Gneisses of the KTB Vorbohrung and Hauptbohrung: II. Source rocks and petrogenesis.

Hiltrud Müller, Mineralogisch-Petrographisches Institut Freiburg & Birgit Mingram, GeoForschungsZentrum Potsdam

Introduction

The chemical composition of KTB gneisses is investigated in order to monitor changes in source material as well as element mobility during metamorphic and retrogressive overprint. Except for some intercalations of hornblende or allanite-bearing gneisses discussed below, all gneisses of the KTB boreholes are of sedimentary origin. The gneiss sections of the Vorbohrung sum up to more than 3000 m, which corresponds to a gneiss pile of about 1500 m thickness when corrected for an average dip of 60° and for tectonic repetitions (e.g. g4a´ and g4b´, description of lithological units in Part I, Harms et al.). This nearly completely cored gneiss sequence allows to look for relictic sedimentary informations in the paragneisses. Corresponding to the uniform modal composition (gt-bio-qz-pl ± ky, sil), paragneiss chemistry is quite homogeneous. Formation of anatectic quartz-feldspar schlieren occurs but locally and evidence of metasomatic overprint is lacking. It was shown earlier that the ubiquitous retrogressive chloritization and sericitization did not significantly change element concentrations (Müller et al. 1990, Wimmenauer 1991). This is further confirmed by $\delta^{18}O$ measurements indicating an undisturbed premetamorphic isotopic signature in the gneisses (Simon & Hoefs 1993). Hence, it can be assumed that the original sedimentary composition has mostly survived the metamorphic and deformational history of the rocks.

Geochemical relationships in sediments

Main and trace element contents of clastic sedimentary rocks mirror lithological composition of the source areas, climate conditions during weathering and characteristic processes during transport and sedimentation. Easily soluble elements (e.g. Na and K) are used to delineate intensity of weathering. Refractory elements such as Y, Ti, Zr, Hf, Sc, and REE typically have short residence times in seawater and are generally used to characterize provenance and tectonic setting (Taylor & McLennan 1985, Bhatia & Crook 1986). While mature sediments show a considerable fractionation of Zr and Hf with the heavy mineral zircon into the sand fraction and of Ti, Cr, Y, Nb and other trace elements with clay minerals into the clay fraction, this differentiation is less significant in immature greywackes (McLennan et al. 1990).

Analytical methods

Representative, texturally homogeneous gneiss samples have been analysed for main and trace elements by XRF and for REE (and partly for Sc, Y, and Zr) by ICP. Thin sections of every sample were consulted for the evaluation of gneiss texture, modal composition, and degree of alteration. Severely chloritized, pyrite impregnated or cataclastic samples were excluded.

Results

a) Paragneisses

KTB paragneisses have high Na_2O of 2.5 to 4 wt-% and SiO_2/Al_2O_3 ratios of 3 to 7 characteristic for immature greywackes and pelitic greywackes (Fig.1, Table 1). Few samples are of shale composition. CaO is typically less than 1.5 wt-% indicating the absence of carbonates in the sedimentary protolith. Based on earlier investigations of low-grade metasediments, a SiO_2/Al_2O_3 ratio of 4 is usually taken as a hypothetical limiting value between greywacke and pelitic greywacke protoliths (Wimmenauer 1984, Müller 1989). A close correlation between microscopic gneiss texture and protolith type exists for large sections of the gneiss profile. Equigranular, fine grained gneisses with weakly developed biotite foliation correspond to greywacke composition ($SiO_2/Al_2O_3 > 4$) whereas medium to coarse grained flasergneisses with pronounced segregation in biotite-rich layers and quartz-feldspar-rich layers correspond to pelitic greywackes ($SiO_2/Al_2O_3 < 4$). This microscopic observation can be generalized to the macroscopic subdivision of the gneiss sequence into an interlayering of these two fabric types (see Part I). The interlayering is observed from meter to centimeter scale and is interpreted as a relic of a turbiditic layering of the sedimentary protolith.

Main and trace elements show a certain variation with depth. MnO > 0.15 wt-% is confined to gneisses of the uppermost 560 m in the Vorbohrung (v1) which are also slightly enriched in Fe,

Table 1: Average chemical composition of KTB gneisses

	(1) n=124		(2) n=9		(3) n=23		(4)	(5)
	mean	sdev	mean	sdev	mean	sdev		
SiO_2	66.30	4.50	62.70	2.90	57.50	3.80	50.70	61.00
TiO_2	0.82	0.10	1.01	0.14	1.38	0.35	1.13	0.27
Al_2O_3	16.00	1.90	16.60	1.50	16.80	2.00	22.00	18.20
Fe_2O_3	6.26	1.25	8.15	1.14	9.05	1.38	7.11	6.63
MnO	0.11	0.05	0.28	0.06	0.17	0.06	0.06	0.12
MgO	2.23	0.48	3.07	0.28	3.13	0.58	3.53	0.52
CaO	1.29	0.34	1.85	0.50	4.37	2.33	4.76	1.81
Na_2O	2.80	0.40	3.00	0.40	3.50	1.10	5.10	4.40
K_2O	2.58	0.53	2.55	0.30	2.57	0.99	2.51	6.10
P_2O_5	0.11	0.03	0.11	0.04	0.28	0.20	0.13	0.11
Cu	21	13	25	12	33	25	< 5	11
Zn	93	23	132	29	115	39	68	203
Ga	19	3	20	3	22	4	23	40
Rb	77	19	87	16	70	42	76	52
Sr	170	58	221	84	245	83	428	200
Ba	546	103	571	164	599	147	575	323
Pb	16	5	23	9	13	7	12	20
Th	8	3	11	2	7	3	5	15
Zr	207	23	217	42	258	90	248	1245
Hf	7	5	19	8	11	10	< 5	103
Nb	11	3	19	6	33	32	6	197
Y	31	4	36	8	43	12	15	113
La	30	7	41	10	44	14	25	120
Sc	9	4	10	1	13	4	8	< 5
V	139	30	164	24	155	48	127	< 5
Cr	102	38	125	23	126	41	152	< 5
Co	13	6	20	4	24	7	23	< 5
Ni	37	21	51	8	48	24	38	7

(1) average ky/sil-gt-bi-gneiss, (2) average paragneiss above 560 m, (3) average hbl-gt-bi-gneiss, (4) allanite-bi-gneiss 3573.4 m, (5) meta-trachytic layer 256.7 m

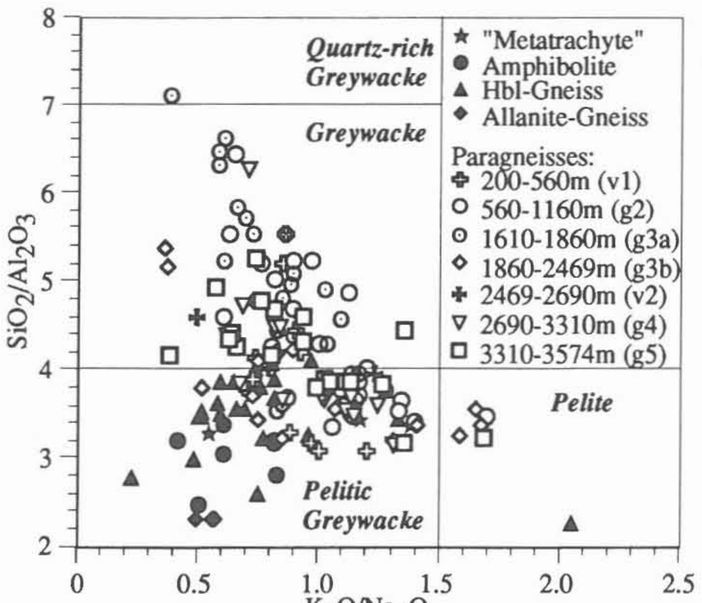


Fig. 1: Discrimination of sedimentary protolith

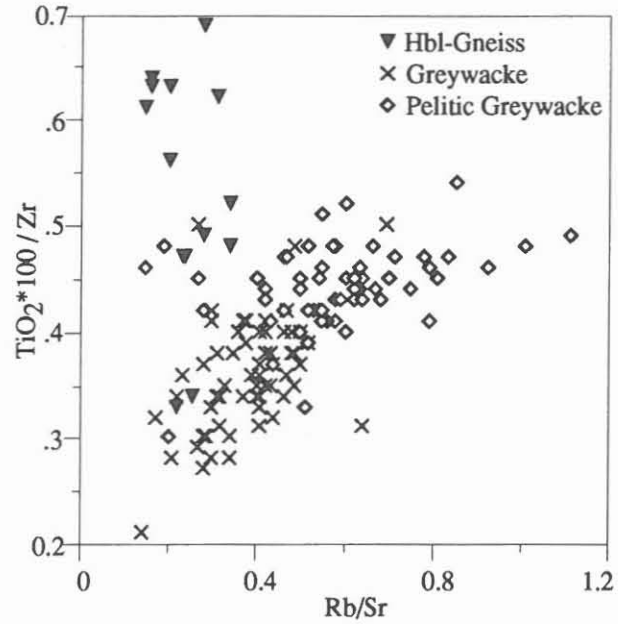


Fig. 2: Trace element characteristics of KTB paragneisses according to sedimentary protolith

Mg, Ca, V, Cr, Co, and Ni. Pelitic greywacke protoliths are dominant. This is probably due to the distinctive lithology of this section with frequent interlayering of gneisses, hornblende gneisses, alkalibasaltic amphibolites, meta-trachytic and calc-silicatic layers. v1 is interpreted as a volcano-sedimentary sequence differing from other KTB gneiss sections not only by its geochemical characteristics but also by higher Sm/Nd model ages (v. Drach & Köhler 1993) and by a slightly different metamorphic pT-history indicated by lower gt-bi temperatures (Reinhardt 1990) and by different chlorite compositions (pers. comm. Kontny 1993).

Variations in the other gneiss units are minor: g3a and to a lesser extent g2 have a pronounced greywacke character (Fig.1). Correlation between textural type and protolith geochemistry seams to be disturbed in sections g4a and g4b, where medium to coarse grained plagioclase-rich gneisses with greywacke chemistry are dominant. Rb/Sr and Ti/Zr ratios confirm a slight enrichment of plagioclase and of heavy minerals like zircon in the greywacke protoliths and of clayminerals in the pelitic greywacke protoliths (Fig.2). A comparison with saxothuringian sedimentary units of the Erzgebirge demonstrates the immature character of the KTB protoliths with low La/Zr and Rb/Sr ratios, which are determined by important influx of granitoid as well as of basic detritus (Fig.4).

b) Hornblende-bearing gneisses

Layers of hornblende(± garnet)-bearing gneisses occur within all paragneiss units, particularly frequently or even dominantly in v1 and v2. They are higher in Ti, Fe, Mg, Ca, Na, Sr, V, Cr, Co, and Ni and lower in Si than the paragneisses (Table 1) and have to be deduced from basic detritus, volcaniclastic material or thin basaltic lava streams in the sedimentary protolith.

c) Leucocratic hornblende-bearing gneisses (metatrachytic layers)

Plagioclase-rich gneisses characterized by bluish hornblende and large contents of zircon and allanite occur in several quite inhomogeneous thin layers in section v1 between 200 and 350 m. Incompatible elements (Na, K, REE, Y, Nb, Zr, Hf, Th) are enriched while Mg, Ti, V, Cr, Ni are depleted (Table 1.). Geochemical data suggest a nearly quartz-saturated trachytic protolith (Müller 1992). In the context of associated amphibolites of alkaline basaltic character (Patzak et al. 1991), these metatrachytes might indicate a bimodal alkali pronounced volcanism in section v1.

d) Allanite-rich gneiss

A granular, hornblende-free and plagioclase-rich allanite gneiss forms the transition between paragneiss (g5) and metabasite (b3) at 3574 m in the Vorbohrung. It is about 1 m thick, homogeneous and has sharp boundaries both against gneiss and amphibolite. This transition zone is the only core-documented paragneiss-metabasite contact that is not disturbed by cataclastic overprint. It is of special interest due to a clear discrepancy between the pT-paths of gneisses and metabasites. While the metabasites were subjected to an eclogite facies stage (O'Brien et al. 1992), paragneisses obviously have never been at higher pressures than 10 kb (Reinhardt 1990). Until now it is unclear when and how gneisses and metabasites have come together. Compared with average KTB paragneiss the allanite gneiss is higher in Na, K, REE, Y, Nb, Zr, Hf, and Th but lower in Mg, Ti, V, Cr, and Ni (Table 1). A detailed geochemical profile over the transition zone does not display

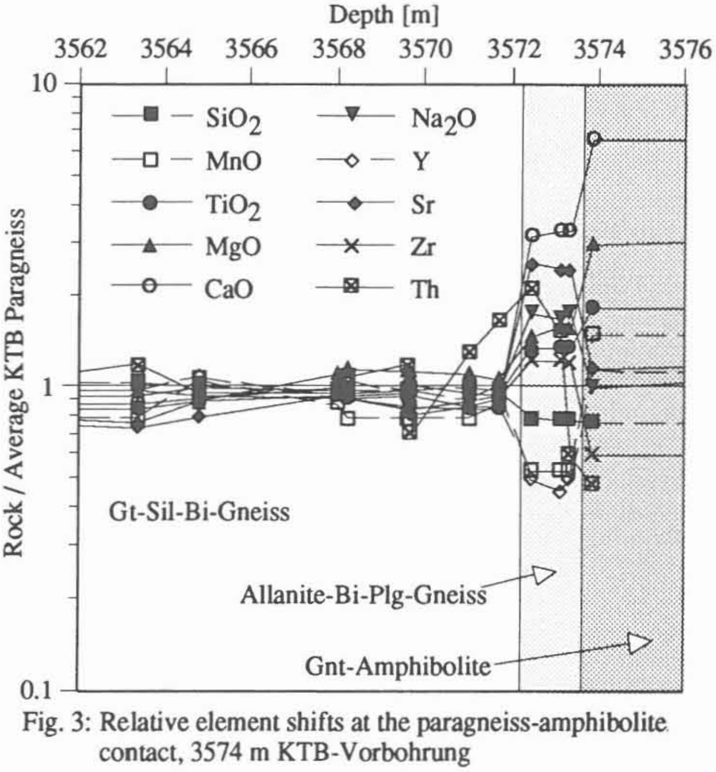
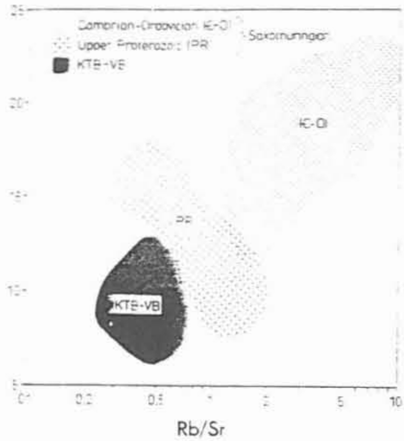


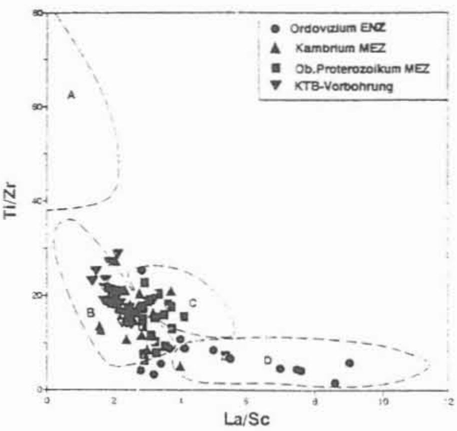
Fig. 3: Relative element shifts at the paragneiss-amphibolite contact, 3574 m KTB-Vorbohrung

any trends indicating element mobilisation but merely sharp decrease or increase of element contents (Fig.3). Enrichment and depletion of some elements (e.g. Y, Mn, Sr, Ca) compared to both paragneiss and metabasite are indications of an independent, probably magmatic origin of the allanite gneiss. It might represent some leucocratic differentiation or border facies of the basaltic intrusion.



◄ Fig 4: Comparison of geochemical characteristics of KTB paragneisses with saxothuringian metasediment units from the Erzgebirge

► Fig. 5: Geotectonic setting of KTB paragneisses (greywacke protolith) and of psammites from the Erzgebirge (Bhatia & Crook 1986: A oceanic island arc, B cont. island arc, C active contin. margin, D passive contin. margin)



Indications of tectonic setting

Several discrimination diagrams of major oxides and trace elements are used for determination of tectonic environment for sediments (e.g. Bhatia & Crook 1986). Most informative are ratios of immobile trace elements, that remain essentially undifferentiated between source and sedimentary deposition. Full range of elemental variation, however, is best shown as multi-element patterns normalized to average sediment compositons from different tectonic settings (Floyd et al. 1991). KTB paragneisses are best compared with greywackes from active continental margin settings or from continental island arcs (Fig.5, 6).

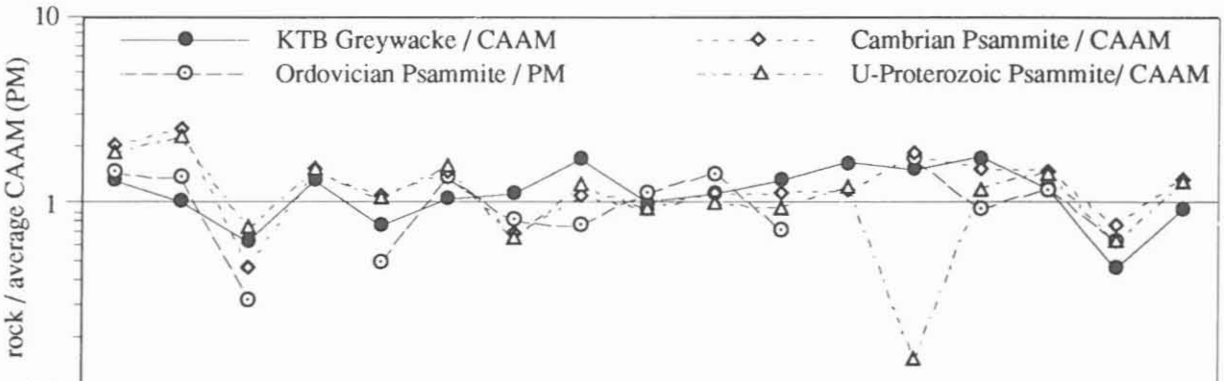


Fig. 6: Multielement patterns of KTB paragneisses with greywacke protolith and of psammitic units from the Erzgebirge, normalized to average greywacke composition from continental arc/active margin (CAAM) except for Ordovician psammites, which are best compared with sediments from passive margins (PM).

References

Bhatia, M. R. & Crook, K. A. W. (1986) - Contrib. Mineral. Petrol. **92,** 181-193.
Drach, V. v., Köhler, H. (1993) - 6. Koll. DFG-Schwerpunktprogramm KTB, 1.-2.4.1993, Gießen
Floyd, P. A., Leveridge, B. E., Franke, W., Shail, R., Dörr, W. (1990) - Geol. Rdsch. **79**, 611-626.
O'Brien, P. J., Röhr, C., Okrusch, M. & Patzak, M. (1992) - Contrib. Miner. Petrol. **112,** 261-278.
Patzak, M., Okrusch, M. & Röhr, C. (1991) - KTB Report **91-1,** 63-82.
Reinhardt, J. (1990) - KTB-Report **90-4**, 535.
McLennan, S. M., Taylor, S. R., McCulloch, M. T. & Maynard, J. B. (1990) - GCA **54,** 2015-2050.
Müller, H. (1989) - Tectonophysics **157**, 97-108; ___ (1992) - 7th Geol. Workshop Kutna Hora (CSFR), 24.-27.4.92.
___, Romacker, M. & Wimmenauer, W. (1990) - Eur. J. Mineral. **2, Beih. 1,** 182.
Simon, K. & Hoefs, J. (1993) - Contrib. Miner. Petrol. **114,** 42-52.
Taylor, S.R. & McLennan, S.M. (1985): The continental crust: its composition and evolution. - Blackwell, 312 p.
Wimmenauer, W. (1984) - Fortschr. Miner. **62,** Bh2, 69-86; ___ (1991) - KTB Report **91-1,** 106-135.