ACCRETIONARY COMPLEXES NORTH OF THE ANTARCTIC PENINSULA

TROUW, R.A.J., RIBEIRO, A. and PACIULLO, F.V.P. Federal University of Rio de Janeiro, Brazil.

Summary

Metamorphic successions with a large proportion of ocean floor material, named the Scotia metamorphic complex, have been interpreted as representing accretionary complexes, related to the Mesozoic-Cenozoic Antarctic Peninsula magmatic arc. According to metamorphic age three units can be identified: the South Orkney Islands with ages of 180-200 Ma, the Elephant Island group with ages in the range 90-110 Ma, and Smith Island with ages around 50 Ma. These units show similar deformational structures although with different orientation. A first deformation phase, D_1, associated with the growth of relatively high pressure metamorphic minerals, including blue amphibole, records southward subduction with respect to the present geographic position of these islands. A second phase appears to represent collision with an ocean plateau or sea-mount, resulting in intense refolding of D_1 structures, with a sinistral strike-slip component at Elephant Island. These local collisions seem to have provided suitable conditions for preservation. Metamorphic conditions during D_2 are at higher temperature but lower pressure as compared to D_1. Later structures, labelled D_3, are related to heterogeneous uplift and regional rotation, under declining metamorphic conditions.

The deformation and metamorphism of the Trinity Peninsula Group and correlatives, composed of Permo-Triassic tubidite successions, show several features similar to the Scotia metamorphic complex. Although these were deposited along an inactive continental margin they were, during the Jurassic, involved in accretionary wedge deformation as testified by their structural style.

Introduction

Subduction of Pacific Ocean floor underneath the Antarctic Peninsula during most of the Mesozoic and Cenozoic, produced the Antarctic Peninsula batholith and associated volcanic rocks (Leat et al. 1995; Pankhurst and Millar, this volume). The host rocks of this batholith are sparsely exposed orthogneisses of Palaeozoic age (Pankhurst and Millar, this volume) and Permo-Triassic turbiditic submarine fan sequences known as the Trinity Peninsula Group and correlatives. Few, isolated fragments of metamorphic sequences, referred to as the Scotia metamorphic complex (Tanner et al., 1982; Dalziel, 1984) constitute remnants of accreted subduction complexes, that crop out along the northern border of the peninsula, on the South Shetland and South Orkney islands (Fig. 1). According to metamorphic age (Tanner et al., 1982; Hervé et al., 1990, 1991; Trouw et al., 1990, 1997a; Grunow et al., 1992) three units can be distinguished, the succession that crops out on the western South Orkney Islands with ages of 180-200 Ma, the succession exposed at the Elephant Island group with ages mainly in the range 90-110 Ma, and the rock units underlying Smith Island with ages of about 50 Ma. The objective of this paper is to review the current knowledge of the evolution of these subduction complexes.

South Orkney Islands

These islands are the exposed part of a microcontinental block, now separated from the Antarctic Peninsula by the Powell basin. The eastern part of the islands is underlain by the Greywacke-Shale Formation, considered to be equivalent to the Trinity Peninsula Group on the mainland. It is essentially a continent derived turbidite sequence, with associated diamictites and a single chert occurrence (Scapa Rock, Dalziel, 1984), bearing Triassic microfossils (Dalziel et al., 1981). The formation is metamorphosed to prehnite-pumpellyite facies and deformed to a predominantly steep-standing position. The rock units that crop out in the western part of the islands are part of the Scotia metamorphic complex. They are predominantly garnet albite biotite schists with intercalations of amphibolites, calcsilicate rocks and metachert rich in garnet. The composition of these rocks points to an ocean floor environment (Storey and Meneilly, 1985). The metamorphism is of albite-epidote amphibolite facies and the deformation is intense and polyphase. In the central part, a gradual transition between the Greywacke-Shale Formation and the metamorphic complex was reported (Dalziel, 1984; Trouw et al., 1997b). At Powell Island, a gradual transition in metamorphic grade from prehnite-pumpellyite facies in the south, to biotite garnet schists of the upper greenschist facies in the north, is documented by the appearance of three isograds. These are, from lower to higher grade, the garnet isograd, the biotite isograd and an “abundant” biotite isograd. The order of these isograds and b_0 data from white mica (Trouw et al., 1997a,b) point to relatively high pressures. For this reason and also because of the structural style and the rock types involved, the deformation and associated metamorphism were interpreted as related to subduction in early to middle Jurassic times. Meneilly and Storey (1986) and Storey and Meneilly (1985) reached a similar conclusion for the metamorphic successions of Signy Island, western South Orkney Islands.

Apart from a general description of the structures (Dalziel, 1984), the structural evolution was studied in detail at Signy Island (Meneilly and Storey, 1986) and at Powell Island (Trouw et al., 1997b). Five phases of deformation (D_1-D_5)

were recognised at Powell Island. The first three, defined respectively by the creation of a penetrative slaty cleavage (S_1) during D_1, folding of S_1 during D_2, and refolding of S_1 and D_2 structures during D_3, were related to southward subduction with respect to the present orientation of the islands. The fourth phase (D_4) produced north-south extensional structures under retrograde metamorphic conditions, related to uplift. These movements resulted, by the end of Jurassic time, in the exposure of the metamorphic sequence. This is evident from the presence of Late Jurassic to Early Cretaceous alluvial fan deposits (Spence Harbour and Powell Island Conglomerate; Elliot and Wells, 1982) covering the metamorphic sequences unconformably and containing abundant detrital fragments of the metamorphics. The final uplift and erosion in Cenozoic times was accompanied by brittle deformation (D_5) that affected the conglomerates as well.

In conclusion it may be stated that the reason for uplift of this part of the metamorphic complex may have been the D_4 extension, possibly related to the break-up of Gondwana.

Elephant Island group

Introduction

This group includes, apart from Elephant Island itself, Clarence Island and the Gibbs Island group, including Gibbs, Aspland, Eadie and O'Brien islands. The main rock types are grey, green and locally blue phyllites and schists. Amphibolite is also common in the higher grade parts and metachert, marble and calc-silicate rocks occur at many outcrops as intercalations of up to about one metre thick. A large ultramafic sheet at Gibbs Island was described by de Wit et al. (1977). The chemistry of mafic rocks indicates them to be derived from ocean floor and oceanic island tholeiitic basalts (Valeriano et al., 1997). Other rock types are probably derived from ocean floor sediments and from arc and/or continent derived turbidity current sediments.

Metamorphism

Seven metamorphic zones, separated by isograds, were mapped on Elephant Island (Trouw et al., 1998a). They accompany the gradual increase in metamorphism from pumpellyite-actinolite facies in the north, to crossite-epidote blueschist facies, to greenschist facies, to epidote-amphibolite facies and finally to amphibolite facies in the south. The isograds are respectively: (1) pumpellyite-out, approximately coinciding with blue amphibole-in, (2) spessartine-in in metachert, (3) almandine-in, (4) blue amphibole-out, green amphibole-in, (5) biotite-in and (6) oligoclase-in. The metamorphism of Clarence Island is roughly comparably to the low-grade north-eastern part of Elephant Island, whereas the Gibbs Island group correlates with the biotite zone, between isograds (5) and (6).

Based on geothermobarometry peak metamorphic conditions were estimated to be about 7 kbar and 350°C along isograd (1) and 5 kbar and 500°C along isograd (6), with clockwise P-T-t paths (Trouw et al., 1998a).

Structures

The structure of this part of the complex is described by Dalziel (1984), Grunow et al. (1992) and Trouw et al. (in press). The following summary is based on the latter publication.

At Elephant Island, a first deformation phase, D_1, produced a strong SL fabric with steep stretching and mineral lineations, partly defined by relatively high pressure minerals, such as crossite and glaucophane. D_1 is interpreted to record southward subduction along an E-W trench with respect to the present position of the island. A second phase, D_2, led to intense folding with steep E-W trending axial surfaces. The local presence of sinistral C' type shear bands related to this phase and the oblique inclination of the L_2 stretching lineations are the main arguments to interpret this phase as representing oblique sinistral transpressive shear along steep, approximately E-W trending shear zones, with the northern (Pacific) block going down with respect to the southern (Antarctic Peninsula) block. The sinistral strike-slip component may represent a trench-linked strike-slip movement as a consequence of oblique subduction. Lithostatic pressure decreased and temperature increased to peak values during D_2, interpreted to represent the collision of thickened ocean crust with the active continental margin. The last deformation phase, D_3, is characterised by post metamorphic kink bands, partially forming conjugate sets consistent with E-W shortening and N-S extension. The rock units that underlie the island probably rotated during D_3, in Cenozoic times, together with the trench, from a NE-SW position to the present ENE-WSW direction, during the progressive opening of the Scotia Sea.

Structures in the rock units that crop out on the other islands of the group show a similar sequence of deformation phases, however with different orientation, interpreted to be the result of rigid block rotation along Cenozoic faults.

Smith Island

The youngest of the three complexes (47-58 Ma, Hervé et al., 1990) is exposed, exclusively, at Smith Island (Fig. 1); it is the most homogeneous in terms of metamorphic grade and also the one with the more typical high pressure-low temperature metamorphism. 0n this island blue and green phyllites predominate with intercalations of metachert, grey phyllite and marble (Dalziel, 1984; Grunow et al., 1992; Trouw et al., 1998b). Chemical analyses of mafic samples indicate them to be derived, at least in part, from mid ocean ridge basalts (Valeriano et al., 1997). However, one sample contains relic pyroxenes with a composition indicative of an origin in alkali basalts that may have been generated along a fracture zone or in an ocean island setting (Valladares and

Trouw, 1998). The other rock types represent probably hemipelagic sediments from an ocean floor environment (Grunow et al., 1992; Trouw et al., 1998a).

Typical metamorphic minerals are albite, blue amphibole, actinolite, epidote, chlorite and phengitic white mica. Locally jadeite bearing clinopyroxene (up to Jd_{40}) and lawsonite are present, but no stable coexistence of glaucophane and lawsonite was reported. Peak pressure conditions were estimated at 8 kbar with a temperature of ~300 ºC (Trouw et al., 1998a, b).

The structural evolution was subdivided into three phases in a similar way as in the Elephant Island group (Dalziel, 1984; Grunow et al., 1992). As on southern Elephant Island intense D_2 deformation produced transposition of S_0 and S_1. S_2 planes dip about 60º to the NW and D_2 fold axes and mineral/extension lineations plunge moderately to the NE. It is, at present, not clear how this direction relates to a proposed subduction direction to the SE (McCarron and Larter, 1998) at the time of peak metamorphic conditions (~50 Ma).

Relation with the Trinity Peninsula Group

The deformation and metamorphism of the Trinity Peninsula Group and correlatives, composed essentially of Permo-Triassic tubidite successions, show several features similar to the Scotia metamorphic complex. Although the metamorphism is predominantly of very low grade, hampering a precise definition of P-T ratios (Smellie et al., 1996) at least at Cape Legoupil and Powell Island, South Orkney Islands (Trouw et al., 1997a,b) this ratio revealed a similar high P-low T regime as in the complex.

The structural style shows also similarities. For instance, the structure north of Botany Bay, north-eastern part of the Antarctic Peninsula, is dominated by very thick (>10 km) steep standing E-W striking sequences, with top to the south, often slightly overturned, position. This structure is interpreted to result from N-S compression related to subduction with stacking of thrust slices that became progressively rotated to a vertical or slightly overturned position. This structure is very similar to the structure of Elephant Island, thought to result from a similar mechanism.

Although the Trinity Peninsula Group and correlatives were deposited along an inactive continental margin, in Permo-Triassic times, they were apparently later, during the Jurassic period, involved in accretionary wedge deformation.

Conclusions

According to metamorphic age the Scotia metamorphic complex was subdivided into three accretionary subduction complexes, all three related to the Mesozoic-Cenozoic subduction that led to the formation of the Antarctic Peninsula batholith. The three complexes crop out, respectively, at the western South Orkney Islands (180-200 Ma), Elephant Island group (90-110 Ma) and Smith Island (~50 Ma). All three are characterised by metamorphism with a relatively high P/T ratio, with a tendency to become higher in time, and in space, from east to west. Deformational structures show intense shearing accompanied by the formation of cleavage and stretching lineation during a first deformation phase (D_1), related to subduction. A second phase (D_2) produced intense folding and was interpreted to represent the arrival of thickened oceanic crust leading to a local decrease of subduction velocity. During this phase the rock units suffered increase in temperature and decrease in pressure. A sinistral strike-slip component detected at Elephant Island was interpreted to reflect oblique subduction. Later uplift under low grade to non metamorphic conditions, accompanied by rigid block rotation, led to the formation of kink bands and brittle faults (D_3). In the South Orkney Islands a sequence of five deformation phases was recognised both at Signy Island and at Powell Island. An important extension phase recognised at Powell Island (D_4) is interpreted as related to the break-up of Gondwana. The cause of uplift and preservation of the complexes is probably not unique. For the South Orkney Islands extension may have played a major role, whereas at Elephant and Smith islands the arrival of thickened oceanic crust was probably a crucial factor.

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