.11	0.05	1.63	2.06	2.20	2.47	0.12	1.51	0.10	—	100.00	
JP1/43	73.31	0.61	12.13	0.82	2.84	0.04	1.61	0.98	2.24	2.25	0.10	2.56	0.01	0.10	99.60	

99.74 % of total variance of primary analyses. Three end members explained 99.86 %.

3. It does not require to state a priori chemical composition of particular end members and, especially, in larger sets enables their optimum choice. It suggests, in general, infinite number of mathematically equivalent solutions.

The so-called objective methods of Q-mode factor analysis do not suppose the presence of pure end members in the set of analyses, which, when mixed, generate the other rocks in the set, but they try to calculate their hypothetical chemical compositions. We supposed that suitable end members would be a) published analyses of quartzite paragneisses, Al_2O_3-rich paragneisses of the Jarabá Group crystalline complex of the Western Carpathians (H o v o r k a, 1975) and tholeiite (H y n d m a n, 1972); b) the most contrasting analyses in the set of rocks under study: sample No. J-121 appeared the most basic and JP1/43 the most acid.

The choice of tholeiite (H y n d m a n 1972), and/or the most contrasting ("the most basic") amphibolite J-121 as a representative of volcanic end member in mixing model appears logical and well-founded. Their mutual exchange does not cause considerable changes in the modelling results. The choice of sedimentary one/ones is, however, a critical point of the model.

The region under study is a typical region of the Jarabá Group development. H o v o r kk a (1975) divided the Jarabá Group parametamorphites as follows:

metamorphite	probable protolith
1. Al-rich gneisses	schists, redeposed kaolin, laterite weatthering products
2. Biotite-plagioclase paragneisses	graywackes
3. Quartzite paragneisses	graywackes, subgraywackes
4. Metaquartzite	qurtzite sandstones
5. Pyroxene gneisses	calcareous (marl) sediments

Notes to Tab. 1: J-119 — biotite gneiss with garnet, Špíglová dolina valley; J-66 gneiss with biotite and garnet, Struhár massif; J-128 biotite gneiss, Struhár massif; J-88 biotite gneiss, Gelfusová dolina valley; J-91 biotite gneiss, Špíglová dolina valley; J-115 biotite gneiss with muscovite, Špíglová dolina valley; J-37 biotite gneiss, Prostredná dolina valley; J-35 gneiss with muscovite, Špíglová dolina valley; J-44 biotite-clinozoisite gneiss with garnet, Gelfúsová dolina valley; J-129 biotite gneiss, Šifrová dolina valley; J-71 biotite-amphibole gneiss, Špíglová dolina valley; J-72 amphibole gneiss with biotite, Špíglová dolina valley; J-111 amphibole gneiss with biotite, Prostredná dolina valley; J-60 biotite-amphibole gneiss, Prostredná dolina valley; J-118 amphibole gneiss, Špíglová dolina valley; J-112 amphibole gneiss, Prostredná dolina valley; J-42 biotite-amphibole gneiss, Prostredná dolina valley; J-38 biotite-amphibole gneiss, Prostredná dolina valley; J-2 amphibole-biotite gneiss, Prostredná dolina valley; J-58 amphibolite with quartz, Prostredná dolina valley; J-83 biotite amphibolite, Špíglová dolina valley; J-63 biotite amphibolite, Špíglová dolina valley; J-121 amphibolite, Špíglová dolina valley; SP-20 amphibolite, Jarabá.

Tholeiite — oceanic tholeiite (H y n d m a n, 1972) mean of 161 anal.; Al-gneiss — Al-rich paragneiss (H o v o r k a, 1975) mean of 8 analyses; Q-gneiss — quartzite gneiss (H o v o r k a, 1975) mean of 23 analyses; JP1/43 — muscovite-biotite gneiss P e c h o et al., 1980) analyst: GP = Geological Survey Laboratory, Spišská Nová Ves; GÚ = Laboratory of the Geological Institute of the Slovak Acad. Sci.

Table 2

Factor analysis mixing models

	1		2			3		
	A	B	A	B	C	Q	P	T
JP1/43	100	0	100	0	0	100	7	—7
J-119	90	10	91	9	0	87	16	—3
J-66	95	5	97	3	0	95	10	—5
J-128	86	14	88	12	0	81	23	—4
18	86	14	87	12	0	76	41	—17
J-89	76	24	77	23	0	73	10	17
17	77	23	78	22	0	72	17	11
J-91	73	27	74	26	0	67	20	13
J-115	82	18	83	17	0	73	36	—9
J-37	67	33	68	32	0	58	28	14
J-35	77	23	78	22	0	67	35	—2
J-44	50	50	52	47	1	36	49	5
JP1/1	47	53	48	51	1	25	70	5
JP1/33	45	55	45	54	1	27	51	22
JP1/10	30	70	31	69	0	14	37	49
J-129	84	16	86	14	0	81	18	1
JP1/23	75	25	76	24	0	69	22	9
J-71	57	43	58	42	0	49	20	31
JP1/20	53	47	54	46	0	44	23	33
J-72	55	45	56	44	0	47	20	33
J-111	38	62	38	62	0	25	28	47
J-60	30	70	31	69	0	16	30	54
J-118	32	68	33	67	0	25	2	73
J-112	30	70	30	70	0	20	12	68
J-42	28	72	29	71	0	18	15	67
J-38	23	77	24	76	0	13	11	76
JP2/13B	22	78	22	77	1	4	40	56
JP1/32	22	78	23	76	1	—5	81	24
J-2	17	83	18	82	0	2	28	70
14	16	84	16	84	0	1	26	73
JP1/12	15	85	15	85	0	—2	32	70
J-58	26	74	27	73	0	14	18	68
J-83	22	78	21	78	1	5	35	60
J-63	20	80	21	79	0	9	13	78
13	4	96	4	96	0	—8	8	100
J-121	0	100	0	100	0	—14	12	102
37/1	15	85	15	85	0	0	27	73
37/2	17	83	17	83	0	8	0	92
37/3	16	84	.16	84	0	7	1	92
37/4	28	72	28	72	0	21	—2	81
38/1	5	95	5	95	0	—8	8	100
38/2	11	89	12	88	0	0	9	91
38/3	11	89	11	89	0	0	8	92
SP-20	13	87	13	87	0	1	9	90
T	10	90	—	—	—	0	0	100
P	31	69	—	—	—	0	100	0
Q	97	3	—	—	—	100	0	0

Notes to Tab. 2: Results of paragneisses and amphibole rocks mixing models from the Nízke Tatry Mts. crystalline complex — factor analysis. End members: A = gneiss No. JP1/43; B = amphibolite No. J-121, Q = quartzite paragneiss H o v o r k a, 1975), P = Al-rich paragneiss H o v o r k a 1975), T = oceanic tholeiite H y n d m a n, 1972), C = hypothetical end member. Data in wt. %.

Table 3

GENMIX models

Sample	1			2			3				4			
	A	B	R	Q	T	R	A	P	B	R	Q	P	T	R
JP1/43	100	0	0.0	102	—2	1.1	100	0	0	0.0	101	6	—7	0.9
J-119	88	12	2.3	88	12	2.8	85	11	4	1.9	85	17	—2	1.9
J-66	95	5	1.4	97	3	1.7	93	7	0	1.2	94	11	—5	0.9
J-128	83	17	4.5	82	18	4.5	75	27	—2	3.3	76	28	—4	3.8
18	85	15	4.7	84	16	5.3	76	32	—8	3.0	77	37	—14	3.1
J-89	78	22	3.5	76	24	2.8	75	12	13	3.2	74	13	13	2.3
17	77	23	2.3	75	25	2.6	73	14	13	1.7	71	18	11	1.4
J-91	74	26	3.0	71	29	2.9	68	20	12	1.9	67	22	11	1.2
J-115	78	22	4.0	76	24	4.7	68	32	0	1.8	69	37	—6	1.6
J-37	65	35	2.5	62	38	4.1	60	18	22	1.5	57	27	16	2.5
J-35	76	24	5.4	74	26	5.2	66	36	—2	3.7	67	34	—1	3.3
J-44	48	52	6.7	42	58	6.7	33	54	13	2.8	31	53	16	3.2
JP1/1	45	55	7.1	39	61	8.6	29	57	14	3.0	27	65	8	3.6
JP1/33	45	55	5.6	40	60	7.0	35	38	27	3.7	31	46	23	4.3
JP1/10	32	68	4.3	23	77	5.0	23	29	48	2.7	16	34	50	3.0
J-129	83	17	3.7	82	18	3.8	78	18	4	3.0	77	22	1	2.8
JP1/23	75	25	3.6	72	28	2.9	69	19	12	1.8	69	20	11	1.5
J-71	57	43	3.6	51	49	2.8	52	19	29	2.8	48	19	33	1.6
JP1/20	54	46	4.1	48	52	4.1	50	15	35	3.7	44	17	38	3.5
J-72	56	44	3.8	50	50	3.0	50	20	30	3.1	46	19	35	1.9
J-111	38	62	3.3	32	68	5.9	34	13	53	3.0	26	27	47	5.0
J-60	31	69	3.6	24	76	5.9	27	16	57	3.1	18	28	54	4.8
J-118	34	66	2.5	25	75	1.8	35	—5	70	2.5	25	0	75	1.8
J-112	32	68	3.0	23	77	2.4	29	9	62	2.8	20	13	67	1.9
J-42	29	71	2.3	21	69	5.0	28	4	68	2.2	18	16	66	4.6
J-38	26	74	2.8	16	84	3.0	24	7	69	2.7	14	12	74	2.6
JP2/13B	22	58	5.2	12	88	6.5	16	23	61	4.5	6	32	62	5.3
JP1/32	25	75	9.3	16	84	11	7	65	28	5.7	2	73	25	6.1
J-2	18	82	3.4	7	93	4.7	12	19	69	2.7	2	26	72	3.6
14	17	83	2.7	7	93	4.6	13	13	74	2.3	2	22	76	3.9
JP1/12	18	82	3.7	6	94	4.4	11	24	65	2.5	1	29	70	2.7
J-58	28	72	2.9	18	82	3.0	23	15	62	2.3	14	19	67	2.0
J-83	23	77	4.6	12	88	4.8	15	26	59	3.5	7	30	63	3.3
J-63	26	76	3.1	13	87	2.6	22	5	73	3.0	11	10	79	2.4
13	8	92	4.2	—5	105	4.2	9	—4	95	4.2	—5	2	103	4.2
J-121	0	100	0.0	—13	113	4.6	0	0	100	0.0	—15	12	103	4.4
37/1	20	80	3.9	10	90	5.6	17	13	70	3.6	6	23	72	5.0
37/2	23	77	4.1	13	87	5.5	27	—14	87	3.8	14	—2	88	5.5
37/3	21	79	3.1	10	90	2.3	22	—6	84	3.1	10	—1	91	2.5
37/4	31	69	2.8	22	78	1.5	33	—7	74	2.7	22	—2	80	1.5
38/1	9	91	2.9	—3	103	4.6	9	—1	92	2.9	—5	8	97	4.5
38/2	14	86	3.7	2	98	1.3	12	8	80	3.6	1	9	90	0.8
38/3	15	85	2.7	4	96	4.1	16	—2	86	2.7	3	6	91	4.0
SP-20	15	85	3.3	3	97	1.7	14	5	81	3.2	2	8	90	1.6
T	13	87	4.2	0	100	0.0	13	—1	88	4.2	0	0	100	0.0
P	29	71	11	20	80	12	0	100	0	0.0	0	100	0	0.0
Q	99	1	1.2	100	0	0.0	100	—5	5	1.0	100	0	0	0.0

Notes to Tab. 3: Results of paragneisses and amphibole rocks mixing model from the Nízke Tatry Mts. crystalline complex — GENMIX program (Le Maitre, 1981). End members — see Tab. 2. R = distance between model and real sample composition. Data in wt. %.

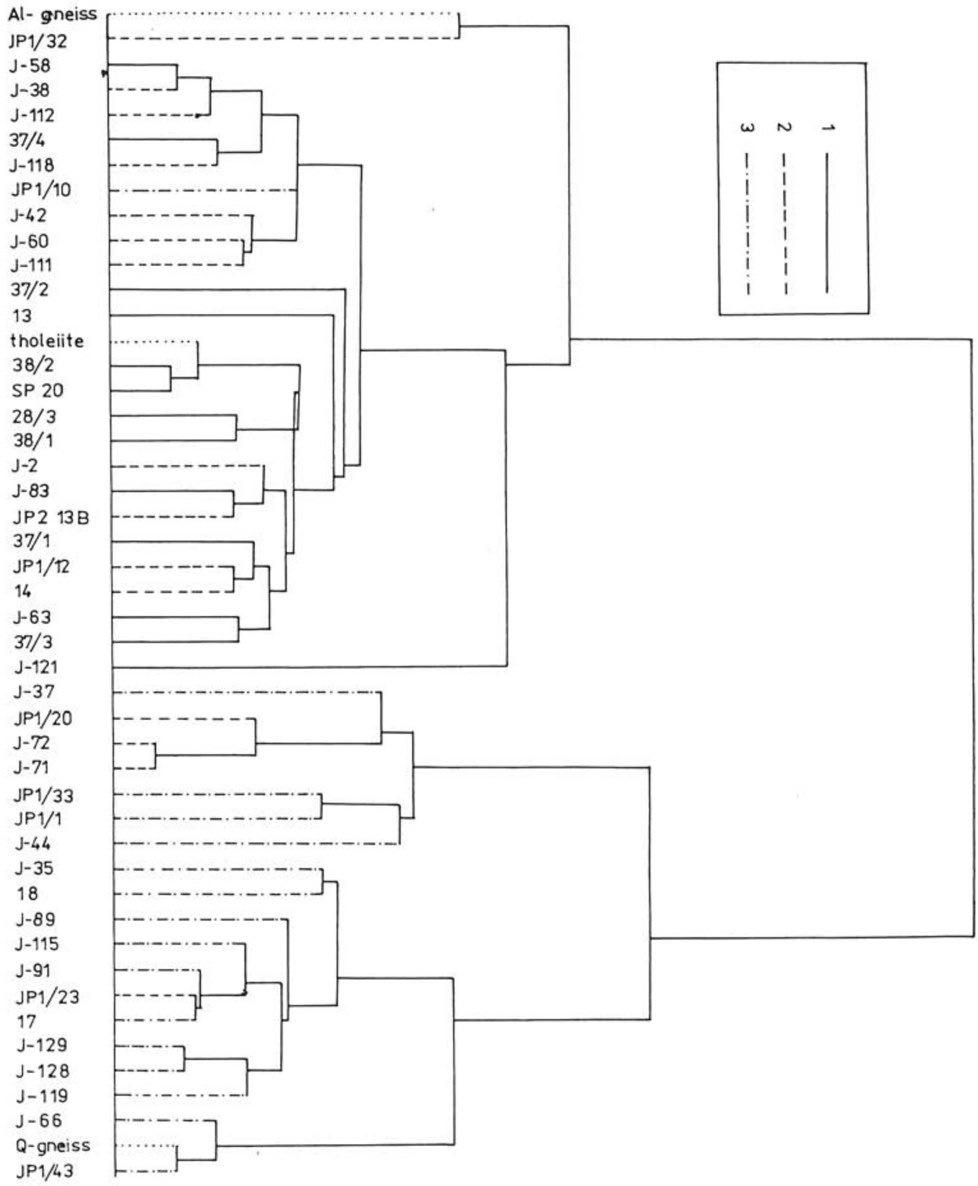

Fig. 3. Dendrogram of paragneisses and amphibole rocks from the Nízke Tatry Mts. crystalline complex.

Explanations: 1. — rocks indicated as amphibolites, 2. — amphibole gneisses, 3. — paragneisses — Al-gneiss — Al-rich paragneiss, Q-gneiss — quartzite paragneiss (H o v o r k a, 1975), tholeiite — oceanic tholeiite (H y n d m a n, 1972).

Relative abundances are estimated by author (l. c.) in given order approximately in 1 : 80 : 17 : 1 ratio. Mean of 23 analyses of quartzite paragneisses, published by Hovorka (l. c.), and that of 8 analyses of Al-rich paragneisses were chosen for the basic sedimentary member. Marl sediments were not taken into consideration. Analyses of rocks with pyroxene were not included into the set. They are not frequent in the region under study. Neither we considered graywackes as an end member, because as a typical geosynclinal sediment they are well reproducible just as a mixture of basic volcanic and terrigenous sedimentary material. The second most contrasting sample from the processed set of analyses — Miko's analysis JP1/43 was chosen as another representative of sedimentary end member.

We therefore calculated the following mixing models of paragneisses and amphibole rock protoliths of the Nízke Tatry Mts. crystalline complex:

1. quartzite paragneiss: Al-rich paragneiss: tholeiite
2. quartzite paragneiss: tholeiite
3. JP1/43: Al-rich paragneiss: J-121
4. JP1/43 J-121

These variants were calculated by factor analysis (Tab. 2) as well as GENMIX program (Tab. 3). We must note that negative values of end member ratios in the models usually indicate that the end members were not chosen the most contrasting rocks then, e. g., in the set there exists more basic rocks than the most basic end member. In such cases factor analysis as well as GENMIX require negative quotient to be subtracted from the mixture of the other end members. Use of linear programming methods in mixing model analysis or choice of the most contrasting end members enables to eliminate negative values. Interrelations of chemical compositions of particular samples are appropriatelly shown in dendrogam (Fig. 3) as a result of cluster analysis according to adapted simple program by Spencer (1984). The cluster analysis followed this algorithm:

1. For processed non-standardized primary data relative distances of particular samples were calculated in Euclidean, in our case 9-dimensional, oxide space.

2. In every step we united two most similar analyses into a cluster. After unifying each cluster is represented by mean of analyses included in it.

3. Clusters gained in this way were illustrated in the dendrogram, where horizontal lines connect clusters (analyses) on equal levels of similarity. Fig. 3 shows the most similar analyses J-71 and J-72.

Methods used here can by studied in detail in special literature (Jöreskog et al., 1976; Le Maitre, 1981; Spencer, 1984).

Discussion

Tab. 2 presents the results of Q-mode factor analysis. Columns 1 and 2 present 2- and/or 3-factor model while end members are presented by the most contrasting analyses of the Nízke Tatry Mts. metamorphites from the sample set — paragneiss JP1/43 and amphibolite J-121. Column 3 in Tab. 2 gives a 3-factor model where end members are represented by analyses of tholeiite, Al-rich paragneiss and quartzite paragneiss (Hyndman, 1972; Hovorka, 1975). The third factor in column 2 presents a hypothetical, in our case non-interpreted, end member. It is of low importance. We remark that mixing models in columns 2 and 3 in Tab. 2 also mathematically well represent original analyses. In general, models in columns 1 and 2 are identical. Rocks identified as gneisses (analyses JP1/43 to J-129) contain according to these mixing models from 0 to 70 % of basic volcanic admixture, which is, of course, unreal. This can be partially explained, in case of samples J-44, JP1/1 and JP1/33, by 3-factor model in column 3 where these samples show a great portion of Al-rich end member (Al-rich gneiss). Like sample J-44 also the others may be supposed to differ from the other gneisses in protolith — admixture of marl material. If negative and the highest values eliminated, according to 3-factor model the Nízke Tatry Mts. paragneisses contain an admixture of basic volcanic material within the range 0—22 %.

Rocks identified as amphibole gneisses (JP1/23 to JP1/12) according to 2-factor model in columns 1 and 2 (Tab. 2) contain from 25 to 85 % and in column 3 from 9 to 76 % of basic volcanic end member. As for low contents there is the only exception. After its elimination we get more real range, from 43 to 85 % and/or from 31 to 76 % of basic volcanic admixture.

According to models in columns 1 and 2, amphibolites contain volcanic component within the range 75—100 % and column 3 60—100 %.

Tab. 3 presents the results of modelling of protolith paragneisses and amphibole rocks using the program GENMIX (Le Maitre, 1981) together with the distance of model and real analyses in 9-dimensional space of oxides in question. This distance has percentual dimension and varies inversely as model quality.

Column 1 (Tab. 3) presents mixing model with JP1/43 gneiss and J-121 amphibolite as end members, column 2 model with quartzite paragneiss: tholeiite (Hovorka 1975; Hyndman, 1972), column 3 mixing model with JP1/43: Al-rich paragneiss: J-121, and finally, column 4 model with quartzite gneiss: Al-rich paragneiss: tholeiite as end members.

At first glance nearly perfect consistency can be stated between the corresponding mixing models gained by Q-mode factor analysis and those by GENMIX program. From this standpoint they can be considered equivalent.

Compared to Tab. 2 there are more models in columns 2 and 3. Model with quartzite paragneiss and tholeiite as end members is practically consistent with the 2-factor one JP1/43: J-121, which is presented in Tab. 2, column 1.

According to mixing model with end members represented by analyses JP1/43: Al-rich paragneiss: J-121 in column 3 of Tab. 3 rocks indicated as gneisses (if negative values and the highest unreal one of 48 % eliminated) have basic volcanic component ranging within 0—27 %.

Rocks indicated as amphibole gneisses (if the lowest value eliminated) contain within 28—74 % and amphibolite within 70—100 % of basic volcanic component respectively. These values are close to 3-factor model in Tab. 2, column 1.

Distances of model and real analyses in Euclidean oxide space give us important information on the quality of mixing model (Tab. 3, column R). If mixing models based on the published end members (quartzite gneiss, Al-rich gneiss, tholeiite) and the most contrasting analyses of the Nízke Tatry Mts. metamorphites (paragneiss JP1/43 and amphibolite J-121) are compared, then the latter show higher quality. Naturally, models based on 3 end members also show higher degree of quality if compared to those based on 2 end members.

It is difficult to determine an objective boundary of the distance between model and real analyses over which a particular analysis does not correspond to model. A possible solution is the mean value of this or that model distances + standard deviation and over this boundary another allochemical metamorphism, alterations, and/or other end member in metamorphite protolith, must be taken into consideration. For example, in case of mixing model JP1/43: J-121 (Tab. 3) the critical value defined like this is that of the distance 5,66. Over this boundary there are models of J-44, JP1/1, JP1/32 analyses and that of Al-rich paragneiss. In the first and second cases there are non adequate models — marl should be considered as another end member. Similar non-adequate is naturally the last case as well.

Dendrogram in Fig. 3 gives an adequate survey and supplementary information on the character of paragneiss set under study and amphibole rocks of the Nízke Tatry Mts. crystalline complex. Cluster analysis clearly divided the rocks into six groups. According to 2-factor mixing models each of them, except the first, has a characteristic range of volcanic end member portion (e. g., model JP1/43: J-121 in Tab. 3).

set of analyses	range of basic end member portion (model JP1/43: J-121) in %
1. Al-rich gneiss and JP1/32	71—74
2. J-58 to J-111	62—74
3. 37/2 to J-121	76—100
4. J-37 to J-71	35—46
5. JP1/33 to J-44	52—55
6. J-35 to JP1/43	0—26

The first set is rather independent. In 3-factor model these two rocks have the highest portion of Al-rich paragneiss. 2-factor models do not explain chemical compositions of these rocks sufficiently. The second and third sets contain the highest portion of basic volcanic component from the whole set of metamorphites. It is set of amphibole gneisses and amphibolite.

The fourth set contains rather low portion of Al-rich paragneiss and rather much quartzite gneiss and basic volcanite in 3-factor mixing models. In this set there are samples of banded amphibole rocks which are structurally quite different from current types of metamorphites of the Nízke Tatry Mts. crystalline comples (Fig. 1).

The fifth, rather independent, set of rocks appears to differ from the others by the admixture of marl material in protolith which is supported by high contents of clinozoisite and high basicity of plagioclase in sample J-44. Therefore the used 2- and 3-factor models are not suitable for modelling of these three rocks protolith.

The samples of the sixth set show the lowest portion of basic volcanic material in all mixing models. They represent quite least contamined paragneisses.

Cluster analysis together with mixing models clearly show some incogruities between petrographical arrangement of the samples and their chemical compositions which is obvious especially in the case of distinguishing of amphibole gneisses and amphibolites. In metamorphites ot the Nízke Tatry Mts. crystalline complex (especially in the Jasenie—Kyslá region) their petrographical identification is more difficult. Volcanoclastic and terrigenous sedimentary material was not sufficienly homogenized in the process of metamorphism and its stratification is not always distinguished macroscopically. Therefore small petrographical thin sections are not always representatives of the rocks as a whole. Cluster analysis renders objective causes for the elimination or resetting of some analyses which by their chemical composition apparently do not correspond to original petrographical identification.

The presented models suggest that 2-factor models are quite suitable for simplicity, reproducibility, and quality of discourse. In special case the need to solve the problem of a particular sample mixing model by 3-, and/or more-factor models is natural which, however, need not mean its higher objectivness and interpretability. Simple 2-factor models can be well applied only in well-founded cases — rather monotonous sets, such as we chose from the published and original analyses. In case if this set was supplemented with the other rock types of the Nízke Tatry Mts. crystalline complex (pyroxene gneisses, migmatites, etc.), 2-factor model should not naturally be suitable. 2- as well as 3-factor model based on published end members and the most contrasting ones of our set appeared equivalent in general, though, from mathematical point of view models based on the most contrasting end members of the set rendered a little better results. This method may be, of course, recommended only in the case of sufficiently large and homogenous set, where it can be supposed that the most contrasting members represent actual end members of protolith.

Conclusion

Comparison of protolith mixing models of the Nízke Tatry Mts. metamorphites from the Jarabá Group gained on the basis of Q-mode factor analysis and GENMIX program (Le Maitre) showed that these two methods render practically equivalent results and aptly complement each other.

With respect to simplicity and quality of discourse we consider optimal the 2-factor mixing model based on the most contrasting representatives of the Nízke Tatry Mts. metamorphites — paragneisses JP1/43 (paper by O. Miko) and amphibolite J-121.

Following this model we can suppose that typical paragneisses of the Nízke Tatry Mts. crystalline complex may contain from 0 to 25 % of admixture of basic volcanic material in its protoliths and, on the contrary, amphibolites admixture of terrigenous sedimentary material approximately within the range 0—25 %.

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