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SINGLE ZIRCON GEOCHRONOLOGY OF ORTHOGNEISSES FROM PAROS, GREECE

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ABSTRACT

This study is concentrated on the geochronology of basal formations on the island of Paros that belong to the Attic-Cycladic massif. The investigated rocks are augengneisses that were derived from granitoid protoliths. We dated six gneisses using the Pb/Pb single zircon evaporation method. Besides some rare inherited grains of Proterozoic age, the prevailing ages of the gneisses are between 325 Ma and 302 Ma. The average obtained is at 317±2 Ma. Scanning electron microscope and cathodoluminescence investigations of these zircons demonstrate their magmatic origin and therefore underline the interpretation of this age as the igneous intrusion age of the precursors of the augengneisses. These results indicate that large parts of the pre-alpine basement formed in a magmatic episode during the upper Carboniferous.

KEY WORDS: Paros, Greece, Attic-Cycladic massif, basement, zircon geochronology

1. INTRODUCTION

This geochronological study is focussed on the pre-alpine crystalline basement of the island of Paros that is situated in the centre of the Attic-Cycladic massif (Fig. 1). This crystalline belt extends from SE Greece (Euboea/Attica) and the Cyclades islands to SW Turkey (Dürr 1975, 1986). Geochronological investigations on this belt are rare and so there is little information on the pre-alpine geological evolution of the area. For the neighbouring island of Ios, Lower Ordovician intrusion ages of about 500 Ma were published for augengneiss precursors, obtained by a Rb/Sr whole-rock isochron (Henjes-Kunst & Kreuzer 1982). U/Pb data for zircons from Ios of about 300 Ma to 305 Ma were interpreted as the age of the amphibolite facies metamorphism (Henjes-Kunst & Kreuzer 1982). However, the Rb/Sr age is difficult to evaluate because of the sensitivity of the Rb/Sr system to secondary alteration and because of the unknown scale and conditions of isotopic equilibrium during the postulated Carboniferous metamor-

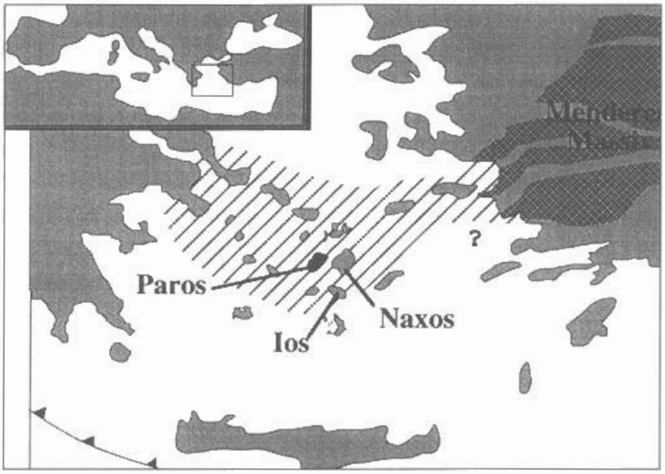

Fig. 1: Location of the island of Paros within the Attic-Cycyladic massif (hatched)

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phism or during a possible alpine overprint. Contrary to the Rb/Sr system, the U/Pb or Pb/Pb isotopic systems of zircons in general survive such a low to medium grade metamorphic overprint, protected by the robust lattice of the hosting zircon crystal. The basement rocks of neighbouring islands of Paros and Naxos are similar to those of Ios and therefore might be contemperanous. Andriessen et al. (1987) demonstrated Palaeozoic intrusion ages of about 375 Ma on core gneisses from Naxos, obtained by U/Pb measurements on zircons. Recent investigations on orthogneisses from Naxos yielded intrusion ages of 233 Ma, 275 Ma and 316 Ma (Reischmann, this volume). According to this data base, simple correlations of the various gneiss units of the Cyclades are not possible. At least, the data indicate a Palaezoic to Early Mesozoic origin of the basement gneisses. It is left to be proven that such an origin is also valid for the basement gneisses of Paros. We therefore dated augengneisses from Paros in order to constrain their age and their relationship to the basement of the neighbouring islands. For this purpose we used the single grain Pb/Pb evaporation method (Kober 1987) with zircon because this mineral is resistent against secondary alteration caused by weathering or metamorphism.

2. GEOLOGICAL BACKGROUND

The nappe structure of the Hellenides and the Attic-Cycladic massif had been demonstrated by many geologists (e.g. Dürr 1986, Jacobshagen 1986 and references therein). The basal units are built up by metamorphic rocks such as granitoid gneisses, various crystalline schists and amphibolites. This rock assemblage is tectonically overlain by a cover series. After Dürr (1986), this contains a sequence of marbles, metabauxites, schists, quartzites, and metavolcanics. These rock units are isoclinally folded and extremly strained in places. On some islands of the Attic-Cycladic massif such as Mykonos, Paros and Naxos, remnants of non-metamorphic upper units are preserved which contain ophiolites, shallow-water carbonates and younger sediments (Dürr, 1986). Apart from these uppermost nappes the two main units are affected by intense alpine metamorphism, a high-pressure/medium-temperature phase of the glaucophane schist facies during the Eocene and a Barrovian-type phase of greenschist facies during the Miocene. (e.g. Andriessen et al. 1979, Wijbrans & McDougall 1986).

The **geology of Paros** (Fig. 2), which is situated in the centre of the Cyclades, is characterized by nappes that are separated by two major thrusts (Papanikolaou 1980). The main part of the island is formed by the basal metamorphic unit which Papanikolaou (1980) named "Marathi unit". It consists of orthogneisses with various degrees of deformation, which are overlain by an assemblage of isoclinally folded gneisses, schists and marble layers. In some places the marbles contain meta-bauxite (emery), which were mined in past. This lower unit was subjected to metamorphism of amphibolite facies conditions (Barrovian-type). In small areas in the SE, SW and W part of the island remnants of the structurally higher nappe called "Dryos unit" are exposed. The rocks of this nappe are characterized by low grade metamorphism. They consist of phyllites, metadiabases and dark, finegrained limestones of Permian age (Dürr, 1986). The "Marmara unit" that is exposed in the W and in the E, SE, and NE of the island is the uppermost nappe of Paros. This comprises ophiolites, and marine sediments of Cretaceous to Tertiary age that were not affected by the metamorphism seen in the lower nappes. The metamorphics of Paros were synkinematically intruded by small bodies of Miocene S-type granites which might correspond to contemporaneous granitoids of Naxos (Altherr et al. 1982). More details on the geology of the island are given in Papanikolaou (1980) and Robert (1982).

In this study we analyzed gneisses of the Marathi unit, which are the most frequent rock type of this lowermost rock assemblage. With regard to the mineral contents, there are only small differences between the gneisses despite the variations in grain size and deformation. All samples are augengneisses, typically consisting of minerals such as quartz, feldspar, muscovite and biotite. Muscovite is always more frequent than biotite, which can be taken as an argument for their S-type character of the rocks.

According to their geochemical composition (unpublished data), the gneisses of the Marathi unit are classified as granodiorite, quartzdiorite, and granite. Their A/CNK ratio is slightly >1.1, which is in agreement with their S-type character. Further geochemical features indicate a continental collision or active continental margin environment as tectonic setting.

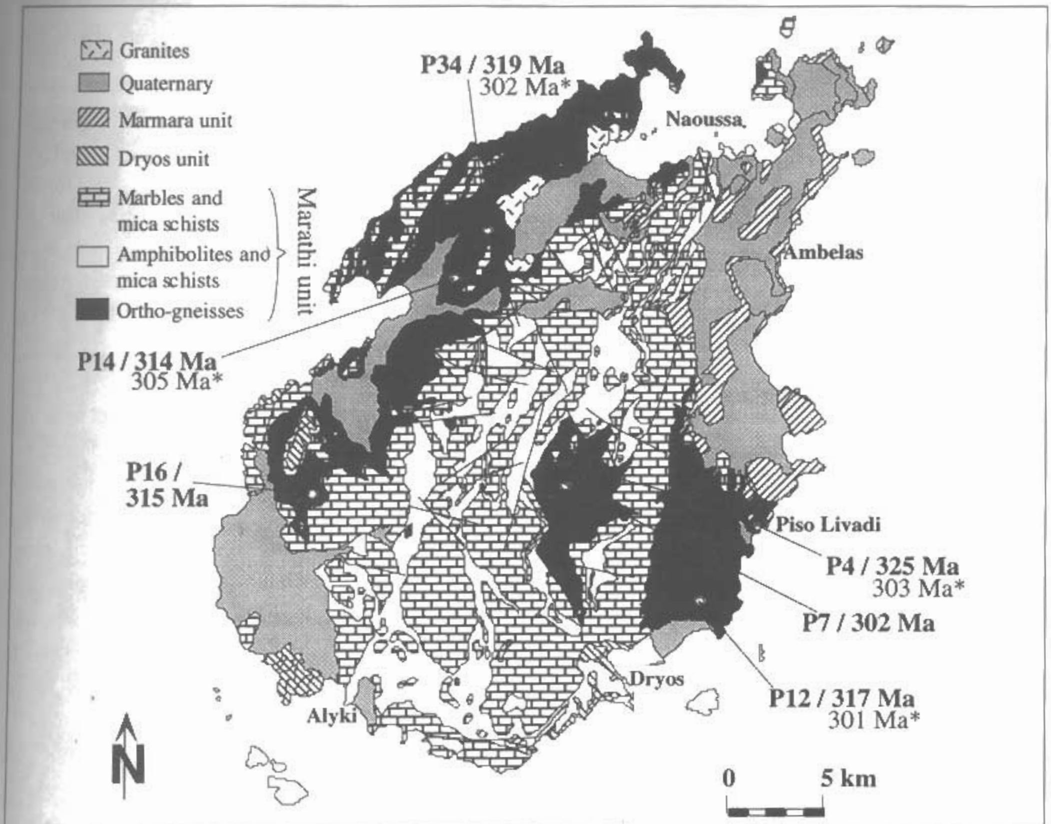

Fig. 2: Simplified geological map of Paros with sample locations (modified after Papanikolaou 1977)

3. ANALYTICAL METHODS

The method for age determination used in this study is the Pb/Pb single-zircon evaporation method that was developed by Kober (1987). The zircon populations of the analyzed gneisses were investigated by scanning electron microscope (SEM) and cathodoluminescence (CL). Images of typical zircon grains are shown in Figs. 3. and 4. Isotope analyses were performed at the Max-Planck-Institut für Chemie in Mainz using a Finnigan MAT 261 mass-spectrometer. Further details of the analytical procedures are given in Reischmann (this volume). Uncertainties of the isotope ratios and the mean ages of the samples are quoted as 2-sigma mean. The analytical data are listed in Table 1 and presented in histograms (Fig. 5).

4. Geochronological results

Augengneiss P4 was sampled in an outcrop at the coast in the SE part of the island near Piso Livadi. It is a fine-grained, leucocratic gneiss that was affected by a high degree of deformation. The feldpar augen reach a grain size of up to 1 cm. It is a typical granitic gneiss and the content of muscovite is significantly higher than that of biotite.

Zircons of this gneiss are either reddish, or colourless and mainly clear. The majority of the zircon grains is smaller than 0.1 mm. The prevailing population is long-prismatic and characterized by prism planes, where (100)<<(110) (Fig. 3). In the pyramides only (101) planes are developed, the (211) could hardly be identified. After Pupin & Turco (1972) the most frequent types belong to the P1 and P2 zircon type, which indicates crystallization temperatures of about 650 to 700°C.

In CL photographs (Fig. 4) such grains display a typical magmatic zonation and leave no doubt that these zircons formed from a magma. Inherited cores are rare in this population. The ages of zircons from this sample can be divided into two groups. The mean of the dominant ages is 325±4 Ma which is interpreted as the age of zircon growth and thus as intrusion age of the granite. Two grains are around 303 Ma, possibly indicating lead loss at that time or a second magmatic event.

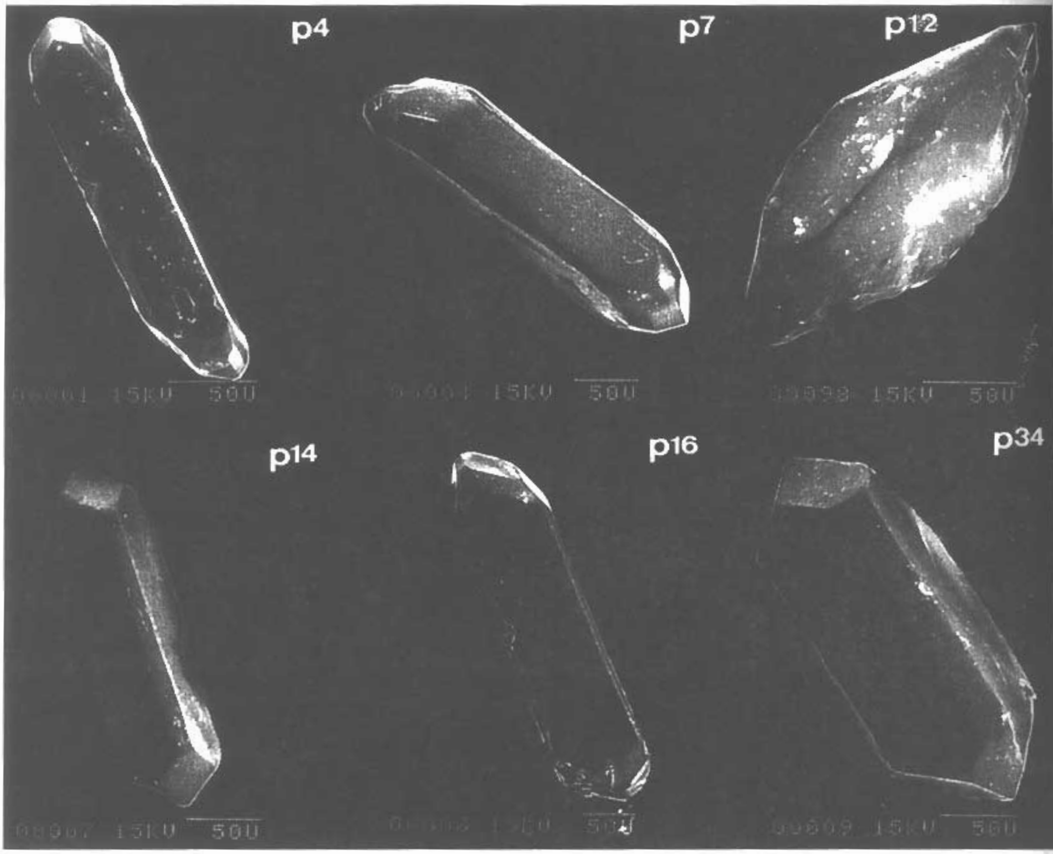

Fig. 3: SEM images of typical zircons of the basement gneisses of Paros.

The gneiss sample P7 was taken from the centre of a gneiss body SE of Lefkes. The rocks are variably deformed and penetrated by shear zones that are characterized by the dominance of biotite. Apart from such shear zones deformation is weak, and thus the primary granitic structure is preserved. The main mineral assemblage of quartz, feldspar, biotite and small amounts of muscovite has grain sizes of about 2 mm. Feldspar augen are rare and small in size.

Most zircons of this rock are long-prismatic, colourless, and have a typical igneous habitus, as is visible on SEM photographs (Fig. 3). CL images display a clear internal zonation which is typical for magmatic growth (Fig. 4). The (100) planes are smaller than (110) and the pyramides are formed by (101) and (211). The main population belongs to S3 (Pupin & Turco 1975). The ages of the zircons vary from 300 Ma to 312 Ma, with a clear maximum at 302±2 Ma. Since all zircon grains yielded similar results, we interpret this age as the intrusion age of the granitic precursor.

Augengneiss P12 was sampled from the southern part of the gneiss occurrance in the SE of the island, a few km SW of the sample P4. The rock is fine grained and shows a distinct foliation. The grain size is <1 mm except for the feldspar augen, which reach up to 2 mm. The predominant mineral assemblage is feldspar, quartz, and mica where muscovite is more frequent than biotite.

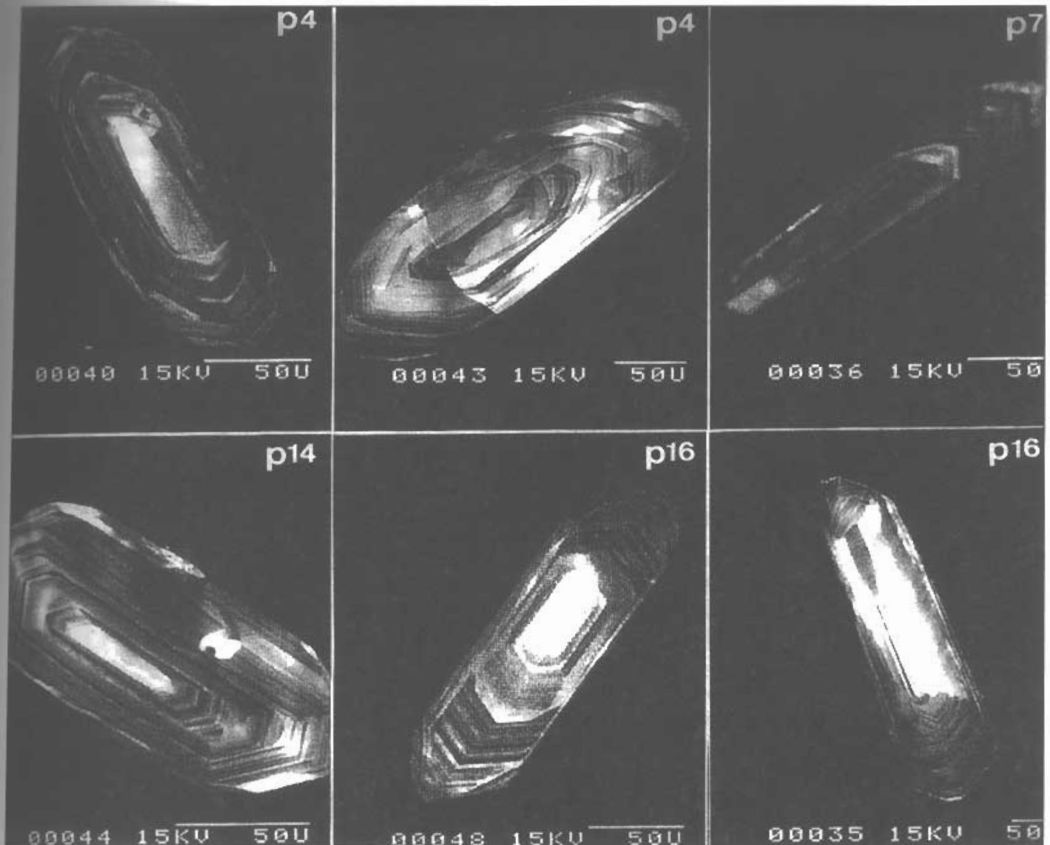

Fig. 4: Cathodoluminescence images of typical zircons of the basement gneisses of Paros

Zircons of this sample are similar to that of P4. The majority is long-prismatic, clear and reddish or colourless. The prisms are distinguished by (100) < (110), and pyramide terminations are characterized by the (101). This zircon population belongs to the P1-type of Pupin & Turco (1975). The zircon morphology and the internal structure (Fig. 3 and 4) infer that they are of igneous origin. Some grains show inherited older cores.

The inherited grains can also be recognized by the isotope analyses that yielded ages between 301 Ma and 925 Ma. The dominant age is 317±1 Ma which we interpret as the igneous formation age. The early Palaeozoic and even Proterozoic ages are difficult to evaluate. Since the Pb/Pb ages are minimum ages, they at least prove the existence of Proterozoic crustal material.

Augengneiss P14 was sampled in the NW gneiss area 3 km NE of Paroikia. It is a fine to medium-grained gneiss with feldspar augen that reach 2 cm in size. The mineral assemblage is similar to the other samples and consists of quartz, K-feldspar, plagioclase, muscovite and little biotite. The gneisses show a distinct foliation.

The predominant zircon fraction of this sample is long-prismatic, colourless or reddish and belongs to S2 and S3 type of Pupin & Turco (1975). The crystals are characterized by the dominance of the (110) versus (100). The prism planes (101) and (211) are of equal size. Similar to the other samples, the morphologies of the zircons strongly favour an igneous origin.

The age scatter considerably and it is difficult to determine the true age. However, most of the zircons analysed yield similar ages and we take the mean of 314±3 Ma as the age of intrusion of the granite. The older ages are tentatively taken as ages of inherited grains. Some grains also indicate an age close to ca. 300 Ma.

Table I

Sample	grain	207Pb/206Pb	ratios	age		2 sm	mean (Ma)	2 sm (Ma)	n
P4	1	0.0524743	74	306	*	7			
	2	0.0529921	55	**329**		11			
	3	0.0528058	88	**321**		2			
	4	0.0528532	78	**323**		4			
	5	0.0523375	121	300	*	2	303 *	6	2
	6	0.0529575	139	**327**		3	**325**	**4**	**4**
P7	1	0.0524426	49	**305**		5			
	2	0.0523561	76	**301**		8			
	3	0.0525221	71	308		3			
	4	0.0526099	81	312		2			
	5	0.0523982	163	**303**		1			
	6	0.0523286	102	**300**		2	**302**	**2**	**4**
P12	1	0.0529151	200	325		3			
	2	0.0623126	140	684		7			
	3	0.0527561	159	**318**		3			
	4	0.0527055	198	**316**		4			
	5	0.0523624	57	301	*	10			
	6	0.052739	246	**318**		2			
	7	0.0561589	140	458		4	301 *	10	1
	8	0.0698802	34	925		8	**317**	**1**	**3**
P14	1	0.052369	84	302	*	4			
	2	0.1429129	92	2263		4			
	3	0.0524977	85	307	*	5			
	4	0.0570747	113	494		5			
	5	0.0525533	63	**310**		3			
	6	0.0525825	89	**311**		2			
	7	0.0660786	55	809		1			
	8	0.0527639	236	**319**		1			
	9	0.052454	100	305	*	5			
	10	0.0525966	90	**311**		2			
	11	0.0531878	121	337		3			
	12	0.0526886	93	**315**		5	305 *	3	3
	13	0.052741	111	**318**		2	**314**	**3**	**6**
P16	1	0.0526912	90	**316**		3			
	2	0.0527002	143	**316**		4			
	3	0.0526133	155	**312**		4			
	4	0.0527301	148	**317**		3			
	5	0.0547085	379	400		2			
	6	0.0527041	58	**316**		9			
	7	0.052599	310	**312**		1			
	8	0.0527225	71	**317**		7	**315**	**2**	7
P34	1	0.0527509	91	**318**		9			
	2	0.0523086	133	299	*	6			
	3	0.0770694	95	1123		3			
	4	0.0527936	29	**320**		6			
	5	0.0527024	120	**316**		3			
	6	0.0528823	138	**324**		5			
	7	0.0524601	108	306	*	6			
	8	0.0523606	129	301	*	5			
	9	0.0528519	146	**322**		3			
	10	0.0527192	54	**317**		7	302 *	7	3
	11	0.0527005	256	**316**		4	**319**	**2**	**7**

bold = used for average calculation and histograms, (*) = average of a minor second population

Table 1: Single zircon Pb-evaporation data

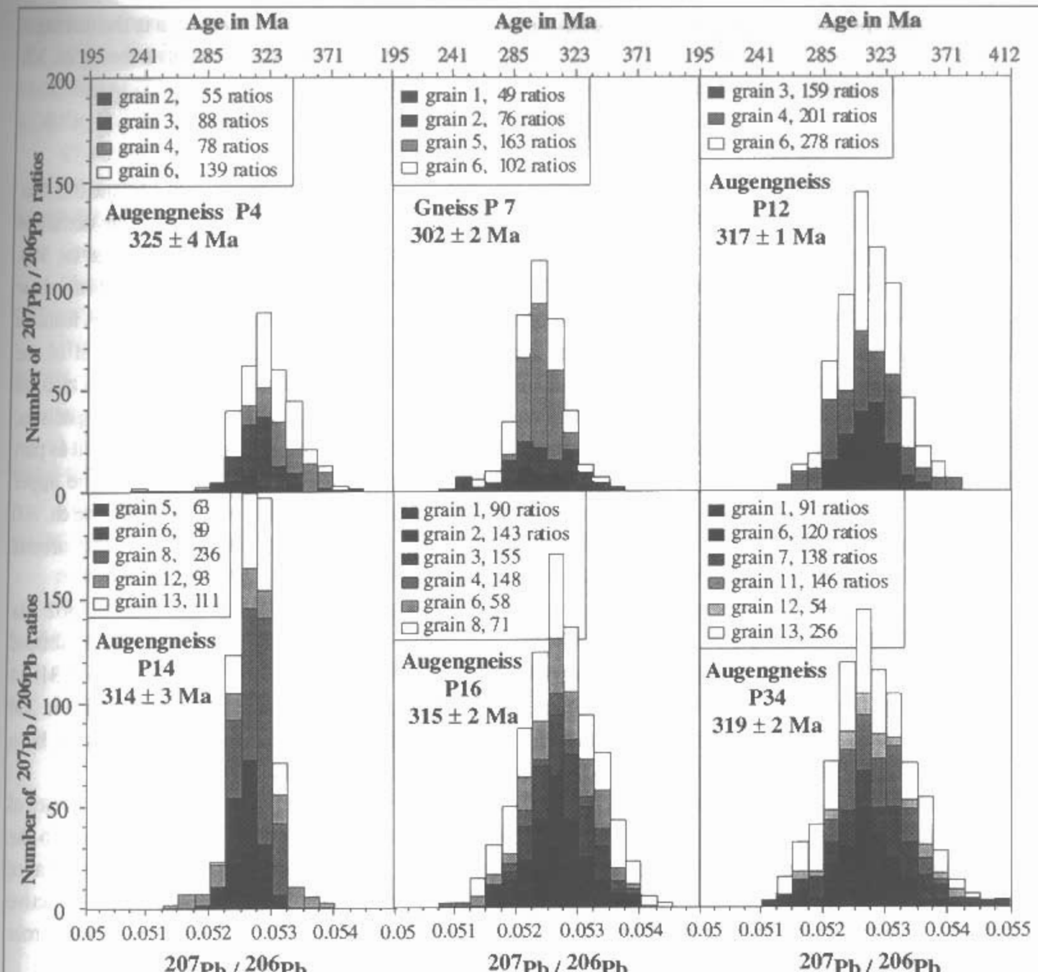

Fig. 5: Histograms showing $^{207}Pb/^{206}Pb$ ratios of single zircon analyses. The uncertainties of the ages are 2 sigma mean.

Augengneiss P16 is a fine grained augengneiss (∅ ± 1 mm), with a typical granitoid mineral assemblage such as quartz, feldspar, muscovite, and minor biotite that is well exposed in a road cut in the W of Paros (Fig.2). The foliation is pervasive throughout the exposure.

The separated zircons are clear and colourless. They have (100) < (110) as prism planes and at the pyramid terminations the (101) planes are as big as or slightly smaller than the (211). The majority of the grains therefore can be classified as S2 and S3 after Pupin & Turco (1975). With one exception, the age data are coherent with a mean age of 315±2 Ma, which can be interpreted as intrusion age.

Augengneiss P34 was collected from the NW gneiss area of Paros (Fig. 2) and is characterized by a lower degree of deformation. It is a medium-grained gneiss with conspicuous feldspar augen of 2 cm in diameter. Similar to the other samples, the major minerals are quartz, K-feldspar, plagioclase, and equal amounts of muscovite and biotite.

The shape of these zircons is long-prismatic. In contrast to the other samples, the (100) plane is absent, in favour of the (110). The (101) seems to be smaller than (211), which classifies the zircon population as representative of the L1 and L2 group of Pupin et Turco (1975). The age spectrum is heterogeneous. One zircon with Proterozoic age is obviously an inherited grain. The other ages obtained from this sample can be divided into two gr[...]. A small but significant part of the zircon population has a mean age of 302±7 Ma. We interpret the 319 Ma which is the dominent age as the intrusion age. The significance of the younger age is uncertain. Another igneous event at ca. 300 Ma has to be considered.

4. DISCUSSION AND CONCLUSIONS

The investigations of zircons of these basal gneisses of Paros yield ages between 300 Ma and 325 Ma. The majority of measured ages scatters around 317±2 Ma, which therefore is interpreted as the dominant age of the zircon crystallisation. A minor age peak, which is documented in some samples, lies at ca. 300-305 Ma. As SEM- and CL-photographs (Fig. 3 and 4) demonstrate, the analysed zircon populations show distinct magmatic zonations and typical igneous morphologies. The lack of sedimentary transport features such as rounded terminations or pitted surfaces further support the primary magmatic origin of the zircons. Furthermore, the Tertiary metamorphism did not affect the lead isotope system of the zircons. Consequently, the ages obtained are interpreted as intrusion ages of the igneous precursors of the gneisses. Thus, the lowermost metamorphic rocks on the islands from the Marathi unit have to be considered as part of the pre-alpine basement that formed during a main magmatic episode at ca. 317±2 Ma in the upper Carboniferous. Because of the limited number of age data, it remains an open question whether the ca. 300 Ma age represents an igneous event of its own or whether it is part of the major magmatic episode around 316 Ma.

The ages we present here are in good agreement with other Carboniferous age data of 302 Ma (Mountrakis 1984) and 302 ± 5 Ma (Yarwood & Aftalion 1976) from the Pelagonian zone in mainland Greece. Furthermore, the zircon data from the gneisses of Naxos also include Carboniferous ages of 316±4 Ma (Reischmann, this volume). In the light of these data, the presumed metamorphic age for Ios of ca. 300 Ma (Henjes-Kunst & Kreuzer 1982) probably has to be re-interpreted and we suggest this to be a magmatic age. The significance of their ca. 500 Ma Rb/Sr-isochron is therefore questionable.

The comparison of the zircon data of the augengneisses from Paros presented in this study with ages of the neighbouring regions indicate that the upper Carboniferous magmatic event is not restricted to the island of Paros, but possibly connects with the Pelagonian zone in the NW, and therefore is of importance for a larger part of the Hellenides. According to the geochemical data, a continental collision or active continental margin is the most plausible tectonic setting for the origin of this upper Carboniferous magmatic episode.

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