EARLY PALAEOZOIC U-Pb ISOTOPIC AGE FOR AN ORTHOGNEISS FROM NORTH-WESTERN PALMER LAND, ANTARCTIC PENINSULA

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ABSTRACT. North-western Palmer Land constitutes part of the Mesozoic magmatic arc of the Antarctic Peninsula. Within this area basement rocks of pre-Mesozoic age have been identified. Recently obtained Rb–Sr isotope whole-rock data suggested that the calc–alkaline orthogneiss exposed at Campbell Ridges in north-western Palmer Land had an original intrusive age of 440(±57) Ma. However, new U–Pb isotope data from zircons extracted from a specimen of this orthogneiss, define the intrusive age as 506(+8/−7) Ma. This represents the oldest, well-constrained age of basement material from the Antarctic Peninsula. Together with other evidence of Palaeozoic calc–alkaline plutonism, this suggests that the Antarctic Peninsula represented a part of the Pacific margin of Gondwana from at least the end of Cambrian times.

INTRODUCTION

The geology of the Antarctic Peninsula is dominated by an arc-trench system comprising an accretionary prism, magmatic arc and fore- and back-arc basins (Storey and Garrett, 1985). This system formed as a result of essentially continuous eastward subduction of proto-Pacific and Pacific oceanic crust beneath the Antarctic Peninsula from early Mesozoic times until the Tertiary (Barker, 1982; Storey and Garrett, 1985).

Much of the magmatic arc zone, which is situated mainly within the mainland of the Antarctic Peninsula (Fig. 1), contains numerous exposures of metamorphic rocks, particularly along the east coast of Graham Land and in northern Palmer Land. Originally all of these rocks were considered to be basement rocks of Palaeozoic age or older (Adie, 1954). Subsequent work, using Rb–Sr and K–Ar isotope geochemistry (Rex, 1976; Gledhill and others, 1982; Pankhurst, 1982, 1983), showed that most of these metamorphic rocks were deformed early magmatic arc rocks of Mesozoic age. However, Pankhurst (1983) did obtain poorly constrained Palaeozoic ages (245 Ma metamorphic event masking a possible early Palaeozoic or older history) from gneisses in eastern Graham Land, suggesting that at least some of these metamorphic rocks were pre-Mesozoic in age. Most recent isotope studies have confirmed this. Milne and Millar (in press) presented two mid-Palaeozoic ages (410±15 and 426±12 Ma), using the Rb-Sr whole rock method, for orthogneisses from eastern Graham Land. Harrison and Piercy (in press) presented two other mid-Palaeozoic ages (399±35 and 440±57 Ma), also using the Rb–Sr whole-rock method, for orthogneisses from north-western Palmer Land. This latter work is not as well

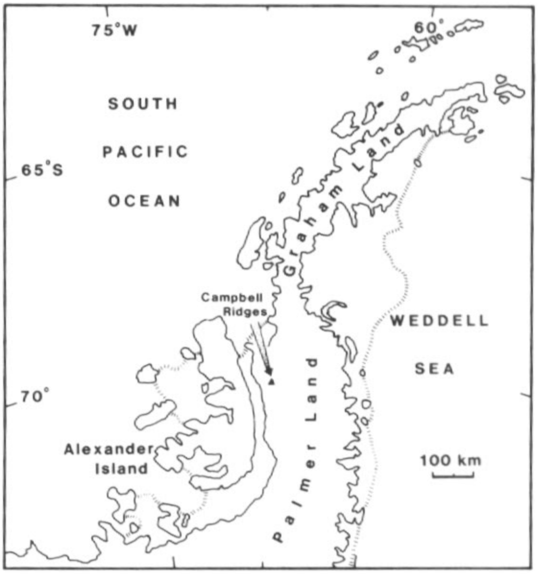

Fig. 1. Map of the Antarctic Peninsula showing the location of Campbell Ridges.

constrained as the data of Milne and Millar (in press), particularly the 440 ± 57 Ma age obtained from the orthogneiss exposed at Campbell Ridges (Fig. 2).

New U–Pb data for zircon extracted from one specimen of the Campbell Ridges orthogneiss are presented here. These provide a well-constrained U-Pb age, confirming a Palaeozoic origin for this orthogneiss but indicating that the age of igneous crystallization is older than the Rb-Sr isotope age determined by Harrison and Piercy (in press).

Geological Setting

The geology of north-western Palmer Land is described in Harrison and Piercy (1986), Harrison and Piercy (in press) and Piercy and Harrison (in press) and is summarized here in Table I. Essentially pre-Mesozoic metamorphic rocks, which underwent high grade amphibolite facies metamorphism and migmatization in the early Jurassic, comprise orthogneiss, metapelite and marble (Harrison and Piercy, in press). An early group of the magmatic arc rocks, 200–150 Ma old, retrogressively metamorphosed and locally deformed during the Late Jurassic, comprise metadiorite and metagranitoid rocks and younger amphibolite dykes and metagabbro. The youngest group of magmatic arc rocks, approximately 150–80 Ma old, are undeformed and include subhorizontally layered volcanic rocks, granitoids and late porphyry and andesitic dykes.

The specimen of orthogneiss was taken from locality R.2730 at Campbell Ridges (Fig. 2) in an area where some of the best cross-cutting field relationships of north-western Palmer Land are displayed. Exposures of all three strato-tectonic units (Table I), represented by the orthogneiss, metagranitoid and undeformed granodiorite, are present and a dense swarm of amphibolite dykes (individually up to 15 m wide) cuts both the metaplutonic rocks and the orthogneiss but is itself cut by the undeformed granodiorite.

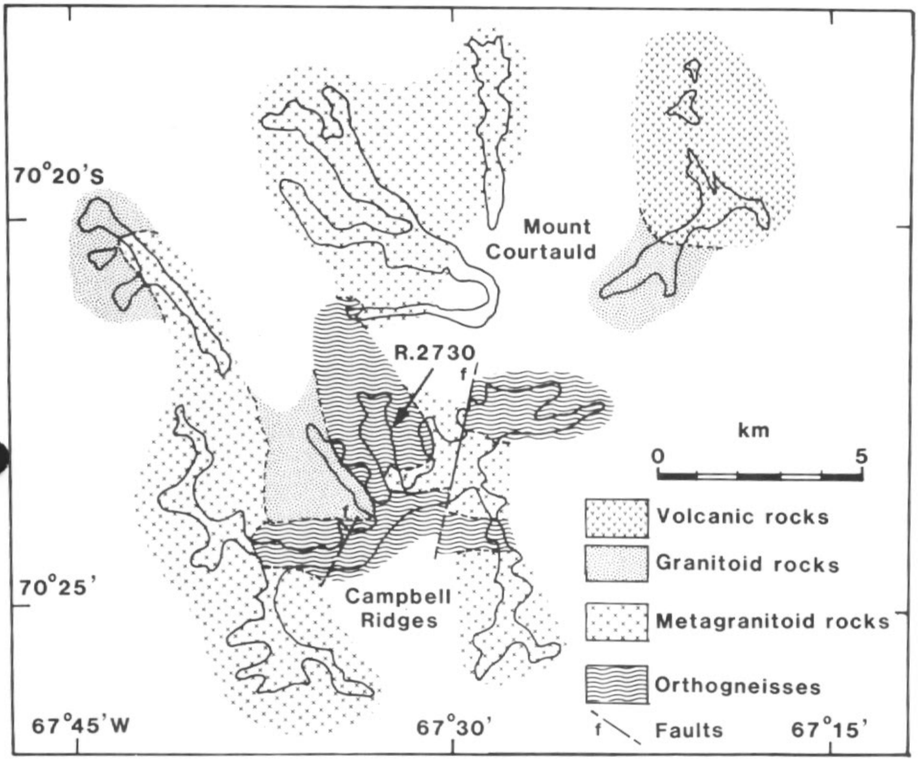

Fig. 2. Geological sketch map of the Campbell Ridges and Mount Courtauld area showing locality R.2730, where the dated specimen of orthogneiss was collected.

Table I. Strato-tectonic diagram summarizing the geology of north-western Palmer Land. The three plutonic units exposed at Campbell Ridges are shown in boxes

YOUNGING ↑		ROCK UNITS	METAMORPHISM	
	Younger magmatic arc rocks	Late dykes [Granitoids] Volcanic rocks	No deformation	
	Older magmatic arc rocks	Metagabbros Amphibolite dykes [Metagranitoids]	Partial recrystallization / cataclasis	Metamorphic complex
	Pre-magmatic arc rocks	[Orthogneisses] Marble Metapelites Granulites	High grade metamorphism and migmatization	Metamorphic complex

Sample Description

In hand specimen, the rock is coarse-grained, is an overall grey colour with a felsic to mafic mineral ratio of approximately 3:1. It has a variable gneissose fabric defined by stretched aggregates of biotite. These aggregates rarely exceed 1 cm in thickness but in outcrop, gneissose banding up to 20 cm thick occurs.

In thin section, the main phases are quartz, plagioclase(An_{30}), K-feldspar, biotite and an opaque oxide; accessory phases include apatite, zircon, sphene and allanite. The texture is heterogeneous with porphyroclasts (up to 4 mm) of both plagioclase and K-feldspar set in a finer but inequigranular matrix of quartz, feldspar and biotite. Both the plagioclase and K-feldspar porphyroclasts have ragged recrystallized edges. The former have poorly structured albite twinning, often breaking down to multiple sets, and the latter are microperthitic orthoclase. Within the matrix the quartz forms polycrystalline aggregates, whereas the feldspars occur as fine symplectitic intergrowths with poorly defined grain boundaries. Greenish–brown biotite forms lath-like, lensoid aggregates, often developed in a subparallel alignment. The opaque oxide is irregularly shaped, rarely exceeds 1.5 cm in diameter and mostly occurs with biotite-rich areas. Of the accessory phases the zircon is variable in size and shape (discussed below) and occurs randomly throughout the rock, even as inclusions within the porphyroclasts.

Analytical Techniques

After crushing and grinding the sample, weighing 9.5 kg, the heavy minerals were concentrated on a Wilfley table. The zircon was purified using heavy liquids (bromoform and di-iodomethane) and a Frantz Isodynamic Magnetic Separator. The concentrate of 1.77 g of zircon was then split into nine sieve fractions, of which seven provided sufficient zircon for dating. The zircon crystals were cleaned with 2 M HCl acid for approximately 20 sec in an ultrasonic bath and then dissolved in HF (48%) acid at 150 °C in a teflon liner. U and Pb were enriched by standard ion exchange techniques. Their concentrations were determined by the isotope dilution technique using a ^{235}U–^{208}Pb mixed spike. Within the period of the measurements a total blank of 0.15 ng for Pb and 0.05 ng for U had been determined. Composition and contents of common lead were calculated according to the lead evolution model of Stacey and Kramers (1975).

Analytical errors for the $^{207}Pb/^{235}U$, $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ratios are suggested not to exceed 1.0%, 1.0% and 0.7% respectively. The regression line for the data was calculated using the least squares method of York (1969) assuming [illegible] correlation for the errors. The laboratory work and all measurements were carried out on an NBS (National Bureau of Standards) designed, 12 inch radius, 90° sector solid-source mass spectrometer at the Zentrallaboratorium für Geochronologie in Münster.

Morphology of the Zircon

All zircon extracted from the specimen is euhedral to subhedral; most crystals are elongate, but short prismatic crystals are also present. The zircon is non-magnetic and generally of pale yellow colour, although some grains, mainly in the coarser sieve fractions ($> 125\ \mu m$), are a brownish to purplish colour. Within these coarser fractions the ratio between crystals with and without internal fractures, probably due to microcracks and lattice disturbances, is much higher compared to the fractions $< 125\ \mu m$.

Table II. U–Pb isotope data for the seven sieve fractions of zircon extracted from the sample of orthogneiss, R.2730.2

Size (μg)	Weight (mg)	*Measure isotope ratios* $^{208}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{204}Pb$	U (ppm)	Pb_{tot} (ppm)	$^{206}Pb_{rad}$ (nmol)	*Isotope ratios (corr.)* $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	*Apparent ages (Ma)* $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
> 160	4.4	0.074163	0.059102	6075	646	33.1	0.5397	0.05269	0.4120	0.056710	331	350	480
160–125	6.7	0.074276	0.059957	4424	591	31.4	0.8984	0.05440	0.4251	0.056668	342	360	479
125–100	12.0	0.072581	0.057749	6844	526	26.4	1.3569	0.05150	0.3950	0.055612	324	338	437
100–80	7.5	0.102628	0.067797	1132	661	32.0	0.9798	0.04737	0.3586	0.054902	298	311	408
80–63	7.5	0.107413	0.069367	1012	666	32.0	0.9735	0.04670	0.3538	0.054939	294	308	410
63–40	7.9	0.109227	0.069702	969.4	706	32.7	1.0443	0.04491	0.3383	0.054636	283	296	397
40–31	5.1	0.122401	0.074488	792.6	789	34.9	0.7050	0.04199	0.3153	0.054468	265	278	390

Constants used: Steiger and Jager (1977).
Common Pb composition: Stacey and Kramers (1975) for 200 Ma.
Composition of Pb-blank: 208/204, 207/204, 206/204: 37.5, 15.5, 17.72.

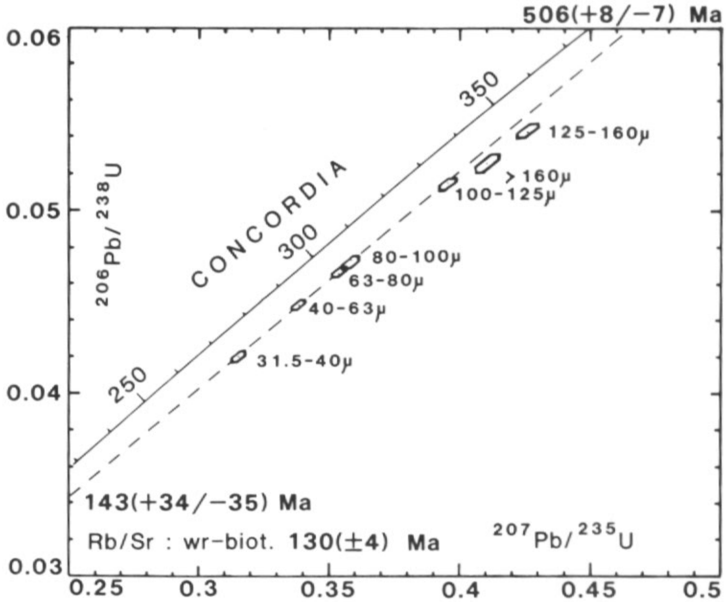

Fig. 3. Concordia plot showing the upper and lower intersects of the discordia calculated from the U–Pb isotope data for separate fractions of zircon extracted from the sample of orthogneiss.

Opaque and colourless inclusions are common in all zircon fractions. The colourless inclusions are either bubble-shaped, indicating a gas or fluid inclusion, or bordered by crystal faces indicating a solid content. Colourless cores and zoning, visible in translucent light, are not very common.

Only inclusion-free zircon was selected for the U–Pb analysis and the evidence of the crystal morphology suggests that all this zircon is co-genetic.

U-Pb Systematics of the Zircon

The apparent $^{206}Pb/^{238}U$ ages of the zircon range from 265($\pm$2.7) to 342($\pm$3.4) Ma (Table II). Excluding the sieve fractions > 160 μm, a negative correlation between grain size and U content was observed, whereas the apparent ages are positively correlated with the grain size. The degree of discordance is positively correlated to the U contents, which allows for a co-genetic history of the zircon fractions (Gebauer and Grünenfelder, 1977).

A best-fit regression line, calculated with the data from the zircon fractions < 125 μm, intersects the concordia at 143(+34/−35) Ma and 506(+8/−7) Ma (Fig. 3). The sieve fractions > 125 μm plot below the calculated isochron, perhaps due to a loss of radiogenic lead along microcracks or to the presence of older, invisible U-poor cores.

It is suggested that the upper intersection of the regression line with the concordia curve of U–Pb evolution represents the primary crystallization age of the zircon in a granitic magma. A metamorphic event, which caused an incomplete lead loss from zircon during the late Jurassic, is represented by the lower intercept of the best-fit line with the concordia. To confirm this younger age, the same specimen was dated using the Rb–Sr whole-rock–biotite method and this yielded an age of 130($\pm$4) Ma (Table

Table III. Rb–Sr whole-rock–biotite isotope data for the sample of orthogneiss, R.2730.2

	Rb (ppm)	*Sr (ppm)*	${}^{87}Rb/{}^{86}Sr$	${}^{87}Sr/{}^{86}Sr$
Whole rock	154.4	438.2	1.020	0.71359
Biotite	804.2	4.78	533.4	1.6939

Constants used: Steiger and Jäger (1977).
Errors are 0.5% on Rb/Sr and 0.01% on ${}^{87}Sr/{}^{86}Sr$ (1-sigma).

III). The value of such a 2-point isochron is clearly restrictive, particularly with biotite and whole-rock analyses, where the difference in ${}^{87}Rb/{}^{86}Sr$ ratios is so large. However, assuming that the Rb–Sr system of the biotite would close at a later stage of the metamorphic event than that indicated by the zircon, there is fairly good correspondence between the U–Pb and Rb–Sr data.

Discussion

The age of 506 Ma, obtained for the original crystallization of the orthogneiss represents the oldest isochron yet obtained from the Antarctic Peninsula. Given the isotope data that have been obtained in recent years (Pankhurst, 1982; Harrison and Piercy, in press; Milne and Millar, in press) it is clear that continental Palaeozoic rocks do exist in the Antarctic Peninsula, both in Graham Land and Palmer Land. Harrison and Piercy (in press) have identified paragneisses in north-western Palmer Land and it is possible that these could represent even older basement material.

Harrison and Piercy (in press) compared the mineralogy and geochemistry of representative samples of orthogneiss, exposed in north-western Palmer Land, with the Mesozoic calc–alkaline granitoids of the same region. They found that the chemical signature of the orthogneiss was almost identical to that of the younger granitoids, concluding that the orthogneiss must also be calc–alkaline. From this they suggested that the Antarctic Peninsula was undergoing subduction-related magmatism at least during the mid-Palaeozoic, probably as a part of the Pacific margin of Gondwana. The new U-Pb zircon data now extend the age-range of magmatism back to late Cambrian times.

Palaeozoic calc–alkaline magmatism has been reported from other regions that formed the Pacific margin of Gondwana, including southern South America, Marie Byrd Land and Victoria Land in Antarctica, eastern Australia and New Zealand (see Milne and Millar (in press) for a summary) suggesting that there was a contiguous destructive margin along this Pacific edge. Ages for magmatism vary from region to region but most fall within the range of 500–300 Ma ago. As yet, there are few radiometric age determinations for pre-Mesozoic rocks of the Antarctic Peninsula. Until further data are available it is unknown whether the ages obtained so far represent the complete time span for this early subduction-related magmatism.

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