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Zircon typology in metasediments from the Strona-Ceneri Zone (Serie dei Laghi, Western Southern Alps): indications on their protoliths and evolution

by *Valeria Caironi*[1]

Abstract

The typologic study of zircon populations from Gneiss Minuti and Cenerigneiss (Strona-Ceneri Zone, Serie dei Laghi, Western Southern Alps) gave interesting indications on their protoliths and evolution. Both rock types contain detrital zircon populations, mainly deriving from the erosion of intrusive calcalkaline rocks. Despite some differences in the degree of mechanical abrasion, the homogeneity of zircon characteristics within each sample suggests that each population mainly derives from a single source rock; similarity of the typologic characteristics and progressive variations of the typologic distributions among the different samples suggest that the igneous source rocks of the sediments were genetically linked.

The Cenerigneisses petrographically and chemically show mixed sedimentary and igneous character; beside the typical zircons of paragneisses, they also contain euhedral, non-abraded zircons of granitic origin. These crystals are similar to the populations of some two-mica orthogneisses, representing the Hercynian metamorphic product of granitoid rocks which intruded the Serie dei Laghi in the Ordovician.

The study of Cenerigneiss samples from the Vira-Magadino area (Switzerland), where the Serie dei Laghi is affected by a subsequent very limited partial melting (attributed to a Permian thermal disturbance induced by the uprise of mafic magmas), shows that "recrystallized" and non-recrystallized zircons coexist in the same sample. Therefore, the recrystallization process at high grade metamorphic conditions does not affect the whole zircon population at the same time.

Keywords: zircon typology, metasediments, Strona-Ceneri Zone, Serie dei Laghi, Southern Alps.

Introduction

The paper presents results of a typologic study of zircon populations from two typical lithologies of the basement of the Strona-Ceneri Zone (Serie dei Laghi, Western Southern Alps): Cenerigneiss and Gneiss Minuti. The study was aimed to contribute to the petrological interpretation of these rocks, which have a complex history, by obtaining indications on their protoliths and on their evolution processes.

As demonstrated by Pupin (1976, 1980), zircon crystals, during primary magmatic crystallization, develop different crystallographic forms, which are strongly influenced by the physico-chemical characters of the magma. The crystal "typology", i.e. a given combination of prisms and bipyramids, is preserved without major changes during most sedimentary and metamorphic processes, due to the high resistance of zircon against mechanical and chemical corrosion (Pupin, 1976; Blatt et al., 1980). Therefore, the typologic study of zircon populations can give indications on the character of the primary parent magmatic rock. In metamorphic rocks, this study may help to distinguish ortho-derived from paraderived rocks and to identify their protolith.

However, some limitations to the use of the typologic study of zircon populations in metamorphic and sedimentary rocks must be mentioned. An important one is the possible loss of the original character due to recrystallization with increasing metamorphic grade.

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In the typology method (PUPIN, 1976), which is based on the observation of the external morphology, the term "recrystallization" indicates an abrupt change in the crystal morphology, which leads to a new crystal shape and typical character. Nothing is implied about the actual mechanism of the morphological change. The progressive recovery of the radiation-damaged crystal lattice with increasing temperature is not taken into consideration, since it does not affect the external shape. Under the microscope we can only observe that, during low-to-medium grade metamorphism, colour, zoning and overgrowths progressively disappear, as a consequence of the recovery of the crystal structure, and the crystal edges become slightly "smoothed" (TURCO and PUPIN, 1982). The occurrence of crystals with overgrowths in low-to-medium grade metamorphic rocks was explained by some authors with the crystallization of outer shells of new zircon material; however, most of the described "new shells" show the typical features of late-magmatic overgrowths, and must be considered as an original character of the crystals of the protolith (for a detailed discussion of this point see PUPIN, 1976).

A complete "recrystallization" of zircons leading to new crystalline forms is reported by several authors (e.g. GASTIL et al., 1967; DAVIS et al., 1968; PUPIN, 1976; ALINAT et al., 1979; BLATT et al., 1980) in anatectic migmatites and, more generally, in rocks having experienced high-grade metamorphic conditions. This seems confirmed by a recent paper by FARGES (1994) on the thermal annealing of metamict zircons: he observed a first stage below 600°, characterized by the decrease of the a_0 cell parameter, and a second stage above 600°, characterized by zircon crystallization.

If the zircon population is recrystallized, a mere typologic study cannot give petrological information about the environment where zircons first crystallized, since the new typologic characters may be or may be not influenced by the morphology of the inherited cores (PUPIN, 1994, in press).

In sedimentary rocks, and in their low-to-medium grade metamorphic products, the abraded edges or the "rounded" shape of the detrital crystals can make it difficult or impossible to recognize their typology. However, many sedimentary petrologists agree that a single sedimentary cycle is generally not enough to generate well rounded crystals. Since a single sample may contain zircons which suffered more than one sedimentary cycle (recycled crystals), crystals with a different degree of abrasion must be considered separately as different subpopulations.

The zircon typology method

The typologic classification (PUPIN and TURCO, 1972a) is based on the presence ("type") and relative development ("subtype") of the most common crystallographic forms. The subtypes are identified on a "typologic grid" (Fig. 1) by two empirical coordinates: the A index, horizontal, is associated to the variations in the relative development of bipyramids; the T index, vertical, is associated to the variations in the relative development of prisms. Several factors were proposed to explain the typologic variations: for the bipyramids, the relative content of Al vs alkalies of the magma (PUPIN, 1976); for the prisms, the zircon crystallization temperature (PUPIN and TURCO, 1972b; PUPIN et al., 1978), the degree of zircon supersaturation in the liquid (VAVRA, 1990) and the concentration of distinct trace elements relative to Zr (BENISEK and FINGER, 1993).

I.T \ I.A	100	200	300	400	500	600	700	800	
100	B	AB1	AB2	AB3	AB4	AB5	A	C	0
200	H	L1	L2	L3	L4	L5	G1-3	I	110
300	Q1	S1	S2	S3	S4	S5	P1	R1	110>>
400	Q2	S6	S7	S8	S9	S10	P2	R2	110>
500	Q3	S11	S12	S13	S14	S15	P3	R3	110=
600	Q4	S16	S17	S18	S19	S20	P4	R4	100>
700	Q5	S21	S22	S23	S24	S25	P5	R5	100>>
800	E	J1	J2	J3	J4	J5	D	F	100
	211	211>>	211>	211=	101>	101>>	101	301	

Fig. 1 Position of the main types and subtypes in the typologic grid (PUPIN, 1976).

Starting from the observed frequencies of subtypes, simple calculations give a "mean point" of $\bar{A}$, $\bar{T}$ coordinates for the whole population. Other characters which can be optically observed are: colour, overgrowths, zoning, type of inclusions, occurrence of cores; they are also taken into consideration to obtain indications of petrological interest.

The typology is determined under the microscope at 250 × magnification on zircon concentrates, obtained by routine separation processes and mounted between microscope slides with Canada balsam.

Geological setting

The typologic study of zircon populations was performed on Cenerigneiss and Gneiss Minuti from the Strona-Ceneri Zone, which represents the north-western part of Serie dei Laghi (Western Southern Alps).

The Serie dei Laghi (Fig. 2) is a metamorphic unit in amphibolite facies, separated from the Ivrea-Verbano Zone, to the West, by the Cossato-Mergozzo-Brissago and Pogallo fault system, and from the Val Colla Zone, to the East, by the Val Colla fault. It is composed of metasediments and metaplutonites, intruded by Permian mafic rocks and granites. According to the studies of Boriani and coworkers, summarized in Boriani et al. (1990) and Boriani and Giobbi Origoni (1992), the Serie dei Laghi consists of: a) a metapelitic series (Scisti dei Laghi: micaschists and paragneisses); b) a heterogeneous sequence of alternated layers of metapelite, metarenite and metabasite (Strona-Ceneri Border Zone; Boriani and

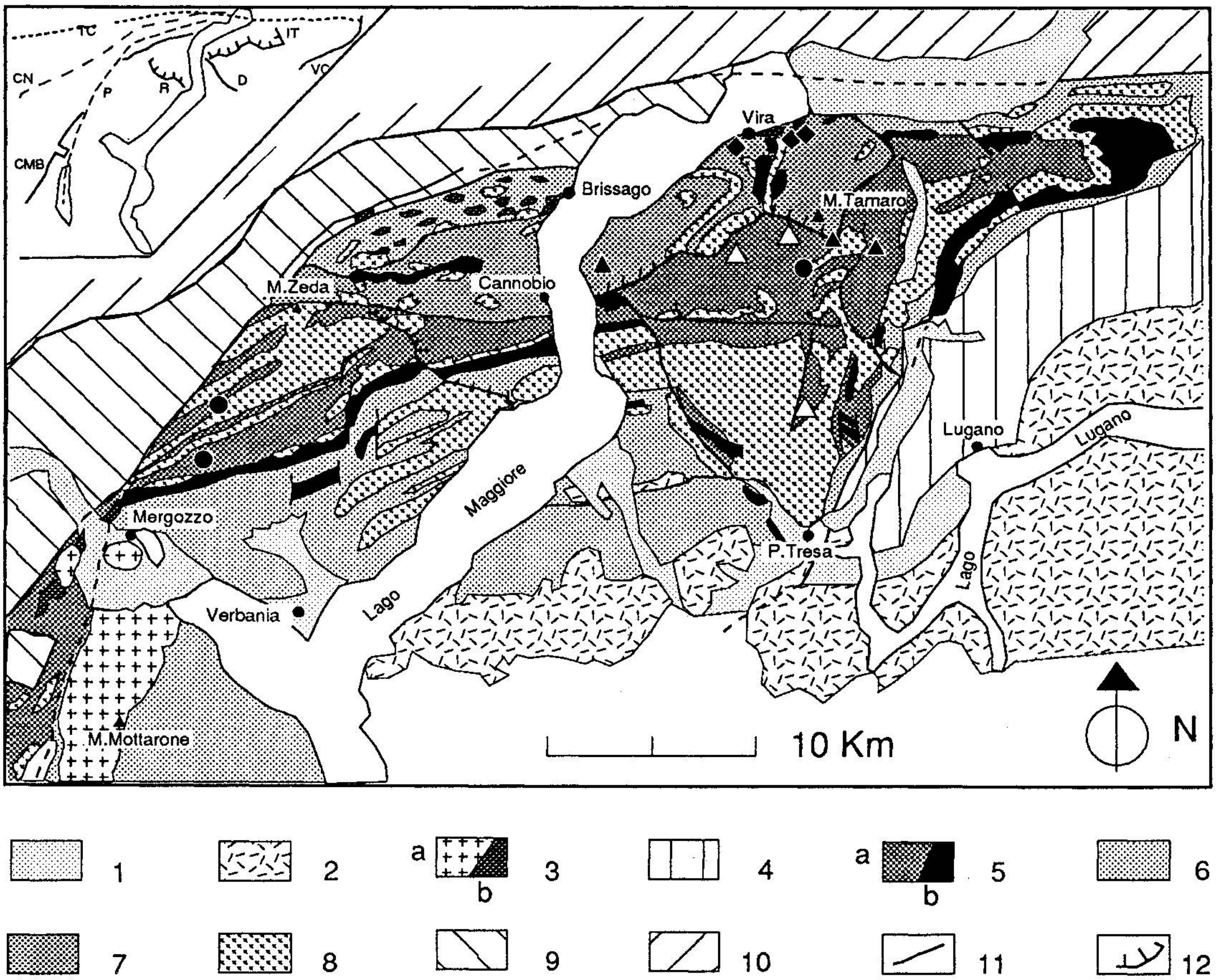

Fig. 2 Geological sketch map of Massiccio dei Laghi (modified after Boriani et al., 1990): 1- Quaternary. 2- Volcanic and sedimentary Permo-Mesozoic cover. 3- Late-Hercynian intrusives: a- granites; b- mafic stocks and dykes (Appinites). 4- Val Colla Zone. Serie dei laghi: 5- *Strona-Ceneri Zone:* a- Gneiss Minuti and Cenerigneisses; b- metabasites and subordinate ultramafites of the Strona-Ceneri Border Zone. 6- *Scisti dei Laghi* (micaschists, paragneisses). 7- *Monte Riga* and *Gambarogno Zone:* Strona-Ceneri and Scisti dei Laghi rocks with complex deformation. 8- Ordovician metagranitoids. 9- Ivrea-Verbano Zone. 10- Alpine domain. 11- *Faults:* CN = Canavese; TC = Tonale-Centovalli; CMB = Cossato-Mergozzo-Brissago; P = Pogallo-Lago d'Orta; D = Val Dumentina; VC = Val Colla. 12- *Overthrusts:* R = Riale di Cannero; IT = Indemini-Monte Tamaro. Sample location: open triangles: Gneiss Minuti; triangles: Cenerigneiss with little K-feldspar; dots: K-feldspar-rich Cenerigneiss; diamonds: Cenerigneiss with limited partial melting.

GIOBBI ORIGONI, 1992); c) a metapsammitic sequence (Strona-Ceneri Zone), composed of coarse metarenites to metaconglomerates (Cenerigneiss) and metarenites (Gneiss Minuti); d) thick orthogneiss lenses (Ordovician intrusions: 466 ± 5 Ma, Rb/Sr w.r. isochron; BORIANI et al., 1982–83). The abundant geochronological data on the Serie dei Laghi rocks are interpreted in different ways. The "Caledonian" ages obtained on paragneiss zircons (lower intercept ages around 430–500 Ma: PIDGEON et al., 1970; KÖPPEL and GRÜNENFELDER, 1971) and monazites (concordant age of 450 Ma: KÖPPEL and GRÜNENFELDER, 1971), as well as the Rb/Sr w.r. isochron of about 473 on paragneisses (HUNZIKER and ZINGG, 1980) were referred by these authors to a high grade metamorphic event, causing the anatectic formation of the orthogneisses in Caledonian times. On the contrary, after BORIANI et al. (1985, 1990) these ages may be explained with the temperature raise and the fluid circulation connected with the Ordovician intrusions. Most K/Ar and Rb/Sr mineral ages point to a main Hercynian metamorphism (ages mainly between 200 and 300 Ma on muscovite, biotite and hornblende: MCDOWELL, 1970; HUNZIKER, 1974; KÖPPEL, 1974; BORIANI et al., 1982–83).

The Cenerigneisses are grey, medium-to-coarse grained gneisses, with a typical glomeroblastic texture, consisting of polycrystalline aggregates of polygonal plagioclase and decussate mica flakes (BÄCHLIN, 1937; BORIANI, 1970). They are composed of biotite, plagioclase, quartz and minor muscovite and K-feldspar; the latter may be present as porphyroclasts, up to 5 cm long, often showing the Carlsbad twinning, surrounded by myrmekites, or as relics, almost completely replaced by thin recrystallized myrmekites; garnet and kyanite (and / or sillimanite) may occur in the mica aggregates. The coarser-grained varieties of Cenerigneiss contain plenty of "enclaves": quartz pebbles, lithic clasts of dioritic or pelitic rocks, fine-grained gneisses, and variably-sized (centimetres to 1–2 metres) zoned Ca-silicate enclaves (BORIANI et al., 1977).

Due to the presence of both sedimentary and igneous characters, the Cenerigneisses were interpreted in different ways: BÄCHLIN (1937) and GRÄTER (1951) considered the Cenerigneisses of the Malcantone and Ceneri region as mixed gneisses with prevailing "para" material, that is, original paragneisses transformed by pervasive alkaline solutions; REINHARD (1964) regarded them as paragneisses; BORIANI (1970) considered the Cenerigneisses of the M. Zeda area as anatectic migmatites. In the following years, after detailed studies on the stratigraphy and metamorphic evolution of Serie dei Laghi, BORIANI et al. (1977) and GIOBBI ORIGONI et al. (1982–83) proposed an origin from epicontinental, shallow water sediments. BORIANI et al. (1990) consider the Cenerigneisses as the metamorphic product of coarse sandstones to conglomerates, representing the poorly sorted, coarse-grained portion of turbidites. The occurrence of K-feldspar porphyroclasts, also observed in the amphibolites of the Strona Ceneri Border Zone (BORIANI and GIOBBI MANCINI, 1972), is interpreted as due to a pervasive feldspathization or granitization which affected the non-metamorphic or anchimetamorphic sediments before the main Hercynian metamorphism and could be connected with the Ordovician intrusions (BORIANI et al., 1990).

The Gneiss Minuti ("Hornfelsgneise" of the Swiss literature) are grey, fine-grained, massive gneisses, with a typical granoblastic microstructure and the same mineralogical composition as the Cenerigneiss, but without K-feldspar. They show relics of sedimentary structures, such as grain size gradation, alternating layers of different grain size and composition (mica-rich or quartz-rich). They are sometimes interlayered with the Cenerigneiss. In contrast to the latter, the Gneiss Minuti do not reveal traces of pervasive feldspathization. They are injected by many pre-metamorphic aplitic and pegmatitic veins, which are presumably also related to the Ordovician magmatic event. Besides Ca-silicate enclaves similar to those of Cenerigneiss, the Gneiss Minuti also contain cm-sized Al-silicate nodules: they are widespread in the area of injection of the pegmatites and are interpreted as the regional metamorphic product of original chiastolite porphyroblasts (BÄCHLIN, 1937; BIGIOGGERO and BORIANI, 1975), which were formed by contact metamorphism. The formation of chiastolite is considered by BORIANI et al. (1990) as indicative that contact metamorphism developed in the Ordovician on anchimetamorphic rocks.

After the main regional metamorphism, partial melting processes affected the rocks of the Serie dei Laghi in a narrow belt along the Cossato–Mergozzo–Brissago line. The close space and time relationships between anatexis and the mafic intrusions of the Permian magmatic cycle (Appinites; BORIANI et al., 1974) suggest that this process could be related to the thermal disturbance induced by the uprise of the mafic magma (BURLINI and CAIRONI, 1988). In the Quarna-Mergozzo area, partial melting mainly affected orthogneisses and Cenerigneisses. In the latter BURLINI and CAIRONI (1988) observed an increasing anatectic mobilization on approaching to the Cossato–Mergozzo–Brissago line, where the Appinitic intrusions reach their maximum density. The first macroscopic appearance of thin discordant leucocratic veins is accompanied, at the microscopic scale, with myrmekite-like Ms + Qz intergrowths containing relic sillimanite; this peculiar texture is explained with an incipient dehydration melting of muscovite and a subsequent recrystallization in a water-poor environment. This is followed by the appearance of Bt + Qz intergrowths, K-feldspar crystals and zoned plagioclase (25–15% An), together with andalusite poikiloblasts containing biotite and sillimanite; at the same time, the rocks become more and more migmatitic at the mesoscopic scale. The age of the anatectic event may be indirectly estimated from a concordant U/Pb monazite age of 295 ± 5 Ma (Köppel, 1974) of an Appinite-related migmatite from lower Val Strona; this is in good agreement, within analytical error, with the intrusion age of Appinites: 285 ± 5 Ma (concordant U/Pb on monazite, Cumming et al., 1987). In the eastern part of Serie dei Laghi, very limited partial melting is observed in the Cenerigneisses of the Vira-Magadino area (Switzerland), where only thin leucosomatic veins interrupting the regional foliation are sometimes present, and Ms + Qz intergrowths are rare.

Zircon typology

The studied samples are Gneiss Minuti (FA61, FA35, MIN), Cenerigneiss with (FA60, CH1, CH17) or without (FA26, FA36, CEN) K-feldspar porphyroclasts, and Cenerigneiss affected by very limited post-Hercynian anatectic processes (FA68, FA41, FA140). For sample location see figure 2.

All samples contain zircons with more or less fractured and abraded edges, pitted faces and rounded or broken corners, which point to a sedimentary transport; they are in strong contrast to the clean faces and the only slightly smoothed edges and corners shown by zircons of adjacent Ordovician metagranitoids (Caironi, 1986, 1994a).

The detrital crystals were divided into two groups on the basis of their degree of mechanical abrasion (Tab. 1): VA = fragments and very abraded crystals, sometimes with ovoidal shape; their typology can be rarely recognized (Fig. 3a); A = slightly abraded crystals, showing irregular and fractured edges and corners, but relatively well preserved faces; their typology can be generally recognized (Figs 3 b, c).

The samples of Cenerigneiss also contain variable amounts of euhedral, non-abraded crystals (EU) with rectilinear, slightly smoothed edges and even faces (Tab. 1; Fig. 3d; Figs 4 a, b). They resemble the crystals of orthometamorphic rocks.

A peculiar type of crystals (Tab. 1; Figs 4 c, d) is exclusively present in some Cenerigneiss samples of the Vira area, affected by very limited partial melting: they are subidiomorphic, with slightly smoothed edges and clean faces, and show the typical characters of zircons from anatectic migmatites (see detailed description and references in the following specific paragraph). They are indicated as "recrystallized" crystals (R), to stress that their new morphology

Tab. 1 Main characters and occurrence of the different groups of zircon crystals. Groups: A_1 = abraded crystals of magmatic origin; A_2 = abraded crystals of migmatitic origin (recrystallized before sedimentation); VA = very abraded crystals; EU_1 = non-detrital crystals of magmatic origin; EU_2 = non-detrital crystals of migmatitic origin; R = zircons recrystallized during very limited partial melting. GM = Gneiss Minuti; CG = Cenerigneiss.

Group	Edges Corners	Faces	Inclusions	Zoning	Cores	Overgrowths	Occurrence
A_1	fractured	pitted	magmatic type, ++	rare	no	some coloured	all samples
A_2	fractured	pitted	rare bubbles	rare	large corroded	colourless no inclusions	some GM-CG
VA	rounded or very fractured	pitted	magmatic type, ++	no	no	rare, broken	most samples
EU_1	regular, smoothed	even, clean	magmatic type, + +	rare	no	rare	all CG
EU_2	regular, smoothed	even, clean	rare bubbles or dust-like	rare	large corroded	colourless no inclusions	most CG
R	slightly smoothed	clean, curved	rare bubbles or dust-like	rare	large corroded	colourless no inclusions	anatectic CG

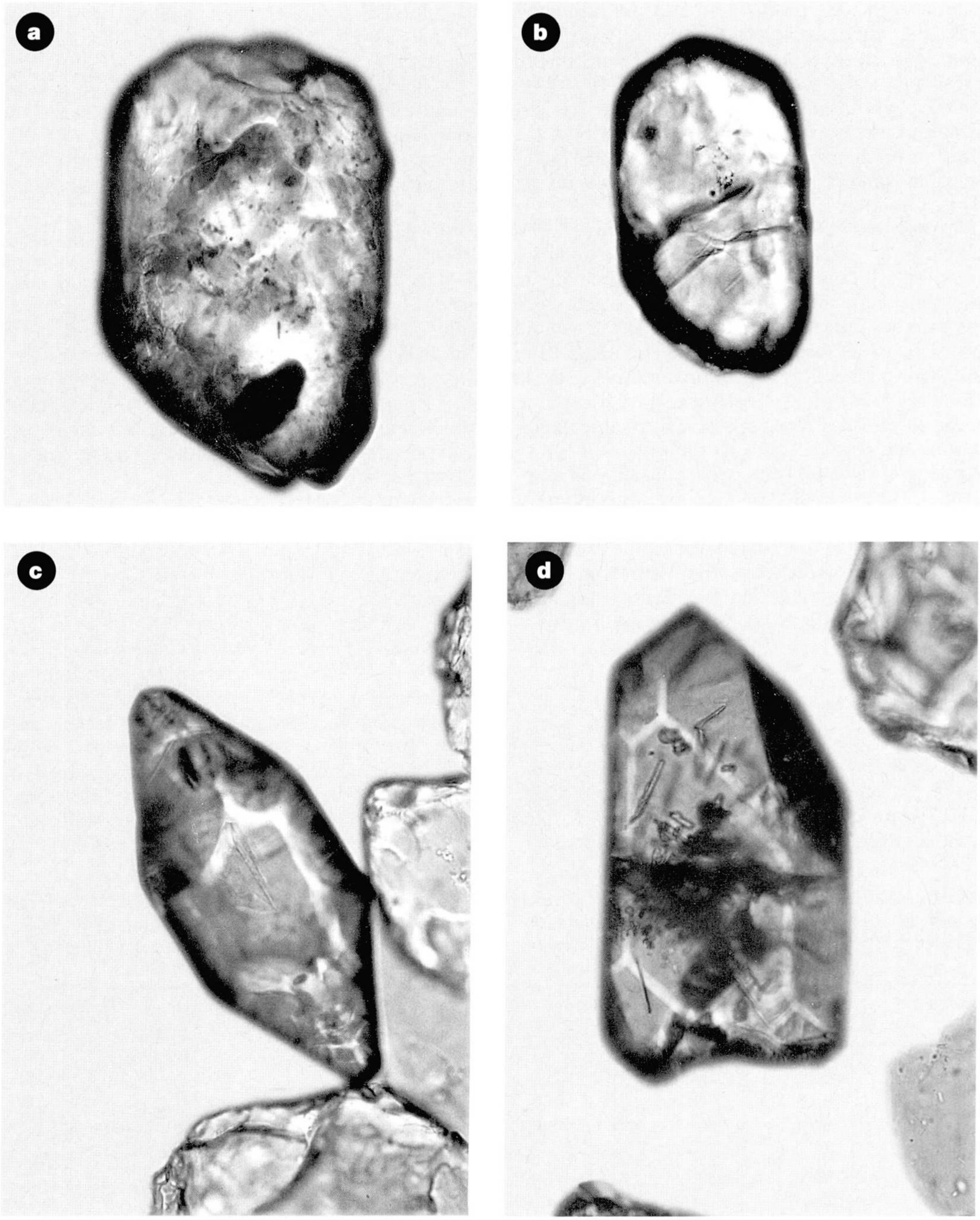

Fig. 3 Zircon types. *Detrital crystals:* a = very abraded crystal (VA) of igneous origin: rounded corners and edges, irregular and pitted faces; appr. S19–S18, sample CEN. b = abraded crystal of igneous origin (A_1): slightly abraded edges and faces, rounded corners; U18, sample FA68. c = abraded crystal of migmatitic origin (A_2): irregular, slightly abraded edges and faces; clear overgrowth forming the bipyramidal terminations on a large, faintly zoned core; S6 developed on appr. S8, sample CEN. *Non-detrital crystals:* d = euhedral crystal of igneous origin (EU_1): slightly smoothed, well defined edges, even and clean faces; S18, sample CH1.

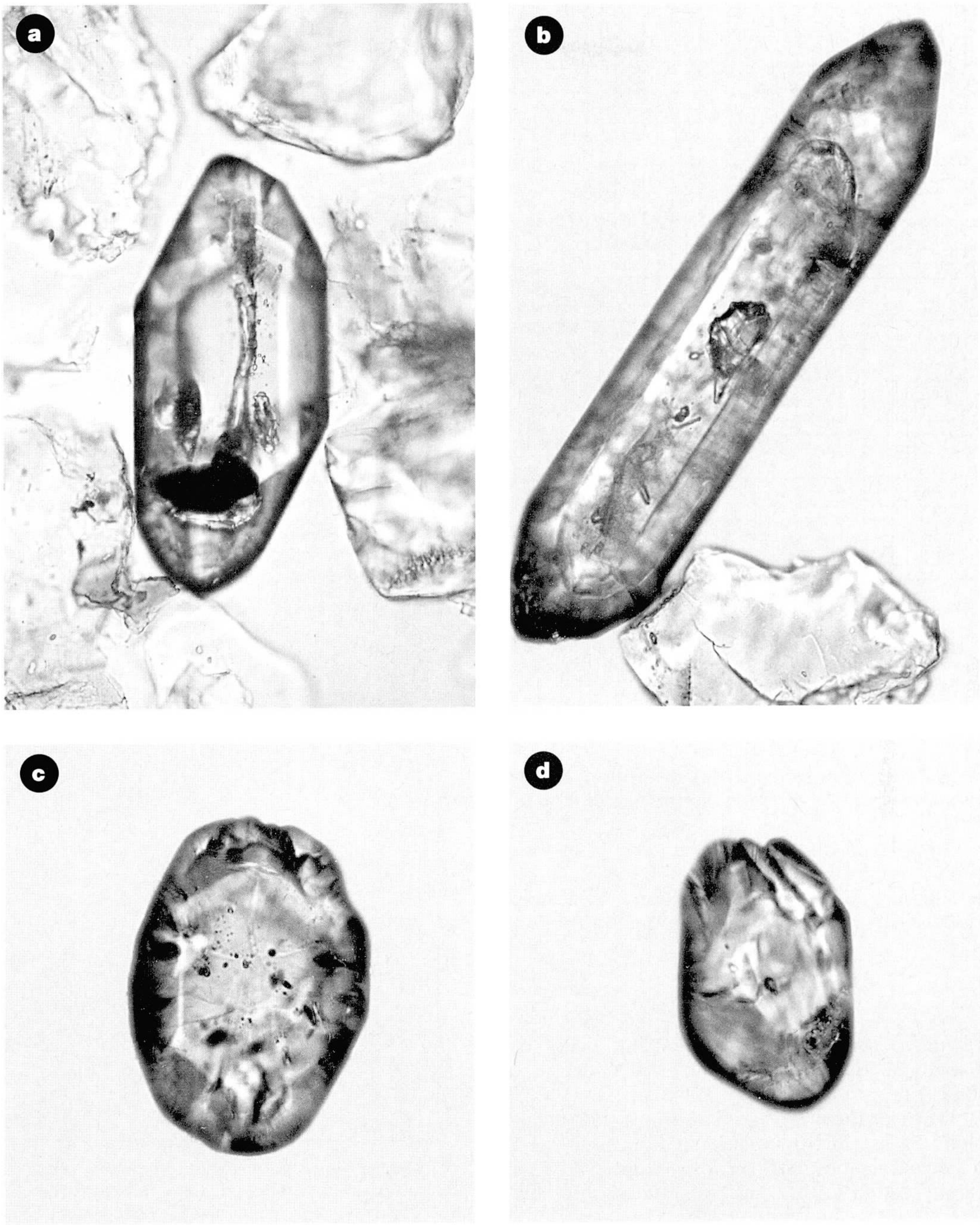

Fig. 4 Different types of *non-detrital zircons* in Cenerigneiss. a = euhedral magmatic crystal (EU_1) with channel-like cavity and opaque globular inclusions; S7, sample CH1. b = EU_2 crystal with well defined inherited core, typical of zircons from anatectic rocks; S7 on appr. S8; sample CEN. *Recrystallized zircons* (R): c, d = subidiomorphic crystals: slightly rounded edges and corners, some curved faces, small pyramidal faces of high index (c; S8, sample FA68); multiple terminations, few inclusions defining a large core (d; S7, sample FA41).

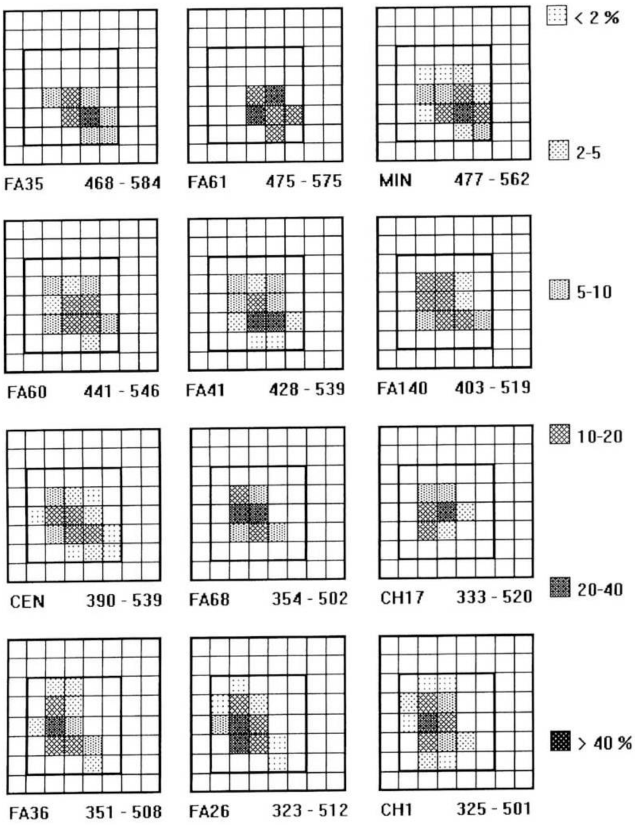

Fig. 5 Typologic distributions and $\bar{A}/\bar{T}$ coordinates of the A_1 zircon populations in Gneiss Minuti (first row) and Cenerigneiss.

probably results from partial resorption and/or overgrowth at high-grade metamorphic conditions.

In order to compare the characters of the different groups of zircon crystals, the typologic distributions and the mean points were separately calculated for each group in each sample.

GNEISS MINUTI

Abraded crystals (A) are less frequent in samples FA35 and FA61 than in sample MIN, but they always represent the most abundant type (Tab. 2). Most of them (A_1) contain the typical inclusions of magmatic zircons: apatite, high relief crystals, opaques; dark brown overgrowths and faintly zoned crystals are sometimes observed. The typologic distributions (Fig. 5) are very similar in the three samples, with high frequencies of subtypes S19–S18, followed by S24. The same subtypes may be recognized in figure 6 of KÖPPEL and GRÜNENFELDER (1971); they attribute the occurrence of relatively well formed crystal faces to recrystallization, whereas in my opinion these crystals belong to the A group of less worn detri-

Tab. 2 Frequency of the different types of zircon crystals; % calculated on the total typologically determined crystals, except sample FA35, where the frequencies are calculated on the total observed zircons. Groups as in table 1. GM = Gneiss Minuti; CG = Cenerigneiss; Kf-CG = K-feldspar-rich Cenerigneiss; A-CG = anatectic Cenerigneiss

Type	Sample	A_1	VA	A_2	EU_1	EU_2	R
GM	FA35	55	45	-	-	-	-
GM	FA61	67	33	-	-	-	-
GM	MIN	78	15	7	-	-	-
CG	FA36	76	14	-	5	5	-
CG	CEN	78	5	2	12	3	-
CG	FA26	62	12	4	11	11	-
Kf-CG	FA60	61	10	-	28	-	-
Kf-CG	CH 1	46	10	8	30	6	-
Kf-CG	CH17	46	6	-	35	13	-
A-CG	FA41	58	5	5	5	-	27
A-CG	FA140	56	-	-	9	-	35
A-CG	FA68	49	-	8	10	-	33

tal crystals. The regular distribution of frequencies and the similar inclusions suggest that each population is very homogeneous. The oblique

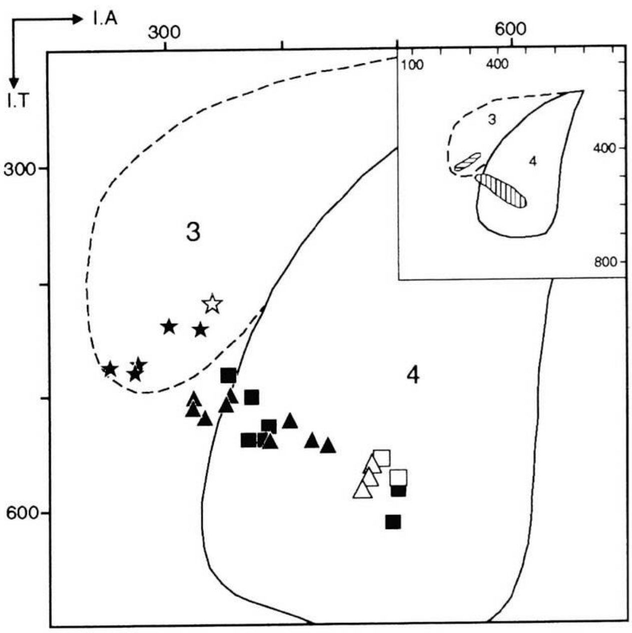

Fig. 6 Mean points $\bar{A}$ / $\bar{T}$ in the typologic evolution diagram for the detrital populations in Gneiss Minuti (open symbols) and Cenerigneiss (filled symbols). Squares = very abraded populations VA; triangles = abraded populations of magmatic origin A_1; stars = abraded populations of migmatitic origin A_2. Inset: localization of the studied samples in the classification diagram of PUPIN (1988); field 3: aluminous granodiorites and granites; 4 = calcalkaline series; hatched areas: vertical = VA and A_1 populations of magmatic origin; horizontal = A_2 populations of migmatitic origin.

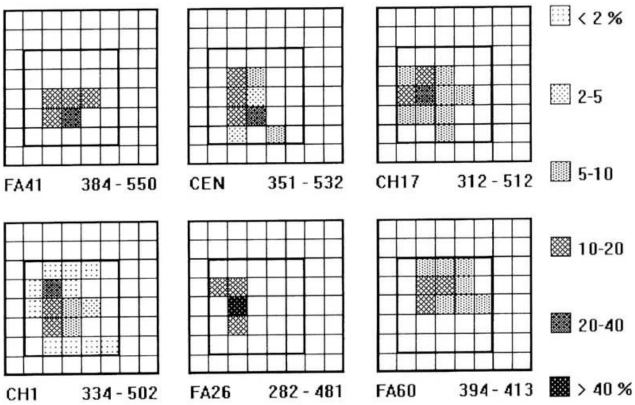

Fig. 7 Typologic distributions and $\bar{A}/\bar{T}$ coordinates of the euhedral zircon populations EU_1 in selected Cenerigneiss samples. The typologic distributions of the samples containing a small number of these crystals are not reported.

pattern of frequency distribution, the position of the mean points on the typologic evolution diagram (Fig. 6) and the occurrence of some crystals with supplementary bipyramidal faces ({311}, {511} and {321}) are typical of calcalkaline rocks of basic-to-intermediate composition (gabbrodi-

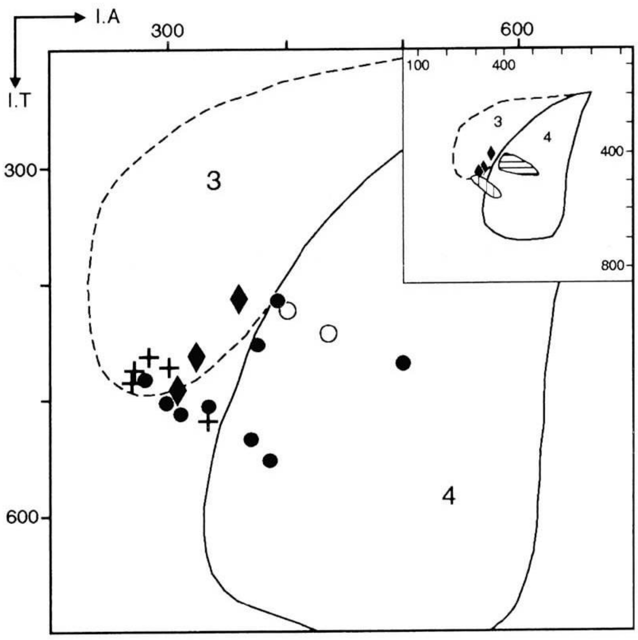

Fig. 8 Mean points $\bar{A}$ / $\bar{T}$ in the typologic evolution diagram for the EU and R populations in Cenerigneiss. Dots = EU_1 populations; crosses = EU_2 populations; diamonds = R populations (samples with limited partial melting); for comparison: circles = magmatic populations of two-mica orthogneisses from Serie dei Laghi (CAIRONI, 1994). Inset: localization of the studied samples in the classification diagram of PUPIN (1988); fields as in figure 6; hatched areas: horizontal = low $\bar{T}$ index EU_1 populations; vertical = EU_2 and high $\bar{T}$ index EU_1 populations; diamonds = R populations.

orites to diorites; PUPIN, 1976, 1980). Some detrital crystals showing large rounded cores surrounded by clear and translucent overgrowths, both very poor in inclusions (similar to the crystal in Fig. 3c), are only present in sample MIN (A_2: 7% of the population; Tab. 2).

Very abraded crystals (VA) are relatively frequent, particularly in FA61 and FA35 (up to 45%; Tab. 2). Most of them are too abraded to be typologically identified, and no determination was possible in sample FA35. The typologic distribution of the few determined crystals (not reported), the kind of inclusions and the mean points (Fig. 6) correspond very well to those of the A_1 populations. This suggests that they may have the same origin, despite the different degree of abrasion.

CENERIGNEISS

Abraded crystals (A) prevail in all samples (54–80%; Tab. 2). For most crystals (A_1) a primary magmatic origin is deduced from the typical inclusions (short-prismatic to acicular apatite, opaques, "negative crystals"; PUPIN, 1976); dark brown overgrowths and internal zoning are sometimes observed. All typologic distributions (Fig. 5) are very homogeneous; a comparison among the different samples shows a similar oblique pattern, with small differences in the frequency of each subtype, resulting in a progressive shift of the highest frequencies from subtypes S18, S17 to S12 and S7. This is also reflected by the mean points of the populations, which plot along a trend with decreasing $\bar{A}$ index at decreasing $\bar{T}$ index (Fig. 6); this is the typical evolution trend of calcalkaline "tonalitic" series (PUPIN, 1976, 1980). The characteristics of the populations are compatible with a provenance from diorites to tonalites (PUPIN, 1976). The occurrence of some crystals with the supplementary bipyramids {321} and {311} is also a typical character of zircons from dioritic rocks (PUPIN, 1976). It is interesting to observe that the mean points of the abraded populations A_1 from the Gneiss Minuti plot at the base of the trend of the Cenerigneisses, suggesting that some relation exists between the two rock types. Whether the differences in the zircon populations really correspond to different source rocks, or result from sedimentary processes, will be discussed later.

In some samples there are few detrital crystals (A_2; Tab. 2) similar to typical zircons from high grade metamorphic rocks (PUPIN, 1976; CAIRONI, 1986): they show a clear and colourless overgrowth, devoid of inclusions, developed on a large corroded core (Fig. 3c); the latter is sometimes evidenced by abundant bubble-like or dust-like inclusions (Tab. 1). Such crystals generally show well developed {211} and {110} forms. The mean points calculated for these crystals plot in a small area (Fig. 6), which is very typical for anatectic migmatites (PUPIN, 1976). Their possible origin will be discussed later.

Very abraded crystals (VA) are less frequent than in the Gneiss Minuti (Tab. 2), and a larger number of them can be typologically determined. The typologic distributions (not reported) and main characters are again compatible with a derivation from dioritic or tonalitic rocks; the mean points plot more or less along the trend defined by the abraded populations A_1 of both Cenerigneiss and Gneiss Minuti (Fig. 6). This suggests that the difference in the degree of sedimentary reworking does not reflect different source rocks, but a different transport process.

The alternative hypothesis that the typologically determined VA crystals in both the Gneiss Minuti and the Cenerigneiss may be recycled crystals (i.e., they derive from the erosion of a sedimentary rock) is less likely, unless we admit that source rocks of different ages may have very similar zircon populations. A recycled origin cannot be excluded for those crystals which are too abraded to be typologically determined, since their source rock cannot be recognized.

Euhedral crystals (EU): they are frequent (28–48% of the total population) in the Cenerigneisses with K-feldspar porphyroclasts, but they also occur (up to 22%) in the other samples (Tab. 2), where the original presence of K-feldspar is indicated by thin recrystallized myrmekites. Their average grain size is slightly coarser than that of the detrital populations. Most of these zircons (EU_1) show typical magmatic characters (Tab. 1). The more feldspatic samples show larger typologic variations (Fig. 7) than the less feldspathic ones, but some common characters are observed, such as the abundance of subtypes S17–S12–S7. These typologic distributions are not very different from those of the detrital populations of some Cenerigneiss samples (Fig. 5), but the much less worn aspect of the crystals (Fig. 3d; Figs 4 a, b) suggests that a detrital origin can be excluded. According to the slightly smoothed edges and corners, these crystals resemble those of metagranitoid rocks (PUPIN, 1976), suggesting that they underwent a low-to-medium grade metamorphism.

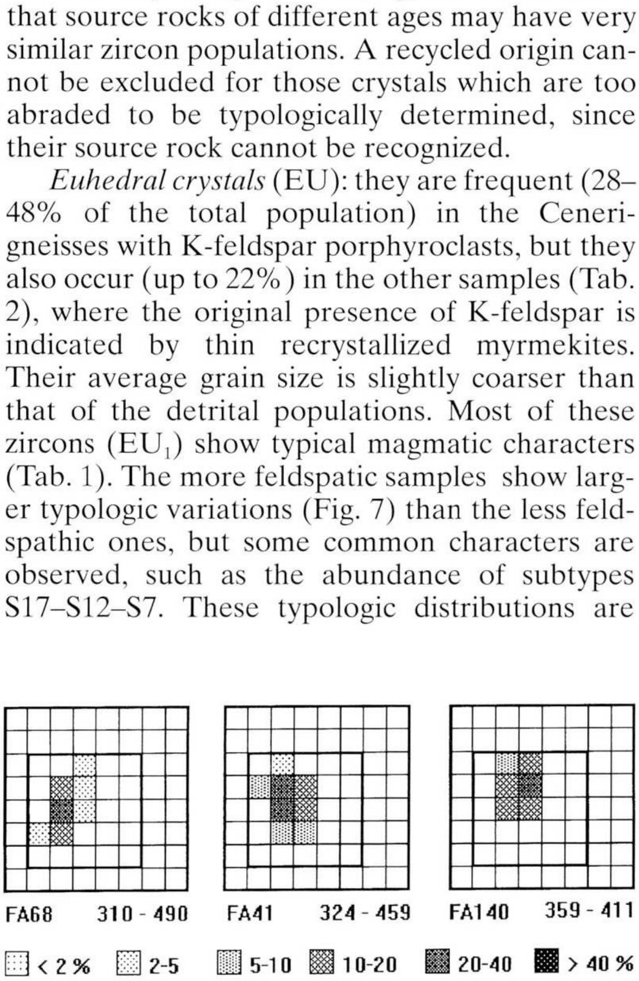

Fig. 9 Typologic distributions and $\overline{A}/\overline{T}$ coordinates of the recrystallized (R) populations in Cenerigneiss samples with limited partial melting.

The main characters of the euhedral populations EU_1 and the positions of their mean points on the typologic diagram (Fig. 8) are compatible with granodioritic (samples with higher $\overline{T}$ index) or granitic compositions (lower $\overline{T}$ index).

The EU_1 crystals may be accompanied by other idiomorphic, non-detrital crystals with well developed {110} and {211} forms; they show corroded cores, thin colourless overgrowths and other characters recalling those of high-grade metamorphic zircons (EU_2; Tab. 1, 2). Their mean points (Fig. 8) plot in the area of anatectic migmatites (PUPIN, 1976). I think that these crystals do not correspond to the R crystals described below, since they are slightly different and since the samples do not show traces of anatexis. In my opinion, their origin is also connected to the process which produced the EU_1 crystals and will be discussed in the same paragraph.

Recrystallized crystals (R): these crystals are only observed in the Cenerigneiss samples affected by limited partial melting (Tab. 2). Their characters (Tab. 1; Figs 4 c, d) are typical of high-grade metamorphic zircons (PUPIN, 1976; CAIRONI, 1986; PUPIN, 1994, in press): they are clear and colourless, and contain few inclusions (small "bubbles", unidentified irregular grains, "dusty" aggregates; very rare acicular apatite), which sometimes define a large corroded core, surrounded by newly-grown clear zircon. A dissymmetric development of the pyramidal faces is often observed, as well as the presence of two or more pyramids on the same termination of the crystals (Fig. 4d). Beside these characters, which are common to all recrystallized zircons, they show some other peculiar features: the pyramidal faces are sometimes curved or badly-defined, and the pyramidal terminations may be made up of many small faces with high indices (Fig. 4c); their length / width ratio is low. The same features are observed by HOPPE (1962), PUPIN (1976) and DUCHESNE et al. (1987) in zircons from granulites and charnockites, and attributed to recrystallization under unfavourable conditions (high total pressure, dry environment).

The typologic distributions (Fig. 9) of the R populations show small variability along the A axis, suggesting relatively constant chemical environment during zircon recrystallization; the distribution along the T axis ranges between values of 300 and 600, which are frequently observed in recrystallized populations from anatectic migmatites (PUPIN, 1976). On the typologic evolution diagram the mean points (Fig. 8) define a linear array in the typical area of anatectic migmatites (PUPIN, 1976).

Discussion

Detrital populations with different degrees of abrasion (A and VA) occur in both the Gneiss Minuti and the Cenerigneiss. Nothing can be said about the origin of those VA crystals, whose typology could not be determined; they could represent recycled zircons. The typologically determined crystals (most A_1 and some VA) show very homogeneous characters within each sample, in contrast to most sediment-derived rocks, which usually contain zircons of different origins (PUPIN, 1976; ALINAT et al., 1979, and the author's experience). These characters are compatible with calc-alkaline intrusive source rocks.

The different typologic distributions may reflect source rocks with a different degree of evolution (gabbrodiorites to diorites for the Gneiss Minuti; diorites to tonalites for the Cenerigneiss), or may result from some sedimentary process that concentrated the "less evolved" subtypes in the Gneiss Minuti protolith and the "more evolved" subtypes in the Cenerigneiss protolith. Since the grain size of the two rocks is different, and since a slightly higher proportion of small crystals is contained in the Gneiss Minuti, we can take into consideration a grain-size selection during transport and deposition.

Starting from distinct source rocks, such a process could result in a typologic selection only if all the crystals belonging to a given subtype had comparable dimensions. This is highly unlikely, since it is commonly observed that crystals of the same subtypes coming from different plutonic rocks may show very different size, as well as, vice versa, the same absolute size may be shown by crystals of different typologies, mostly related to the grain-size of the rock. As a consequence, a grain-size selection would probably lead to more heterogeneous typologic distributions. For example, in a recently studied quartzarenite sample (CAIRONI, 1994b), the size-fraction 0.062–0.150 mm contains zircons derived from high-grade metamorphic rocks, peraluminous granites and high-K calcalkaline granites, each group showing a comparable range of grain size.

Starting from a unique magmatic source rock, containing all the observed subtypes, a grain-size selection could have concentrated the less evolved subtypes in the finer-grained sediments (Gneiss Minuti), if they originally had smaller dimensions than the more evolved ones. However, in plutonic rocks with wide typologic distributions it is more commonly observed that the early crystals of the population are coarser than the late stage ones (PUPIN, 1976 and my own experience). Moreover, crystals belonging to the same less evolved subtype (for example S24 or S19) are on the average coarser in the Cenerigneiss than in the Gneiss Minuti, suggesting that they belong to different primary populations.

Therefore, in my opinion, sedimentary processes concentrated large zircons from coarse-grained diorites-tonalites in the coarser sediments (Cenerigneiss) and small zircons from fine-grained gabbrodiorites-diorites in the finer sediments (Gneiss Minuti). The higher degree of abrasion and the higher proportion of very abraded crystals in the Gneiss Minuti with respect to the Cenerigneiss, together with the different grain size of the two rocks, may suggest that the former represent more distal sediments. Alternatively, if we accept the hypothesis that the two rock types represent different levels of a turbiditic sequence (BORIANI et al., 1990), the grain-size selection could occur during resedimentation: starting from a continental shelf deposit, containing zircons from different members of a calcalkaline intrusive sequence, the mass flow deposit towards the base of the turbidite (now Cenerigneiss) concentrated the coarser zircons, derived from the more evolved rocks, whereas the well sorted deposit from a turbidity current at the top of the sequence (now Gneiss Minuti) concentrated the finer zircons, derived from the less evolved rocks.

We must also discuss the possibility that the observed populations do not correspond to the original ones, due to the selective destruction of metamict zircons during sedimentary processes. This could lead to the disappearance of specific morphologies, namely "late stage" subtypes, which are usually enriched in radioactive elements, so that the detrital populations are apparently less evolved than the original ones. However, a single sedimentary cycle is not enough to obtain considerably abraded crystals, and zircons with metamict overgrowths and wholly metamict crystals in sediments are reported by several authors (for example, POLDERVAART, 1955; PUPIN, 1976; FARGES, 1994). I have also observed such crystals in quarzarenites from Himalaya (CAIRONI, 1994b). In the studied paragneiss populations, some crystals with dark brown overgrowths occur, which exhibit low birefringence, or are nearly isotropic. Since the degree of mechanical abrasion of the studied crystals is low, it seems likely that the absence or scarcity of metamict zircons is a primary feature of the source rocks and is not due to their preferential destruction.

It seems therefore that the source rocks of the zircon populations of Gneiss Minuti and Cenerigneiss were mainly gabbrodiorites to diorites and diorites to tonalites, respectively. This seems also supported by the occurrence of lithic clasts of dioritic igneous rocks in the conglomeratic levels of Cenerigneisses.

The occurrence of some detrital crystals showing the typical characters of high-grade metamorphic zircons may indicate the presence of anatectic migmatites in the eroded area. Alternatively, these crystals could represent inherited zircons already present in the eroded magmatic source rock. The coexistence of high-grade recrystallized and magmatic zircons is sometimes observed in the populations from plutonic rocks (PUPIN, 1976; CAIRONI, 1994a).

Euhedral crystals with magmatic characters occur in the Cenerigneisses, and particularly in those with K-feldspar porphyroclasts. They show well defined crystalline forms and no trace of sedimentary abrasion. In my opinion, they are not detrital crystals of the same source rock that were protected from abrasion during transport by having been included within lithic clasts, for the following reasons: a) the typologic characters of the euhedral crystals indicate slightly more acidic compositions than those of the detrital crystals; it is unlikely that only the late stage crystals of the magmatic source rock were preserved from abrasion during transport; b) the studied samples do not contain lithic clasts, but show a homogeneous grain size; furthermore, lithic clasts of granitic composition were never observed in the Cenerigneiss. On the other hand, the slightly smoothed edges and corners indicate that after magmatic crystallization these crystals suffered a low-to-medium grade metamorphic event; indeed, they are very similar to zircons from metagranitoid rocks. It seems therefore likely that they crystallized in the sediments before the main metamorphism.

An interesting point is that the EU_1 zircons are very similar to the populations of some two-mica orthogneisses of Serie dei Laghi (CAIRONI, 1986, 1994a); this is particularly evident for samples FA60, FA140 and FA68, whose mean points plot near or among the mean points of these orthogneisses (Fig. 8). In the other samples, however, the crystals show some features which are commonly observed in volcanic and subvolcanic rocks, e.g., aggregates of 2–3 crystals, "lacks" of growth (i.e., slightly skeletal growth), absence of overgrowths, irregular-shaped or channel-like cavities (Fig. 4a). Therefore, their higher $\bar{T}$ indices might be related to more rapid nucleation and crystallization of zircon, which hindered a further evolution of the population, and not to less acidic compositions; we may suppose that these populations also crystallized in a magma with granitic composition, as those with lower $\bar{T}$ indices.

The chemical composition of the Cenerigneisses offers an argument for the interpretation of the origin of the EU_1 zircon populations: recent studies (GALBIATI, 1993) show that Cenerigneisses have the typical compositions of turbiditic arenaceous sediments for most elements, whereas their contents in Na, K and Ca place them in the field of granitic rocks. Furthermore, the more feldspathic Cenerigneisses differ from the less feldspathic ones for their enrichment in silica, alkalies, aluminium and incompatible elements. These observations suggest that the Cenerigneisses probably consist of two components: a sedimentary one, mainly derived from the erosion of mafic-to-intermediate intrusives, and a granitic one, which was probably added to the sediments before the main metamorphic event. The typologic characters of the EU_1 zircons point to a similarity between this magmatic component and some Ordovician granites, now represented by two-mica orthogneisses. The occurrence of both EU_1- and EU_2-type crystals is also observed in these orthogneisses, where it is interpreted as an indication of assimilation processes (CAIRONI, 1994a). Alternatively, a limited partial melting of the sediments triggered by the intrusions could account for the origin of the small amount of EU_2 crystals, showing the typical "core + overgrowth" morphology of anatectic zircons.

The occurrence of euhedral crystals together with detrital ones in the Cenerigneiss was already reported by KÖPPEL and GRÜNENFELDER (1971), who referred them to recrystallization processes. However, the euhedral crystals shown in figure 7 of their paper correspond very well to the above-described EU_1 crystals and do not show the typical characters of high-grade recrystallized or anatectic crystals. The sample of KÖPPEL and GRÜNENFELDER comes from the same locality (Ponte Casletto) as sample CH17 and the sample reported by RAGETTLI et al. (1992), on which a concordant zircon age of about 458 Ma was obtained on two coarse-sized fractions. If the crystals analyzed by RAGETTLI et al. (1992) correspond to the EU_1 crystals of the present study, it is possible that this age represents that of their magmatic crystallization.

This data seem to support the hypothesis of a pervasive granitization of non-metamorphic arenaceous sediments, probably during the Ordovician magmatic activity, as proposed by BORIANI et al. (1990), even if it is not clear how this process occurred. Recent studies (BORIANI et al., work in progress) suggest that this process was also responsable for the formation of the so-called "feldspathized amphibolites" of BORIANI and GIOBBI MANCINI (1972). It is interesting to observe that the Gneiss Minuti, which after BORIANI et al. (1990) is not pervasively granitized (it was only injected by aplitic veins), does not contain euhedral zircon populations.

Recrystallized zircons are only observed in the Cenerigneiss from the Vira-Magadino area affected by very limited partial melting, once more confirming the close relationship between morphological recrystallization (as explained before) and high-grade metamorphism. They represent 27–35% of the total determined crystals (Tab. 2). Their occurrence together with non-recrystallized zircons in the same samples suggests that recrystallization did not affect the whole original population at the same time. Several hypothesis may explain this behaviour: a) local differences in the availability of fluids may play a role in the recrystallization process; b) zircons included in refractory minerals are more protected than those included in reactive minerals; c) the temperature required to induce recrystallization depends on the crystallization temperature of the original crystal.

Conclusion

The typologic study of zircon populations has shown, in both the Gneiss Minuti and the Cenerigneiss, the occurrence of abraded crystals, which are the product of sedimentary processes of erosion, transport and deposition. For all samples, the main source rocks inferred from the zircon characteristics are calcalkaline intrusives of mafic-intermediate composition. Several considerations suggest that the typologic differences observed between the Gneiss Minuti and the Cenerigneiss reflect different compositions of their source rocks: gabbrodiorites to diorites for the Gneiss Minuti, diorites to tonalites for the Cenerigneiss. Very abraded crystals of unknown origin possibly represent recycled crystals from the country rocks of the intrusives.

These results indicate the existence, in the source area of the siliciclastic sediments, of a crystalline basement of probable Proterozoic age (upper intercept ages between 900 and 2500 Ma, U–Pb on zircons, PIDGEON et al., 1970; KÖPPEL and GRÜNENFELDER, 1971), where calcalkaline intrusive rocks were dominant. The sedimentary characters of Gneiss Minuti and Cenerigneiss are compatible with sedimentation along an active continental margin (continental shelf deposits or turbidites).

The occurrence of euhedral zircons of magmatic origin, together with detrital crystals, in the Cenerigneisses seems to confirm their composite nature. The striking similarity between such euhedral crystals and those observed in two-mica orthogneisses of the same area (CAIRONI, 1994a) seems to support the hypothesis of a pervasive granitization of non-metamorphic or anchimetamorphic sediments during the Ordovician magmatic cycle (BORIANI et al., 1990). At the present state of knowledge, we favour this working hypothesis, which is also supported by petrological and field data.

The coexistence of recrystallized and not recrystallized zircons in the Cenerigneiss affected by incipient partial melting indicates a variable sensitivity of different zircon crystals to recrystallization processes.

The results of the typologic study of zircon populations in the metasediments of the Strona-Ceneri Zone allowed to obtain interesting information on the nature of their main source rocks and on the processes which affected the sediments before the main Hercynian metamorphism (granitization) or after this (anatexis). These data also give indications on the possible geodynamic environment where these rocks formed and evolved. Further research concerning the base of the sedimentary sequence (Strona-Ceneri Border Zone) will contribute to a better knowledge of the genesis and evolution of this segment of the Western Southalpine basement.

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