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Autor: Sturm, Robert

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Longitudinal and cross section of zircon: a new method for the investigation of morphological evolutional trends

by *Robert Sturm*[1]

Abstract

A new preparation technique is introduced that allows the investigation of prism and pyramidal development within one crystal of zircon. The technique consists of two steps: longitudinal sectioning of the crystals and subsequent sectioning perpendicular to their c-axes. The preparation is applied to two granitoid rocks (Pearl-Gneiss and Schlieren-Granite) of the Austrian Moldanubian region, which were both formed by regional anatexis. In the case of the Pearl-Gneiss, longitudinal and cross sections of representative zircons reveal a morphological evolution that runs from subtype S_{23} to subtype S_1/S_6. Growth inhibition of some crystal faces leads to the formation of the S-faces {110} and {211} and might have been controlled by the adsorption of cations and water molecules. The internal morphology of zircons from the Schlieren-Granite shows an evolution running from G type to subtype S_{24}/J_4 and therefore approaches the theoretical growth morphology which is marked by the predominance of the F-faces {100} and {101}. In general, the morphological trends obtained by the preparation technique correspond with the typological evolutional trends obtained by the statistical evaluation of external crystal shapes.

Keywords: zircon, longitudinal section, cross section, internal morphology, morphological evolution.

1. Introduction

In the last four decades, zircon has been the best studied igneous mineral regarding the relationship between the crystal shape and the geological context of the investigated rock samples (e.g. PUPIN and TURCO, 1972, 1975, 1981; PUPIN 1980; SPEER, 1982; SUNAGAWA, 1984, 1987). While POLDERVAART (1956) thought that the morphology of zircon does not change with the variation of environmental factors, numerous authors of the late 1960's and early 1970's (e.g. KÖHLER, 1970; KARNER and HELGESEN, 1970; VENIALE et al., 1968) revised this theory and showed that zircon morphology changes continuously during the single stages of magma differentiation. This hypothesis was confirmed by the fundamental work of PUPIN (1980) who introduced the typological evolutional trend (TET), a method for deriving morphological evolutions from the statistical evaluation of external crystal shapes. Further, Pupin used the zircon typology for a genetic classification of igneous rocks and even for an estimation of the crystallization temperature (geothermometer). However, Pupin and his predecessors in the field of zircon research had no insight into the internal zircon morphology. This was introduced by special preparation and imaging techniques at the beginning of the 1990's (VAVRA, 1990, 1993, 1994; PATERSON et al., 1992; BENISEK and FINGER, 1993). These developments allow the possibility of studying the zircon morphology in terms of crystal growth. Also, factors responsible for the formation of a specific crystal tracht were examined and probably found in the case of prism growth. Therefore, the formation of {100} and {110} prisms mainly depends on the concentrations of the elements U, Y, and P which produce a growth block of {110} and lead to the disappearance of {100} in the course of crystal growth (BENISEK and FINGER, 1993). In the case of pyramidal growth, a similar theory is still missing, but VAVRA (1994) suggested that adsorbing cations (Na, K, Al) could be controlling factors.

A drawback of the studies published so far about internal zircon morphology is that an exact morphological description is hitherto limited to either the prism growth alone or the pyramidal

[1] Institut für Mineralogie, Universität Salzburg, Hellbrunnerstrasse 34, A-5020 Salzburg, Austria.
<Robert.Sturm@sbg.ac.at>

growth alone. A combined investigation of both growth phenomena has not been carried out until now, because of the lack of appropriate preparation methods. In this work, a method is introduced which gives a view into prism and pyramidal growth within anyone zircon crystal. This method makes the morphological evolution of single zircons available. Another aim of this study is to compare PUPIN's theory about the specific development of zircons in various rocks with the results won by this new kind of preparation technique.

2. Materials and methods

The separation of the zircons from well known Austrian granitoid rocks was carried out by moderate crushing and sieving followed by densimetric (bromoform) and magnetic separations of the heavy minerals fraction. 100 to 150 crystals of each rock sample were investigated according to their typology and plotted into the typology diagram (PUPIN and TURCO, 1972).

After the determination of the main typologies, representative zircons of each sample were picked under a stereo microscope and fixed on a glass slide using epoxy resin (Köropax 439). The c-axes of all zircons were oriented parallel to the longer side of the slide before the resin had set (Fig. 1A). This is best done by means of a fine preparation needle. After fixing single grains, the slide was fully covered by the resin which hardened at a temperature of 60 °C within about 3 hours. The preparation was ground and then polished with diamond paste (grain diameters: 3 and 1 µm), until the median sections of the zircons were reached more or less exactly (Fig. 1B). The sections were coated with carbon and analyzed by BSE-imaging using a JEOL JXA-8600 microprobe at the Institute of Mineralogy, University of Salzburg. The beam diameter was set to 1 µm, and the acceleration voltage was 15 kV. For each investigated grain, the beam current and the gain of the photomultiplier were adjusted individually to optimize the resolution. For the production of electron micrographs an AGFAPAN film (ASA

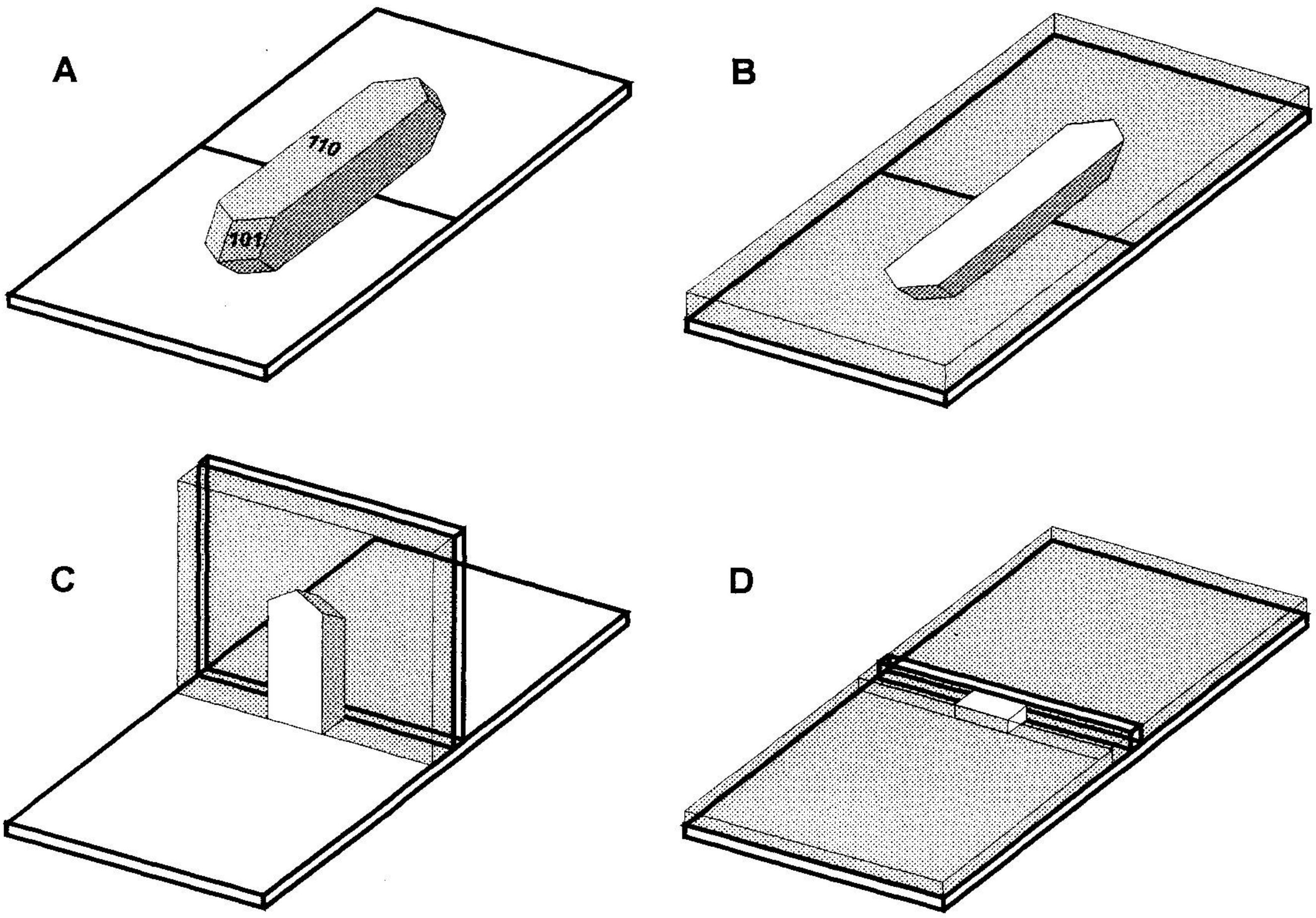

Fig. 1 Procedure of the preparation technique. (A) Crystals are oriented with their c-axes parallel to the longer side of the glass slide and fixed with resin. (B) Crystals are polished until their median sections are reached. (C) After microprobe work, longitudinal sections are halved and fixed on another slide. (D) Crystals are polished perpendicular to their c-axes. The final cross sections are 30 to 50 µm thick.

100) was used. After the investigation of the longitudinal sections, each preparation was ground along the longer side of the glass slide, beginning at one end and reaching the middle. The halved slide was fixed on another glass slide, as shown in figure 1C, and finally ground starting from the other end. The cross sections of zircon grains were polished, until they reached a thickness of 30 to 50 µm (Fig. 1D). The sections were investigated by microprobe again using the same setup as when imaging the longitudinal sections.

3. Petrographic description of the investigated samples

Zircons were separated from a peraluminous and a high-K calcalkaline granitoid of the Austrian Moldanubicum which have been already described in detail by numerous authors (e.g. FUCHS and MATURA, 1976; FINGER, 1986; FRASL and FINGER, 1991; STURM, 1995). The external zircon morphologies of the rock samples were determined and their frequency distributions were plotted into the typological diagram (Fig. 2). It can be recognized that the typologies correspond with the theory of PUPIN (1980) according to which relationships exist between zircon morphology and granitoid type.

The Pearl-Gneiss, which occurs mainly in the southwestern Moldanubian region, is a peraluminous granitoid of S-type. The sedimentary protolith of the gneiss underwent an anatectic event which led to a partial loss of the original texture. The mineral composition is mainly marked by "pearls" of oligoclase (40–50 vol.%) as well as biotite (15–30 vol.%), quartz (20–30 vol.%), and cordierite (up to 10 vol.%). Sodium feldspar is only a subordinate constituent and never exceeds 10 vol.%. The rock chemistry is characterized by rather high contents of Y, Sr, and Ba, while Nb and Zr are contained in lesser amounts. The zircon population of the Pearl-Gneiss mainly includes the subtypes S_1 and S_6 (Fig. 2), as predicted by PUPIN (1980) from cordierite-bearing, aluminous to hyperaluminous rocks.

As the Pearl-Gneiss, the Schlieren-Granite is a product of a regional anatexis that led to the melting of high-grade metamorphic biotite-plagioclase gneisses. These preanatectic protoliths are

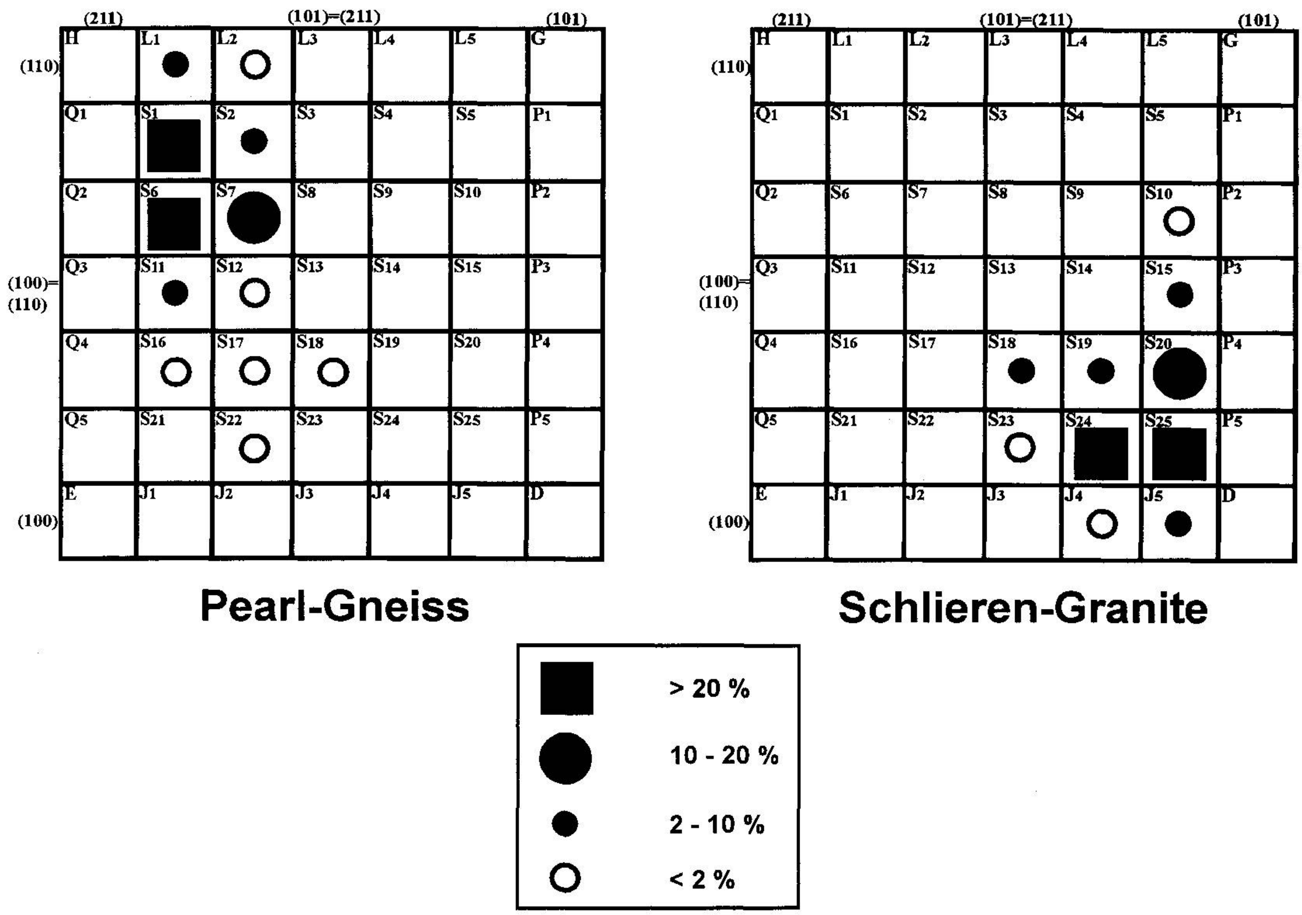

Fig. 2 Typology diagrams of the investigated granitic rocks (according to PUPIN, 1980).

locally included as lumps in the Schlieren-Granite. The mineralogy of the I-type rock is marked by high contents of plagioclase (30–50 vol.%). Further, the granitoid consists of quartz (20–30 vol.%), sodium feldspar (20–30 vol.%), and biotite (10–20 vol.%). Sometimes, amphibole and titanite can be also recognized as important constituents. Trace element chemistry is characterized by rather high concentrations of Zr, Y, and Nb typical for an calcalkaline rock. The most frequent zircon typologies of the Schlieren-Granite are S_{24} and S_{25}, followed by the subtypes S_{20} and J_5 (Fig. 2). PUPIN (1980) describes similar subtypes in calcalkaline igneous rocks.

4. Results

4.1. MORPHOLOGICAL EVOLUTION OF ZIRCON FROM THE PEARL-GNEISS

Zircons from the cordierite-bearing Pearl-Gneiss often include a dark and rounded core which probably originates from a host rock and served as a nucleus for crystallization (Fig. 3A, C). The core is surrounded by growth zones of variable widths. Core and overgrowth are locally separated by smoothly rounded dissolution surfaces. Outer parts of only a few grains are also marked by deep corrosion pits. Crystal B of figure 3 consists of a prism part with clearly visible growth zones as well as bright and weakly zoned pyramids. Here, only the morphological evolution of the middle part was of interest for the investigation. In general, the surfaces of the zircons are rather euhedral. Concerning the evolution of the pyramids, {101} faces grew faster than {211} faces. Hence, the external morphology is dominated by a large {211} pyramid that is remarkably bigger than the {101} face. The development of the prisms started with a large {100} that grew much faster than {110} and therefore continuously lost its predominance. At the end of the evolution, the growth inhibited {110} face became bigger than {100}. Combining the prism and pyramidal evolution, it can be recognized that zircon morphology developed from

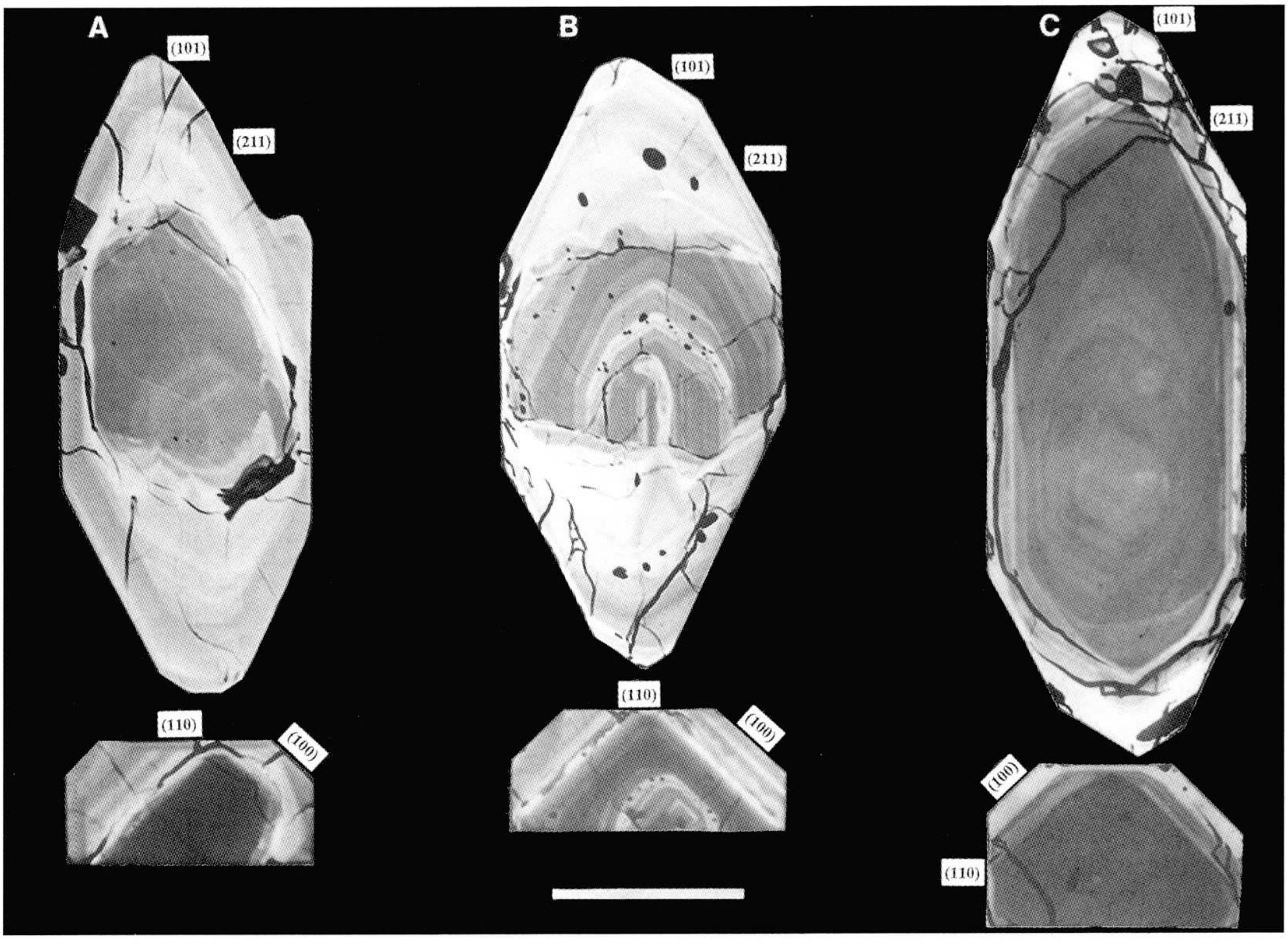

Fig. 3 Longitudinal and cross sections of zircons from the Pearl-Gneiss. While the evolution of the prism faces (below) is marked by a growth inhibition and final predominance of {110}, the pyramidal development starts with {101} faces that are in the same order of magnitude as {211} faces (A and B) and decrease continuously because of their higher growth speed. Bar = 30 µm.

subtype S_{23} to subtype S_1/S_6 according to PUPIN's classification (Fig. 5A). Prism growth was nearly as fast as that of the pyramidal faces resulting in stubby to moderately elongated crystal habits. Only in the final growth stage, the growth-inhibited {110} face also increased at the expense of the pyramides.

4.2. MORPHOLOGICAL EVOLUTION OF ZIRCON FROM THE SCHLIEREN-GRANITE

Most investigated crystals show a euhedral concentric zoning that provides insight into the morphological evolution. In most cases, the growth of the prism faces was of the same order of magnitude as that of the pyramids which led to normal elongated crystal habits. In the outer zones of many zircons, stages of crystal corrosion are interspersed that are probably the result of magma mixing (see also VAVRA, 1994). The development of the pyramids started with a dominant {101} face that grew at nearly the same speed over the whole evolution of the grain and therefore decreased only a little bit (Fig. 4 A–C). The steep {211} pyramid appeared only at the end of the growth period. Prism development started with a large {110} face that increased its relative growth rate dramatically in some cases. So, the external morphology is sometimes marked by the exclusive appearance of the {100} prism (Fig. 4A). All investigated crystals showed at least a clear predominance of {100} over {110} in the outermost layer. If the developments of prism and pyramidal faces are combined, a typological evolutional trend from G type to S_{24}/J_4 subtype can be observed (Fig. 5B). This trend is contrary to that obtained by Pupin (1980) for zircons from calcalkaline rocks.

5. Discussion

As the results of this study show, zircons from S-type granites pass through another morpholog-

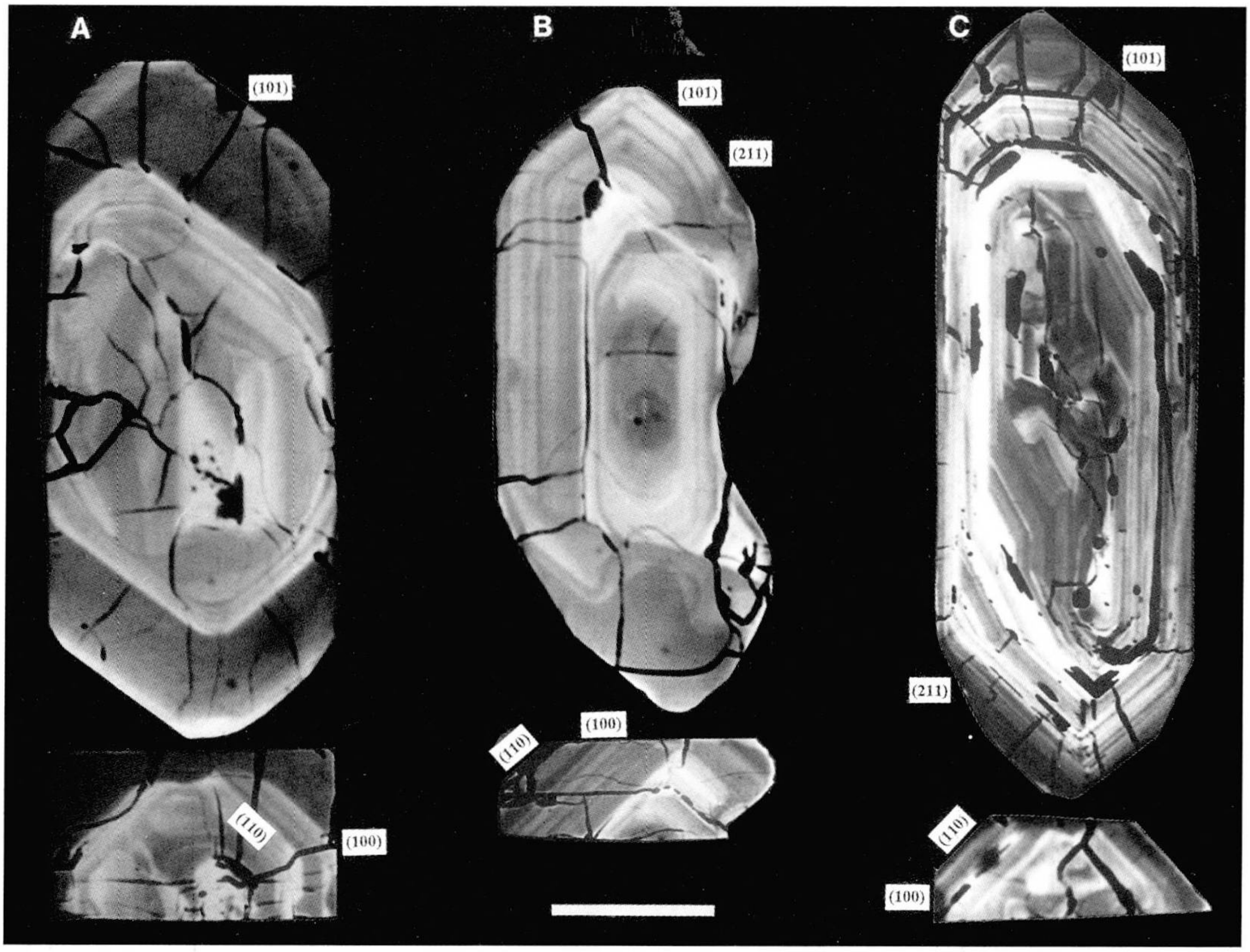

Fig. 4 Longitudinal and cross sections of zircons from the Schlieren-Granite. The prism evolution is characterized by a growth inhibition of the F-face {100} that leads to a clear predominance of this face in the outermost layer. Pyramidal development shows large {101} faces that only decrease slightly over the entire growth period. Bar = 30 µm.

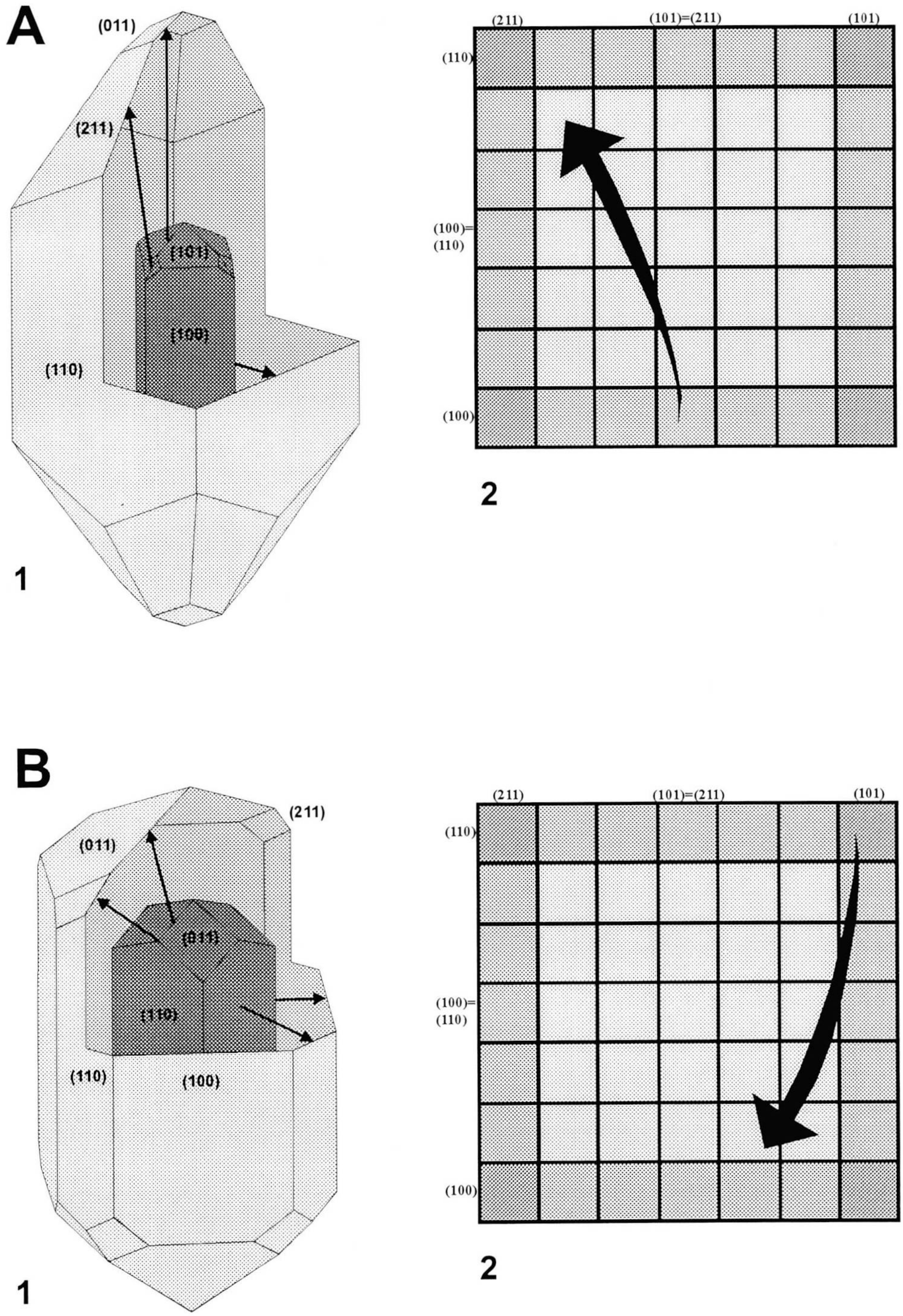

Fig. 5 Morphological evolution of zircons from the Pearl-Gneiss (A) and from the Schlieren-Granite (B). (1) Simplified shell model of the typological evolution showing the first and the last growth stage. (2) Evolution plotted into the typology diagram (PUPIN and TURCO, 1972).

ical development than crystals from an calcalkaline I-type granite. The morphologies of zircons from S-type granites (Pearl-Gneiss) are often marked by deviations from the theoretical growth form which mainly result from an adsorptive growth blocking of the S-forms {211} and {110} (WOENSDREGT, 1992; HARTMANN, 1987) by elements such as U (Th), Y (REE) or water molecules (BENISEK and FINGER, 1993; VAVRA, 1994). As a consequence, an outer morphology with large {211}-pyramids and {110}-prisms is formed. The inhibited growth stage usually develops after an initial ideal growth phase which is characterized by dominant {101} and {100} faces. The inhibition phenomenon seems to be an effect that probably takes place in response to an enrichment of growth-blocking elements during fractional crystallization. The results obtained largely correspond to the observations of PUPIN (1980) who predicted a similar morphological evolutional trend for zircons from aluminous leucogranites. Therefore, the zircon populations of these rocks include the subtypes $L_{1\text{-}2}$ and $S_{1\text{-}2\text{-}3\text{-}6\text{-}7}$. In the case of the Pearl-Gneiss, the morphological evolution obtained by the analysis of the typology diagram (Fig. 2) is quite the same as that obtained by the study of longitudinal and cross sections of zircons (Fig. 5A).

The typological development of zircons from calcalkaline I-type granites is often characterized by the formation of the theoretical morphology which is not influenced by adsorption effects or other external factors at all. Corresponding to the PBC-theory (WOENSDREGT, 1992) this kind of growth leads to the formation of the F-forms {100} and {101} whose growth rates are of the same order of magnitude. Hence, stubby to normal elongated crystal habits commonly emerge. In the case of needle-shaped dendritic nuclei, long prismatic zircon habits may also form, especially in rapidly cooling melts. As previously shown by VAVRA (1994), such an ideal growth stage with dominant {100} and {101} faces may often be realized over the entire growth period of single zircons. PUPIN (1980) also describes the formation of the D type or adjacent subtypes in calcalkaline granites, but according to his studies, the typological evolutional trend ends with the formation of G types. This trend was not found in the present study, as shown in figure 2 and figure 4. Again, the statistical evaluation of the outer zircon morphologies corresponds with the obtained internal morphological evolution very well (Fig. 5B).

It can be concluded that the presented method gives insight into the morphological evolution of zircon crystals, though it might be a little bit time consuming. This new method largely supports Pupin's theory of the relationship between morphological evolution of zircon and type of granitic rock. It must be noted that external morphology always results from more or less distinct growth of prism and pyramidal faces which can bear high diversifications. These complex growth phenomenona can be studied very well with the preparation technique introduced here.

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