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Isotopic age determinations of crystalline rocks of the Upper Harz Mountains, Germany

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With 10 figures and 5 tables

Zusammenfassung

Eine altersmäßige Einstufung der im Oberharz vorkommenden kristallinen Gesteine wurde durch U-Pb-Isotopenuntersuchungen an Zirkonen und Titanit sowie Rb-Sr-Isotopenmessungen an Gesamtgesteinsproben und Biotiten durchgeführt.

U-Pb-Daten von idiomorphen und runden, detritischen Zirkonen der allochthonen Eckergneis-Scholle deuten auf ein Alter des Ursprungsgebietes der weitgehend metasedimentären Gesteine von etwa 1.6 Ga oder älter hin und sie weisen ferner auf ein mögliches Metamorphose-Ereignis vor rund 560 Ma im Eckergneis oder im Liefergestein der Zirkone des Eckergneises hin. Der konkordante Datenpunkt bei ca. 295 Ma einer Titanit-Fraktion aus einer Metavulkanit-Probe dokumentiert die kontaktmetamorphe Beeinflussung des Eckergneises durch die variskischen Intrusionen des Oberharzes.

Die Platznahme der Intrusionen der Gesteine des Harzburger Gabbronorit-Massivs sowie des Brokken- und Oker-Granits erfolgten innerhalb der analytischen Fehlergrenzen zeitgleich vor 293–295 Ma. Dies deutet auf eine gemeinsame geotektonische Ursache des Aufdringens der Magmen. Damit verbunden war der Aufstieg der Eckergneis-Scholle, die jetzt zwischen Harzburger Gabbronorit und Brockengranit »eingeklemmt« ist.

Mineralalter der Plutonite liegen nahe bei den Intrusionsaltern und weisen auf rasche Abkühlungsvorgänge in seichtem Krustenniveau hin.

Abstract

Dating of crystalline rocks occurring in the Upper Harz Mountains was carried out by means of U-Pb isotope investigations on zircons and sphene as well as by Rb-Sr isotope measurements on whole-rock samples and biotites.

U-Pb data of euhedral and rounded, detrital zircons of the allochthonous block of the Ecker gneiss point to an age (upper intercept) of the source area of the predominantly metasedimentary rocks of about 1.6 Ga or older. The lower intercept indicates a possible metamorphic event at ca. 560 Ma in the Ecker gneiss or in the source rock of the zircons of this complex. The concordant data point of a sphene fraction from a metavolcanic sample documents contact metamorphic influence on the Ecker gneiss by the Variscan intrusions of the Upper Harz Mountains.

Emplacement of the intrusions of the Harzburg gabbronorite and the Brocken and Oker granites occurred contemporaneously 293–297 Ma ago within the analytical error limits. This points to a common geotectonic cause of the ascent of the magmas. Uplift of the Ecker gneiss block, now squeezed in between Harzburg gabbronorite and Brocken granite, was connected to these processes.

The mineral ages of the plutonites are close to the intrusion ages indicating fast cooling processes in shallow crustal levels.

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Résumé

Des mesures d'âge ont été effectuées sur des roches cristallines de l'Oberharz par les méthodes de l'U-Pb sur zircon et sphène et du Rb-Sr sur roches totales et sur biotites. La méthode U-Pb, appliquée aux zircons idiomorphes et détritiques arrondis de l'écaille allochtone des gneiss d'Ecker, fournit un âge (intersection supérieure) d'environ 1,6 Ga au moins pour la source des matériaux surtout métasédimentaires. L'intersection inférieure indique la possibilité d'un événement métamorphique à ± 560 Ma soit dans les gneiss d'Ecker, soit dans les roches-sources de leurs zircons. Un résultat concordant à ± 295 Ma fourni par le sphène d'une métavolcanite enregistre l'action du métamorphisme de contact engendré dans les gneiss d'Ecker par les intrusions varisques.

La mise en place des intrusions du massif gabbronoritique du Harzburg et celle des granite de Brocken et d'Ocker ont été contemporaines: âges de 293 à 297 Ma, compris dans l'intervalle d'approximation des mesures. Ce résultat est en faveur d'une même cause géotectonique pour l'ascension de ces magmas. C'est en relation avec ce processus que s'est produit le soulèvement de l'écaille des gneiss d'Ecker, actuellement coincée entre le gabbro du Harzburg et le granite de Brocken.

Les âges minéraux des plutons sont voisins des âges d'intrusion, ce qui indique un refroidissement rapide dans un niveau crustal peu profond.

Краткое содержание

С помощью метода урана-свинца на цирконах и титанитах, а также с помощью метода рубидия-стронция на цельной породе и биотитах определили возраст кристаллиновых пород верхнего Гарца.

Данные по урану-свинцу и круглые детритные цирконы из аллохтонной глыбы гнейса Эккер указывают на возраст исходной области преимущественно метаседиментных пород равный 1,6 Га, или более, а также на возможный позднейший метаморфизм гнейсов, или исходных пород цирконов этих гнейсов, имевший место около 560 Ма тому назад. Изохронная диаграмма с конкордией, вычерченная по фракции титанита из пробы метавулканитов, отмечает контактный метаморфизм гнейсов при интрузии герцинского возраста в верхние слои Гарца и дает цыфру в 295 а.

Интрузии в массив габброонорита Гарцбурга, а также гранитов Броккена и окера имели место в период от 293 по 295 Ма; причем здесь учтены и возможные погрешности анализа. Это указывает на общие геотектонические причины – внедрение магм. С этим связано и поднятие глыбы гнейсов Эккера, оказавшейся в наше время втиснутой между габбро Гарцбурга и гранитами Броккена.

Возраст плутонитов лежит близко к возрасту интрузии и указывает на быстрое охлаждение слоев коры, залегавших близь поверхности.

1. Introduction

The Harz Mountain Range (in the following: the Harz) represents an uplifted segment of the Rhenohercynian externides of the central European Variscan orogene. It is surrounded by Permian and Mesozoic sedimentary rocks. Main uplifting began in Early Cretaceous. Towards the south the Harz basement gently dips under Permian and Triassic sedimentary piles of the foreland. In the north the Harz block was uplifted up to 3 km at the northern margin fault (*Harznordrandverwerfung*) and thrust over Mesozoic strata of the foreland (Flick, 1986). These strata are steep to overturned immediately north of the main fault. Wrede (1988) could demonstrate that the tectonic border of the northern Harz margin is part of a wrench-fault-system generated during the Variscan orogeny and reactivated by Saxonian movements.

The basement of the Harz consists of Devonian and Lower Carboniferous clastic strata folded during the Asturian orogenic phase (Mohr, 1978), Variscan plutonic complexes and the pre-Variscan Ecker gneiss. The sedimentary rocks are anchimetamorphic at the present exposure level. Contact metamorphism has overprinted the rocks in the vicinity of intrusive bodies. In the area of the Devonian anticline of the Upper Harz (Oberharzer Devonsattel) enhanced vitrinite reflectivities of coalified organic matter in sedimentary rocks also point to low-grade contact metamorphism – in this case probably due to a large intrusive body in some km depth (Jordan & Koch, 1979).

The Harz is usually subdivided into three geological units (Mohr, 1978) with various crystalline complexes (Fig. 1). From the west to east these units are:

(1) Upper Harz with the Oker granitoid complex, the Ecker gneiss slab, the Harzburg gabbronorite massif, the western part of the Brocken

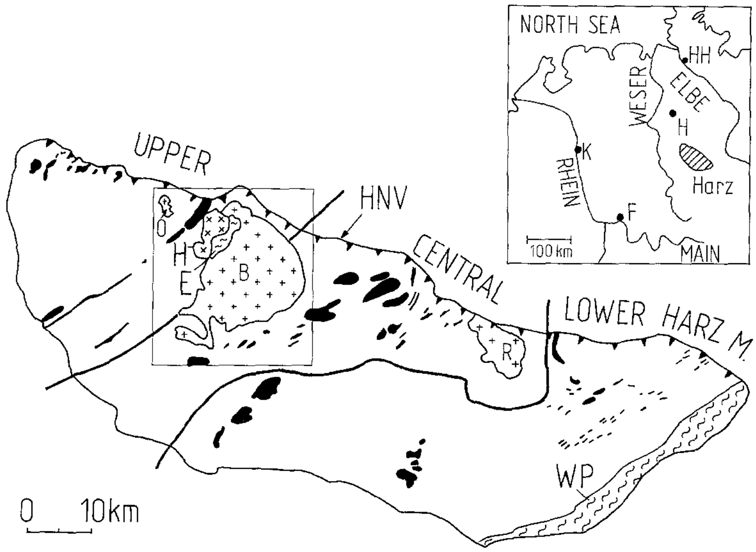

Fig. 1. Crystalline rocks of the Harz Mountains. O = Oker granite, H = Harzburg gabbronorite, E = Ecker gneiss, B = Brocken granite, R = Ramberg granite, WP = phyllites of the Wippra zone, black spots and areas = volcanics (diabase, rhyolite, tuffs, tuffites), HNV = Harz northern margin fault. Inset map indicates area of Fig. 2. General map: HH = Hamburg, H = Hannover, K = Köln, F = Frankfurt.

granite massif and the Upper Harz diabase range (*Oberharzer Diabaszug*),

(2) Central Harz with the eastern part of the Brocken massif, various occurrences of volcanics and the Ramberg plutonic complex,

(3) Lower Harz with Variscan phyllites of the Wippra zone of the eastern margin and many small volcanic bodies.

Crystalline rocks of the Upper Harz are subject of this investigation. Former petrological aspects concerning the plutonites of the Upper Harz were discussed by MOHR (1978) and MÜLLER (1978). More recent investigations were subsequently carried out by several authors: Brocken granite (GERS, 1980), western contact zone of the Harzburg gabbronorite (HENTSCHKE, 1982), REE studies on the Brocken granite (MORTEANI et al., 1986), Ecker gneiss (MÜLLER & STRAUSS, 1985; SCHLÜTER, 1983), Oker pluton (STÜTZE, 1977), granitoid dykes in the Harzburg gabbronorite massif (STÜTZE, 1980), Harzburg gabbronorite massif (VINX, 1982). Important new results were (a) the proof of a largely independent development of each particular plutonic complex (VINX, 1982) and (b) reconstruction of the pre-metamorphic and metamorphic history of the Ecker gneiss (SCHLÜTER, 1983). MÜLLER & STRAUSS (1987) published a review about the rocks of the Harz.

The detection of considerable amounts of largely »magmatic« zircons in rocks of the cumulate series of the Harzburg gabbronorite massif (VINX, 1982) stimulated the idea to work out a U-Pb geochronology of zircons for all western Harz plutonites and the Ecker gneiss as well.

2. Upper Harz crystalline complexes – Short review

2.1. Ecker gneiss

The Ecker gneiss (Fig. 2) is a unique rock association not only within the Harz but also within the whole Rhenohercynian belt of central Europe. Degree of metamorphism, style of deformation and age are not matched by any other geological unit therein. The Ecker gneiss crops out as a slab of 7 km^2 at the surface – completely surrounded by the plutonites of the Brocken granite and the Harzburg gabbronorite (Fig. 2). The lithology consists to > 99% of metasedimentary components (predominantly biotite-cordierite-bearing schistose hornfelses). SCHLÜTER (1983) detected some occurrences of preserved sedimentary textures and rare basaltic intercalations. The degree of metamorphism points to an origin from an intermediate tectonic level. The amphibolite facies metamorphism (SCHLÜTER, 1983) with relatively moderate pressure (0.4 GPa) and temperatures slightly above 600 °C corresponds to the Abukuma or Buchan type. Details of the lithology and petrogenesis of the Ecker gneiss will be reported by VINX & SCHLÜTER (in prep.).

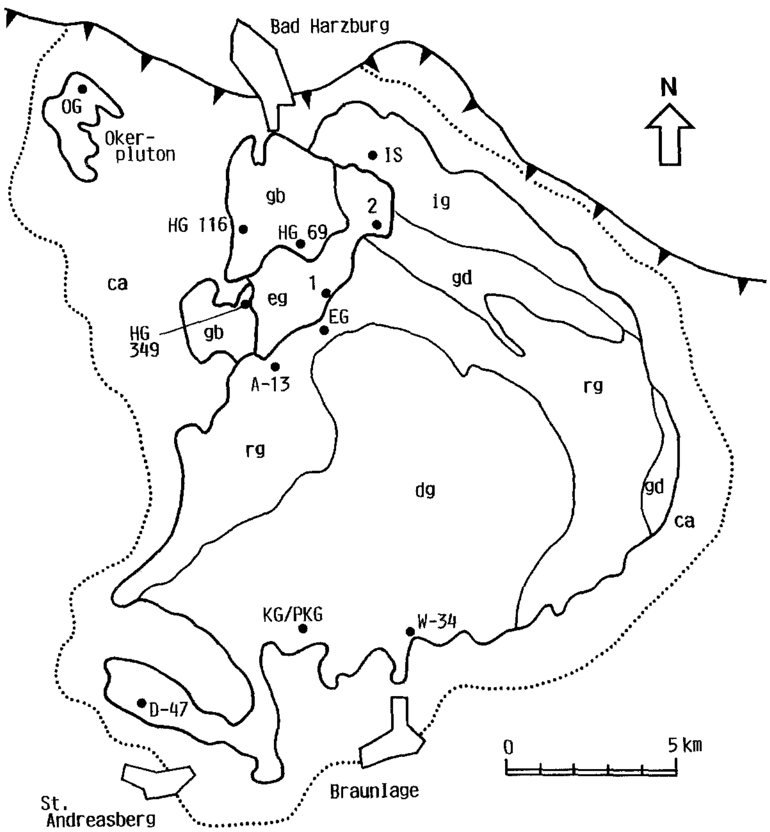

Fig. 2. Sketch map of the Upper Harz crystalline complexes and sample sites. Brocken granite complex: ca = contact aureole, ra = Randgranit, da = Dachgranit, gd = granodiorite, ig = Ilsestein granite. Ecker gneiss = eg, Harzburg gabbronorite = gb.

Additional contact metamorphic recrystallization of variable intensity is observable throughout the entire Ecker gneiss because the complex is only a few 100 m thick and is completely underlain by the Harzburg gabbronorite. The reason for the ascent of the Ecker gneiss slab squeezed in between the underlying Harzburg gabbronorite and the overlying Brocken granite is yet unclear. The most plausible conception is that the Ecker gneiss was passively carried up by the ascending gabbronorite magma as an allochthonous slab.

2.2 Harzburg gabbronorite

Most recent petrological studies of the Harzburg gabbronorite massif were carried out and reported in detail by Vinx (1982, 1983). Results which are fundamental in context to this investigation are briefly referred to:

The Harzburg gabbronorite is a relatively large example of a synorogenic and even syntectonic layered mafic/ultramafic intrusion with only a minor portion outcropping at the present erosion level. It is comparable to the more frequent synorogenic layered mafic intrusions of the Caledonides, e. g. of Scandinavia (Wilson et al., 1981; Otten, 1983) to some extent. It is, however, more strongly fractionated and intruded into a much higher crustal level. Most cumulate rocks are pronouncedly devoid of primary OH-bearing phases except for some phlogopite/biotite in late differentiates. There is no comparable occurrence in the Rhenohercynian belt or the European Variscides in general.

The rocks of the Harzburg intrusion comprise a complete and strongly fractionated tholeiitic sequence of cumulates ranging from chromite-rich dunites which are only known from an exploration drill hole (*Flora I*) to fayalite-bearing ferrodiorites with various gabbronorites as intermediate and dominating constituents. Vinx (1982) subdivided the Harzburg gabbronorite complex into three stratigraphic series:

A basal lower series exhibits the largest lithological variation with abundant forsterite-rich olivine and generally noritic rocks and with a strong tendency towards ultramafic cumulus assemblages. Conspicious magmatic layering is confined to this section.

A monotonous gabbronorite series in a medium position is devoid of olivine but contains plagioclase, orthopyroxene and clinopyroxene as cumulus phases.

The rocks of an upper ferrogabbro series with fayalite-rich olivine and pigeonite overlap the gabbro/diorite classification boundary. The most important fact in the context to this study is the strong enrichment of zirconium with values exceeding 3000 ppm. Consequently all rocks of the ferrogabbro series contain abundant zircon crystals favourable for U-Pb geochronological investigations of the Harzburg intrusion.

Orogenetic strain affecting the intrusive body prior to the end of crystallization of late intercumulus melts and especially of the ferrogabbroid magmas led to a complicated primary internal geometric pattern of a large portion of the intrusion. Late-stage fractionation products are missing in places. These can be backveined instead into earlier cumulates or they are squeezed into the Variscan country rocks and into the Ecker gneiss.

2.3 Brocken and Oker granites

The granitoid massifs of the Brocken and Oker plutons (Fig. 2) are concentric intrusions, independent from each other at the present erosion level. A direct connection in depth is also unlikely on reasons of considerable petrographical deviations. Leucocratic dykes within the gabbronorite massif and in the Ecker gneiss which formerly were considered as covered connections to the Brocken and Oker granitic complexes are independent contact anatectic products (STÜTZE, 1980).

The Brocken granite is the largest of the Harz intrusive complexes with 150 km^2 at the present surface level. The Brocken granite intrusion is probably a phacolith, whose feeder channel is located in the area of the eastern margin diorites. The rocks are granitic except for the eastern margin and a small streak in the northern part of the intrusion (Fig. 2). Proceeding from the eastern margin different facies string together in concentric semicircles. The concentrations of incompatible elements increase to the west (GERS, 1980). This pattern may be interpreted most plausibly by inflow of a pre-differentiated magma from the east.

Turbid, reddish K-feldspars, largely chloritised biotites and plagioclases impregnated by mixtures of sericite, epidote and partly calcite as well as miarolitic spots, vugs and locally occurring tourmaline aggregates point to intensive hydrothermal and pneumatolytic activity.

Contact metamorphic rocks at the southern rim of the Brocken granite consist mainly of very hard and brittle hornfelses originating from slates and fine-grained greywackes and of calcsilicates (MOHR, 1978). The sedimentation age of these rocks is assumed to be Lower Carboniferous since the Brocken granite body borders to slates and greywackes of this age in the south. The hornfels contact metamorphism bears isochemical character in general (MOHR, 1978).

The Oker intrusion is disconnected at the present erosion level. Dozens of small isolated outcrops within pelitic and graywacke hornfelses form an integrated concentric structure (STÜTZE, 1977): A succession of granodiorite, monzogranite, syenogranite is placed around a tonalitic core, situated near the northern margin fault of the Harz. Hints for similar strong effects of fluid phases as in the Brocken granite complex are lacking in the Oker complex.

3. Previous age information on the Harz crystalline rocks

The Ecker gneiss was primarily considered to be a Paleozoic formation overprinted by Variscan contact metamorphism (ERDMANNSDÖRFER, 1909). Because of the mineralogical composition, which is quite different from that of the Carboniferous contact metamorphic rocks, and on grounds of pronounced directional fabrics the Ecker gneiss was later on classified as part of an old crystalline basement of pre-Variscan origin (CHATTERJEE et al., 1960).

The geological frame suggests an intrusion age for the plutonites between Lower Carboniferous (Lower Namurian) and Upper Cretaceous (Senonian). Namurian sedimentary rocks were crosscut by the plutonites and pebbles of the igneous rocks do not occur earlier than in Senonian sequences. Before isotopic ages were available the emplacement in the Upper Carboniferous was assumed on the basis of geological and petrographical arguments which point to a strong relationship with other Variscan granites (SCHOELL, 1972a).

The Harzburg gabbronorite was orogenetically strained during later stages of its crystallization and is therefore considered to be late-syntectonic (VINX, 1982). Oker and Brocken granites are lacking the intensive deformation and the Variscan NE-SW elongation as is typical for the gabbronorite massif.

The first isotopic date from the Harz was reported by EVERNDEN et al. (1961)[1] who obtained a K-Ar biotite age of 313 Ma (327 Ma with obsolete constants) from a Harzburg gabbro sample. KULP (1961)[1] referred to this date as 311 ± 10 Ma (325 ± 10 Ma) and classified the Harzburg gabbronorite as beeing emplaced in the interval post-Visean/pre-Stephanian.

Detailed studies on isotopic ages of the Upper Harz plutonic rocks were published by Schoell (1970a, b, 1972a, b)[1]: K-Ar and Rb-Sr investigations on biotites of the Harzburg gabbronorite massif, the Oker and Brocken granites resulted in common uniform cooling ages of 290–296 Ma which are in close agreement with Rb-Sr whole rock isochron ages of 298 Ma for the Brocken granite and 295 for the Oker granite (Table 5). BENEK (1967) reported a coincident K-Ar age of 296 Ma for the Ramberg plutonic complex in the Central Harz.

The Rb-Sr whole rock isochron age of an aplitic dyke in the Brocken granite points to Sr homogenization in the decimeter range for this rock at 261 Ma (SCHOELL, 1972)[1] probably due to a younger thermal event. Since biotites yielded a K-Ar cooling age of 291 Ma the Rb-Sr isochron age cannot be interpreted as intrusion age. The Sr homogenization may be related to the Permian (»Rotliegend«) volcanism.

Lippolt et al. (personal communication) determined $^{40}Ar/^{39}Ar$ ages of 289 Ma and 293 Ma for sanidines and biotites, respectively, from an alkali rhyolite dyke of the southwestern Harz.

For the Ecker gneiss SCHOELL et al. (1973)[1] obtained a Rb-Sr whole rock isochron age of 392 Ma which was interpreted as the time of the dominant metamorphism.

4. Analytical procedures

Preparation of whole rock samples, separation of micas and zircons, chemical extraction of U and Pb (method after KROGH, 1973), Rb and Sr for isotopic composition and isotopic dilution measurements were carried out according to the description of BERG & BAUMANN (1985).

Concentrations were determined by isotope dilution mass spectrometry, using mixed ^{87}Rb-^{84}Sr and ^{208}Pb-^{235}U spikes. Blanks are 0.1–0.2 ng for Rb, 0.1–0.3 ng for Sr and U and 0.5–1 ng for Pb.

Isotope analyses were performed using an NBS-designed Teledyne thermal ionisation mass-spectrometer (12″, 90°), equipped with a single Faraday collector. Mass fractionation was determined to 0.3% per mass unit for Rb and 0.12% per mass unit for Pb, using NBS SRM 984 (RbCl) and SRM 981 as well as SRM 982 (Pb), respectively, as standards. The composition of the Pb blank is: $^{208}Pb/^{204}Pb$ = 37.5, $^{207}Pb/^{204}Pb$ = 15.52, $^{206}Pb/^{204}Pb$ = 17.72. The $^{87}Sr/^{86}Sr$ ratios were normalized to $^{86}Sr/^{88}Sr$ = 0.1194. The $^{87}Sr/^{86}Sr$ ratio used for blank correction is 0.710. The isotopic compositions of Pb and Sr blanks were measured in mixtures of aliquots of the solutions used for analytical processing. The average value measured for the NBS SRM 987 Sr carbonate standard is 0.71038 ± 0.00003 (2σ, 8 analyses). However, no corrections regarding this Sr standard were made on the $^{87}Sr/^{86}Sr$ ratios of the individual samples.

The analytical errors indicated in the tables and/or diagrams are 2σ (internal precision) for $^{87}Sr/^{86}Sr$, ± 1% for $^{87}Rb/^{86}Sr$, as estimated from duplicate analyses on reference standards, and 2σ for $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$. The calculation of the error ellipses in the concordia diagrams were performed according to LUDWIG (1979). It takes into account the internal precision (2σ) of the isotopic ratio measurements, the estimated uncertainty of the U/Pb ratio in the spike (± 0.15%), the individual error magnification from the spike/sample ratio, and the estimated uncertainty in the isotopic composition of the initial Pb (± 0.2%) and blank Pb (± 1%).

Regression lines were calculated according to YORK (1969), using the analytical errors as indicated above. Ages and element concentrations were computed with the constants recommended by STEIGER & JÄGER (1971).

5. Sample description

The Ecker gneiss consists mainly of metasedimentary rocks forming finely laminated biotite-cordierite-bearing schistose hornfelses grading into gneissic and quartzitic rocks (CHATTERJEE et al., 1960). A sample of the schistose hornfelses (EGN-1) contains heterogeneous zircon populations characterized by two prominent types with continuous transitions:

- anhedral, rounded (detrial) zircons with pitted surfaces,
- euhedral, short-prismatic crystals, some of them containing rounded cores.

All zircon types are translucent and have light pink colors. Metavolcanics intercalated between the metasedimentary rocks contain very low concentrations of zirconium, therefore, zircons are lacking and

[1]All Rb-Sr and K-Ar ages of EVERNDEN et al. (1961), KULP (1961), SCHOELL (1970a, b, 1972a, b) and SCHOELL et al. (1973) have been recalculated with the Rb- and K-decay constants recommended by STEIGER & JÄGER (1977).

only light pink anhedral sphene crystals have been analysed from this rock type (sample EGN-2).

The three samples for U-Pb investigations on zircons of the Harzburg gabbronorite complex are a quartz-bearing gabbronorite (HG-69) of the gabbronorite series and two specimens of the ferrogabbro series: gabbronorite (HG-349) and ferrohortonolite gabbronorite (HG-116). Sample HG-69 is obviously affected by crustal contamination as the SiO_2 content exceeds by 5% that of normally fractionated rocks with similar Fe/Mg ratios. Xenolithic blocks occasionally occur in the quartz gabbronorite.

Unfractionated theoleiitic magmas generally contain zirconium in minor amounts only (60–160 ppm Zr; ERLANK et al., 1978). This incompatible element is being partitioned into early cumulates even less. Thus gabbroic rocks are in general depleted or devoid of zircons. If zircons occur in these rocks in higher concentrations and together with apatite – as in the case of the Harzburg gabbronorite complex – only late differentiation products or contamination by foreign rocks or combinations of both may be responsible for that phenomenon. In the Harzburg complex zircons occur in Fe-dominated rocks of the gabbronorite series and most abundantly in all rocks of the ferrogabbro series.

The zircons of all three samples (see Table 1 for Zr concentrations) have a uniformly pink tinge, are transparent and rarely show fluid inclusions. Euhedral habit and in some cases casts from adjacent plagioclase grains point to a predominantly magmatic origin of the zircons. A few inherited components are indicated by rounded cores.

Samples of the Brocken granite have been collected from various sites (Fig. 2) and different granitic varieties in the sense of MOHR (1978):

- Regular roof granite (*Dachgranit*): D-47, W-34,
- porphyric roof granite: KG,
- micropegmatitic granite of the western margin (*Randgranit*): EG, A-13.

Additionally samples from two profiles of the sharp *Dachgranit*-hornfels contact in the Königskopf quarry have been taken and cut into slabs (Fig. 3):

	Profile I	Profile II
hornfels	PKG-2, PKG-3,	PKG-11, PKG-12, PKG-13
biotite-rich granite	PKG-4,	PKG-14
biotite granite	PKG-5,	PKG-15, PKG-16, PKG-17, PKG-18.

Hornfels sample PKG-1 and granite sample PKG-6 have been taken at distances of 5 m and 2 m, respectively, from the contact. Sample PKG-7 from another position of the contact zone where the immediate contact is diffuse, consists of a metasomatically altered, porphyroblastic, granitized contact hornfels with feldspars up to 1 cm in a fine-grained matrix of quartz, feldspars and chlorite. According to chemical analyses the composition of this rock is granitic (Table 1). An up to 3 cm wide reaction zone with increased biotite content occurs where the contact is sharp (biotite-rich granite, samples PKG-4 and PKG-14).

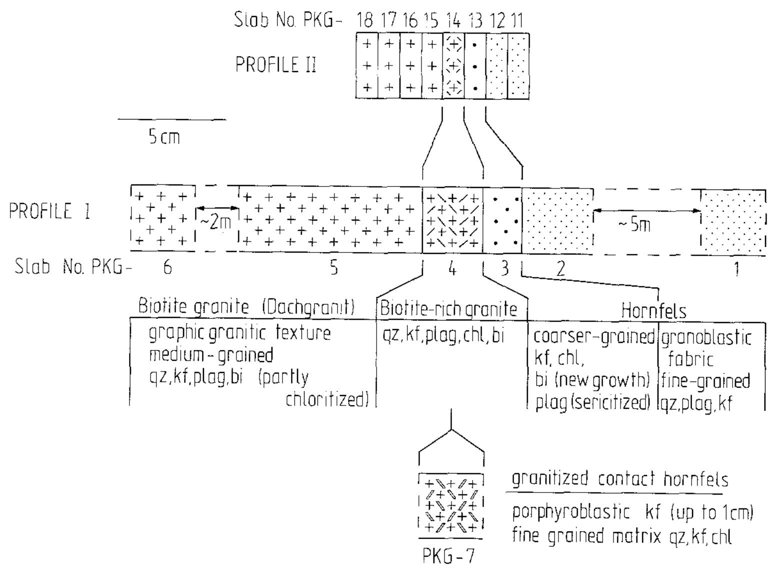

Fig. 3. Schematic sketch of two profiles across the Brocken granite-hornfels contact zone in the Königskopf quarry.

Sample	HG- 69	HG-116	HG-349	PKG- 1	PKG-11	PKG-12	PKG-13	PKG- 7	PKG-14	PKG- 6	PKG-15	PKG-16	PKG-17	PKG-18	KG	EG	OG	
Rock	quartz gabbro norite	olivin gabbro norite	gabbro norite	<------- hornfels			------->	grani- tized hornfels	biotite- -rich granite	<---------- Dachgranit				---------->	porphr. Dach- granit	m.pegm. Rand- granit	Oker (biotite) granite	
Main elements (weight %)																		
SiO_2	53.56	42.72	54.21	69.09	69.75	69.67	69.10	73.14	66.69	74.74	67.27	74.23	75.55	74.82	71.98	75.05	74.08	SiO_2
Al_2O_3	15.80	12.61	17.06	12.54	13.43	13.58	13.39	13.31	13.20	12.67	12.35	12.53	12.50	12.59	12.90	12.78	12.89	Al_2O_3
Fe_2O_3	0.61	0.56	0.62	4.87	4.46	4.36	5.07	1.97	8.03	1.95	8.01	3.02	1.54	1.78	2.79	1.96	1.78	Fe_2O_3
FeO	8.78	21.47	9.24															FeO
MnO	0.14	0.40	0.21	0.05	0.06	0.06	0.07	0.03	0.14	0.04	0.13	0.05	0.03	0.03	0.06	0.05	0.04	MnO
MgO	4.59	5.03	2.48	1.74	1.70	1.72	1.51	0.40	1.41	0.22	0.78	0.30	0.17	0.19	0.40	0.09	0.18	MgO
CaO	9.09	8.25	7.25	2.62	3.91	3.51	3.23	0.60	2.10	0.95	1.58	0.81	0.61	0.69	0.96	1.06	0.68	CaO
Na_2O	2.01	2.09	2.08	2.71	2.85	2.93	2.80	2.99	2.90	2.80	2.38	2.29	2.28	2.66	2.73	2.90	3.16	Na_2O
K_2O	1.61	0.88	1.75	3.03	0.45	0.65	0.75	5.77	2.28	5.23	3.91	5.53	5.94	5.53	4.73	5.01	5.20	K_2O
TiO_2	1.28	3.65	2.14	0.74	0.70	0.70	0.68	0.32	0.67	0.24	0.99	0.32	0.17	0.19	0.42	0.20	0.22	TiO_2
P_2O_5	0.36	1.38	0.53	0.12	0.13	0.13	0.12	0.08	0.16	0.06	0.33	0.09	0.05	0.06	0.07	0.03	0.06	P_2O_5
SO_3	0.26	0.37																SO_3
L.I.				2.18	2.34	2.41	2.48	1.44	1.57	0.80	1.23	1.28	1.02	1.13	2.06	0.60	1.70	L.I.
H_2O^+	2.50	1.94	1.54															H_2O^+
H_2O^-	0.07	0.09	0.15															H_2O^-
TOTAL	100.52	101.04	99.05	99.61	99.76	99.70	99.20	99.99	99.13	99.61	98.95	100.44	99.84	99.67	99.10	99.68	99.99	TOTAL
Trace elements (ppm)																		
Ni	30	20	10															Ni
Cr	152	56	50	78	78	80	74	12	71	10	40	20	10	11	10			Cr
Zr	297	741	2039	184	162	157	150	233	268	216	1105	298	160	195	359	297	400	Zr
Rb[1)]	104	32	98	144	22	38	56		248	265	314	294	308	287	172	255	170	Rb[1)]
Sr[1)]	267	204	222	138	229	222	173		59	51	61	47	42	48	92	48	95	Sr[1)]
Ba	446	194	119	500	220	177	157	701	96	420	197	256	259	332	917	523	470	Ba
Sc	38	28	19															Sc
V	172	300	73	83	75	53	55	25	25		45				30		11	V
La		58	38		48	14		21	46	43	440	81	40	65	83	32	40	La
Ce	54	134	123	30	45	36	43	75	150	90	665	171	75	109	197	100	149	Ce
Nd	31	72	51	12	18	11	31	27	63	34	260	65	42	36	87	32	45	Nd
Y				14	24	29	30	24	69	38	104	67	55	56	46	22	49	Y
Cu	9	14	398		148	276	365		88		55	20	30					Cu
Zn	75	117	88	49	30	41	73	19	209	31	175	57	22	14	73	60	35	Zn
Pb					40	33	31	23	40	33	56	55	42	41	40	49	50	Pb
Fe*	66	82	74															Fe*
a/cnk	0.73	0.65	0.92					1.09	1.19	1.06	1.12	1.12	1.11	1.08	1.14	1.05	1.07	a/cnk
CIPW norm (%)																		
ap	0.8	3.1	1.2					0.2	0.4	0.1	0.7	0.2	0.1	0.1	0.1	0.1	0.1	ap
pr	0.3	0.4																pr
il	1.9	5.4	3.1					0.5	1.0	0.3	1.5	0.5	0.2	0.3	0.3	0.3	0.3	il
or	9.9	5.5	10.9					35.0	14.3	31.8	24.6	33.8	36.2	33.8	29.5	30.4	31.7	or
ab	18.7	19.9	19.7					27.6	27.6	25.9	22.7	21.3	21.1	24.7	25.8	26.8	29.3	ab
an	30.4	23.7	33.8					2.5	9.9	4.5	6.1	3.6	2.8	3.1	4.8	5.2	3.1	an
c								1.4	2.9	0.9	2.5	1.7	1.5	1.3	1.9	0.8	1.1	c
mt	0.7	0.6	0.7															mt
q	6.8		11.4					29.3	28.7	33.3	29.0	34.2	35.5	33.9	32.6	33.6	31.6	q
hy	19.5	18.2	18.9					3.6	15.2	3.2	12.9	4.8	2.5	2.9	5.1	2.9	2.8	hy
di	11.1	8.0	0.4															di
ol		15.2																ol

Table 1. Main and trace element XRF data of plutonic rocks and hornfelses and CIPW norm of plutonic rocks of the Upper Harz Mountains. [1)] = Isotope dilution data. Fe* = 100 FeO/(FeO+MgO), $Fe_{tot.}$ as FeO, a/cnk = mol[Al_2O_3/(CaO+Na_2O+K_2O)]

Reddish colored granite varieties from this quarry contain miarolitic vugs with tourmaline, epidote, albite, sheaflike desmine, quartz and violet fluorite. The whole granite body of the quarry is crosscut by aplitic dykes.

Zircons have been separated from a *Randgranit* sample of the Ecker valley (EG), from a *Dachgranit* sample of the Königskopf quarry (KG) and from several samples of the two profiles through the granite-hornfels contact zone of the Königskopf quarry (PKG-1 to PKG-7).

The zircon crystals of the granite samples PKG-5, PKG-6, KG and EG are uniformly euhedral and show largely intact prismatic and pyramidal planes. Zircons in the granite at the immediate granite/hornfels contact of the Königskopf quarry (samples PKG-5, PKG-7) additionally show rounded edges and sometimes small hollows. The hollows may be explained as the effect of corrosion. The color of the zircons is light pink in most cases. The *Randgranit* sample contains zircons showing all transitons to dark brown, turbid crystals occasionally with fissures and fractures. Most zircons have oriented inclusions and cloudy turbidities, often the crystals are concentrically zoned as can be observed under the microscope.

The hornfelses (samples PKG-1, PKG-2, PKG-3) contain rounded, detrial zircons on the one hand and well developed euhedral, short prismatic crystals on the other hand as well as all transitions between either group.

The Okergranite sample investigated (OG) was collected from the southeastern part of the complex because the zirconium concentrations are higher there than in other parts of the intrusion (STÜTZE, 1977). The granite sampled is coarse-grained, the main components quartz, feldspar and biotite have grain sizes up to 1 cm.

Zircon crystals are euhedral, prismatic, light pink, slightly turbid and partly contain many inclusions: rounded opaque foreign components, gas bubbles and fluid inclusions.

Chemical analyses of main and trace elements and the normative composition of the rock samples are listed in Table 1.

6. Results and discussion

6.1 Ecker gneiss

Seven zircon fractions have been analysed. The uranium concentrations in the zircons are relatively low with 200–500 ppm (Table 2).

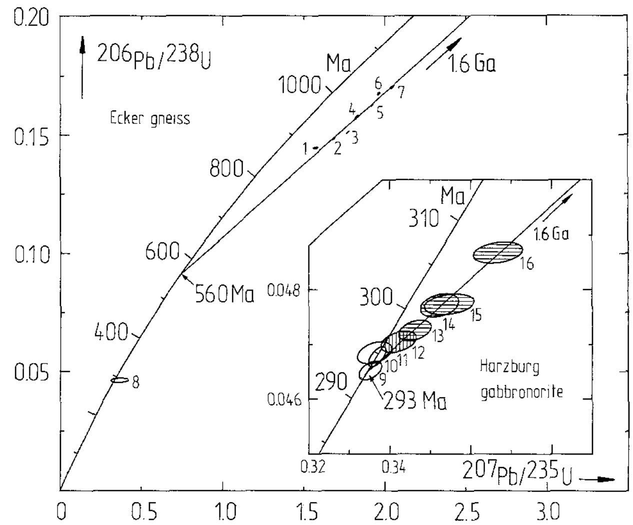

Fig. 4. Concordia diagrams of Ecker gneiss zircon (EGN-1: # 1–7) and sphene (EGN-2: # 8) data (main diagram) and Harzburg gabbronorite zircon data (inset diagram: HG-116: # 12; HG-349: # 13–16; HG-69: # 9–11). Numbers of points refer to column »*« in Table 2.

The U-Pb data points of the zircons are highly discordant in the concordia diagram (Fig. 4) and scatter arround a regression line with upper and lower intercepts corresponding to ages of about 1.6 Ga and 560 Ma. The anhedral fractions (6 and 7 in Fig. 4) show slightly higher discordance with respect to the lower intercept than the euhedral ones (1 and 2), the data of unsorted fractions (3, 4 and 5) occupy intermediate positions in the concordia diagram. The upper intercept is explained as representing the approximate age of the primary zircon growth and the lower one is interpreted as indicating the time of episodic radiogenic lead loss of the zircons in the present host rock or in precursor rocks probably due to a regional metamorphic event during the Cadomian orogenic cycle.

Variscan overprinting by contact metamorphism is documented by the quasi-concordant U-Pb data point of sphenes (8 in Fig. 4) from a metabasaltic Ecker gneiss sample (EGN-2) at about 295 Ma.

Though the regression line is poorly defined due to the large scatter of the data points of the Ecker gneiss zircons the data do not reflect tectonometamorphic events later than Cadomian. This is in line with examples of zircons recrystallized or newly crystallized during the time synchronous with the Caledonian orogeny. These zircons behaved as closed systems for U and Pb and were not affected isotopically during Hercynian metamorphism about

Sample	*	sieve fraction (µm)	concentrations U (ppm)	concentrations Pb (ppm)	measured ratios $^{208}Pb/^{206}Pb$	measured ratios $^{207}Pb/^{206}Pb$	measured ratios $^{206}Pb/^{204}Pb$	calculated ratios $^{206}Pb/^{238}U$	calculated ratios $^{207}Pb/^{235}U$	calculated ratios $^{207}Pb/^{206}Pb$	apparent ages (Ma) $^{206}Pb/^{238}U$	apparent ages (Ma) $^{207}Pb/^{235}U$	apparent ages (Ma) $^{207}Pb/^{206}Pb$
Ecker gneiss													
EGN-1	4	80-100 t	317	53.4	0.1409	0.09236	1684	0.15740	1.8230	0.08400	942	1054	1293
Zircons	6	80-100 r	312	56.4	0.1470	0.09564	1316	0.16752	1.9623	0.08496	998	1103	1315
(in meta-sediment)	1	80-100 e	216	32.4	0.1321	0.08685	1795	0.14452	1.5736	0.07897	870	960	1171
	5	63- 80 t	365	62.4	0.1295	0.08942	3690	0.16252	1.9184	0.08561	971	1087	1329
	7	63- 80 r	358	67.6	0.1647	0.10360	843	0.17036	2.0428	0.08700	1014	1130	1360
	2	63- 80 e	503	78.7	0.1327	0.08882	2199	0.14832	1.6854	0.08241	892	1003	1255
	3	< 63 t	436	68.6	0.1208	0.08754	5618	0.15095	1.7698	0.08503	906	1034	1316
EGN-2 Sphene (in metavolcanite)	8	< 100	54.6	4.94	0.6833	0.20216	100	0.04630	0.3626	0.05680	291	314	484
Harzburg gabbronorite													
HG-349	16	165-200	130	7.25	0.2272	0.07770	633	0.04868	0.3667	0.05464	306	317	398
	13	125-165	251	13.2	0.2014	0.06884	931	0.04725	0.3462	0.05313	298	302	335
	15	100-125	191	10.6	0.2250	0.08078	544	0.04773	0.3547	0.05389	301	308	367
	14	80-100	153	8.16	0.2050	0.06924	932	0.04771	0.3523	0.05354	300	306	352
HG-116	12	80-100	73.6	4.30	0.3514	0.07463	668	0.04705	0.3422	0.05275	296	299	318
HG-69	9	> 165 f	284	14.4	0.1807	0.06619	1052	0.04652	0.3352	0.05227	293	294	297
	10	> 165 e	279	14.1	0.1904	0.06221	1468	0.04677	0.3369	0.05223	295	295	296
	11	125-165	330	17.1	0.1923	0.07058	791	0.04685	0.3362	0.05205	295	294	288
Oker granite													
OG	17	125-165	320	17.1	0.2334	0.07344	694	0.04675	0.3374	0.05234	295	295	300
	18	80-100	387	20.3	0.2228	0.06682	1026	0.04662	0.3378	0.05254	294	295	309
	19	< 63	646	48.4	0.7601	0.06935	893	0.04653	0.3398	0.05296	293	297	327

t - total zircon sieve fraction, r - rounded zircon crystals, e - euhedral, prismatic zircons, f - zircon fragments

Table 2. U-Pb data of zircons (and sphenes) of the Ecker gneiss, Oker granite and Harzburg gabbronorite complexes in the Upper Harz Mountains. * = Numbers of points in Figures 4 and 5. Initial lead used for common Pb corrections: model lead composition (STACEY & KRAMERS, 1975) at 560 Ma: Ecker gneiss zircons; at 295 Ma: Ecker gneiss sphenes, Harzburg gabbronorite and Oker granite zircons.

150 Ma later in gneisses, e. g. of the Silvretta nappe and the Gotthard massif (GRAUERT & ARNOLD, 1968), the Ceneri zone (PIDGEON et al., 1970) of the Alps and of the crystalline basement of NE Bavaria in the Bohemian massif (GEBAUER & GRÜNENFELDER, 1974). The poor fit of the data points of the Ecker gneiss zircons to the regression line may, however, be a hint to post-Cadomian slight disturbances.

SCHOELL et al. (1973)[1] obtained a Rb-Sr whole-rock isochron age for the Ecker gneiss of 392 $\pm$ 10 Ma and interpreted this as the age of the dominant metamorphism. The isochron is predominantly defined by the spread of data from samples of one particular site although some data of samples from sites several kilometers apart were included in isochron calculation. The Variscan intrusions obviously did not affect the whole-rock Rb-Sr isotopic systems by contact metamorphism.

The age of 392 Ma corresponds to the Lower to Middle Devonian boundary. The Ecker gneiss which was later uplifted by ascending Variscan magmas had resided in an intermediate crustal level at that time. The 392 Ma event coincides temporally with the emplacement of voluminous basaltic magmas (*Oberharzer Diabas*) not only at or near the surface but neccessarily also in intermediate levels of the crust. The commencement of the basaltic volcanism can be stratigraphically dated as Eifelian (Lower/Middle Devonian; MOHR, 1978). This volcanism and synchronous basin subsidence plus sedimentation within the Harz area indicate a tensional tectonic regime. This is in apparent contrast to the obviously compressive character of the main deformation and metamorphism of the Ecker gneiss. The 392 Ma Sr isotopic equilibration event could be most plausibly be explained in the context of wide-spread ascent and emplacement of basaltic magmas and the associated fluid activity.

The 392 Ma Ecker gneiss age records an event which is synchronous with the Acadian event of the New England Appalachians (RODGERS, 1970) with ages between 370 and 400 Ma. Similar ages were reported from crystalline rock complexes of the Saxothuringian and Moldanubian zones of the Variscides at the northwestern margin of the Bohemian Massif (GEBAUER & GRÜNENFELDER, 1979; KREUZER et al., 1989; SÖLLNER et al., 1981a, b; TEUFEL, 1988), from the Venn-Stavelot Massif, Ardennes, Belgium/Germany (KRAMM & BUHL, 1985), bore hole Saar 1, Germany (granite; LENZ & MÜLLER, 1976), Spessart Mountains, Germany (»Rotgneis«; KREUZER et al., 1973), Appalachian Belt, England, Scotland, Greenland and Norway (FAIRBAIRN, 1971), Massif Central, France (BERNARD-GRIFFITHS et al., 1977), Sierra de Guadarrama, Spain (WILDBERG et al., 1989). Many of these isotopic ages were interpreted as reflecting tensional tectono-metamorphic processes.

Of the isotopically documented ages (560 Ma, 392 Ma and 295 Ma) none can be unambiguously attributed to the main metamorphism of the Ecker gneiss. The event at 392 Ma most probably documents a tensional process with synchronous emplacement of basaltic magmas and the 295 Ma sphene age records contact metamorphic overprinting by the emplacement of the Variscan plutons. The lower intercept age of zircon data of 560 Ma may either indicate metamorphism of the Ecker gneiss or may be an inherited age of the source area of the detrital zircons. The present data do not allow to make a decision in favour of either possibilities. Samples from Ecker gneiss outcrops located in a formerly prohibited area near the now abandoned German Democratic Republic/Federal Republic of Germany border may contribute to solve this problem.

The isotopic results very clearly support the interpretation based on structural investigations that the Ecker gneiss is a fragment of the pre-Variscan basement (CHATTERJEE et al., 1960). It was transported upwards as an allochthonous slab by the ascending Harzburg gabbronorite magma (VINX, 1983).

The different results of the U-Pb and Rb-Sr isotopic investigations point to a poly-phase development of the Ecker gneiss.

6.2 Harzburg gabbronorite massif

Eight zircon fractions from three samples have been analysed. Compared to, e. g. zircons of granites the present zircons of the gabbronorite complex are rather uranium-poor and, moreover, their uranium concentrations are different in the particular rock types: olivine gabbronorite (HG-116, 12 in Table 2 and Fig. 4): ~75 ppm, gabbronorite (HG-349, 13–16): 130–250 ppm, quartz gabbronorite (HG-69, 9–11): 280–330 ppm.

The U-Pb data points of three zircon fractions of sample HG-69 are concordant at 294 $\pm$ 1 Ma (9–11 in Fig. 4). The data points of the two other samples (HG-116, HG-349) are slightly discordant and define a discordia with a lower intercept age of 293 $\pm$ 2 Ma. This age is considered as the crystallization age of the zircons coincident with the final stage of the magmatic main crystallization and thus represents the intrusion age of the Harzburg gabbronorite complex.

The zircons of the samples HG-116 and HG-349 contain small amounts of inherited pre-Variscan components. The resulting upper intercept age of about 1.6 Ga points to a Proterozoic age of inherited zircon components. The coincidence with the upper intercept age of the Ecker gneiss zircons is striking and points to similar sources of the inherited zircon components for either rock unit.

It is noteworthy that the inherited pre-Variscan zircon component has been found so far only in rocks of the ferrogabbro series. It does not occur in the sample of the gabbronorite series although this rock seems to represent a product of an already advanced stage of crustal contamination of the gabbronorite magma as compared to the much more abundant completely zircon-free gabbronorites. This fact suggests that zircons from the country rocks obviously have not been preserved in the gabbroic magmas of the early and medium evolution stages due to zirconium undersaturation. These zircons, however, caused enrichment of zirconium in the successive residual magmas until these allowed the crystallization of zircons with synchronously increasing SiO_2. Subsequently incorporated old zircons were not completely dissolved any more. Consequently the zirconium concentration is highest in the gabbronorite sample (Table 1) of the ferrogabbro series.

The coincidence of the K-Ar and Rb-Sr biotite ages of 290.5 ± 1.3 Ma and 296 ± 5 Ma, respectively (SCHOELL, 1972)[1], with the intrusion age points to a short cooling history of the Harzburg gabbronorite complex in a high crustal level. The ferrogabbro series as end product of a closed, extremely tholeiitic differentiation path may be also an indicator for the crystallization in a shallow and consequently cool crustal level. Further evidence for rapid cooling is the occurrence of incompletely inverted pigeonite in rocks of the ferrogabbro series.

A pre-Variscan formation of the Harzburg gabbronorite as part of an ophiolite complex and merely tectonic Variscan emplacement was assumed by ANDERSON (1975). This is contradicted – apart from the now well established intrusion age – by clear magmatic contacts of the gabbronorite massif with the country rocks folded in the Variscan.

Data of Rb-Sr and Sm-Nd isotopic investigations on whole-rock samples of a representatively selected collection over the total spectrum of fractionation of the Harzburg gabbronorite massif did not deliver consistent age information. Analytical results and detailed discussion will be published elsewhere.

6.3 Brocken granite

6.3.1 Results of U-Pb zircon analyses

6.3.1.1 Zircons from granite

Uranium concentrations of the Brocken granite zircons are high compared with zircons of the Ecker gneiss and Harzburg gabbronorite with one exception (PKG-7 >100 μm: 267 ppm U), they range between 530 and 2090 ppm (Table 3). The brown, turbid fraction 100–125 μm of sample EG even contains > 0.5% U.

The U-Pb data points of the zircon samples EG (*Randgranit*) are slightly discordant between 280 and 290 Ma (31–35 in Fig. 5), whereby the U-rich, dark-brown, turbid fraction (31) is most discordant with respect to the upper concordia intercept. Due to the small spread of the data a regression line through the points with an upper intercept age at 301 Ma and a trajectory ± through the origin is poorly defined.

The data of the *Dachgranit* zircons from the Königskopf quarry comprising samples KG, PKG-5, PKG-6 and also PKG-7; 20–26 and 28–30 in Fig. 5) define a similar line with an upper intercept age of $303 \pm ^{11}_{6}$ Ma. The point of zircon fraction 80–100 μm of sample PKG-6 (27) is offset from this line whereas the point of the zircon fraction >100 μm of PKG-7 (30) is concordant at 296 Ma, an age which coincides with the Rb-Sr whole rock isochron and biotite ages and the K-Ar biotite age obtained by SCHOELL (1970a, b, 1972)[1] on Brocken granite samples (Table 5).

From the data the following interpretation for the Brocken granite zircon pattern is tentatively suggested: Zircons grown during the crystallization of the Brocken granitic magma contain small amounts of older inherited zircon components causing weak but variable primary discordances. Sub-recent to recent radiogenic lead loss possibly as a result of the uplift of the Harz slightly shifted the primary data points towards the origin to their present positions. The extrapolation of the regression line through the present data points and the origin therefore yields an upper intercept age slightly higher than the true age of intrusion which must be lower than 300 Ma according to Rb-Sr data (see below). Because of their relatively high U concentrations the Brocken zircons are much more subject to radiation damage than the other Harz zircons. Therefore they are probably more susceptible to lead loss through microfissures caused by pressure release in the sense of GOLDICH & MURDREY (1972) when the Brocken granite was uplifted. Reaching the groundwater level may have

Sample	*	sieve fraction (µm)	U concentrations (ppm)	Pb concentrations (ppm)	measured ratios $^{208}Pb/^{206}Pb$	measured ratios $^{207}Pb/^{206}Pb$	measured ratios $^{206}Pb/^{204}Pb$	calculated ratios $^{206}Pb/^{238}U$	calculated ratios $^{207}Pb/^{235}U$	calculated ratios $^{207}Pb/^{206}Pb$	apparent ages (Ma) $^{206}Pb/^{238}U$	apparent ages (Ma) $^{207}Pb/^{235}U$	apparent ages (Ma) $^{207}Pb/^{206}Pb$
EG	33	> 100	1114	51.4	0.1304	0.05899	2237	0.04476	0.3236	0.05244	282	285	305
	32	80-100	1598	76.2	0.1512	0.06596	1074	0.04471	0.3226	0.05232	282	284	299
	35	- 80	1667	79.8	0.1417	0.06262	1424	0.04576	0.3303	0.05235	288	290	301
	34	< 50	1898	87.6	0.1285	0.05929	2141	0.04491	0.3248	0.05246	283	287	305
	31	100-125 b	5734	285	0.2030	0.07058	687	0.04410	0.3177	0.05225	278	280	297
KG	23	> 125	540	42.6	0.5195	0.20404	96.7	0.04287	0.3142	0.05316	271	278	336
	22	80-100	667	47.0	0.4671	0.18101	114	0.04153	0.3026	0.05285	262	268	322
	21	50- 80	729	43.0	0.3725	0.14275	163	0.03998	0.2913	0.05284	255	260	322
	20	< 50	990	58.4	0.4328	0.13147	181	0.03927	0.2858	0.05278	248	255	319
PKG-1	40	> 100 e	2919	140.3	0.1608	0.06345	1365	0.04504	0.3274	0.05272	284	288	317
	39	> 100 r	456	45.3	0.1640	0 09190	2383	0.09157	1.0859	0.08601	565	747	1338
	36	0-100 e	1915	95.8 8	0.1581	0.06538	1111	0.04701	0.3441	0.05310	296	300	333
	38	80-100 r	625	52.9	0.1662	0.08750	1839	0.07866	0.8656	0.07981	488	633	1192
	37	63- 80 e	1319	71.1	0.1793	0.07373	782	0.05005	0.3801	0.05509	315	327	416
PKG-2	44		639	50.4	0.2482	0.11180	311	0.07099	0.6933	0.07083	442	535	953
PKG-3-	43	r	360	31.3	0.1594	0.08870	1576	0.08105	0.8910	0.07973	502	647	1190
	42	e	326	24.2	0.1938	0.07927	1168	0.06875	0.6350	0.06699	429	499	837
PKG-4	41	e	1236	72.4	0.2118	0.08934	457	0.05098	0.4042	0.05750	321	345	511
PKG-5	25	80-100	897	46.7	0.2540	0.10391	284	0.04195	0.3026	0.05232	265	268	299
	24	< 80	852	42.8	0.2306	0.09698	328	0.04215	0.3042	0.05235	266	270	301
PKG-6	27	80-100	616	39.3	0.3306	0.13169	186	0.04604	0.3429	0.05402	290	299	372
	26	63- 80	2089	104.9	0.1925	0.08015	535	0.04447	0.3222	0.05255	281	284	309
PKG-7	30	> 100	267	13.1	0.1800	0.06498	1153	0.04691	0.3384	0.05231	296	296	299
	29	80-100	544	26.1	0.1724	0.06921	889	0.04483	0.3261	0.05276	283	287	319
	28	63- 80	529	32.8	0.3258	0.13216	183	0.04469	0.3231	0.05244	282	285	305

b - brown zircon crystals, e - euhedral, prismatic zircons, r - rounded zircons

Table 3. U-Pb data of zircons of the Brocken granite complex in the Upper Harz Mountains. * = Numbers of points in Figures 5 and 6. Initial lead used for common Pb corrections: Pb isotopic composition of Brocken granite K-feldspar (WEDEPOHL et al., 1978): Brocken granite zircons; model lead composition (STACEY & KRAMERS, 1975) at 560 Ma: rounded zircons from the hornfels samples; at 295 Ma: euhedral zircons from the hornfels samples.

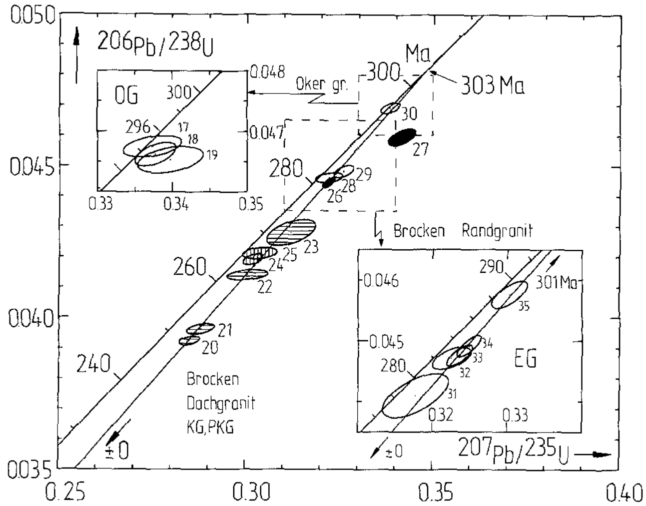

Fig. 5. Concordia diagrams of zircon data of the Oker granite (inset diagram upper left; OG: # 17–19), Brocken *Dachgranit* (main diagram: PKG-5: # 24, 25; KG: # 20–23; PKG-6: # 26, 27; PKG-7: # 28–30) and Brocken *Randgranit* (inset diagram lower right: EG: # 31–35). Numbers of points refer to columns »*« in Tables 2 and 3.

favoured lead leaching processes. This interpretation seems to be supported by the fact that the zircon fraction with the concordant data point (30) has indeed the lowest U concentration of all Brocken granite zircons.

6.3.1.2 Zircons from hornfels

Generally the rounded hornfels zircons from the contact zone in the Königskopf quarry have lower U concentrations (38, 39, 43: 360–625 ppm) than the euhedral ones (36, 37, 40–42: 330–2920 ppm). In Fig. 6 all points of the hornfels zircons are plotted together with the granite zircons of the Königskopf quarry. The rounded, detrial zircons indicate highly discordant ages pointing to about 2 Ga. A regression line through the data points of both the euhedral and rounded zircon fractions of hornfels sample PKG-1 (36–39) intersects concordia at 297 ± 4 Ma and about 1.8 Ga. The euhedral zircon fraction >100μm of PKG-1 (40), however, is set off from this line and rather behaves like the granite zircons. The data point of prismatic zircons of the biotite-rich granite sample PKG-4 (41) also fits this regression line. A similarity with the regression lines through the data points of the Ecker gneis and Harzburg gabbronorite zircons is obvious and probably indicates an origin of the inherited zircon components from similar Proterozoic sources for all three rock complexes.

The data points of the zircon fraction of the hornfels samples PKG-2 and PKG-3 (42–44) show a different pattern. The dashed regression line through these points intersects concordia at 373 Ma and about 2.2 Ga. With the present scarcity of data and status of information it remains a matter of question whether the lower intercept age of 373 Ma is a real inherited age of the zircons in the hornfelses.

6.3.2 Results of Rb-Sr analyses

Rb-Sr data from all Brocken granite samples are compiled in Table 4. The data points of samples *outside the Königskopf quarry* (samples A-13, EG, W-34, D-47 and PKG-6 as reference) scatter in an isochron diagram and do not define an isochron (Fig. 7). This is in contrast to the results of SCHOELL (1970, 1972a, b)[1], who obtained a Rb-Sr whole rock isochron of 298 ± 12 Ma (Fig. 7). Furthermore, this author assumed that Brocken and Oker granites belong geochemically and temporally to o n e intrusion and with the Rb-Sr data of both intrusions he calculated a common isochron of 295 ± 6 Ma.

The Rb-Sr data points of the granite and hornfels samples of the *Königskopf profiles across the granite-hornfels contact* define an isochron with a slope corresponding to an age of 293 ± 3 Ma (Fig. 8). The data of hornfels slabs 1, 11 and 12 which are most distant from the contact as well as of the granite slab 18 which contains a certain amount of chlorites as alteration products of biotite have not been used for calculation. The isochron indicates that the hornfels approximated isotopic equilibrium with the granite by contact metamorphism in the few centimeters of the immediate contact zone.

The biotite age of the biotite-rich granite sample PKG-4 was determined as 293 ± 5 Ma and is iden-

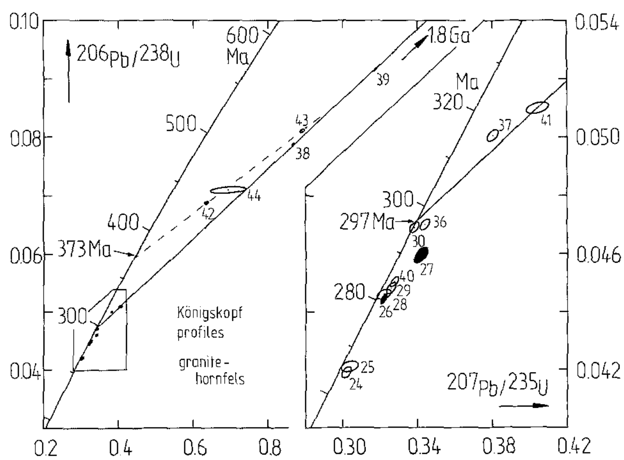

Fig. 6. Concordia diagrams of Brocken granite (PKG-5 – PKG-7: # 24–30) and hornfels (PKG-1 – PKG-3: # 36–44) zircon data of samples from the contact zone in the Königskopf quarry. Numbers of points refer to column »*« in Table 3.

Sample	Rock	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
PKG-1	hornfels	143.7	138.0	3.0167	0.71920±0.00008
PKG-2	hornfels	135.8	154.8	2.5410	0.72051±0.00015
PKG-3	hornfels	122.7	265.1	1.3403	0.71587±0.00014
PKG-4	bio-rich granite	344.9	111.2	9.0112	0.74899±0.00005
PKG-4	" - " bio	1021.9	6.43	566.46	3.0747 ±0.0011
PKG-5	granite	281.1	57.6	14.213	0.76900±0.00011
PKG-6	granite	265.4	51.0	15.156	0.77353±0.00005
PKG-11	hornfels	22.3	228.7	0.28179	0.70981±0.00004
PKG-12	hornfels	38.2	222.2	0.49790	0.71143±0.00004
PKG-13	hornfels	55.7	173.4	0.93052	0.71420±0.00018
PKG-14	biotite-rich granite	247.8	58.7	12.276	0.76194±0.00018
PKG-15	granite	313.9	60.6	15.077	0.77366±0.00019
PKG-16	granite	293.9	47.4	18.080	0.78554±0.00012
PKG-17	granite	308.0	41.9	21.439	0.79870±0.00019
PKG-18	granite	286.5	47.6	17.551	0.78061±0.00009
D 47	Dachgranit	276.6	54.7	14.716	0.76727±0.00004
W 34	Dachgranit	280.3	59.6	13.683	0.76445±0.00009
EG	micropegmatitic Randgranit	255.2	47.6	15.613	0.77401±0.00015
A 13	micropegmatitic Randgranit	291.9	40.9	20.827	0.79358±0.00019
IS	Ilsestein granite	232.8	39.6	17.104	0.77153±0.00011
OG	biotite granite	170.4	95.3	5.1850	0.73463±0.00022
HG-69	quartz gabbro-norite	103.7	267.4	1.1230	0.71578±0.00014
HG-116	olivine gabbro-norite	32.3	203.7	0.45908	0.71404±0.00006
HG-349	gabbronorite	97.7	222.4	1.2754	0.71700±0.00005

Table 4. Rb-Sr whole-rock and biotite data of plutonic rocks of the Upper Harz Mountains. (bio = biotite). Brocken granite sample sites: PKG = Königskopf, D = Dreibrode Steine, W = Wurmberg, EG = Eckertal, A = Abbensteinkopf, IS = Ilsestein. OG = Oker granite, HG = Harzburg gabbronorite.

tical with the Rb-Sr whole-rock isochron age of the Königskopf profile and coincides with the Brocken granite ages of SCHOELL (1970a, b, 1972a, b)[1].

The data point of the biotite-rich granite sample PKG-4, however, does not fall on the isochron of Fig. 8. The whole rock isochron age of the Königskopf granite samples only (without the hornfels samples) is 282 ± 6 Ma (Fig. 9) and is thus significantly lower than the K-Ar and Rb-Sr biotite cooling ages of SCHOELL (1970a, b, 1972a, b)[1] and the results from above. The linear arrangement of data points of the granitic samples seems to have been caused by re-equilibration of radiogenic Sr due to a later event.

This interpretation becomes more obvious in Rb-Sr profile diagrams according to BACHMANN & GRAUERT (1986) for the rock profiles across the contact zone (Fig. 10). At about 293 Ma an adjustment of the Sr isotopic values seems to have occurred between the granite and a very narrow range of hornfels immediately adjacent to the contact. This is probably a result of an equilibration directly related to the intrusion. Granite samples PKG-18 and PKG-17 as well as hornfels samples PKG-1, PKG-11 and PKG-12 which are all at greater distances from the contact did not reach isotopic equilibrium at that time.

From the profile diagrams it seems likely that the Sr isotopic ratios were equilibrated only among the g r a n i t e samples until about 282 Ma – which is the isochron age of the granite slabs at the contact. This may be due to the effect of (auto?)-metasomatic

Complex/rock/mineral	Method		$(^{87}Sr/^{86}Sr)_I$	Age (Ma)	Geological significance	References
Brocken granite massif						
aplite/W.R.	Rb-Sr	isochron	0.722 ±0.003	261±5	-- Sr homogenization with host rock	2
				261±7		3
aplite/biotite	K-Ar	mineral age		291±5	-- (C) cooling age	3
granite-hornfels/W.R. (profiles Königskopf)	Rb-Sr	isochron (MSWD 0.97)	0.7102 ±0.0002	293±3	-- (I) intrusion age	1
granite/W.R. (profiles Königskopf)	Rb-Sr	isochron (MSWD 0.65)	0.7128 ±0.0011	282±3	-- (auto ?)metasomatic *overprinting*	1
biotite-rich granite/ biotite (PKG-4)	Rb-Sr	mineral age	0.7114 ±0.0008	293±5	-- (C)	1
"hornfels"/biotite	K-Ar	mineral age		291±6	-- (C)	4
Dachgranit/zircon (PKG-5 -- PKG-7, KG)	U-Pb	UCI		$303\pm^{11}_{6}$	-- (G) zircon growth during emplacement (few inherited comp.?)	1
		LCI		±0	-- (R) recent radiogenic lead loss	1
Randgranit/zircon (EG)	U-Pb	UCI		301	-- (G)	1
		LCI		±0	-- (R)	1
granitized hornfels/ zircon (PKG-7 >100µm)	U-Pb	1 concordant fraction		296±1	-- (Z) zircon growth during emplacement	1
hornfels + biotite-rich granite/zircon (PKG-1, PKG-4)	U-Pb	UCI		1.8 Ga	-- (S) zircon growth in the source areas of inherited zircon components	1
		LCI		297±4	-- (E) zircon growth during emplacement (*and probably episodic* radiogenic lead loss in the old zircon components)	1
hornfels/zircon (PKG-2, PKG-3)	U-Pb	UCI		2.2 Ga	-- (S)	1
		LCI		373	-- inherited age ?	1
granite/W.R.	Rb-Sr	isochron	0.712 ±0.004	298±12	-- (I)	2
granite/biotite	Rb-Sr	mineral age		298±4	-- (C)	2
granite/biotite	K-Ar	mineral age		291±0.9	-- (C)	2
				290±2		3
				290±1.4		4
Oker granite complex						
granite/zircon (OG)	U-Pb	3 concordant fractions		295±1	-- (Z)	1
granite/W.R.	Rb-Sr	isochron	0.7135 ±0.0017	295±13	-- (I)	2
granite/biotite	Rb-Sr	mineral age		306±4	-- (C)	2
	K-Ar	mineral age		292.5±0.9	-- (C)	2
				293±2		3
				293.0±0.9		4
augite diorite/biotite	Rb-Sr	mineral age		310±4	-- (C)	4
quartz diorite/biotite	Rb-Sr	mineral age		304±5	-- (C)	4

Complex/rock/mineral	Method		$(^{87}Sr/^{86}Sr)_I$	Age (Ma)	Geological significance	References
Ramberg plutonic complex						
granite/biotite	K-Ar	mineral age		296±10	-- (C)	5
Rhyolites of the southwestern Harz						
Alkali rhyolite dyke/						
sanidine	$^{40}Ar/^{39}Ar$	min. age		289±1	-- (C)	6
biotite	$^{40}Ar/^{39}Ar$	min. age		293±1	-- (C)	6
Harzburg gabbronorite massif						
gabbro/biotite	K-Ar	mineral age		313	-- (C)	8
gabbro/biotite	K-Ar	mineral age		311±10	-- (C)	9
gabbro/biotite	K-Ar	mineral age		290.5±1.3	-- (C)	2
				289±2		3
	Rb-Sr	mineral age		296±5	-- (C)	2
mica-bearing basite/ biotite	K-Ar	mineral age		289.6±1.8	-- (C)	4
mica norite/biotite	Rb-Sr	mineral age		296±4	-- (C)	4
quartz gabbronorite/ zircon (HG-69)	U-Pb	3 concordant fractions	0.7111[1)]	294±1	-- (Z)	1
olivine gabbronorite (HG-116) + gabbro-norite (HG-349)/ zircon	U-Pb	UCI	0.7121[1)]	1.6 Ga	-- (S)	1
		LCI	0.7117[1)]	293±2	-- (E)	1
Ecker gneiss complex						
metasedimentary rock/ zircon (EGN-1)	U-Pb	UCI		1.6 Ga	-- zircon growth in the source areas which supplied detritus to the original sediments	1
		LCI		560±100	-- episodic radiogenic lead loss due to regional metamorphism of the Ecker gneiss or of the source area of the detrital zircons	1
schist/W.R.	Rb-Sr	isochron	0.7122 ±0.0010	392±10	-- tensional tectonic event synchronous with the emplacement of basaltic magmas (?)	7
metavolcanic rock/ sphene (EGN-2)	U-Pb	quasi-concordant		~295	-- episodic radiogenic lead loss from sphenes or sphene new *growth due to contact metamorphism in the course of* plutonic activity	1

Table 5. Synopsis of isotopic ages of crystalline rocks from the Harz Mountains. References: 1: this study, 2: SCHOELL (1972a), 3: SCHOELL (1970a), 4: SCHOELL (1970b) and SCHOELL (1972b) cited in: MÜLLER & STRAUSS (1987), 5: BENEK (1967), 6: LIPPOLT et al. (alkaline rhyolite dyke, Großer Knollen near Bad Lauterberg; personal comunication, publication in preparation), 7: SCHOELL et al. (1973), 8: EVERNDEN et al. (1961), 9: KULP (1961). W. R. = whole-rock; UCI, LCI = upper, lower concordia intercepts. Rb-Sr and K-Ar data of references 2–4 and 7–9 were recalculated with the decay constants recommended by STEIGER & JÄGER (1977).[1)] = Model initial ratios calculated from Rb-Sr isotope data (Table 4) for 295 Ma.

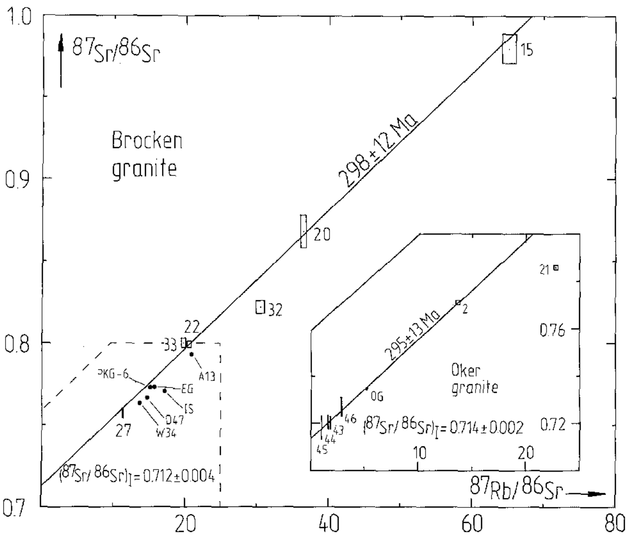

Fig. 7. Rb-Sr isochron diagrams of the Brocken granite (main diagram) and Oker granite (inset diagram). Isochrons and numbered points with error boxes: data from SCHOELL (1970b, 1972a, b). Dots (A13, PKG-6, EG, D47, W 34, IS and OG): data of this study with analytical errors smaller than the symbol sizes.

volatile and fluid phases forming void filling minerals as tourmaline, epidote, desmine, fluorite etc. During crystallization of the Brocken granite magma up to 4% of volatiles could have been released (SEIM, 1963). The compact hornfelses probably acted as impermeable wall rock and prevented volatilization of the magmatic residual fluids thus favouring local metasomatic processes.

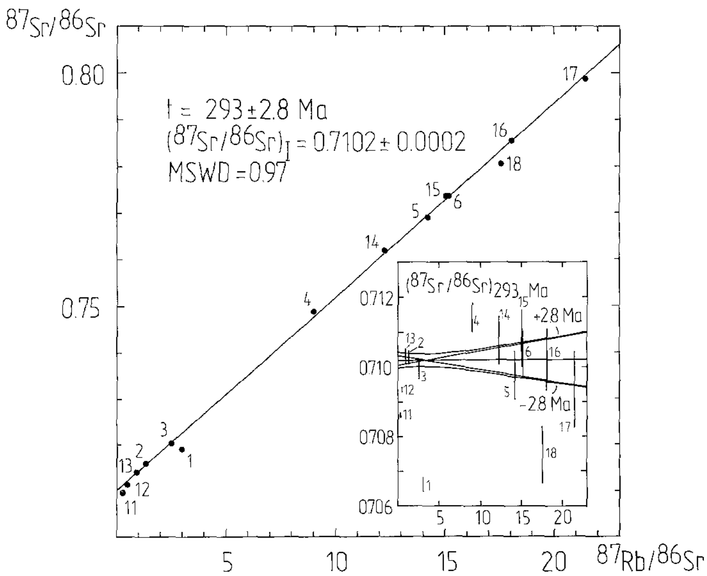

Fig. 8. Rb-Sr isochron diagram of Brocken granite and hornfels samples of the contact zone in the Königskopf quarry. Inset diagram = error envelope. Complete sample numbers are labelled with the prefix PKG-.

The phenomenon of Rb-Sr whole-rock ages significantly younger than Rb-Sr mineral ages or in other words rotation of isochrons is found to be a common feature for acid igneous rocks, e. g. Proterozoic granites of Wärmland, southern Sweden (PERSSON et al., 1987), Variscan granites of the southern Schwarzwald, Germany (BROOKS et al., 1970; WENDT et al., 1970; MÜLLER-SOHNIUS et al., 1976) and of the Erzgebirge, Germany (GERSTENBERGER, 1989), Permian rhyolites of the Schwarzwald (SCHLEICHER et al., 1983), Mesozoic granite-granodiorite of Sorkh-Kuh, central Lut, East Iran (TARKIAN et al., 1984). It is understood as due to autometasomatic processes by residual magmatic solutions with simultaneous Rb addition taking place several million years after the time of emplacement (e. g. GERSTENBERGER, 1989).

6.4 Oker granite

Uranium concentrations of the zircons range from 320 to 650 ppm decreasing with increasing grain sizes (Table 2).

The U-Pb data points of three zircon fractions are concordant or quasi-concordant at 295 ± 2 Ma (Fig. 5). This is in good agreement with the K-Ar biotite age of 292.5 ± 0.9 Ma and the Rb-Sr whole-rock isochron age of 295 ± 13 Ma (SCHOELL, 1972)[1]. In contrast to these data the Rb-Sr biotite ages of 304–310 Ma (SCHOELL, 1970b, cit. in MÜLLER & STRAUSS, 1987)[1] are unexplainably high.

A Rb-Sr data point of an Oker granite sample (OG) measured for this study fits the 295 Ma isochron (Fig. 7) of SCHOELL (1972a, b).

The coincidence of the age of zircon crystallization in the course of the granite emplacement with the biotite cooling age points to high level intrusion and consequently to fast cooling processes as is also evident from the position of the granite as small cupolas within Variscan sediments.

According to the chemical and mineralogical composition (Table 1) and the initial $^{87}Sr/^{86}Sr$ ratios (Table 5) the Brocken and Oker granite samples investigated indicate S-type affinities.

7. Conclusions

A synopsis of isotopic ages of crystalline rocks of the Harz is presented in Table 5. Results of U-Pb zircon and Rb-Sr isotopic investigations on these rocks are:

(1) Inherited components in zircons of the Ecker gneiss and the Harzburg gabbronorite point to

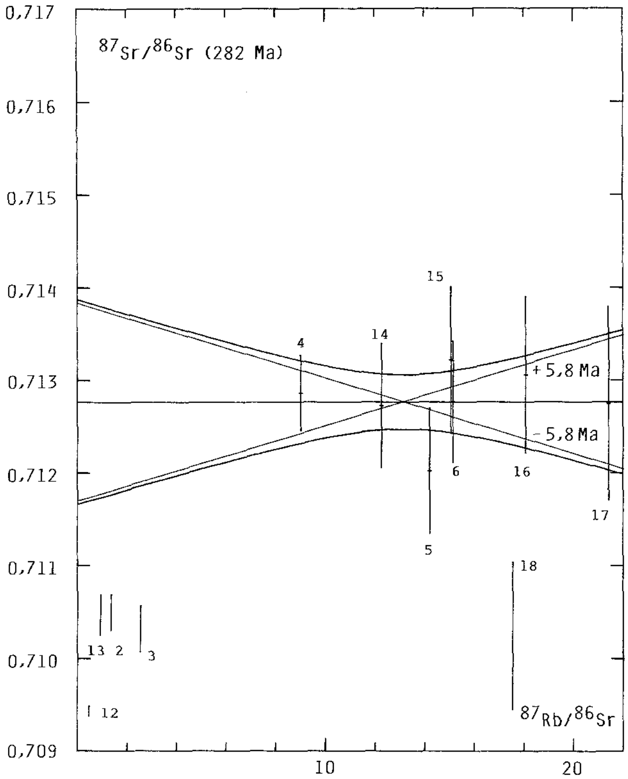

Fig. 9. Rb-Sr error envelope diagram for an isochron through the data of only the granite samples of the Königskopf quarry with a slope corresponding to an age of 282 Ma. Complete sample numbers are labelled with the prefix PKg-.

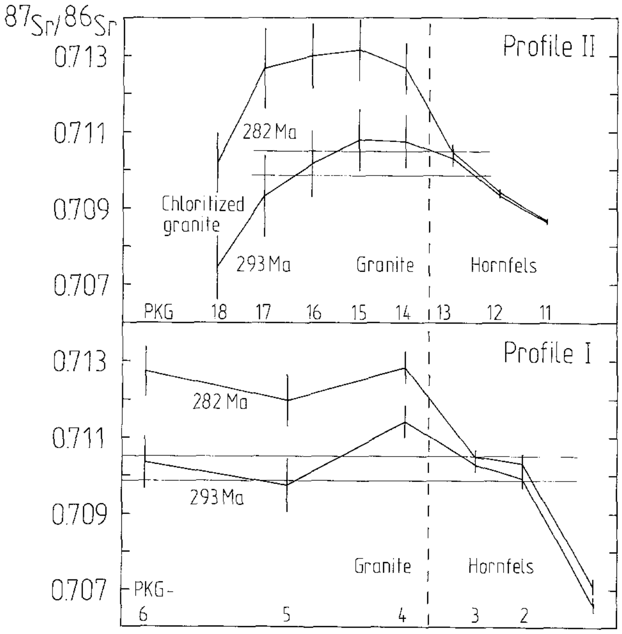

Fig. 10. Rb-Sr profile diagrams of the Brocken granite-hornfels contact zone in the Königskopf quarry. Complete sample numbers are labelled with the prefix PKG-.

primary Proterozoic ages of about 1.6 Ga, detrial, rounded zircons from hornfelses of the contact zone Brocken granite/hornfels in the Königskopf quarry contain 1.8 to 2.2 Ga old constituents.

(2) An event at about 560 Ma severly affected zircons of the Ecker gneiss and may be interpreted either as the prominent metamorphic overprinting of this complex during »Cadomian« orogeny or as an inherited age of the source area of the detrital zircons.

(3) Another event affecting the Ecker gneiss at 392 Ma – whose real nature, however, is yet unclear – was dated by SCHOELL et al. (1973)[1)] by means of a Rb-Sr whole-rock isochron. Emplacement of voluminous basaltic magmas and associated fluid activity could be responsible for the resetting of the Rb-Sr system. Isotopic ages between 370 and 400 Ma – corresponding to the Acadian event – are well-known from other European Variscan fold belts.

(4) K-Ar and Rb-Sr mineral and whole-rock ages of the Oker granite pluton (293 to 295 Ma) and the Harzburg gabbronorite complex (289 to 296 Ma) obtained by SCHOELL (1970a, b, 1972a, b)[1)] were confirmed by concordant U-Pb ages of zircons: Oker granite 295 ± 1 Ma, Harzburg gabbronorite 294 ± 1 Ma and a lower intercept age of slightly discordant zircon data of the Harzburg gabbronorite: 293 ± 2 Ma. These data set up narrow intrusion age limits and document short cooling histories of the plutonites emplaced in shallow crustal levels.

(5) In the case of the Brocken granite the U-Pb data of zircons and Rb-Sr isotopic data yielded only partially consistent age informations. The zircons of the Brocken granite recorded a complex history involving probable incorporation of inherited components, new growth during granite emplacement and recent lead loss due to uplift of the Harz. New Rb-Sr data of whole-rock samples from different sites of the Brocken granite complex are scattered and do not allow to calculate a meaningful age. However, dating of the Brocken granite intrusion was possible by investigations of samples from two profiles across a granite-hornfels contact zone. A Rb-Sr granite-hornfels whole rock isochron yields an age of 293 ± 3 Ma which is identical with the Rb-Sr biotite age of a sample from the immediate contact (293 ± 5 Ma). Indirect dating of the Brocken granite intrusion was also possible with zircons (296 ± 1 Ma and 297 ± 4 Ma) of contact metamorphic hornfels samples. These ages coincide with those of the Brocken granite of SCHOELL (1970a, b, 1972a, b)[1)]: 298 ± 12 Ma (Rb-Sr whole-rock isochron age), 298 ± 4 Ma (Rb-Sr biotite age) and 290 ± 2 Ma (K-Ar biotite age), respectively.

(6) The present isotopic age data do not allow to

distinguish different intrusion ages of the Harzburg gabbronorite, Brocken granite and Oker granite. They rather document nearly synchronous origin of the three independent intrusive complexes. The approximately contemporaneous formation and spatial vicinity of the plutonic bodies points to a common geotectonic trigger effect for the ascent of the magmas. This must have also forced the ascent of the Ecker gneiss complex now squeezed in as an allochthonous slab between the Harzburg gabbronorite and the Brocken granite.

(7) Rb-Sr data of the granite samples from the Brocken granite-hornfels contact document local resetting of the Rb-Sr system > 10 Ma after the granite emplacement due to the effect of autometasomatic (?) volatile and fluid phases.

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