Polarforschung 57 (1/2): 59—69, 1987

Zircon Provenance and Gondwana Reconstruction: U-Pb Data of Detrital Zircons from Triassic Trinity Peninsula Formation Metasandstones

By Hubert Miller*, Werner Loske* and Ulrich Kramm**

Summary: Morphological and U-Pb isotope studies on sedimentary zircons reflect the orogenic evolution of their former host rocks. The orogenic history of detrital zircons from the Trinity Peninsula Formation (TPF) defines the former geological surrounding of the sedimentation basin of the TPF.
Some few well rounded, polycyclic zircons of Precambrian age and Cambrian overprint give hints for an old cratonic source rock. Because of their very low frequency compared with euhedral types, the contribution of an cratonic shield area to the bulk of the sedimentary debris is neglectable low.
Euhedral zircons of granitoid origin and Carboniferous age indicate a derivation from an area of widespread Carboniferous intrusions. Except for southern South America and unsurveyed regions in the Antarctic Peninsula itself, no region could deliver zircons with a Carboniferous age record.
The only acceptable explanation for the origin of these zircons is a position of the Antarctic Peninsula during the sedimentation of the TPF approximately southwest of southern South America.

Zusammenfassung: Aus morphologischen und isotopengeochronologischen Untersuchungen an detritischen Zirkonen läßt sich die geologische Entwicklung ihrer Herkunftsgesteine ableiten. Sie sind damit ein Abbild der geologischen Umrahmung des Sedimentationsraumes der Trinity Peninsula Formation (TPF).
Wenige, im Zirkonspektrum vorhandene polyzyklische Zirkone mit starker Abrundung haben präkambrische Entstehungsalter, die durch einen Bleiverlust im Kambrium überprägt wurden. Der im Vergleich zu idiomorphen Zirkonen äußerst geringe Anteil der polyzyklischen Zirkone am Gesamtspektrum beweist, daß ein „Alter Schild" nur unwesentliche Sedimentmengen zur Bildung der TPF beigetragen hat.
Die idiomorphen Zirkone lassen aufgrund ihrer Morphologie und U-Pb-Systematik auf eine Herkunft aus unterkarbonen Granitoiden schließen. Damit schränkt sich deren Herkunftsgebiet auf das südliche Südamerika und bisher unerforschte Gebiete der Antarktischen Halbinsel ein.
Diese charakteristische Zirkonführung kann nur durch eine westliche bis südliche Lage der Antarktischen Halbinsel relativ zum südlichen Südamerika während der Sedimentation der TPF erklärt werden.

1. INTRODUCTION

Palaeogeographic reconstructions of the western margin of Gondwana before its Cretaceous splitting up, which include the relative positioning of South America and the Antarctic Peninsula, are supported by informations from the scarce pre-Andean relics.

Geometric, palaeomagnetic, petrologic and sedimentologic investigations resulted in the proposal of various palaeogeographical situations for the location of the Antarctic Peninsula relative to South America (Fig. 1) and the geotectonic setting of the different geological sequences (e. g. DALZIEL & ELLIOT 1971, ASHCROFT 1972, CRADDOCK 1975, BARKER & GRIFFITHS 1972, 1977, DALZIEL 1982, QUILTY 1982 and MILLER 1983a). A consensus about the western margin of Gondwana has not been reached, so far. We suggest that a comparison of the pre-Andean age structures of the today's Gondwana fragments, which reflect the tectonometamorphic history of their modern plates, can supply new arguments for the fitting of South America and the Antarctic Peninsula.

This paper presents U-Pb data of detrital zircons from Triassic metasandstones of the Antarctic Peninsula and the South Shetland Islands, which shed some new light on the environment around the Early Mesozoic Trinity Peninsula Formation sedimentation basin.

---

* Prof. Dr. Hubert Miller and Dr. Werner Loske, Institut für Allgemeine und Angewandte Geologie der Universität, Luisenstraße 37, D-8000 München 2.
** Dr. Ulrich Kramm, Institut für Mineralogie der Universität, Corrensstraße 24, D-4400 Münster.

2. METHODOLOGY

The best way to get a direct information of the pre-Andean age structure of the rocks would be to date magmatic or metamorphic rocks from various segments of the former Gondwana continent. Unfortunately such rocks are either not yet known or have been formed or strongly overprinted during Andean metamorphic events.

Metasediments of Palaeozoic-Triassic age are widely distributed in the Antarctic Peninsula. The clastic detritus of these sediments, deposited on the western margin of Gondwana reflects the eroded geological surrounding of their sedimentation basin. An age dating method which is insensitive for various exogen processes affecting the provenance rocks during weathering, erosion, transport, diagenesis and anchimetamorphic processes could be appropriate to get at least indirect information of the age structure and orogenic evolution of the pre-Andean crust of this part of Gondwana.

In contrast to K-Ar and Rb-Sr systems, the U-Pb system of zircons preserves the genetic history quite well. Crystallisation age and times of episodical Pb loss are reflected by their U-Pb systematics. Main problem in tracing the history of zircons is the selection of uniform, cogenetic suites. Some criteria differentiating homogeneous zircon populations are their susceptibility (e. g. SILVER & DEUTSCH 1963, KROGH 1982), their fluorescence and luminescence, their colour, shape and size (e. g. GRAUERT et al.

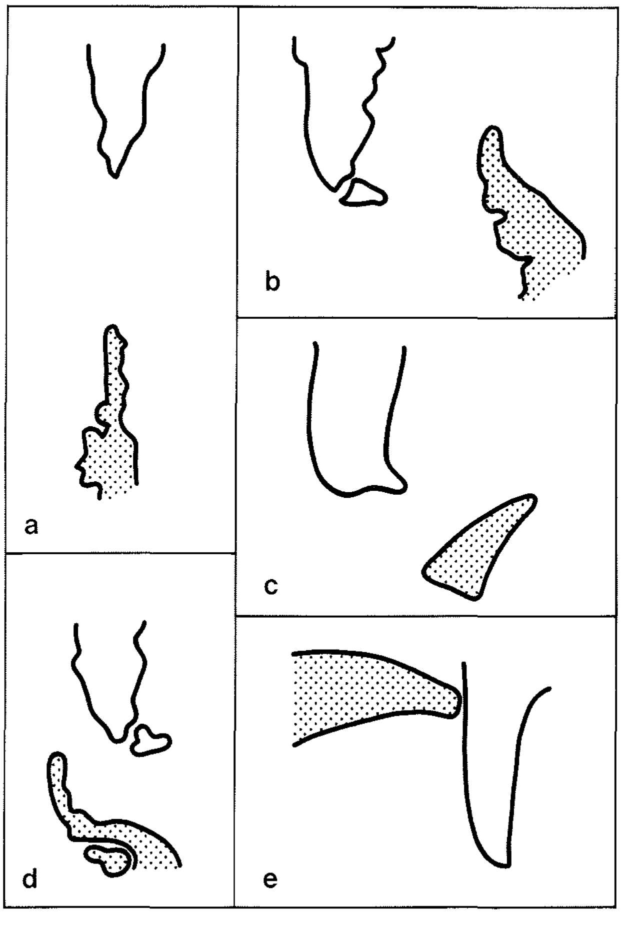

Fig. 1: Five selected sketches as to the position of the Antarctic Peninsula (dotted) relative to the southern tip of South America before the break-up of Gondwana. a) after DALZIEL & ELLIOT (1971), b) after CRADDOCK (1975), c) after DALZIEL (1982), d) after QUILTY (1982), e) after BARKER & GRIFFITHS (1977).

Abb. 1: Fünf ausgewählte Beispiele zur Lage der Antarktischen Halbinsel relativ zur Südspitze Südamerikas vor dem Gondwana-Zerfall. a) nach DALZIEL & ELLIOT (1971), b) nach CRADDOCK (1975), c) nach DALZIEL (1982), d) nach QUILTY (1982), e) nach BARKER & GRIFFITHS (1977).

1973, GIRTY & WARDLAW 1985). Some others might be their contents of inclusions or visible cores, the nature of the mineral surfaces and their form (PUPIN 1980, LOSKE 1985).

The interpretation of a discordia becomes more difficult, the more events have affected the U-Pb systematics of the zircons (GRAUERT et al. 1973). Therefore we favoured as host rocks of the detrital zircons quartzitic sandstones of a very low metamorphic grade.

3. GEOTECTONIC SETTING

The basement rocks of the Scotia Arc and the Antarctic Peninsula (Fig. 2) are composed of two different types of rocks. Low up to medium grade metamorphic rocks of Andean age appear at the Antarctic Peninsula, at Smith Island and the Elephant Island Group (Scotia Metamorphic Complex SMC, TANNER et al. 1982, DALZIEL 1982, HERVE & PANKHURST 1984, HERVE et al. 1984). The second group of basement rocks covering parts of Livingston Island and the Antarctic Peninsula is a turbiditic sequence of graywackes, sandstones and mudstones (Trinity Peninsula Formation TPF: HYDEN & TANNER 1981) of Late Palaeozoic (?) to Early Mesozoic age.

Conglomerates are quite rare (AITKINHEAD 1975, ELLIOT 1965, 1967, FLEET 1967). The turbiditic character of the TPF and the missing metamorphism led DALZIEL & ELLIOT (1973) to the idea of a deposition on a passive continental margin. SMELLIE (1981, 1985 in press) compared the depositional environment with a fore arc, upper slope basin, but BURN (1984) and STOREY & GARRETT (1985) favour a subduction complex (trench slope basin).

Palaeontological evidence for the age of this series is given at Williams Point (Livingston Island), where LACEY & LUCAS (1981) describe a Triassic flora, and at Cape Legoupil, where a marine fauna indicates a Triassic age of deposition (THOMPSON 1975) as well.

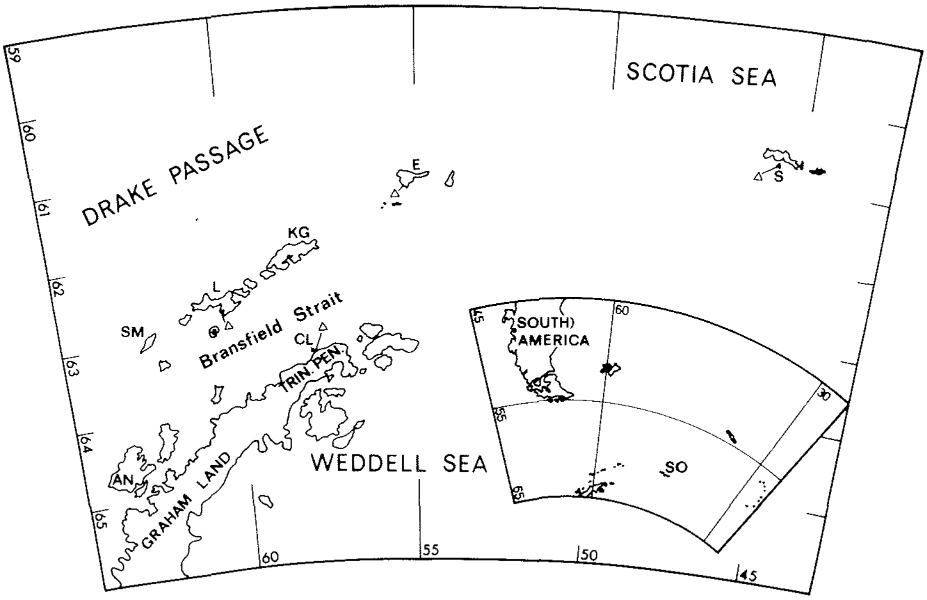

Fig. 2: Sketch map of the Antarctic Peninsula. AN = Anvers Island, CL = Cape Legoupil, E = Elephant Island, KG = King George Island, L = Livingston Island, S = Signy Island, SM = Smith Island, SO = South Orkney Islands.

Abb. 2: Geographische Übersicht über die Antarktische Halbinsel. AN = Anvers Island, CL = Cape Legoupil, E = Elephant Island, KG = King George Island, L = Livingston Island, S = Signy Island, SM = Smith Island, SO = South Orkney Islands.

4. ANALYTICAL PROCEDURE

The zircons were separated from sandstone samples of 92 kg (Livingston Island) and 182 kg Gandara Island: Antarctic Peninsula, Cape Legoupil) using common separation techniques. A detailed description of the procedure and the samples is given in LOSKE et al. (in prep., b). Homogeneous zircon populations from various size fractions were obtained by microscopic grain by grain selection according to the morphologic and colour characteristics of the crystals.

The mass spectrometric work has been done at the Central Laboratory of Geochronology in Münster. Analytical techniques and error calculations are described in LOSKE et al. (in prep., b).

5. TYPOLOGY OF THE DETRITAL ZIRKONS

Two main types of morphologically different zircons are found in both metasandstone samples, an euhedral and a xenomorphic type. The dominant euhedral zircons are characterized by pale reddish and brownish colours. In the sample from Livingston Island they can be split up into two populations with and without high indexed pyramidal faces, respectively. In contrast, the metasandstone from Gandara Island exhibits only the complex type of euhedral zircons.

According to PUPIN (1980) the morphology suggests a granitoid origin of all these euhedral crystals. The perfect conservation of the crystal shapes supports the concept of a short time — short distance sedimentary reworking. Only some 2% of the zircons are well rounded crystals with dark red and pink colours. The grain surfaces are covered with V-shaped transport marks, which cause a frosted appearance of the grains. A detailed description can be found in LOSKE et al. (in prep., a) and LOSKE et al. (in prep., b).

We suggest that euhedral and xenomorphic zircons represent two genetically different populations. The genetical homogeneity of the euhedral group of the zircons of each locality remains unclear. The two morphological types of euhedral zircon crystals of the Livingston Island metasandstone suggests a further subdivision into cogenetic groups, yet the morphological studies of PUPIN place both forms into the same granitic crystallisation environment.

6. U-Pb ISOTOPIC DATA

Isotopic data, the apparent U-Pb ages and the U and Pb concentrations of various zircon populations are given in Table 1. Euhedral zircons of both localities are characterized by a narrow range of apparent $^{207}Pb/^{235}U$ ages between 350 Ma and 520 Ma. All these zircon populations are highly discordant. In contrast, the well rounded zircons with apparent $^{207}Pb/^{235}U$ ages between 750 Ma and 1050 Ma are less discordant. The U-Pb systematics corroborate the morphologic character as a genetical discriminant. Five of the six fractions of euhedral Gandara zircons define a discordia which intersects with the concordia curve of U-Pb evolution at 322 Ma +7/—8 Ma and 1157 Ma +39/—37 Ma (Fig. 3). The degree of discordance of the populations along this discordia is correlated with the U content of the zircons and their grain size. This suggests a complex structure of the zircon grains with an old core and a young overgrowth close to the lower intercept date. Because of the morphological characteristics we interpret this date as the age of cooling down of a granitoid intrusion.

The U-Pb ratios of the euhedral Livingston zircons do not define a discordia, but plot in a Concordia diagram in a V-shaped data field which originates at the lower discordia intercept of the Gandara zircons. This field includes the Gandara zircons. Neither grain size, nor U content of the Livingston zircons correlate completely with the degree of their discordance, yet there is an obvious correlation between morpho-

Size	Weight	Measured Isotope ratios			U	Pb$_{tot}$	^{206}Pb$_{rad}$	Isotope ratios (corr.)			Apparent ages (Ma)		
(µm)	(mg)	$\frac{^{208}Pb}{^{206}Pb}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{206}Pb}{^{204}Pb}$	(ppm)	(ppm)	(nmol)	$\frac{^{206}Pb}{^{238}U}$	$\frac{^{207}Pb}{^{235}U}$	$\frac{^{207}Pb}{^{206}Pb}$	$\frac{^{206}Pb}{^{238}U}$	$\frac{^{207}Pb}{^{235}U}$	$\frac{^{207}Pb}{^{206}Pb}$
euhedral zircons LIVINGSTON ISLAND / HURD PENINSULA													
250—200	0.7	0.191514	0.086993	470.7	228	13.4	0.0520	0.05482	0.4241	0.056107	344	359	457
200—160	1.6	0.126858	0.065616	1657.6	372	21.1	0.0867	0.05596	0.4387	0.056853	351	369	486
160—125 m	2.2	0.146976	0.081618	604.8	914	58.3	0.2244	0.05885	0.4671	0.057560	369	389	513
160—125 sb	2.0	0.154892	0.072227	1090.8	479	30.5	0.1201	0.06011	0.4884	0.058922	376	404	564
160—125 cb	1.1	0.130609	0.074777	999.2	409	28.3	0.1145	0.06703	0.5572	0.060289	418	450	614
160—125 cr	4.5	0.118987	0.069426	1700.7	637	41.0	0.1659	0.06247	0.5458	0.060058	412	442	606
160—125 sr	1.2	0.141907	0.075566	789.1	538	32.6	0.1287	0.05740	0.4522	0.057133	360	379	497
160—125crb	1.1	0.115472	0.068168	1784.7	577	38.5	0.1587	0.06591	0.5458	0.060058	412	442	606
125—100	3.0	0.115408	0.070434	2048.0	565	37.8	0.1541	0.06544	0.5719	0.063386	408	459	721
100— 80	3.1	0.124715	0.074402	1226.7	620	40.7	0.1632	0.06310	0.5449	0.062623	395	442	695
80— 63	3.7	0.124601	0.073824	1275.0	762	51.5	0.2060	0.06480	0.5582	0.062484	405	450	691
63— 40	2.0	0.152732	0.082965	692.1	691	47.2	0.1817	0.06311	0.5401	0.062067	395	439	676
〈 40	6.4	0.162955	0.085691	601.9	769	51.9	0.1957	0.06099	0.5183	0.061636	382	424	662
well rounded zircons LIVINGSTON ISLAND / HURD PENINSULA													
160—125	0.5	0.145669	0.103549	744.9	443	58.9	0.2249	0.12163	1.4221	0.084796	740	898	1311
125—100 p	0.6	0.119872	0.087713	1611.9	665	80.2	0.3238	0.11671	1.2703	0.078942	712	833	1171
125—100a	0.5	0.131417	0.089632	1130.0	510	58.8	0.2354	0.11061	1.1757	0.077092	676	789	1124
100— 40	0.3	0.111303	0.089460	2206.2	596	73.2	0.3014	0.12121	1.3889	0.083103	738	884	1272
euhedral zircons GANDARA ISLAND													
160—125	2.7	0.098800	0.062792	6768.4	409	29.0	0.1210	0.07084	0.5925	0.060659	441	473	627
125—100	2.7	0.097208	0.066340	5262.1	439	32.6	0.1357	0.07415	0.6503	0.063599	461	509	728
100— 80 a	3.3	0.102800	0.065545	5037.7	500	35.9	0.1488	0.07142	0.6172	0.062677	445	488	697
100— 80 r	1.0	0.099762	0.065615	3885.9	479	33.4	0.1393	0.06975	0.5953	0.061899	435	474	671
80— 63	1.9	0.100657	0.065075	4164.5	541	37.4	0.1553	0.06878	0.5842	0.061600	429	467	660
63— 40	1.1	0.109944	0.065041	3829.6	581	39.4	0.1630	0.06730	0.5685	0.061267	420	457	649
well rounded zircons GANDARA ISLAND													
125—100	0.8	0.095912	0.075354	4338.3	588	66.8	0.2769	0.11299	1.1228	0.072067	690	764	988
100— 80	0.6	0.109329	0.090232	2540.5	518	71.4	0.2874	0.13293	1.5524	0.084698	805	952	1309
80— 63	0.3	0.104345	0.091974	3509.9	591	87.5	0.2976	0.14489	1.7580	0.087996	872	1030	1382

Tab. 1: Zircon isotopic data. s = S-type zircons, c = C-type zirkons, r = reddish colour, b = brownish color, p = pink colour, a = all colours, m = metamict. Used constants: STEIGER & JÄGER (1977). Common-Pb composition: STACEY & KREAMERS (1975). Euhedral zirkons 400 Ma, xenomorphic zircons 700 and 800 Ma. Composition of Pb-blank: 208/204, 207/204, 206/204: 37.5, 15.5, 17.72

Tab. 1: Isotopendaten aus Zirkonen. s = S-Typ-Zirkone, c = C-Typ-Zirkone, r = rötliche Farbe, b = bräunliche Farbe, p = rosafarben, a = alle Farben, m = metanict. Konstanten nach STEIGER & JÄGER (1977). Pb-Zusammensetzung nach STACEY & KREAMERS (1975). Euhodrale Zirkone 400 Ma, xenomorphe Zirkone 700 und 800 Ma. Zusammensetzung des Pb-rein: 208/204, 207/204, 206/204: 37.5, 15.5, 17.72.

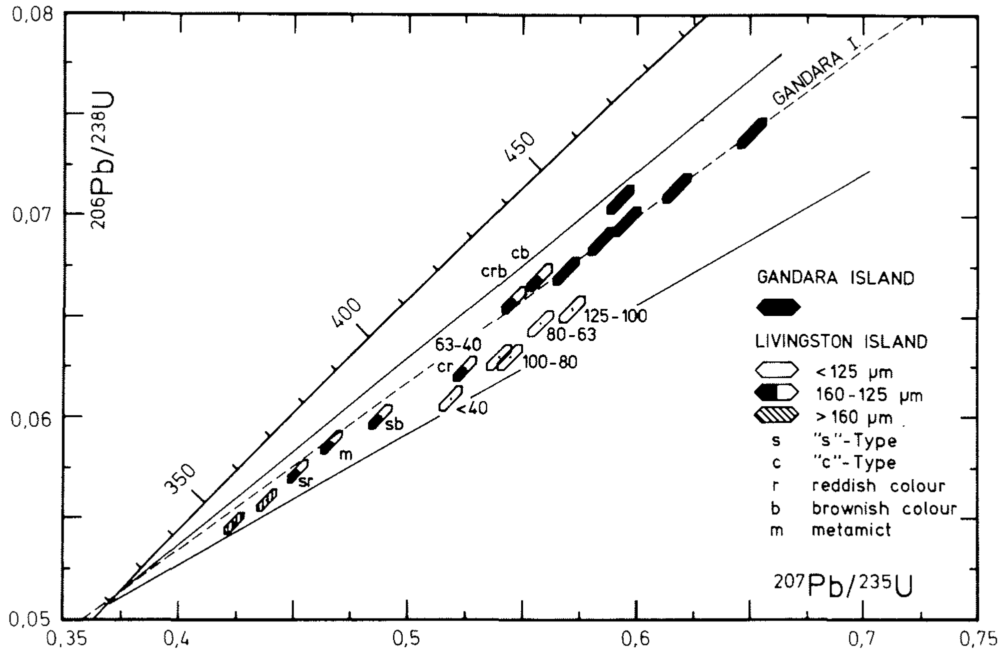

Fig. 3: Concordia diagram of various types of euhedral zircons from Livingston Island and Gandara Island.

Abb. 3: Concordia Diagramm der verschiedenen Typen idiomorpher Zirkone von Livingston und Gandara Island.

logy of the crystals and colour, respectively, and the degree of their rejuvenation. In the grain size fraction 160—125 µm the morphologically complex crystals are less discordant than the simple faced zircons, and the brownish grains are less discordant compared to the reddish ones. The largest zircons (>160 µm) are the most discordant ones.

Since the morphology of the Livingston zircons suggests a crystal growth in a granitoid melting environment, too, we conclude that either the selected fractions are not cogenetic or, that the zircon crystals contain Proterozoic cores of widely varying crystallisation ages. The U-Pb systematics are in accordance with an Early Carboniferous intrusion event, whose existence was proved by the cooling down event of the cogenetic Gandara Island zircons.

The xenomorphic zircons of Gandara Island plot along a chord intersecting the Concordia curve at 595 Ma +19/—21 Ma and 2016 Ma +62/—86 Ma (Fig. 4). The considerable scatter of the U-Pb rations along this regression line confirms a poly-event history for this zircon type. An incomplete Panafrican resetting of the U-Pb systematics is likely.

It is noteworthy that both Gandara zircon types, the euhedral as well as the xenomorphic ones are less discordant than the respective zircons from Livingston Island. This fact may reflect subordinate influence of a Cretaceous metamorphism which affected the Livingston Island sandstone. A more detailed discussion of the U-Pb data is presented in LOSKE et al. (in prep., a, b).

7. ZIRCON PROVENANCE AND GONDWANA RECONSTRUCTION

The today discussed models for a reconstruction of Gondwana can be subdivided into two main groups.

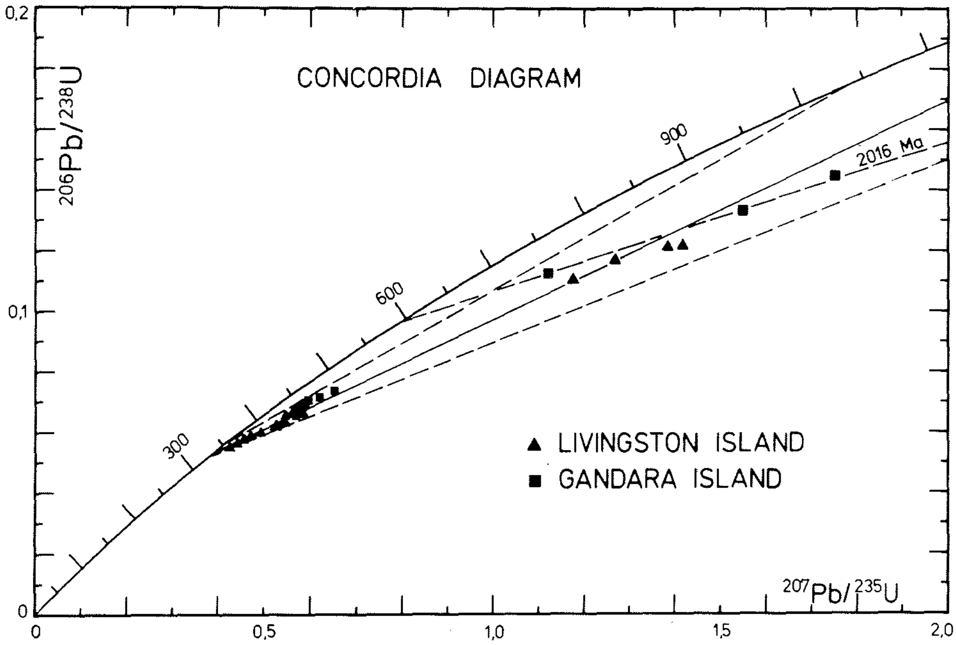

Fig. 4: Concordia diagram of well rounded and euhedral zirkons from Livingston Island and Gandara Island.

Abb. 4: Concordia Diagramm der gut gerundeten und idiomorphen Zirkone von Livingston und Gandara Island.

One group puts main emphasis on a good fit between the Antarctic Craton and the other continents resulting mainly in an eastward position of the Antarctic Peninsula relative to South America (e. g. SMITH & HALLAM 1970). The second group favours a good fit between South America and Westantarctica, presuming a westward or southward position of the Antarctic Peninsula relative to South America (Fig. 5). This presupposes independent movements of the Antarctic Peninsula relative to the Antarctic Craton, but avoids the impossible overlap of the Antarctic Peninsula and the Falkland Plateau.

Palaeomagnetic data (e. g. BARKER & GRIFFITHS 1977) indicate a different wandering of the magnetic poles from the East Antarctic Shield (Antarctic Craton) and the Antarctic Peninsula. Even the Antarctic Peninsula region itself seemes to be subdivided into several small segments having independent histories (BARKER & GRIFFITHS 1977). Various fracture zones, the younger ones today still visible, within the plates may have caused a segmentation of the former sedimentation basin of the Trinity Peninsula Formation (BARKER 1982). Vertical movements ranging up to several kilometers (BARKER 1982) might be responsable for a different tectonic and metamorphic evolution of the sediments in neighbouring tectonic segments. In our opinion this might be an explanation for the equivalent zircon populations found at Elephant Island (LOSKE et al. 1985, SMC) and their possible Trinity Peninsula Formation equivalents southwestwards of the Shackleton Fracture Zone, despite of their different geological aspect. The lithologic similarities between the Mesozoic metasedimentary rocks of the Yaghan Formation of southern South America and the green arenaceous metasediments of northern Elephant Island furthermore emphasize a joint history of both continental tips.

Nearly all euhedral zircons found within probably Carboniferous to Triassic sedimentary rocks at the western side of the Trinity Peninsula and on the South Shetland Islands are of Early Carboniferous age. Morphological features give hints for a granitoid origin. Only some 2% of the zircon grains are well rounded and show further morphological criteria pointing to a polycyclic provenance of Panafrican age.

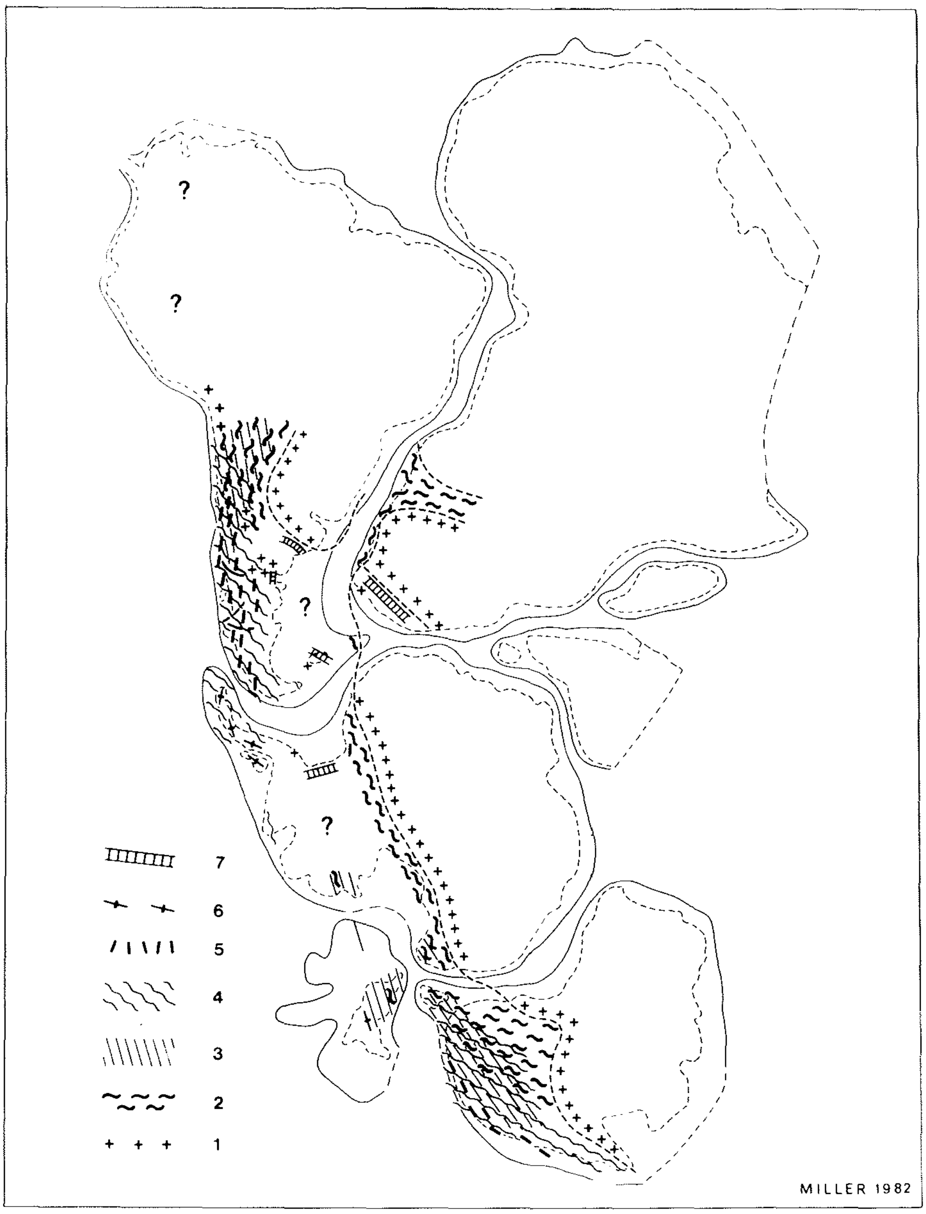

Fig. 5: Gondwana reconstruction based on pre-Andean orogenic belts along the border between the continent and the Proto-Pacific Ocean. 1 = Precambrian basement, 2 = Middle Cambrian to Early Ordovician orogenies, 3 = Late Silurian to Middle Devonian orogenies, 4 = Carboniferous orogenies, 5 = Permo-Triassic orogenies, 6 = Late Triassic to Early Jurassic orogeny, 7 = Palaeozoic aulacogens.

Abb. 5: Gondwana-Rekonstruktion nach der Abfolge präandiner Orogengürtel am pazifischen Rande des Kontinents. 1 = Präkambrisches Grundgebirge, 2 = Mittelkambrische bis frühordovizische Orogenesen, 3 = Spätsilurische bis mitteldevonische Orogenesen, 4 = Karbonische Orogenesen, 5 = Permotriassische Orogenesen, 6 = Spättriassische bis frühjurassische Orogenesen, 7 = paläozoische Aulacogene.

Where might these zircons derive from? Our present knowledge suggests two different source regions: Firstly, the Antarctic Peninsula and West Antarctica itself, secondly, the surrounding Gondwana continents in their pre-drift position. In the Antarctic Peninsula Lower Carboniferous granitoids are poorly known. During the past years several Palaeozoic isotopic ages have been reported (e. g. REX 1976, PANKHURST 1983), but they scatter widely and do not show the remarkable monotony documented by the sedimentary zircons of Cape Legoupil and Livingston Island. Thus it is improbable that the zircons derived from the Antarctic Peninsula.

From Marie Bird Land Early Carboniferous ages have been reported (WADE 1972, HALPERN 1968, 1972), but the good conservation of the euhedral zircons would be unlikely for a such long distance of transport. At other sites of West Antarctica Palaeozoic data occur, but scatter widely without any peak at the Early Carboniferous (STUIVER & BRAZIUNAS 1985). Thus, a derivation of the Early Carboniferous euhedral zircons from West Antarctica cannot be excluded, but is not very probable.

In East Antarctica, excluding the Transantarctic Mountains, dates are mostly Precambrian or Ordovician, other dates are rather scarce; Late Palaeozoic is nearly lacking at all. In Victoria Land Carboniferous ages sometimes do occur, but they are always related to a prevailing Early Palaeozoic history (STUIVER & BRAZIUNAS 1985).

From southern Africa Lower Carboniferous granitoids are not known (TANKWARD et al. 1982, CAHEN et al. 1984). The majority of our sediments, consequently does not derive from this continent.

In southern South America Early Carboniferous (''Hercynian'') dates of granitoid rocks have been reported from several regions (best overview in STIPANICIC & LINARES 1975, LINARES 1977, 1981) of central and southern Argentina. They are not well separated from younger nor from older ages, but recent work in Patagonia revealed above all Carboniferous dates (CAMINOS & PARICA 1985, LLAMBIAS, RAPELA & PARICA 1985). These Rb-Sr determinations of granitoid rocks cover the interval 320—330 Ma, which is exactly the lower intercept age got from Livingston and Gandara Island TPF zircons.

8. CONCLUSIONS

Gondwana reconstructions which juxtapose the Antarctic Peninsula immediately to East Antarctica or to South Africa do not take into account that all or at least great part of the sedimentary zircons in the Carboniferous to Triassic TPF sediments are of Carboniferous age. Therefore they cannot derive from southern Africa, because there are no corresponding rocks known.

In case of an African or East Antarctic source the zircon populations should be a mixture of various Precambrian shield derived grains and clearly defined Cambro-Ordovician ones from the Damara or Ross orogene.

It is, however, not yet possible to decide if the source rocks are situated in the ice-covered vastness of West Antarctica or the Antarctic Peninsula on the one hand, or on the southern tip of South America on the other hand. Both regions show Lower Carboniferous granitoids, both regions are situated in a general geotectonic distance from the shields which allows for accretion of Late Palaeozoic orogens (MILLER 1983 a, b).

Nevertheless, the scarcity of older than Carboniferous zircons is so obvious that the deposition area must have been shielded from older than Variscan orogens and from Precambrian regions anyway. The South Patagonian Massiv and the Falkland Plateau may well have worked as such a barrier. Thus we favour a source area at the NE of the Peninsula (today's coordinates) and a former position of the Peninsula about southwest of Tierra del Fuego before Gondwana's breakup.

9. ACKNOWLEDGEMENTS

We gratefully thank the Alfred-Wegener-Institut für Polar- und Meeresforschung and the Instituto Antártico Chileno for logistical support during the field work. This research was granted by the Deutsche Forschungsgemeinschaft.

References

Aitkinhead, N. (1975): The geology of the Duse Bay — Larsen Inlet area, north-east Graham Land (with particular reference to the Trinity Peninsula Series). — Scient. Rep. Br. antarct. Surv. 51: 62 pp., Cambridge.

Ashcroft, W. A. (1972): Crustal structure of the South Shetland Islands and Bransfield Strait. — Scient. Rep. Br. antarct. Surv. 66; Cambridge.

Barker, P. F. (1982): The Cenozoic subduction history of the Pacific margin of the Antarctic Peninsula: ridge crest-trench interactions. — J. geol. Soc. London 139: 787—801.

Barker, P. F. & Griffiths, D. H. (1972): The Evolution of the Scotia Ridge and Scotia Sea. — Phil. Trans. R. Soc. Lond. A 279: 151—183.

Barker, P. F. & Griffiths, D. H. (1977): Towards a more certain reconstruction of Gondwanaland. — Phil. Trans. R. Soc. Lond. B 279: 143—159.

Burn, R. W. (1984): The geology of the Le May Group, Alexander Island. — Scient. Rep. Br. antarct. Surv. 109: 64 pp., Cambridge.

Cahen, L., Snelling, N. J., Delhal, J. & Vail, J. R. (1984): The geochronology and evolution od Africa. — 512 pp., Oxford.

Caminos, R. & Parica, C. A. (1985): The Significance of new Rb-Sr ages of igneous rocks from northern Patagonia. — Comunicaciones Dep. Geol. Univ. Chile, 35: 41—43.

Craddock, C. (1975): Tectonic evolution of the Pacific margin of Gondwanaland. — In: Campbell, K. S. W. (ed.): Gondwana Geology: 609—618, Canberra.

Dalziel, I. W. D. (1982): The Early (Pre-Middle Jurassic) History of the Scotia Arc Region: A Review and Progress Report. — In: Craddock, C. (ed.), Antarctic Geoscience: 111—126, Madison .

Dalziel, I. W. D. & Elliot, D. H. (1971): Evolution of the Scotia Arc. — Nature 233: 246—252.

Dalziel, I. W. D. & Elliot, D. H. (1973): The Scotia Arc and Antarctic Margin. — In: Nairn, A. E. M. & Stehli, F. G. (eds.): The Ocean Basins and Margins, V. I, The South Atlantic: 171—246, New York.

Elliot, D. H. (1965): Geology of north-west Trinity Peninsula, Graham Land. — Bull. Br. antarct. Surv. 7: 1—24.

Elliot, D. H. (1967): The geology of Joinville Island. — Bull. Br. Antarct. Surv. 12: 23—40.

Fleet, M. (1967): Metamorphosed limestone in the Trinity Peninsula Series of Graham Land. — Bull. Br. Antarct. Surv. 7: 73—76.

Girty, G. H. & Wardlaw, M. S. (1985): Petrology and provenance of pre-Late Devonian sandstones, Shoo Fly Complex, northern Sierra Nevada, California. — Geol. Soc. Amer. Bull. 96: 516—521.

Grauert, B., Hänny, R. & Soptrajanova, G. (1973): Age and origin of detrital zircons from the pre-Permian basement of the Bohemian Massif and the Alps. — Contrib. Mineral. Petrol. 40: 105—130.

Halpern, M. (1968): Ages of Antarctic and Argentine Rocks bearing on Continental drift. — EPSL: 159—167.

Halpern, M. (1972): Rb-Sr total rock and mineral ages from the Marguerite Bay Area, Kohler Range and Fosdick Mountains. — In: Adie, R. J. (ed.), Antarctic Geology and Geophysics: 197—204, Oslo.

Herve, F. & Pankhurst, R. J. (1984): The Scotia Metamorphic Complex at Cape Bowles, Clarence Island, Western Antarctica. — Br. Antarct. Surv. Bull. 62: 15—24.

Herve, F., Marambio, F. & Pankhurst, R. J. (1984): El Complejo Metamórfico de Scotia en cabo Lookout, islas Shetland del Sur, Antártica: evidencias de un metamorfismo cretaćico. — Ser. Cient. INACH, 31: 23—37. Santiago de Chile.

Hyden, G., Tanner, P. W. G. (1981): Late Palaeozoic-early Mesozoic fore-arc basin sedimentary rocks at the Pacific margin in Western Antarctica. — Geol. Rdsch. 70: 529—541.

Krogh, T. E. (1982): Improved accuracy of U-Pb zircon ages by the creation of more concordant systems using an air abrasion technique. — Geochim. Cosmochim. Acta 46: 637—649.

Lacey, W. S. & Lucas, R. C. (1981): The Triassic Flora of Livingston Island, South Shetland Islands. — Br. Antarct. Surv. Bull. 53: 157—173.

Linares, E. (1977): Catálogo de edades radimétricas determinadas para la República Argentina II-Años 1974—1976 Realizados por INGEIS sin publicar I-Años 1972—1974. — Publ. Especiales, AGA, B 4: 38 pp; Buenos Aires.

Linares, E. (1981): Catálogo de edades radimétricas determinadas para la República Argentina IV-Años 1979—1980 Catalogo de edades radimétricas realizadas por INGEIS y sin publicar III-Años 1977—1978. — Publ. Especiales, AGA, B 10: 63 pp; Buenos Aires.

Loske, W. P. (1985): Die Zirkonvarietätenanalyse als Beitrag zur Ermittelung von Sedimentschüttungen im Ebbe-Sattel (Unterdevon, Rheinisches Schiefergebirge). — N. Jb. Geol. Paläont. Abh. 170: 385—417.

Loske, W. P., Miller, H. & Kramm, U. (1985): Dataciones radiométricas U-Pb en rocas de las Islas del grupo Piloto Pardo, Antártica. — Ser. Cient. INACH 32: 39—46.

Loske, W. P., Miller, H. & Kramm, U. (in prep., a): Charakter und Alter der Liefergesteine des Trinitiy Peninsula Formation Metasandsteins bei Cape Legoupil, Antarktische Halbinsel: U-Pb Isotopenuntersuchungen an detritischen Zirkonen.

Loske, W. P., Miller, H. & Kramm, U. (in prep., b): U-Pb systematics of detrital zircons from low-grade metamorphic sandstones of the Trinity Peninsula Formation (Antarctica).

Llambias, E. J., Rapela, C. W. & Parica, C. (1985): Rb-Sr geochronology of La Esperanza Eruptive Complexes, North Patagonian Massif (68'28''W, 40'28''S). — Comunicaciones Dep. Geol. Univ. Chile, 35: 139—143.

Miller, H. (1983a): Gebirgszusammenhänge zwischen Südamerika und der Antarktischen Halbinsel. — N. Jb. Geol. Paläont. Abh. 166: 50—64.

Miller, H. (1983b): The position of Antarctica within Gondwana in the light of Palaeozoic orogenic development. — In: Oliver, R. L., James, P. R. & Jago, J. B. (eds.) Antarctic Earth Science: 579—581, Cambridge.

Pankhurst, R. J. (1983): Rb-Sr constraints on the ages of basement rocks of the Antarctic Peninsula. — In: Oliver, R. L., James, P. R. & Jago, J. B. (eds.) Antarctic Earth Science: 367—371; Cambridge.

Pupin, J. P. (1980): Zircon and Granite Petrology. — Contrib. Mineral. Petrol. 73: 207—220.

Quilty, P. G. (1982): Tectonic and other implications of the Middle-Upper Jurassic rocks and marine faunas from Ellsworth Land, Antarctica. — In: Craddock, C. (ed.) Antarctic Geoscience: 669—678, Madison.

Rex, D. C. (1976): Geochronology in relation to the stratigraphy of the Antarctic Peninsula. — Br. Antarct. Surv. Bull. 43: 49—58.

Silver, L. T. & Deutsch, S. (1963): U-Pb isotopic variations in zircons: a case study. — J. Geol. 71: 721—758.

Smellie, J. L. (1981): A complete arc-trench system recognized in Gondwana sequences of the Antarctic Peninsula region. — Geol. Mag. 118: 139—159.

Smellie, J. L. (1985): Sandstone detrital modes and basinal setting of the Trinity Peninsula Group, Northern Graham Land, Antarctic Peninsula: A Preliminary Survey. — (in press).

Smith, A. G. & Hallam, A. (1970): The fit of the southern continents. — Nature 258: 701—702.

Steiger, R. H. & Jäger, E. (1977): Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology. — Earth Plan. Sci. Lett. 36: 359—362.

Stipanicic, P. N. & Linares, E. (1975): Catálogo de edades radimétricas determinadas para la República Argentina I-Años 1960—1974. — Publ. Especiales AGA, B 3: 42 pp.; Buenos Aires.

Storey, B. C. & Garrett, S. W. (1985): Crustal growth of the Antarctic Peninsula by accretion, magmatism and extension. — Geol. Mag. 122: 5:14.

Stuiver, M. & Braziunas, T. F. (1985): Compilation of Isotopic Dates from Antarctica. — Radiocarbon 27, 2 A: 304 pp.; New Haven.

Tankard, A. J., Jackson, M. P. A., Eriksson, K. A., Hobday, D. K., Hunter, D. R. & Minter, W. E. L. (1982): Crustal evolution of Southern Africa — 3.8 Billion years of Earth history. — 523 pp., New York, Heidelberg, Berlin.

Tanner, P. W. G., Pankhurst, R. J. & Hyden, G. (1982): Radiometric evidence for the age of the subduction complex in the South Orkney and South Shetland Islands, West Antarctica. — J. geol. Soc. London 139: 683—690.

Thomson, M. R. A. (1975): New Palaeontological and Lithological Observations on the Legoupil Formation, North-West Antarctic Peninsula. — Br. Antarct. Surv. Bull. 41/42: 169—185.

Wade, F. A. (1972): Geologic survey of Marie Byrd Land. — Antarct. Jl. U. S. 7: 144—145.