Late Palaeozoic-Early Mesozoic Fore-Arc Basin Sedimentary Rocks at the Pacific Margin in Western Antarctica.

By G. HYDEN & P. W. G. TANNER, Cambridge *)

With 4 figures

Zusammenfassung

Wir folgern, daß die Formationsgruppe der Halbinsel Trinity in der antarktischen Halbinsel in ein Vorderbecken des Kompositentyps abgelagert wurde, das sich zwischen dem aus plutonischen und älteren gneißosen Urgesteinen bestehenden Bogengebirgsmassiv von Gondwana und einem Unterziehungskomplex befindet, der jetzt durch „Grünschiefer“ und „Blauschiefer“ und Albit-Epidot-Hornblende tragenden Gesteine von dem vorjurassischen metamorphen Komplex vertreten wird.

Die Formationsgruppe der Halbinsel Trinity ist hinsichtlich des Typs nochmals geprüft geworden und kann in Hope Bay-, View Point- und Legoupil-Formationen eingeteilt werden. Sedimentgesteine von allen Formationen sind von Turbiditfazies: Metalagerlaven werden zum ersten Mal durch diese Gesteine beschrieben.

Mehrphasige Schichtenfaltung ist in allen Formationen bemerkt geworden, und Regionalmetamorphose erreichte Prehnit- und Pumpellytfazies.

Analysen mit Mikrosonden der Relectpyroxenen in den Lagerlaven weisen darauf hin, daß das Stammagma wahrscheinlich Innenplattealkalibasalt war. Analysen der Schuttgranaten zeigen, daß sie sich von den metamorphen Granaten im Unterziehungskomplex auf Grund von Komposition unterscheiden, was darauf hinweist, daß diese dem Vorderbogenbecken keine bedeutende Belieferung von Material beschaffte.

Eine nahe Ähnlichkeit mit dem Terrane von Torlesse in Neuseeland wird bemerkt und wir schließen daraus, daß eine spätpalaeozoische — frühmesozoische Vorderbogenbeckenumgebung um den Rand des Pazifiks von Südamerika bis Neuseeland fast ununterbrochen erkannt werden kann.

Abstract

We infer that the Trinity Peninsula Group of the Antarctic Peninsula was deposited in a fore-arc basin(s) of composite type located between the Gondwanian arc massif (consisting of plutonic and older gneissose basement rocks) and a subduction complex, now represented by "greenschists", "blueschists" and albite-epidote-hornblende-bearing rocks of the pre-Jurassic metamorphic complex.

The Trinity Peninsula Group has been re-examined in the type area and can be divided into the Hope Bay, View Point and Legoupil Formations. Sedimentary rocks of all formations are of turbidite facies; meta-pillow lavas are described for the first time from these rocks.

Multiphase folding has been observed in all formations and regional metamorphism reached prehnite-pumpellyite facies.

Microprobe analyses of relict pyroxenes in the pillow lavas indicate the parent magma was probably within-plate alkali basalt. Analyses of detrital garnets show that they are different in composition from metamorphic garnets in the subduction complex, indicating that the latter did not supply a significant amount of material to the fore-arc basin(s).

A close similarity with the Torlesse terrane in New Zealand is noted and we conclude that a late Palaeozoic-early Mesozoic fore-arc basin environment can be traced almost continuously around the Pacific margin from South America to New Zealand.

*) Address of authors: G. HYDEN and P. W. G. TANNER, British Antarctic Survey, Natural Environment Research Council, Madingley Road, Cambridge CB3 OET, UK.

Résumé

Nous pensons que le Groupe de la Péninsule Trinity de la Péninsule Antarctique a été déposé dans un bassin de l'arce externe de type composite situé entre le massif de l'arc Gondwanien (composé de roches plutoniques et de gneiss d'un socle plus ancien) et d'un complexe de subduction, représenté actuellement par des « schistes-verts », « schistes-bleus » et des roches ă hornblende, albite et épidote du complexe métamorphique pré-Jurassique. Le Groupe de la Péninsule Trinity a été réexaminé dans la région-type; il peut être subdivisé en formations de Hope Bay, de View Point et de Legoupil. Les roches sédimentaires de toutes les formations sont du faciés turbiditique; pour la premiére fois des laves en coussins mêtamorphisées y sont décrites.

Un plissement multiphasé est observé dans toutes les formations, et le faciés préhnite-pumpellyte marque le métamorphisme régional. Des analyses par microsonde de restes de pyroxene dans les laves en coussins démontrent que le magma parental etait probablement un basalte alcalin. Des analyses de grenats détritiques démontrent que les grenats sont d'une composition différente des grenats métamorphiques dans le complexe de subduction, indiquant que ces derniers n'ont fourni que peu de matériaux au bassin de l'arc externe.

La ressemblance est proche avec le terrain Torlessse de la Nouvelle Zélande et nous concluons qu'un environement de bassin d'arc externe (fin du Paléozoique à début du Mésozoique) peut être tracé presque sans interruption auteur de la marge Pacifique, entre l'Amérique du Sud et la Nouvelle-Zélande.

Краткое содержание

Авторы пришли к выводу, что свиты полуострова Тринити антарктического полуострова отложены в бассейне передней дуги сложного типа, находившимся между дуговым массивом Гондваны, составленными плутонитами и древними гнейсовыми породами фундамента, и субдуцированным комплексом, представлаенным сегодня „зеленым сланцем“, „голубыми сланцами“ и породами, вмещающими альбит, эпидот и роговую обманку из доюрского метаморфоного комплекса. Исследовали свиты полуострова Тринити по их типам и подразделили на формации: Hope Bay, View Point и Legoupil. Осадочные породы всех этих формаций проявляют фаций мути; среднеподушечные давы описаны здесь впервые.

Многофазная складчатoчть слоев отмечена но всех отложениях, а региональный метаморфизм достигает фация Prehnit'а и Pumleppyit'а.

Данные анализа с помощью микрозондов остаточных пироксенов в подушечных лавах указывают на то, что исходная магма, вероятно, являлась внутриплитоным щелочным базальтом. Анализ обломков граната показал, что эти резко отличаются по своему составу от метаморфизированных гранатов в субдуцированном ареале; это говорит о том, что в бассейн передних дуг не поставлялось значительных количеств материала.

Отмечается сходство с областью Torlesse в Новой Зедандии, и авторам кажется, что здесь в позднем палеозое-раннем мезозое простиралась непрерывная дуга от Южной Америки до Новой Зеландии, которая обрамляла Тихий океан.

Introduction

The name Trinity Peninsula Series was introduced by Adie (1957) to describe a sequence of siliceous greywackes and shales found in northern Antarctic Peninsula (Fig. 1). These rocks were mapped in more detail in the 1960s by members of the British Antarctic Survey (Elliot, 1965, 1966, 1967 a; Fleet, 1965, 1968; AITKENHEAD, 1975) and comprehensive summaries of this work have been given by DALZIEL & ELLIOT (1973) and ELLIOT (1975). THOMSON (in press) has formally proposed that the Trinity Peninsula Series be called Trinity Peninsula Formation in the type area. However, in view of recent fieldwork discussed below we propose to upgrade Trinity Peninsula Formation to Trinity Peninsula Group (TPG).

The more important features of the rocks of this group may be summarised as follows:

I) They are of turbidite facies and consist largely of sandstone and mudstone with minor conglomerate, quartzite, chert, greenschist and rare limestone.

II) Age control is poor but the most likely age range is (?) Carboniferous to late Triassic (ADIE, 1957; THOMSON, 1975).

III) The sandstones are arkosic and indicate a source terrain composed dominantly of intermediate to acid plutonic, hypabyssal and volcanic rocks with lesser amounts of metamorphic and sedimentary rocks.

IV) There is no known base to the group and estimates of its thickness are complicated by the deformation but we suggest that the group is at least several kilometres thick.

V) All rocks have been affected by low-grade regional metamorphism and multiphase deformation.

VI) The group is unconformably overlain by middle Jurassic sedimentary and volcanic rocks and has been intruded and locally thermally metamorphosed by 'Andean' plutons.

A better understanding of the TPG is crucial to unravelling the pre-middle Jurassic history of the Antarctic Peninsula and we present the results of a pilot

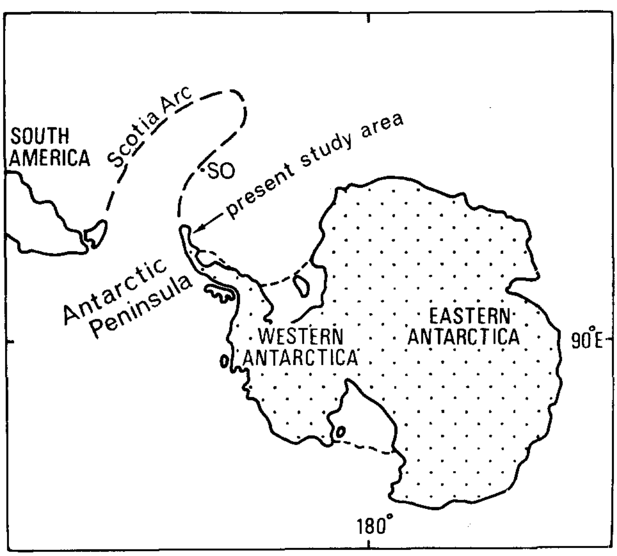

Fig. 1. Sketch map showing present-day positions of Antarctic Peninsula, South Orkney Islands (SO) and South America.

study carried out north of Russell East Glacier (Fig. 2). This work shows that stratigraphic (and probably also structural) relations are more complex than was previously thought and that this group of rocks was probably deposited in a late Palaeozoic — early Mesozoic composite fore-arc basin.

Other formations having similar features include the Miers Bluff Formation (South Shetland Islands), Greywacke-Shale Formation (South Orkney Islands) and the LeMay Formation (Alexander Island) (Fig. 2) (for reference to previous work and discussion, see Dalziel & Elliot, 1973; Elliot, 1975; Dalziel, in press). Relations within the LeMay Formation are complex (R. W. Burn pers. comm. 1979) and it probably encompasses a number of formations of differing age.

Trinity Peninsula Group

Stratigraphy

Recent fieldwork by G. H. in northern Trinity Peninsula from Hope Bay to Russell East Glacier (Fig. 2, inset), suggests that at least three lithological associations occur within the TPG. Each association is considered to be a distinct, mappable unit which extends over a significant area and hence merits formational status. We propose that these lithological associations be named the Legoupil Formation (Halpern, 1965), Hope Bay Formation (for strata around Hope Bay) and View Point Formation (for strata in the area of the Cugnot Ice Piedmont between View Point and Russell East Glacier) (Fig. 2, inset). The

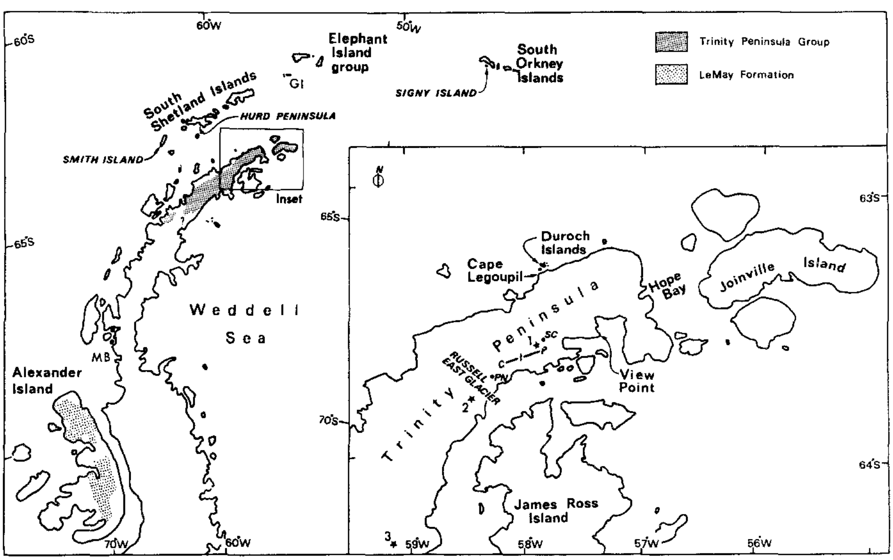

Fig. 2. Outline map of the Antarctic Peninsula showing the main outcrops of the Trinity Peninsula Group (TPG) and LeMay Formation. GI: Gibbs Island; MB: Marguerite Bay. The inset location map shows the only known outcrops (starred, 1—3) of metabasic rocks within the TPG. C-I-P: Cugnot Ice Piedmont; PN: Panhard Nunatak; SC: Stepup Col.

major differences between these formations lie in the varying proportions of fine to coarse grained rocks and the presence of interbedded siliceous sandstone and mudstone units in the View Point Formation. Both the Hope Bay and View Point Formation are marked by an unconformable contact with overlying middle Jurassic sedimentary and volcanic rocks but no base was observed to any of these three formations. Neither the precise age ranges nor the lateral relations of these formations are known.

The Hope Bay Formation

This formation consists of sub-equal proportions of massive and thinly interbedded sandstones and mudstones. Beds are generally upright, gently dipping ($< 50°$) and conform to textural zone 1 of BISHOP (1972).

The View Point Formation

This formation comprises both massive and thinly interbedded sandstones and mudstones and thinly interbedded siliceous sandstone and mudstone units, these latter units being restricted to this formation, and minor amounts of conglomerate. Sandstones form less than 30 % of exposed strata. Beds are generally overturned, with abundant M- and Z-folds and can be classified as belonging to textural zone 2 A (BISHOP, 1972). A deformed oxycone ammonoid was collected from this formation on the northwest side of the Cugnot Ice Piedmont; it has been interpreted as being of probable Mesozoic age by Dr. M. R. A. THOMSON.

The Legoupil Formation

This formation was defined by HALPERN (1965) and consists largely of massive, thinly interbedded sandstones and mudstones. Mudstone is the dominant lithology and massive sandstones are thinner (< 50 cm) than in the other formations. Minor amounts of conglomerate and pebbly mudstone were recorded by HALPERN (1965). Beds are generally upright and belong to textural zone 1 (BISHOP, 1972).

Lithology

Sandstone

Massive, graded sandstones up to 2 m thick are common in the Hope Bay and View Point Formations. A few outcrops show that some of these 'massive' units comprise a series of graded sandstone beds making an amalgamated bed. The component beds are up to several centimetres thick, often have irregular bases, show scour marks and contain mudstone clasts suggesting deposition from a turbidity flow. The massive sandstones have sharp bases and are laterally continuous on a nunatak scale (1—2 km).

Mudstone

Massive, structureless mudstones attain thicknesses of a few metres and rarely contain thin sandier beds. Cleavage is well developed in this lithology in the View Point and Legoupil Formations, but is only poorly developed in the Hope Bay Formation.

Interbedded sandstone and mudstone units

These units, a few centimetres thick, are common in the Hope Bay and View Point Formations. The sandstones are commonly cross-bedded in the Hope Bay Formation but elsewhere they are usually graded. Bases and tops are usually plane-parallel, but parallel wavy partings also occur. Possible syn-sedimentary slumping occurs in this lithology at View Point and Stepup Col (Fig. 2, inset).

Interbedded siliceous sandstone and mudstone units

These units have been observed only in the View Point Formation and have similar sedimentary features to the above lithology. In hand specimen the sandstones are greeny-grey with a vitreous-like surface (?reworked tephra deposits).

Conglomerates

Conglomerates are restricted to the View Point area in the present study but have been recorded from near Mt. Bradley and Longing Gap (both south of Russell East Glacier) (Aitkenhead, 1975) and from the Duroch Islands (Fig. 2, inset) (Halpern, 1965). At View Point they occur as organised and disorganised beds and vary in thickness from 0.3—3.0 m. They contain clasts of granite, diorite, acidic and lesser amounts of basic volcanic rocks, schist and ?low-grade metasedimentary rocks (intraformational clasts). They are clast supported.

Sandstones, mudstones and siliceous sandstones of the thinly interbedded facies are commonly less than 5 cm thick and may represent distal turbidites, levée deposits or contourites. These rock types often occur in conjunction with massive sandstones, massive mudstones, or both, where they are thought to represent levée deposits associated with a meandering channel.

The sedimentary sequences observed in Northern Trinity Peninsula could be produced in a fan environment, the amalgamated and massive sandstones being deposited in channels, the interbedded sandstones and mudstones as levée or overbank deposits and the mudstones as a blanket deposit over the fan.

Pillow lavas

Metamorphosed pillow lavas and hyaloclastites (found by R. D. Hamer & M. C. Sharp) are described for the first time from the TPG. They occur in the View Point Formation and together with two previously recorded outcrops of metabasalt (Aitkenhead, 1975) and three of greenschist (Elliot, 1966) are the only known rocks in the TPG with a basic composition. The pillow lavas vary from close-packed to isolated forms, are significantly vesicular and attain maximum dimensions of about 2 m. The associated hyaloclastites are interbedded with sandstones that are indistinguishable from other sandstones in the TPG, and both hyaloclastites and sandstones show a deformation style similar to that of the first phase of ductile folding observed elsewhere in this area.

Structure

Rocks of the TPG north of Russell East Glacier have undergone two main episodes of ductile deformation: an early phase of folding associated with the development of a penetrative cleavage, and a later phase in which a crenulation cleavage and lineation were formed.

The first phase produced mainly small-scale isoclinal folds trending roughly NE/SW with plunges showing extreme variation from horizontal to vertical. The associated axial planar cleavage is developed in mudstones and more rarely in fine-grained sandstones; away from fold closures it becomes parallel with bedding. Both the axial planes of the folds and cleavage dip towards the Pacific at angles of 60° to 80°. With the exception of a major anticline on Panhard Nunatak (Aitkenhead, 1975) (Fig. 2, inset), traceable to the adjacent nunatak to the north, and one outcrop at View Point, recognisable folding of this generation is restricted to the fine grained rocks and thinly interbedded units. Graded bedding and the distribution of Z- and S-minor folds suggest the beds are overturned southeast of a northeast trending line through Panhard Nunatak and upright to the northwest of this line.

The second phase of folding produced more open folds trending approximately NE/SW, refolding the first phase folds and associated cleavage and only very locally developing an axial planar fabric. They have axial planes which trend at 000° to 120° and dip at 50° to 70° to the northwest.

A more brittle phase of deformation occurred at View Point where tectonic inclusions of interbedded conglomerates and sandstones (to 60 m) are present in the more normal sedimentary facies described above, giving rise to a broken formation (Berkland et al., 1972). The bedding/cleavage relations in any one outcrop around the inclusions are constant but both bedding and cleavage are seen to deviate markedly around the inclusions. We infer from these structural relations that the broken formation developed later than the first phase of folding.

Although gentle folding (Aitkenhead, 1975, p. 55) and localised cleavage development are seen in the overlying Jurassic rocks, the two main phases of folding are restricted to the TPG and are of a Gondwanian age.

Metamorphism

The few available geochemical analyses of the TPG (Elliot, 1967 b; Tanner & Hyden, unpub. data) show low CaO (wt. % < 3 %) and up to 0.6 wt. % of CO_2 and have a chemical composition which is unlikely to result in low-grade metamorphic minerals diagnostic of any one facies. Petrographic examination of these rocks has not recorded zeolite minerals or new biotite growth (Aitkenhead, 1975) and prehnite is rare. Pumpellyite has not been recorded from TPG sedimentary rocks but the associated meta-pillow lavas contain both prehnite and pumpellyite. However, caution must be exercised in interpreting the pressure-temperature conditions under which TPG rocks have been metamorphosed since the occurrence of both prehnite and pumpellyite is not restricted to the prehnite-pumpellyite facies (cf. Coombs, 1954; Boles and Coombs, 1977).

From the poor development of low-grade diagnostic metamorphic minerals in the TPG north of Russell East Glacier, we suggest that metamorphic conditions reached the prehnite-pumpellyite facies.

Boles and Coombs (1977) tentatively suggested prehnite and pumpellyite formed at approximately 90° und 190° respectively in the sedimentary rocks of the Murihiku Supergroup. We suggest that metamorphic temperatures in the area around the pillow lavas were probably at least 190° C, and that rocks of the TPG were affected by medium to high pressure metamorphism.

Mineralogy

Two minerals from the TPG have been analysed by electron microprobe: detrital garnets from the coarse sandstones and fine conglomerates and relict pyroxenes from the meta-pillow lavas and metabasalts.

Garnet

Garnet is an uncommon mineral in the TPG. It was first reported by AITKENHEAD (1975) in sandstones from View Point and from Hurd Peninsula by SMELLIE (1979) (Fig. 2). The detrital garnets are almandine-rich with some substitution of calcium and magnesium for ferrous iron. They are sufficiently richer in Mg to differentiate them from garnets which we have analysed from the pre-Jurassic metamorphic suite (Fig. 3) occurring in the South Orkney and South Shetland Islands (Fig. 2). We conclude that the analysed detrital garnets were not derived from the pre-Jurassic metamorphic suite.

Pyroxene

Relict pyroxene occurs in the meta-pillow lavas from north of the Cugnot Ice Piedmont (loc. 1, Fig. 2) and from interbedded metabasalts near Mt. Tucker and Victory Glacier (locs. 2 & 3, Fig. 2) (AITKENHEAD, 1975).

Analyses of these pyroxenes plotted on the Di-Wo-Fs triangle (Fig. 4 a) have alkaline affinities although one rock shows a possible quench trend towards the non-alkaline field of LE BAS (1962). The same analyses plotted on the TiO_2-MnO-

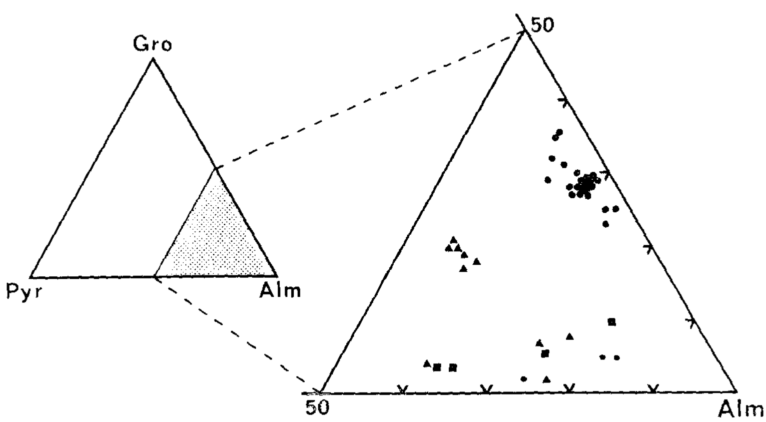

Fig. 3. Comparison of the chemistry of detrital garnets from the TPG with that of garnets from metamorphic assemblages in the pre-Jurassic metamorphic complex. Locations of samples: squares, View Point, (TPG) (D. 3877.0 & D. 3807.2); triangles, View Point, (TPG) (R. 751.2 & R. 769.1); small circles, Miers Bluff Formation (= TPG) (P. 43.1) and large circles, pre-Jurassic metamorphic complex from several localities within the South Orkney and South Shetland Islands (HYDEN & TANNER, unpubl. data).

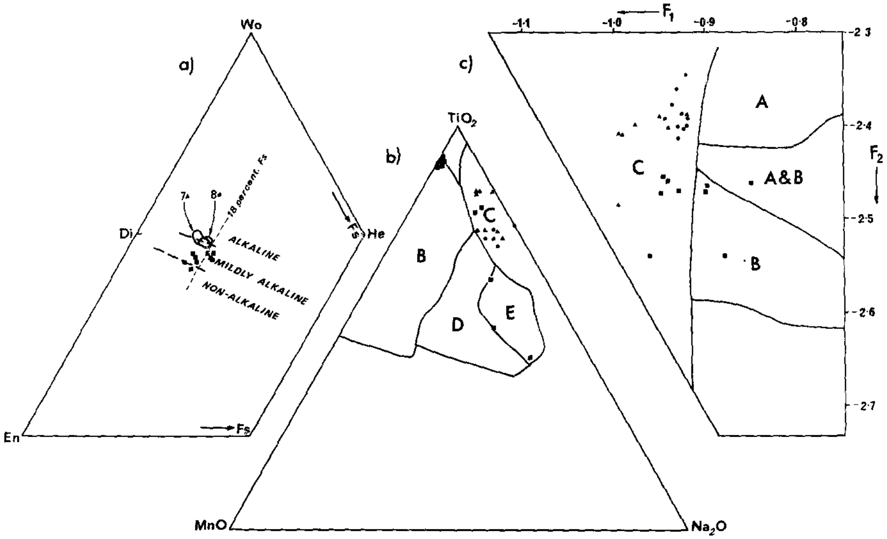

Fig. 4. Analyses of relict igneous pyroxenes from metabasic rocks of TPG. a) En-Wo-Fs diagram showing the alkaline, mildly alkaline and non-alkaline fields of LE BAS (1962); b) TiO_2-MnO-Na_2O diagram for discriminating between pyroxenes from different magma types (NISBET & PEARCE, 1977) and c) Plot of discriminant functions F_1 against F_2 for pyroxene analyses from basic lavas of various magma types (NISBET & PEARCE, 1977). The fields on b) and c) are as follows: A, volcanic arc basalts; B, ocean-floor basalts; C, within-plate alkali basalts; D, all basalts; E, volcanic arc, within-plate tholeiite and within-plate alkali basalts. Triangles, R. 650.2, loc. 1, Fig. 2; squares, D. 3923.3, loc. 2, Fig. 2; Circles, D. 4268.1, loc. 3, Fig. 2.

Na_2O triangle and F_1 vs. F_2 diagram of NISBET and PEARCE (1977) (Fig. 4 b & c) suggest that the original tectonic environment and magma type was within-plate alkaline basalt. This interpretation argues against the possibility that the metabasalts were generated at a mid-ocean spreading centre or in an island arc environment. However, the analyses compare well with pyroxene analyses from a fracture zone in the north Atlantic (SHIBATA et al., 1979, analyses 11 & 12, Table 1, p. 131), and we suggest that the pillow lavas and metabasalts from the TPG originated in a fracture zone in an oceanic plate.

Depositional setting

The outcrop of the TPG lies between the inferred position of a trench which resulted from subduction of Pacific ocean floor during the late Palaeozoic — early Mesozoic (SMELLIE & CLARKSON, 1975; RIVANO & CORTÉS, 1976) and the corresponding volcanic arc. "Blueschists", "greenschists" and albite-epidote-hornblende-bearing rocks found in the South Orkney and South Shetland Islands probably belong to the pre-Jurassic subduction complex (SMELLIE & CLARKSON, 1975; SUÁREZ, 1976; DALZIEL, in press; HYDEN & TANNER, in prep.), but the age of most of this complex has not been directly substantiated. The position of the arc massif is more difficult to define: the most compelling evidence so far comes from Marguerite Bay (Fig. 2) where gneisses thought to be part of the Gondwanian arc give an apparent Rb-Sr isochron of 175 ± 7 Ma (GLEDHILL et al., in press). Plutonic rocks of late Palaeozoic — early Mesozoic age have proved difficult to identify by radiometric dating, but the presence of a gneissose basement older than at least the younger part of the TPG on the eastern side of the Antarctic Peninsula is suggested by concordant biotite and hornblende K-Ar ages of 237—243 Ma (REX, 1976; GLEDHILL et al., in press).

The TPG is considerable less deformed and metamorphosed than members of the subduction complex and the rocks retain primary features that are no longer recognisable in the latter. SUÁREZ (1976) suggested that the TPG was deposited in a fore-arc situation close to the contemporary trench; DALZIEL (in press) has inferred deposition in a trench or 'mid-slope' basin and SMELLIE (1979) has refined these suggestions and proposed a fore-arc basin setting similar to that recently suggested for the Great Valley sequence in California by DICKINSON & SEELY (1979). We support Smellie's proposal and draw attention to a present day analogue seen off the west coast of South America where a series of discontinuous fore-arc basins occur between a structural high sited on the subduction complex and the present coastline (COULBOURN & MOBERLY, 1977). The basins contain turbidites and are separated by basement culminations. MANSFIELD (1979) from work on the Great Valley sequence has also stressed the discontinuous nature of sedimentary sequences in fore-arc basins and the problems of correlating separate formations over distances as small as 10 to 20 km.

The TPG appears to have been deposited in a basin whose floor consists in part of the (?) deeply eroded arc massif. To the north the contact with rocks of the subduction complex is seen only in the South Orkney Islands, where DALZIEL et al., (1977) have reported a metamorphic/structural transition and stratigraphic correlation between the Greywacke-Shale Formation and the pre-Jurassic metamorphic complex. We infer that this contact, across which there has been considerable telescoping in degree of deformation and metamorphic PT conditions, is a zone of high strain (? thrust contact) which has evolved over a long period between the subduction complex and the sedimentary rocks of the fore-arc basin, and that no correlation of rock units across the zone is possible.

The Gibbs Island dunite/serpentinite complex (TYRRELL, 1945; DE WIT et al., 1977) is a dismembered ophiolite sequence preserved on Gibbs Island (Fig. 2). It forms a southerly dipping sheet which is separated from the underlying subduction complex by a major shear zone. The tectonic position of this slice of oceanic crust is difficult to explain but we list three possible explanations:

a) it represents mantle intrusion in a transform fault which subsequently underwent ocean-floor deformation and emplacement into its present position within the fracture zone or in a trench environment (DE WIT et al., 1977).
b) it could be the only exposed portion of trapped oceanic crust underlying the western part of the TPG basin.
c) it may be a sliver of oceanic crust accreted into the trench pile during the subduction process.

From the fragmentary evidence which is available we conclude that the TPG was deposited in a fore-arc basin(s), probably of composite type with a floor partly of sialic crust (eroded plutons and volcanic rocks; older metamorphic basement) and partly of trapped oceanic (Pacific) crust. Evidence from the composition of detrital garnets in the TPG suggests that the subduction complex, in which garnetbearing assemblages are common, was not a significant source of sediment. Pillow lavas within the sequence were probably formed in a transform fault or fracture zone but their mechanism of emplacement is not known. An anomalous outcrop of undeformed fossiliferous Triassic rocks occurs at Williams Point in the South Shetland Islands (ORLANDO, 1968). These beds were probably deposited in a small basin on the subduction complex in the region of a structural high (SMELLIE, 1979).

Comparison with other sequences along the Pacific margin of Gondwana

Scotia Arc and Trinity Peninsula

Lithologic, petrographic and structural features of the three formations which make up the TPG are similar. Other formations having similar features were mentioned above (p. 532) and are critically discussed by DALZIEL & ELLIOT (1973).

New Zealand

Attention has previously been drawn to the close similarities between the pre-Jurassic rocks, mainly Trinity Peninsula Group of the Antarctic Peninsula, and similar sequences in the Madre de Dios basin of South America (DALZIEL & ELLIOT, 1971, 1973; DALZIEL, in press).

Re-examination of part of the TPG has led us to make an equally close comparison with another late-Palaeozoic — Mesozoic sequence found along the Pacific margin — the Torlesse terrane of New Zealand.

The Torlesse terrane (COOMBS et al., 1976) has the following features in common with the TPG:

I) It consists of greywacke and argillites deposited in a deep water fan. Chert, red and green argillite and limestone are uncommon.

II) Sparse faunal assemblages range in age from Late Carboniferous (JENKINS & JENKINS, 1971) to Early Cretaceous (CAMPBELL & WARREN, 1965).

III) It is derived from an unknown mixed provenance of plutonic and sedimentary rocks and lesser amounts of volcanic rocks; similar to TPG in mean wt. % of SiO_2, Na_2O and K_2O (REED, 1957; ELLIOT, 1967 b; TANNER & HYDEN, unpub. data), although the number of analyses is small.

IV) It contains coarsely vesicular meta-pillow lavas that are not accompanied by other members of an ophiolite suite and are in some cases of alkali basalt parentage.

V) Multiphase deformational history with steeply plunging and overturned folds (LILLIE & GUNN, 1964) and mélange zones (BRADSHAW, 1973).

VI) Low-grade metamorphism, mainly of zeolite and prehnite-pumpellyite facies.

In the reconstruction of the South Pacific by MOLNAR et al. (1975) the Torlesse terrane is situated close to Marie Byrd Land. It is therefore not inconcievable that rocks of the Madre de Dios basin, Trinity Peninsula Group and related formations and the Torlesse terrane were deposited in a complex extended series of fore-arc basins along the Pacific margin of Gondwana during late Palaeozoic to Mesozoic times.

Acknowledgements

We would like to thank colleagues for discussions and for critically reading the manuscript.

References

ADIE, R. J.: The petrology of Graham Land: III. Metamorphic rocks of the Trinity Peninsula Series. — Scient. Rep. Falkld. Isl. Depend. Surv. 20, 26 pp., London 1957.

AITKENHEAD, N.: The geology of the Duse Bay-Larsen Inlet area, Northeast Graham Land. — Sci. Rep. Br. Antarct. Surv. 51, 62 pp. London 1975.

BERKLAND, J. O., RAYMOND, L. A., KRAMER, J. C., MOORES, E. M. & O'DAY, M.: What is Franciscan? — Bull. Am. Ass. Petrol. Geol. 56, pp. 2295—2302, Chicago 1972.

BISHOP, D. G.: Progressive metamorphism from prehnite-pumpellyite to greenschist facies in the Dansey Pass area, Otago, New Zealand. — Bull. geol. Soc. Am. 83, pp. 3177—3197. Rochester, New York 1972.

BOLES, J. R. & COOMBS, D. S.: Zeolite facies alteration of sandstone in the Southland Syncline, New Zealand. — Am. J. Sci. 277, pp. 982—1012, New Haven 1977.

BRADSHAW, J. D.: Allochthonous Mesozoic fossil localities in mélange within the Torlesse rocks of North Canterbury. — J. R. Soc. N. Z. 3, pp. 161—167. Wellington 1973.

CAMPBELL, J. D. & WARREN, G.: Fossil localities of the Torlesse Group in the South Island. — Trans. R. Soc. N. Z. Geology, 3, pp. 99—137. Dunedin 1965.

COOMBS, D. S.: The nature and alteration of some Triassic sediments from Southland. — Trans. R. Soc. N.Z. 82, pp. 65—109. Dunedin 1954.

COOMBS, D. S., LANDIS, C. A., NORRIS, R. J., SINTON, J. M., BORNS, D. J. & CRAW, D.: The Dun Mountain ophiolite belt, New Zealand, its tectonic setting, constitution and origin with special reference to the southern portion. — Am. J. Sci. 276, pp. 561—603. New Haven 1976.

COULBOURN, W. T. & MOBERLY, R.: Structural evidence of the evolution of fore-arc basins off South America. — Can. J. Earth Sci. 14, pp. 102—116. Ottawa 1977.

DALZIEL, I. W. D.: The pre-Jurassic history of the Scotia Arc: A review and progress report. — 3rd Symposium on Antarctic Geology and Geophysics Madison 1977, in press.

DALZIEL, I. W. D. & ELLIOT, D. H.: Evolution of the Scotia Arc. — Nature 233, pp. 246—252. London 1971.

—: The Scotia arc and Antarctic margin. — In: The ocean basins and their margins: 1. The South Atlantic (F. G. Stehli & A. E. M. Nairn, eds.), pp. 171—246, New York 1973.

DALZIEL, I. W. D., ELLIOT, D. H., THOMSON, J. W., THOMSON, M. R. A., WELLS, N. A. & ZINSMEISTER, W. J.: Geologic studies in the South Orkney Islands, R/V Hero Cruise 77-1, January 1977. — Antarct. J. U. S. 12, pp. 98—101. Washington, D. C. 1977.

DICKINSON, W. R. & SEELY, D. R.: Structure and stratigraphy of fore-arc regions. — Bull. Am. Ass. Petrol. Geol. 63, pp. 2—31. Chicago 1979.

ELLIOT, D. H.: Geology of north-west Trinity Peninsula, Graham Land. — Bull. Br. Antarct. Surv. 7, pp. 1—24. London 1965.

—: Geology of the Nordenskjöld Coast and a comparison with northwest Trinity Peninsula, Graham Land. — Bull. Br. Antarct. Surv. 10, pp. 1—43. London 1966.

—: The geology of Joinville Island. — Bull. Br. Antarct. Surv. 12, pp. 23—40. London 1967 a.

—: The geochemistry of rocks from the Nordenskjöld Coast and north-west Trinity Peninsula. — Bull. Br. Antarct. Surv. 11, pp. 83—95. London 1967 b.

—: Tectonics of Antarctica: a review. — Am. J. Sci. 275 A, pp. 45—106. New Haven 1975.

FLEET, M.: Metamorphosed limestone in the Trinity Peninsula Series of Graham Land. — Bull. Br. Antarct, Surv. 7, pp. 73—76. London 1965.

—: The geology of the Oscar II Coast. — Sci. Rep. Br. Antarct. Surv. 59, 46 pp. London 1968.

GRIKUROV, G. E.: Tectonics of the Antarctandes. — In Antarctic Geology and Geophysics (R. J. Adie, ed.), pp. 163—167. Oslo 1972.

GRIKUROV, G. E. & DIBNER, A. F.: New data on the Trinity Series (C_{1-2}) in West Antarctica. — Dokl. Akad. Nauk SSSR. 179, pp. 410—412. Leningrad 1968.

GLEDHILL, A., REX, C. D. & TANNER, P. W. G.: Rb-Sr and K-Ar geochronology between Anvers Island and Marguerite Bay. — In 3rd Symposium on Antarctic Geology and Geophysics, Madison 1977. Madison, in press.

HALPERN, M.: The geology of the General Bernado O'Higgins area, northwest Antarctic Peninsula. — In Geology and Paleontology of the Antarctic (J. B. Hadley, ed.), Antarct. Res. Ser. 6, pp. 177—209. Washington, D. C. 1965.

JENKINS, D. G. & JENKINS, T. B. H.: First diagnostic Carboniferous fossils from New Zealand. — Nature 233, pp. 117—118. London 1971.

LEBAS, M. J.: The role of aluminium in igneous clinopyroxenes with relation to their parentage. — Am. J. Sci. 260, pp. 267—288. New Haven 1962.

LILLIE, A. R. & GUNN, B. M.: Steeply plunging folds in the Sealy Range, Southern Alps. — N. Z. J. Geol. Geophys. 7, pp. 403—423. Wellington 1964.

MANSFIELD, C. F.: Upper Mesozoic subsea fan deposits in the southern Diablo Range, California: Record of the Sierra Nevada magmatic arc. — Bull. geol. Soc. Am. Part 1, 90, pp. 1925—1946. Rochester 1979.

MOLNAR, P., ATWATER, T., MAMMERICKX, J. & SMITH, S. M.: Magnetic anomalies, bathymetry and the tectonic evolution of the South Pacific since the late Cretaceous. — Geophys. J. R. astr. Soc. 60, pp. 383—420. London 1975.

NISBET, E. G. & PEARCE, J. A.: Clinopyroxene composition in mafic lavas from different tectonic settings. — Contrib. Mineral. Petrol. 63, pp. 149—160. Berlin 1977.

ORLANDO, H. A.: A new Triassic flora from Livingston Island, South Shetland Islands. — Bull. Br. Antarct. Surv. 16, pp. 1—13. London 1968.

REED, J. J.: Petrology of the lower Mesozoic rocks of the Wellington district. — Bull. geol. Surv. N. Z. 57, 60 pp. Wellington 1957.

REX, D. C.: Geochronology in relation to the stratigraphy of the Antarctic Peninsula. — Bull. Br. Antarct. Surv. 43, pp. 49—58. London 1976.

RIVANO, S. & CORTÉS, R.: Note on the presence of the lawsonite-sodic amphibole association on Smith Island, South Shetland Islands, Antarctica. — Earth Planet. Sci. Lett. 29, pp. 34—36. Amsterdam 1976.

SCHOPF, J. M.: Plant material from Miers Bluff Formation in the South Shetland Islands. — Rep. Inst. Polar Stud. Ohio State Univ. 45, Columbus 1973.

SHIBATA, T., THOMPSON, G. & FREY, F. A.: Tholeiitic and alkali basalts from the Mid-Atlantic Ridge at 43 °N. — Contrib. Mineral. Petrol. 70, pp. 127—141. Berlin 1979.

SMELLIE, J. L.: Aspects of the geology of the South Shetland Islands. — Unpub. Ph. D. thesis, University of Birmingham, UK. 198 pp. 1979.

SMELLIE, J. L. & CLARKSON, P. D.: Evidence for pre-Jurassic subduction in Western Antarctica. — Nature 258, pp. 701—702. London 1975.

SUÁREZ, M.: Plate-tectonic model for southern Antarctic Peninsula and its relation to southern Andes. — Geology 4, pp. 211—214. Boulder, Colorado 1976.

THOMSON, M. R. A.: New palaeontological and lithological observations on the Legoupil Formation, North-west Antarctic Peninsula. — Bull. Br. Antarct. Surv. 41 & 42, pp. 169—185. London 1975.

TYRRELL, G. W.: Report on rocks from West Antarctica and the Scotia Arc. — 'Discovery' Rep. 23, pp. 37—102. Cambridge, UK. 1945.

DE WIT, M. J., DUTCH, S., KLIGFIELD, R., ALLEN, R. & STERN, G.: Deformation, serpentinisation and emplacement of a dunite complex, Gibbs Island, South Shetland Islands: Possible fracture zone tectonics. — J. Geol. 85, pp. 745—762. Chicago 1977.