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The plutonic rocks of the Elbe valley zone (Germany): evidence for different fractionation processes from morphology and internal structure of zircons

by *Th. Wenzel*[1] and *D. Wolf*[1]

Abstract

A sequence of monzodioritic – monzonitic – monzogranitic and related plutonic rocks from the Meißen massif in the Elbe valley zone (E-Germany) was characterized according to morphology and internal constitution (cores, zoning, inclusions) of zircons.

Using the zircon typology method a distinction could be made between Cadomian granodiorites (Dohna, Laas) and Variscan diorite to monzogranite intrusions (e.g. Freital, Gröba). SEM and cathodoluminescence allowed a more detailed reconstruction of petrogenetic relations: The Freital- and Gröba-types contain zircons which have formed during ± normal magma fractionation. Other types (Hauptgranit, Riesensteingranit) show recrystallized zircons representing Precambrian relics. Abundant inclusions can be explained by crustal contamination. Zircons from Leuben monzonites have characteristic "Freital" features. They reflect non-equilibrium interaction of Freital-type monzodiorites with a syenitic melt. This supports earlier petrologic observations.

Keywords: Zircon typology, scanning electron microscope, cathodoluminescence, monzodiorite, magma fractionation, Elbe valley zone, Germany.

Introduction

Since the fundamental work of POLDERVAART (1950) and HOPPE (1962) accessoric zircons are used increasingly as petrogenetic indicators. This refers, for instance, to relations between morphology and growth conditions of granitic zircons in the melt (PUPIN and TURCO, 1972; PUPIN, 1980; PUPIN, 1988) as well as to the dependence of the main crystal faces of zircons on kinetic variables (e.g. VAVRA, 1990). More detailed reconstructions may be obtained regarding internal zircon structures like growth patterns, cores, different inclusions or microchemical data (e.g. SPEER, 1982; KRASNOBAJEV, 1986; VAVRA, 1990; SOBOLEV et al., 1991; PATERSON et al., 1991). In addition to other petrologic investigations and as a base for single-zircon age determinations, 22 zircon fractions separated from 7 different plutonic rock types of the Elbe valley zone (Meißen massif, Dohna and Laas granodiorites) were characterized according to morphology and internal constitution (zoning, associations of mineral inclusions) of the grains. Previous results seem to indicate relations to the main fractionation processes reconstructed by means of mineralogical and whole-rock geochemical investigations (WENZEL, MERCOLLI and OBERHÄNSLI, 1991).

Geological setting and sample locations

The Elbe valley zone (PIETZSCH, 1956) is situated in the E of Germany between the geological units of the Erzgebirge, Granulitgebirge and Lausitzer Block (Fig. 1).

WENZEL, MERCOLLI and OBERHÄNSLI (1991) suggest a magmatic development of the plutonic rocks of the *Meißen massif* by the following fractionation processes:

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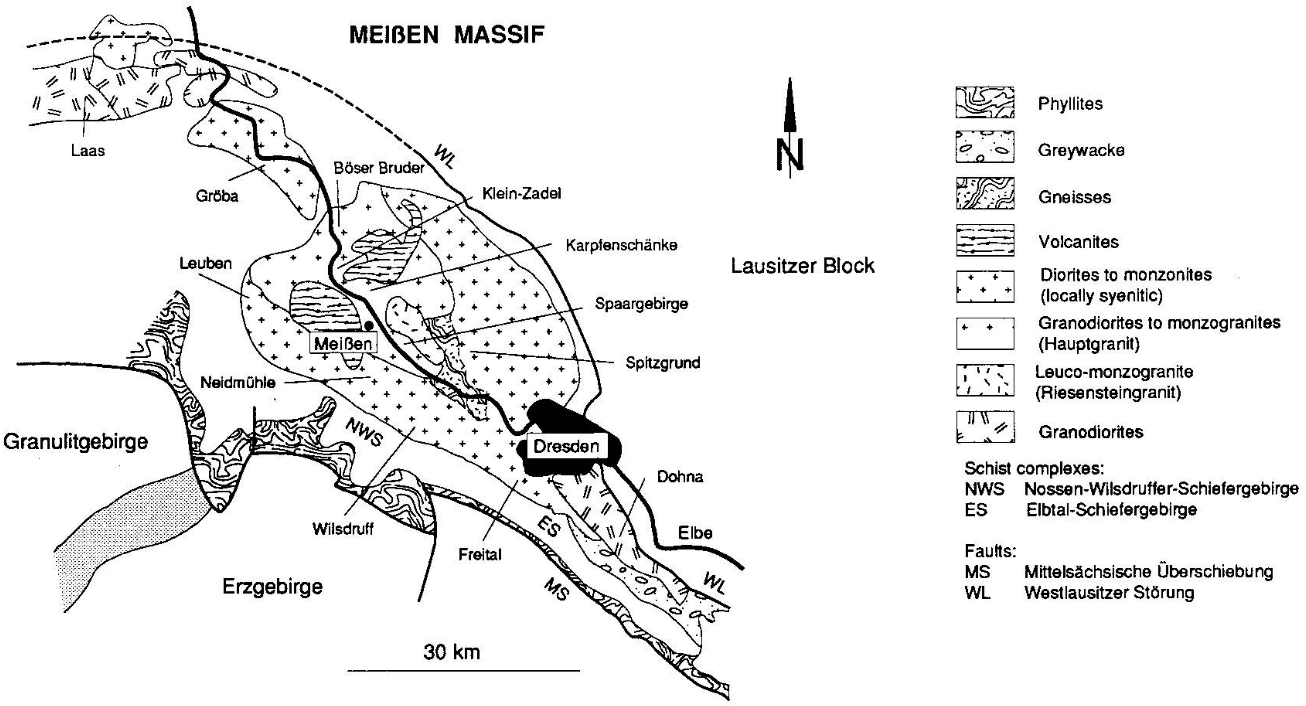

Fig. 1 Simplified geological map of the Meißen massif and the surrounding areas (modified after Pietzsch, 1956).

– The diorite-monzodiorite-monzonite sequence of Freital is due to closed system fractional crystallization of an undersaturated basaltic magma of alkaline affinities. On the contrary, the monzodiorite of Gröba derived from a silica-saturated parental melt.

– Near Leuben, a "Freital-type" monzodiorite was subsequently digested by syenite melt. Mineral chemical data and fabric patterns of the resulting monzonite as well as the occurrence of "hybrid layers" reflect incomplete interaction, i.e. non-equilibrium conditions of an open system. Other localities (Wilsdruff, Spitzgrund) represent probably different stages of homogenization of such hybrid "mush" or melts.

– For major elements, the Hauptgranit and Riesensteingranit follow the monzonite trend, whereas some trace element patterns are distinctly nonlinear. Such deviations occur for samples with magmatic muscovite and are interpreted as the local result of crustal contamination.

– Non-equilibrium characteristics prevail in the Porphyrartiger Granit. Assimilation of Freital-type material by a late granitic melt perhaps by magma mingling is indicated.

Based on petrographic and geochemical signs, the *granodiorites from Laas and Dohna* are quite different to the rocks of the Meißen massif showing strong affinities to anatexites (Tischendorf et al., 1987). The geological map and sample locations are given in figure 1 (see Wenzel, Mercolli and Oberhänsli, 1991 for details):

Analytical procedure

About 50 kg fresh material were derived from each sample location. After a stepwise crushing, pure mineral fractions were obtained using percussion frame, heavy liquids and hand picking.

According to Pupin (1980), 150 to 200 zircons from the 63–315 µm fraction of each sample were classified based on the combination of the four main crystal faces.

Another representative split of each fraction was embedded in epoxy such that the largest prisms were oriented parallel to the surface of a mounting glass. Then the mounts were ground and polished. The internal characteristics of 50 to 100 grains per sample were studied on a Cam Scan S4 scanning electron microscope using 15 kV accelerating voltage and the backscattered observation mode. Mineral inclusions in the zircons were identified by means of a Tracor Northern EDX system using natural standards. Some results were verified by WDS analyses realized on a Cameca SX 50 microprobe. On this base, the frequency of different types of zircons could be estimated.

Results and discussion

The *typological classification* of zircon populations from different rock types is presented in figure 2 using results of Retsch (1989), Demus (1990) and Wenzel et al. (1990): If the modified

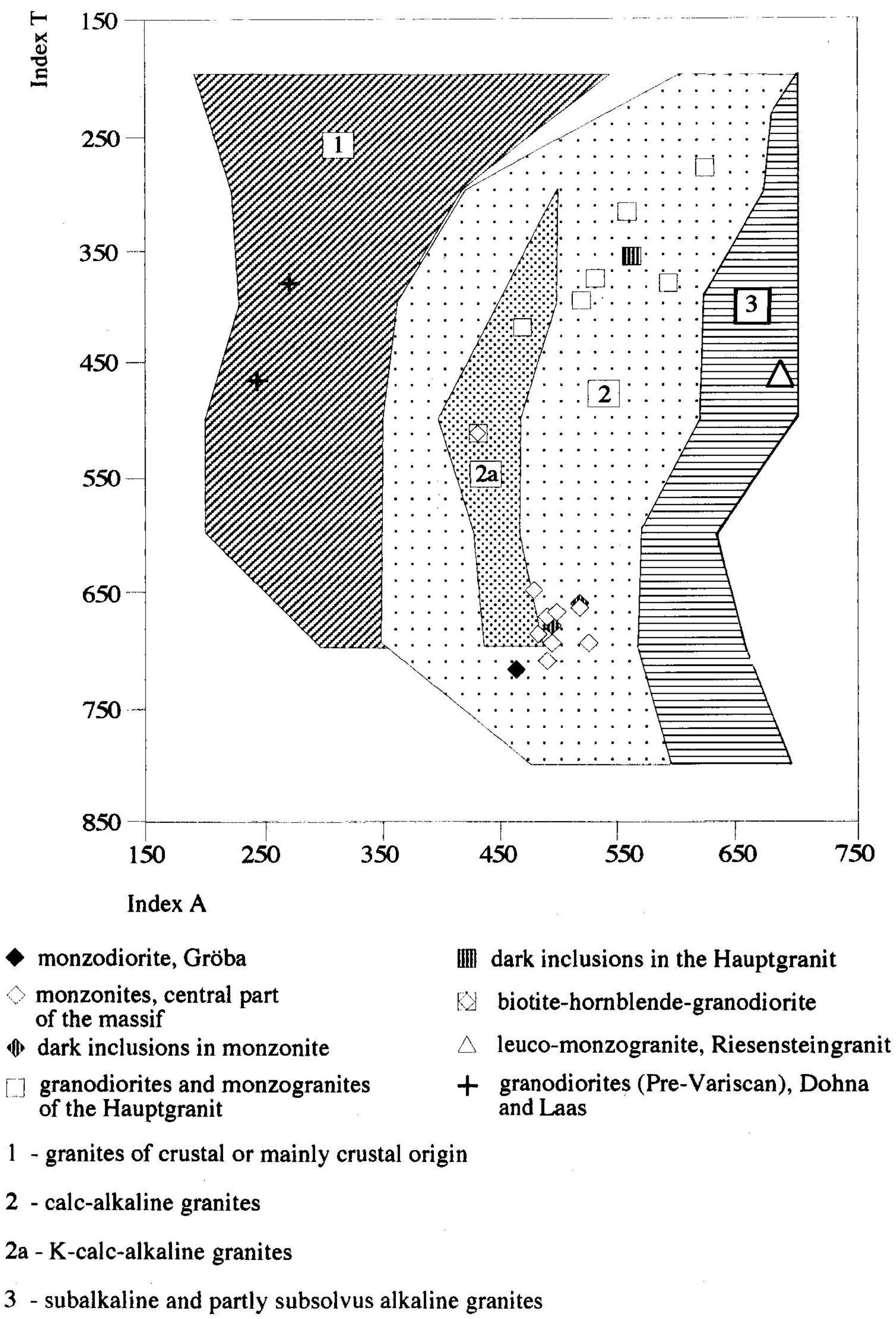

Fig. 2 Morphological classification of 22 zircon populations of various plutonic rocks of the Meißen massif according to Pupin (1980). Data of Retsch (1989), Demus (1990) and Wenzel et al. (1990) are summarized. Fields of different genetic types of granites are shown for comparison (simplified after Pupin, 1988, Fig. 5).

Tab. 1 Overview of the internal constitution of 22 zircon populations from the Meißen massif and the granodiorites from Dohna and Laas. The abundance of different types of individuals is estimated; image of the zircon crystals from BSE-imaging; mineral inclusions detected by SEM and microprobe investigations.

rock type/locality	image of the zircon crystals	mineral inclusions
monzodiorite, *Gröba*	homogeneous, non-fractured	apatite, ± iron oxide, quartz
monzodiorite and monzonite, *Freital*	homogeneous, fractured type b) partly as core in a)	a) iron oxide, plagioclase alkali feldspar, quartz, apatite, sphene, chlorite, epidote; **60%** b) mainly free of inclusions, **40%**
monzonite, *Leuben*	a) homogeneous, fractured; **32%**	iron oxide, amphibole, plagioclase, alkali feldspar, quartz, apatite, chlorite, epidote
	b) zoned, with metamict spots; **68%**	iron oxide, sphene, plagioclase, alkali feldspar quartz, apatite, white mica
	c) homogeneous, non-fractured, due to partial recrystallization of a) and b)	
monzonites, *Wilsdruff, Spitzgrund*	a) completely zoned, **50–90%**	iron oxide, plagioclase, alkali feldspar, quartz, apatite
	b) partly zoned, **10–50%** different cores:	
	– euhedral-zoned	apatite
	– rounded-homogeneous	free
	– irregular, zoned	plagioclase, alkali feldspar, chlorite, white mica
monzogranites Hauptgranit, *Spaargebirge* *NW Karpfenschänke* *Klein-Zadel*	a) zoned rims around voluminous cores; **87%** b) completely zoned; **13%**	cores: mainly free rims: biotite, alkali feldspar, plagioclase, quartz, apatite
leuco-monzogranite, Riesensteingranit, *Meißen*	a) completely but often irregularly zoned, **80%**	iron oxide, biotite, ilmenite, mixtures of Fe-Ti-oxid phases, monazite, alkali feldspar, quartz, apatite
	b) zoned rims around (partly recrystallized) cores, **20%**	rims: as above cores: albite, alkali feldspar, quartz, white mica
granodiorite, *Dohna,* *Laas*	a) weakly zoned, **78–85%**	biotite, alkali feldspar, quartz, apatite
	b) rims around clearly detectable cores: – rounded-homogeneous – subhedral-zoned – irregular, with metamict spots; **5–10%**	plagioclase, ilmenite, white mica
	c) recrystallized individuals?	

interpretation of Pupin (1988) is accepted, the zircon populations of the pyroxene-monzodiorite from Gröba, the several monzonites as well as the monzogranites of the Hauptgranit are characteristic for calc-alkaline granites. On the other hand, the derivation of the zircons from Dohna and Laas from Al-rich melts of crustal or mainly crustal origin seems to agree with similar conclusions by Tischendorf et al. (1987). By means of the single-zircon evaporation technique of Kober (1987) it was shown, that the first group represents the Variscan orogenic cycle, whereas the latter two intrusions belong to the Cadomian cycle (Wenzel, Hengst and Pilot, 1991).

It is more difficult to get an answer whether the zircon typological method can help to reconstruct the genetic relationship between the monzonites and the different granites of the Meißen massif. It is to note, that the populations of the Hauptgranit have markedly lower T-indices than the monzonitic populations. Reasons for the distinct trend toward the G-type of zircons may be an increasing water activity or increasing trace element concentrations in the Hauptgranit parental melt (Pupin, 1980; Vavra 1990). The position of the zircon population of the Riesensteingranit in the fields of "subalkaline" and "subsolvus alkaline granites" would indicate a mantle or hybrid nature of this melt, but such interpretation seems to be doubtful. However, late leucogranitic intrusions of similar plutonic complexes (Ballons, France; Balagne, Corsica) also contain zircons with very high A-indices (Pupin, 1981), but the rock series show clearly calc-alkaline signatures.

More detailed information about different petrogenetic processes was obtained by the investigation of the *internal zircon structures* mainly using BSE images and regarding the association of inclusions (see Tab. 1 for comparison): the only sample without detectable cores is the population of the pyroxene-monzodiorite from Gröba. The slightly zoned zircons crystallized in early magmatic stages and contain mainly inclusions of older apatite. According to BSE images, the zircon individuals of the Freital dioritic to monzonitic rocks are homogeneous and frequently fractured, sometimes containing "cores" (Fig. 3a). However, they are weakly zoned, what was only detectable by investigations under cathodoluminescence. The strong enrichment of Zr from monzodiorite to monzonite (Wenzel, Mercolli and Oberhänsli, 1991) as well as inclusions of alkali feldspar, quartz and sphene imply that the zircons began essentially to crystallize at or after the monzodiorite stage within the diorite-monzodiorite-monzonite fractionation sequence. Rare inclusions of chlorite and epidote may be interpreted as relics of a crustal contamination. On the contrary, the chlorite inclusions are chemically similar to chlorite pseudomorphs after biotite which occur in paragenesis with epidote, sericitized plagioclase and actinolite in the Freital monzodiorite (Wenzel, Mercolli and Oberhänsli, 1991). As this indicates subsolidus hydrothermal alteration processes (phase relations after Apted and Liou, 1983), a few zircons probably crystallized during this process thereby enclosing chlorite and epidote. Unzoned grains without inclusions, comparable to the "cores" in the first zircon type, could either represent very early magmatic generations or relics. First single-zircon age determinations favour the latter interpretation (Wenzel, Hengst and Pilot, 1991).

The homogeneous-fractured grains of the Leuben monzonite look like the corresponding zircons of Freital (Fig. 3b). They are concentrated in the "monzodioritic" rock parts and show – as in the case of Freital – a slight zoning which is detectable only under cathodoluminescence. On the other hand, the markedly zoned individuals (Fig. 3c) belong to the syenite parts mentioned above. This melt was probably enriched in water and peraluminous as indicated by inclusions of white mica in the zircons.

In opposition to Leuben, zircons with regular magmatic zoning predominate in the populations of the monzonites from Wilsdruff and Spitzgrund. This seems to be in agreement with increasing tendencies toward equilibrium fabrics as well as the transition to nearly linear trace element patterns, thought to indicate a crystallization from homogenized (Leuben type?) hybrid melts (Wenzel, Mercolli and Oberhänsli, 1991). According to single-zircon age determinations (Wenzel, Hengst and Pilot, 1991), rounded and unzoned cores represent relics of a contamination. On the contrary, the different growth zoning between euhedral "cores" and the surrounding "rims" is probably due to changes of the PTX conditions during the magmatic history (cf. Vavra, 1990). Similar circumstances were observed on zoned apatite crystals under cathodoluminescence (Wenzel and Ramseyer, 1992).

As indicated by the predominance of zircons with rounded or ovalshaped cores (Fig. 3d), crustal influences play an important role in the genesis of the Hauptgranit magma. Single-grain age determinations support the occurrence of Precambrian relics with $^{207}Pb/^{206}Pb$ evaporation ages between 580 and 2220 Ma (Wenzel et al., 1990). Only 13% of the grains are completely zoned (Fig. 3e) and, thus, entirely grown in the Hauptgranit melt. Different relic ages as well as different kinds of cores yield evidence for either one

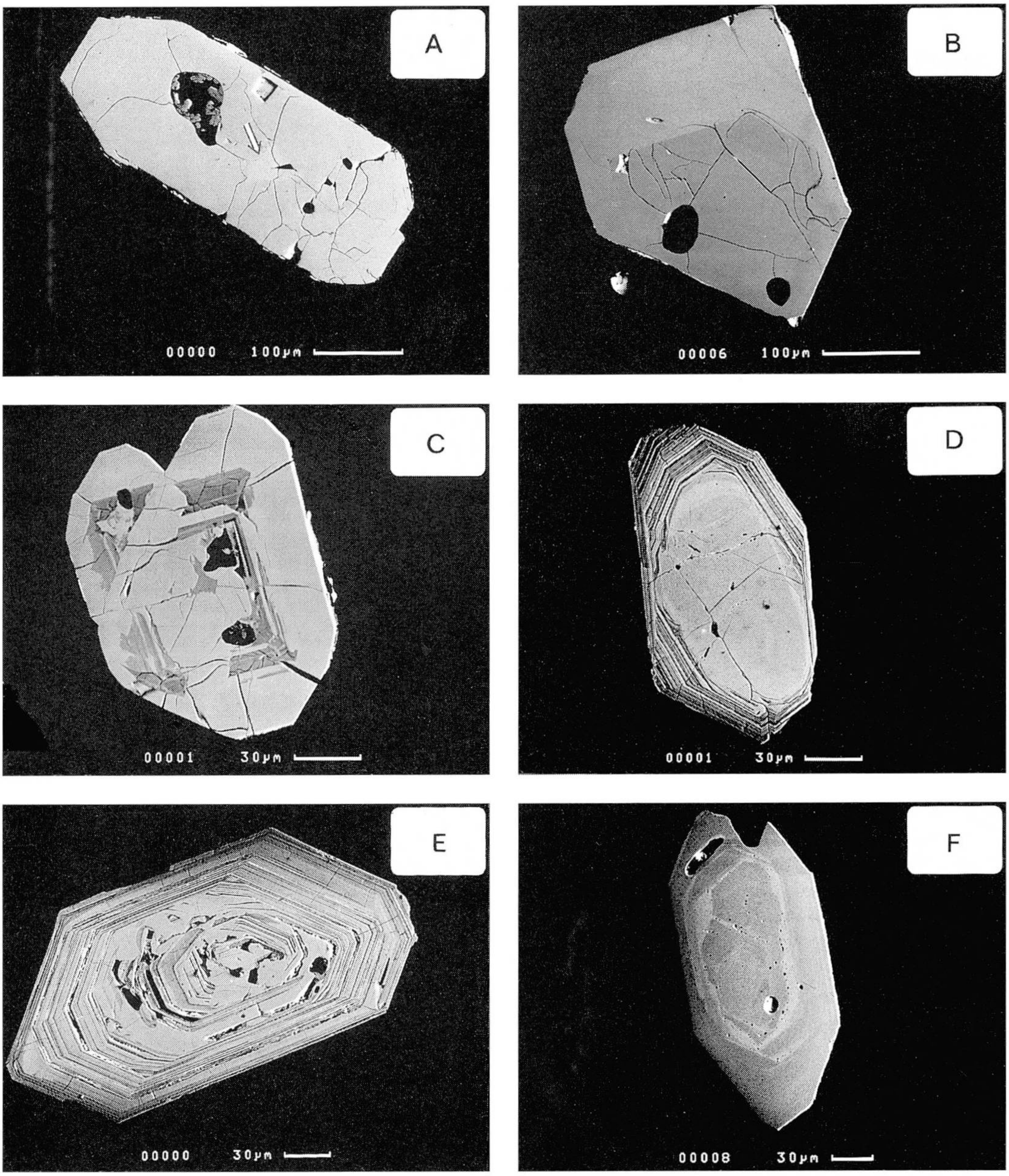

Fig. 3 Back-scattered electron images of polished zircon sections:
a: Characteristic zircon of the monzonite from Freital with inclusions of plagioclase and iron oxide. Note the system of radial fractures around the light core in the center (arrow).
b: Freital-type zircon with inclusions of plagioclase and apatite (lower part), surrounded by a new zircon generation; monzonite from Leuben.
c: Syenite-type zircon with inclusions of alkali feldspar and quartz; monzonite from Leuben. Note the destruction of the zoning by partial recrystallization.
d: Characteristic type of zircons from the Hauptgranit showing a thin zoned rim around a voluminous core; monzogranite from Spaargebirge.
e: One example of the generally zoned crystals of the monzogranite from Spaargebirge.
f: Clear; euhedral zircon type with a partly recrystallized core and inclusions of apatite; granodiorite from Laas.

contaminant with a heterogeneous zircon population or as a second opportunity for different crustal sources.

According to the abundance of mineral inclusions, the zircons of the Riesensteingranit crystallized from a "crystal mush". Inclusions of biotite are chemically similar to the biotite of the host rock. Ilmenite and monazite were detected in some zircons but not in the granite matrix (see also PFEIFER, 1964), possibly caused by intensive late magmatic alteration processes. Inclusion associations of quartz + white mica in cores may indicate the presence of crustal components which is also suggested by first Nd isotopic data (WENZEL and VON QUADT, 1991).

Consequently, the zircon investigations yield further evidence that the sequence of dioritic to monzonitic rocks and some granite intrusions (Hauptgranit and Riesensteingranit) can not be the exclusive result of fractional crystallization. There are rather tendencies toward increasing crustal signatures of the late granitic rocks.

The identification of cores in zircons of the Cadomian granodiorites from Dohna and Laas agrees well with the detection of Precambrian relic ages (WENZEL et al., 1990; BOMBACH et al., 1990) in both samples. However, most of the relics recrystallized in the granodiorite magma (Fig. 3f). The new zircon generation is either inclusion free or contains minerals of the granodiorite host rock (e.g. quartz, alkali feldspar and biotite). Incomplete recrystallization of cores is interpreted to be the reason for some variations of the consolidation ages (WENZEL, HENGST and PILOT, 1991).

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