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NEW DATA ON THE GEOTHERMOMETRY AND GEOBAROMETRY OF THE SOMOGY-DRÁVA BASIN, SW TRANSDANUBIA, HUNGARY

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ABSTRACT

The mineral assemblages of the medium grade polymetamorphic rocks of the Somogy-Dráva Basin are rich in critical minerals which make it possible to expand our knowledge on the metamorphic p—T evolution of the area using mineral equilibria and different geothermo-barometric methods. Previous studies (ÁRKAI 1984; ÁRKAI *et al.* 1985) revealed three metamorphic events.

Applying four geothermo-barometric methods which provided consistent data with the mineral assemblage, the estimated p—T conditions were about 500—1030 Mpa and 539—685°C during the first metamorphic event.

The second, low pressure metamorphism produced 4 different mineral assemblages which crystallized as a result of different reactions during the prograde metamorphism.

1/ andalusite+biotite +/- staurolite relics

2/ andalusite+garnet+biotite (sometimes with sillimanite and staurolite relics)

3/ andalusite+biotite+cordierite +/- sillimanite, garnet, plagioclase, muscovite, with rare staurolite relics in the andalusite.

4/ andalusite+biotite+staurolite, where the andalusite and the staurolite crystallized simultaneously along with the biotite.

These mineral assemblages refer to a maximum temperature of about 600°C. There is only a few geothermo-barometric data on the second stage of the metamorphism which show pressures consistent with the mineral assemblages (200—350 Mpa) but the temperatures seem to be a little low (520—536 °C).

The third, retrograde metamorphism, related to milonitisation, was a very low-low grade one which usually did not exceed the biotite isograde (ÁRKAI 1984), disregarding some exceptional cases.

INTRODUCTION

The Somogy-Dráva Basin is situated in the south-western part of Transdanubia as a part of the Pannonian Basin (*Fig. 1a*). The crystalline basement of the Somogy-Dráva Basin is covered by thick neogene sediments. All the samples are exposed by hydrocarbon exploratory boreholes of the National Hydrocarbon and Gas Trust.

Detailed textural and microprobe analyses were carried out on several core samples, so as to contribute to the better understanding of the polymetamorphic history of the crystalline basement of the Somogy-Dráva Basin. The location of the studied samples with indication of the most important metamorphic minerals, and the depth of the core sample is presented in *Fig. 1b*.

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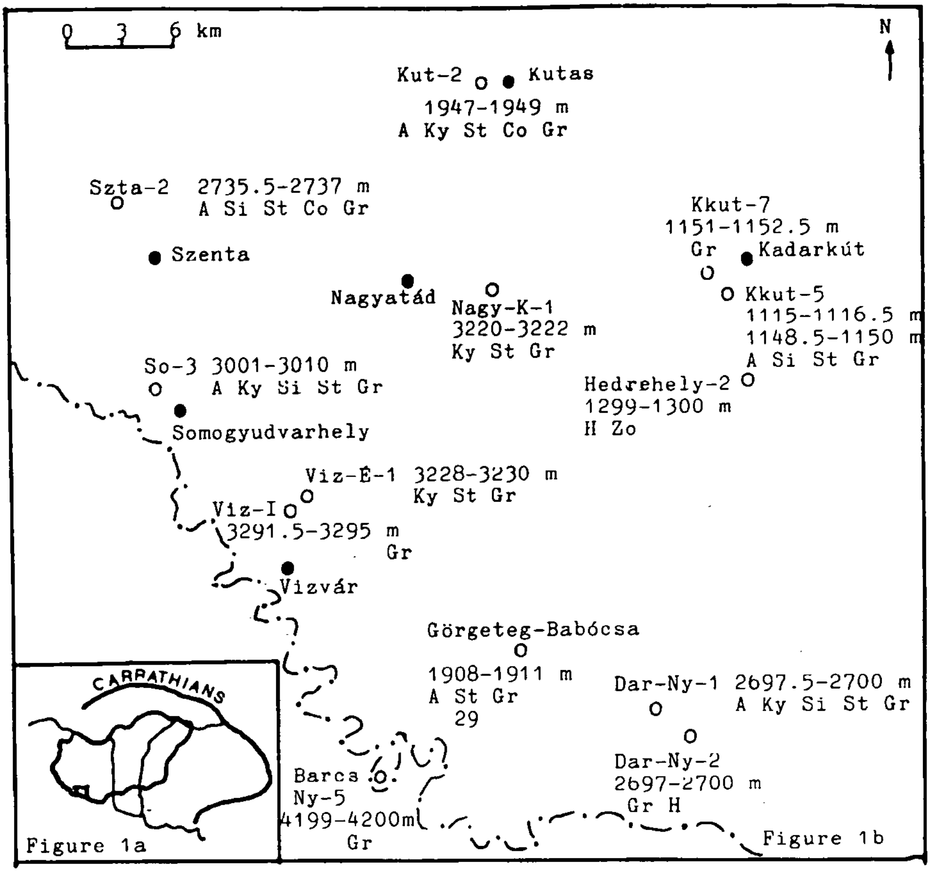

Fig. 1a. Location of the Somogy-Dráva Basin in Hungary

Fig. 1b. Location of the studied boreholes in the Somogy-Dráva Basin with indication of the most important metamorphic minerals and the depth of the studied core samples.
Legends: A—andalusite, Ky—kyanite, Si—sillimanite, Co—cordierite, St—staurolite, Gr—garnet, H—hornblende, Zo—zoisite.
o—borehole, •—village

GEOLOGY OF THE STUDIED AREA

The medium grade, mostly metasedimentary rocks of the Somogy-Dráva Basin underwent a complex, polymetamorphic history, summarized in Table 1. The main rock types of the crystalline basement are mica-schist, gneiss, and milonite. Amphibolite and amphibole gneiss was exposed only in some boreholes on the territory of the Somogy-Dráva Basin.

The age of the first metamorphic event is a topic of great discussions, because there is no reliable radiometric age data available so far. It varies from Proterozoic (pre-Baikalian) to early Hercynian depending on the geological analogies used by the author in question. The K—Ar measurements conducted by BALOGH *et al.* (1981), indicate the Hercynian age for the second stage of the metamorphism in the neighbourhood of the Somogy-Dráva Basin. The third metamorphic event, related to milonitisation is assumed to be late Hercynian or Alpine.

TABLE 1.

Polymetamorfic evolution of the Somogy–Dráva Basin

metamorphic event	p—T conditions, critical minerals	references
1./ Barrow-type medium grade	510—600 °C 590—890 MPa kyanite, staurolite	SZEDERKÉNYI (1976) ÁRKAI (1984) ÁRKAI *et al.* (1985)
2./Abukuma-type medium grade	andalusite	LELKES-FELVÁRI-SASSI (1981)
3./very low-low grade, milonitisation		TÖRÖK (1986)

The crystalline basement of the Somogy-Dráva Basin has a close genetic connection with the surrounding metamorphic complexes of the Slavonian Mountains, the Transsylvanian Midmountains the South- and the Eastern Carpathians and the Serbo-Macedonian Massif (SZEDERKÉNYI 1976, 1984; JANTSKY 1979; ÁRKAI *et al.* 1985).

TEXTURAL ANALYSIS AND MINERAL ASSEMBLAGES

The mineral assemblages, referring to different metamorphic stages, were distinguished by textural analysis. In accordance with the previous authors (LELKES-FELVÁRI and SASSI 1981; ÁRKAI 1984; ÁRKAI *et al.* 1985) the kyanite-staurolite-garnet-plagioclase-biotite-muscovite (sillimanite?) paragenesis is thought to be the oldest one. These early micas form the S_1 schistosity, which preserved in some early porphyroblasts, or in certain places, where the development of the S_2 and S_3 schistosity was not effective enough to clear all the previous information.

Two generations of garnet can be distinguished during the first metamorphic event. The oldest one is pretectonic, the youngest is syntectonic with "S" shaped inclusion trails. Some of the garnets display compositional zoning. These porphyroblasts have cores richer in grossularite component relatively to their rims (see Table 2.), showing the effect of the prograding metamorphism. The staurolite crystallized in two stages as well. The first generation forms inclusions in syntectonic garnet, while the second generation is posttectonic along with the kyanite porphyroblasts. There is no textural evidence for the formation of sillimanite during the first metamorphism, but it cannot be excluded either.

The mineral assemblages of the second metamorphic stage preserved more information on the metamorphic reactions, therefore they were studied in more details. The most characteristic mineral is andalusite which is present in two generations. The oldest one is posttectonic regarding the S_1, but pretectonic to the S_2 schistosity. The second generation is posttectonic to the S_2 schistosity. Both generations contain abundant staurolite relics or sometimes fibrolite. The presence of the staurolite relics was also revealed by ÁRKAI (1984). Cordierite is also present, but it is quite rare. It was found together with the younger generation of the andalusite. The third generation of staurolite also formed together with the second andalusite, but never coexists with cordierite. Sillimanite is present as fibrolite along the S_2 schistosity, or unoriented.

According to the textural analysis, four different mineral assemblages could be distinguished during the second period of the metamorphism.

1/ andalusite+biotite ± staurolite relics as inclusions in andalusite. This mineral paragenesis is the most frequent of all. The probable reactions involving staurolite breakdown and formation of the paragenesis are:

$$\text{staurolite+muscovite+quartz=}Al_2SiO_5\text{+biotite+}H_2O \qquad (1)$$

$$\text{Mg-chlorite+staurolite+muscovite+quartz=}Al_2SiO_5\text{+biotite+}H_2O \qquad (2)$$

The reaction (2) takes place at 200 Mpa and 575 ± 15 °C according to HOSCHEK (1969) *Fig. 2.*

2/ andalusite+garnet+biotite (sometimes with sillimanite and staurolite relics). This paragenesis was also observed by LELKES-FELVÁRI *et al.* (1989) in sample originating from the Vajta-3 borehole in the northern part of South Transdanubia. In this case it is necessary to take into account the breakdown of the staurolite near the andalusite/sillimanite stability border in the following reaction:

$$\text{Fe-staurolite+quartz=}Al_2SiO_5\text{+garnet+}H_2O \qquad (3)$$

(GANGULY 1972), where the Al_2SiO_5 phase can be both sillimanite and andalusite (FERRY 1980; PIGAGE and GREENWOOD 1982) *Fig. 2.*

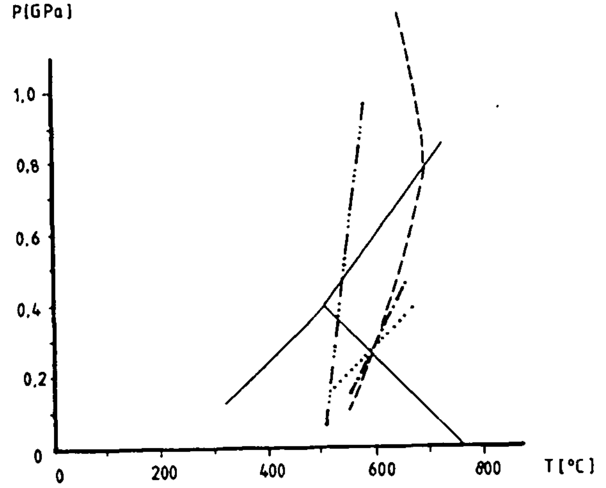

Fig. 2. Stability and reactions of the critical minerals.

Legends: —.—.— staurolite+quartz+muscovite=Al_2SiO_5+biotite+H_2O /1/ (HOSCHEK 1969).

— — — Fe-staurolite+quartz=Al_2SiO_5+almandine+H_2O /3/, (PIGAGE and GREENWOOD 1982)

...... staurolite+quartz=cordierite+Al_2SiO_5+H_2O /6/ HOSCHEK (1969)

— . . . — chlorite+muscovite=staurolite+quartz+biotite+H_2O /7/ (WINKLER 1976)

The Al_2SiO_5 stability fields are after HOLDAWAY (1971)

3/ andalusite+biotite+cordierite ± sillimanite, garnet, plagioclase, muscovite, with rare staurolite relics in the andalusite. This complex mineral assemblage might have formed in several reactions in the course of the prograding metamorphism.

chlorite+muscovite+quartz=andalusite+cordierite+biotite+H_2O (4)

reaction indicates the beginning of the medium grade. According to HIRSCHBERG and WINKLER (1968) this reaction occurs at 525 ± 10 °C and 200 Mpa, or at 555 ± 10 °C and 400 Mpa.

As the temperature rises, the old staurolite becomes unstable and brakes down in the following reaction:

staurolite+Na-rich muscovite+quartz=Al_2SiO_5+biotite+K-rich muscovite+
+albite+almandine+H_2O (GUIDOTTI 1970). (5)

According to GANGULY (1972) the reaction

staurolite+quartz=cordierite+Al_2SiO_5+H_2O (6)

is also possible (*Fig. 2*).

The last step was in the prograde reactions, when the micas partly transformed into fine grained aggregates of fibrolite as the temperature reached the sillimanite stability field.

4/ andalusite+biotite+staurolite, where the andalusite and the staurolite crystallized simultaneously along with the biotite. This assemblage is more common than the andalusite+biotite+cordierite, which can be the alternative of the assemblage 4., because staurolite never coexists with cordierite.

The mineral assemblages of both the first and the second metamorphic event preserved only at that places, where the subsequent milonitisation and retrograde metamorphosis had no effect on the rock. In the milonitized zones the old mineral assemblages has been altered. The only indicators of the preexisting mineral assemblages are the chlorite pseudomorphs after garnet, or the sericite ± chlorite pseudomorphs after kyanite, andalusite, or staurolite. The milonites usually contain carbonate minerals, sometimes in great quantity, pirite, newly formed muscovite, sericite, in one sample new biotite, rarely anhydrite and gypsum. The newly formed micas show the S_3 schistosity, related to the milonite formation.

The P—T conditions of the first and second metamorphic stages can be estimated on the basis of the mineral reactions and mineral equilibria. The temperature conditions of the first metamorphism may have been limited between the "staurolite in" and the "sillimanite in" isograde. However there is a good amount of uncertainty in the case of the upper limit, because the presence of the sillimanite has not been proved, but there is no evidence to anticipate it either. The pressure may have a wide range variation in the common stability field of the kyanite and staurolite. The second metamorphism has the lower temperature limit where the cordierite or the staurolite appears, and the andalusite is stable as well. The upper temperature limit is over the „sillimanite in" isograd. According to the reactions, displayed on *Fig. 2.*, the temperature during the second metamorphic event may have been between 520—620 °C. The pressure is limited by the stability of andalusite. It is assumed to have been between 200—400 Mpa. The third, retrograde metamorphism, related to milonitisation, was a very low-low grade one which usually did not exceed the biotite isograde (ÁRKAI 1984), disregarding some exceptional cases.

Microprobe measurements were carried out on garnets, biotites, muscovites, plagioclases and hornblendes from selected samples. The samples are mica-schists and gneisses, except one sample, the Hedrehely—2 which is amphibole-biotite gneiss. The analytical data are displayed in Tables 2—6. The measurements were made in Novosibirsk at the Institute of Geology and Geochemistry of the Siberian Branch of the Academy of Sciences of the Sovietunion on a Cameca microprobe (E_o=20 kV, I_s=40 nA, T=10 s).

The mineral assemblages made it possible to apply several geothermometers and geobarometers:

1/ *Garnet-biotite geothermometer* (FERRY and SPEAR 1978). All of the selected samples contained garnet and biotite, except for the Hedrehely—2 (*Fig.1b*) amphibole gneiss. The geothermometer gives a temperature interval between 539 and 666 °C, but most of the temperature data fell within the range from 572—607 °C. The temperature was also calculated using the Hoinkes (1986) calibration of the garnet-biotite geothermometer which takes into account the grossularite content of the garnet. But the temperatures provided by this method are unrealistically high (600—805 °C), which is not supported by the mineral assemblage, that is why this method was not taken into account further.

2/ *Plagioclase-biotite-muscovite-garnet geothermo-barometer* (GHENT and STOUT 1981). It provided a wide pressure interval — 650—1030 Mpa — and a quite uniform temperature range between 558 and 685 °C. The geothermo-barometer gives systematically higher temperatures than the garnet-biotite geothermometer. This difference is between 17 and 30 °C.

3/ *Hornblende-plagioclase geothermo-barometer* (PLJUSNINA 1982). The hornblende-plagioclase geothermo-barometer could be applied only on one sample (Hedrehely—2), and provided 520 °C—530 °C temperature and 300 Mpa—350 Mpa pressure. The obtained temperature and pressure data (Table 7.) are comparable with those obtained by ÁRKAI *et al.* (1985) from the hornblende-plagioclase assemblage of a mafic resistite from the "Mórágy granite" rather than with the temperature and pressure conditions of the Darány—2 amphibolite from the Somogy-Dráva Basin (ÁRKAI 1984). This fact indicates, that this hornblende-plagioclase assemblage crystallized during the second metamorphism.

4/ *Plagioclase-garnet-Al_2SiO_5-quartz geobarometer* (GHENT 1976). The temperature data, needed for the geobarometer, were provided by the average value of the garnet-biotite geothermometer (FERRY and SPEAR 1978) and the plagioclase-biotite-muscovite-garnet geothermo-barometer (GHENT and STOUT 1981). The equations ($agr_{gro}=X^{3gr}_{gro}x\tau^{3gr}_{gro}$; $a^{pl}_{an}=X^{pl}_{an}x\tau^{pl}_{an}$) and the activity coefficient of the anorthite in plagioclase were used for calculation of the activity of the grossularite component in garnet and anorthite component in plagioclase, given by GHENT (1976). The activity coefficient of the grossularite in garnet was obtained from ASWORTH and EVIRGEN (1985).

The estimated pressures provided by the geobarometer, are between 500 and 915 Mpa. These values are quite close to those obtained from the plagioclase-biotite-muscovite-garnet geothermo-barometer. The difference ranges between 71 and 3 Mpa.

TABLE 2.

Garnet analyses

locality	Szenta-2					Barcs-Ny-5			Kkút-5 1115 m		Darány-Ny-1		Kadarkút-7		Kutas-2	Kadarkút-5 1148 m			Víz-É-1	
	rim	core	rim	core	rim	rim	rim	core	rim	rim	rim	rim	rim	rim	rim	rim	rim	rim	rim	rim
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.
SiO_2	37.50	38.02	37.42	38.10	38.36	37.57	36.48	37.67	36.23	36.29	37.13	36.88	36.04	36.31	36.96	36.80	36.13	36.73	36.42	35.92
TiO_2	0.07	0.05	0.05	0.07	0.04	0.03	0.04	0.08	0.02	0.00	0.01	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al_2O_3	21.05	21.10	20.96	21.32	21.48	21.23	20.98	21.22	20.60	20.83	21.22	20.98	20.55	20.80	20.75	20.97	20.68	21.02	20.66	20.90
FeO*	33.45	32.05	33.36	32.25	34.19	34.26	33.83	30.98	35.44	36.06	35.28	35.11	35.57	36.07	34.35	35.05	34.83	35.46	34.59	33.08
MnO	0.86	0.73	2.17	0.75	2.23	1.30	1.82	2.11	1.66	1.21	0.77	1.58	2.25	1.52	4.36	1.49	1.57	1.26	3.93	2.51
MgO	2.60	2.18	2.79	2.10	2.79	2.45	2.47	1.25	2.67	3.24	3.17	2.89	3.18	3.36	3.33	2.81	2.82	3.15	3.24	3.71
CaO	4.46	6.42	3.24	5.35	3.32	4.69	3.00	8.01	3.34	2.19	3.57	3.33	2.26	2.08	1.86	2.86	3.02	2.82	1.73	3.94
Na_2O	0.03	0.04	0.03	0.03	0.03	0.05	0.04	0.03	0.08	0.09	0.08	0.15	0.13	0.05	0.18	0.10	0.11	0.12	0.12	0.14
K_2O	0.00	0.01	0.01	0.01	0.01	0.01	0.61	0.00	0.02	0.01	0.01	0.01	0.02	0.00	0.01	0.01	0.03	0.02	0.01	0.54
total	100.02	100.60	100.03	99.98	102.45	101.59	99.63	101.30	100.06	99.92	101.26	100.93	99.87	100.46	101.80	100.09	99.19	100.58	100.70	100.75
Cation numbers on the basis of 12 oxygen																				
Si	3.005	3.021	3.006	3.037	3.008	2.981	2.987	2.991	2.945	2.945	2.958	2.958	2.936	2.933	2.954	2.971	2.952	2.954	2.944	2.896
Ti	0.004	0.002	0.003	0.004	0.002	0.001	0.002	0.004	0.001	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Al	1.988	1.976	1.984	2.003	1.985	1.985	2.005	1.986	1.973	1.992	1.992	1.983	1.973	1.980	1.954	1.995	1.991	1.992	1.968	1.987
Fe	2.242	2.129	2.241	2.150	2.242	2.273	2.294	2.054	2.409	2.447	2.350	2.355	2.409	2.437	2.296	2.367	2.380	2.385	2.338	2.231
Mn	0.058	0.049	0.147	0.050	0.148	0.087	0.125	0.141	0.114	0.083	0.051	0.107	0.155	0.104	0.295	0.101	0.108	0.085	0.296	0.171
Mg	0.310	0.258	0.334	0.249	0.326	0.289	0.289	0.147	0.323	0.391	0.376	0.345	0.386	0.437	0.396	0.338	0.343	0.377	0.390	0.446
Ca	0.383	0.546	0.278	0.457	0.279	0.398	0.260	0.681	0.290	0.190	0.306	0.286	0.197	0.180	0.159	0.247	0.264	0.243	0.149	0.341
Na	0.004	0.006	0.004	0.004	0.004	0.007	0.006	0.004	0.012	0.014	0.012	0.023	0.020	0.007	0.028	0.015	0.017	0.018	0.018	0.022
K	0.000	0.001	0.001	0.001	0.001	0.001	0.063	0.000	0.002	0.001	0.001	0.001	0.002	0.000	0.001	0.001	0.003	0.002	0.001	0.056
total	7.994	7.988	7.998	7.955	7.995	8.022	8.031	8.008	8.069	8.063	8.046	8.058	8.078	8.078	8.083	8.035	8.058	8.056	8.077	8.149

TABLE 3.

Biotite analyses

locality	Szenta-2				Barcs-Ny-5				Vízvár-É-1		Kkut-5 1115		Kutas-2		Kkut-5 1148		Kkut-7		Darány-Ny-1	
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.
SiO_2	34.15	34.68	34.59	35.29	35.27	35.11	34.78	35.57	35.61	30.80	35.61	34.86	37.34	36.57	33.12	34.67	36.31	34.14	35.60	35.12
TiO_2	1.99	1.96	2.05	2.42	2.31	2.13	1.98	2.14	1.59	0.24	1.43	1.49	1.79	1.88	1.19	1.83	1.55	1.34	1.73	1.49
Al_2O_3	19.21	19.35	19.76	20.22	19.92	20.33	18.97	19.20	18.31	19.77	19.92	19.72	21.60	20.12	18.46	19.34	19.79	19.41	19.41	19.65
FeO*	21.60	21.04	20.96	20.35	21.70	21.52	23.93	23.40	20.65	21.84	21.31	21.35	15.57	17.75	21.68	22.79	19.57	19.40	22.02	23.40
MnO	0.13	0.11	0.13	0.13	0.20	0.19	0.25	0.23	0.13	0.17	0.05	0.04	0.12	0.11	0.14	0.12	0.14	0.12	0.09	0.10
MgO	8.99	9.06	8.68	8.55	8.33	8.45	6.91	6.95	9.95	13.20	8.90	8.85	10.04	10.56	9.34	8.65	10.01	9.49	8.33	8.48
CaO	0.04	0.03	0.04	0.03	0.00	0.00	0.00	0.01	0.00	0.93	0.04	0.03	0.02	0.01	0.07	0.03	0.02	0.01	0.04	0.05
Na_2O	0.22	0.35	0.18	0.33	0.24	0.25	0.19	0.25	0.26	0.49	0.25	0.23	0.23	0.23	0.57	0.26	0.18	0.20	0.28	0.27
K_2O	8.55	8.57	8.34	8.57	8.84	8.83	8.88	9.00	9.41	8.98	8.92	8.99	7.72	8.78	8.54	8.71	9.10	8.00	8.87	7.37
total	94.89	95.15	94.74	95.89	96.81	96.81	95.89	96.76	95.95	96.40	96.42	95.57	94.44	96.01	93.10	96.41	96.67	92.71	96.37	95.97
Cation numbers on the basis of 11 oxygen																				
Si	2.635	2.658	2.655	2.665	2.661	2.645	2.686	2.709	2.771	2.383	2.689	2.665	2.760	2.717	2.623	2.644	2.711	2.673	2.701	2.673
Ti	0.115	0.113	0.118	0.139	0.131	0.121	0.115	0.123	0.091	0.014	0.081	0.086	0.099	0.105	0.071	0.105	0.087	0.079	0.099	0.085
Al	1.747	1.747	1.787	1.800	1.771	1.805	1.726	1.723	1.643	1.803	1.773	1.777	1.882	1.762	1.723	1.741	1.742	1.791	1.735	1.762
Fe	1.394	1.348	1.346	1.285	1.369	1.365	1.545	1.491	1.315	1.413	1.346	1.365	0.962	1.103	1.436	1.454	1.22	1.270	1.397	1.490
Mn	0.009	0.007	0.009	0.009	0.013	0.012	0.017	0.015	0.009	0.011	0.003	0.003	0.008	0.007	0.009	0.008	0.009	0.008	0.006	0.007
Mg	1.034	1.034	0.993	0.963	0.936	0.949	0.795	0.790	1.129	1.522	1.002	1.009	1.107	1.169	1.102	0.984	1.114	1.108	0.942	0.962
Ca	0.003	0.002	0.003	0.003	0.000	0.000	0.000	0.000	0.003	0.077	0.003	0.002	0.002	0.001	0.006	0.002	0.002	0.008	0.004	0.004
Na	0.032	0.052	0.027	0.048	0.035	0.036	0.029	0.038	0.038	0.073	0.036	0.034	0.032	0.034	0.087	0.038	0.027	0.031	0.041	0.040
K	0.842	0.837	0.817	0.825	0.850	0.849	0.875	0.874	0.913	0.886	0.859	0.877	0.728	0.832	0.862	0.847	0.867	0.799	0.859	0.715
total	7.813	7.800	7.755	7.645	7.776	7.774	7.788	7.763	7.852	8.181	7.791	7:817	7.580	7.730	7.919	7.823	7.778	7.767	7.783	7.738

TABLE 4.

Muscovite Analyses

locality	Szenta—2				Barcs—Ny—5	Barcs—Ny—5			Viz—É—1		Kkut—5 1115		Kutas—2		Dar—Ny—1		Kkut—7		Kkut—5 1148,5	
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.
SiO_2	48.04	48.79	47.16	47.04	49.89	50.67	46.86	48.54	44.96	45.02	46.06	45.54	44.72	44.61	46.83	47.41	44.55	45.29	47.39	46.95
TiO_2	0.62	0.55	0.56	0.60	0.59	0.42	0.64	0.65	0.23	0.50	0.42	0.44	0.45	0.33	0.40	0.43	0.62	0.54	0.36	0.39
Al_2O_3	36.02	36.56	35.74	35.06	32.09	30.40	34.84	31.82	34.40	34.15	36.51	36.09	35.80	36.63	36.91	37.34	34.48	35.39	35.24	36.95
FeO*	0.89	0.80	0.73	0.86	1.46	1.80	1.11	1.81	1.72	2.04	1.08	1.08	0.64	0.66	0.85	0.85	1.38	0.98	1.19	0.92
MnO	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.11	0.02	0.02	0.00	0.02	0.01	0.02	0.00	0.00	0.01	0.00	0.01
MgO	0.63	0.65	0.55	0.80	1.57	2.08	0.92	1.84	0.74	1.22	0.48	0.47	0.51	0.44	0.44	0.45	0.92	0.66	0.95	0.47
CaO	0.02	0.02	0.04	0.03	0.01	0.00	0.01	0.01	0.15	0.06	0.01	0.01	0.05	0.05	0.02	0.01	0.05	0.03	0.02	0.02
Na_2O	0.83	0.86	0.98	1.01	0.62	0.673	0.80	0.62	1.08	1.05	1.42	1.37	1.48	1.40	1.13	0.85	1.13	1.13	0.64	1.12
K_2O	8.80	8.68	9.09	9.20	9.05	9.10	9.40	9.29	8.54	8.69	8.77	8.52	8.69	8.53	8.36	8.11	8.79	8.46	8.85	8.50
total	95.68	96.92	94.60	94.85	95.28	95.11	94.58	94.66	91.97	92.76	94.76	93.53	92.21	92.60	94.95	95.45	91.93	92.43	94.62	95.31
Cation numbers on the basis of 11 oxygen																				
Si	3.130	3.137	3.114	3.122	3.279	3.343	32.117	3.233	3.084	3.069	3.054	3.056	3.043	3.020	3.078	3.089	3.058	3.071	3.134	3.078
Ti	0.031	0.026	0.028	0.030	0.029	0.021	0.032	0.032	0.012	0.026	0.021	0.022	0.023	0.017	0.020	0.021	0.032	0.027	0.018	0.019
Al	2.766	2.77	2.782	2.742	2.486	2.363	2.732	2.498	2.781	2.744	2.853	2.854	2.871	2.922	2.859	2.867	2.789	2.828	2.747	2.855
Fe	0.048	0.043	0.040	0.048	0.080	0.099	0.062	0.106	0.099	0.117	0.060	0.061	0.037	0.037	0.047	0.046	0.079	0.055	0.066	0.050
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.001	0.001	0.000	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000
Mg	0.061	0.063	0.055	0.079	0-.153	0.205	0.091	0.182	0.076	0.124	0.047	0.047	0.051	0.045	0.043	0.044	0.095	0.067	0.093	0.046
Ca	0.002	0.002	0.003	0.002	0.001	0.000	0.001	0.000	0.011	0.005	0.001	0.001	0.004	0.004	0.002	0.001	0.004	0.002	0.001	0.001
Na	0.105	0.108	0.125	0.130	0.079	0.081	0.103	0.080	0.144	0.139	0.182	0.178	0.195	0.184	0.144	0.107	0.150	0.141	0.082	0.142
K	0.732	0.712	0.765	0.779	0.759	0.766	0.798	0.789	0.748	0.756	0.741	0.729	0.741	0.731	0.701	0.674	0.769	0.732	0.747	0.711
total	6.875	6.861	6.913	6.931	6.867	6.878	6.935	6.921	6.960	6.981	6.961	6.948	6.966	6.960	6.895	6.848	6.976	6.924	6.889	6.902

TABLE 5.

Plagioclase analyses

locality	Barcs—Ny—5				Szta—2				Viz—É—1		Kkut—5 1115		Kutas—2		Dar—Ny—1			Kkut—7		Kkut—5 1148,5		Hedrehely—2			
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.
SiO_2	65.91	65.44	65.12	65.53	63.02	62.86	64.42	63.95	64.49	62.27	63.27	63.14	60.29	63.36	63.75	61.92	61.74	63.15	63.10	62.02	61.88	61.35	60.48	67.85	68.83
TiO_2	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.04	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00
Al_2O_3	21.46	21.25	21.24	20.54	22.71	22.80	21.84	21.77	21.91	23.91	22.03	22.00	23.68	21.98	21.73	23.56	23.07	22.08	21.66	23.68	23.12	23.07	23.39	19.61	10.21
FeO*	0.04	0.00	0.04	0.02	0.05	0.02	0.01	0.04	0.01	0.05	0.01	0.02	0.04	0.00	0.16	0.02	0.00	0.02	0.01	0.00	0.13	0.04	0.05	0.12	0-.02
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.02	0.02	0.01	0.03	0.02	0.00	0.02	0.01	0.00	0.02	0.01	0.00	0.00	0.00
MgO	0.001	0.00	0.001	0.00	0.01	0.01	0.01	0.01	0.04	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.02	0.02	0.12	0.05	0.01	0.02	0.03	0.02
CaO	2.65	2.52	2.64	1.79	4.13	4.29	3.41	3.56	3.,21	6.07	3.57	3.63	3.65	3.77	3.05	5.15	4.91	3.58	3.46	4.34	3.62	4.63	5.22	0.44	0.32
Na_2O	9.67	10.04	9.38	10.18	9.29	9.41	9.45	9.12	8.76	7.54	9.43	8.70	7.66	8.95	8.97	8.29	8.23	9.33	9.35	7.80	7.93	8.66	8.23	11.15	10.50
K_2O	0.10	0.12	0.18	0.12	0.11	0.10	0.08	0.11	0.13	0.08	0.10	0.11	1.20	0.09	0.17	0.08	0.10	0.09	0.13	0.46	0.90	0.19	0.15	0.06	0.07
total	99.85	99.39	98.63	98.20	99.35	99.51	99.24	98.58	98.68	99.99	98.46	97.63	96.57	98.18	97.86	99.05	98.10	98.28	97.76	98.55	97.64	97.96	97.57	99.27	98.98
Cation numbers on the basis of 8 oxygen																									
Si	2.895	2.893	2.896	2.924	2.804	2.796	2.857	2.855	2.868	2.755	2.834	2.844	2.762	2.841	2.862	2.765	2.781	2.833	2.845	2.776	2.797	2.772	2.748	2.985	3.022
Ti	0.001	0.001	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Al	1.111	1.107	1.113	1.080	1.191	1.195	1.142	1.145	1.148	1.247	1.163	1.168	1.278	1.162	1.150	1.240	1.225	1.168	1.151	1.249	1.232	1.229	1.253	1.017	0.994
Fe	0.001	0.000	0.001	0.001	0.002	0.001	0.000	0.000	0.004	0.002	0.000	0.001	0.001	0.000	0.006	0.000	0.000	0.000	0.000	0.005	0.005	0.001	0.002	0.005	0.001
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.001	0.000	0.001	0.001	0.000	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.000
Mg	0.001	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.002	0.001	0.002	0.002	0.002	0.001	0.002	0.008	0.003	0.001	0.001	0.002	0.001
Ca	0.125	0.119	0.126	0.086	0.197	0.205	0.162	0.170	0.153	0.288	0.171	0.175	0.179	0.181	0.147	0.246	0.237	0.172	0.167	0.208	0.175	0.224	0.254	0.021	0.015
Na	0.824	0.860	0.809	0.881	0.802	0.811	0.812	0.789	0.756	0.647	0.819	0.759	0.681	0.779	0.781	0.718	0.719	0.812	0.818	0.677	0.695	0.759	0.725	0.951	0.894
K	0.006	0.007	0.100	0.007	0.006	0.006	0.005	0.006	0.007	0.004	0.006	0.006	0.070	0.005	0.008	0.005	0.006	0.005	0.007	0.026	0.052	0.011	0.009	0.004	0.004
total	4.963	4.987	4.957	4.979	5.004	5.014	4.980	4.969	4.939	4.946	4.996	4.955	4.974	4.970	4.957	4.977	4.969	4.991	4.991	4.951	4.960	4.998	4.992	4.984	4.930

TABLE 6.

Hornblende analyses

	1. /n=4/	2. /n=4/
SiO_2	46.01	46.56
TiO_2	0.61	0.66
Al_2O_3	7.76	7.96
FeO^*	17.66	17.20
MnO	0.32	0.31
MgO	11.90	11.97
CaO	11.54	11.52
Na_2O	1.30	1.32
K_2O	0.86	0.85
total	97.96	98.35
Cation numbers on the basis of 23 oxygen		
Si	6.888	6.917
Ti	0.068	0.074
Al	1.37	1.39
Fe	2.213	2.137
Mn	0.040	0.038
Mg	2.655	2.651
Ca	1.851	1.830
Na	0.377	0.379
K	0.164	0.162
total	15.626	15.578

5/ *Muscovite-biotite geothermometer* (HOISCH 1989). The pressure data, needed for the calculation of the muscovite-biotite geothermometer, were obtained from the plagioclase-biotite-muscovite-garnet geothermo-barometer (GHENT and STOUT, 1981). The data, obtained from the muscovite-biotite geothermometer give a temperature range between 542 and 675 °C. These values are mostly higher by 3—93 °C than those provided by the garnet-biotite geothermometer, with one exception in the case of the Darány-Ny-1 sample where the garnet-biotite geothermometer gives higher temperature, by 23—50 °C.

All of the temperature and pressure data, obtained from the geothermometers and geobarometers listed above are summarized in Table 7. The *Fig.3.* shows a comparison of data provided by the different geothermometers and geobarometers including those published by ÁRKAI (1984) and ÁRKAI *et al.* (1985). In the case of single geothermometers (like the garnet-biotite geothermometer and the muscovite-biotite geothermometer) and geobarometer (like the plagioclase-garnet-Al_2SiO_5-quartz geobarometer) the obtained data were plotted with pressure or temperature data calculated from other methods from the same sample. The combination of the pressure and temperature data are listed in the figure caption.

TABLE 7.

Summary of p—T data provided by different geothermo-barometers.
Pressure and temperature conditions, obtained from different geothermometers and geobarometers

Locality	T_1	T_2	T_3	P_1	P_2
Kutas—2	558	539	542	650	0
Kutas—2	0	0	559	0	500
Víz—É—1	600	583	0	703	747
Víz—É—1	615	598	628	678	626
Kkút—5. 1115	595	572	611	845	817
Kkút—5. 1115	660	639	599	774	760
Szta—2	585	563	641	890	906
Szta—2	630	605	630	900	915
Szta—2	630	607	675	890	887
Kkút—7	600	579	672	757	684
Kkút—7	625	604	612	770	717
Dar—Ny—1	685	666	616	820	914
Dar—Ny—1	662	642	619	810	847
Kkút—5. 1148.5	605	587	597	740	718
Kkút—5. 1148.5	650	630	0	830	847
Barcs—Ny—5	605	575	0	1030	0
Barcs—Ny—5	620	590	0	920	0
Hedrehely—2	520	0	0	350	0
Hedrehely—2	530	0	0	300	0

O not determinable, because the composition of the determined minerals is out of the required range.
T_1, P_1—plagioclase-biotite-muscovite-garnet geothermo-barometer (GHENT and STOUT 1981).
T_2—garnet-biotite geothermometer (FERRY and SPEAR 1978).
T_3—muscovite-biotite geothermometer (HOISCH 1989).
P_2— plagioclase-garnet-Al_2SiO_5-quartz geobarometer (GHENT 1976).
The pressure (P_1) and temperature (T_1) data of the Hedrehely—2 (Hed—2) sample were provided by the hornblende-plagioclase geothermo-barometer (PLJUSNINA 1982).

SUMMARY

The pressure and temperature data provided by the different geothermometers and geobarometers mostly refer to the first metamorphic event, except for those obtained from the hornblende-plagioclase geothermo-barometer. There is no considerable difference between the datasets provided by different methods. Most of the temperature data fell within the range of 570 and 630 °C. It is a little bit higher than the interval between 510—600 °C, published by ÁRKAI (1984) and ÁRKAI *et al.* (1985), but it is still in a good agreement with the mineral assemblage. The different geothermometers had almost the same difference between the minimum and the maximum temperature values with a little shift to higher temperatures in the following order: the garnet-biotite, then the muscovite-biotite and finally the plagioclase-biotite-muscovite-garnet geothermometer. The relatively great difference between the minimum (539 °C) and maximum (685 °C) temperature can be

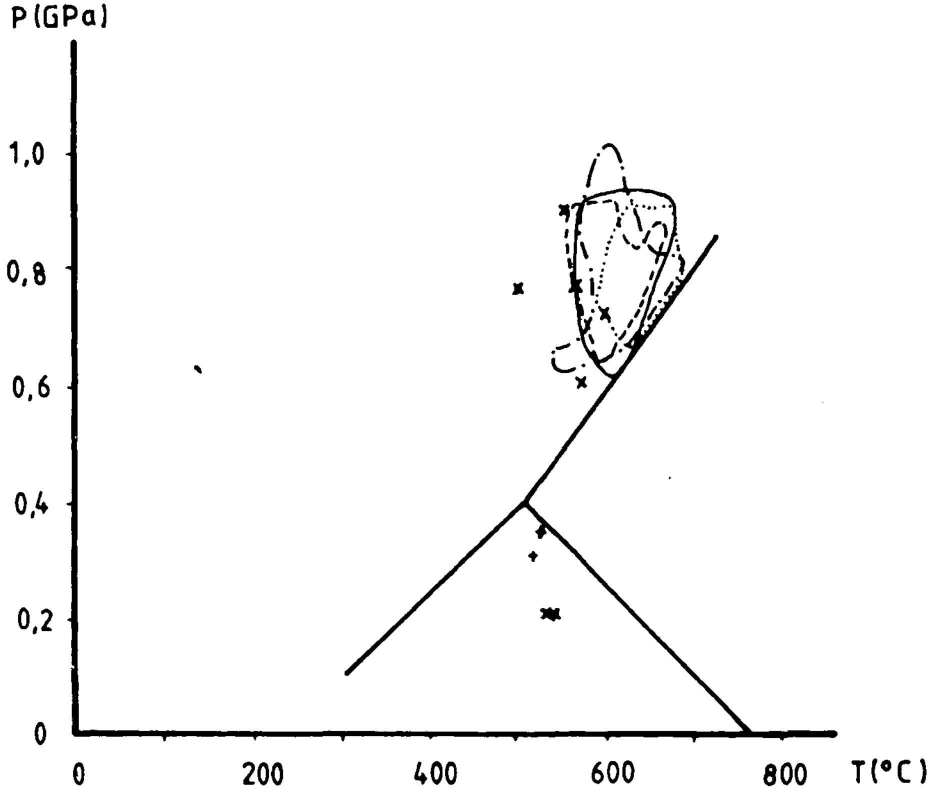

Fig. 3. Summary and comparison of p—T data provided by different geothermometers and geobarometers. See text for details, and Table 7. for more legends.

——— p—T interval, plotted from $P_2 - \frac{T_1 + T_2}{2}$

—.—.— p—T range, obtained from the plagioclase-biotite-muscovite-garnet geothermo-barometer (GHENT and STOUT 1981).

...... p—T field provided by T_3-P_1

— — — p—T field drawn from $T_2 - \frac{P_1 + P_2}{2}$

+ data obtained from hornblende-plagioclase geothermo-barometer (PLJUSNINA 1982)

x geothermo-barometric data published by ÁRKAI (1984) and ÁRKAI *et al.* (1985).

The Al_2SiO_5 stability fields are after HOLDAWAY (1971)

explained as original differences in the metamorphic grade, though there is no systematic change either in the pressure or in the temperature of the first metamorphic event. The pressure seems to be less uniform than the temperature. It varies highly from 500 Mpa to 1030 Mpa. ÁRKAI *et al.* (1985) had the same observation with a range between 590 and 890 Mpa, both in the Somogy-Dráva Basin and in the other parts of the crystalline basement of the Pannonian Basin.

The mineral equilibria and the available geothermo-barometric data give support to two possible conclusions:

1/ The temperature of the first metamorphic stage was quite uniform (mainly between 570 and 630 °C), and it was the pressure which had greater variation.

2/ The different samples with different recorded pressures represent equilibrium under different pressure conditions during either the top or the retrograde stage of the first metamorphism. In this case the p—T path may have been quite steep.

The pressure and temperature data of the first metamorphism do not seem to support the possibility of the formation of the sillimanite during this time, because neither of the p—T data was plotted within the stability field of the sillimanite.

The pressure and temperature conditions of the second metamorphic event is determined mainly by mineral equilibria. There are only two geothermo-barometric data determined by ÁRKAI *et al.* (1985), for the metamorphic terrain near the Somogy-Dráva Basin (534—536 °C, and about 200 Mpa), and two provided by this study for the Somogy-Dráva Basin (520—530 °C and 300—350 Mpa). These data indicate low pressure and temperature near the beginning of the medium grade. The pressure data are consistent with the observed andalusite-staurolite-sillimanite, and the andalusite-cordierite-sillimanite critical mineral assemblage, but the temperature was probably higher than those obtained from the hornblende-plagioclase geothermo-barometer. In compliance with the appearance of the sillimanite in the mineral assemblage, the temperature may have been about 600 °C (*Fig.* 2).

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