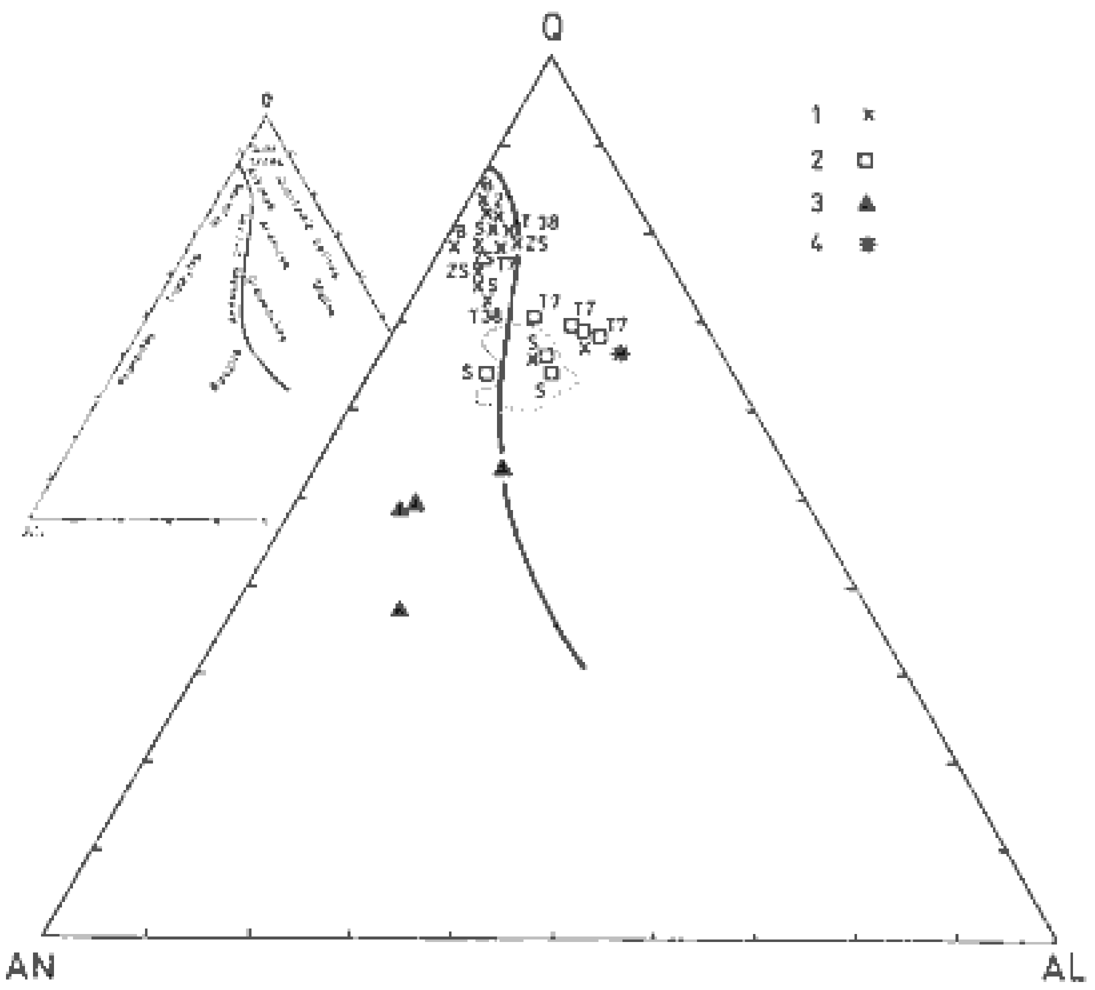

Fig. 7.10 Classification diagram after Weisbrod (1976). 1 - acid granulites, 2 - subacid, 3 - pyroxene-bearing granulites, 4 - average shales.

8. P-T evolution of granulite complex

8.1 P-T CONDITIONS OF METAMORPHISM

8.1.1 Crustal assemblages

P-T conditions of metamorphism were calculated using conventional geothermometers and geobarometers.

Close-to-peak metamorphic pressure was determined using the net-transfer equilibrium in the assemblage garnet - plagioclase - Al-silicate - quartz. Calibration of Newton & Haselton (1981; NH81), employing thermodynamic data of Cressey et al. (1978) and Goldsmith (1980), and model of Newton et al. (1980a) for Pl is preferred. Koziol & Newton (1988, 1989) and Powell & Holland (1988) calibrations give slightly higher pressures (by 0.6-0.7kb).

Retrograde pressure evolution is constrained by phengite barometry for the limiting assemblage Kfs-Phlog-Qtz (Massone & Schreyer 1987).

The empirical method of Schreurs (1985) based on the Ti/Al^{VI} ratio in biotites was used to define the temperature range of Bt stability, and Fe-Mg partitioning between garnet and biotite - calibrations of Ferry & Spear (1978), Hodges & Spear (1982) and Indares & Martignole (1985b) - for more precise quantification. Grt-Cpx Fe-Mg exchange thermometry (calibration of Powell 1985) was used for derivation of T in pyroxene-bearing rocks.

Two-feldspar thermometry on the pairs of alkali feldspar (AF) - plagioclase (Pl) both coexisting in equilibrium was done on several samples, making use of the ternary thermometer calibrated by Fuhrman & Lindsley (1988). In order to ascertain the original feldspar composition, an electron beam of 20 micron diameter was used in perthites - such a diameter is sufficient to include both AF and Pl phases, because perthites are not very coarse grained.

A. Biotite, Grt-Bt thermometry

Biotite inclusions in garnet, Bt in the rock matrix, biotite crystallizing in the foliation and biotite at garnet and kyanite rims were analysed.

From the plots in the Al^{VI}/Ti diagram of Schreurs (1985; Fig. 8.1) is obvious, that inclusions of biotite in garnet are of two types: higher-T and lower-T ones; the latter are probably of secondary character, as their Ti contents is commonly similar to late retrograde biotites. Biotites in the rock foliation record medium to high temperatures (even T > 750°C). Static crystallization of biotites in the rock matrix occurred under 650-750°C. Biotites at garnet rims display wide range of temperature (even T > 750°C), consistent with various degree of retrograde reequilibration by Fe-Mg exchange between garnet and biotite during cooling (cf. Schreurs 1985). 'Retrograde' biotites associated with garnet and kyanite are the lowest-temperature ones. A special case represent biotites from sample of garnet-kyanite migmatite gneiss, forming intergrowths with muscovite, and recording very high temperature.

Grt-Bt thermometry (Tab. 8.1) confirmed the high temperature character of the biotite in the matrix as well as in the foliation. Since the majority of biotites analysed has high Al and/or Ti contents and some garnets of granulites studied are too rich in Ca, calibrations employing corrections for these elements should be used instead of Ferry and Spear (1978; FS78) one, which is constrained to low-(Ti+Al) biotites and low-(Ca+Mn) garnets.

The Hodges & Spear (1982; HS82) calibration that accounts for Ca and Mn in garnet gives results rather consistent with the FS78 calibration for Ca-poor garnets; however, for Ca-rich garnets, the resulting T is by as much as 80°C higher, which is considered to be unrealistic.

Indares & Martignole (1985b; IM85) calibration containing corrections on Ti and Al in biotite, amounts of which are often quite high in studied rocks, was used for samples containing biotites with specific substitution (see IM85). This method gives relatively high T for pairs with Ca-rich garnet, and relatively low for those with Al and Ti-rich Bt. In the majority of the cases, the FS78 calibration is considered to give the most reasonable results.

Scatter of temperatures obtained by various methods for biotite in the foliation, i.e. in the deformed rocks, is lower than in the undeformed ones (static Bt). This reflects the catalytic effects of deformation on the rate of reequilibration of mineral composition. The wide range of temperatures in undeformed rocks then indicates a disequilibrium resulting from insufficient reequilibration. Similar phenomena were observed by Lardeaux et al. (1986) in eclogite.

High-Ti biotite inclusions might record prograde temperature, especially in case that they display a 'prograde' zonation (MgO decrease from core to rim). However, for inclusions with an opposite zonation trend, the effects of retrograde Fe-Mg reequilibration (exchange between Grt and Bt) have to be taken into account. In such a case, the Fe-Mg distribution between garnet and biotite inclusions does not reflect the prograde, garnet-forming process, but rather the retrograde one. This is supported also by generally increasing values of Mg# in analysed biotite in the order matrix biotite < biotite adjacent to garnet < Bt inclusion in garnet. According to Petrakakis (1986), recorded T than corresponds to

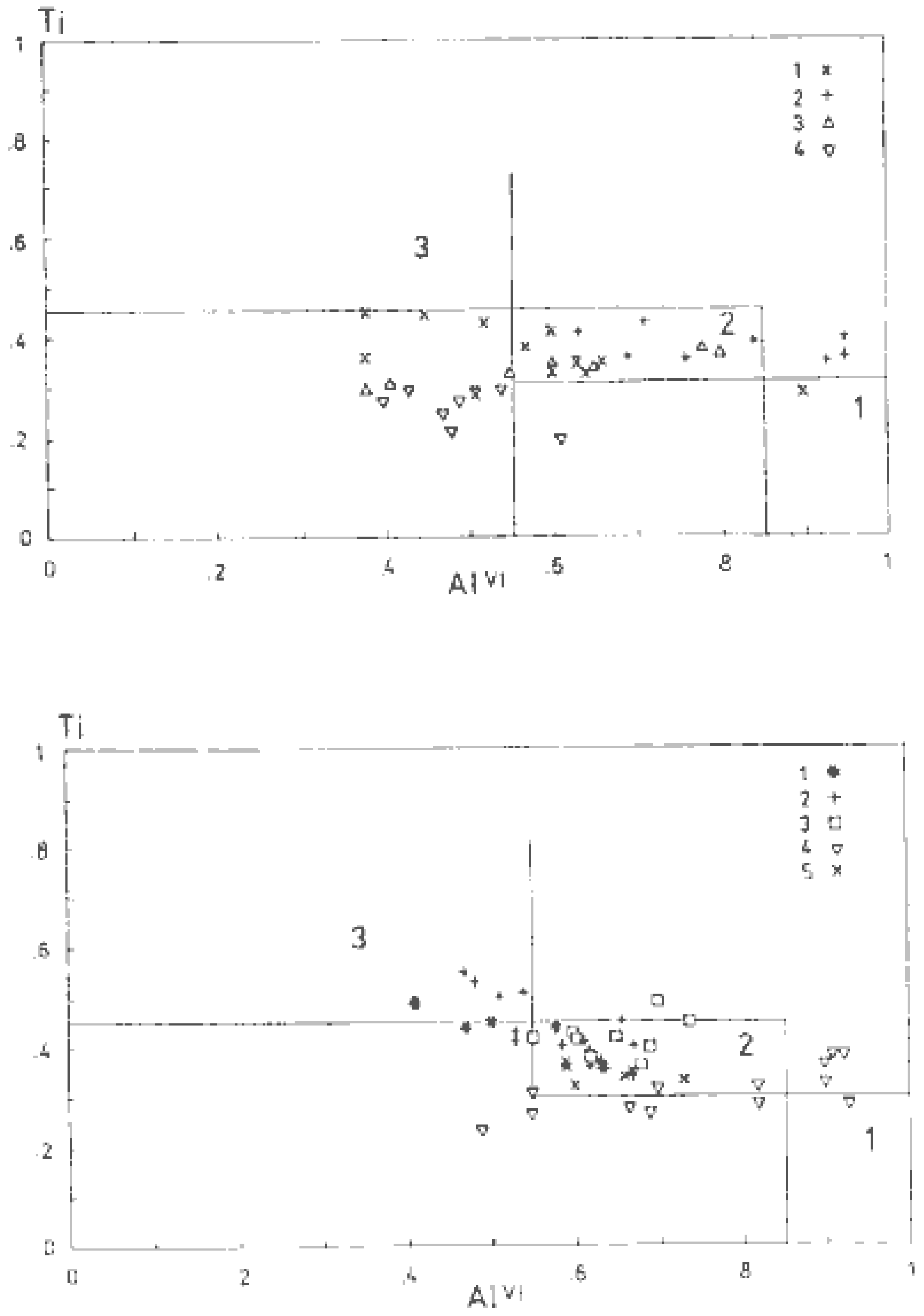

Fig. 8.1 Schreurs (1985) Ti/Al diagram for biotites. Field 1 - T<650°C, field 2 - 650-750°C, field 3 - T>750°C. a: 1 - large Bt flakes in the matrix of kyanite-bearing orthogneiss; 2 - biotite in the foliation; 3 - biotite in the matrix of granulites; 4 - low-grade biotite (garnet rims, matrix); 5 - medium-grade biotites (garnet rims). b: 1 - biotite at garnet rim, 2 - biotite in the foliation, 3 - high-grade biotite inclusions in garnet, 4 - low grade biotites in garnets.

either homogenization temperature or local closure temperature during cooling of the rocks, the latter being favoured by similar values obtained for biotite inclusions and biotite in the matrix (Indares & Martignole 1985a).

In any case, the highest temperature from the biotite inclusions (i.e. 750°C) represents the lower limit of the peak metamorphic temperature. Pairs garnet rim - matrix biotite represent retrograde temperatures. Composition of garnet and biotites at their rims (X_{Fe}^{Grt}, X_{Fe}^{Bt}) constrain the reaction Grt+Kfs+H_2O = Bt+Ms+Qtz to the high-T part of di-variant field (Vielzeuf 1984); therefore, the garnet breakdown occurred under high temperatures. The temperature might even have increased after the metamorphic (pressure) peak. Temperatures derived for some pairs with biotite in the foliation and garnet rims (which is especially the case of 'prograde'-zoned garnets) are too high (up to 840°C/10kb), even above the curve of water-absent melting for biotite-bearing assemblages; this would support the idea of dehydration melting in the area.

Table 8.1 Results of garnet - biotite thermometry

Sample	Locality	T (10/15kb)	K_D	Calibration	Note
162	Stráž	830/852	0.296	IM85,FS78	Grt rim - Bt foliation
10a	Stráž	841/866	0.376	IM85	ditto
41a	Kamen.	666/688	0.256	IM85	Grt rim - Bt matrix
		806/829	0.288	FS78	ditto
13a	Želina	465/481	0.104	FS78	ditto
28	Kadaň	741/763	0.253	FS78	ditto
11A	Zásada	742/764	0.254	FS78	ditto
T7,133m	Třebívlice	728/747	0.205	FS78	Bt inclusion in Grt
		706/722	0.234	FS78	ditto
		587/606	0.172	FS78	ditto
		725/750	0.255	FS78	Bt at Grt rim
RPZ31, 314m	Mrsklesy	665/685	0.213	FS78	paragneiss, matrix Bt
		750/772	0.258	FS78	Grt-Bt foliation

B. Garnet-clinopyroxene thermometry

Clinopyroxene grains have rather homogeneous composition. As they are generally separated from Grt by the matrix, the retrograde exchange was probably not effective.

Values of up to 942°C were calculated for a pair with Grt, the core of which has extremely high Mg/Fe. Remaining values ranging from 796 to 855°C represent probably cooling temperatures (Tab. 8.2).

C. Two-feldspar thermometry

A wide spread of temperatures derived by two-feldspar thermometry was found in granulites (Tab. 8.3). As evidenced by discordance in three calculated temperatures (T_{Or}, T_{Ab}, T_{An}), there is a certain degree of disequilibrium in the majority of the feldspar pairs. Reequilibration of the system is reflected also by recrystallization in the matrix of majority of the samples.

Highest T give pairs with perthite having high Ab+An/Or ratios, i.e. with the most equal proportions of Ab, An and Or. Temperatures above 800 °C were derived for a coarse-grained sample from T7 borehole. In this case, deviation from the equilibrium reflects low K contents in Pl, caused either by underestimated exsolution of Or from Pl, or by Or loss. The latter is typical for slowly cooled rocks (FS88).

It is assumed that resulting temperatures do not define the metamorphic peak; they rather reflect various stages during the retrograde evolution (recrystallization of the rocks). Some T can be underestimated due to presence of the extragranular exsolution of Ab from AF and Or from Pl. A few test analyses did not confirm any exsolution from Pc.

D. GASP barometry

Garnets of granulites containing the GASP assemblages commonly display retrograde Ca zoning. Their core composition should therefore record the peak metamorphic pressures. This is not the case of garnets with preserved 'prograde' zonality, with Ca values corresponding to the peak pressures situated apart from the centre. The assumption that plagioclase forms by exsolution from original ternary feldpar implies that the calculated pressures should be considered as minimum values.

Garnets from subacid rock composition represent more reliable basis for GASP barometry; acid rock garnets are generally too poor in Ca, which brings about larger uncertainties in pressure estimates (Essene 1982, Newton & Haselton 1981).

Combination of various portions of large garnet with inlusions of plagioclase allowed derivation of pressures that indicate decompression of the order of 2-3 kb. Ca contents of garnets in the matrix (Grt II) are consistent with even lower pressures. For the Ohře crystalline area and the České středohoří Mts. basement, the highest pressures of 17kb are characteristic. In strongly deformed rocks of the zone Balhuňov-Málkov and RPZ31 borehole, however, the resulting pressures are even higher (up to 21, resp. 19 kb)(Tab. 8.4).

E. Phengite barometry

Muscovite in the foliation of the well-deformed rocks of the zone Blahuňov-Málkov crystallized under a pressure of 7 kb (for 700°C; 3.26 Si p.f.u.); pressures of 10-11kb (for 700°C) can be inferred for the Ms foliation of area A sample (as much as 3.34 Si p.f.u.). Si contents of muscovites from the foliation of the RPZ borehole rocks (area C) are 3.13-3.19 p.f.u; combined with the results of garnet-biotite thermometry (T=600-700°C), it is consistent with the pressure of 4-5 kb. Pressures inferred for samples without biotite (for 3.13-3.21 Si p.f.u.) are minimum values because of the absence of the limiting assemblage (Massone & Schreyer 1987).

Contents of 3.1-3.2 Si p.f.u. in retrograde muscovites imply pressures of 4-5 kb for 650°C. The lowest values of Si were found in Ms forming at the expense of Ky (3.1 Si p.f.u.).

Ti contents in muscovite in granulites (0.12-0.19 p.f.u.) are characteristic of high metamorphic grade (Guidotti 1984).

8.1.2 Mantle assemblages

a) Garnet lherzolites and dunites

Results of geothermobarometry in lherzolites are given in Tab. 8.5. Calibrations that reproduce the best P-T conditions of experiments made on 'natural' multicomponent garnet lherzolites as follows from studies of Carswell & Gibb (1987) and Brey & Köhler (1990) are emphasized. All Fe was taken as Fe^{2+} (cf. Carswell & Gibb 1987). Calculations were made for 30 kb pressure.

The Ellis & Green (1979) calibration is said to overestimate for T < 1300-1400°C (by 70°C for 900°C; Brey & Köhler 1990). Higher T resulting from Grt-Cpx vs. Grt-Opx thermometry can be caused by more rapid equilibration in the Grt-Opx pair; at the same time, ignoring of Fe^{3+} implies that the calculated temperatures should be regarded as minimum ones (Harley 1984). Brey & Köhler (1990) conclude, that Harley's thermometer is slightly

Table 8.2 *Results of garnet - clinopyroxene thermometry*

Sample	T (17kb)	lnK_D	XCa^{Grt}	Note
T38, 329m	805°C	1.70	0.238	
	800°C	1.68	0.225	Grt rim
	833°C	1.72	0.275	small garnet
	944°C	1.52	0.319	Fe-rich Grt core
95b/a Stráž	930°C	1.55	0.316	Cpx (+Pl) inclus. in Grt
	804°C	1.58	0.170	Grt rim
	769°C	1.73	0.207	Grt rim
	795°C	1.99	0.322	Grt core

Table 8.3 *Results of two-feldspar thermometry (temperatures in °C)*

Sample	T(5kb)	T(10kb)	Rock texture
T7,133m	566 *	618 #	fine-grained recryst.
	$ c	754 $ a	
T7,203m		766 $ a	coarse-grained
T7,437.4m	430 *	490 #	fine-grained recryst.
	575 *	637 *	
T7,455.7m	777 $ b1	840 $ b1	coarse-grained in rex
	831 $ b1	890 $ b1	
	710 $ a	778 $ b1	
	724 $ a	794 $ a	
Xen.Sviňky	440 *	470 *	polygonal fine-grained
Xen.Újezd	579 $ a	664 #	fine-grained recryst.
	583 #	636 #	larger Pl adj. to Ky
8a-Stráž	757 $ a	835 $ a	medium-grained
	732 $ a	807 $ b1	
63a-Stráž	640 #	641 #	medium-grained
11A-Zásada	515 *	564 #	coarse-grained
12C-Zásada	540 #	741 #	very coarse-grained
	685 $ b1	717 $ b1	
41-Kamenec	565 #	609 *	coarse-grained

* - equilibrium # - close to equilibrium $ - disequilibrium a-c

Table 8.4 *Results of GASP barometry*

Sample	P (kb/800°C)	Note
6a Stráž	16.5	Pl inclusion (core) in Grt I
	13.4	Grt I rim - matrix Pl
6 Stráž	15	Pl inclusion in Grt I
10a Stráž	16.9,15.4	Grt I core,rim - matrix Pl
162 Stráž	16.5,14.7	ditto
	17.3	Grt I core - matrix Pl
8a Stráž	14.2	dtto
	12.4	Grt I rim - matrix Pl
63a Stráž	16.5	Grt I core - matrix Pl (low Ca)
	13.4	Grt rim - matrix Pl (low Ca)
40 Kamenec	9.5-11.4	Grt II - matrix Pl
41 Kamenec	14.8	Grt I - matrix Pl
70 Stráž-N	10.1	dtto
28 Kadaň	12.5-13	dtto
11a Mikulov	10,14.8	Grt rim,core (low Ca)
T7 (133m)	16.9	Grt core - matrix Pl
T7 (455.7m)	15.9,16.4	dtto
RPZ31	14.8,16.1	Grt core,rim - matrix Pl (low Ca)
	16.9 - 18.5	small Grt - matrix Pl (low Ca)
73 Blahuňov	20.7,21.9	Grt core,rim - matrix Pl (low Ca)
75a Zelená	20,22.4	Grt core - matrix Pl

overestimating for low temperatures, which might be the case here when seeing to other recommended calibrations.

Calculated temperatures are relatively low, when compared to those of other Variscan peridotites (cf. Medaris & Carswell 1990). The P-T data given above correspond at best to the second evolution stage of mantle assemblages of Carswell (1991). Existence of the HT stage I (ibid.) might be indicated by Opx, Cpx and Ol porphyroclasts preserved in dunitic compositions; however, no spinel pre-dating garnet was observed. Further analyses are needed to document presence of this stage.

Relative homogeneity of central part of garnet grains with some Fe enrichment and Mg+Ca depletion of their rims reflect homogenization of garnet lherzolites under high P-T conditions, and successive partial reequilibration and decompression (Medaris & Wang 1986 in Medaris & Carswell 1990).

Thermobarometry in dunites (Tab. 8.6) is based on average analyses of Fiala & Paděra (1977). The application of the Brey & Köhler (1990) calibration of Opx-Cpx thermometer results in higher T (this work) than Grt-employing calibrations used by Medaris & Carswell (1990). This new result is comparable to T derived for Grt core-Px pairs in lherzolites, while the results of other calibrations correspond rather to Grt rim - Px pairs. Underestimation of T using calibration that employ garnet can be caused by high Cr contents in Grt in dunites.

Table 8.5 *P-T conditions of metamorphism of garnet lherzolite (borehole T7, depth 303m)*

	Calibration	Temperature (°C)
Grt-Ol	**O'Neill & Wood (1979)**	916, 985 (Grt core)
Grt-Opx	**Harley (1984)**	942, 1022 (Grt rim,core)
Grt-Cpx	**Powell (1985)**	914, 990 (garnet rims)
	Ellis & Green (1979)	934, 1006 (ditto)
	Mori & Green (1978)	921, 1007 (ditto)
Cpx-Opx	Wells (1977)	893, 897 (neoblast cores)
	Wood & Banno (1973)	1002, 1006 (ditto)
-	**Brey & Köhler (1990)**	961, 951 (ditto)
Opx	**Brey & Köhler (1990)**	921, 947
		Pressure (kb)
Grt-Opx	**Nickel & Green (1985)**	27.7, 30/900°C
		32.6, 35/1000°C
Ol-Cpx	**Köhler & Brey (1990)**	35.9/1000°C

Composition of coexisting garnet II and Cr-rich spinel in corona around Grt I was used to estimate the P of the third evolution stage of dunites. Increased amounts of any minor element make the chemical system of dunite more complex. Due to high Cr content in the rocks, the univariant reaction marking the transition from garnet to spinel peridotites becomes a multivariant field. The width of the field increases with increasing Cr/Cr+Al ratio - by ca 2.8 kb with 0.1 X_{Cr} (O'Neill 1981). Pressures of 28-29 kb were derived, making use of Benoit & Mercier (1986) diagram (Fig.8.2) indicating decompression of the order of ca 4kb.

Temperatures of this stage, determined from GrtII and PxIII of this corona are ca 100°C lower than those for the stage II. However, two-pyroxene-based temperatures and pressures for the two stages are quite close, due to the almost identical composition of pyroxenes of the second (matrix) and third (corona) generation.

b) Garnet clinopyroxenites

Garnet-clinopyroxene thermometry yields temperatures ranging between 830° and 950°C (Tab. 8.7). Ellis & Green (1979) calibration provides temperatures systematically higher (by c. 15°C) than the calibration of Powell (1985).

Pair garnet - clinopyroxene inclusion in garnet gives two values differing by c. 100°C from each other. This results from the clinopyroxene zonation - enrichment in Fe and depletion in Mg in the core, corresponding to decrease of temperature during the crystal growth. The highest T (~950°C) was derived for the pair Cpx inclusion in garnet - Grt interior. As X_{Mg}^{Grt} is lower than the

Table 8.6 *P-T conditions of the two stages of dunite evolution (borehole T7, depth 273 and 315m)*

		Stage II		Stage III
		MC90	this work	this work
Grt-Ol	O'N & W (1979,80)	859±1		
Grt-Opx	Harley (1984)	939±1	969	822.5
Grt-Cpx	Powell (1985)	922±24	925.9	819
Opx-Cpx	Br & Köh (1990)		987.5	963.1
Opx	Br & Köh (1990)		921	921
	Nic& Gr (1985)	32.7±2.1		
	Ben & Merc (1986)			28-29
	Köh & Brey (1990)		27.5/ 1000°C	27.9/1000 °C

Table 8.7 *Results of garnet-clinopyroxene thermometry in garnet pyroxenite (borehole T7, 404m)*

T (°C/30kb) (Powell 1985)	note
937	Grt internal part - core of Cpx inclusion
832	Grt internal part - rim of Cpx inclusion
843	Grt rim - Cpx matrix
921	Grt rim - Cpx matrix
883	Grt rim - Cpx matrix
830	Grt rim - Cpx matrix

maximum value obtained for this rock garnets, this temperature is considered as a minimum one. Similar T was obtained for the pair Grt rim - matrix Cpx. Other temperatures correspond to retrograde reequilibration.

Jadeite contents of omphacite is 27.7-32.6 mol %, without any dependence on core-rim composition. Temperatures of 950°C correspond to the pressure at least 17 kb, using the PT diagram for the system Di-Jd-SiO_2 of Gasparik & Lindsley (1980), based on data of Holland (1979, 1980) and Kushiro (1969) (Fig. 8.3).

8.2 P-T paths and their siginificance

8.2.1 Crustal assemblages

The peak of metamorphism represented by granulite stage I lies at pressures of 15-17 kb (NH81). Composition of biotites included in garnets are consistent with temperatures of 600-750°C; the highest T calculated by the FS78 thermometer is 750°C/15kb. Rocks containing homogeneous garnets must have experienced temperatures exceeding 600-650°C, given by Andersen and Olimpio (1977) as the blocking temperature for the diffusion of ions in garnet. Temperatures above 800°C were obtained by two-feldspar thermometry (Tab. 8.8). For pyroxene-bearing granulites, temperatures as high as 944°C, and cooling T up to 833°C, were derived.

Pressures as high as 18.5 kb were calculated for the RPZ31 borehole rocks, and 22 kb for the Blahuňov-Málkov granulites. These results can be subject to some imprecissions due to the low Ca contents in Pl and/or garnet. By analogy with the results of K.Rötzler (1992) for similar occurrences in the Eastern Krušné hory Mts., temperatures at the pressure peak could have been lower in the area B than in the two other ones.

The high T stage was followed by certain decompression of the order of ca 3 kb, based on barometry on Pl inclusions in garnet. Pressures corresponding to GtII crystallization, therefore the granulite stage II and deformation I, correspond to 13-14 kb. Decompression is also documented by Al_2O_3 decrease from core to rim in clinopyroxenes of pyroxene granulites (Anovitz 1991).

The assemblage Grt-Cpx-Pl-Qtz preserved in these rocks place them in the interval between high pressure (Grt-Cpx) and low pressure (Opx-Pl± Spl) fields. In the P-T space, boundary between these two fields is closely related to the kyanite/sillimanite transition for T between 600 and 850°C, as defined by Green & Ringwood (1967). The decompression occurred under still high T - formation of both garnet and kyanite-bearing melts observed in the rocks indicates temperatures close to 800°C and P corresponding to ca 13 kb (LeBreton & Thompson 1988).

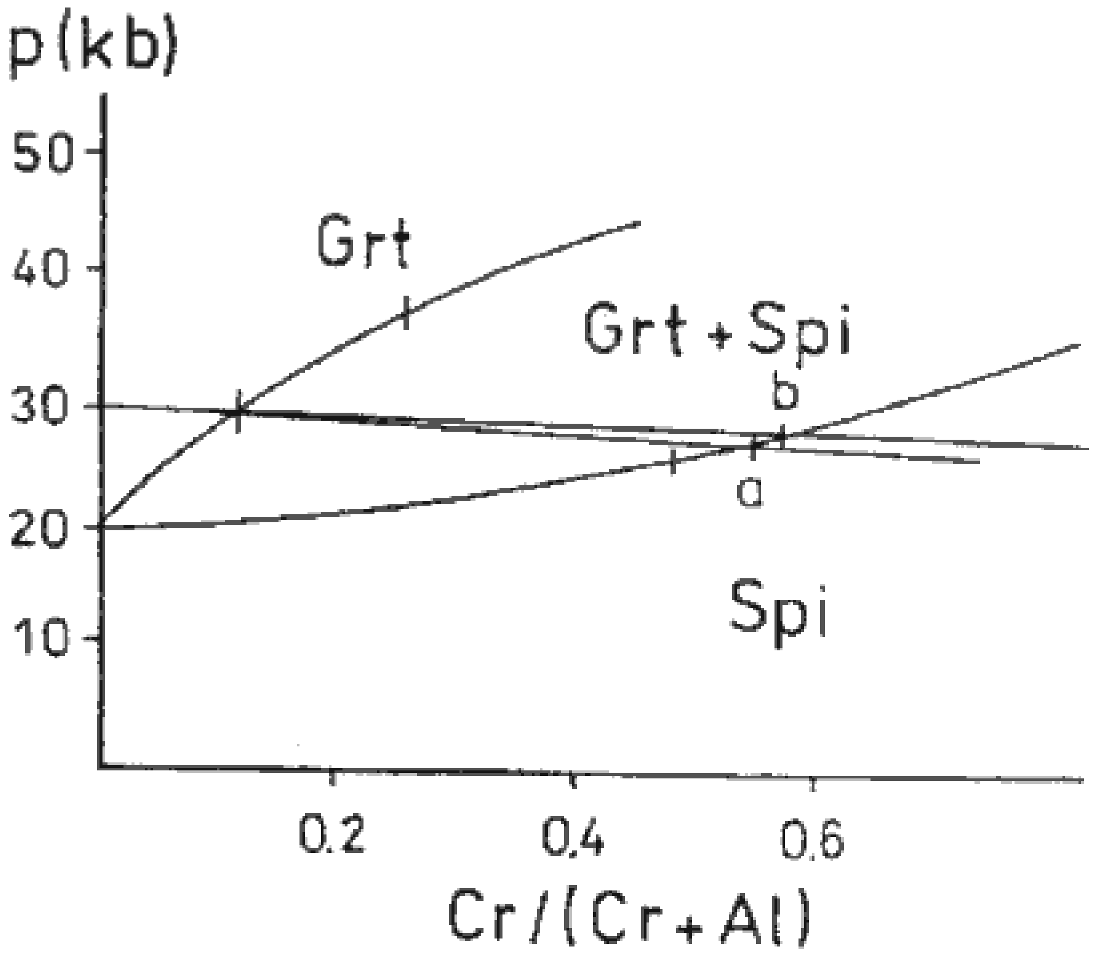

Fig. 8.2 *Barometry for coexisting spinel and garnet in peridotite. According to Benoit & Mercier (1985).*

Persisting high temperature conditions are documented also by the composition of the stage III biotites (Vielzeuf 1984, see above). The Ti/AlVI ratios of biotites in the rock foliation correspond to T even above 750°C; garnet-biotite thermometry resulted in 800-850°C. Static biotites plot in the field of 600-750°C, Gt-Bt thermometry resulted in 670-730°C (IM), resp. 730-830°C (FS).

Muscovite composing together with biotite the rock foliation contains 3.34 Si p.f.u., which corresponds to 10-11 kb /700°C. It probably crystallized later, as its stability is limited by T~700°C

Table 8.8 *P-T conditions of metamorphism*

GRANULITES			
GRANULITE STAGE I			
Biotite inclusions	600-750°C (S85)	GASP	15-17 kb (NH81)
Gt-Bt	750°C (FS78)		
Gt-Cpx	800-930°C (P85)		
GRANULITE STAGE II			
melting	800°C (LBT88)	GASP	13-14 kb (NH81)
STAGE III (HYDRATION)			
Bt foliation	750°C (S85)	GASP	10-11 kb (NH81)
Gt-Bt	800-850°C (IM85)	Phengite	10-11 kb (MS87)
Static Bt	600-750°C (S85)		
Gt-Bt	670-730°C (IM85)		
Late hydration			
Biotite	600°C (S85,FS78)	Phengite	4-5 kb (MS87)

T: Schreurs 1985 (S85), Ferry & Spear 1978 (FS78), Indares & Martignole 1985 (IM85), Powell 1985 (P85), Le Breton & Thompson 1988 (LBT88)
P: Newton & Haselton 1981 (NH81) , Massone & Schreyer 1987 (MS87)

(Massone & Schreyer 1989). Stage III biotite foliation is at places obliterated by Ky- or Grt-bearing undeformed partial melts, which indicates that dehydration melting in kyanite stability field was active after this deformational phase.

Further cooling is indicated by Grt-Bt and two-feldspar equilibrium temperatures below 600°C. Alternatively, development of the low-T biotite generation may result from later reactivation of the system at T below 600°C (Harley 1989). Low temperatures are documented by presence of titanite, which according to Hunt & Kerrick (1977) breaks down above 650°C, and zoisite, stable at temperatures of 200-600°C at 6 kb (Perkins et al. 1980).

The retrograde portion of the P-T-t path of granulites corresponds to initial isothermal decompression under low a(H_2O), that was followed by cooling accompanied by less significant pressures decrease, and increase of water activity. All the retrograde evolution proceeded in the stability field of kyanite (Fig. 8.4). This is supported also by stability of the association Zoi + Qtz, lying on the higher pressure side of the reaction (10). As defined by Newton et al. (1966) and Boettcher (1970), the reaction curve approaches the kyanite/sillimanite stability limit for T 600-800°C.

'Prograde' Ca zoning preserved in cores of some large garnet grains can be interpreted as a record of a pressure increase before the metamorphic peak, as also assumed by Pin & Vielzeuf (1988). High temperatures derived for pyroxene-bearing granulites can reflect HT crystallization of these rocks, intruding the complex in the lower crustal levels. For the south Bohemian granulites, this is indicated by absence of an older component indication in Sm-Nd zircon ages, contrasting to the felsic granulites (Wendt et al. in prep.).

Table 8.8 *(continued)*

PERIDOTITES					
STAGE I	HT?/HP				
STAGE II	neoblasts				
	lherzolite		dunite		Grt pyroxenite
2-px	893 - 961°C	28-35kb	988°C	33kb	
Opx	921 - 947°C		921°C		
Grt-Ol	916 - 985°C		859°C		
Grt-Opx	942 - 1022°C		939, 969°C		
Grt-Cpx	934 - 1007°C		922°C		830-950°C
STAGE III	Grt-Spl corona				
			dunite		
2-px			963°C	28-29 kb	
Opx			921°C		
Grt-Opx			823°C		
Grt-Cpx			922°C		

list of methods for peridotites (accentuated ones) given in Tab. 8.5 and 8.6

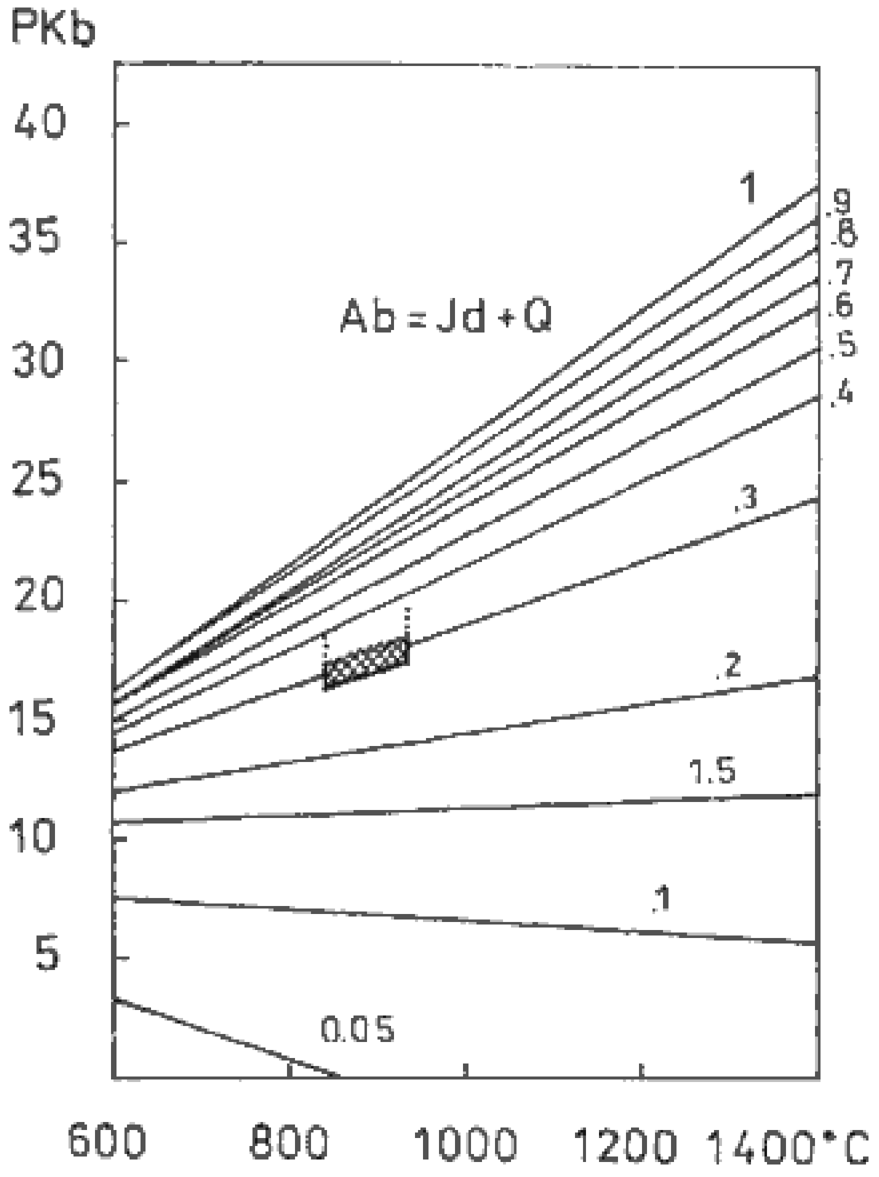

Fig. 8.3 *Barometry in eclogite. Borehole T7, 404m. According to Gasparik & Lindsley (1980).*

8.2.2 Mantle assemblages

Presence of large Ol and Opx porphyroclasts and the exsolution of spinel from clinopyroxene enclosed in large garnet grain (in dunite) may indicate higher T than calculated, which might correspond to the crystallization from the melt (c.f. Carswell 1991). However, no primary spinel was observed.

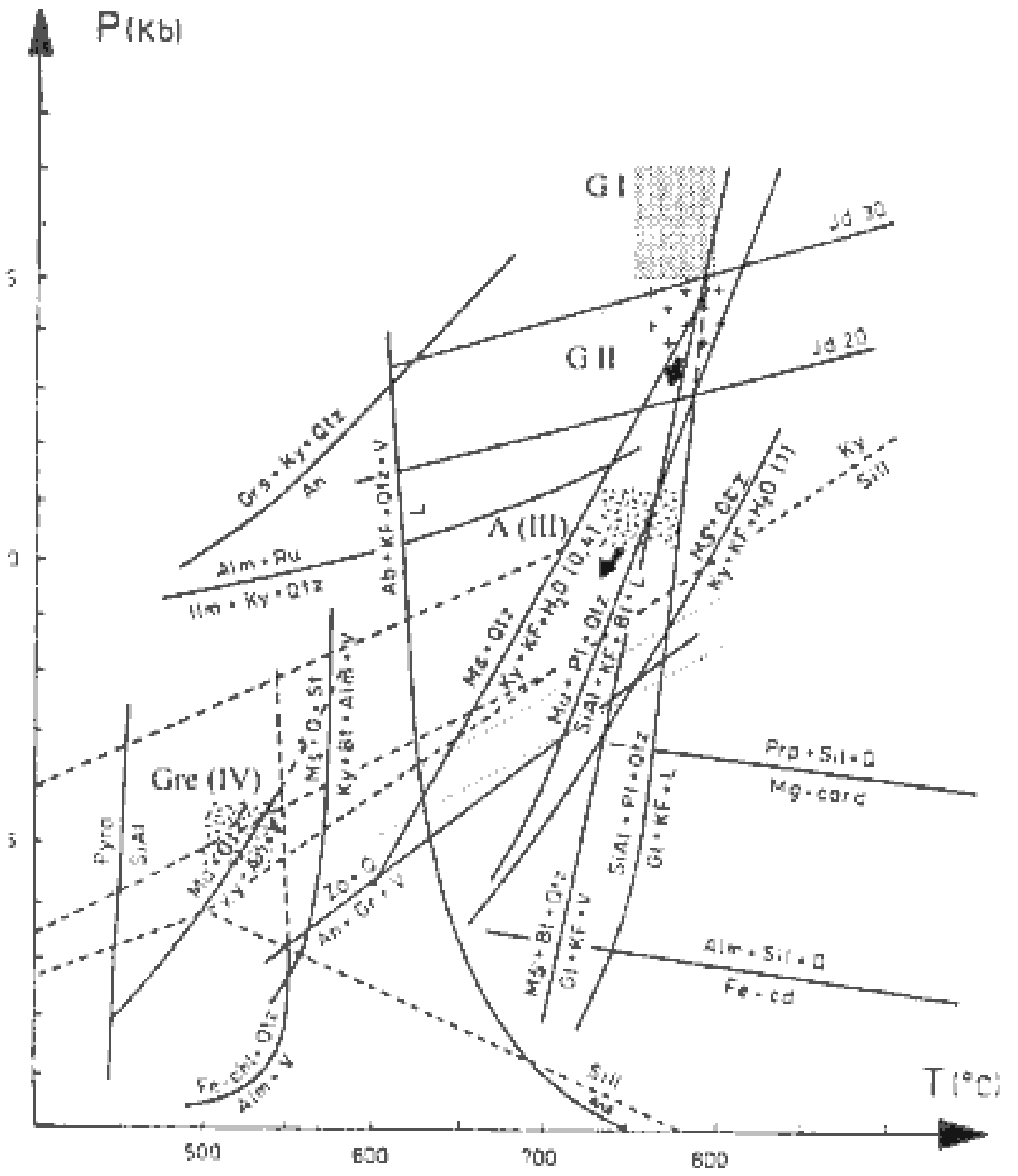

Fig. 8.4 P–T–t path of granulites. Al–silicate triple point according to Holdaway (1971). Reaction boundaries according to Vielzeuf (1984), Newton (1966), Koons & Thompson (1985), Hsu (1968), Chatterjee (1976), Thompson (1982), LeBreton & Thompson (1988), and Holdaway & Lee (1977). Phengite contents from Massone & Schreyer (1987), Jd contents from Gasparik & Lindsley (1980).

Garnet lherzolite stage (stage II; 'eclogite facies' of Carswell 1991) is characterized by temperatures of 859-1022°C and pressures of 28-33 kb (Tab. 8.8). These data represent minimum values, as mineral compositions might have undergone certain reequilibration during later cooling. 'Prograde' Mg zoning in central part of Grt in garnet pyroxenite could indicate prograde metamorphic conditions during the initial garnet formation.

Successive significant decompression is documented by formation of spinel-bearing coronas around garnets. Stage III (Grt+Spl coronas) is characterised by only slight pressure decrease (by 4-5 kb) and probably also some cooling. Presence of Spl-Opx-Cpx coronas (stage IV) places the rocks in the spinel stability field, with upper pressure limit of ca 20kb/1000°C (O'Hara et al. 1971). Additional analyses are needed to define precise pressures, which in case of a high Cr contents can be even higher than 20kb.

Striking is, that Spl coronas are absent in the rocks of lherzolitic composition, in contrast with the dunitic rocks. A viable explanation is that these structures were overprinted by the influence of intensive deformation and recrystallization - replaced by products of Opx, Spl and Ol breakdown reactions. This would be consistent with higher modal amount of Opx in lherzolites compared to dunites, and presence of chlorite ± amphibole ± talc rims around garnets in lherzolites.

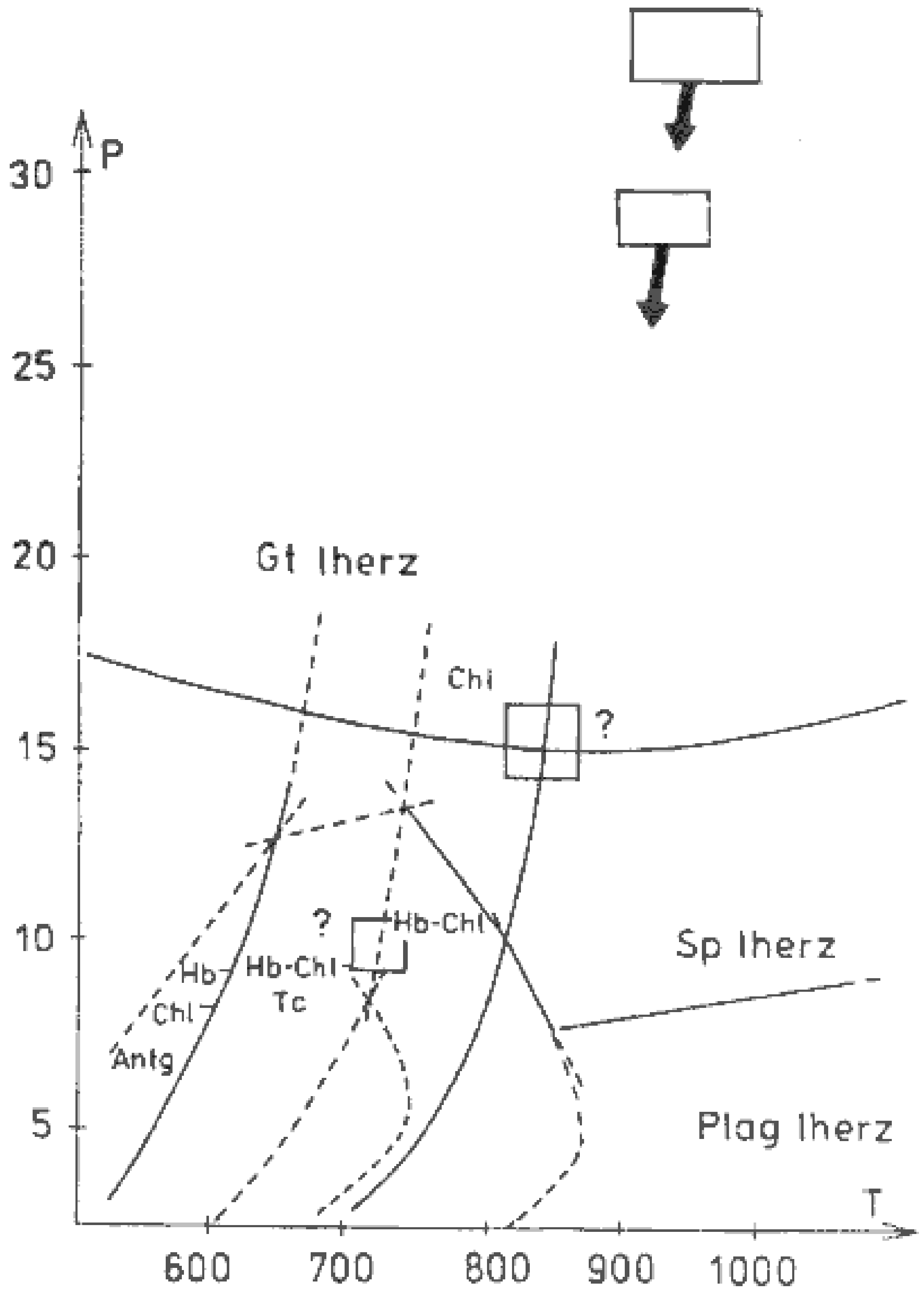

Fig. 8.5 P–T–t path of peridotites. Grid according to Jensen (1981).

P-T-t path of mantle assemblages is comparable to that of the crustal ones. It corresponds to initial near-isothermal decompression, followed by cooling under less significant pressure decrease (near-to-isobaric cooling)(Fig. 8.5).

9. Reconstruction of tectonometamorphic evolution

9.1 Interpretation of the P-T-t paths, tectonic implications

Calculated pressures of 17kb (~ 50km depth) suggest that the granulites studied were formed in the thickened crust. Moreover, isothermal decompression (ITD) paths are conventionally attributed to the later stages of the thermal evolution of overthickened crust. Generally, decompression in the higher pressure domain of the granulite ITD path is consistent with their genesis in settings dominated by tectonic thickening (Harley 1989). Many features such as association with garnet peridotites, high- pressure assemblages and non-depleted LILE and REE character rank the north Bohemian granulites to the geotectonic Group I defined for Variscan granulites by Pin & Vielzeuf (1983) and Vielzeuf & Pin (1989),