

SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 737 AVHANDLINGAR OCH UPPSATSER ARSBOK 71 NR 12

LENNART SAMUELSSON AND STELLAN AHLIN

ZIRCON MORPHOLOGY
IN THE POLYMETAMORPHIC ROCKS
OF SOUTH-WESTERN SWEDEN



STOCKHOLM 1978

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ABSTRACT

The possibilities of using zircon morphology as a tool for making petrogenetic interpretations in a polymetamorphic gneiss terrain are investigated. The sampled rocks are from the Göteborg area in south-western Sweden.

A diversity of form adjustment may occur during the stages of high regional metamorphism. It is shown that metamorphic and tectonic processes affect the initial appearance of the zircons by fracturing, corrosion and the development of external shells and their colourings. It is observed that there is a tendency for each metamorphic episode to form a shell around the older core and that the appearance of this shell is characteristic of that specific episode. In accordance with these changes, it is of importance to investigate the cores of the zircons, in order to get information about the original character of the rock. Concerning the morphology of the zircon cores, the investigated rocks fall into two groups. One group, with supracrustal characters of the zircon populations, comprises fine- to medium-grained gneisses with compositional banding, coarse augen gneisses and anatectic parts of highly migmatized rocks. The other group, with predominantly magmatic characters of the zircon populations, contains rocks of clearly plutonic provenance, including a tonalite-granodiorite-granite suite and two, separate,

granitic intrusions. Judging from the field evidence, the latter granites are younger than the first metamorphic episode. This is also shown by their zircons, which have one shell less than the tonalite-granodiorite-granite suite. There is some slight overlap in the statistics of the zircon-core morphology in the two groups. This is interpreted as being mainly due to tectonic processes causing fragmentation and "rounding" of zircons in some plutonic intrusives. The partial assimilation of sedimentary rocks is also sometimes operative in this connection.

INTRODUCTION

The present investigation was initiated as a consequence of the problems which arose during mapping by the Geological Survey of Sweden in the area east of Göteborg (Fig. 1). The bedrock of the area has gone through several periods of

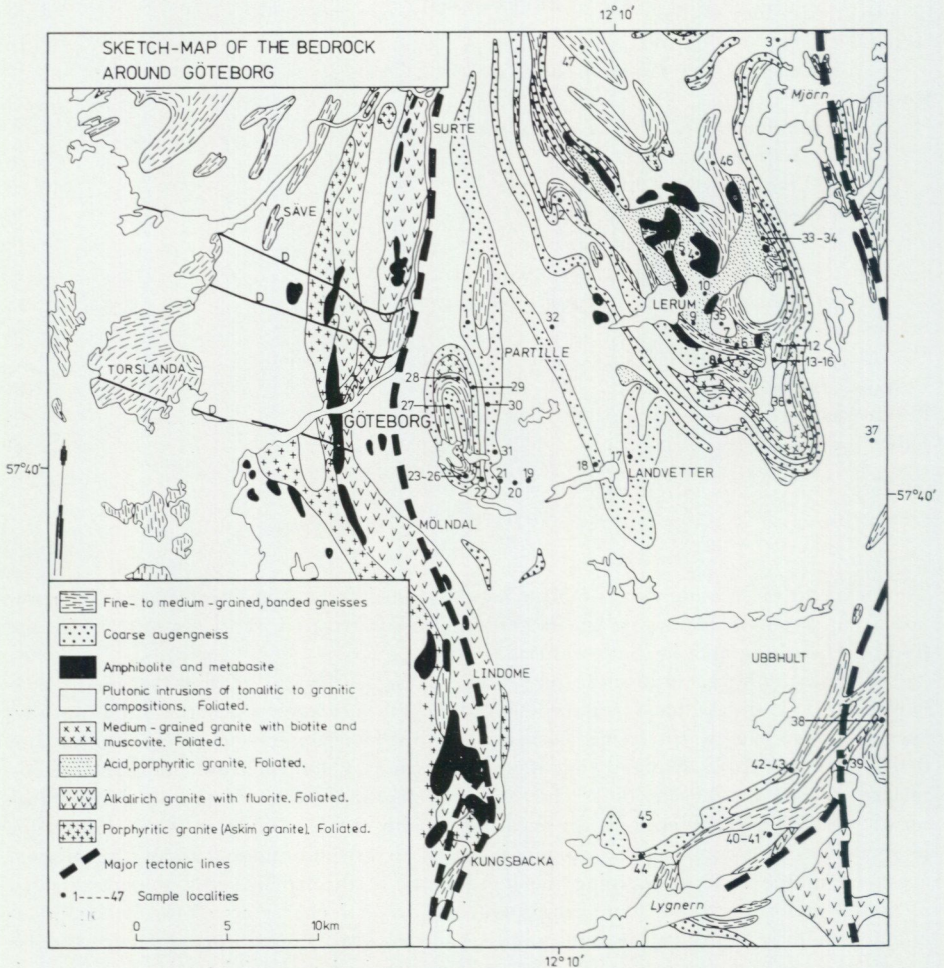


Fig. 1. Sketch map of the bedrock around Göteborg. The sketch map has been compiled from Lundegårdh (1958) and unpublished information from the present mapping by the Geological Survey of Sweden.

thermal and kinetic metamorphism. In scattered areas, where the alteration of the rocks was less pronounced, it was possible to establish a provisional stratigraphy (see below). The conformity in the appearance of rocks of both sedimentary and igneous derivation was due to the metamorphic events. Primary structural differences were obliterated by the strong deformation, locally resulting in the formation of mylonite belts, while mineralogical and chemical differences were obscured by intense recrystallization, veining, formation of pegmatites and migmatization.

It was necessary to look for a rock feature that was, as far as possible, unaffected by the thermal and kinetic events and would thus be useful as a tool for making comparisons, classifications and petrogenetic interpretations of the bedrock. It was suggested that the study of zircons might be worth while in this respect. A set of 32 zircon concentrates was prepared and studied along more or less traditional lines. The results of this study were not useful for the solutions of the initial problems (see p. 43). However, during the microscopical study, some features of the inner morphology of the zircons were observed. They seemed promising as a basis for further investigations. The sample set was then enlarged and some samples in the original set were re-analysed, using the new morphological criteria. The selection from the first 32 samples was based on their importance in the solutions of the geological problems.

The method of sampling used was largely dictated by the field problems. We are aware that an investigation aimed purely at the study of the internal morphology of zircons from a metamorphic terrain, would have benefited from a different sampling method. A study on the present principles would have been favoured by a careful selection of material from rocks with a better-established, petrogenetic record. However, we find that the present results are useful for the solution of the initial problems and also illustrate fairly well the principle of the method.

PREVIOUS WORK

The study of zircons has been used as a tool in the solution of different kinds of geological problems. Marshall (1967) lists stratigraphic correlation, division into sedimentary, igneous and metamorphic terrains, petrogenesis, palaeogeographic interpretation, provenance, radiometric dating, in sedimentary rocks as a maturity index, and in soils as a stability index. As regards petrogenesis, which is the subject of the present work, compilations have been made by Marshall (1967), Hoppe (1963), and Mehnert (1968), for example. As regards the prerequisites for the zircon analysis applied to petrogenesis, some basic facts can be summarized, as follows.

MINERALOGY OF ZIRCON IN MAGMATIC AND METAMORPHIC CONDITIONS

Zirconium is widely distributed among igneous rocks, but as a rule in low concentrations. Mason (1966, p. 45) gives 210 ppm for granite (G—1) and 100 ppm for diabase (W—1) and a crustal average of 165 ppm. Degenhardt (1957, p. 289) discusses the average concentrations thoroughly and gives 175 ppm for granites, 125 ppm for diorites, 110 ppm for gabbros, and an average content in the lithosphere of 156 ppm. Nockolds and Allen (1953, p. 138) studied the geochemistry of igneous-rock series and found that "in general, the zirconium content is low in the basic end of each series and then tends to rise, after which it seems more or less constant until the extreme acid end, when it tends to fall". During the differentiation of a basic magma, the element is first built into pyroxenes as a trace element. At a later stage, a genuine zirconium mineral, zircon, is formed and is stable (Wager and Mitchell 1951, p. 192). In intermediate and acid igneous rocks, the tendency of zirconium to form zircon is strong, and the mineral is thus, as a rule, present as an accessory mineral (Deer *et al.* 1962, p. 64). In syenitic rocks, zirconium may occur in higher concentrations and form more complex minerals (Goldschmidt 1954, p. 424).

An important question is at what stage during the crystallization of a granitoid magma zircon forms and what the optimal conditions for its crystallization are. Mehnert (1968, p. 183) has discussed the first subject and finds that zircon crystallizes early and is sometimes transported as crystals during magmatic events. Marshall (1967, p. 124) has discussed the metamorphic conditions proper for zircon crystallization and states that an amphibolite facies is the best. In granulite facies, crystallization occurs but often produces subhedral or rounded grains (Marshall 1967, p. 125; Murthy and Siddique 1964, p. 125; Hoppe 1963, p. 58). In P, T conditions lower than amphibolite facies, crystallization and recrystallization are slight or negligible (Marshall 1967, p. 125). However, some observations that contradict the general observations have been reported (Saxena 1966 a, p. 26, 1966 b, p. 276, and 1968, p. 145). The main rules were outlined by Marshall (1967, p. 124). During crystallization from a granitoid magma the zircons tend to become idiomorphic (Poldervaart 1956, p. 530). During recrystallization under optimal metamorphic conditions, the zircons tend to become idiomorphic and similar to magmatically formed zircons (Poldervaart 1950, p. 574; Schidrowski 1963, p. 68). Under favourable magmatic conditions, the elongation of the zircon grains may well exceed 5.0 (Poldervaart 1956, p. 545). On the other hand, zircons from an adamellite have been shown to have a y -axis shorter than the x - and z -axes (Phillips 1974, p. 715). In volcanic rocks, zircons may show both idiomorphic and irregular habits, the latter being due to obstacles to crystallization. The obstacles may cause a low mean elongation, lower than 2.0. Gaseous inclusions are common in zircons from volcanic rocks (Hoppe 1963, p.

61). Poldervaart (1956, p. 531) reports that magmatic corrosion is relatively common on zircons in effusive rocks.

Zircon normally contains a small percentage of hafnium. This is due to the great chemical similarities between the two elements (Goldschmidt 1954, p. 422). Thus, hafnium normally forms no minerals of its own. Kresten (1970, p. 414) has compiled the Zr/Hf ratios in zircons from different rocks and found great variations. The Zr/Hf ratio is found to vary from around 5 to 90 and is dependent on rocktype, as well as on the metamorphic history of the rock. Zircon may contain Th, Y and other trace ions to a fairly large extent (Deer *et al.* 1962, p. 61). Dennen and Shields (1956, p. 656) found it probable that the yttrium content of zircon is due to an admixture of xenotime (YPO_4) and the content of yttrium in zircon was found to be log-normally distributed, with the mode at about 2.5 % and with a minimum of 1.6 % and a maximum of 4.3 %. The composition may thus be complicated, especially as the radioactive components cause disturbances and decay of the lattice, resulting in a more or less metamict state. These varieties have special names, like malacone, cyrtolite and orvillite (Deer *et al.* 1962, p. 61).

Chemical compositions reported from the analysis of zircons sometimes do not reflect the composition of a homogeneous phase. On the contrary, for instance, Kresten (1974, p. 86) found that hafnium and yttrium were concentrated in a thin marginal zone of some zircon crystals. Brotzen (1952, p. 175) discusses very fine ("hairline") zoning (for illustration, see Fig. 2), and interprets this usual feature as being due to a reiterated yttrium admixture during the growth of the zircon grains.

ZIRCON IN SURFACE CONDITIONS

Zircon is a hard ($H=7.5$) and, in most cases, a chemically resistant mineral (Poldervaart 1955, p. 437), although strongly acid (Degenhardt 1957, p. 295) or alkaline solutions can dissolve the mineral to some extent. Vortisch (1975, p. 64) described the corrosion of zircons from the Hardeberga sandstone in southern Sweden. He had to assume that strongly basic solutions were the corrosive agents. His conclusions were supported by Nickel (1973), who experimentally showed the incongruent solution of SiO_2 from the zircon lattice at pH 10.6. In soils, zircon remains unweathered for a comparatively long time and this fact has been used as a stability index (Marshall 1967, p. 123). The zirconium content of a profile through weathered Harz granite has been given by Degenhardt (1957, p. 294). The profile ranges from a depth of 5 m, where the rock is unaltered, to 30 cm below the surface, where it is weathered to a clayish soil. The Zr content of the samples increases from 195 ppm in the unweathered rock to 306 ppm in the uppermost sample. The concentration of Zr in the upper part of the profile is regarded as having been caused by the removal of other constituents. Feldspars and dark minerals are weathered and soluble parts have been washed out. The

greater part of the zirconium (as zircon) is left behind and is thus concentrated. Doe and Wewell (1965, p. 613) analysed the amount and the proportions of uranium isotopes in zircons exposed to weathering conditions. In the remaining parts of the zircons, the primary amount and composition of uranium were preserved.

In clastic sediments, zircon is present, as a rule, and is one of the most resistant minerals (Pettijohn 1949, p. 504). The Zr content in clays shows fairly constant values (about 150 ppm). Sandstones and quartzites have a pronounced variation, usually between 50 and 500 ppm Zr (Degenhardt 1957, p. 301).

The process of rounding the grains during sedimentation is complicated and is not properly understood (Pettijohn *et al.* 1972, p. 81). Factors like the original shape, the size and the environment of the grains, as well as other factors, co-operate. In sedimentary processes, zircons become rounded, although long reworking may produce broken and angular grains (Poldervaart 1955, p. 439). Elongation is less than 2.0 in most sediments. Roundness ranges in sands can be estimated directly on the angularity of zircons, as well as on the quartz grains (Pettijohn *et al.* 1972, p. 84).

Rounded zircons are thus the rule in sands, but a certain minimum size is required. Poldervaart (1955, p. 439, 1956, p. 532) states that above a length of 50 μm zircons in sediments are more markedly rounded. If they are smaller, a greater proportion of them is angular, such as zircons from shales and siltstones, which are small and consequently angular to a high degree.

INFLUENCE OF ROCK DEFORMATION AND METAMORPHISM ON ZIRCON MORPHOLOGY

Few studies have been found of the change of zircon morphology during tectonisation, but Poldervaart and von Backström (1949, p. 463) report the influence of tectonisation on zircons in a probably originally uniform rock. Zircons from tectonised parts are smaller and are often aggregated. Elongation is decreased by tectonisation.

The effects of metamorphism on zircons have been studied by Poldervaart (1950, p. 574), Schidlowski (1963, p. 68), Hoppe (1965, p. 273), and Malcuit and Heimlich (1972, p. 1193), for instance. Metamorphism causes a partial recrystallization of the zircons, so that a shell is developed around the original grain. Thus, zircons from metamorphosed rocks often show a development of core and shell to a high degree. If the conditions of metamorphism are optimal for zircon crystallization, the shell tends to have an idiomorphic habit, like zircons from igneous rocks. Malcuit and Heimlich (1972, p. 1203) also observed the formation of entirely new zircon grains during metamorphism.

SOME COMPLICATIONS OF THE PREREQUISITES FOR ZIRCON ANALYSIS IN PETROGENESIS

The main rule, stated above, for rounded, little elongated zircons to be found in sediments and rocks derived from them and idiomorphic, greatly elongated zircons in granitoid igneous rocks, has been confirmed many times. There are, however, also a large number of exceptions to this rule, some of which may be outlined as follows:

- A. Tectonization can cause fragmentation or other changes of the zircon habit.
- B. Metamorphism can cause the growth of a shell which obscures the original habit.
- C. Crystallization and recrystallization of zircon grains sometimes occur in a metamorphic milieu that does not provide optimal conditions for the idiomorphic growth of zircon. Granulite-facies zircons, even of clearly igneous origin, are sometimes almost spherical (Hoppe 1963, p. 66).
- D. The primary elongation of zircons from granites seems to vary from rather low values (2.0) to high values (Poldervaart 1956, p. 535).
- E. Many granites have obviously assimilated the wall-rocks to some extent. During this assimilation, resistant minerals, like zircon, may have been incorporated without fusion. Thus, the granite will have a more or less heterogeneous zircon population (Poldervaart 1956, p. 530).
- F. Corrosion of zircon grains occurs under different conditions. Corrosion under surface conditions has been discussed (p. 7). Corrosion acting on zircon grains during rock formation or metamorphism has also been reported. These observations refer to the irregular, granular surfaces of zircons from some rocks. Few of these rocks are, however, plutonic, granitoid rocks, and most of them are volcanic (Poldervaart 1956, p. 531).
- G. Zircons from effusive and plutonic rocks (intermediary and acid) may, at least in some aspects, be rather similar (Hoppe 1963, p. 67).
- H. As previously discussed, the zircons in a sediment are not always rounded. A more or less heterogeneous zircon population is thus to be expected in sedimentary rocks.

OBSERVATIONS AND MEASUREMENTS IN ZIRCON ANALYSIS

In studying zircons from a rock, some basic facts must be considered:

- A. The more or less heterogeneous zircon population should be represented by a not too small number of randomly chosen grains. Hoppe (1963, p. 7) made observations on 300 grains per sample, and Poldervaart (1956, p. 546) measured 200 unbroken grains. A method of random selection of the grains from the sample has been described by Poldervaart (1955, p. 436).

- B. Valuable observations are only available from isolated zircon grains. Poldervaart (1956, p. 529) has pointed out how misleading conclusions have emanated from observations made on thin sections. The true form of the crystal can only be adequately observed if the grain is separated from the rock. Another reason that necessitates separation and thus concentration of the grains is the scarcity of zircon grains in ordinary rocks.
- C. The sizes of the grains analysed, and especially the lower limit, influence the result considerably. Poldervaart (1956, p. 532) discusses this and finds a minimum length of 50 μm to be recommendable. In sediments, the small grains are more irregular, and in igneous rocks, the small grains are more rounded than the medium-size grains.

The most important aspects of zircons that have been considered relevant for petrogenetical analyses in previous works (Poldervaart 1956, p. 534; Hoppe 1963, p. 10; Malcuit and Heimlich 1972, p. 1193; Byerly *et al.* 1975, p. 956) are (1) external form (rounding), (2) dimensional data (length, breadth and elongation), (3) colour, (4) inclusions, and (5) internal structure (zoning).

METHODS

SAMPLING

The rock specimens were sampled from apparently homogeneous parts of the rocks. The sample size was approximately 1500 g. The samples were crushed and milled in a rotary mill. Material that passed a 125- μm sieve was washed in a sedimentation beaker. Grains that sedimented 20 cm or more in 120 seconds were selected. This corresponds to a grain size of at least about 16 μm of grains, if a density of 4.0 g/cm^3 is assumed (Krumbein and Pettijohn 1938, p. 95). The widths of the collected zircon grains can be estimated as being somewhere between 125 μm and 16 μm . The grain samples were dried and mineral separation was performed with a hand magnet, a Franz isodynamic magnet-separator and heavy liquids.

Strongly magnetic material was removed manually with the hand magnet, and other mafic components (biotite, epidote, amphiboles, etc.) were isolated with a Franz isodynamic magnet-separator. The highest current used was 1.0 A. The remaining mineral grains were then separated in tetrabromethane (density 2.95 g/cm^3), di-iodomethane (density 3.40 g/cm^3) and finally Clerici solution (density 4.1 g/cm^3). After this treatment, the heavy residue was enriched in zircon grains, the composition ranging from almost pure samples to approx. 30 % zircon grains, together with other heavy minerals. The samples were not washed with acid, as soluble contamination was negligible. Details of sample preparation are well de-

scribed by Poldervaart (1955, p. 435) and Eckelmann and Kulp (1956, p. 307), for instance. There are special ways of separating the zircons from the rock by entirely chemical agents and thus all mechanical damage can be eliminated during preparation (Hoppe 1963, p. 6). This was not considered necessary, as a rather high proportion of zircon grains seems to resist the previously described treatment.

MOUNTING AND MICROSCOPY

The zircon samples were mounted on the microslide in liquids with refractions as close to that of the zircon grains as possible ($n = 1.86$). The micro-cover glass was sealed with stearine. This type of slide is usually destroyed in about 24 hours by the evaporation of the liquid, but it can be stored and remounted. The mounting method described minimizes optical interference phenomena between mounting material and zircon grains, and thus the zircon grains are easily identified and their internal structures are easily investigated. In investigating the slide, the method of selecting grains for measurement described by Kalsbeek (1965, p. 179) was used. Thus, a random sample of approx. 150 unbroken zircon grains was described, together with a varying number of broken grains. Measurements of length and breadth were performed with a calibrated scale in the ocular. An essential feature of the present investigation is the discrimination of different features in the morphology of the inner parts of the zircon grains. Some of these features have been touched upon in the section on previous works (for example, p. 8). Below, an account is given of the observations relevant to the present study. The discrimination of boundaries between different parts of the zircon grain is the basis for the distribution between groups with one, two or three shells and a core. The following features, alone or together, are important in this respect:

1. The observations of a Becke line separating the central part, which has optical properties different from those of the outer part.
2. The observation of a surface "discordantly" cutting the oscillatory zoning in an inner part of the grain (Fig. 2b).
3. The observations of distinctly different properties of the central part in comparison with these of the outer part. Examples are different colours, different inclusions (kind and frequency) and different kinds and/or orientations of oscillatory zoning.
4. The observation of a surface with distinct pigmentation or "pitting".
5. The observation of different kinds of cracks and fractures in concentric parts of the grains.
6. The observation that crystallization has been partly obstructed in the inner part and not in the outer part.

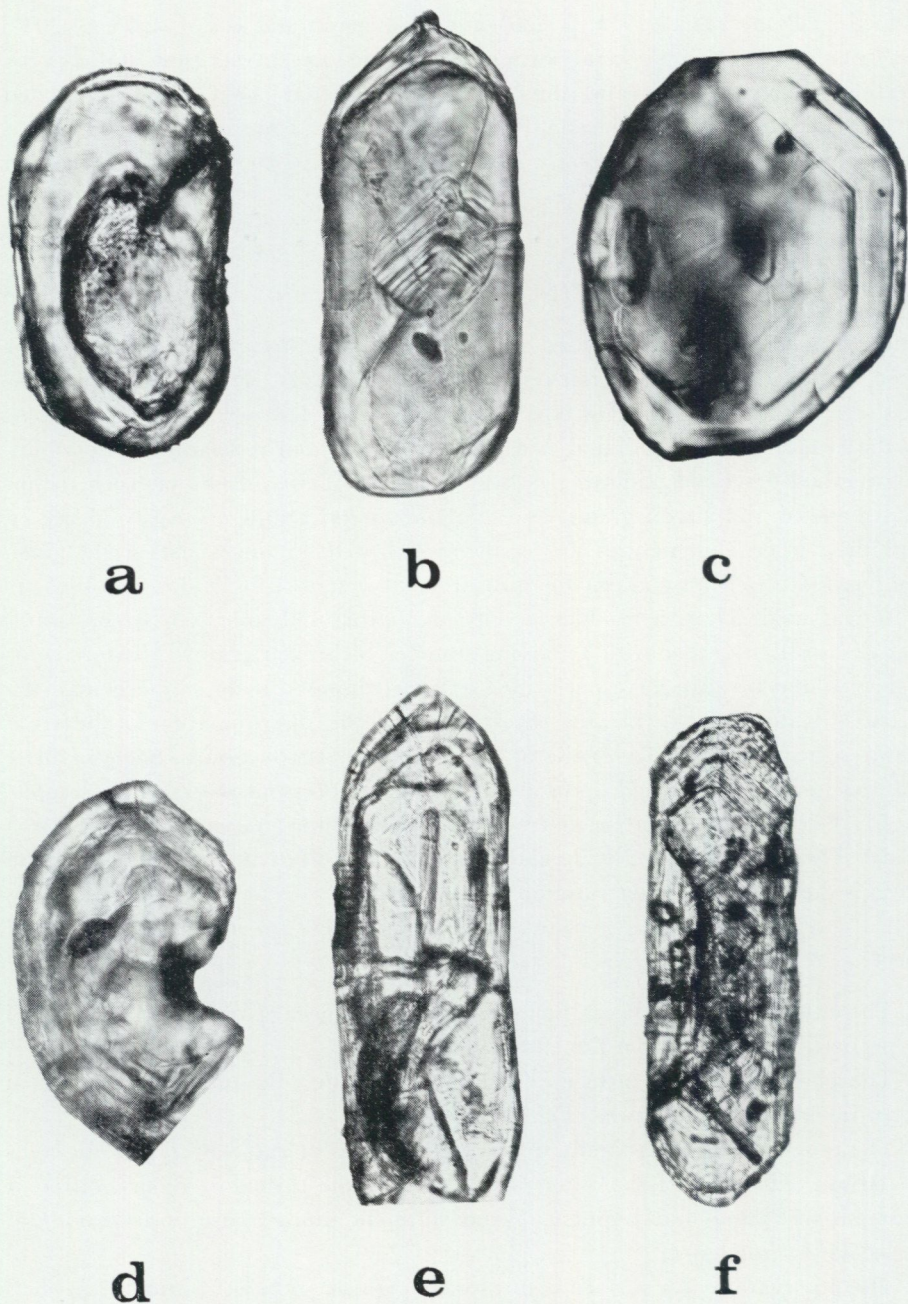


Fig. 2. Zircons illustrating different morphological features. The *c*-axis is parallel to the vibrating plane of the lower nicol. Length of grains is about 150 μ .

A. The outermost shell (= no. 1) is irregular and thin, the next shell (= no. 2) and the core (= shell no. 3) are round. Sample 31.

B. The core (= shell no. 3) consists of a fragment with hairline zoning. Sample 47.

7. Observation of fracturing of a more central part of a grain. If the fracture plane cuts through even the outermost shell, the grain is regarded as "freshly broken" and is excluded from the petrogenetic discussions.

The criteria as regards shell delimitations listed above are in some respects dependent on each other, and usually more than one critical observation can be made in the actual case. The concentric shells of the zircon grains have been denoted "shell no. 1" for the outermost one, "shell no. 2" for the second outermost one, etc. The highest number thus denotes the core of the grain.

The discrimination of different shells in the zircon grains has been combined with the recording of the morphology of the outer, delimitating surface of each shell. The grouping is as follows:

1. Euhedral: as far as is observable, the delimitating surface is consistent with crystal growth surfaces.
2. Subhedral: the delimitating surface is almost consistent with crystal growth surfaces. Slight modifications of the ideal form are accepted, such as slight rounding of some corners.
3. Crystallization partly obstructed: it can instantly be seen that an external obstacle has influenced the crystal growth (Fig. 2d). This is a group with a low frequency.
4. Rounded grains: the delimitating surface cuts across the crystallographic growth surfaces. The latter are often outlined by the presence of oscillatory zoning. Owing to the prominence of the *c*-axis direction of the zircon crystals, the most common form of the "rounded" zircons is ellipsoidal rather than spheroidal (Fig. 2a).
5. Fragmented grains: the fracture surface is usually irregularly perpendicular to the *c*-axis.
6. Irregular grains: none of the above-mentioned criteria is adequate. Usually, when the core is concerned, it is consistent, with a fungous, grey to brown mass. When the outermost shell is denoted "irregular", this usually means that it has a thin coating, thickest at the terminal ends of the grain. It is not thick enough to produce a habit independent of the underlying shells. The external form of the zircon grains as a whole cannot be judged by a study of "shell no. 1" alone.

C. Shell no. 1 is subhedral and thin. Shell no. 2 is also subhedral and the core is euhedral. Sample 19.

D. Crystallization obstructed. Sample 35.

E. Shells nos. 2 and 3 have been broken "irregular", the pieces slightly moved and then healed by shell no. 1. Sample 32.

F. Hairline zoning in subhedral shell no. 2 (= the core) and an irregular and thin shell no. 1. Sample 10.

SAMPLING OF DATA

During the microscopic investigation, the grains were examined one by one and a total of 150 unbroken grains was recorded. The following aspects were noted, as regarded the zircon:

1. Broken or unbroken grain
2. Length of grain
3. Breadth of grain
4. Habit of grain, recorded for unbroken grains only:
 - Euhedral
 - Subhedral
 - Crystallization partly obstructed (Fig. 2d)
 - Rounded
 - Irregular
5. Shells. See the discussion on p. 11. Zoning due to one or more shells around a core was recorded with a description of each shell. Each shell was described by the following alternatives:

Euhedral

Subhedral

Crystallization partly obstructed. A fairly regular crystal growth is evidently obstructed in a small part.

Irregular (when the outer shell is very thin and is observed only in some parts of the grain, it is denoted irregular).

Rounded

Fragments (Fig. 2b). Cores with a fragment habit can be clearly identified.

Oscillatory zoning is recorded as either present or absent (Fig. 2f).

If there was no division between shell and core, this was recorded as "core lacking". Then, of course, only points 1—4 were relevant, supplemented with a note as to whether zoning was present or not.

PREPARATION OF DATA

Observations and measurements were coded with numbers, which could be treated by computer. The bulk of the observations from each sample was arranged as follows (see also Table 3):

Number of unbroken grains

Number of broken grains

Proportion of broken grains in total

Total amount of grains

Length, unbroken grains, mean value¹

Length, unbroken grains, standard deviation²

Length, broken grains, mean value¹

Breadth, unbroken grains, mean value¹

Breadth, unbroken grains, standard deviation²

Breadth, broken grains, mean value¹

Elongation (length/breadth) of unbroken grains, mean value¹

Elongation, standard deviation²

- 1 Arithmetical mean value,
where x_j = each value and n = number of values

$$M = \frac{\sum_{i=1}^n x_i}{n}$$

- 2 Standard deviation
for symbols, see footnote 1

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (x_i - M)^2}{n}}$$

Observations on shells. For all zircons with shells in the sample, the habit of the outer shell, no. 1, is described and then each following shell. At most, four shells were described. Zircons with no observable shells are treated separately, with the same six classification groups.

The number of grains with the following habit of the respective shell were recorded:

Euhedral habit, total
Euhedral habit, zoned
Subhedral habit, total
Subhedral habit, zoned
Crystallization partly obstructed, total
Crystallization partly obstructed, zoned
Irregular, total
Irregular, zoned
Rounded habit, total
Rounded habit, zoned
Fragments, total
Fragments, zoned

The computer also plotted seven graphs for each sample:

Histogram for length of unbroken grains
Histogram for breadth of unbroken grains
One histogram for each shell (maximum four) with six classes of habit for each. The zoned quota of each class was registered as a subgroup and recorded as a separate line in the columns of the histograms.

Finally, matrixes correlating observations in different shells were constructed (Fig. 14). Shell no. 1 was compared with no. 2, and no. 2 with no. 3. The observations were the same as those previously described for each individual shell. However, a simplified model was also constructed, in which, for each category, for instance, euhedral, zoned and unzoned were added together.

The program was constructed by Anders and Lars Ekelund at the Institute of Geology, University of Gothenburg. It is written in the "BASIC" computer language and is available from the present authors.

GENERAL GEOLOGY OF THE AREA

The rocks examined were all collected from the same, fairly homogeneous, tectonic block (Fig. 1). The north-south extension of this geological unit is considerable. It is possible to follow it continuously from the coast some 20 km south of Kungsbacka to the southern shore of Lake Vänern between Vänersborg and Lidköping. This is a distance of more than 120 km. Rocks of this unit are also expected to occur north and north-west of Lake Vänern (Magnusson *et al.* 1963, pp. 125—164; see also Gorbatshev 1971, p. 5). The east-west extension of this tectonic unit in the present area is only about 25 km. The western border is essentially consistent with the Göta älv and Kungsbacka fjord valley, which is a prominent, topographic expression for a repeatedly active, tectonic line (Lundegårdh 1958, pp. 75—81; Samuelsson 1975, p. 10). The eastern limit is a similar tectonic feature, "the mylonite zone", according to Magnusson *et al.* (1963, p. 129; see also Lindh 1974, p. 183). Both tectonic lines dip westwards, the former usually 30° to 60°, and the latter 15° to 40°. Radiometric datings of this tectonic mega-unit from the area between Vänersborg and Grästorps have yielded an age of 1735 ± 85 Ma (Welin and Gorbatshev 1976, p. 378). This age is interpreted as coinciding with a major, regional-metamorphic, migmatization event. The intrusion age of the actual major geological unit is, as a maximum, estimated to be 1964 Ma. At present, our mapping area has its northern borderline about 20 km to the south of the sampling traverse of Welin and Gorbatshev. We have so far not been able to identify any lithological break and consequently consider the above-mentioned ages to be pertinent to the area of the present study. The dated rocks are consistent with the "plutonic intrusions of tonalitic to granitic composition" in the stratigraphic scheme below. Considering the ages of the other rocks included in this study, it is at present not possible to make any plausible connection with previously published radiometric datings from south-western Sweden (cf. Welin and Gorbatshev 1976 for references). Welin and Blomqvist (1964, p. 43) report 930 Ma as the age of some pegmatites situated close to the present area. Skiöld (1976, p. 26) has given 910 Ma as the date of the end of igneous activity, including pegmatites, in south-western Sweden.

The present stratigraphy is based on field evidence. All the rocks, except the very latest pegmatites, are greatly metamorphosed and tectonically overprinted. The majority of the rocks went through at least two episodes of great deformation and metamorphism. The presently observable metamorphic grade is difficult to specify owing to the absence of important index minerals, like the aluminosilicates. The general metamorphic grade is, however, a low almandine-amphibolite facies, *sensu* Winkler (Winkler 1967, p. 106). This is indicated by the general mineral assemblage in granodioritic rocks, $Qz + \text{microcline} + \text{plagioclase} (\text{An } 23-30) + \text{biotite} + \text{hornblende} \pm \text{garnet} + \text{epidote} + \text{accessories}$. The element distribution between garnet and biotite has been studied by Ahlin (1976, p. 337). The temperature of crystallization was estimated to be $580^\circ \pm 20^\circ$, which is in accordance with the assumption based on mineral assemblage. With some variations, the estimated temperature of metamorphism seems valid for the investigated part of the mega-unit considered, according to Ahlin (in preparation), who also estimated that the pressure was high during the regional metamorphism of the area.

The geological evolution of the Precambrian gneiss terrain east of Göteborg can preliminarily be summarized as follows:

Youngest

Pegmatite, aplite and veining probably 930—960 Ma (Welin and Blomqvist 1964, p. 43)

Strong tectonization, producing mylonite in certain zones

Porphyritic granite

Metabasites of "deep hypabyssal" character

Metamorphism, producing veins, migmatite, anatexite, pegmatite and aplite

Tectonization, producing foliation and local mylonitization

Plutonic intrusions of tonalitic to granitic composition

Intrusions of gabbroic, ultrabasic and anorthositic rocks

Development of supracrustal rocks, including rocks from which coarse augen gneisses with a locally similar field appearance.

Though a schedule of the sequence can be established, based on favourable reference localities in the field, identification of the rock types is a general problem. Owing to the strong and repeated metamorphism and deformation of the rocks, it is rather difficult to distinguish between gneisses of different genesis, especially when they have approximately the same chemical composition and metamorphic overprinting. Zircon analysis was thus performed in order to solve problems concerning the petrogenesis and classification of the rocks. The analysis was supposed to contribute to the solution of problems such as:

1. The intrusive, extrusive or sedimentary heritage of greatly deformed and metamorphosed gneisses.
2. The genetical classification of the augen gneisses.
3. The relations between the porphyritic gneiss granite and the coarse augen gneisses with a locally similar field appearance.

CHARACTER OF THE SAMPLED ROCKS

This study was focussed on four rock units, viz. the fine- to medium-grained, banded gneisses, the tonalite — granite suite, the bandiform augen gneisses and the porphyritic gneiss granite. In addition, some greatly migmatized, in part anatectic rocks were investigated.

The fine- to medium-grained, banded gneisses (samples nos. 12, 13, 14, 15, 21, 23, 25, 27, 33, 34, 38, 42, 46, and 47 = group A) comprise a rather heterogeneous collection of rocks. The original structures and compositions have usually been completely destroyed by subsequent metamorphic episodes. Their present appearance is usually a fine- to medium-grained gneiss with a more or less pronounced compositional banding (Fig. 3). Thin bands of quartzitic composition as well as bands with calc-silicates (diopside, epidote, hornblende, garnet) and calcite, occur. However, most of the rocks assigned to this group are quartzofeldspathic, with varying amounts of biotite (Table 2a). At three localities, it



Fig. 3. Fine- to medium-grained gneiss, banded. Group A. Sample 33.



Fig. 4. Augen gneiss. Group B. North of Lake Aspen.

has been observed that centimetre-wide bands of magnetite constitute a spectacular part of these gneisses. No conglomerates have been found. At the present stage of the investigation, this group of rocks is regarded as older than the others in the area. In places, it is obvious that members of this group are derived from sediments. However, basic and acid volcanic rocks, more or less reworked, should be expected. It is also possible that early mylonitization and subsequent recrystallization of igneous plutonic rocks have contributed to this unit.

The coarse augen gneisses (samples nos. 1, 2, 8, 11, 16, 17, 18, 24, 29, 30, 31, 43, and 44 = group B) constitute a prominent structural feature in the petrographic map of the area (Fig. 1). They are usually foliated parallel to the outlines of the bands in which they occur. They are, however, locally completely massive, especially in the hinge zones of the folded bands (Fig. 4). They are composed of large microcline porphyroblasts, usually 3–8 cm in diameter, in a medium-grained matrix comprising plagioclase, quartz, biotite and microcline. They are frequently found in association with minor occurrences of fine- to medium-grained, quartzofeldspathic gneisses (group A).

The intrusive rock suite (samples nos. 3, 19, 20, 22, 37, 40, and 45 = group C), ranging from tonalite to granite in composition, occupies most of the investigated area. According to field observation, petrography and geochemistry, it is a comagmatic assembly intruded and crystallized at plutonic levels. The main part of this suite has a granodioritic composition. All the rocks underwent re-

peated deformation and metamorphism; the more acid, the greater the alterations (Fig. 5).

The porphyritic gneiss-granite (samples nos. 4, 5, 6, 7, 9, and 10 = group D) is found mainly at the village of Lerum, in the northern, central part of the area. The augen are composed of microcline-perthite and may reach a diameter of 5 cm. They are usually crushed and sometimes recrystallized. The matrix consists of quartz, plagioclase, microcline, biotite, and occasionally some hornblende as the main constituents. The rock is sometimes greatly deformed and foliated (Fig. 6). It contains fragments of the supracrustal gneiss, basic intrusives and the tonalite—granite suite. Dikes of this granite also cut a migmatite with rafts of supracrustal gneiss and mafic rocks.

The above description concerns the prominent groups of rocks in the present study. In addition, a few other rock types are treated, as they presented special problems during the petrographical mapping. Samples nos. 26, 28, 32, 36, and 41 are assumed to have crystallized from anatectic magmas derived from older rocks and to be of a local origin. Nos. 3 and 35 were collected from areas of foliated granodiorite with traces of contamination with supracrustal material,



Fig. 5. Strongly veined gneissic granite. Group C. At Kåsjön.

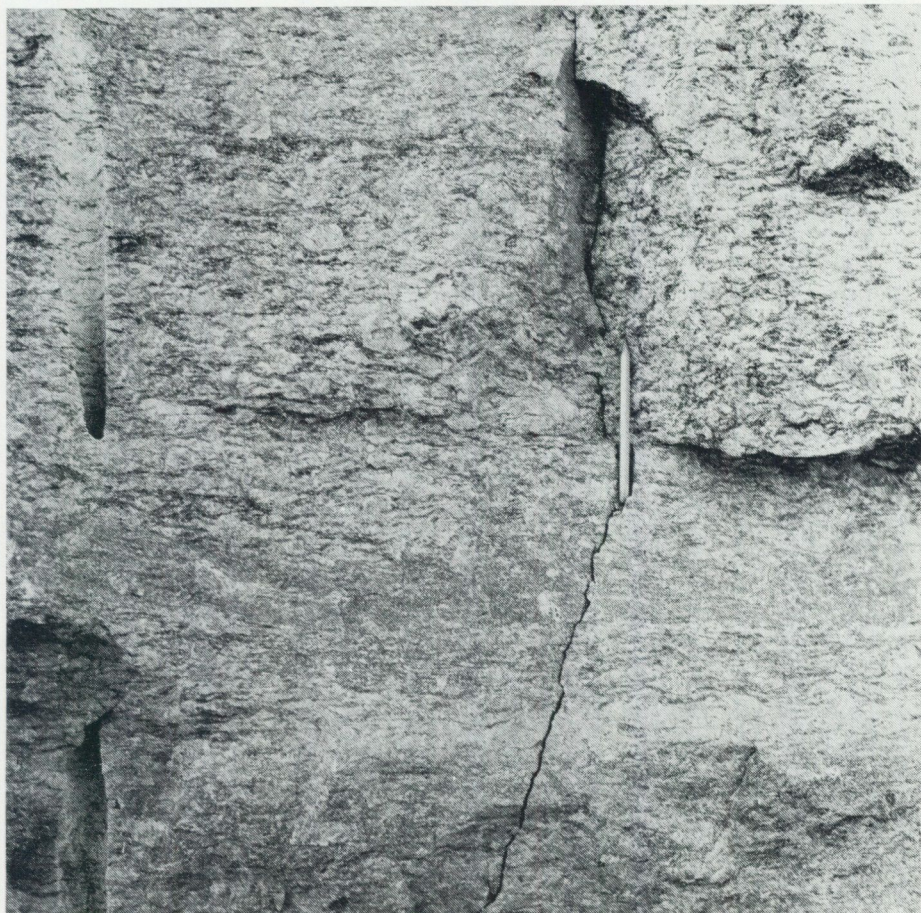


Fig. 6. Strongly tectonized porphyritic granite. Group D. Lerum.

while no. 39 is a single sample of an isolated, gneiss-granite occurrence in the south-eastern part of the area.

As was mentioned in the introduction (see p. 5), all the samples were not studied by the same methods. A more complete study was devoted to the samples in Table 3.

RESULTS

DIMENSIONAL DATA FOR THE ZIRCON SUITES

Data pertaining to zircon crystal breadth, length, and elongation (length/breadth) are presented in Table 3 and Figs. 7—8. The arithmetical means and standard deviations of the data are summarized in Table 3. The amount of broken grains can also be read from Table 3.

The breadth of the crystals is the dimensional parameter that varies least, and it is not possible to make any grouping of the material based on this. The average breadth is usually 60—70 μm , indicating that the sampling interval does not cut off important parts of the zircon population of the rock.

The length parameter seems to have a small and random variation through the different samples, save nos. 4, 7, 10, and 26, which have a distinctly higher mean than the rest.

The elongation of the crystals in samples nos. 4 and 7 and to a lesser degree in sample no. 10 is greater and more variable than that in the other samples. Nos. 4, 7, and 10 are from the porphyritic gneiss granite. No. 9 is from the same rock. However, the elongation is only 1.91. This is discussed below. For the rest of the samples, no significant difference is observable, either when the mean of each group is considered or when the variation within each group is compared (Table 3, Figs. 7—8).

A general idea of the actual meaning of the elongation ratio from a greatly tectonized and metamorphosed granite intrusion can be obtained from a closer analysis of sample no. 4. The mean elongation of the grains unbroken in shell no. 1 gives 2.78. This includes all grains fragmented in shell no. 2 (= the core, see p. 27). These fragments represent 35 % of all grains with shell no. 2. There are no measurements of the actual sizes of these shell no. 2 fragments, but a general idea of this is given by the measurements of freshly broken grains. The mean length of the latter is 133 μm and their mean breadth is 70.5 μm . The mean length represents the average of the pieces of the broken zircon crystals. The mean breadth of these fragments is 70.5 μm , which is slightly greater than the mean breadth of the unbroken crystals, viz. 66.1 μm . This means that the fragments represent pieces of crystals broken at a wide angle to the *c*-axis. The mean length of the fragments is consequently consistent with the half length of the crystals before breaking up. This gives an initial mean length of approximately 266 μm . With the mean breadth of 70.5 μm , an approximate elongation of 3.77 is attained for the grains broken after the crystallization of shell no. 1. It can be assumed that some grains were broken along surfaces with less than 90° to the *c*-axis. The sum of the lengths of the pieces will thus be greater than the length of the unbroken grain. This will slightly diminish the deduced approximate elongation.

It is reasonable to think that the fragments of shell no. 2 (= the core) had at least approximately the same elongation as the freshly broken grains. According to their proportion (35 %) of the amount of grains with shell no. 2, the true elongation of sample 4 before the deformation of shell no. 2 should have been between 3.0 and 3.5.

Sample no. 9 has a still smaller elongation than no. 4. It has likewise a larger amount of fragments in shell no. 2 (40 %). Three per cent of the grains ex-

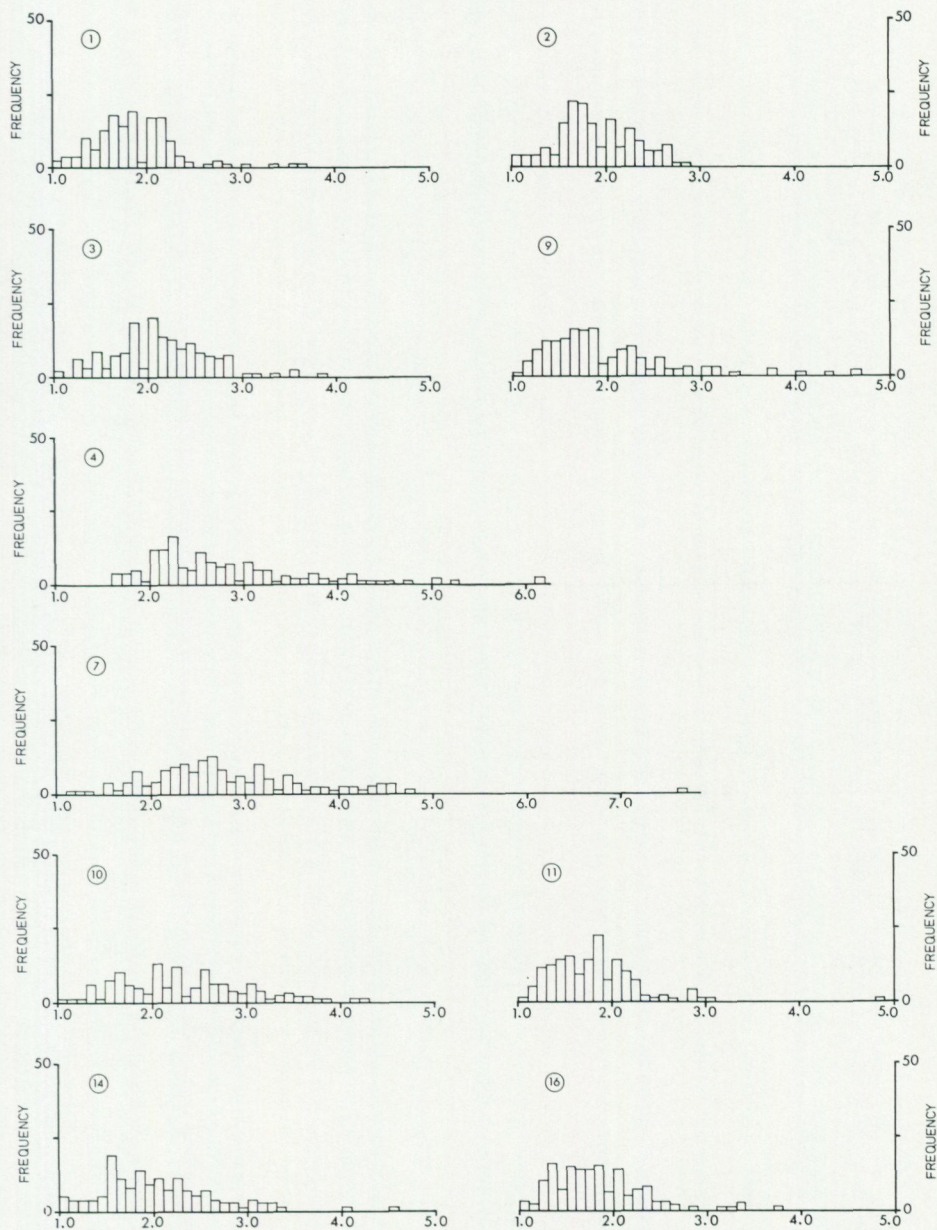
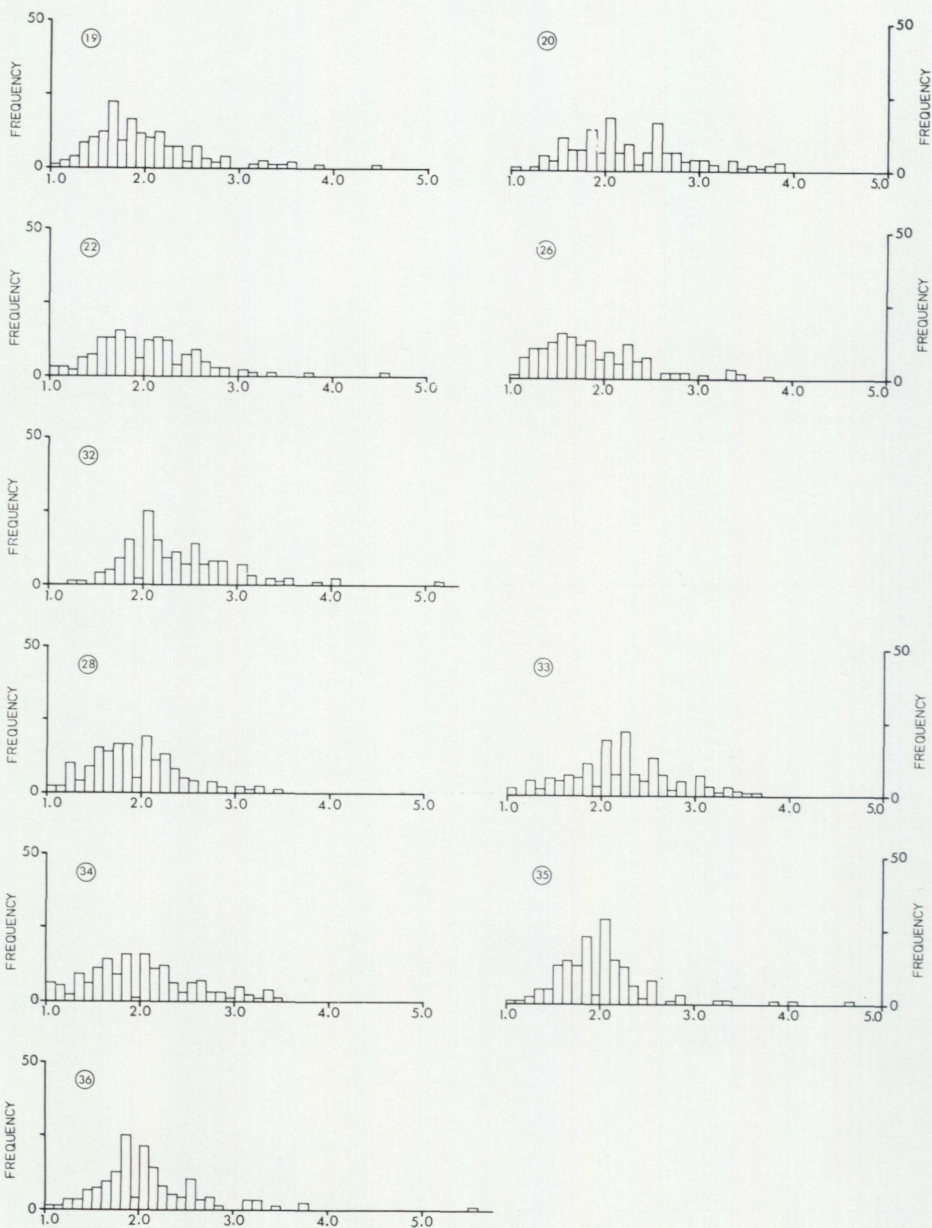


Fig. 7. First part.

mined in shell no. 2 are broken, their fragments being only slightly re-orientated and then healed by shell no. 1. Obviously, the zircons were deformed after their



first crystallization. According to the larger amount (27%) of rounded, shell no. 2 outlines, the deformation was great enough to actually cause a rounded form. That the rounded grains of shell no. 2 are not detrital grains is indicated by the almost complete absence of rounded, shell no. 3 grains (only one grain re-

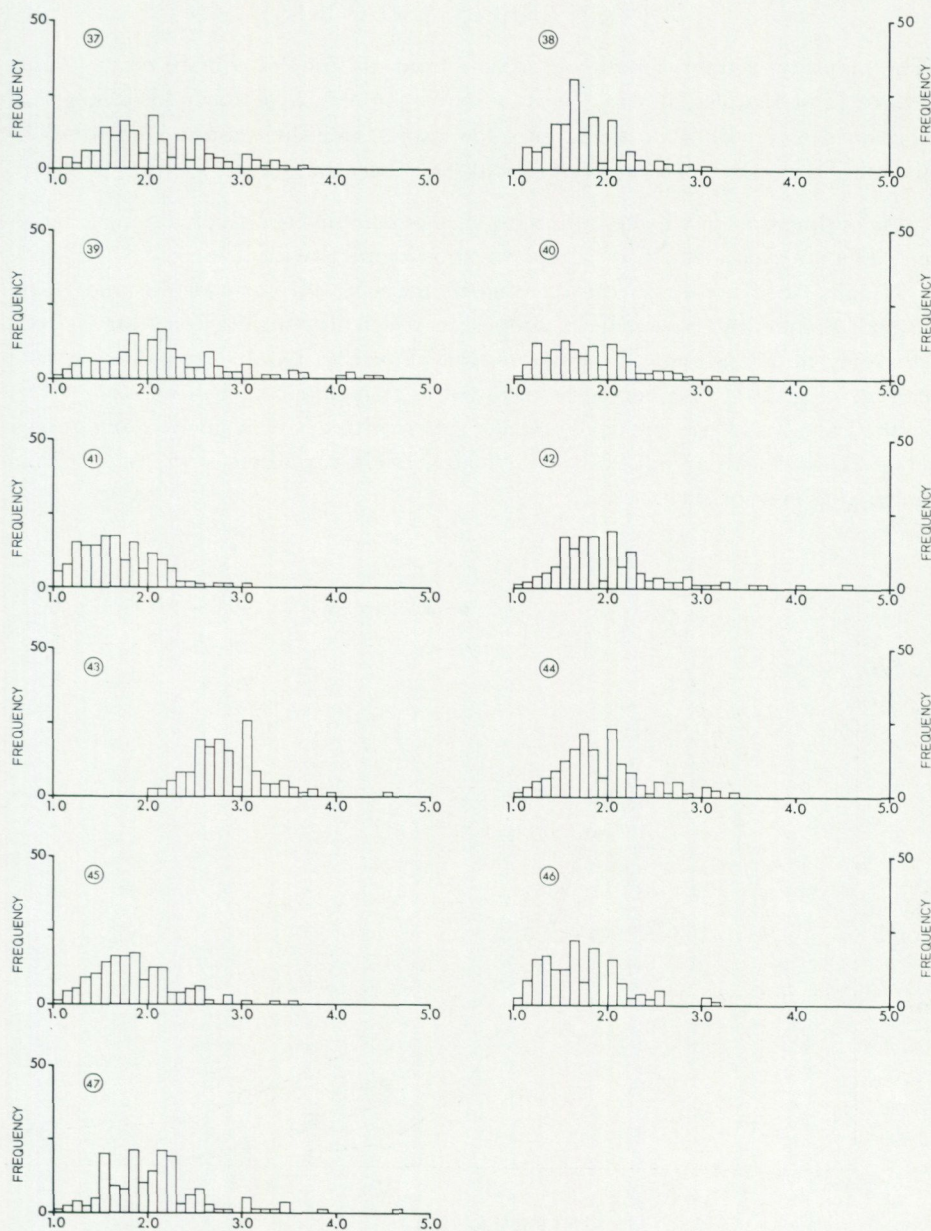


Fig. 7 (pp. 23—25). Histograms of the actual numbers of grains with different elongations (length/breadth).

corded) and the similarity (colour, refraction, zoning, etc.) between the rounded grains, the fragments and the unbroken grains in shell no. 2 position.

ZIRCON SHELLS AND CORES

The majority of unbroken zircon crystals from all samples contain cores (Table 4). In most samples, it was observed that about 30 % of the unbroken grains contained a core and two shells. In a few cases, three shells and a core were observed. There are also some crystals with no observable shells.

As outlined on p. 13, the outermost shell was numbered no. 1, the next no. 2, etc. The innermost "shell" of a zircon is thus identical with its core.

Usually, shell no. 1 is a thin coating reproducing the form of the underlying crystal. Frequently, especially in samples in which this shell is very thin, it consists only of a somewhat irregular outgrowth in the basal terminations of the crystals (Fig. 2b). This habit was recorded as "irregular" in shell no. 1.

Shell no. 2 is characteristically thicker, often with a somewhat irregular zoning (Fig. 2f) and with an euhedral to subhedral habit, regardless of the habit of the underlying core or shell.

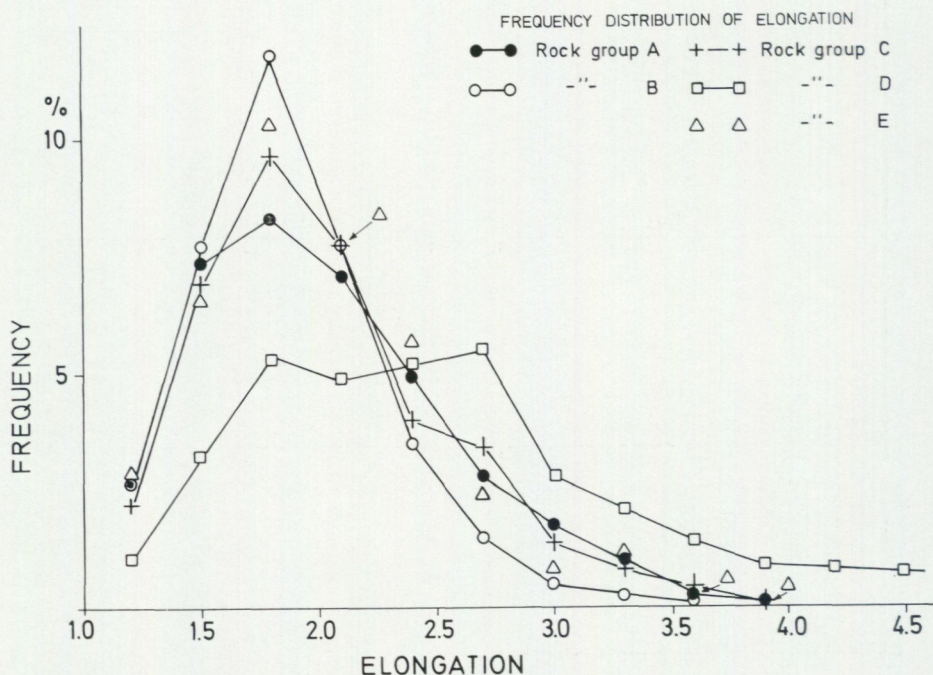


Fig. 8. Frequency distribution of elongation, unbroken grains.

- Rock group A = fine- to medium-grained, banded gneisses (5 samples, about 750 grains)
 Rock group B = coarse augen gneisses (6 samples, about 900 grains)
 Rock group C = tonalite—granite suite (6 samples, about 900 grains)
 Rock group D = porphyritic gneiss granite (4 samples, about 600 grains)
 Rock group E = anatectic granitic rocks (3 samples, about 450 grains)

To make a correct comparison between, for example, shells no. 2 in different samples, it is necessary to make sure that the outermost shell has been correctly designated. As noted above, shell no. 1 is usually thin and should be expected to be absent in many cases. This would mean that, for the grains concerned, there will be a shift (to the left), so that the outermost shell is genetically related to what is usually called shell no. 2. A morphological comparison between shells with designations 1 and 2, respectively, would thus be genetically meaningless, unless a detailed check on the shells to be compared is introduced. This is taken into consideration below when the matrixes are treated.

FREQUENCIES OF DIFFERENT SHELLS

The shell and core aspects of the zircon morphology may firstly be treated as regards the frequency of the presence of the different shells, counting from the outermost one inwards. Shells nos. 1 and 2 are present in more than 90 % of the unbroken grains of all samples and it is thus not possible to base any grouping on this. Shell no. 3 is present in varying amounts, as shown in Fig. 9. Most of the samples have more than 30 % of the grains made up of two shells and a core. The exceptions are nos. 4, 7, 9, 10, 22, 36, 39, 40, and 46. The large amount of grains with two shells and a core is regarded as evidence for the rock having been subject to two strong metamorphic events after the formation of the cores. The observations are in this respect consistent with the field geology, as regards samples nos. 4, 7, 9, and 10. These samples all belong to a porphyritic gneissic granite which is intrusive in the older migmatite and thus younger than the latter (Samuelsson 1978). No. 39 likewise belongs to another gneissic granite which is younger than the older generation of migmatite. For the rest of the samples with a small amount of grains with shell no. 3, other explanations must be investigated.

The alternatives to the fact that one of the shells is not observed are, A, the rock is younger than the oldest metamorphic episode, as described above, B, one of the metamorphic episodes failed to redistribute the zirconium of the rock into a new shell on some grains, C, the small amount of three-shell grains is accounted for by the difficulty of delimitation between different shells. In our experience, this is especially the case in samples with euhedral or subhedral out-

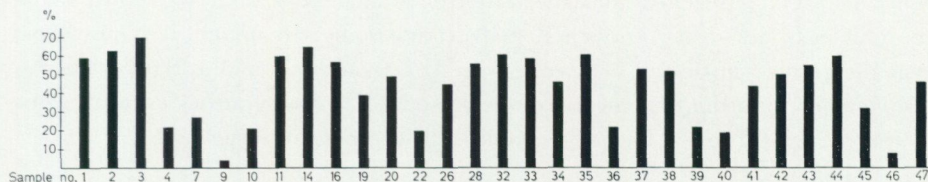


Fig. 9. Proportions of zircons with three shells.

lines and oscillatory zoning of their cores and whose next outermost shell is also euhedral or subhedral with oscillatory zoning. This coincidence should theoretically occur in intrusive rocks with a moderate deformation connected with subsequent metamorphism.

Case A seems to be responsible for the relatively limited number of three-shell grains in sample no. 36, which is from the most extensive body of granite formed by anatexis of locally derived material. Case B should be expected in no. 46, which comes from fine-grained gneiss with preserved bedding and only minor traces of the younger migmatization. Here it is usually the shell with the same characteristics as shell no. 1 that is missing. That this rock still belongs to the same generation of supracrustal rocks as the other samples is shown by its presence as xenoliths in the surrounding intrusives, which are clearly affected by two recognizable migmatizing events. The correlation between the supracrustal gneisses in larger bodies and in smaller xenoliths has been facilitated by the identification of magnetite-banded, quartzitic and calc-silicate-rich parts. Case B must also be partly responsible for the small amount of three-shell grains in sample no. 40. This is a tonalitic intrusion, which was very greatly deformed before the development of the outermost shell of the zircons. When recorded in grains with three shells, the latter is very thin.

The factors of Case C seem to be responsible for the low, recorded, three-shell, grain ratio, especially in sample no. 22, and to some degree also in sample no. 45. It can also be assumed to affect the rest of the intrusive rocks, and this may explain the generally lower amount of three-shell grains in these rocks, as compared with the supracrustal rocks.

Rock deformation was shown to cause fracturing and probably also mechanical rounding of the zircons in sample no. 9 from the porphyritic gneiss granite (p. 22). In the case of a three-shell grain, this may obliterate shell delimitation or at least make it more difficult to recognize, if fracturing occurred between the shell no. 1 and the shell no. 2, zircon-growth episode. According to the observations of the zircons of sample no. 40, this seems to be a contribution to the small amount of three-shell grains. This is in accordance with the field evidence for an extraordinarily strong rock deformation in that locality. This circumstance should also cause a shift in the morphology of shell no. 3. This feature is dealt with below (p. 41).

Summing up the observations concerning the frequencies of different shells, the conclusion is reached that the majority of the rocks underwent two metamorphic episodes strong enough to redistribute some zirconium. It is also clear that the granitic intrusions at Lerum (nos. 4, 7, 9, and 10) and at Sättila (no. 39) are younger than the first metamorphic episode. The two granites do not belong to the same intrusion, a fact also established on geochemical grounds.

FORMS OF SHELLS AND CORES

The histograms

The actual number of the zircon grains with the frequencies of their respective shells are given for each sample in Figs. 10, 11, and 12. The number of zircons with a specific type of habit are illustrated by separate columns. The number of grains within each column that are zoned are also given as a horizontal line in the columns.

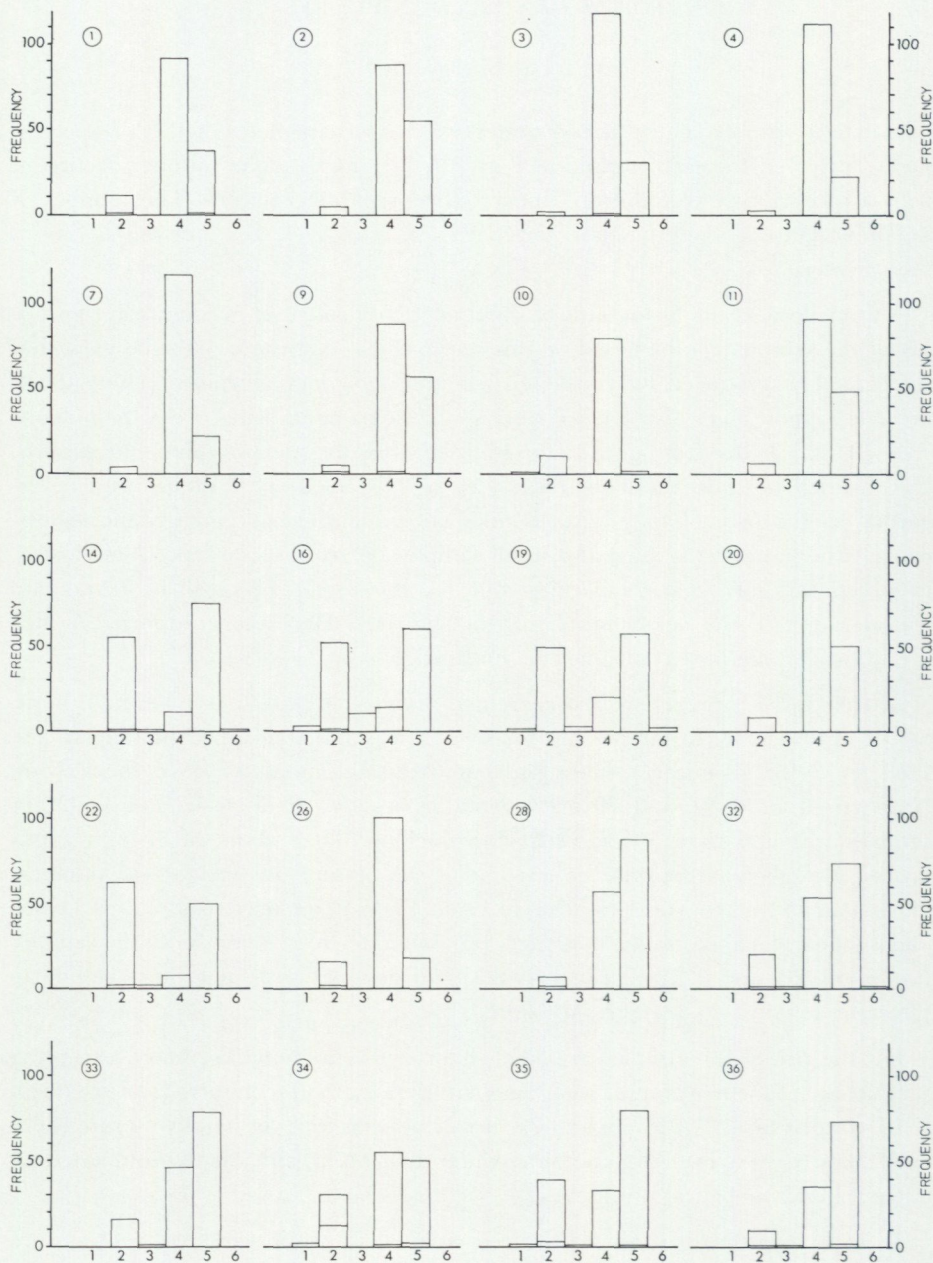
A quick look at the histograms of shell no. 1 confirms that no significant grouping of the samples can be based on this shell. This is consistent with the view that shell no. 1 is produced by crystal growth during a metamorphic episode. Shell no. 2 is in most cases also formed during a strong migmatizing event. Samples 4, 7, 9, 10, and 39 are from granites crystallized after the metamorphic episode producing shell no. 2 in the older rocks (see p. 27). Shell no. 2 should thus be regarded as the core of these zircons and, consequently, has petrogenetic significance. The same status must also in all samples be given to shell no. 2 in zircons, in which this shell is the innermost one (= the core). This will be taken into consideration in the next chapter on the matrixes. Here the groupings, as they are shown by the histograms, will be outlined.

As shell no. 4 is present in a very limited number of cases (the maximum number of grains is 32, in sample no. 3), it is at least a good approximation to use shell no. 3 for genetic considerations based on the initial forms of the zircons. Numbers 4, 7, 9, 10, and 39 are treated separately, as discussed above. Other samples with less than 50 grains having shell no. 3 (= about 30 % of the unbroken grains) must likewise be left out of the present analysis, as the numbers are too small for statistical treatment. From Fig. 12, we may read that euhedral and subhedral habits, taken together, predominate over other forms in samples nos. 3, 19, 20, and 37. According to the field designations, these rocks belong to the same tonalitic to granitic intrusion.

For the rest of the samples, rounded shape is the predominant habit, excepting sample no. 14, where fragmented cores are slightly more common than rounded.

In samples nos. 4, 7, 9, 10, and 39, it can be seen that the relatively rare shells no. 3 mostly show rounded contours, while shell no. 2 is distinctly dominated by euhedral and subhedral outlines.

It is obvious that, if only the innermost shell is considered, two rock groups can be distinguished. One of these consists of intrusive rocks dominated by euhedral and subhedral forms. The second group consists of fine- to medium-grained, banded rocks, coarse augen gneisses and migmatites dominated by rounded and, in one case, fragmented grains. In Fig. 13 are collected data from shell no. 3 for group A—D samples, including those with less than 30 % of



three-shell grains. The two-shell grains for the younger granitic intrusions (samples nos. 4, 7, 9, 10, and 39) are also given. The significance of the shell morphology is further dealt with in the next section.

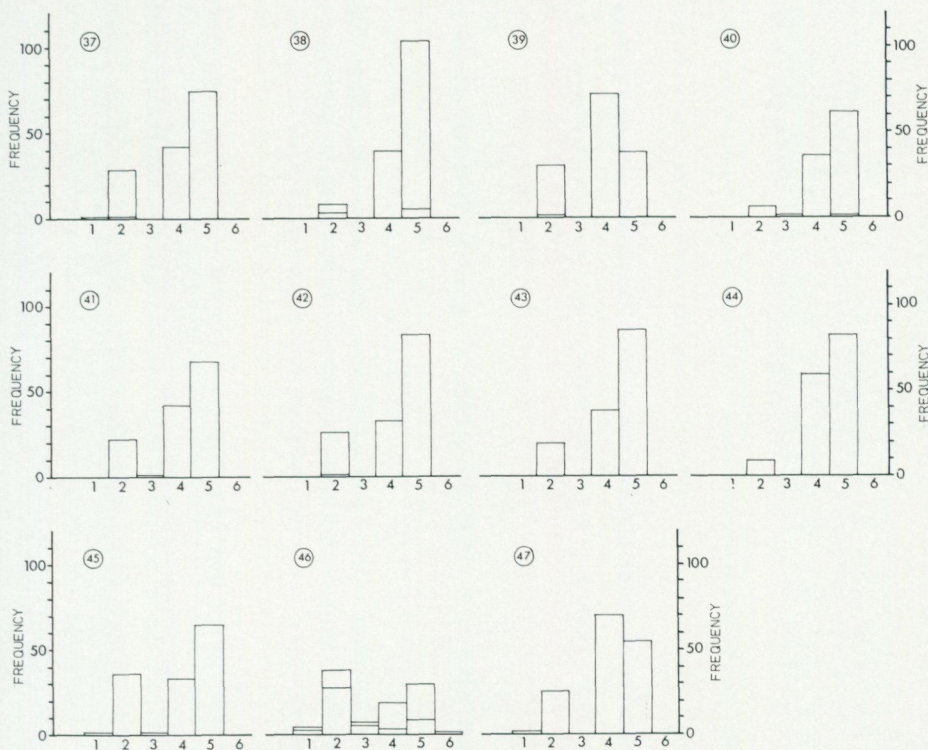
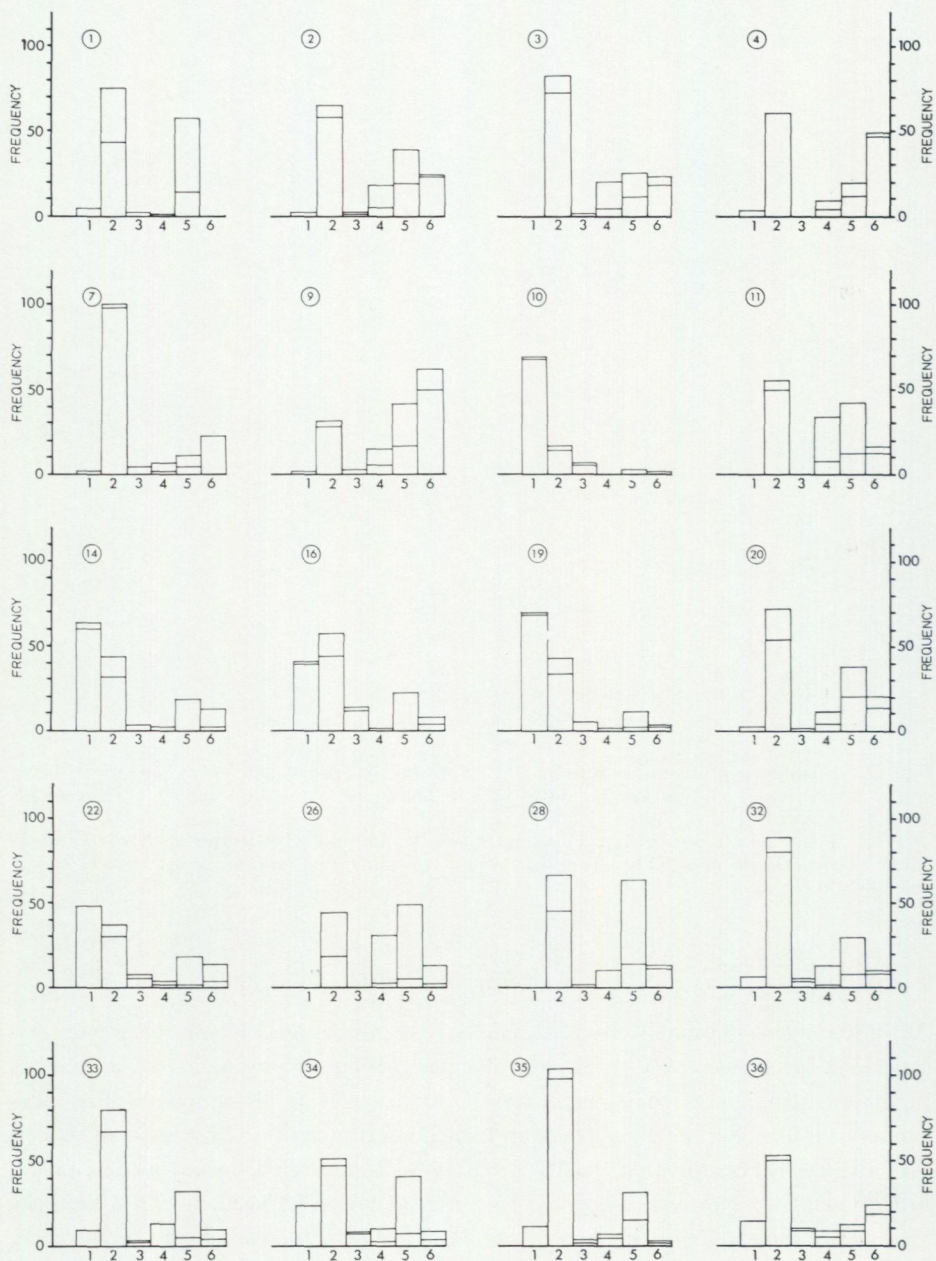


Fig. 10. Frequency of forms in shell no. 1. Notation on the x -axis: 1 = euhedral, 2 = subhedral, 3 = obstructed growth, 4 = irregular, 5 = rounded, 6 = fragmented grains.

A horizontal line within a column gives the frequency of grains with zoned shells (below the line). The absence of such a line means that zoning in that column is nil.

Matrix analysis of zircon shells

A common observation in zircon analysis is the heterogeneity of the zircon populations. This may be due to several causes, such as originally heterogeneous populations in igneous or sedimentary rocks, as well as alterations of the morphology of the zircons by metamorphism or tectonization. Metamorphism can give rise to recrystallization, partly resulting in a new shell on old grains, partly in a growth of entirely new grains. If recrystallization is weak, it can sometimes affect only some part of the zircon population. The difference may, for instance, be due to variations in host crystals. Recrystallization can also cause zircons of varying initial forms to take on identical outer habits. Some of these observations concerning recrystallization lead to the need of the distinction between "stratigraphic" classification of shells and classification based merely on the position in a sequence of shells ("geometrical" classification). The outermost shells of the



grains of a zircon population may have different stratigraphic abodes. This may be caused by a recrystallization affecting only part of a population, as earlier described. The shells of the second latest recrystallization may still be outermost

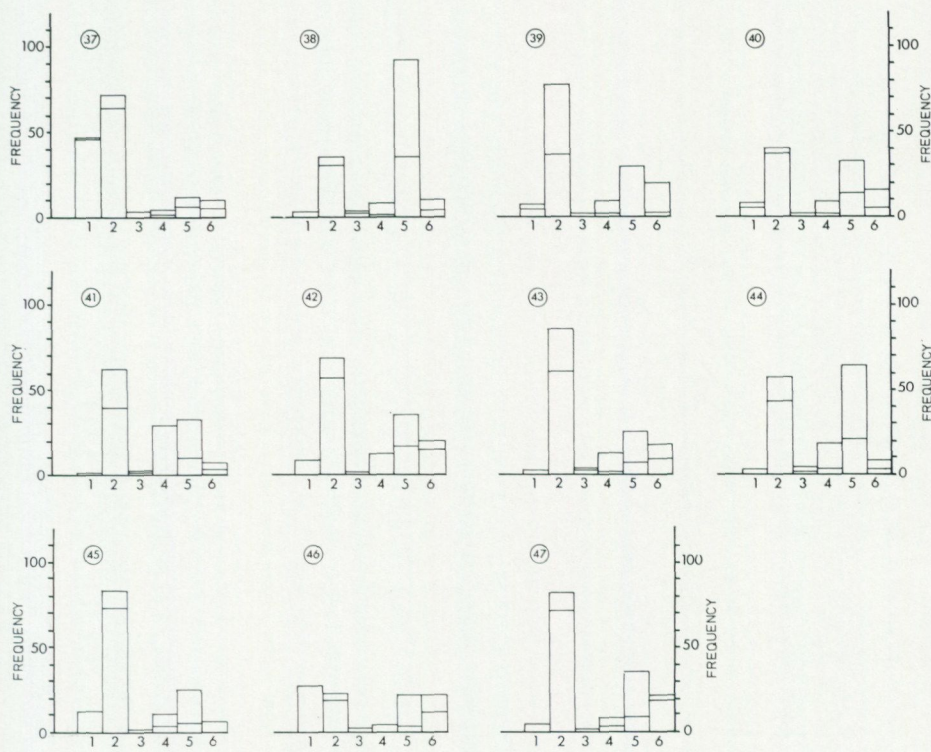
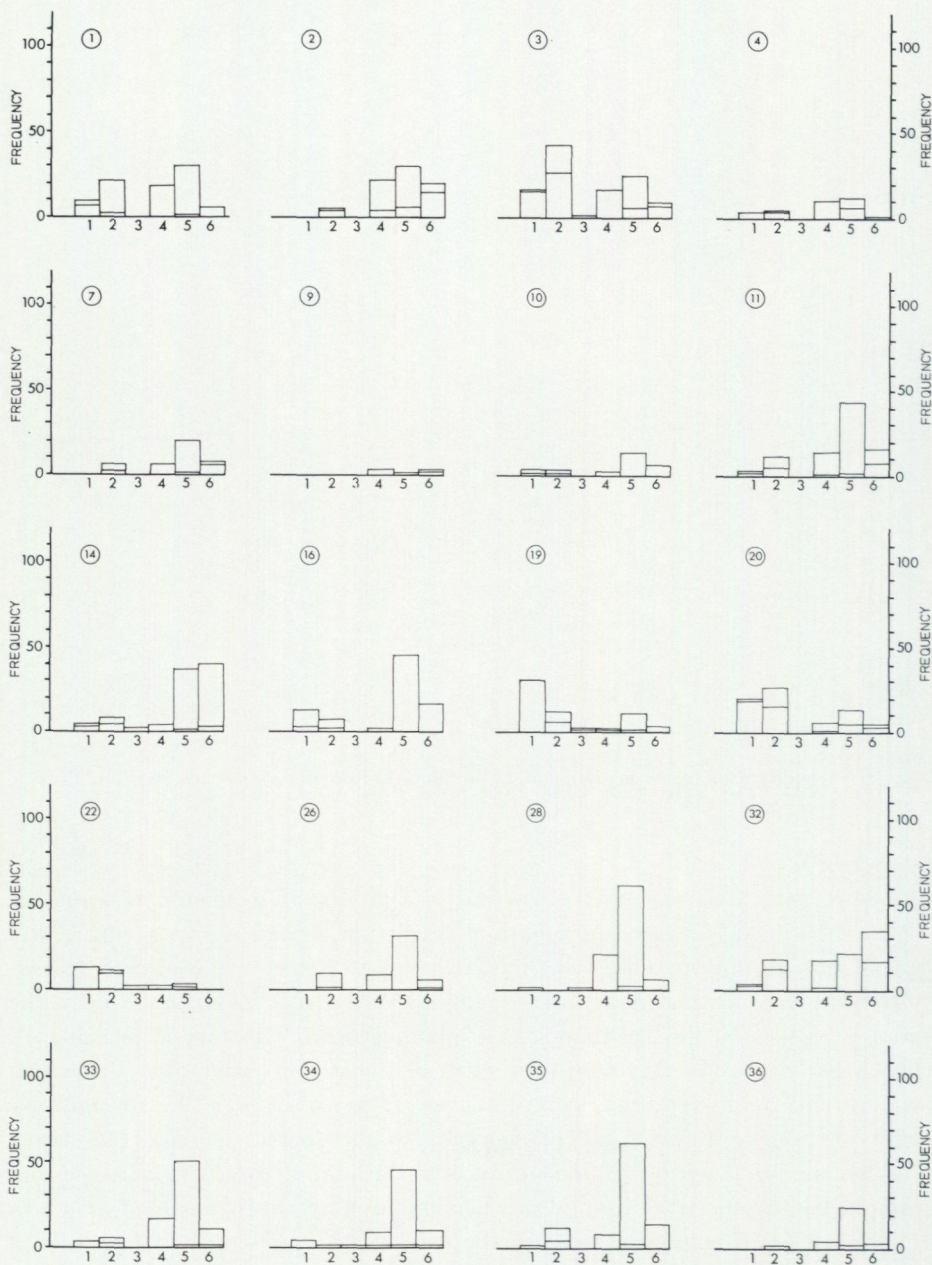


Fig. 11. Frequency of forms in shell no. 2. For notation on the x-axis, see Fig. 10.

in many grains and may then, in a purely descriptive (geometrical) sense, be "latest". If, in such a case, the outermost shells are treated as one group, it will for obvious reasons be found to be inhomogeneous, as each event of recrystallization may give a characteristic form, zoning, colour, etc. to its shells. Thus, if the group of outermost shells is found to be inhomogeneous, this may in principle be due to two causes. It may consist of shells of the same stratigraphic abode, but with varying habits, or it may consist of two groups of shells, in the stratigraphic sense of the word, each fairly homogeneous. It should therefore be tested whether the inhomogeneous group consists of the sum of two more homogeneous groups. The observations from a zircon population are thus presented in a way that permits information to be derived about the distribution of the qualities of one shell, compared with those of the adjacent shell(s).

This may be illustrated by the following example. In a zircon population, some outermost shells are round and some euhedral. The same goes for the second shell. But, when the outermost shell is euhedral, what is the typical habit of the second shell? Is there a tendency for one type of second shell to be more



common when the outermost is euhedral or is there just an approximately random distribution? If, for example, it is found that the grains with a round outermost shell all have a round, second, outermost shell and vice versa, then it can be

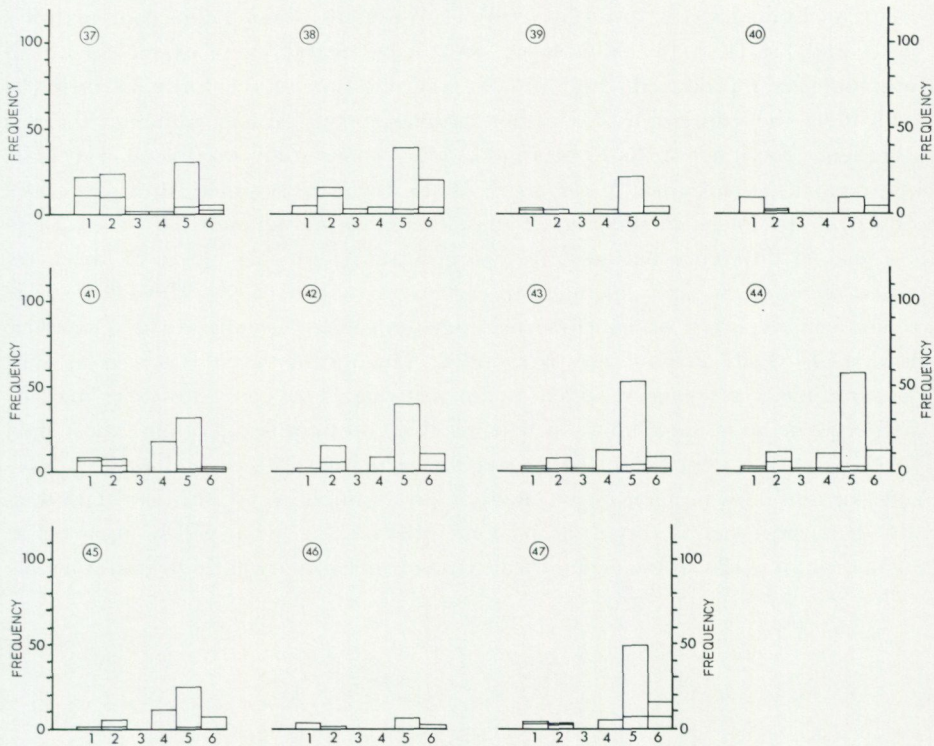


Fig. 12. Frequency of forms in shell no. 3. For notation on the x -axis, see Fig. 10.

concluded that the inhomogeneous zircon population consists of two, more homogeneous populations. If covariance is generally searched for, problems involving mixed populations, correlation of shells, etc. can be more easily solved. As a means of illustrating the distribution of the qualities of two adjacent shells, the matrixes are plotted.

The matrixes are constructed in two sets. The first set compares the morphological features in shell no. 1 (the y -axis) with those in shell no. 2 (the x -axis). The second set makes the same comparison between shell no. 2 and shell no. 3. Within each set are two matrixes. The more complete matrix in each set (matrixes nos. II and IV) takes into consideration the existence of zoning within each shell and the reduced matrixes (nos. I and III) overlook this feature. All the numbers on a line or a column together give the number of zircons with that specific shape of that specific shell. The total number which is not written out is thus split up into parts, corresponding to how it is distributed with respect to form alternatives in the other shells of the matrix. The matrixes make it possible to study the correlation of one property of a shell with any other property in an adjacent shell.

Due to limited space, it is only possible to present a complete set of matrixes nos. I and III (Fig. 14). Sample no. 34 can be treated as an example with all four matrixes reproduced (Fig. 15). Simple addition of the forms of different shells gives the impression of a rather inhomogeneous sample, although there is a tendency for inner shells to be round. Then let us study matrix no. III (Fig. 14), comparing shells no. 2 and no. 3. If the lines are summed, there are more subhedral specimens in shell no. 2 than there are round ones. However, there is a distinct difference between the two groups. Where shell no. 2 has been reported as round, it rarely includes an earlier core (shell no. 3). However, where it has been reported as euhedral or subhedral, there usually exists a further, third shell, which in most cases is rounded. This means that the core is in most cases rounded, a tendency which is fairly strong. The core, however, may be shell no. 2 or no. 3, depending on whether the "stratigraphically" outermost shell — often, when it exists, reported as irregular, which means thin — has been developed or not. This problem is not unusual. In a sample where the "stratigraphically" outermost shell is very thin and sometimes lacking, what will be reported as the outermost shell (in the geometrical sense of the word) will be stratigraphically

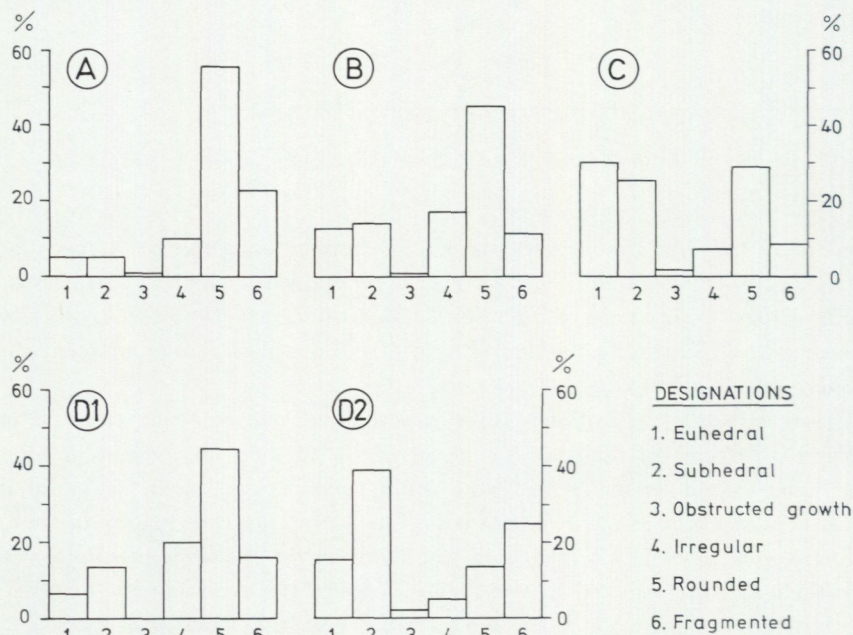


Fig. 13. Proportions of forms in shell no. 3 and in shell no. 2 for Group D rocks.

- A = fine- to medium-grained, banded gneisses.
 B = coarse augen gneisses.
 C = tonalite—granite suite.
 D1 = porphyritic gneiss granites, forms in shell no. 3.
 D2 = porphyritic gneiss granites, forms in shell no. 2.

SHELL	→ 2																																						
	A	B	C	D	E	F	G																																
A	17	0	0	0	0	0	0	31	0	0	0	0	0	0	0	72	0	0	0	0	0	0	0	59	0	0	0	0	0	0	0	48	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
C	0	1	8	0	1	2	0	0	1	3	0	0	1	0	0	0	2	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	4	0	0	0	0	0	
D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
E	0	3	56	2	0	36	0	0	0	42	2	15	13	17	0	0	64	0	19	17	19	0	3	56	0	9	10	41	0	1	83	4	6	5	23				
F	0	1	16	0	0	23	0	0	1	20	0	3	25	7	0	0	17	1	1	8	4	0	0	4	0	0	10	10	0	0	17	0	0	6	0				
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

SHELL	→ 3																																		
	A	B	C	D	E	F	G																												
A	17	0	0	0	0	0	0	31	0	0	0	0	0	0	72	0	0	0	0	0	0	59	0	0	0	0	0	0	48	0	0	0	0	0	0
B	2	1	1	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0
C	25	9	14	0	12	16	4	25	0	5	0	11	13	11	10	14	29	1	9	13	7	39	2	5	0	7	9	1	69	0	5	0	6	17	7
D	2	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0
E	0	0	0	0	1	0	0	10	0	0	0	3	5	0	11	0	3	0	1	4	1	6	1	0	0	1	1	0	5	0	0	0	1	0	0
F	32	0	7	0	6	14	2	23	0	0	0	3	7	6	7	1	6	0	6	5	0	17	1	0	0	1	1	0	9	0	0	0	1	1	1
G	0	0	0	0	0	0	0	13	0	0	0	5	4	2	12	2	5	0	1	2	1	47	0	0	0	2	2	0	21	0	0	0	0	2	0

SAMPLE 1 2 3 4 7

SHELL	→ 2																																		
	A	B	C	D	E	F	G																												
A	70	0	0	0	0	0	0	142	0	0	0	0	0	0	15	0	0	0	0	0	0	30	0	0	0	0	0	0	20	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0
C	0	0	4	0	1	0	0	0	9	1	1	0	0	0	0	0	6	0	0	0	1	0	36	13	1	0	3	5	0	25	18	4	0	5	3
D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	9	0	0	1
E	0	1	17	2	11	12	50	0	61	16	5	0	1	1	0	0	43	0	32	13	11	0	3	2	1	1	2	2	0	5	6	1	0	1	2
F	0	0	11	0	3	31	15	0	1	0	0	0	1	0	0	0	11	0	3	31	6	0	28	31	1	1	13	5	0	9	35	0	1	17	2
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

SHELL	→ 3																																		
	A	B	C	D	E	F	G																												
A	70	0	0	0	0	0	0	142	0	0	0	0	0	0	15	0	0	0	0	0	0	30	0	0	0	0	0	0	20	0	0	0	0	0	0
B	0	0	0	0	0	0	1	50	2	1	0	1	12	6	0	0	0	0	0	0	0	11	3	6	0	3	18	26	11	8	1	0	1	14	7
C	30	0	0	0	1	0	1	12	1	2	0	1	1	0	19	2	6	0	5	20	8	10	1	1	1	1	18	14	21	5	4	0	1	23	6
D	2	0	0	0	0	0	0	5	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	6	0	1	0	0	4	3
E	15	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	4	0	4	10	6	2	0	0	0	0	0	0	1	0	0	0	0	0	0
F	43	0	0	0	0	0	0	2	0	0	0	0	0	0	20	0	1	0	6	14	3	18	0	0	0	0	1	0	18	0	1	0	0	4	0
G	61	0	0	0	2	1	1	1	0	0	0	0	0	0	12	1	1	0	0	4	0	11	0	1	0	0	1	0	5	0	0	0	0	2	1

SAMPLE 9 10 11 14 16

Fig. 14. First part.

either the outermost or the second outermost. When this is the case and the sample is in other respects fairly homogeneous, the effect may be traced with the matrixes.

The complete matrixes for sample no. 34 can now be studied. When the outer-

SHELL		→ 2																																		
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	
	A	77	0	0	0	0	0	51	0	0	0	0	0	71	0	0	0	0	0	40	0	0	0	0	61	0	0	0	0	0						
	B	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0						
	C	0	38	12	0	0	1	0	0	9	0	0	0	0	32	21	1	2	4	6	0	0	7	0	2	7	1	0	0	5	0	0	1	1		
	D	0	0	0	3	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	E	0	7	10	0	1	3	0	0	0	44	1	7	16	19	0	1	2	1	1	0	3	0	0	37	0	29	30	10	0	0	33	1	7	16	3
	F	0	28	23	1	0	7	1	0	2	22	0	4	23	2	0	16	15	4	0	14	4	0	0	2	0	1	14	2	0	0	31	0	3	49	9
	G	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SHELL		→ 3																																		
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	
	A	77	0	0	0	0	0	51	0	0	0	0	0	71	0	0	0	0	0	40	0	0	0	0	61	0	0	0	0	0	0	0	0	0		
	B	31	25	8	0	2	8	0	1	1	0	0	0	43	1	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	C	27	7	4	1	0	3	3	30	12	20	0	3	8	2	33	4	0	0	1	0	0	15	0	5	0	2	20	4	21	1	0	0	12	31	4
	D	4	0	0	1	0	0	0	1	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	E	1	0	0	0	0	0	0	7	2	1	0	1	0	2	1	0	0	0	0	0	0	20	0	2	0	3	6	1	6	0	0	1	0	3	0
	F	10	1	0	0	0	0	0	23	1	7	0	2	6	0	7	3	4	0	1	3	0	39	0	3	0	4	4	1	34	0	0	0	8	23	1
	G	3	0	0	0	0	0	0	13	5	0	0	0	0	3	6	4	2	1	0	0	0	10	0	0	0	0	3	0	5	0	0	0	1	6	1
SAMPLE		19							20							22							26							28						

SHELL		→ 2																																		
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	
	A	39	0	0	0	0	0	46	0	0	0	0	0	80	0	0	0	0	0	6	0	0	0	0	46	0	0	0	0	0	0	0	0	0		
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
	C	0	4	13	1	1	1	1	0	2	12	1	0	1	1	0	7	11	0	2	11	1	0	4	31	0	1	5	0	0	7	1	0	1	0	1
	D	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
	E	0	0	38	3	7	7	1	0	6	24	1	10	6	2	0	11	26	6	7	7	1	0	2	21	2	4	6	0	0	1	20	3	4	3	6
	F	0	2	41	1	5	21	7	0	1	47	0	3	26	6	0	4	16	2	1	24	6	0	4	56	0	1	21	2	0	6	34	6	4	10	17
	G	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SAMPLE		32							33							34							35							36						

most shell is irregular (and then equal to stratigraphic shell no. 1), shell no. 2 is, as a rule, euhedral or subhedral. Shell no. 2 is in this case zoned, without exception. This seems to be typical of stratigraphic shell no. 2. For all samples, the shell outside the rounded core is, as previously mentioned, usually idiomorphic or hypidiomorphic and is then usually zoned. Thus, a typical appearance of the

SHELL	→ 2																																		
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
A	58	0	0	0	0	0	0	18	0	0	0	0	0	0	77	0	0	0	0	0	0	61	0	0	0	0	0	0	52	0	0	0	0	0	0
B	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
C	0	16	13	0	0	0	1	0	1	3	0	1	1	2	0	2	17	1	1	8	3	0	3	3	0	0	0	0	0	0	19	0	0	2	2
D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0		
E	0	12	26	0	2	4	0	0	0	3	1	4	29	2	0	4	40	0	8	11	13	0	2	12	1	3	6	13	0	0	16	1	20	5	2
F	0	20	36	3	2	8	9	0	2	29	2	3	62	6	0	1	24	0	0	11	4	0	2	26	0	6	28	3	0	1	30	1	10	26	3
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		

SHELL	→ 3																																		
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
A	58	0	0	0	0	0	0	18	0	0	0	0	0	0	77	0	0	0	0	0	0	61	0	0	0	0	0	0	52	0	0	0	0	0	0
B	18	9	10	0	0	10	2	3	0	0	0	0	0	0	4	0	0	0	0	3	0	5	2	0	0	0	0	1	1	0	0	0	0	0	0
C	34	12	11	0	1	15	2	12	2	1	0	1	12	7	55	3	2	0	1	16	4	31	6	1	0	0	3	0	16	7	6	0	14	20	2
D	1	0	0	1	0	0	1	2	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0
E	4	0	0	0	0	0	0	3	0	1	0	1	2	1	8	0	0	0	1	0	0	8	0	0	0	0	1	0	24	0	0	0	4	2	0
F	4	0	2	0	0	6	0	41	2	13	2	1	24	9	29	0	0	0	0	1	0	27	0	1	0	0	4	2	23	1	0	0	0	10	0
G	8	1	1	0	0	0	0	9	0	0	0	0	0	1	18	0	0	0	0	2	0	13	1	0	0	0	1	1	7	0	0	0	0	0	0
SAMPLE	37							38							39							40							41						

SHELL	→ 2																																		
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G							
A	19	0	0	0	0	0	0	21	0	0	0	0	0	0	15	0	0	0	0	0	0	27	0	0	0	0	0	0	80	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1	1	0
C	0	3	21	1	2	0	0	0	0	18	0	0	0	2	0	1	4	1	0	3	0	0	7	22	0	5	4	0	0	15	9	0	1	5	10
D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2	1	0	1	2
E	0	1	18	0	3	3	9	0	1	19	2	10	2	6	0	0	27	0	7	21	7	0	2	22	1	3	5	2	0	3	6	0	1	3	6
F	0	4	32	0	7	33	11	0	1	52	1	2	24	10	0	1	28	3	11	42	1	0	3	43	0	3	15	4	0	8	6	0	1	12	3
G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

SHELL	→ 3																																		
	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G							
A	19	0	0	0	0	0	0	21	0	0	0	0	0	0	15	0	0	0	0	0	0	27	0	0	0	0	0	0	80	0	0	0	0	0	0
B	5	0	3	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	1	0	8	1	2	0	0	0	1	25	0	0	0	0	1	2
C	23	0	8	0	3	31	6	33	1	6	1	7	37	4	18	2	4	1	4	24	6	54	0	2	0	7	18	6	15	3	1	0	0	4	0
D	1	0	0	0	0	0	0	2	0	0	0	0	1	0	3	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0
E	9	0	1	0	1	1	0	6	0	0	0	1	5	0	7	0	1	0	2	7	1	8	0	0	0	1	2	0	4	0	0	0	0	0	0
F	23	1	2	0	1	7	2	15	0	0	0	3	6	2	26	0	6	0	3	27	4	18	0	1	0	2	5	0	22	0	0	0	0	0	0
G	12	0	1	0	3	2	2	9	1	1	0	1	4	2	6	0	0	0	0	1	1	6	0	0	0	0	0	0	22	0	0	0	0	0	0
SAMPLE	42							43							44							45							46						

stratigraphic shells of the discussed zircon population can be deduced. Shell no. 1 is thin, "irregular" and sometimes lacking. In a few cases, it may have grown to a subhedral or euhedral habit. It is usually not zoned. Shell no. 2 is euhedral or subhedral and generally zoned. Shell no. 3 is rounded and unzoned. This general appearance is here fairly simple to deduce. The reason for this is that the po-

SHELL	→ 2						
	A	B	C	D	E	F	G
A	22	0	0	0	0	0	0
B	0	0	1	0	0	0	0
C	0	0	21	0	2	2	1
D	0	0	0	0	0	0	0
E	0	3	44	0	5	11	10
F	0	1	19	1	1	24	11
1	G	0	0	0	0	0	0

SHELL	→ 3						
	A	B	C	D	E	F	G
A	22	0	0	0	0	0	0
B	3	0	0	0	0	0	1
C	37	1	3	0	4	26	14
D	1	0	0	0	0	0	0
E	8	0	0	0	0	0	0
F	17	3	0	0	1	14	2
2	G	12	0	0	0	0	10
SAMPLE	47						

Fig. 14 (pp. 37—40). Matrixes I and III (zoning disregarded).

The meanings of the letters in matrix I (shell no. 1 compared with no. 2) and III (shell no. 2 compared with no. 3) are as follows:

- A = the shell is missing. For shell no. 1 the recorded figure refers to broken grains and grains without shells.
- B = euhedral habit.
- C = subhedral habit.
- D = crystallization partly obstructed.
- E = irregular habit. For the shell no. 1, this means a thin, discontinuous shell.
- F = rounded habit.
- G = fragments. For shell no. 1, the figure is 0.

pulation is basically homogeneous, though the numbers of shells differ.

The majority of the cores of the zircons from sample no. 34 are thus rounded. The rock should then be interpreted as a paragneiss. However, according to the field observations, the rock sampled is a local mobilizate in a migmatized gneiss. These observations are, as a matter of fact, in good agreement. A formation of neosome is not likely to result in a total fusion and recrystallization of the zircon grains. If this was the case, subhedral or irregular grains would have been more predominant. Incorporation of the zircons as rather well-preserved grains, is, according to the observations presented, a more likely interpretation. The shape of the cores then gives information on the genesis of the original rock, which is the paleosome in the migmatized gneiss. The latter is here interpreted as having been of a sedimentary origin.

As will be seen from the example cited, it is possible to trace the forms of the innermost shell (the core) with the aid of the matrixes. This has been systematically done for all the samples of Table 3. The cores with euhedral + subhedral

habits are put into a first group and the cores with rounded + fragmented grains into a second group. The ratio between these two groups is given in Fig. 16. The reason for the groupings is that the euhedral + subhedral habits are thought to represent igneous, plutonic conditions and the rounded + fragmented habits to be characteristic of supracrustal conditions. It has been shown, however (p. 24), that the fragmented and to some degree also the rounded habits may also be formed by rock deformation. A discussion of this is given below.

The designations of the different samples in Fig. 16 are based on observations in the field. The samples fall into two groups, which are not bounded by any hiatus. The plutonic intrusives constitute one group, with proportions of euhedral + subhedral cores of between 45 and 90 % (with two exceptions). In the other group, the proportions of euhedral + subhedral cores range between 45 and 5 %.

The latter group contains the fine- to medium-grained, banded gneisses and the coarse augen gneisses, as well as the locally derived anatectic granites. It has been pointed out above (p. 24) that rock deformation has the capacity to produce rounded grains in a core position. This effect selectively affects the angular grains (the euhedral + subhedral crystals). Consequently, it causes a shift towards a higher ratio of rounded and fragmented grains in rocks originally with high ratios of euhedral + subhedral grains. No corresponding shift occurs in rocks with originally high ratios of rounded and fragmented grains. This is probably a reason for the general spread of the ratios of the intrusive plutons, and it is a feature recorded in samples nos. 9, 39, and 40.

The petrogenetic interpretation of the habits of the zircon cores is that the plutonic, intrusive rocks are derived from magmas which carried the main part of the zirconium in solution. The group with fine- to medium-grained, banded gneisses, coarse augen gneisses and locally derived anatectic granites are all genetically separated from the former group. There are several possible explanations of this. Firstly, the greater part of the zircon cores is the detrital grains of sedimentary and/or reworked volcanic material. Secondly, the greater part of the zircon cores has become rounded and fragmented by a deformation older than the intrusion of the oldest intrusives identified. The ultimate origin of the zircon cores may thus be detrital, volcanic or igneous-plutonic.

There is strong field evidence for a sedimentary origin of samples nos. 33, 34, 46, and 47. It is fairly strong for nos. 11, 14, 16, and 42. According to the record of zircon grains, we find it most probable that the fine- to medium-grained, banded gneisses (= the group with high ratios of rounded and fragmented zircon cores) are derived from sedimentary rocks with possible intercalations of reworked volcanic material.

SHELL		→ 2													
		A	B	C	D	E	F	G	H	I	J	K	L	M	
↓	1	A	80	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	C	0	0	2	0	0	0	0	0	0	0	0	0	0	0
	D	0	0	6	2	8	0	0	2	0	0	0	1	0	0
	E	0	0	1	1	0	0	0	0	0	11	0	0	0	0
	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	G	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	H	0	0	11	0	26	1	5	5	2	4	2	1	0	0
	I	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	J	0	0	4	1	15	0	2	1	0	19	5	2	2	2
	K	0	0	0	0	0	0	0	0	0	0	0	1	1	1
	L	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0

SHELL		→ 3													
		A	B	C	D	E	F	G	H	I	J	K	L	M	
↓	2	A	80	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	C	6	0	2	0	0	0	0	3	0	10	1	1	1	1
	D	3	0	0	0	0	0	0	0	0	1	0	0	0	0
	E	12	0	1	0	1	0	1	4	0	24	0	6	0	0
	F	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	G	1	0	0	0	0	0	0	0	1	3	0	2	0	0
	H	7	0	0	0	0	0	0	1	0	0	0	0	0	0
	I	1	0	0	0	0	0	0	0	0	1	0	0	0	0
	J	29	0	0	0	0	0	0	0	0	6	0	0	0	0
	K	4	0	1	0	0	0	0	0	0	2	0	0	0	0
	L	5	0	0	0	0	0	0	0	0	0	0	0	0	0
	M	3	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 15. Matrixes II and IV (zoning noted).

The meanings of the letters in matrixes II (shell no. 1 compared with no. 2) and IV (shell no. 2 compared with no. 3) are as follows:

A = the shell is missing. For shell no. 1 the recorded figure refers to broken grains and grains without shells.

PROPORTIONS OF DISCRIMINATING FORMS OF THE ZIRCON CORES

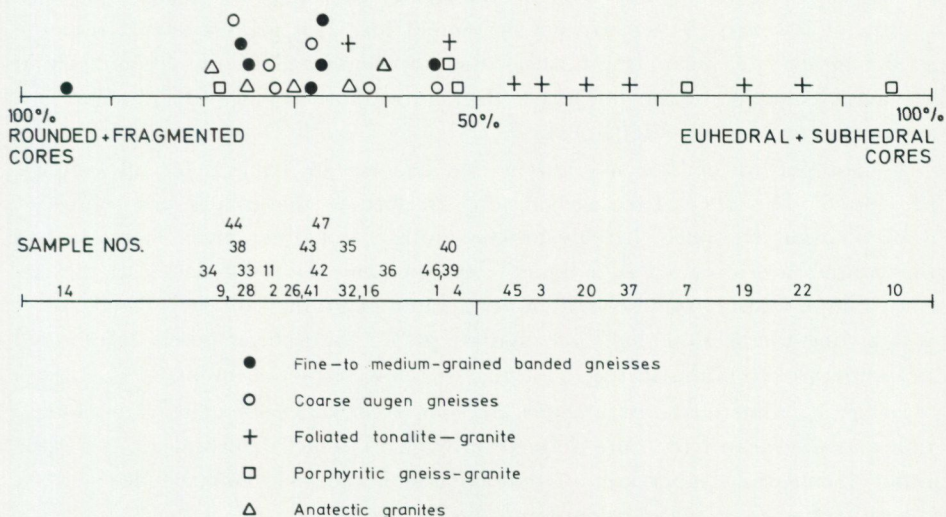


Fig. 16. Proportions of discriminating forms of the zircon cores.

COMPLEMENTARY STUDIES OF SOME OTHER ZIRCON FEATURES

At the beginning of this investigation, it was thought possible to get discriminating data from the different rocks by studying the dimensional data, inclusions, colour and general habits of zircon grains mounted in an ordinary thin section, with araldite as mounting medium ($n = 1.54$). The difference in refraction between the medium and the zircon grains restricted the study of the contours and the internal features of the grains. An attempt was made, however, and the parameters systematically recorded are listed in Table 5. Some samples in Table

-
- B = euhedral habit, unzoned.
 C = euhedral habit, zoned.
 D = subhedral habit, unzoned.
 E = subhedral habit, zoned.
 F = crystallization partly obstructed, unzoned.
 G = crystallization partly obstructed, zoned.
 H = irregular habit, unzoned. For shell no. 1 this means a thin discontinuous shell.
 I = irregular habit, zoned. For shell no. 1, this means a thin discontinuous shell.
 J = rounded habit, unzoned.
 K = rounded habit, zoned.
 L = fragments, unzoned. For shell no. 1, the figure is 0.
 M = fragments, zoned. For shell no. 1, the figure is 0.

5 are also treated in Table 3. Comparisons may be made between the mean length, the elongation and the proportion of broken grains. In Table 5, the mean lengths are usually somewhat greater than in Table 3. The discrepancies are to some degree explained by the facts that in Table 5 zircon grains with lengths of less than 50 μm are not accounted for. This gives a varied response in the figures for mean length, according to the spread of the frequencies in the actual sample. It also influences the figures of the elongation, though to a less degree and not so systematically.

The proportion of broken grains is much higher in Table 3 for all samples, save no. 7. This general feature must be ascribed to the greater possibilities of discrimination (between "freshly broken grains" and other grain forms) when the samples are mounted in a liquid with the same refraction index as the zircons. Sample no. 7 has a considerable amount of grains broken in shell no. 2, which, due to the thin shell (see matrix, p. 37), have been falsely interpreted as freshly broken grains in the mounting with low refraction indexes.

In fig. 17, some of the parameters are compared with each other. The elongation and the mean length are defined on page 15. The "habit index" (y) is the ratio of euhedral + subhedral to rounded grains and the "colour index" (x) is the ratio of red + brown to colourless grains.

There is an insufficient number of samples to get any clusterings of data belonging to different rock groups. However, it may be observed that the six samples of group-D rock (the porphyritic gneiss granite) are split into two groups by differences in elongation, mean length and habit. These three parameters are dependent on each other. Nos. 4, 7, and 10 are high in elongation, mean length and habit index, while nos. 5, 6, and 9 are low in these respects. Nos. 4, 7, and 10 have been shown (p. 22) to contain rather big crystals with shells nos. 1 and 2 (the core) and euhedral + subhedral habits. Sample no. 9 has also been investigated by the same methods (p. 22). It almost exclusively contains grains with shells nos. 1 and 2 (the core). The difference between no. 9 and nos. 4, 7, and 10 was due to the large amount of grains broken in shell no. 2 (the core) of sample no. 9. It is thus obvious that rock deformation and subsequent zircon recrystallization may lead to considerable changes of such basic parameters in zircon statistics as elongation and mean length.

The incapacity of the colour index to discriminate clearly between the different groups of rocks is also illustrated by Fig. 17. This can be ascribed to many different causes. In the present case, we think that the small number of samples from the different rock groups is the main reason. Another possible error is the fact that the colouring recorded in many instances is due to coatings of colour between the different shells or to the colouring of an outer shell. The colouring is thus sometimes a secondary feature independent of the appearance of the original zircon grain. Zircons of different origins may take on the same colour

during subsequent metamorphism. Some hints are, however, given by Fig. 17. Groups A and B show a great spread of the colour index, while groups C and D are rather low. This means that the supracrustal rocks and the augen gneisses show the greatest spread and the plutonic intrusives are low in colour index. The metasupracrustals are on compositional grounds assumed to be derived from both sedimentary and reworked volcanic sources.

Inclusions have been studied, but there seems to be little information to be gained from the results. In the zircons analysed, the following types of inclusions were recorded: colour spots, opaque grains, rods and gaseous inclusions. It must be emphasized that the occurrence of magnetic and gaseous inclusions may change the physical properties of a grain, and this has unfavourable effects during mineral separation. It must also be observed that inclusions may be restricted to a certain shell, and their occurrence may then indicate the "stratigraphy" of the shells. This is evident as regards colour spots, which are often restricted to the surface between two shells. The amount of gaseous inclusions in zircons is a property that can be easily measured, without counting. By heating and decrepitation in a vacuum container, the number of inclusions and some of their properties can be measured (Kantor and Eliás 1974, p. 97). In the samples here analysed, the zircons with gaseous inclusions constitute a small percentage. A not very distinctive tendency could be noted for zircons from paragneisses to have a small number of gaseous inclusions compared with igneous rocks. The same observation was valid for crystal inclusions in the form of rods.

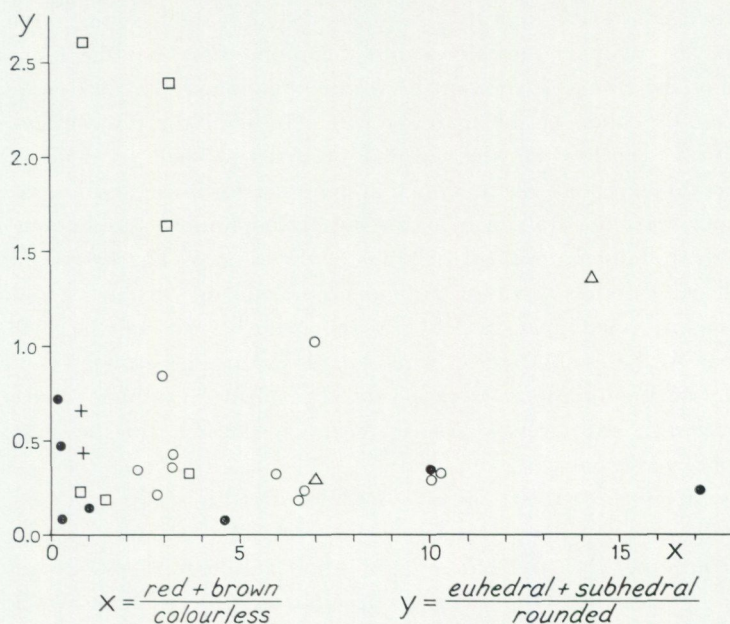


Fig. 17. Diagram of some morphological features. The symbols are the same as in Fig. 16.

SUMMARY OF OBSERVATIONS

The dimensional data of the zircon samples allow of the following groupings. The mean length discriminates nos. 4, 7, 10, and 26 as constituting a group with values between 180 μ and 212 μ . The rest of the samples are scattered between 96 μ and 160 μ . Nos. 4, 7, and 10 belong to the same granitic intrusion, while no. 26 constitutes a gneissic anatexite with an assumed supracrustal derivation. The latter sample also has an extraordinarily large mean breadth (118). Sample no. 9 also belongs to the same gneiss-granite as nos. 4, 7, and 10. Its small mean length has been shown to be caused by a great deformation of the rock before the latest recrystallization (p. 22). Information can thus be gained from the frequency and the type of fragments.

A distinctly high elongation is displayed by nos. 4, 7, and 10, with values from 2.5 and upwards. The rest of the samples cluster around and slightly below 2.0, with one sample as high as 2.33 and another at 2.25. Again, sample no. 9 fails to associate with nos. 4, 7, and 10 for the reason mentioned above.

In considering the frequencies of different shells in the rocks examined, it was concluded that the majority of the rocks went through two metamorphic episodes strong enough to redistribute some zirconium. The interpretation of data from samples nos. 4, 7, 9, 10, and 39 is consistent with these samples representing granitic intrusions younger than the first metamorphic episode.

The discussions of the morphology of the different shells in the zircons investigated (p. 29) resolved themselves into the proposition that the morphology of the cores of the zircons is relevant in an investigation of the rock genesis. It was shown that the study of the matrixes was helpful in the discrimination of the actual cores, regardless of whether they occurred as shell no. 2 or shell no. 3. The generally accepted postulation that rounded forms are typical of sedimentary zircons and euhedral forms of zircons from plutonic intrusives is in accordance with the observations of the cores of the zircons. The correspondence between the outer habits of zircon grains and genetic rock types, as studied in ordinary mounts (medium $n = 1.54$), is shown to be very small (p. 43). This is mainly due to the establishing of a new habit during the growth of shells under conditions of high-grade metamorphism. Fracturing, crushing, resorption and crystallization of entirely new grains are also responsible for the obliteration of the original zircon habit.

The habit of the zircon cores, as revealed by this study, can be used as a petrogenetic criterion for polymetamorphic rocks. The samples in this study fall into two groups. The first has a high ratio of euhedral + subhedral cores to rounded + fragmented cores. This group embraces intermediate to acid, igneous intrusions. The second group is characterized by a high frequency of rounded

and fragmented grains and contains fine- to medium-grained, banded gneisses, coarse augen gneisses and migmatites with a fine-grained, restite component. It is concluded that the rocks of the latter group are of a supracrustal and mainly sedimentary origin.

DISCUSSIONS OF METHODS AND SUGGESTIONS FOR FURTHER INVESTIGATIONS

Some methods have been described from previous work and used in this investigation. In some cases, they were not suited to the actual type of problem. One important factor is polymetamorphism, which, as has been shown, raises obstacles to the evaluation of measurements of colour, habit and inclusions. The obstacles are due to the heterogeneity of the zircon grains, as they consist of different shells, grown during clearly different episodes with presumably different P, T, X conditions. Measurements on zircons from polymetamorphic terrains have to refer to a specific shell if the measurements are to be comparable. The measurements used in this investigation are partly of the former type, treating the grain as a unit, and partly of the latter type, treating the grain as a composite. As has been shown, in a polymetamorphic terrain like the one investigated, the latter approach is to be preferred.

The model of zircons from polymetamorphic terrains as consisting of several shells has consequences as regards the chemical analysis of this mineral, as, for instance, Hoppe (1963, p. 91) has pointed out. Different parts of the grains may have different ages and chemical compositions. In analysing zircon crystals, one should not treat them as entities. Otherwise, confusing results may be obtained. Microscopical comparison of different samples and microanalysis of individual grains may be valuable, in that they may reveal the more complex structure and composition. Hoppe (1965, p. 281) has shown that the age determination of zircons gives more accurate results (less spread) for homogeneous zircons, than for zircons with a shell and core. One conclusion would be that shells may differ in age of crystallization, as concluded in the present work. Age determinations in the investigated area should involve studies of zircon morphology and analyses of homogeneous grains. The "stratigraphic" classification of such homogeneous grains can be made by the methods described in the present work.

Improvement of the methods may be suggested. As has been pointed out, the present investigation was initiated and focussed on a field problem. If the classification of the rock types is primarily clearer, many statements may be more precisely made. Hoppe (1963, p. 91) has pointed out the possibilities of studying the shell growth which an area with metamorphic zoning affords.

Scanning electron microscopy of the surfaces of different shells (exposed by a selective crushing of the grains) may reveal more about the conditions they

have been subjected to. Terms like "irregular" may be adequately defined, as regards discrimination between growth and corrosion, mechanical abrasion and tectonic abrasion. Gaseous inclusions may be subjected to more rapid analysis, as previously mentioned (p. 45). If the inclusions represent a preserved sample from the event of crystallization of the adjacent zircon or zircon shell, analysis of the inclusions would reveal some information about the P, T, X conditions during that episode. It may be possible to identify rock types on these grounds in some cases.

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TABLE 1. Localities of rock samples (Topographic map-sheets 7B, Göteborg SO, and 6B, Kungsbacka NO).

Sample No.	Latitude N.	Longitude E.	Rock
1	57°45'52"	12°03'57"	Coarse augen gneiss
2	57°48'24"	12°07'39"	Coarse augen gneiss
3	57°53'49"	12°20'00"	Medium-coarse porphyritic granodiorite, foliated
4	57°47'29"	12°16'13"	Porphyritic gneiss granite
5	57°47'25"	12°15'42"	Porphyritic gneiss granite
6	57°44'19"	12°17'24"	Porphyritic gneiss granite
7	57°44'29"	12°17'32"	Porphyritic gneiss granite
8	57°44'00"	12°17'03"	Coarse augen gneiss
9	57°45'05"	12°15'17"	Porphyritic gneiss granite
10	57°46'11"	12°17'01"	Porphyritic gneiss granite
11	57°46'55"	12°20'30"	Coarse augen gneiss
12	57°44'58"	12°21'00"	Grey, medium-grained gneiss
13	57°44'42"	12°20'25"	Banded, acid, medium-grained gneiss
14	57°44'42"	12°20'24"	Fine- to medium-grained, banded gneiss, salic
15	57°44'42"	12°20'25"	Contact zone between 14 and 16
16	57°44'42"	12°20'24"	Coarse augen gneiss
17	57°41'26"	12°13'39"	Coarse augen gneiss
18	57°41'02"	12°11'21"	Coarse augen gneiss
19	57°40'18"	12°06'55"	Foliated granodiorite
20	57°40'18"	12°06'52"	Foliated granodiorite
21	57°40'21"	12°06'00"	Fine- to medium-grained, banded gneiss, salic
22	57°40'29"	12°04'51"	Foliated granodiorite
23	57°40'32"	12°04'54"	Grey, medium-grained, banded gneiss
24	57°40'28"	12°04'45"	Coarse augen gneiss
25	57°40'31"	12°03'57"	Medium-grained, banded gneiss, salic
26	57°40'27"	12°04'05"	Foliated granite
27	57°42'49"	12°02'45"	Grey, medium-grained, banded gneiss
28	57°43'20"	12°03'44"	Medium-grained granite
29	57°43'08"	12°04'24"	Coarse augen gneiss
30	57°43'18"	12°05'27"	Coarse augen gneiss
31	57°40'24"	12°05'30"	Coarse augen gneiss
32	57°45'01"	12°08'11"	Foliated granite
33	57°47'28"	12°17'39"	Medium-grained, banded gneiss
34	57°47'16"	12°18'44"	Migmatite, metatect
35	57°45'15"	12°17'40"	Foliated granodiorite
36	57°43'39"	12°20'57"	Slightly foliated granite with muscovite
37	57°42'32"	12°26'19"	Foliated granodiorite
38	57°34'24"	12°27'39"	Grey, medium-grained, banded gneiss
39	57°32'17"	12°25'06"	Foliated granite
40	57°30'29"	12°22'36"	Foliated tonalite
41	57°30'28"	12°22'33"	Aplitic vein in no. 40
42	57°31'02"	12°20'18"	Grey, fine-grained, banded gneiss
43	57°31'03"	12°20'30"	Coarse augen gneiss
44	57°29'11"	12°14'54"	Coarse augen gneiss
45	57°30'00"	12°14'36"	Foliated granodiorite
46	57°49'52"	12°16'55"	Fine-grained, banded gneiss, grey
47	57°52'53"	12°54'15"	Fine-grained, banded gneiss, grey

TABLE 2 a. Modal analyses of some investigated rocks. Sample numbers refer to Table 1. Rock Group A = supracrustal gneisses, B = coarse augen gneisses (only matrix is analysed; microcline porphyroblasts comprise 25–30 %), C = tonalite—granite suite, D = porphyritic gneiss-granite, E = other rocks. (See p. 20.)

Rock group Sample no.	A		B				C		D			E	
	14	47	11	16	43	44	19	37	4	7	10	3	28
<i>Mineral</i>													
Quartz	31	34	44	38	32	36	27	28	47	33	31	21	40
Plagioclase	28	31	26	31	34	37	53	30	14	25	33	48	16
Microcline	32	3	18	12	16	15	10	18	28	34	31	23	43
Biotite	3	28	11	15	14	13	5	19	5	8	5	6	2
Muscovite			+		+	+				+	+		+
Chlorite							+				+		+
Epidote group	4	4	+	2	4	+	4	6	+	+		2	
Common hornblende							+		2				
Garnet	+								+	+			
Opaque minerals	1	+	+	+	+	+		+	1	+	+	+	+
Apatite			+	+	+	+	+	+	+	+			
Zircon	1	+	+	+	+	+	+	+	1	+	+	+	+
Sphene	+	+	+	2	1	+	+	+	1	+	+		
Points counted, N	1423	756	1378	1324	1248	1446	1293	1327	3162	1305	1465	1396	1440

TABLE 2 b. Chemical analyses of some investigated rocks. Sample numbers refer to Table 1. For rock group, see Table 2 a.

Rock group	A		B				C		D		E	
Sample no.	14	47	11	16	43	44	19	37	4	7	3	28
SGU lab. no.	010—7952	010—9567	010—8730	010—7951	010—8389	010—8390	010—7932	010—8383	010—8368	010—8365	010—8370	010—8731
Weight %												
SiO ₂	72.6	65.0	69.9	68.6	69.6	69.7	67.4	66.1	71.5	73.9	68.7	75.9
TiO ₂	0.66	0.59	0.51	0.59	0.52	0.58	0.75	0.90	0.52	0.39	0.43	0.23
Al ₂ O ₃	12.4	15.6	14.6	13.7	14.5	14.4	14.1	14.6	12.7	12.8	15.3	12.5
Fe ₂ O ₃	1.3	1.5	0.8	1.0	1.2	1.0	1.4	2.4	2.9	0.8	1.2	0.3
FeO	1.7	2.8	2.0	2.7	2.1	2.4	2.9	2.9	2.0	2.0	1.6	0.8
MnO	0.08	0.11	0.07	0.08	0.08	0.09	0.10	0.12	0.08	0.06	0.06	0.04
CaO	1.4	3.9	2.2	2.3	2.2	2.2	2.9	3.4	1.5	1.6	3.2	1.0
MgO	0.52	1.9	0.85	1.2	0.96	1.1	1.2	1.5	0.35	0.42	0.77	0.26
Na ₂ O	2.9	3.1	2.8	2.8	2.7	2.8	3.3	2.9	2.9	3.0	3.1	2.6
K ₂ O	5.6	3.1	4.7	5.2	4.8	4.4	3.9	3.8	4.5	4.3	3.5	5.2
H ₂ O > 105°C	0.4	1.3	0.5	0.7	0.9	0.9	0.6	1.1	0.6	0.6	0.8	0.4
H ₂ O < 105°C	0.1	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.3	0.2
P ₂ O ₅	0.08	0.14	0.08	0.11	0.09	0.12	0.22	0.27	0.06	0.09	0.08	0.01
CO ₂	0.06	0.05	0.03	0.07	0.03	0.07	0.06	0.17	0.11	0.03	< 0.01	0.09
F	0.06	0.06	0.10	0.09	0.08	0.09	0.09	0.10	0.06	0.07	0.08	0.02
S	< 0.02	< 0.02	< 0.02	0.03	< 0.02	< 0.02	< 0.02	0.03	< 0.02	0.02	< 0.02	< 0.02
BaO	0.12	0.09	0.08	0.08	0.10	0.08	0.08	0.08	0.11	0.06	0.19	0.03
Sum	100.0	99.54	99.4	99.5	100.2	100.2	99.2	100.7	100.1	100.3	99.3	99.6
Rb, ppm	155		200	165	170	195	115	140	120	150	85	300
Sr, ppm	175		170	180	175	145	260	220	155	125	260	105
Zr, ppm	290		200	200	185	200	260	260	500	270	175	100

TABLE 3. General zircon statistics of the investigated rocks: size fractions.
Arithmetical mean value (A.M.) and standard deviation (S.D.), compare p.15.

Sample No.	Number of zircons	Number of unbroken grains	Broken grains, %	Length (μ)			Breadth (μ)			Elongation	
				Unbroken grains		Broken do.	Unbroken grains		Broken do.	Unbroken grains	
				A.M.	S.D.	A.M.	A.M.	S.D.	A.M.	A.M.	S.D.
1	166	149	10	110	31.5	98	60.6	16.1	59.3	1.85	0.43
2	181	157	13	126	38.7	105	68.0	17.6	73.0	1.87	0.40
3	224	156	30	121	39.0	90	58.3	17.0	60.8	2.12	0.50
4	294	150	49	180	70.2	133	66.1	21.1	70.5	2.78	0.86
7	197	152	23	202	68.7	165	74.8	22.6	86.8	2.77	0.86
9	228	162	29	110	35.0	92	58.8	16.0	55.1	1.94	0.66
10	240	132	45	193	63.2	166	77.3	19.8	91.7	2.50	0.62
11	169	154	9	109	36.5	113	62.3	19.1	63.2	1.78	0.47
14	180	155	14	139	45.1	117	71.1	23.0	66.3	2.06	0.63
16	168	150	11	144	36.5	136	81.8	19.0	64.2	1.81	0.46
19	214	157	27	145	50.0	132	75.4	20.7	83.6	1.97	0.55
20	200	150	25	160	55.0	134	71.5	16.5	82.9	2.25	0.62
22	200	155	23	133	46.8	114	67.5	19.6	71.4	1.99	0.52
26	182	152	16	212	67.0	148	118	37.3	102	1.85	0.53

TABLE 3. Continued.

Sample No.	Number of zircons	Number of unbroken grains	Broken grains %	Length (μ)			Breadth (μ)			Elongation	
				Unbroken grains		Broken do.	Unbroken grains		Broken do.	Unbroken grains	
				A.M.	S.D.	A.M.	A.M.	S.D.	A.M.	A.M.	S.D.
28	220	165	25	117	36.8	99	62.7	18.5	62.9	1.91	0.46
32	195	160	18	131	45.0	109	56.4	15.2	65.7	2.33	0.56
33	196	152	22	141	43.6	113	64.7	15.4	71.4	2.20	0.55
34	225	160	29	116	45.4	100	58.9	19.9	60.9	2.00	0.56
35	168	163	3	112	30.2	112	58.0	15.6	58.5	1.98	0.48
36	171	151	12	135	31.2	118	67.7	16.4	70.2	2.07	0.56
37	211	158	25	134	45.6	114	67.0	20.0	74.6	2.05	0.54
38	169	155	8	100	24.8	97	59.0	12.1	68.7	1.72	0.36
39	225	153	32	147	49.5	110	70.4	20.1	72.9	2.16	0.67
40	170	126	26	117	29.8	87	67.1	17.7	59.4	1.80	0.48
41	191	153	20	119	29.6	108	74.0	21.6	79.6	1.67	0.38
42	167	150	10	125	44.3	128	64.9	21.8	71.1	1.97	0.54
43	171	152	11	128	35.9	100	71.0	18.1	68.8	1.84	0.44
44	172	159	8	134	37.4	102	72.2	19.0	73.5	1.90	0.43
45	170	150	12	111	33.2	104	60.8	14.8	64.7	1.85	0.43
46	181	151	17	96	25.0	82	57.7	11.3	56.7	1.69	0.41
47	179	171	4	122	32.2	115	61.5	15.3	60.1	2.04	0.52

TABLE 4. General zircon statistics of the investigated rocks: types of grains.

Sample no.	1					2					3					4					7									
Shell no.	1	2	3	4	Core lack- ing	1	2	3	4	Core lack- ing	1	2	3	4	Core lack- ing	1	2	3	4	Core lack- ing	1	2	3	4	Core lack- ing					
<i>Habit:</i>																														
Euhedral, total	0	5	10	0	0	0	2	0	0	1	0	0	17	0	0	0	3	4	0	0	0	1	0	0	0	0	1	0	0	0
Euhedral, zoned	0	5	7	0	0	0	2	0	0	0	0	0	16	0	0	0	3	4	0	0	0	1	0	0	0	0	1	0	0	0
Subhedral, total	12	80	22	1	0	5	65	5	0	0	2	83	43	2	0	3	63	5	0	0	4	104	6	0	3	4	104	6	0	3
Subhedral, zoned	1	46	2	0	0	0	58	4	0	0	0	73	27	1	0	0	63	4	0	0	0	102	2	0	1	0	102	2	0	1
Crystallization partly obstructed, total	0	2	0	0	0	0	2	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	4	0	0	0
Crystallization partly obstructed, zoned	0	2	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	4	0	0	0	0	4	0	0	0
Irregular, total	97	1	19	0	0	89	18	22	0	4	119	20	17	19	3	119	9	11	1	1	22	6	6	1	0	22	6	6	1	0
Irregular, zoned	0	0	0	0	0	0	5	4	0	0	1	4	0	0	0	0	4	0	0	0	0	1	0	0	0	0	1	0	0	0
Rounded, total	40	61	31	1	0	56	39	30	0	2	31	25	25	9	1	24	20	13	1	1	23	11	21	2	0	23	11	21	2	0
Rounded, zoned	1	15	1	0	0	0	19	6	0	0	0	11	6	0	0	0	12	7	0	0	0	4	1	0	0	0	4	1	0	0
Fragments, total	0	0	6	0	0	0	24	20	0	0	0	23	9	1	0	0	51	1	0	0	0	23	8	0	0	0	23	8	0	0
Fragments, zoned	0	0	0	0	0	0	23	15	0	0	0	18	7	0	0	0	49	1	0	0	0	23	6	0	0	0	23	6	0	0

TABLE 4. Continued.

Sample no.	9					10					11					14					16									
Shell no.	1	2	3	4	Core lack- ing	1	2	3	4	Core lack- ing	1	2	3	4	Core lack- ing	1	2	3	4	Core lack- ing	1	2	3	4	Core lack- ing					
<i>Habit:</i>																														
Euhedral, total	0	1	0	0	0	1	72	3	0	22	0	0	3	0	0	0	67	4	0	0	3	42	13	1	0					
Euhedral, zoned	0	1	0	0	0	0	71	1	0	22	0	0	2	0	0	0	63	3	0	0	0	41	3	0	0					
Subhedral, total	5	32	0	0	0	11	17	3	0	4	7	58	12	0	0	58	46	8	2	3	55	60	7	0	0					
Subhedral, zoned	1	29	0	0	0	0	14	1	0	4	0	52	5	0	0	1	33	4	2	1	1	46	2	0	0					
Crystallization partly obstructed, total	0	2	0	0	0	0	6	0	0	4	0	0	0	0	0	1	3	2	0	0	11	14	0	0	0					
Crystallization partly obstructed, zoned	0	2	0	0	0	0	5	0	0	0	0	0	0	0	0	0	3	0	0	0	0	12	0	0	0					
Irregular, total	93	15	3	0	2	84	0	2	0	0	96	35	15	1	0	11	2	4	0	0	15	1	2	0	0					
Irregular, zoned	1	5	0	0	0	0	0	0	0	0	0	8	1	0	0	0	0	0	0	0	0	0	0	0	0					
Rounded, total	60	43	1	0	2	2	2	14	1	3	51	44	46	2	0	79	19	38	0	2	64	23	47	2	2					
Rounded, zoned	0	17	0	0	0	0	0	0	0	0	0	13	2	0	0	0	0	1	0	0	0	0	0	0	0					
Fragments, total	0	65	3	0	0	0	1	6	0	1	0	17	17	0	0	1	13	41	1	0	0	8	17	1	0					
Fragments, zoned	0	52	2	0	0	0	1	0	0	0	0	13	8	0	0	0	2	3	0	0	0	4	0	0	0					

TABLE 4. Continued.

Sample no.	19					20					22					26					28						
Shell no.	1	2	3	4	Core lack- ing	1	2	3	4	Core lack- ing	1	2	3	4	Core lack- ing	1	2	3	4	Core lack- ing	1	2	3	4	Core lack- ing		
<i>Habit:</i>																											
Euhedral, total	1	73	32	2	2	0	2	21	0	0	0	50	13	0	11	0	0	0	0	0	0	0	0	1	0	0	
Euhedral, zoned	0	72	32	1	0	0	2	20	0	0	0	50	13	0	10	0	0	0	0	0	0	0	0	1	0	0	
Subhedral, total	51	45	12	1	9	9	75	28	1	0	66	38	11	0	9	17	46	10	0	1	7	69	0	0	0	0	
Subhedral, zoned	0	35	6	0	7	0	56	16	0	0	2	31	10	0	6	2	19	1	0	0	1	47	0	0	0	0	
Crystallization partly obstructed, total	3	5	2	0	0	0	1	0	0	0	2	7	2	0	2	0	0	0	0	0	0	1	1	0	0	0	
Crystallization partly obstructed, zoned	0	5	1	0	0	0	1	0	0	0	0	5	0	0	1	0	0	0	0	0	0	0	0	0	0	0	
Irregular, total	21	1	2	0	1	87	11	6	7	1	8	3	2	0	0	106	32	9	0	6	60	10	21	3	4		
Irregular, zoned	0	0	1	0	0	0	4	1	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	
Rounded, total	60	11	11	4	7	53	39	14	6	0	53	18	3	0	4	19	51	33	0	3	92	66	64	5	2		
Rounded, zoned	0	2	1	0	1	0	21	5	1	0	0	1	1	0	0	0	5	0	0	0	0	14	2	0	0		
Fragments, total	2	3	3	0	0	0	21	5	0	0	0	13	0	0	0	0	13	6	0	0	0	13	6	0	0		
Fragments, zoned	0	2	0	0	0	0	14	3	0	0	0	3	0	0	0	0	2	1	0	0	11	0	0	0	0		

TABLE 4. Continued.

Sample no.	32				33				34				35				36								
Shell no.	1	2	3	Core 4 lack- ing	1	2	3	Core 4 lack- ing	1	2	3	Core 4 lack- ing	1	2	3	Core 4 lack- ing	1	2	3	Core 4 lack- ing					
<i>Habit:</i>																									
Euhedral, total	0	6	3	0	0	0	9	3	0	0	2	24	4	0	2	1	11	1	0	0	0	14	0	0	0
Euhedral, zoned	0	6	2	0	0	0	9	3	0	0	2	24	4	0	2	1	11	1	0	0	0	14	0	0	0
Subhedral, total	21	92	18	1	0	17	83	5	0	1	32	53	1	0	6	41	108	12	0	1	10	55	1	0	6
Subhedral, zoned	1	83	12	0	0	0	70	2	0	1	13	49	1	0	5	3	102	4	0	1	1	52	1	0	6
Crystallization partly obstructed, total	1	5	0	0	0	1	3	0	0	0	0	8	1	0	0	1	3	0	0	0	1	10	0	0	0
Crystallization partly obstructed, zoned	0	3	0	0	0	0	2	0	0	0	0	7	1	0	0	0	1	0	0	0	0	9	0	0	0
Irregular, zoned	56	13	18	1	1	49	13	17	0	0	58	10	9	0	2	35	6	8	0	0	37	9	4	0	5
Irregular, total	0	1	1	0	0	0	0	0	0	0	1	2	1	0	0	0	4	0	0	0	0	5	0	0	0
Rounded, total	77	30	22	0	3	83	33	53	0	1	53	42	48	1	5	84	32	64	3	0	77	13	25	0	15
Rounded, zoned	0	8	0	0	0	0	5	1	0	0	2	7	1	0	1	1	15	2	0	0	2	9	2	0	6
Fragments, total	1	10	36	1	0	0	9	11	1	0	0	8	10	0	0	0	2	14	0	0	0	24	3	0	0
Fragments, zoned	0	8	17	1	0	0	4	1	0	0	0	3	1	0	0	0	1	0	0	0	0	19	0	0	0

TABLE 4. Continued.

Sample no.	37					38					39					40					41					
Shell no.	1	2	3	Core 4 lack- ing		1	2	3	Core 4 lack- ing		1	2	3	Core 4 lack- ing		1	2	3	Core 4 lack- ing		1	2	3	Core 4 lack- ing		
<i>Habit:</i>																										
Euhedral, total	1	49	22	0	0	0	3	4	0	0	0	7	3	0	0	0	8	9	0	0	0	1	8	0	0	0
Euhedral, zoned	0	48	11	0	0	0	3	4	0	0	0	4	2	0	0	0	5	9	0	0	0	1	6	0	0	0
Subhedral, total	30	75	24	1	2	8	35	15	0	1	32	81	2	0	2	6	41	2	0	7	23	65	7	0	1	0
Subhedral, zoned	1	67	10	0	0	3	30	10	0	0	1	38	0	0	0	0	38	1	0	2	0	41	3	0	1	0
Crystallization partly obstructed, total	0	3	1	0	0	0	3	2	0	0	0	1	0	0	0	1	1	0	0	1	1	2	0	0	0	0
Crystallization partly obstructed, zoned	0	3	0	0	0	0	2	2	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0
Irregular, total	44	4	1	5	2	39	8	3	0	0	76	9	2	0	1	37	9	0	0	4	44	30	18	0	10	0
Irregular, zoned	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Rounded, total	78	12	31	11	1	104	92	38	2	3	40	30	22	0	2	65	34	9	1	5	71	34	32	0	3	0
Rounded, zoned	0	6	4	0	0	5	35	2	0	1	0	0	0	0	0	1	14	0	0	0	0	10	1	0	0	0
Fragments, total	0	10	5	2	0	0	10	19	0	0	0	20	4	0	0	0	16	4	0	0	0	7	2	0	0	0
Fragments, zoned	0	5	2	0	0	0	4	3	0	0	0	2	0	0	0	0	5	0	0	0	3	1	0	0	0	0

TABLE 5. Samples nos. 1—13, 15—21 and 23—31. Length, elongation, proportion of broken grains in total, colour and shape.

Sample No.	Mean length in μ	Elongation	Total number of grains	Proportion of broken grains	Red	Brown	Colourless	Shape		
								Idiomorphic	Hypidiomorphic	Round
1	149	1.72	200	0.04	4	178	18	0	48	141
2	126	1.78	200	0.10	3	138	59	2	49	145
3	131	2.10	200	0.25	6	87	107	20	58	114
4	202	2.73	220	0.46	13	154	53	84	56	64
5	170	1.98	200	0.15	3	155	42	1	47	151
6	115	1.92	200	0.08	1	118	81	1	17	180
7	208	2.58	200	0.40	2	90	108	37	92	56
8	138	1.86	200	0.10	7	164	29	4	45	145
9	125	1.91	200	0.17	0	83	117	6	30	160
10	190	2.48	221	0.25	5	162	54	24	108	81
11	135	1.75	200	0.01	0	174	26	0	43	157
12	125	1.82	200	0.05	3	161	36	0	14	186
13	105	1.91	200	0.10	3	49	148	1	15	183
15	144	1.73	200	0.04	4	178	18	0	52	148
16	144	1.81	200	0.03	0	175	25	9	94	96
17	171	1.81	200	0.10	1	148	51	6	86	108
18	150	1.77	200	0.08	2	146	52	0	33	167
19	147	1.98	200	0.09	15	83	102	6	55	139
21	110	1.88	200	0.10	1	40	159	8	54	130
23	128	1.95	200	0.26	1	39	160	26	52	107
24	133	1.91	200	0.18	0	153	47	6	46	143
25	123	1.59	200	0.06	0	189	11	2	37	160
26	130	1.83	200	0.11	6	181	13	4	111	84
27	127	1.76	200	0.17	2	101	97	1	25	168
28	139	1.85	200	0.19	14	161	25	11	35	151
29	155	1.92	200	0.09	1	181	18	0	49	151
30	175	1.82	200	0.06	5	186	29	0	34	166
31	146	1.75	200	0.06	0	158	42	5	54	140

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