Mitt. Österr. Geol. Ges.	ISSN 0251-7493	**86** (1993)	S. 45–59	Wien, August 1994

Key words
Slovakia
Carpathians
Crystalline basement
Paragneisses
Geothermobarometry

Geothermobarometric Characteristics of Some Tatric Crystalline Basement Units (Western Carpathians)

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Geothermobarometrische Charakteristik einiger tatrischer Grundgebirgseinheiten (Westkarpaten)

Zusammenfassung

Die P-T-X Parameter während metamorpher Prozesse in den kristallinen Kerngebirgen wie Male Karpaty (M.K.) Gebirge, Suchy (S.) und Mala Magura (M.M.) Gebirge und Vysoke Tatry (V. T.) zeigen Unterschiede in ihrer progressiven sowie retrograden metamorphen Entwicklung. Die Temperaturen und Drucke der einzelnen Kistallingebiete lassen sich folgendermaßen zusammenfassen:

M.K.: 580–620°C/4.5–5 Kbar, XH_2O = 0.9.
S.: 540–560°C/4–5 Kbar, XH_2O = 0.6–0.8.
M.M.: 620–640°C/4.5–5.5 Kbar, XH_2O = 0.8–1.0.
V.T.: 700–740°C/4.5–7 Kbar, XH_2O = 0.9–1.0.

Diese Daten lassen auf Bedingungen tieferer Niveaus (15–25 km) der variszischen Intrusiva und Kontaktmetamorphose schließen. Die Aufstiegswege der Paragneise des Suchy-Gebirges weisen auf isothermale Dekompression. Die Paragneise des Mala Magura-Gebirges präsentieren hingegen einen Aufstiegweg, der durch eine Dekompression wahrend der Abkühlung determiniert ist. Daraus ergibt sich eine Gliederung dieser metamorphen Komplexe in individuelle kristalline Kerne. Retrograde Reaktionen nach der metamorphen Kulmination weisen auf einen orogenen Block-Transport und strukturelle Umprägungen des kristallinen Untergrundes während der alpidischen Tektonik, und führen zu einer Revision des Konzeptes der metamorphen Zonierungen.

Abstract

P-T-X parameters of metamorphic processes in the crystalline cores of the Male Karpaty (M.K.) Mts., Suchy (S.) and Mala Magura (M.M.) Mts. and Vysoke Tatry (V.T.) Mts. indicate differences in their progressive and retrogressive metamorphic evolution. The determination of metamorphic temperatures and pressures of these particular crystalline complexes are as follows:

M.K. Mts.: 580–620°C/4.5–5 Kbar, XH_2O = 0.9.
S. Mts: 540–560°C/4–5 Kbar, XH_2O = 0.6–0.8.
M.M. Mts: 620–640°C/4.5–5.5 Kbar, XH_2O = 0.8–1.0.
V.T. Mts: 700–740°C/4.5–7 Kbar, XH_2O = 0.9–1.0.

They suggest crustal level conditions of intrusive Variscan magmatism at a depth of 15–25 km and of contact plutonic recrystallisation. Uplift trajectory characteristics in S. Mts. paragneisses indicate their isothermal decompression and display more uniform trajectories determined by decompression during cooling in M.M. Mts. paragneisses. Division of these metamorphic complexes into individual crystalline cores is thus indicated. Post-peak retrograde reactions also infer orogenic block transport and structural disturbances of crystalline basement units during Alpine tectonic movements and lead to a revision of the concept of metamorphic zonation.

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1. Introduction

The Pre-Alpine basement of the Western Carpathians is mainly represented by medium to high-grade paragneisses, orthogneisses, amphibolites and other metamorphic rock complexes which were later intruded by granitoidic rocks of Variscan age. High grade polymetamorphic rocks are found in the "core mountains" which exhibit:

1) dome structure with the crystalline core,
2) special tectonical features and tectonical overprinting by Mesosoic events and
3) a distinct style of Paleogenic sedimentation.

Some of the core mountains are situated in the outer zone of the Western Carpathians (Text-Fig. 1). There are deviations from other more central core mountains that suggest in some cases facial and tectonic similarities with the Eastern Alpine segment. The largest tectonic superunit of the Central Western Carpathians is the Tatricum. It forms the lowermost basement substratum of core mountains ranging between the Klippen Belt in north and other basement superunits further south, the Veporicum and Gemericum (Putiš, 1991; Plašienka et al.1991).

Metapelitic rocks are encountered in the core mountains. The metamorphic zonation is connected with granitoidic intrusive rocks with spatial relationship and metamorphic zonality, while in some areas (e.g. Male Karpaty Mts.) the metamorphic zones exist only in rudimentary remnants and in other places the complete metamorphic zonality profiles have been preserved. The Variscan age of the core mountains crystalline complexes has been confirmed by a large number of geochronological data (see Cambel et al., 1991, for review). Due to the tectonic disturbances of the Variscan orogen it is still unclear whether the crystalline complexes in some core mountains (e.g. Male Karpaty Mts.) are in autochthonous position.

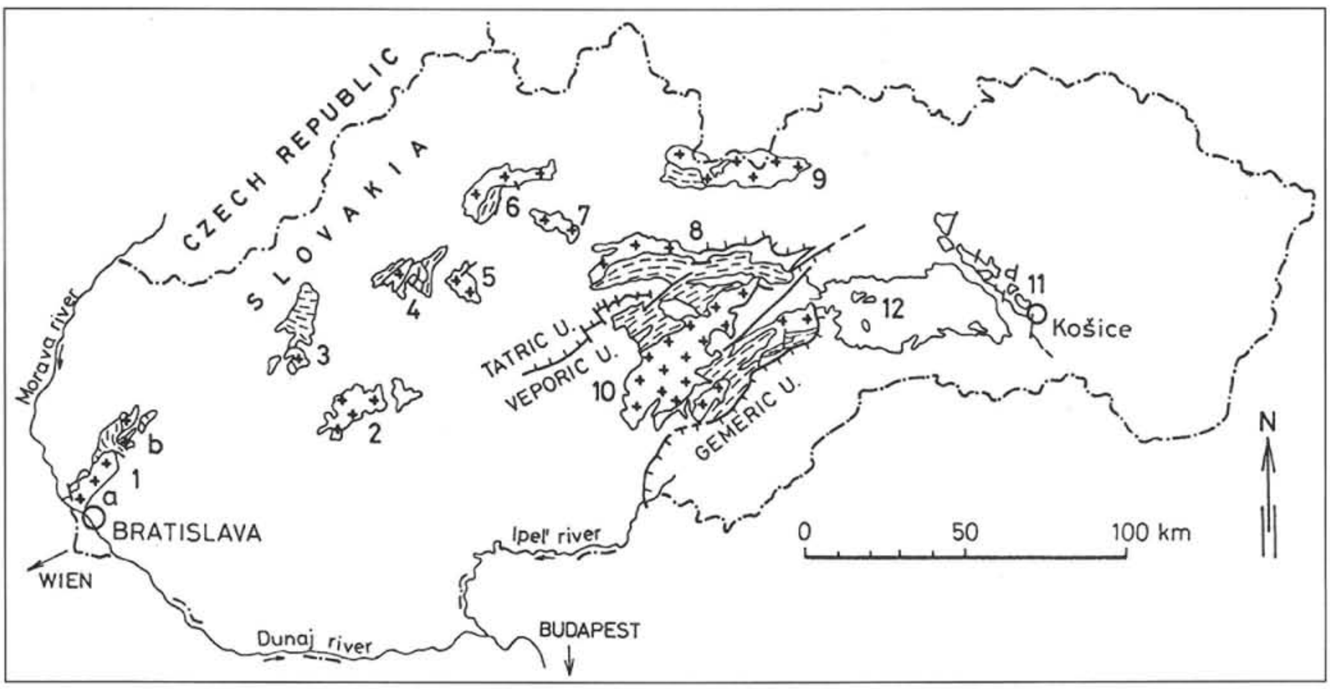
Earlier tectonic concepts (Cambel, 1954, 1976) were not in favor of any Alpidic orogenic activity in the crystalline basement complexes. Only Alpidic retrograde processes and fault development were considered. However, very recent tectonometamorphic research indicates complex tectonic structural development of some core mountains. This requires the assumption of several superimposed nappe units consisting of pre-Alpine crystalline basement with its Mesozoic cover (Putiš, 1991; Plašienka et al., 1991).

The aim of this study is to present temperature-pressure data of metapelites and paragneisses from some Western Carpathian core mountains and to describe some distinctive features of metamorphism leading to new aspects.

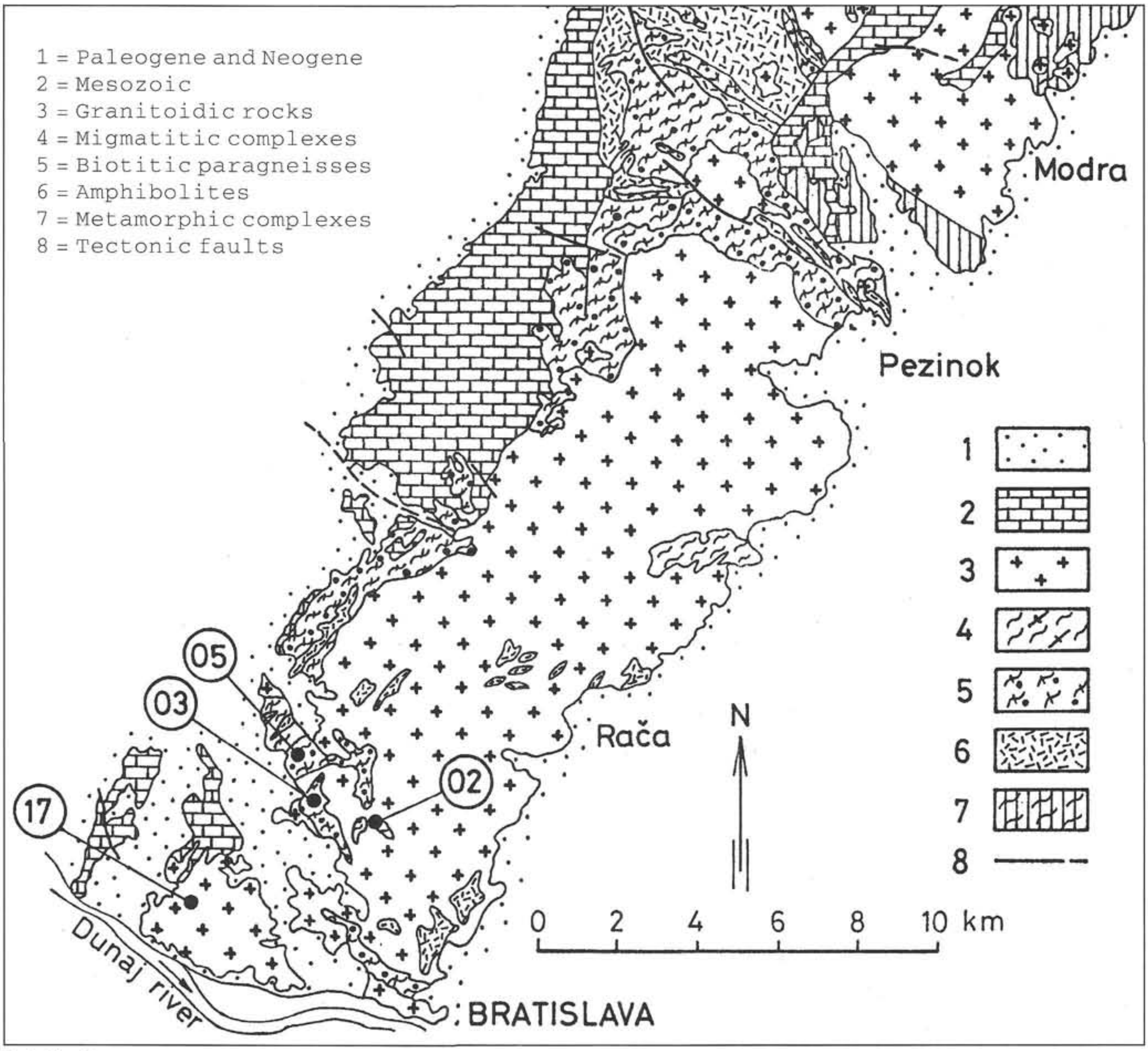
2. Geological Setting

The Male Karpaty Mts.

The westernmost and outermost core mountains in the Western Carpathians are the Male Karpaty Mts. (M.K.). They possess some distinctive features in comparison to other core mountains. The predominant constituent of the M.K. Mts. crystalline complex are Variscan postkinematic granitoidic rocks. They form two separate massifs, the Bratislava and Modra massifs, separated by a 4–8 km wide zone of schists (see Text-Fig. 2).The sedimentary overburden was metamorphosed to greenschist facies before granitoidic intrusions and the periplutonic process became the most dominant in the area. The metamorphic process took place in the late Variscan era (Cambel et al., 1991). According to genetic I/S classification the M.K.Mts. granitoids are transitional. The Modra massif and Bratislava massif granitoids with their geochemical-mineralogical features are suggestive of being I-Caledonian type. The Bratislava massif granitoids show a tendency towards S-type (Cambel & Vilinovic, 1987). Disturbances of the Variscan metamorphic structures caused by Alpidic tectonic movements destroyed the original metamorphic zonation as evident by index minerals. The irregularity of reaction progress, dehydration and



Text-Fig. 1.
Schematic sketch map of the Western Carpathians "core mountains" crystalline complexes.
1 = Male Karpaty Mts., a = Bratislava massif, b = Modra massif.; 2 = Tribec Mts.; 3 = Povazsky Inovec Mts.; 4 = Suchy and Mala Magura Mts.; 5 = Ziar Mts.; 6 = Mala Fatra Mts.; 7 = Velka Fatra Mts.; 8 = Nizke Tatry Mts.; 9 = Zapadne and Vysoke Tatry Mts.; 10 = Veporic tectonic superunit; 11 = Cierna Hora Mts. (Veporic unit); 12 = Gemeric tectonic superunit.



Text-Fig. 2.
Geologic map of the Male Karpaty Mts., showing the major crystalline rock types and sample locations.
The solid dots locate the samples for which peak prograde and closure retrograde temperatures have been calculated.
The legend for the rock types designation has been used for all the following sketch maps presented.

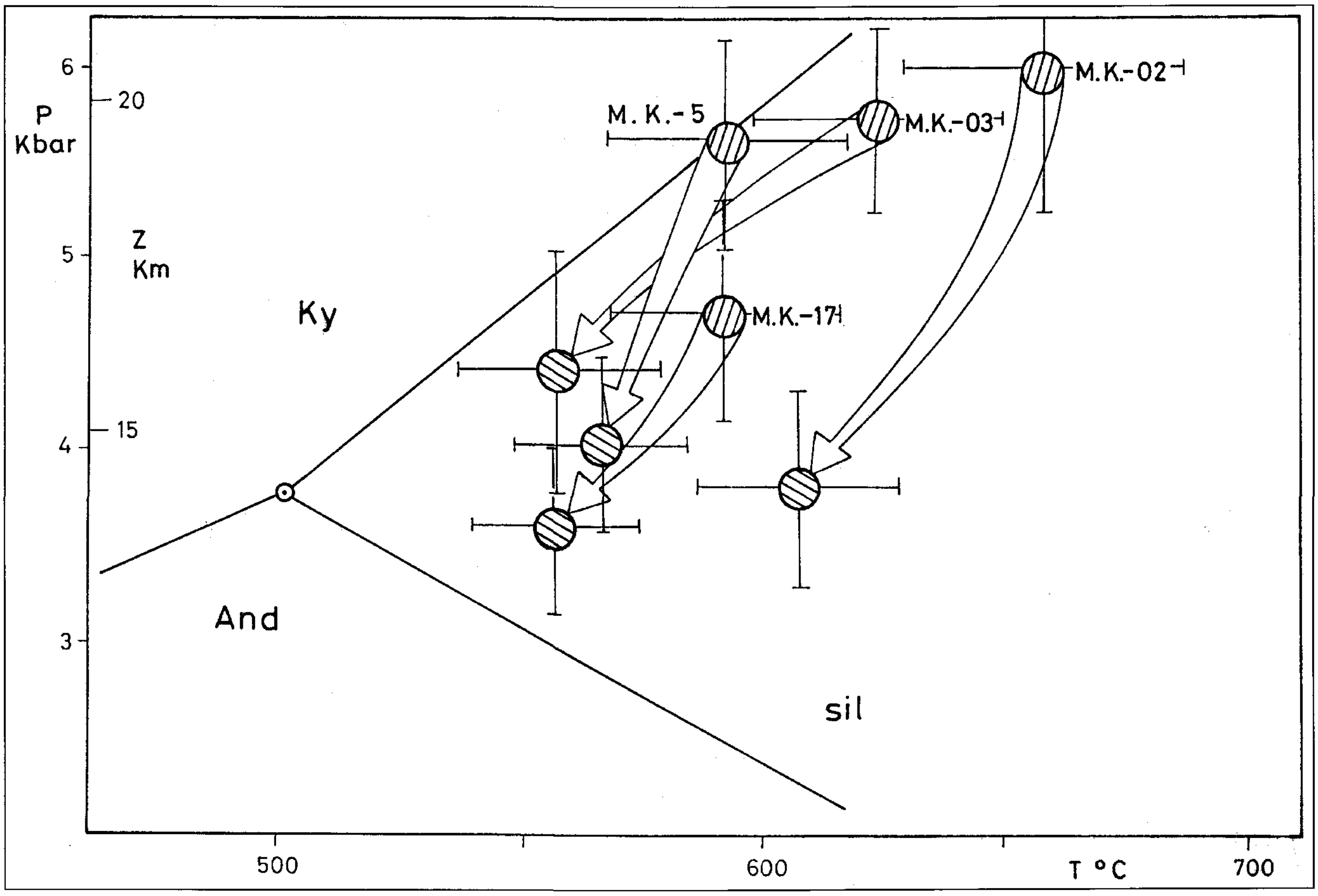
reaction volume changes in metapelites and paragneisses of the periplutonic zones (DYDA & MIKLOS, 1993) represents a petrographic argument for distinguishing between parautochthonous and allochthonous metamorphic zones in M.K. Mts. Dehydration and volume changes do not progress continually in the profiles and have no relation to the distance from granitoidic rock contact. These results support the concept of tectonic destruction of the Variscan periplutonic contact zones around the Bratislava granitoid massif. Temperature zonation is represented by the development of

- the biotite zone
  (Bt + Ms + Chl + Phn + Ab + Qtz, Bt + Chl + Ab + Ep + Cal + Qtz),
- the garnet zone
  (Grt + Bt + Chl + Ms + Plg + Qtz)
- the staurolite zone
  (St + Bt + Grt + Ms + Chl + Plg + Qtz) and
- the sillimanite zone (Sil + Bt + Ms + Grt + Plag + Qtz).

These zones exist as remnants in the north-west part of the Bratislava granitoid massif (Text-Fig. 2.) and represent a steep temperature gradient. Restricted by the biotite zone at the lower temperature side and reaching the plutonic contacts the zonation spans the distance of ca. 600–900 m.

The Suchy and Mala Magura Mts

The crystalline complexes of Suchy (S.) and Mala Magura (M.M.) Mts. (Text-Fig. 6.) are situated in two individual regions that were once separated by the Paleogene Diviaky fault. They are similar in respect to their magmatic, metamorphic and tectonic evolution. Both cores are mainly composed of granitoid rocks and paragneisses. Migmatitic complexes became dominant towards the periphery of the cores. The crystalline bodies as a whole are compact and contain no remnants of the Mesozoic and younger Tertiary units. The age of granitoidic rocks from the S. and M.M. Mts. is determined by Rb-Sr isochron is 393±6 Ma (KRAL et al., 1987). The core of the M.M. (eastern mountains part) displays a lower content of cover rocks and is probably more



Text-Fig. 3.
Pressure–temperature diagram showing calculated P–T conditions of metamorphic recrystallisation in periplutonic zones of the Bratislava granitoidic massif.
Arrowheads indicate the approximated uplift trajectories of rock segments. The similarities of cooling conditions under decompression may be noted. The aluminosilicate phase diagram used is after HOLDAWAY (1971).

uplifted. The most distinct anticlinal structure is parallel to the mountain ridge in the central part of the mountain range (KAHAN, 1979). The pre-Alpine, Variscan tectogenesis is dominant in both cores. The Alpine restructuring of the crystalline complex is relatively poor and did not change the older tectonic pattern substantially (MAHEL', 1985).

The Zapadne and Vysoke Tatry Mts.

The metamorphic processes in Vysoke and ZapadneTatry Mts. have a polyphase nature. The oldest metamorphic event is indicated by metamorphic isotopic homogenisation in Goryczkova gneisses as the whole rock Rb-Sr isochron gives a Paleozoic age of 430–410 Ma (BURCHART, 1968). Isotopic data from other metamorphic and granitoid rocks, based on biotite and muscovite analyses give an age of 300–280 Ma (BURCHART, 1968). This Variscan magmatic and metamorphic events have become dominant and were connected by anatexis. Tectonic studies (GOREK, 1956, 1959) revealed a dome-like structure with block displacements in the region, and thrusting of the crystalline tectonic blocks (KAHAN, 1969; JANAK et al., 1988). In the Western Tatra Mts. four complexes have been distinguished (KAHAN, 1969):

a) a basement complex,
b) a complex in immediate contact with the above lying granitoids ,
c) a complex of granitoid rocks and
d) a complex of paragneisses, migmatites and amphibolites.

Inverted metamorphic zoning in the Western Tatra Mts. proves tectonic reworking of the original metamorphic zones and granitoid rocks.

Sample locations

❒ **Male Karpaty Mts.**
- M.K. 17. – Bratislava-Devin, Liscie diery, outcrop in Mokry Jarok brook.
- M.K. 02. – Zelezna Studnicka, Cesta mladeze, 150 m W of the settlements.
- M.K. 03. – Zelezna Studnicka, 100 m N of Klepac.
- M.K. 05. – Lamac, cottage settlement, 200 NW of settlement, in brook valey.

❒ **Suchy Mts.**
- S. 48. – Valasska Bela, settlement Paniste, 350 m S of road, 50 m S of houses.
- S. 59. – Ksinna, 200 m SE of the elevation Caparka.
- S. 60. – Ksinna, 800 m SE of the elevation Caparka.
- S. 68. – Valasska Bela, settlement Vlckovci, 500 m SW of settlement houses.

❒ **Mala Magura Mts.**
- M.M. 03. – Sec-Flintov Laz, brook valley, 500 m N of the elevation Flintov Laz.
- M.M. 21. – Mala Magura, 200 m SSE of the elevation point 1146.
- M.M. 23. – Mala Magura,1.4 km SSE of the elevation point 1146.
- M.M. 87. – Tuzina, 2.4 km NW of the village, in brook valley.

❐ Vysoke Tatry Mts.

- V.T. 01. – Velicka valley, 350 m NE of the cottage Sliezsky dom.
- V.T. 02. – Velicka valley, 500 m N of the cottage Sliezsky dom.
- V.T. 03. – Tupa, 200 m SW of the peak Tupa, 2276 m a.s.l.
- V.T. 20. – Tupa, 100 m N of the peak Tupa, 2276 m a.s.l.
- V.T. 23. – Senna Kopa, 200 m NE of the peak Senna Kopa 1848.
- V.T. 25. – Senna Kopa, 300 m NW of the peak Senna Kopa 1848.

3. Methods and Data

JEOL SUPERPROBE 733 and JEOL JXA 5A microprobe served for mineral analyses. The operating conditions were 20 kV accelerating voltage,specimen current of 15–20 nA and beam diameter of 1–2 μm. For sodic plagioclase and muscovite the beam diameter was increased to 5–7 μm to avoid sodium loss. In order to obtain the representative chemical analyses of the centre of zoned mineral phases (garnet, plagioclase), only the largest grains assumed to be in equilibrium contact with the surrounding minerals were selected and analysed from polished thin section.

In each sample we have analysed 3–6 grains of each mineral in two to three locations in order to test the homogeneity. Total iron has been calculated as ferous. Fe^{3+} in garnets and in biotites was not calculated as the accuracy depends highly on all of the elements analysed and on the structural balance.

With the thermobarometrical approach some uncertainty occurred from different P–T values calculated from particular calibrated reactions. Uncertainties and their estimates that have appeared in the literature usually adopt values of $\sigma T = 50°C$ and $\sigma P = 1000$ bars. Many samples from single locations (FERRY, 1980; GHENT & STOUT, 1981) reflect this general consensus based on the reproducibility of the P–T data (HODGES & CROWLEY, 1985).

Some rim analyses at multiple mutual junctions had been used for retrograde closing temperature approximation. Geothermometric data based on garnet rims and coexisting matrix biotite approximate the retrograde closure temperature. Garnet cores and the matrix biotite yielded an obviously higher temperature related to a thermal culmination. In some assemblages biotite inclusions reflected thermal peak conditions. In metapelitic rocks with high biotite/garnet modal ratio the later Fe-Mg mass balance reactions slightly change the biotite peak composition (CROWLEY, 1991).

For many applications a single set of mineral equilibria was used to infer P–T conditions that may be calculated

Table 1.
Chemical analyses of garnets from paragneisses of Male Karpaty (M.K.) and Vysoke Tatry (V.T.)
Number of ions in formula unit is based on 12 oxygens.

M.K.	17 C	17 R	02 C	02 R	03 C	03 R	05 C	05 R	VT 01 C	01 R	02 C	02 R
SiO_2	37.36	35.90	36.76	36.35	37.03	35.93	36.52	36.97	36.86	36.99	36.99	36.90
TiO_2	0.04	0.00	0.04	0.03	0.02	0.02	0.09	0.01	0.01	0.04	0.04	0.00
Al_2O_3	21.43	21.17	21.28	21.26	20.98	21.46	20.91	20.14	21.28	21.35	21.02	21.31
FeO	29.15	30.87	29.57	31.35	30.15	31.17	27.24	30.48	27.75	27.54	23.99	24.69
MnO	8.71	7.25	5.46	6.39	7.36	8.38	8.89	6.27	10.00	11.55	13.23	13.95
MgO	2.59	2.65	3.36	3.08	2.66	2.45	2.78	2.48	3.06	2.26	2.98	2.38
CaO	1.30	1.29	1.68	1.42	1.83	2.01	1.94	1.45	1.10	1.08	1.05	1.05
Total	100.58	99.13	98.15	99.88	100.03	101.42	98.37	97.80	100.06	100.81	99.30	100.28
Si	2.995	2.940	2.993	2.945	2.991	2.978	2.987	3.046	2.972	2.976	2.998	2.979
Ti	0.002	0.000	0.002	0.002	0.001	0.001	0.005	0.001	0.001	0.002	0.002	0.000
Al	2.025	2.043	2.042	2.031	1.997	1.986	2.016	1.956	2.023	2.025	2.008	2.028
Fe^{2+}	1.954	2.114	2.013	2.124	2.036	2.047	1.863	2.100	1.871	1.853	1.626	1.667
Mn	0.591	0.502	0.376	0.438	0.503	0.557	0.616	0.437	0.683	0.787	0.908	0.954
Mg	0.309	0.323	0.407	0.372	0.320	0.286	0.338	0.304	0.367	0.271	0.359	0.286
Ca	0.111	0.113	0.146	1.123	0.158	0.169	0.170	0.128	0.095	0.093	0.091	0.090
V.T.	03 C	03 R	20 C	20 R	23 C	23 R	25 C	25 R				
SiO_2	36.54	36.65	37.01	37.04	36.70	36.88	37.54	36.81				
TiO_2	0.08	0.01	0.01	0.00	0.00	0.00	0.00	0.02				
Al_2O_3	21.00	21.22	21.12	21.69	21.52	21.52	21.75	21.19				
FeO	26.94	27.23	32.56	32.62	32.67	29.73	32.28	32.74				
MnO	10.51	10.67	4.94	6.61	5.43	10.14	4.22	5.03				
MgO	2.64	2.29	3.96	3.03	3.48	2.34	4.34	3.64				
CaO	0.62	0.74	0.90	0.60	0.88	1.04	0.67	0.77				
Total	98.33	98.81	100.50	101.59	100.68	101.65	100.80	100.20				
Si	2.995	2.994	2.967	2.953	2.945	2.952	2.977	2.964				
Ti	0.004	0.000	0.001	0.000	0.000	0.000	0.000	0.001				
Al	2.029	2.044	1.996	2.039	2.036	2.031	2.033	2.011				
Fe^{2+}	1.847	1.860	2.183	2.175	2.193	1.991	2.141	2.205				
Mn	0.729	0.738	0.335	0.446	0.369	0.687	0.283	0.343				
Mg	0.332	0.278	0.473	0.360	0.416	0.279	0.512	0.436				
Ca	0.054	0.064	0.077	0.051	0.075	0.089	0.057	0.066				

Table 2.
Chemical analyses of plagioclases from paragneisses of Male Karpaty (M.K.) and Vysoke Tatry (V.T.)
Number of ions in formula unit is based on 8 oxygens.

M.K.	17 C	17 R	02 C	02 R	03 C	03 R	05 C	05 R	VT 01 C	01 R	02 C	02 R
SiO_2	60.39	60.15	61.35	61.39	59.95	59.34	61.45	61.52	62.30	64.03	63.83	63.92
Al_2O_3	24.07	25.06	24.53	25.10	24.07	23.68	23.56	24.03	23.68	24.18	24.17	24.21
FeO	0.08	0.17	0.15	0.01	0.12	0.08	0.10	0.10	0.07	0.00	0.03	0.00
CaO	5.32	6.09	5.80	6.41	5.40	5.67	5.12	5.41	4.44	4.03	5.09	5.05
Na_2O	11.09	10.92	8.49	7.96	8.38	8.58	8.85	8.66	9.22	8.29	8.57	8.16
K_2O	0.07	0.07	0.08	0.07	0.14	0.06	0.06	0.05	0.22	0.22	0.12	0.18
Total	101.02	102.46	100.40	100.94	98.06	97.41	99.14	99.77	99.93	100.75	101.81	101.52
Si	2.685	2.644	2.716	2.701	2.716	2.711	2.750	2.736	2.762	2.832	2.770	2.777
Al	1.261	1.298	1.280	1.302	1.285	1.275	1.243	1.260	1.237	1.204	1.236	1.240
Fe^{2+}	0.002	0.006	0.005	0.000	0.004	0.003	0.003	0.003	0.002	0.000	0.001	0.000
Ca	0.253	0.286	0.275	0.302	0.262	0.277	0.245	0.257	0.210	0.182	0.236	0.235
Na	0.956	0.930	0.728	0.679	0.736	0.760	0.768	0.746	0.792	0.679	0.721	0.687
K	0.003	0.003	0.004	0.003	0.008	0.003	0.003	0.002	0.012	0.011	0.006	0.009

V.T.	03 C	03 R	20 C	20 R	23 C	23 R	25 C	25 R
SiO_2	62.92	62.35	63.88	63.68	62.96	62.87	64.10	64.40
Al_2O_3	23.31	22.85	22.46	24.06	24.18	23.32	23.29	23.42
FeO	0.05	0.02	0.05	0.09	0.00	0.04	0.09	0.14
CaO	3.98	4.15	3.59	4.33	4.42	5.20	4.42	4.36
Na_2O	9.18	9.03	9.64	7.96	8.85	7.87	8.98	8.96
K_2O	0.20	0.17	0.10	0.07	0.16	0.15	0.07	0.09
Total	99.64	98.57	99.72	100.19	100.57	99.45	100.95	101.37
Si	2.790	2.794	2.827	2.793	2.765	2.789	2.802	2.803
Al	1.218	1.207	1.171	1.244	1.252	1.219	1.200	1.202
Fe^{2+}	0.001	0.000	0.001	0.003	0.000	0.001	0.003	0.005
Ca	0.189	0.199	0.170	0.203	0.208	0.247	0.207	0.203
Na	0.789	0.784	0.827	0.677	0.753	0.677	0.761	0.756
K	0.011	0.009	0.005	0.004	0.009	0.008	0.004	0.005

within the precision of the measurement. Thus the accurate position of the sample in the P–T space may be uncertain, but this is of lesser importance considering the regional and tectonic interpretation of the thermobarometric data.

Mineral assemblages of the studied paragneisses include:

Male Karpaty Mts.

Sample:			
17	Qtz,Plg,Bt,Ms	Grt,St,Sil	Ap,Zrn
02	Qtz,Plg,Bt	Grt,St,Sil	Ilm,Ap,Zrn
03	Qtz,Plg,Bt	Grt,Sil	Ilm,Ap,Zrn
05	Qtz,Plg,Bt,Ms	Grt,St,Sil	Ilm,Ap,Zrn

Suchy Mts.

Sample:			
48	Qtz,Plg,Bt,Ms	Grt,St,Sil	Ilm,Ap,Zrn,Gr
59	Qtz,Plg,Bt,Ms	Grt,Sil	Ilm,Ap,Tur,Gr
60	Qtz,Plg,Bt,Ms	Grt,St,Sil	Ilm,Ap,Rt,Tur
68	Qtz,Plg,Bt,Ms	Grt,St,Sil	Ilm,Ap,Zrn

Mala Magura Mts.

Sample:			
03	Qtz,Plg,Bt,Ms	Grt,Sil	Ilm,Rt,Ap,Zrn
21	Qtz,Plg,Bt,Ms	Grt,Sil	Ilm,Rt
23	Qtz,Plg,Bt,Ms	Grt,Sil	Ilm,Ap,Zrn
87	Qtz,Plg,Bt,Ms	Grt,Sil	Ilm,Rt,Ap,Zrn

Vysoke Tatry Mts.

Sample:			
01	Qtz,Plg,Bt,Ms	Grt,Sil	Ilm,Ap,Zrn
02	Qtz,Plg,Bt,Ms	Grt,Sil	Ilm,Ap,Zrn
03	Qtz,Plg,Bt,Ms	Grt,Sil	Ap,Zrn
20	Qtz,Plg,Bt,Ms	Grt,Sil	Ilm,Ap,Zrn
23	Qtz,Plg,Bt,Ms	Grt,Sil	Ap,Zrn
25	Qtz,Plg,Bt	Grt,Sil	Ap,Zrn

These mineral assemblages enabled the use of a number of thermometers and barometers for P–T quantification of metamorphic recrystallisation processes. The following reactions were used for P-T calculations:

- Almandine + Phlogopite = Pyrope + Annite
- Muscovite + Pyrope + Grossularite = 3 Anorthite + Phlogopite
- Muscovite + Almandine + Grossularite = 3 Anorthite + Annite
- 3 Anorthite = Grossularite + 2 Al_2SiO_5 + Quartz

The following calibrations were used for individual reactions:

R1: THOMPSON (1976), FERRY & SPEAR (1978), NEWTON & HASELTON (1981), GANGULY & SAXENA (1984)

R2: GHENT & STOUT (1981), HODGES & CROWLEY (1985)

R3: GHENT & STOUT (1985), HODGES & CROWLEY (1985)

R4: GHENT et al. (1979), NEWTON & HASELTON (1981), POWELL & HOLLAND (1988)

For XH_2O determination the reaction:

Paragonite + Quartz = Albite + Sillimanite + Quartz + H_2O

with the thermodynamic data of FERRY (1980) was used. *Analyses of coexisting minerals of paragneisses from the* studied core mountains regions (Male Karpaty Mts., Vysoke Tatry Mts.) are presented in Tables 1. to 4. Chemical analyses of garnets, plagioclases, biotites and muscovites from Suchy and Mala Magura Mts. were published earlier (DYDA, 1990). The thermobarometric data calculated for prograde peak and retrograde closure temperatures and pressures of

Table 3.
Chemical analyses of biotites from paragneisses of Male Karpaty (M.K.) and Vysoke Tatry (V.T.)
Number of ions in formula unit is based on 22 oxygens.

M.K.	17 C	17 R	02 C	02 R	03 c	03 R	05 C	05 R	VT 1C	VT 1R	VT 2C	VT 2R
SiO_2	34.44	33.92	36.28	34.98	34.98	34.91	35.37	35.80	34.58	33.79	33.35	32.48
TiO_2	1.57	1.35	2.06	2.03	1.87	2.06	1.85	1.79	3.47	3.52	1.91	1.44
Al_2O_3	18.98	19.53	19.68	19.57	19.29	19.63	19.05	19.49	18.57	18.89	18.18	19.27
FeO	19.42	19.38	18.17	18.08	19.72	18.22	17.06	19.60	19.25	18.92	20.83	22.02
MnO	0.15	0.15	0.02	0.19	0.27	0.15	0.21	0.12	0.23	0.28	0.44	0.41
MgO	9.46	10.04	9.17	9.03	8.71	8.78	9.30	9.31	8.45	8.64	9.10	9.61
Na_2O	0.48	0.51	0.46	0.21	0.14	0.24	0.43	0.32	0.33	0.18	0.05	0.08
K_2O	8.20	7.21	8.91	8.28	9.02	9.50	8.63	8.00	11.73	11.65	11.21	10.42
Total	92.70	92.09	94.75	92.37	94.00	93.49	91.90	94.43	96.61	95.87	95.07	95.73
Si	5.374	5.298	5.486	5.423	5.400	5.394	5.499	5.448	5.286	5.204	5.230	5.067
Ti	0.184	0.158	0.234	0.236	0.217	0.239	0.216	0.204	0.398	0.407	0.225	0.168
Al	3.492	3.596	3.508	3.577	3.511	3.576	3.492	3.496	3.346	3.430	3.361	3.544
Fe^{2+}	2.534	2.531	2.298	2.344	2.546	2.354	2.218	2.494	2.461	2.437	2.732	2.873
Mn	0.019	0.019	0.002	0.024	0.035	0.019	0.027	0.015	0.029	0.036	0.058	0.054
Mg	2.200	2.337	2.066	2.086	2.004	2.021	2.155	2.111	1.925	1.983	2.126	2.234
Na	0.145	0.154	0.134	0.063	0.042	0.072	0.129	0.094	0.097	0.053	0.015	0.024
K	1.632	1.436	1.719	1.637	1.776	1.872	1.711	1.553	2.287	2.289	2.242	2.074
V.T.	**03 C**	**03 R**	**20 C**	**20 R**	**23 C**	**23 R**	**25 C**	**25 R**				
SiO_2	33.87	34.62	34.83	34.00	34.69	35.08	35.96	35.65				
TiO_2	3.91	3.81	2.67	2.68	3.26	3.30	3.04	1.86				
Al_2O_3	18.74	18.46	19.13	18.51	18.33	18.58	19.01	19.51				
FeO	20.39	20.69	21.07	20.46	19.95	20.40	19.03	19.61				
MnO	0.22	0.36	0.29	0.31	0.34	0.20	0.36	0.03				
MgO	7.28	7.66	8.61	8.81	7.74	8.44	9.76	10.14				
Na_2O	0.24	0.25	0.36	0.18	0.30	0.18	0.20	0.24				
K_2O	9.27	9.45	9.43	9.61	9.07	9.76	9.49	9.11				
Total	93.92	95.30	96.39	94.56	93.68	95.94	96.85	96.15				
Si	5.284	5.328	5.299	5.283	5.401	5.352	5.376	5.365				
Ti	0.458	0.441	0.305	0.313	0.381	0.378	0.341	0.210				
Al	3.447	3.349	3.431	3.391	3.364	3.342	3.350	3.461				
Fe^{2+}	2.260	2.663	2.681	2.659	2.598	2.603	2.379	2.468				
Mn	0.029	0.046	0.037	0.040	0.044	0.025	0.045	0.003				
Mg	1.692	1.757	1.952	2.040	1.796	1.919	2.174	2.274				
Na	0.072	0.074	0.106	0.054	0.090	0.053	0.057	0.070				
K	1.845	1.855	1.830	1.905	1.801	1.899	1.810	1.749				

paragneisses from Male Karpaty Mts., Suchy and Mala Magura Mts. and Vysoke Tatry Mts. are summarized in Tables 5 and 6, and Text-Figures 3, 7 and 10. The presented P–T data are in accordance with the stability fields of index minerals confirmed by microscopic mineral reaction studies and geological relations to magmatic and migmatitic rocks from these regions (see e.g. DYDA, 1988,1990).

Male Karpaty Mts.

Thermobarometric analyses of the contact periplutonic recrystallisation products give temperatures of 590–650°C and pressures of 4. 5–6 Kbar (Tabs. 5,6., Text-Fig. 3.). These results confirm the earlier P–T data (DYDA, 1977, 1980, 1981; PERTCHUK et al. 1984; KORIKOVSKIJ et al., 1984) and are consistent with mineral assemblages and geological position of these rocks. Contact plutonic zones of higher recrystallisation temperatures have almost homogenous garnets in agreement with high temperature garnet homogenisation (TRZCIENSKI, 1977; ANDERSON & OLYMPIO, 1977; LOOMIS 1983; LASAGA et al., 1977; CROWLEY, 1991). Retrograde garnet rims are in some samples very small (20–50 μm) probably indicating a rapid cooling during uplift. Morphological appearance of these idioblastic garnets (Text-Fig. 4.), absence of minor retrograde reaction features clearly represent the quenched mineral assemblage. As well as these garnet types, non-idioblastic garnets occur in the assemblages of the periplutonic zones (Text-Fig. 5.). The crystal size distribution (CSD) analysis of these two different garnet types (unpublished data) shows

1) linear CSD of idioblastic garnets suggesting a contact aureole metamorphic environment and
2) regional metamorphic conditions for the other garnet group considered to be older.

However, garnets in the metapelitic rocks and paragneisses from the periplutonic area are not rotated and do not possess the foliation wrapped around them suggesting that garnet growth occurred in essentially isothermal static recrystallisation conditions around the magmatic body. The depth 14–18 km of granitoid rock intrusions of the Bratislava massif is approximated by P–T conditions (Text-Fig. 3). As can be seen, a decrease in pressure of at least 2 Kbar from peak P–T conditions is indicated by calculated retro-

Table 4.
Chemical analyses of muscovites from paragneisses of Male Karpaty (M.K.) and Vysoke Tatry (V.T.)
Number of ions in formula unit is based on 22 oxygens.

M.K.	17 C	17 R	05 C	05 R	VT 1 C	VT 1 R		
SiO_2	45.10	45.13	45.49	45.37	45.15	45.33		
TiO_2	0.14	0.12	0.46	0.52	1.01	0.97		
Al_2O_3	35.26	35.37	34.59	34.22	32.93	33.94		
FeO	1.03	1.06	1.31	1.60	1.77	2.09		
MgO	0.53	0.56	0.49	0.50	0.61	0.51		
CaO	0.00	0.02	0.02	0.03	0.04	0.02		
Na_2O	1.48	1.49	1.34	1.20	0.78	0.72		
K_2O	8.59	8.61	8.32	8.67	11.94	10.12		
Total	92.13	92.36	92.02	92.11	94.23	93.70		
Si	6.150	6.141	6.204	6.205	6.175	6.162		
Ti	0.014	0.012	0.047	0.053	0.103	0.099		
Al	5.668	5.674	5.562	5.517	5.309	5.439		
Fe^{2+}	0.117	0.120	0.149	0.183	0.202	0.237		
Mg	0.107	0.113	0.099	0.101	0.124	0.103		
Ca	0.000	0.002	0.002	0.004	0.005	0.002		
Na	0.391	0.393	0.354	0.318	0.206	0.189		
K	1.494	1.495	1.447	1.512	2.083	1.755		
V.T.	02 C	02 R	03 C	03 R	20 C	20 R	25 C	25 R
SiO_2	46.73	46.08	46.06	46.67	46.82	46.24	46.04	46.72
TiO_2	1.15	1.19	0.70	1.20	0.74	1.02	1.13	0.95
Al_2O_3	33.88	33.49	34.37	34.36	33.27	33.61	34.08	33.74
FeO	2.93	2.53	2.50	2.57	3.26	2.69	1.64	1.54
MgO	0.54	0.54	0.50	0.48	0.74	0.54	0.75	0.58
CaO	0.00	0.00	0.01	0.01	0.00	0.03	0.04	0.00
Na_2O	0.59	0.74	0.62	0.61	0.57	0.73	0.54	0.79
K_2O	7.95	9.68	7.26	8.01	7.38	8.64	7.80	9.35
Total	93.77	94.25	92.02	93.91	92.78	93.50	92.02	93.67
Si	6.268	6.219	6.253	6.242	6.331	6.250	6.249	6.289
Ti	0.116	0.120	0.071	0.120	0.075	0.103	0.115	0.096
Al	5.358	5.329	5.501	5.418	5.304	5.356	5.453	5.354
Fe^{2+}	0.328	0.285	0.283	0.287	0.368	0.304	0.186	0.173
Mg	0.107	0.108	0.101	0.095	0.149	0.108	0.151	0.116
Ca	0.000	0.000	0.001	0.001	0.000	0.004	0.005	0.000
Na	0.153	0.193	0.163	0.158	0.149	0.191	0.142	0.206
K	1.360	1.666	1.257	1.366	1.273	1.489	1.350	1.605

grade closure P–T characteristics. The preferred peak initial (core) P–T data of the samples and moderate P–T (rim) conditions indicate the post-peak uplift trajectory.

The prograde path of the trajectories was not estimated due to the absence of diagnostic inclusions such as staurolite, andalusite, kyanite ect. within the garnets. A relative garnet homogeneity was attained during peak temperature recorded in the samples. Preservation of the maximum temperature assemblages is considered to have developed via prograde dehydration reactions, which became effectively irreversible as the water released was lost from the system and the rocks remained dry during cooling without any significant retrograde reactions features. The dominant mineral assemblages have undergone a single high temperature episode of contact plutonic metamorphism.

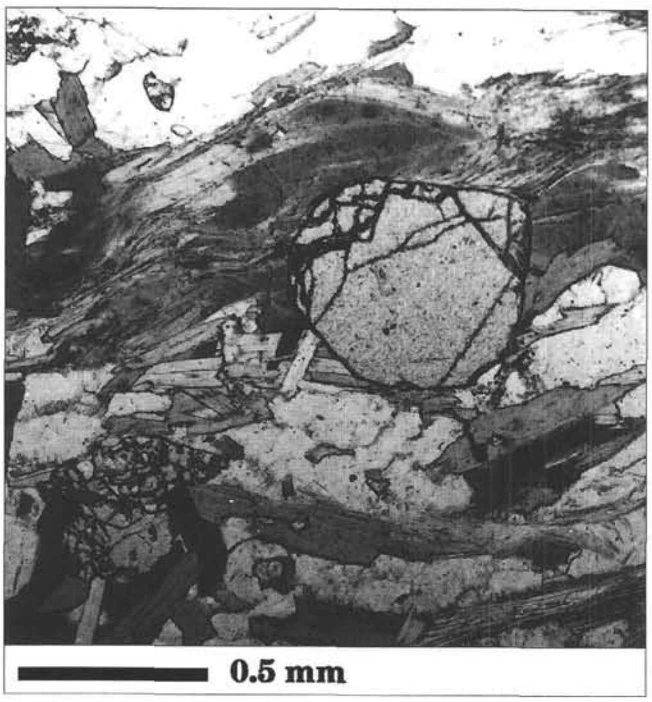
The Suchy and Mala Magura Mts.

The Suchy and Mala Magura Mts. paragneisses are composed of plagioclase (20–50 mod.-%), biotite (15–30 mod. -%), quartz (20–40 mod.-%), and muscovite (0.5–6 mod. -%). From the index minerals garnet, staurolite, sillimanite are present in small quantities, while St-Sil association has been found only in the paragneisses from the Suchy Mts. region. Paragneisses from this area differ further from paragneisses from M.M. Mts. in the presence of turmaline and a higher content of graphitic matter. The M.M. Mts. paragneisses do not show retrograde domains that occur frequently in the S. Mts. region. In retrograde domains muscovite and chlorite were formed. From accessory minerals, ilmenite, rutile, apatite, zircon and graphite occur. The structural and tectonic differences of these crystalline complexes were studied earlier by KAHAN (1979), PUTIŠ (1979), MAHEL' (1985) and later by other authors such as KORIKOVSKIJ et al. (1987), HOVORKA & MERES (1989), DYDA (1988, 1990), and VILINOVICOVA (1990).

No precursor mineral inclusions such as kyanite, andalusite, cordierite which may indicate recrystallisation process before the existing mineral assemblage have been found. The P–T characteristics of metamorphic culmination were obtained on the basis of analyses of coexisting Grt, Pl, Bt, Ms. These data (Tab. 5,6; Text-Fig. 7.) reflect peak-metamorphic conditions at 4–5 Kb/550–650°C and post-culmination trajectories.

The retrogressive P–T path of the M.M. Mts. samples obtained by thermobarometric treatment of garnet cores and rimes is shown by the similarity of peak and post-peak P–T trends which may be approximated by a slope of 18 bar/°C. The P–T trends from S. Mts. region are estimated by the dP/dT value of 86 bar/°C for culmination conditions and 67 bar/°C for closure temperature conditions (DYDA, 1990).

Text-Fig. 4.
Idioblastic garnets with no resorption and decompression reaction signs demonstrate static periplutonic growth and are represented by the linear size distribution (population density versus crystal size).
Sample M.K. 17. Cross-polarized light.



Text-Fig. 5.
Garnets with minor retrogression from near magmatic body occurrences present different morphology (from sample 17) and crystal size distribution that indicates regional metamorphic conditions.
Sample M.K. 05.

These values show tendency to isothermal decompression. This difference indicates a diversity in the culmination P–T conditions as well as the diversity in course of the postmetamorphic uplift stages of these two tectonic blocks. For further comparison purposes the fluid regime of the culmination stages was studied on the basis of the reaction:

Paragonite + Quartz = Albite + Sillimanite + H_2O

The thermodynamic reaction values from FERRY (1980) and activity formulations of RICE & LANG (1986) were used. The results are given in Tab. 7. The S. Mts. paragneisses show lower XH_2O values than the M.M. Mts. paragneisses.

Table 5.
Temperatures of metamorphic recrystallization of the paragneisses from Male Karpaty (M.K.), Suchy (S.), Mala Magura (M.M.) and Vysoke Tatry (V.T.) Mts.

Sample		ln Kd	T	F&S	N&H	G&S
M.K. 17	C	1.701	570	587	602	610
	R	1.797	545	551	566	568
M.K. 02	C	1.491	628	666	687	648
	R	1.626	589	610	626	610
M.K. 03	C	1.610	594	619	641	639
	R	1.813	541	546	568	578
M.K. 05	C	1.675	577	596	619	614
	R	1.764	553	562	579	580
S. 48	C	1.692	571	584	596	616
	R	1.989	500	488	504	533
S. 58	C	1.770	551	557	573	603
	R	1.867	528	524	539	579
S. 59	C	1.835	537	541	556	529
	R	1.888	523	521	533	545
S. 60	C	1.768	552	560	573	566
	R	1.793	545	549	560	556
S. 68	C	1.798	546	554	573	571
	R	1.934	512	506	521	534
M.M. 03	C	1.532	615	645	656	643
	R	1.642	584	559	610	606
M.M. 07	C	1.357	669	723	735	709
	R	1.516	620	650	662	653
M.M. 21	C	1.628	589	609	620	624
	R	1.694	571	583	595	604
M.M. 23	C	1.446	641	681	693	661
	R	1.712	566	575	587	580
M.M. 87	C	1.472	632	666	681	671
	R	1.716	566	578	590	622
V.T. 01	C	1.383	661	713	727	724
	R	1.716	566	578	590	621
V.T. 02	C	1.260	702	773	786	797
	R	1.511	622	654	667	703
V.T. 03	C	1.294	690	755	763	782
	R	1.484	629	665	674	705
V.T. 20	C	1.212	719	798	809	752
	R	1.533	615	645	652	646
V.T. 23	C	1.292	691	756	767	734
	R	1.659	580	598	610	635
V.T. 25	C	1.338	676	734	742	669
	R	1.537	614	644	653	615

Data obtained on the basis of chemical analyses given in Tables 1–4.
C = analyses for garnet core, matrix biotite, matrix plagioclase and muscovite; R = for garnet edge, biotite edge against garnet, plagioclase edge against garnet and muscovite.
The following calibrations were used: T = THOMPSON (1976); F & S = FERRY & SPEAR (1978); N & H = NEWTON & HASELTON (1981); G & S = GANGULY & SAXENA (1984).

			a An	a Gr	G	&S	H&C	N&H	P&H
M.K.	17	C	0.3298	0.0412	4.8	4.1	4.7	4.4	5.3
		R	0.4107	0.0411	3.6	3.6	3.8	3.1	4.1
M.K.	02	C	0.4083	0.0557	6.0			5.9	5.9
		R	0.5053	0.0449	3.8			3.3	4.2
M.K.	03	C	0.4142	0.0574	5.7			5.3	6.1
		R	0.4806	0.0604	4.6			3.8	4.9
M.K.	05	C	0.3920	0.0625	5.9	5.1	5.7	5.5	6.4
		R	0.4458	0.0476	4.0	4.0	4.2	3.4	4.4
S.	48	C	0.3159	0.0343	4.1	3.8	4.1	3.8	6.6
		R	0.4367	0.0478	3.4	3.7	3.1	2.6	3.8
S.	58	C	0.4124	0.0463	4.2	3.7	3.7	3.6	4.6
		R	0.4868	0.0396	2.9	3.0	2.7	2.0	3.1
S.	59	C	0.3646	0.0421	4.0	4.2	4.2	3.5	4.5
		R	0.4100	0.0330	2.6	3.3	3.1	1.9	3.1
S.	60	C	0.2622	0.0345	4.3	4.7	5.0	4.2	5.2
		R	0.3205	0.0328	3.5	4.1	4.2	3.1	4.2
S.	68	C	0.4315	0.0519	4.4	5.2	5.2	3.8	4.8
		R	0.4736	0.0417	2.9	3.5	3.0	2.1	3.2
M.M.	03	C	0.3573	0.0292	3.6	3.5	4.5	3.5	4.2
		R	0.4236	0.0290	2.6	3.2	3.7	2.2	3.1
M.M.	07	C	0.3131	0.0313	4.9	4.0	5.6	5.1	5.6
		R	0.3564	0.0325	4.1	3.7	4.8	4.0	4.7
M.M.	21	C	0.2062	0.0288	4.9	4.4	5.o	5.2	6.0
		R	0.2692	0.0315	4.2	4.0	4.3	4.1	5.0
M.M.	23	C	0.3313	0.0325	4.6	4.0	5.4	4.7	5.2
		R	0.4174	0.0318	2.8	3.1	3.3	2.4	3.3
M.M.	87	C	0.3072	0.0287	4.3	3.8	5.1	4.3	4.9
		R	0.3550	0.0324	3.5	3.4	3.6	3.1	4.0
V.T.	O1	C	0.2718	0.0341	5.9	4.3	6.0	6.2	6.7
		R	0.3365	0.0333	3.8	3.3	3.7	3.4	4.3
V.T.	02	C	0.3131	0.0324	5.9	3.3	5.7	6.1	6.4
		R	0.3784	0.0319	4.0	2.5	3.7	3.7	4.4
V.T	03	C	o.2322	0.0194	4.4	2.8	5.0	4.8	5.2
		R	0.2785	0.0232	3.8	2.8	4.0	3.7	4.4
V.T.	20	C	0.1889	0.0279	7.1	5.0	7.6	8.1	8.4
		R	0.3418	0.0186	1.8	1.9	2.9	1.7	2.4
V.T.	23	C	0.2691	0.0272	5.3	4.0	6.2	5.7	6.1
		R	0.4371	0.0315	2.9	2.7	3.1	2.4	3.2
V.T.	25	C	0.2620	0.0217	4.0			4.5	5.0
		R	0.3061	0.0247	3.3			3.3	4.1

Table 6.
Pressures of metamorphic recrystallization of the paragneisses from Malé Karpaty (M.K.), Suchy (S.), Mala Magura (M.M.) and Vysoke Tatry (V.T.) Mts.
Data obtained on the basis of chemical analyses given in Tables 1–4.
C = analyses for garnet core, matrix biotite, matrix plagioclase and muscovite; R = for garnet edge, biotite edge against garnet, plagioclase edge against garnet and muscovite.
The following calibrations were used: G = GHENT, ROBBINS & STOUT (1979); G & S = GHENT & STOUT (1981); H & C = HODGES & CROWLEY (1985); N & H = NEWTON & HASELTON (1981); P & H = POWELL & HOLLAND (1988).
Activities of anorthite (a AN) and grossularite (a Gr) are calculated on the basis of NEWTON HASELTON's formulation.

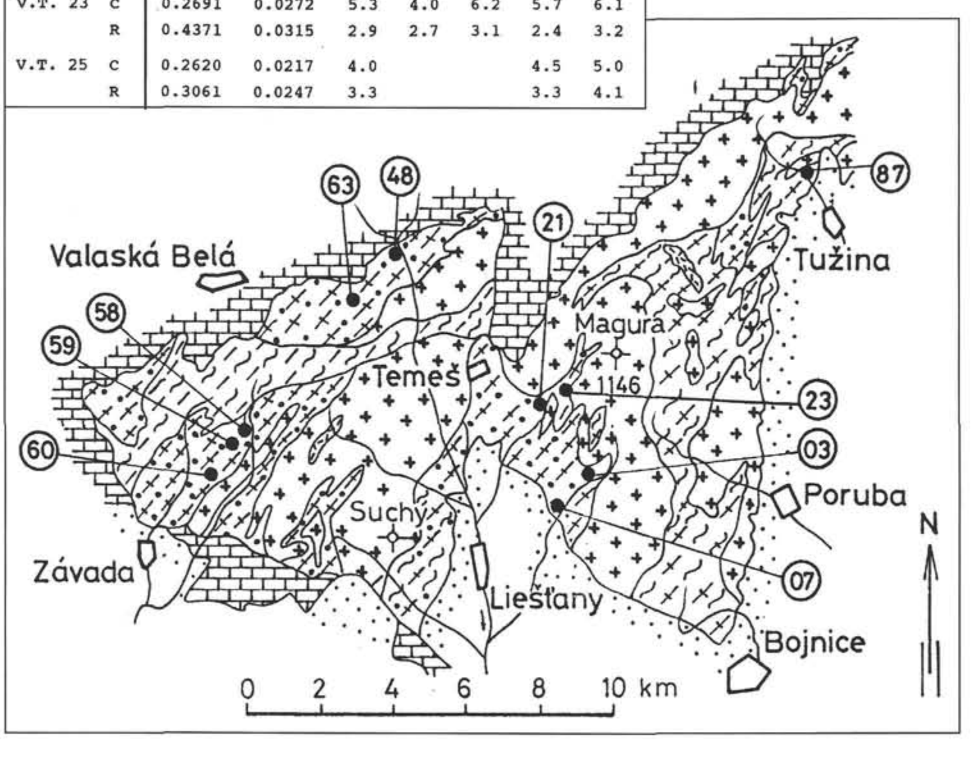
This fact represents differences in composition of metamorphic fluid produced in the stage of metamorphic culmination of individual regions. Since graphite is described in the S. Mts. paragneisses (DYDA, 1990) the fluid phases should also comprise the CO_2, CO, CH_4, H_2 and O_2 within the C-H-O system (FRENCH, 1966; KERRICK, 1974).

These values have mainly a comparative meaning for substantial components of metamorphic fluid H_2O and CO_2 that were produced during devolatilisation reactions of metamorphic culmination in the studied regions (Text-Fig. 8.). Water fugacity calculated from mineral equilibria is higher in M.M. Mts. paragneisses. This explains also the higher water activity in these rocks exposed to higher P–T conditions of metamorphic culmination.

The thermodynamic analyses of these recrystallisation conditions (Tabs. 5,6; Text-Fig. 7) set the metamorphic culmination of M.M. Mts. region at temperatures of 620–640°C and pressures of 4–5 Kbar. In the S. Mts. region the peak conditions are characterized by temperatures of 540–580°C and pressures of 4–4. 5 Kbar.

The post-peak uplift stages support the concept of isothermal decompression (86 bar/°C) in the S. Mts. paragneisses. The uplift occurred probably during the simultaneous intrusion of granitoidic rocks.

The formation of retrograde domains was caused by fluids which could have been exsolved from the crystallizin granitoid melts and/or from sources including dehydration in the underlying rocks undergoing prograde metamorphism. Infiltration occurred during the uplift stages only in S. Mts. paragneisses. However, the water infiltration was local and low, preserving dominant progressive metamorphic assemblages. No sufficient arguments for a developed meta-



Text-Fig. 6.
Sketch map of the Suchy and Mala Magura Mts., showing locations of the elaborated samples for which P–T trajectories have been calculated and approximated.
See Text-Fig. 7 for more details.

Table 7.
Fugacity (f, bars) and mole fraction of water (XH_2O) in metamorphic fluid calculated from the equilibrium.
Par + Qtz = Ab + Sil + H_2O for Male Karpaty (M.K.), Suchy (S.), Mala Magura (M.M.) and Vysoke Tatry (V.T.) Mts.

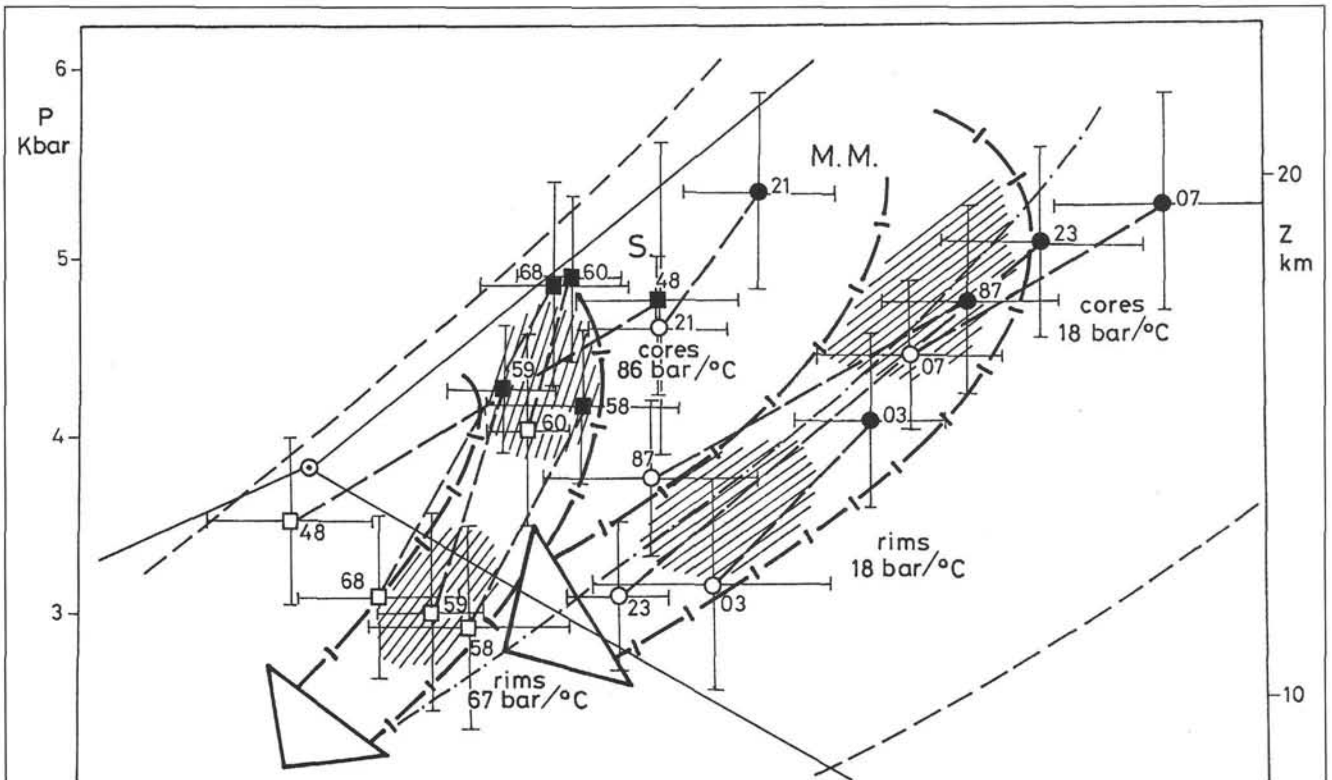
Sample	XAb	XPa	γPa	fH_2O	XH_2O
M.K. 17	0.787	0.286	3.797	2309	0.96
M.K. 05	0.755	0.196	4.789	3734	0.98
S. 48	0.770	0.196	5.368	749	0.63
S. 59	0.783	0.146	5.722	884	0.71
S. 60	0.799	0.144	5.808	1170	0.78
S. 68	0.752	0.131	6.334	718	0.65
M.M. 03	0.751	0.080	6.149	1659	0.97
M.M. 21	0.738	0.109	6.040	1924	0.88
M.M. 23	0.744	0.119	5.729	1675	1.12
M.M. 87	0.772	0.083	6.394	1434	0.78
V.T. 01	0.781	0.090	5.847	4617	0.93
V.T. 02	0.748	0.101	5.680	5122	1.03
V.T. 03	0.797	0.114	5.472	5379	1.08
V.T. 20	0.797	0.105	5.479	9497	1.00
V.T. 23	0.776	0.095	5.697	4882	1.06

Thermodynamic formulation of the reaction is according to FERRY (1980). Paragonite activity formulation of RICE & LANG is accepted.
XAb = mole fraction of albite in plagioclase; γPa = activity coefficient for paragonite.

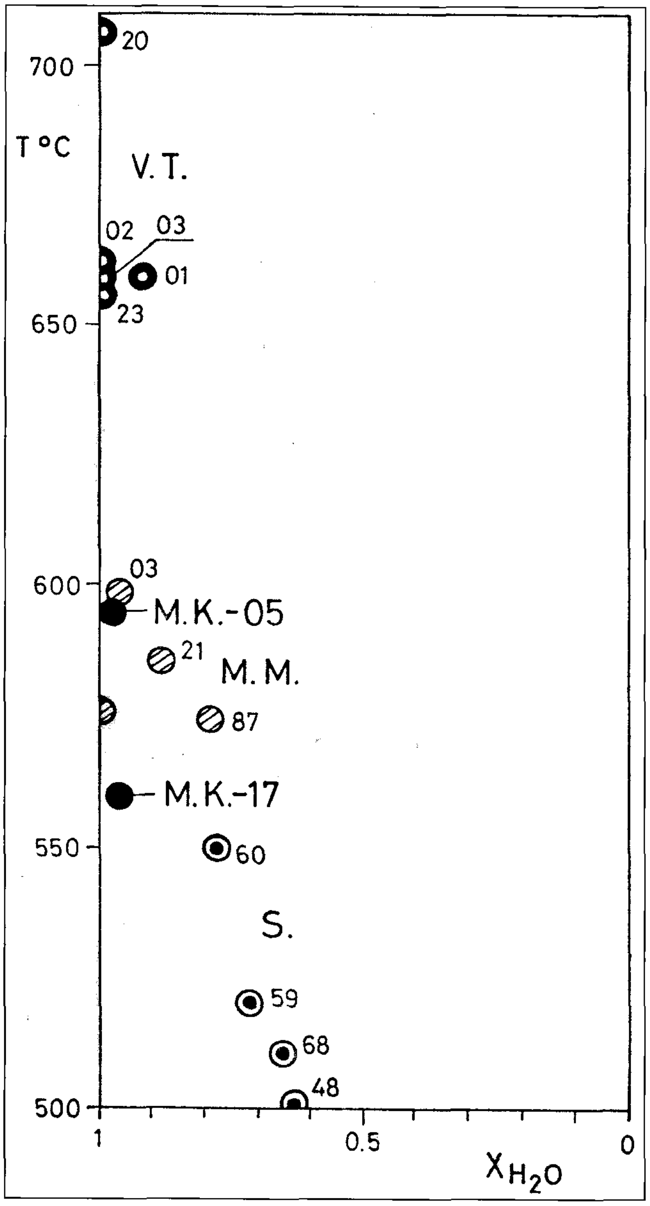
morphic zonation in S. Mts. have been found. The intensity parameters of metamorphic processes of the S. Mts. and M.M. Mts. tectonic blocks indicate differences in their progressive and retrogressive metamorphic development. M.M. Mts. paragneisses have higher temperature and pressure (620–640°C/4–5 Kbar) of their metamorphic culmination than the S. Mts. paragneisses (540–560°C/4–4.5 Kbar). The XH_2O values are lower (0.6–0.7) for S. Mts. paragneisses. The uplift trajectory characteristics (dP/dT) in the S. Mts. tectonic block prove its isothermal decompression and M.M. Mts. tectonic block represents decompression during cooling. These data support the concept of genetic differences in progressive and retrogressive metamorphic development of the Suchy Mts. and Mala Magura Mts. individual crystalline cores.

Zapadne and Vysoke Tatry Mts.

The metamorphic crystalline complexes of Zapadne Tatry Mts. correspond to the medium pressure kyanite-sillimanite regional facies series (JANAK et al., 1988). The basement complex has a parautochthonous position and the upper complexes are allochthonous, forming a nappe structure. In the parautochthonous unit two metamorphic zones (St-Ky-Sil and Ky-Sil), and in the upper allochthonous unit again two zones (Ky and Sil) have been distinguished. In the St-Ky-Sil zone the metamorphic temperatures attained 540–580°C at pressures of 4–6 Kbar. In the Ky-Sil zone the temperature did not exeed 600–640°C at a pressure of 6–7 Kbar. In the upper unit (Ky zone) the P–T conditions of recrystallisation were as high as as 700°C at pressures of about 10–11 Kbar (JANAK, 1991). In the Vysoke Tatry (V.T.) Mts. (Text-Fig. 9.)



Text-Fig. 7.
Generalized P–T conditions of metamorphism of Suchy (S.) and Mala Magura (M.M.) Mts. paragneisses.
Slopes of the metamorphic reactions (dP/dT) in the simplified metamorphic system KMFASH including mineral phases St, Grt, Bt, Ms, Sil, Qtz were used (DYDA, 1990) to approximate the uplift conditions. The methodical approach was taken over from SPEAR & SELVERSTONE (1983), and SPEAR (1988). Triple point Al_2SiO_5 is after HOLDAWAY (1971).



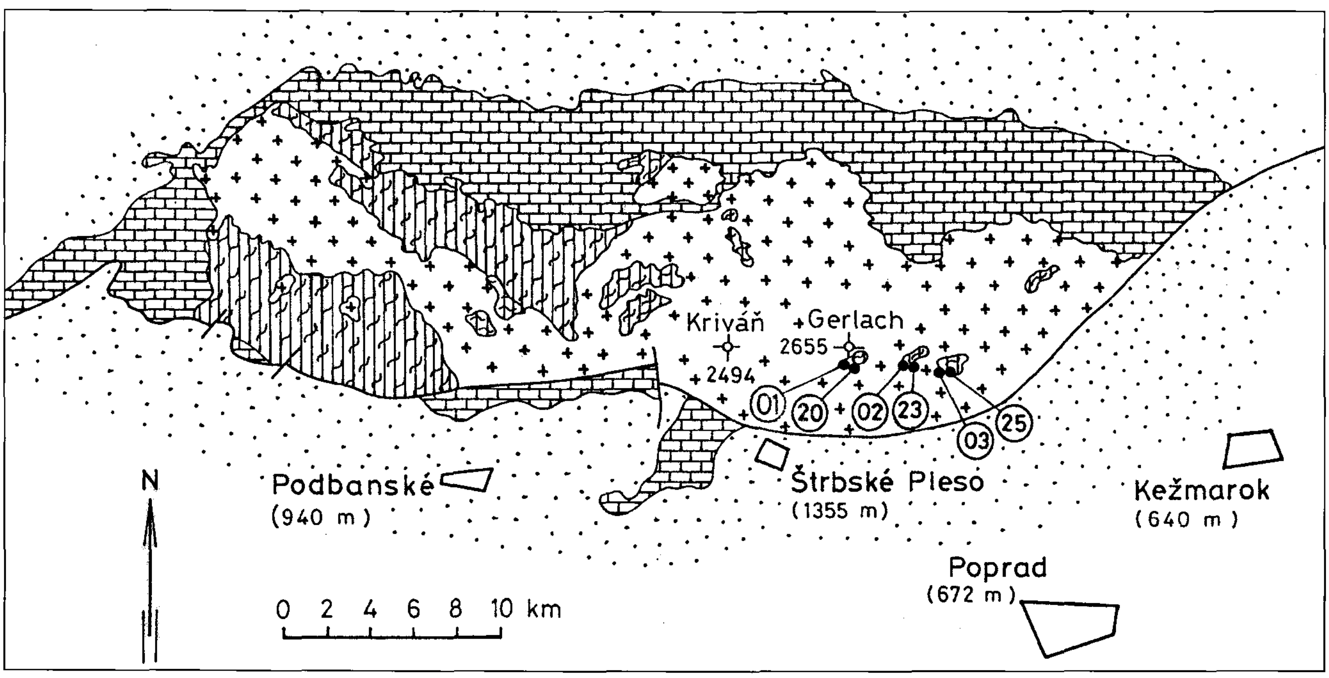
Text-Fig. 8. ◁◁
Composition of metamorphic fluid (XH_2O) released by dehydration reactions during metamorphic culmination.
Calculated according to equilibrium reaction Par + Qtz = Ab + Sil + H_2O using FERRY's (1980) thermodynamic data and LANG & RICE (1985) activity formulation for paragonite.

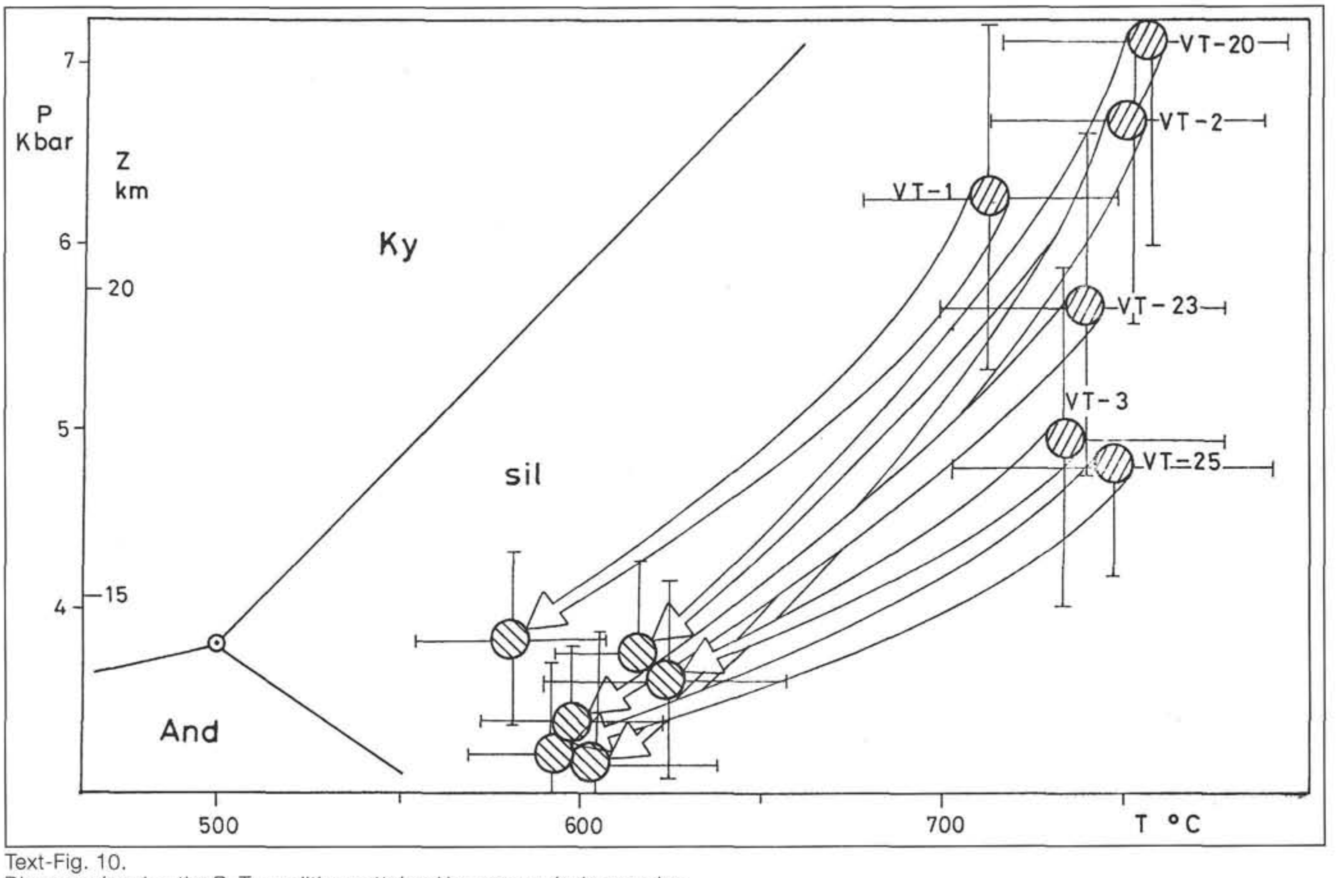
the paragneisses peak recrystallisation temperature attained 700–740°C and 4. 5–7 Kbar of pressure (Tabs. 5,6; Text-Fig 10.). The data suggest different depth levels of the large granitoid intrusion exposed to the surface. The mineralogy of paragneisses supports this high temperature recrystallisation nature and indicates probably the polyphase intrusion of a complex granitoid magmatic body. Calculated pressures determine the approximate depth conditions of assimilation of the overlying paragneisses. The pressure values representing the vertical differences are considered to be significant for further evaluation of the H.T. Mts. uplift history as this core mountains represent the deepest exposure of crustal levels and the highest peaks of the Western Carpathians.

4. Discussion and Conclusions

P–T data of metamorphic processes within the Tatric crystalline basement units indicate differences in their progressive and retrogressive sequences and appear to have been derived from a polyphase metamorphic evolution. The determination of metamorphic culmination temperatures and pressures of the particular core mountain crystalline complex show differences of Variscan tectonothermal activity in the basement units. The crustal level conditions of Variscan magmatism approximated by P–T analyses of contact metamorphism products indicate ca. 15–25 km depth for most granitoidic intrusions.

Text-Fig. 9. ▽▽
Simplified geological map of Zapadne and Vysoke Tatry Mts. with sample locations and main rock types.
Samples were collected from large paragneissic bodies.





Text-Fig. 10.
Diagram showing the P–T conditions attained by paragneissic samples.
The maximum temperatures and pressures represent the deep erosion level of these crystalline complexes uplifted by post-Paleogene movements.

Tectonothermal blocks within the core mountains (e.g. S. Mts. and M.M. Mts.) may represent distinct individual metamorphic and structural development. The metamorphic culmination characteristics and post peak retrograde reactions represent tectono-structural disturbances during the synmetamorphic Variscan thermal event. Further orogenic rock-block transport and tectonic restructuring occurred during Alpine movements. These stimulated metamorphic zonality revision in some areas.

The Tatric crystalline basement experienced two dominant distinct progressive metamorphic events. The earlier, before Variscan granitoid magma intrusions is regionally presented by medium to high pressure and medium to high temperature mineral assemblages (ca. 540–640°C/4–5.5 Kbars). The later metamorphic event is connected with tectonothermal evolution of granitoid rocks (ca. 650–740°C/5–6.5 Kbars). The contact plutonic recrystallisation processes and migmatitic complex development became dominant in most West Carpathian core mountains. The post-peak retrogression processes including retrograde domains development are in relation with fluid infiltration and may form (e.g. Suchy Mts.) a distinctive retrograde event (DYDA, 1988).

Uplift trajectory characteristics obtained on the basis of mineral assemblages in the simplified metapelitic KMFASH system (DYDA, 1990) indicate in some core mountains near isothermal decompression of the tectonic blocks (e.g. Suchy Mts.), but display uniform trajectories characterized by decompression during cooling in the other crystalline complexes (Mala Magura Mts.).

Division of the core mountain metamorphic complexes into individual crystalline tectonic blocks may be represented on the basis of detailed P-T data, peak-metamorphic fluid characteristics and retrograde domain evolution. Formation of retrograde mineral assemblages occurred in core mountains complexes during uplift stages and exhumation shows different intensity of retrograde processes on a scale of particular core mountain metamorphic complexes.

The Alpine tectono-deformation movements destroyed and displaced the polymetamorphic Tatric crystalline basement units and emplaced previously assembled complexes into new structural positions.

Acknowledgements

To Dr. F. CANO from GUDS Bratislava, and Dr. D. JANCULA from Slovak Technical University I wish to express my gratitude for analytical work. Mr. O. KOLACKOVSKY kindly drafted the figures. The constructive review of the preliminary version of the manuscript by Prof. Dr. W. RICHTER, Vienna and Prof. Dr. P.W. MIRWALD, Innsbruck is profoundly and gratefully acknowledged.

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Manuscript received: 29. 10. 1992

Revised version received: 28. 06. 1993

Manuscript accepted: 06. 10. 1993