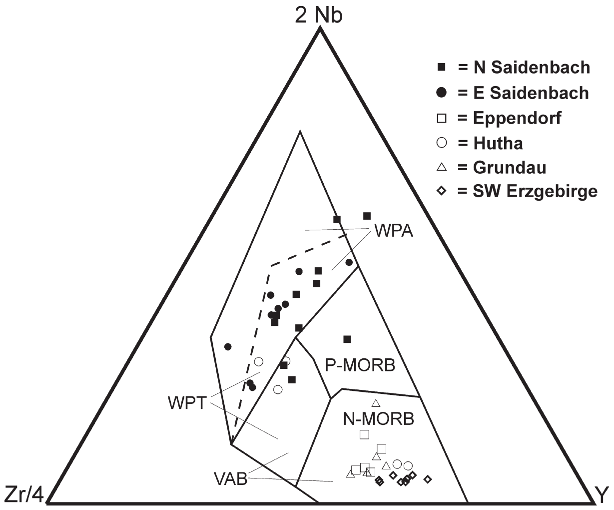
Stop 1-3 – A (Day 1). Eclogite at the Northern Shore

Coordinates: N50°44′14.2″ E13°14′36.1″

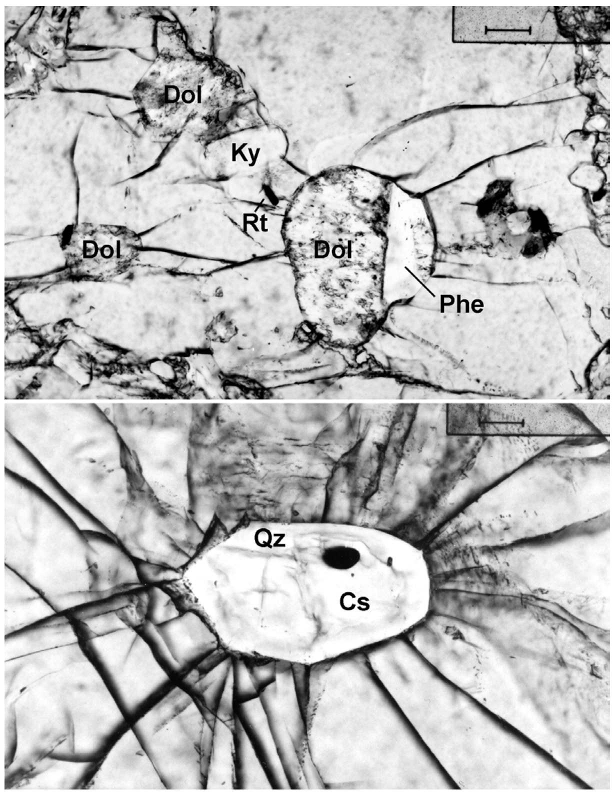
At this site numerous blocks of eclogite are scattered along the strand (Fig. 9) showing a considerable diversity. Massive and foliated types exist, as well as fine and coarser grained varieties. In addition, the chemical variability of the eclogites is remarkable. Samples E99-21 to 24 and E00 (Table 2) demonstrate the significant variation in some minor and trace elements. However, the rare-earth element (REE) patterns of the Saidenbach eclogites are very similar, being characterized by $(La/Sm)_N$ values >1. In contrast, the aforementioned eclogites with N-MORB to P-MORB signatures have $(La/Sm)_N$ values ≤1. Massonne and Czambor (2007) concluded that the eclogites from the Saidenbach reservoir most likely originated from within-plate basalts to trachyandesites or corresponding plutonic rocks, based on various discrimination diagrams such as that shown in Fig. 10 after Meschede (1986).

The mineral assemblages of the eclogite blocks at stop 1-3A are also somewhat variable. Most of these blocks contain fresh garnet and omphacite. Rutile and quartz are pervasive. In a few cases, coesite has been detected in eclogite from this locality (Massonne, 2001; O'Brien and Ziemann, 2008). However, coesite is only preserved as rare inclusions in omphacite and garnet (Fig. 11), although partial transformation to quartz is common. Due to the variable chemical bulk rock composition, especially in regard to certain minor and trace elements such as P, Sr, Ba, and Ce (see Table 2), unusual eclogitic minerals occur. For instance, abundant Ba-rich potassic white mica (Table 4) with decreasing Ba contents from core to rim was found in eclogite that also contains cymrite as rare inclusion mineral (Massonne and Bautsch, 2004). Cl-rich apatite with relatively high amounts of Sr (>4 wt.% SrO) was reported by Massonne and Burchard (2000) from this locality. Kyanite and dolomite can be constituents in eclogite blocks at stop 1-3A (Fig. 11). Such is the case for sample E99-24, which is used here to illustrate the P-T conditions experienced by the eclogites of this site during their metamorphic evolution (chemical compositions of minerals in E99-24 are given in Table 4). Garnet and omphacite in E99-24 are moderately zoned, which is demonstrated by the X-ray maps of Fig. 12. For instance, grossular contents in garnet inner cores are 27 mol% and increase towards the outer core to values between 30–39 mol%. At the outermost garnet rim, grossular contents are between 22 and 26 mol%. Furthermore, relatively large phengite grains enclosed in garnet are richer in Si (close to 3.30 pfu) than moderately zoned potassic white mica (3.19–3.30 pfu) in the matrix. The rims of the latter white mica coexist with biotite (Fig. 12 G+H).

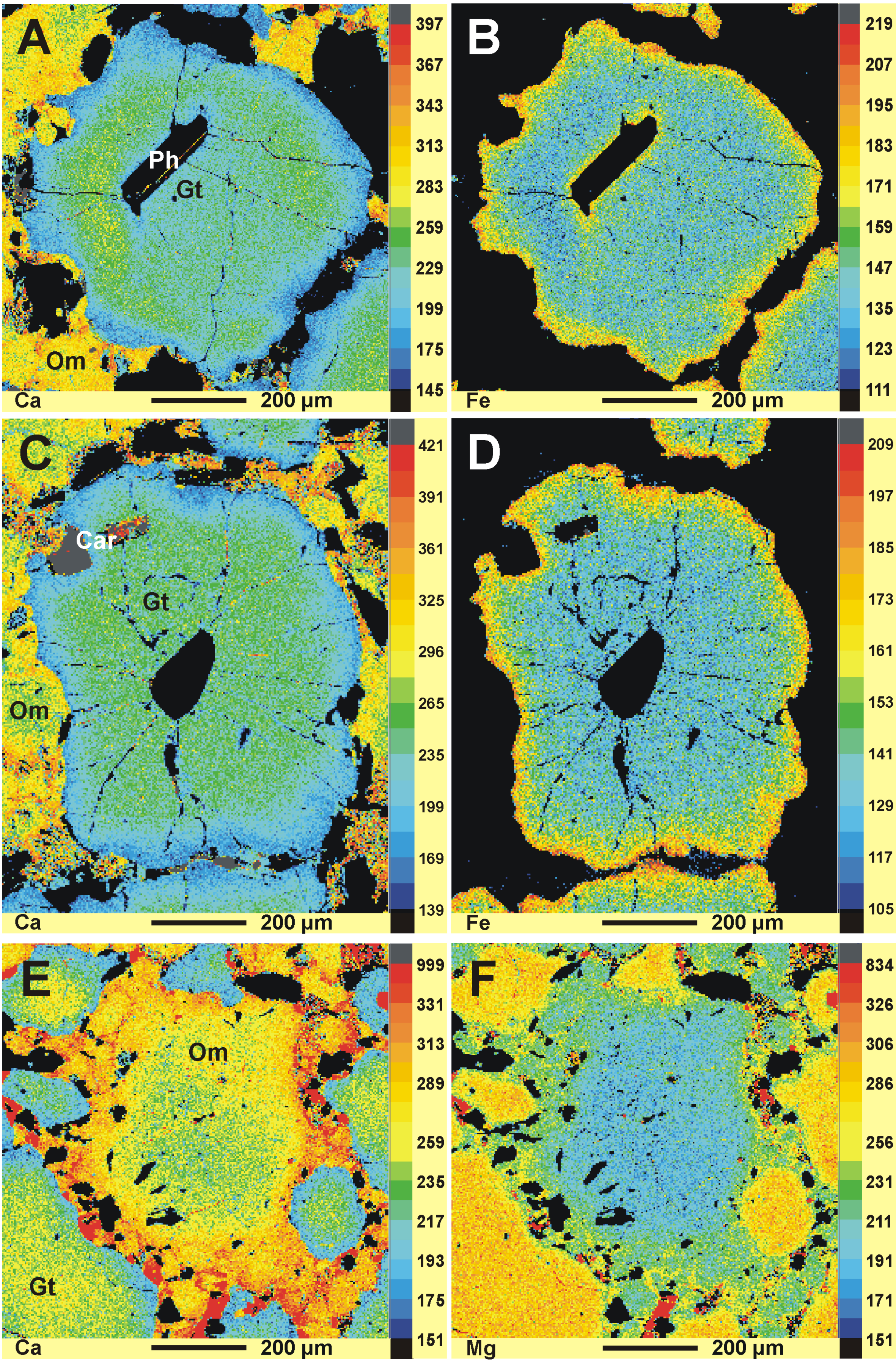
P-T pseudosections were calculated in the NCKFMASH-system with TiO_2, MnO, CO_2 and O_2 for compositions of E99-24 at different contents of H_2O, CO_2, and O_2 (see legend of Fig. 13) to account for three different metamorphic stages. The calculation with the computer program PERPLE_X (Connolly, 2005) was performed as outlined in Massonne (2011a). However, the solid-solution models TiBio(HP) and Omph(HP) were used instead of Bio(HP) and Cpx(HP). In addition, the models Usp(M), mentioned in the legend of Fig. 8, and Ep(HP) were applied. The results of the PERPLE_X calculations for sample E99-24 are



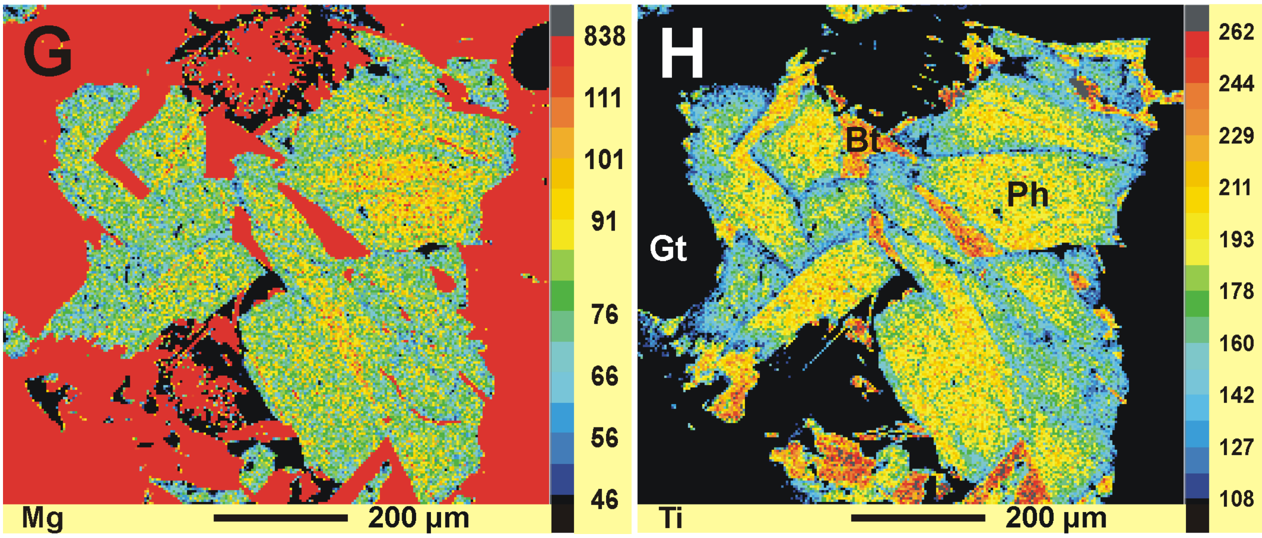
■ **Fig. 10.** Plot of chemical analyses of eclogites from the Saxonian Erzgebirge in the discrimination diagram of Meschede (1986). The graph was taken from Massonne and Czambor (2007).



■ **Fig. 11.** Photomicrographs of inclusions (Dol = dolomite, Ky = kyanite, Phe = phengite, Rt = rutile) in garnet of eclogite sample E99-24 (stop 1-3A) under plain polarized light (Massonne, 2001). Coesite (Cs) is surrounded by quartz (Qz). Image widths are 1.3 mm (at the top) and 5 mm (at the bottom).



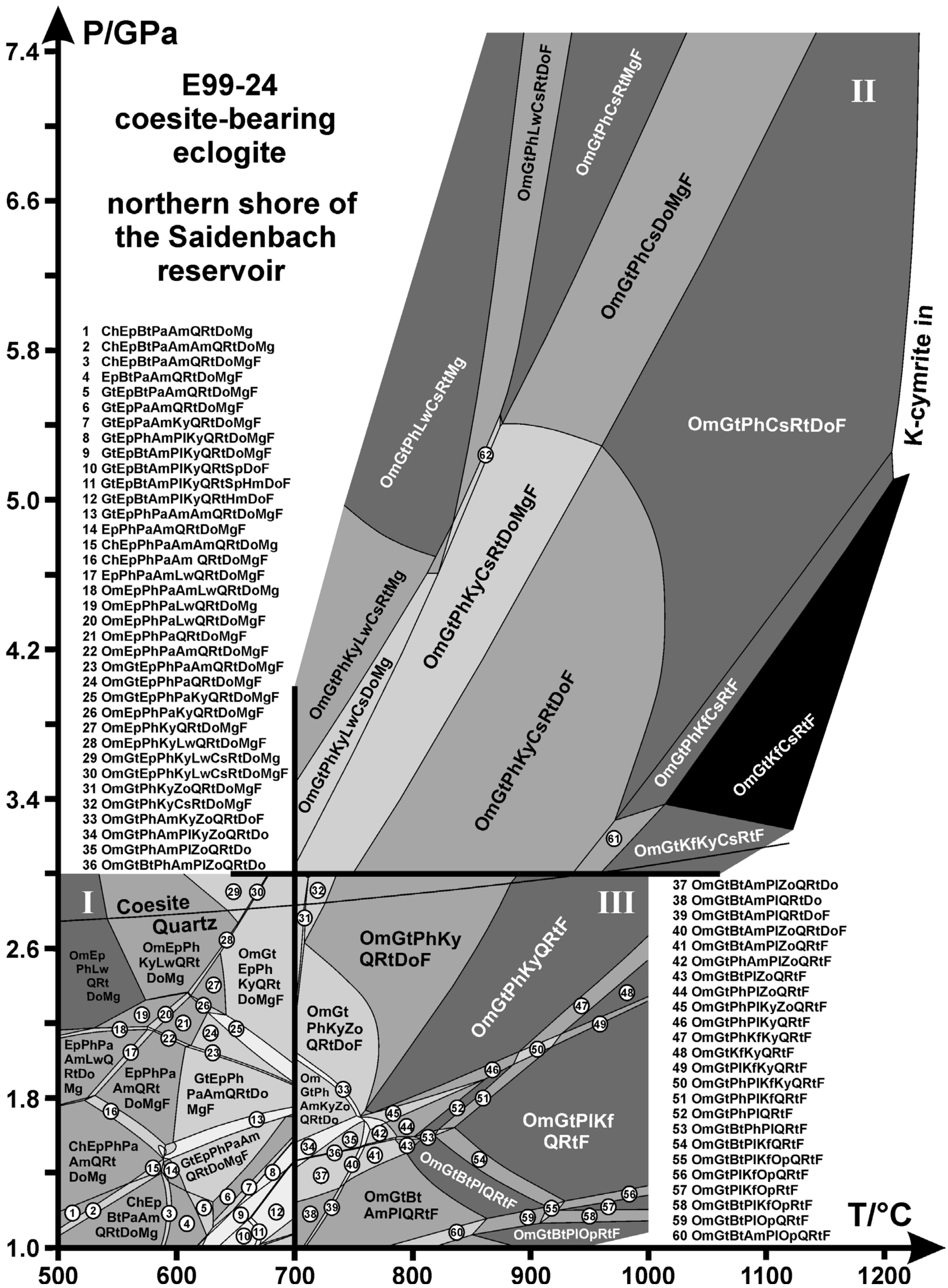
■ **Fig. 12.** Concentration maps of Ca and Fe of garnet (A-D), Ca and Mg of omphacite (E,F), and Mg and Ti of phengite (G,H) in eclogite sample E99-24 (stop I-3A). Bt = biotite, Car = carbonate, which is dolomite partially transformed to calcite, Gt = garnet, Om = omphacite, Ph = phengite.



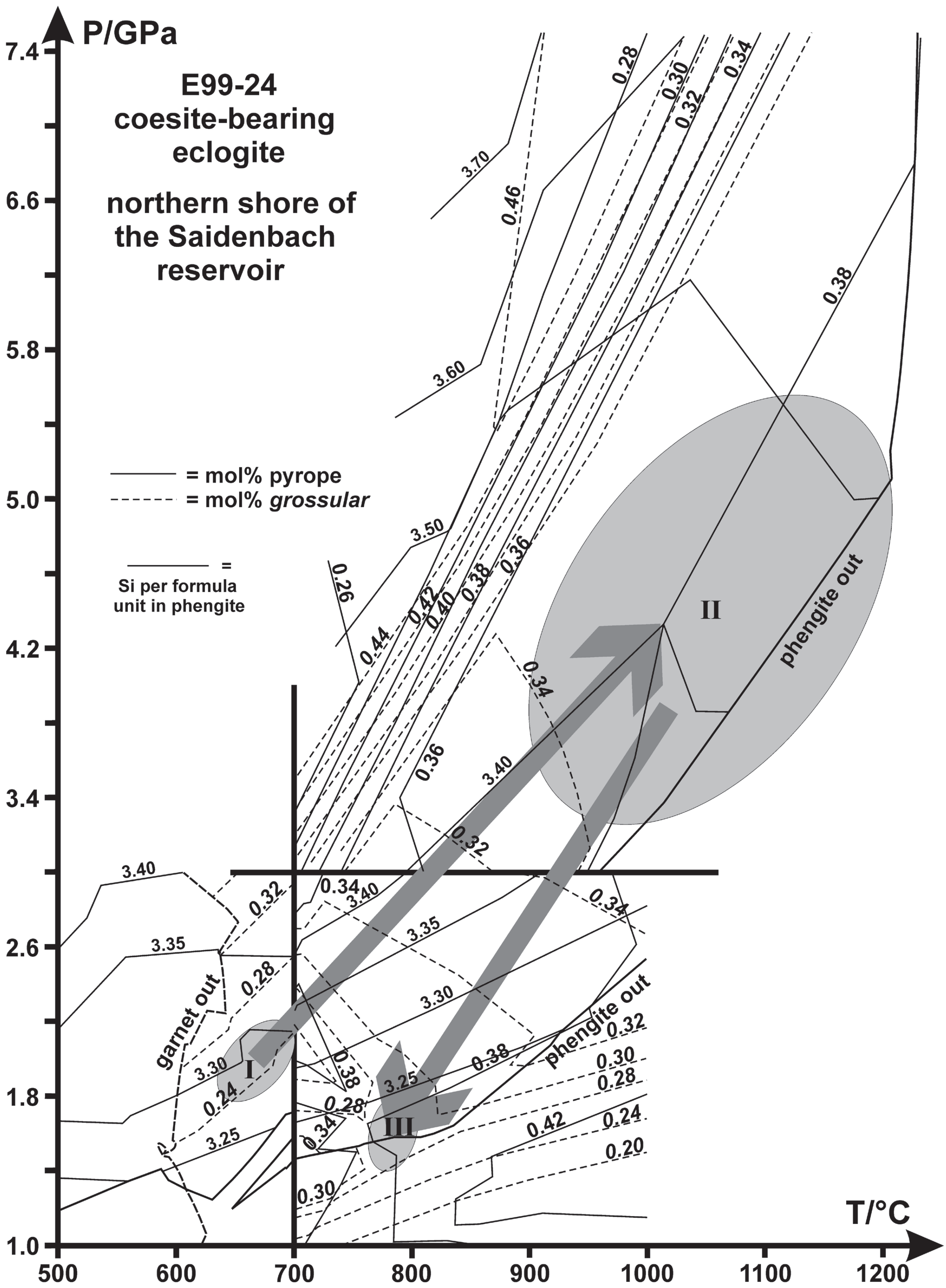
■ **Fig. 12.** (*continued*).

Mineral	garnet outer core	garnet outer rim	omphacite core	omphacite outer rim	phengite inclusion	phengite matrix	dolomite inclusion	kyanite inclusion	K,Ba-mica	**cymrite**
Sample	E99-24	E99-24	E99-24	E99-24	E99-24	E99-24	E99-24	E99-24	E99-23	E99-23
Anal. No.	170558	170560	170523	170528	170519	170516	11617/156	11617/152		
SiO_2	40.62	40.03	55.67	54.02	49.11	48.27	0.10	35.54	37.40	31.54
TiO_2	0.18	0.07	0.22	0.35	2.60	2.49	0.04	0.08	4.42	0.17
Al_2O_3	22.87	22.48	14.34	12.14	27.03	28.29	0.03	63.46	30.11	24.62
Cr_2O_3	0.09	0.08	0.20	0.09			0.04	0.08		
FeO_{tot}	11.39	18.46	2.64	2.94	1.34	1.32	3.30	0.34	0.85	0.31
MnO	0.15	0.39	0.00	0.04	0.00	0.00	0.09	0.03		
MgO	11.35	10.39	7.84	9.58	3.82	3.13	19.23	0.05	2.72	0.17
CaO	13.59	9.36	12.29	16.29	0.00	0.00	32.83	0.03	0.06	0.05
Na_2O	0.04	0.03	7.42	5.36	0.42	0.45	0.02	0.00	0.61	0.12
K_2O			0.00	0.00	10.60	10.82	0.00	0.00	5.06	0.28
BaO					0.74	0.74	0.00	0.01	14.51	39.79
Cl									0.10	0.81
Total	101.29	101.29	100.63	100.81	95.65	95.51	55.68	99.62	95.84	97.86
Si	5.880	5.895	1.947	1.908	6.581	6.495	0.003	0.962	5.632	2.044
Ti	0.020	0.008	0.006	0.009	0.262	0.252	0.001	0.002	0.501	0.008
Al	3.901	3.901	0.591	0.505	4.268	4.486	0.001	2.024	5.344	1.881
Cr	0.011	0.010	0.006	0.002			0.001	0.002		
Fe	1.501	2.275	0.077	0.087	0.150	0.148	0.082	0.008	0.107	0.017
Mn	0.019	0.049	0.000	0.001	0.000	0.000	0.002	0.001		
Mg	2.449	2.280	0.409	0.504	0.762	0.628	0.855	0.002	0.611	0.016
Ca	2.108	1.476	0.461	0.616	0.000	0.000	1.049	0.001	0.010	0.004
Na	0.012	0.010	0.503	0.367	0.109	0.118	0.001	0.000	0.178	0.015
K			0.000	0.000	1.812	1.857	0.000		0.972	0.023
Ba					0.039	0.039	0.000		0.856	1.010
Cl									0.026	0.089

■ **Tab. 4.** Analyses with the wave-length dispersive systems of CAMECA SX50 and SX100 electron microprobes (in wt.%) of minerals in coesite-bearing eclogites from the northern shore of the Saidenbach reservoir (stop 1-2A). The analyses of minerals in E99-23 were taken from Massonne and Burchard (2000). Structural formulae were calculated as given in Table 1 and as follows: dolomite – 2 cations without C, kyanite – 3 cations, cymrite – 16 valencies. Contents of F were below the detection limit.



■ **Fig. 13.** P-T pseudosections calculated for the composition (simplified compared to that given in Table 2) of dolomite-bearing eclogite E99-24 (stop 1-3A) in the system KNCFMASH-Mn-Ti-O-C. The three selected metamorphic stages I (early = mineral assemblage enclosed in garnet), II (peak temperature related to the rim composition of extended garnet cores, which is Mg-richest), and III (late = matrix assemblage including the garnet outermost rim) were related to different H_2O, O_2, and CO_2 contents (after normalization to a total of 100 wt%: I = 2, 0.2, 12 wt%, II = 0.5, 0, 4 wt%, and III = 0.5, 0, 1 wt%) guided by the idea that the growth of the majority of garnet after stage I was caused by decarbonation reactions. Abbreviations: Am = amphibole, Bt = biotite, Ch = chlorite, Cs = coesite, Do = dolomite, Ep = epidote, F = mixed H_2O-CO_2 fluid, Gt = garnet, Kf = alkalifeldspar, Ky = kyanite, Lw = lawsonite, Mg = magnesite, Om = Na-rich clinopyroxene, Op = orthopyroxene, Pa = paragonite, Ph = phengite, Pl = plagioclase, Q = quartz, Rt = rutile, Zo = zoisite. P-T fields labelled with two times Am refer to coexisting Na- and Ca-amphibole. The latter amphibole appears at higher temperatures and lower pressures relative to the occurrence of Na-amphibole.



■ **Fig. 14.** Pseudosection of Fig. 13 contoured by the following sets of isopleths: (1) Si per formula unit in phengite, (2) grossular and (3) pyrope contents in garnet. Grey ellipses mark likely P-T conditions for the three stages I to III (see legend of Fig. 13), and are connected by arrows defining a P-T path for eclogite E99-24.

shown in Figures 13 and 14. For the early metamorphic stage I, characterized by the inclusion assemblage of kyanite, dolomite, phengite, (clino)zoisite and omphacite in garnet (Fig. 13), P-T conditions around 2.0 GPa and 660 °C were estimated (Fig. 14). At this stage there should be little garnet present, according to the calculation results (see Table 5). Garnet grew during further burial mainly at the expense of carbonate minerals (dolomite and inferred magnesite), quartz/coesite and zoisite-epidote. Peak P-T conditions (stage II) cannot be precisely assessed as the garnet composition is not very sensitive at the inferred P-T conditions around 4.5 GPa and 1050 °C (see Fig. 14). Zr in rutile geothermometry yielded ca. 900 °C (at 4.5 GPa) based on the calibration by Tomkins et al. (2007) and 19 of 20 rutile analyses with a mean value close to 1300 ppm Zr. Application of the garnet-omphacite Fe^{2+}-Mg exchange thermometry gave temperatures around 1200 °C at 4.5 GPa, using the calibration by Ellis and Green (1979). However, this temperature estimate is rather uncertain, due to the difficulty in determining the amounts of Fe^{2+} and Fe^{3+} in omphacite. The retrograde stage III, which is characterized by micas and kyanite of the matrix and the garnet and omphacite outermost rims (see Table 3), was defined at P-T conditions around 1.6 GPa and 770–800 °C (Fig. 14).

Eclogite E99-24 yielded a $\delta^{13}C$(PDB) value of −9.2 (analytical method as reported by Massonne and Tu, 2007). Such a result for $\delta^{13}C$ does not exclude freshwater carbonates as a possible source of carbon in the protolith of this eclogite. On the other hand, the $\delta^{13}C$ value would still be compatible with mantle carbon (usually around $\delta^{13}C$(PDB) = −5).

Stage	I	II	III
P/GPa	2.1	4.5	1.8
T/°C	670	1050	780
Om	15.3	20.4	42.3
Gt	2.9	55.7	40.4
Zo/Ep	21.3		
Ph	2.8	4.0	4.2
Pa	4.0		
Ky	6.0		6.0
Q/Cs	21.1	12.1	6.1
Rt	0.7	0.9	0.9
Do	9.4	6.8	
Mg	16.4		
XNa(Om)	0.54	0.59	0.30
XCa(Gt)	0.255	0.355	0.29
XFe(Gt)	0.47	0.26	0.345
XMg(Gt)	0.24	0.38	0.36
Si(Ph) pfu	3.30	3.42	3.25

Stages and mineral abbreviations as in Fig. 13.

■ **Tab. 5.** Modal content (in vol%) and compositional characteristics of minerals calculated with the PERPLE_X software for the simplified eclogite composition of E99-24.

Stop 1-3 – B (Day 1). Saidenbachite at the Eastern Shore

Coordinates: N50°44′10.0″ E13°15′08.6″

Walk back along the shore, cross the Saidenbach creek, turn to the south, and continue to walk along the shore until the forest road changes to a westerly direction. Then, continue walking for about 400 metres to some large boulders that, however, would be partially submerged when the reservoir is at its maximum level.

Boulders of saidenbachite differ from those of migmatitic gneisses ("Flammengneise") that occur abundantly as field stones and blocks along the strand and in the adjacent forest. Saidenbachite is a non- or slightly foliated quartzofeldspathic rock with a homogeneous distribution of abundant mm-sized garnets in a muscovite-rich matrix. Boulders of saidenbachite, which are distributed for 500 metres to the west, occur only very locally and are likely related to (lensoid?) bodies underground surrounded by migmatitic gneisses (see map of Fig. 9).

Microdiamonds up to 30 µm, but generally between 5 to 10 µm, in diameter occur as inclusions in garnet and other phases (Fig. 15) of the saidenbachite and were first reported by Massonne (1999). Nasdala and Massonne (2000) confirmed the existence of these microdiamonds by Raman-spectroscopy. Hwang et al. (2001) and Stöckhert et al. (2001) reported the association of quartz, feldspars, various micas, and occasionally apatite and rutile with diamond within a single inclusion in garnet (Fig. 15). These authors interpreted such polyphase inclusions as trapped siliceous fluid or melt. The microdiamonds themselves contain nanometre-sized inclusions, the minerals of which can hardly be identified and related to the larger inclusion minerals (Dobrzhinetskaya et al., 2003).

Detailed studies of saidenbachite demonstrate that the microdiamonds are enclosed in an intermediate compositional zone of garnet (Massonne, 2003) characterized by relatively low Ca concentrations (Table 6, Fig. 16). Microdiamond inclusions also occur in an intermediate zone of mm-sized kyanite grains, which are relicts corroded by potassic white mica (Fig. 17). Occasionally, abundant small idiomorphic garnets are enclosed in the cores of kyanite.

Microdiamonds also occur in an intermediate growth zone in zircon (Fig. 18). Rare inclusions of graphite, garnet and jadeite were found in zircon cores (Nasdala and Massonne, 2000; Massonne and Tu, 2007). In addition, inclusions of phengite, quartz, and rutile occur in garnet cores. From the assemblage of these inclusions, P-T conditions of 1.8 GPa and 650 °C were derived by geothermobarometry (Massonne and Nasdala, 2003) a result which is the same as the peak pressure estimated for gneisses in the vicinity of the saidenbachites (Willner et al., 1997) and for eclogite of stop 1-2 (see Fig. 8). This coincidence