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Structural Setting of the Neoarchean Terrains in the Commonwealth Bay Area (143–145°E), Terre Adélie Craton, East Antarctica

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Abstract

Geological maps of East Commonwealth Bay Unit (ECB), (Terre Adélie and Georges V Land, Antarctica) are presented with a summary of the main structural and metamorphic data for the region. The ECB unit was developed during Neoarchean–Paleoproterozoic event (at 2.5–2.42 Ga), with (i) granulite metamorphism at 9±1.5 kbar and 800±50°C in the lower crust section and amphibolite metamorphism (P=5 kbar, T=750°C) at the upper crustal levels; (ii) the lower crustal granulites were uplifted, and suffered local partial melting and retrogression to the amphibolite facies at 550±50°C–5 kbar. Granulites were extruded in the core of a crustal-scale anticlinal fold, but retrogressed only on the rims of the anticline. Crustal-scale folding, along with other structural features resulted from intense NE-SW shortening that prevailed during the Neoarchean orogenic cycle. Strike-slip and extensional motions were only minor components in that process; (iii) top-to-the-East thrusting and nappe piling had (at least locally) occurred under lower amphibolite to greenschist facies conditions. Finally, it seems that (iv) the Paleoproterozoic 1.7 Ga structural imprint may have only affected the rims of the Archean units. The tectonic context observed in the 1.7 Ga Cape Hunter phyllites features mainly an E-W shortening component and vertical extrusion. The eastern (Mertz) and western (Port Martin) parts of the Archean block were reactivated by localized dextral shearing.

Key words: East Antarctica, Neoarchean, Paleoproterozoic, granulites, tectonics.

Introduction

The Terre Adélie-George V Land region of the East Antarctic shield is considered as a tectonic collage of Paleoproterozoic and Neoarchean domains separated by major shear zones (Ménot et al., 1995, 1999; Monnier et al., 1996; Fig. 1):

(i) The main Paleoproterozoic-tectonic unit is located to the West of the Terre Adélie Craton or TAC (from Pointe Géologie to Cap Jules; Fig. 1). It consists of metasediments metamorphosed under HT-MP to LP (High Temperature–Medium to Low Pressure) conditions (750°C; 6–5 Kb). This HT metamorphism occurred during a transpressive tectonic event with domes and shear zones forming on a regional scale (Monnier, 1995; Pelletier, 2001; Pelletier et al., 2002). This tectono-metamorphic event gave ages of 1.7 Ga by U-Pb on zircons and 1.5 Ga by Rb-Sr and Ar-Ar on micas (Peucat et al., 1999). A smaller tectonic block occurs at Cape Hunter, within the Neoarchean domain but specific contacts between terranes are not observed. The Cape Hunter block consists of fine-grained metapelites that recrystallized under greenschist facies conditions (500°C, 4–5 Kb) at 1.7 Ga (U-Pb on zircon; Oliver and Fanning, 1997).

(ii) The Neoarchean units, to the East of TAC (from Port Martin to the Mertz Shear Zone or MSZ; Fig. 1), are built up by orthogneisses of silicic to intermediate composition and paragneisses. To the West, from Port Martin to Cape Denison, syn-kinematic intrusions of meta-granodiorites dated at 2.44 Ga, are contemporaneous with amphibolite facies recrystallisations (Monnier, 1995). To the East, from Cape Denison to the Mertz Glacier, granulite conditions have been recorded with subsequent retrogression to amphibolite facies conditions (Stillwell, 1918; Stüwe and Oliver, 1981; Ménot et al., 1999; Pelletier, 2001; Oliver and Fanning, 2002). Such an evolution, from granulite to amphibolite conditions, is believed to have occurred between 2.5 Ga (initial granulite event) and 2.42 Ga (Ménot et al., 1999; Fanning et al., 2002). A localized retrograde imprint at 1.7 Ga was assumed (Oliver and Fanning, 2002). The structural features of the Neoarchean tectonic units are still poorly known. The most striking structures so far described are vertical strike-slip shear zones (Stüwe and Oliver, 1981; Kleinschmidt and Talarico, 2000; Monnier, 1995; Pelletier, 2001), that are commonly regarded as contacts of a tectonic collage of terranes (Ménot et al., 1995, 1999; Monnier et al., 1996). In Port Martin area, such shear zones have been dated at 1.7 Ga by U-Pb on zircon and 1.6 Ga by Ar-Ar on amphibole (Monnier et al., 1996).

Although the 1.7 Ga event has been documented in the Paleoproterozoic units by Monnier et al. (1996),

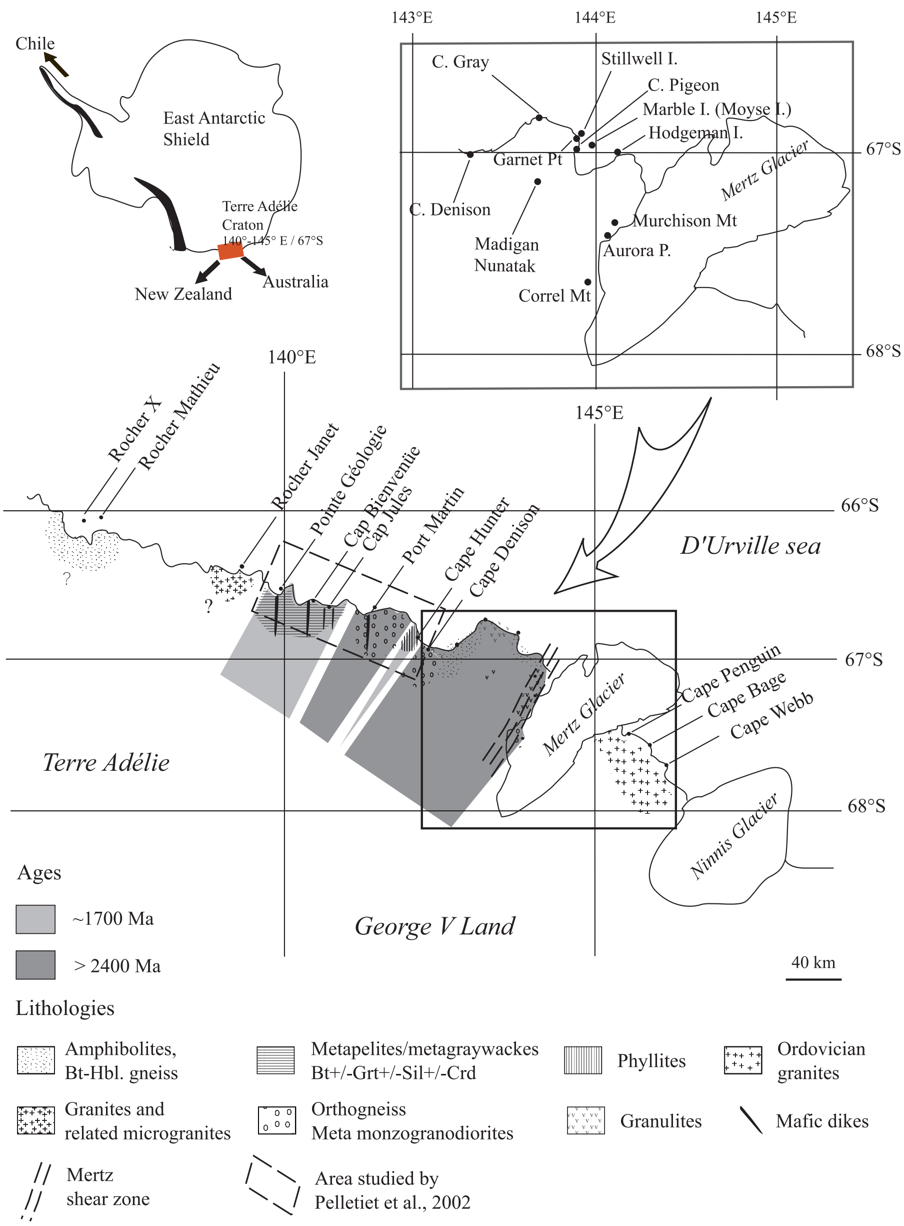

Fig. 1. General geological map of Terre Adélie Craton, with location of the studied area.

Pelletier et al. (2002) and Peucat et al. (1999), little is still known about the structure and lithology of the Archean units. In particular, there has been no structural study at the scale of the Archean domain. Hence, the significance of foliations/lineations within units and the relationships between units of different ages remain speculative.

This paper deals with the geology of the eastern Archean domain, integrating field work by the GEOLETA project during austral summers 1998 and 2003 in East Commonwealth Bay between 142°E to 144.50°E, in the so-called ECB unit (Ménot et al., 1999), for which no maps have yet been published. The ECB unit is bounded to the East to Ordovician granites (Fanning et al., 2002) by the Mertz Shear Zone (MSZ; Kleinschmidt and Talarico, 2000), and to the West by 1.7 Ga Cape Hunter phyllites (Oliver and Fanning, 1997). An inventory and brief discussion of the various lithologies, and metamorphic evolution of the area will be presented in the paper, followed by a synthesis of the structural data. Based on new data, a geodynamic reconstruction at the scale of the Neoarchean domain is proposed.

Lithologies and Metamorphism of the ECB (2.4 Ga) unit

Lithologies

Seven main rock types have been distinguished in the ECB unit (Figs. 2 and 3):

(a) Felsic gneiss with orthopyroxene+quartz+biotite (±plagioclase±K-feldspar±ilmenite±garnet) (Fig. 3);

(b) Aluminous gneiss (metapelites) with plagioclase+K-feldspar+biotite+garnet±cordierite±sillimanite±spinel;

(c) Amphibolites with clinopyroxene relics;

(d) Anatectic granites with biotite+garnet±cordierite±sillimanite nodules;

(e) Orthogneiss with K-feldspar and biotite megacrysts (monzogranodiorites);

(f) Marbles and quartzites;

(g) Aluminous gneiss (metapelites) with biotite±hornblende.

These lithologies form part of two distinct crustal sections: a lowermost characterized by early HT granulite assemblages (a to d) locally retrogressed into amphibolite facies (c and d) and an uppermost crustal section with amphibolite facies assemblages (e to g) and without any earlier granulite imprint (Figs. 2 and 6).

These two groups of lithologies, from lower and upper crust levels respectively, are found in two different structural domains. Fresh granulites (a and b) are found within the core of a NW-SE striking zone, while retrogressed granulites associated with anatectic granites (c and d) are found on both sides of this zone. Uppermost crustal rocks (e to g) are exposed structurally above (i.e., to the E and W) of the retrogressed granulites.

P-T conditions of metamorphism

In deep crustal rocks (a-d), the stability of granulite grade assemblages (a), (b) and (c) as well as complementary thermo-barometric estimates, detailed in Pelletier (2001), yield pressure-temperature (P-T) conditions of P = 9±1.5 Kb and T = 800±50°C for the metamorphic peak and 550±50°C–5 Kbar for the amphibolite facies retrogression.

Other lithologies (e-g) representing the Neoarchean mid- to upper crust sections do not retain any granulite grade relicts. Further, their mineralogical composition is similar to those observed further to the West, into the Neoarchean unit at Port Martin. Mineral assemblages suggest peak metamorphic conditions in the amphibolite facies such as described by Monnier (1995) in the Port Martin area, i.e., at 750±50°C–5 kbar.

Age of metamorphism

Preliminary U-Pb on zircon ages of 2.5–2.42 Ga are obtained for both granulites (a) anatectic granites (d) and orthogneiss (e) of the ECB, without any evidence of a 1.7 Ga reactivation (TIMS and SHRIMP data: Ménot et al., 1999; Peucat et al., in prep.). Consequently, an apparently “purely Archean” domain (ECB) is bounded by the 1.7 Ga Cape Hunter metapelitic unit to the West (Oliver and Fanning, 1997) and by the Mertz Glacier shear zone(s) to the East. An age of 1.7 Ga is assumed for the formation of the megashear found in the Mertz area (Kleinschmidt and Talarico, 2000), although a younger (post-Ordovician?) age cannot be formally ruled out because Palaeozoic rocks are found to the East of Mertz Glacier (Fanning et al., 2002).

Structural Analysis of the ECB (2.4 Ga) Unit

At the local scale

The main structural features are:

The *metamorphic foliation*, defined by (i) granulite or (ii) amphibolite facies minerals. In some outcrops, superposition of these two foliations can be seen through relics of granulitic gneisses within a matrix of amphibolite grade gneisses. Where granulites are preserved from the amphibolite-grade retrogression, the foliation is relatively flat. Locally, a normal sense of shear is observed but in general no shear bands are recorded. In contrast, the amphibolite facies foliation is steeply dipping. Centimetre- to metre-scale shear bands are observed in association

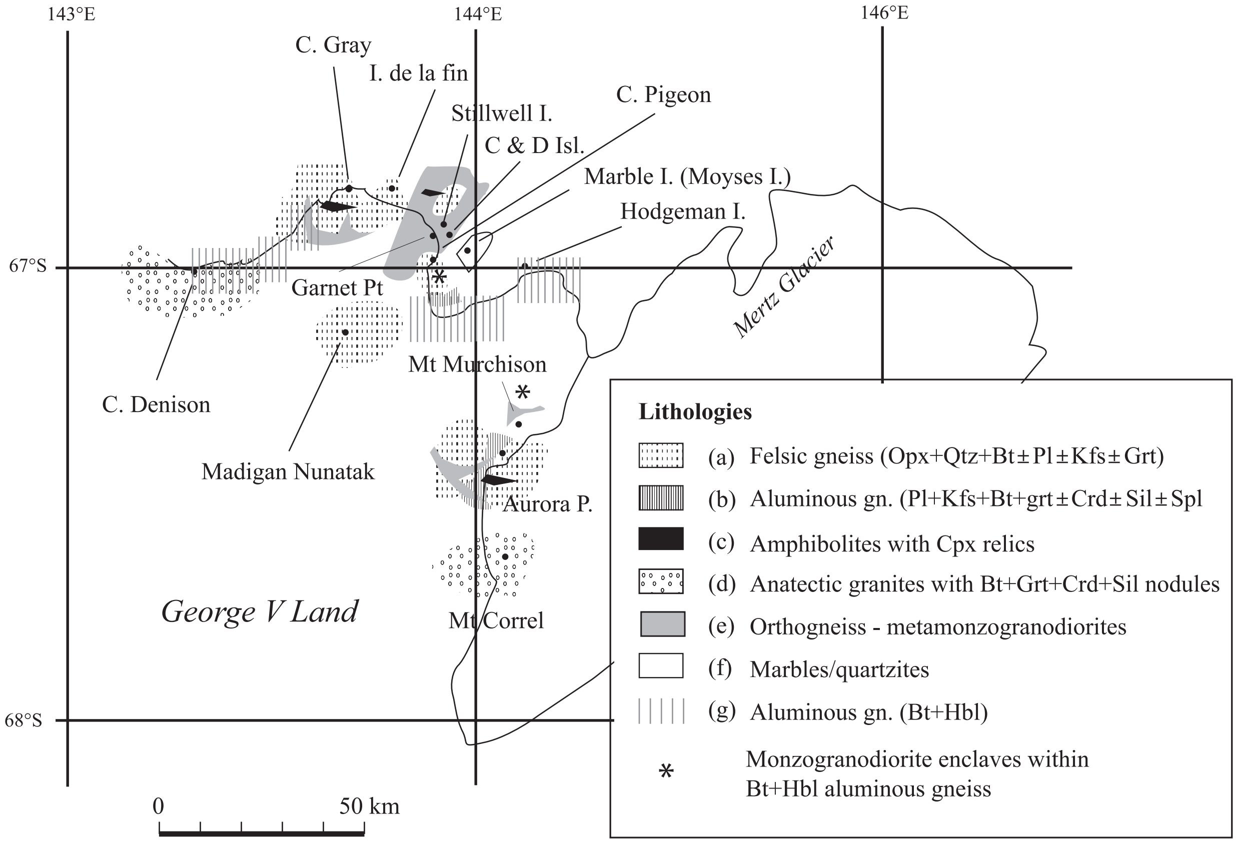

Fig. 2. Lithological map of the East Commonwealth Bay (ECB)units.

with the amphibolitic foliation, but they bear a very variable sense of shear, with both strike-slip and thrust components.

Syn- to post-metamorphic folds, of centimetre- to hectometre-scale and subvertical axial planes, were observed only in the amphibolite-grade zones (e.g., Fig. 4). Most of axes are sub-horizontal and N140°E striking (Fig. 6, diagram 3). They feature intense NE-SW shortening at the time of amphibolite retrogression. Locally, decimetric folds, with steeply dipping axes, were observed (Fletcher Island, Fig. 6, diagram 1) and regarded as drag folds related to vertical shear bands, but no systematic sense of fold vergence and shearing was evidenced. To the East of the ECB, in Marble, A-C and Hodgeman islands (Figs. 5 and 6), our measurements reveal post-metamorphic hectometre-scale folds with variably dipping axes (N29°E SW 33° at Marble Island, part of the Moyes Islands (Fig. 5), N27°E S63° at A-C Island and N131°E NW 29° at Hodgeman Island) (Fig. 6, diagrams 2 and 3). These large folds, with steep axial planes, are in agreement with a strike-slip component (or reactivation) close to the MSZ.

There is limited evidence for a *stretching lineation* as shown by "boudinaging" of amphibolite facies pods. It is always vertical, thus compatible with horizontal shortening and vertical extension, and not with strike-slip deformation.

Shear zones are frequent in the ECB. They are slightly oblique on the amphibolite-grade foliation, and bear a combination of strike-slip and thrust components. The observed C-S structures always indicate both sinistral and dextral strike-slip shear, without any clear predominant motion. They are compatible with a N60°E strike of shortening. From local observations of dextral ductile C-S structures in the Mertz glacier zone (Kleinschmidt and Talarico, 2000), it seems that the eastern rim of the ECB unit is at least partly a dextral shear zone, although, two different shear zone strikes have been observed, N165°E at Mt. Correll and N30°E at Murchison Nunatak.

Thrust shear zones are observed in Cape Pigeon and C-D islands (Fig. 4). These thrusts are metre-thick low-temperature mylonites. Biotite-bearing C-S fish and quartz rubans indicate greenschist to lower amphibolite facies deformation conditions. The thrusts are N-S striking, dipping 40°W in Cape Pigeon, and 70°W in C-D islands, respectively. In both areas, sense of shear is top-to-the East, and the thrust places amphibolite facies (s.s.) metasediments over granulite relics bearing orthogneisses.

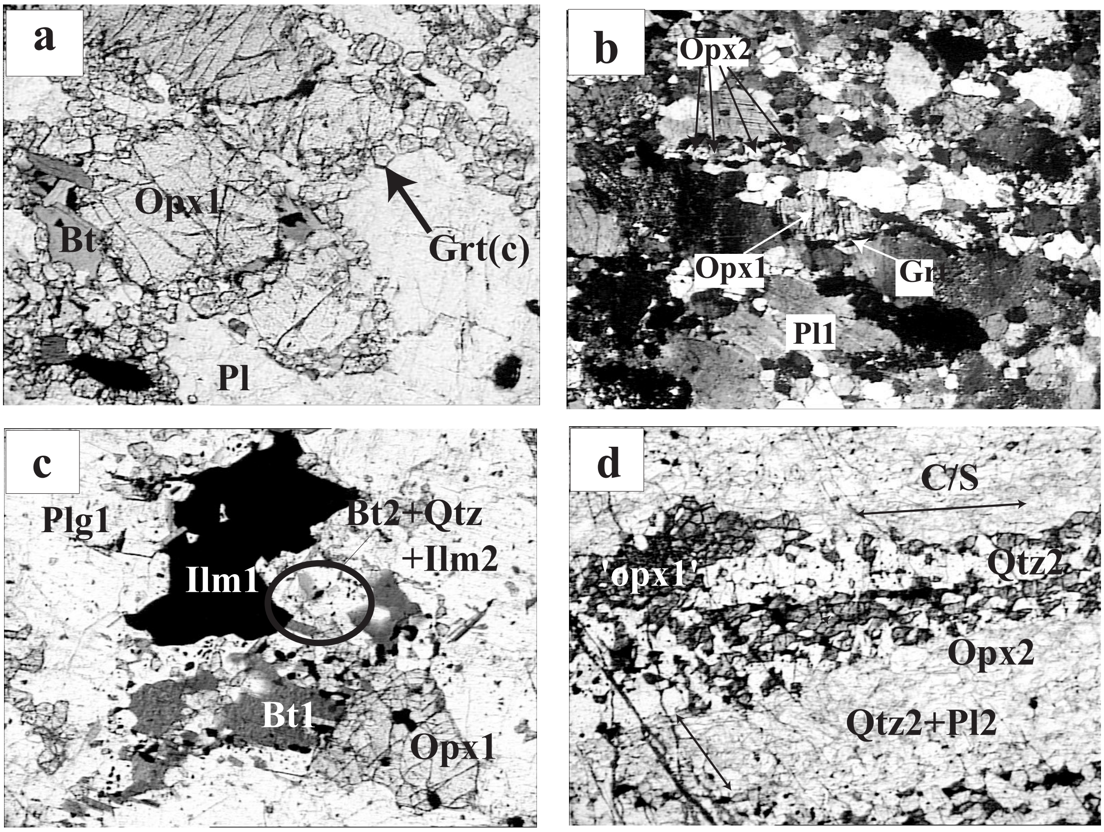

Fig. 3. Thin section pictures of fresh granulites: (a) felsic gneiss with garnet coronas (orthopyroxene+biotite+garnet+plagioclase+quartz±ilmenite) (RPM 98-125, magnification x 50), (b) similar rock with mylonitic foliation in granulite facies conditions (RPM 98–125, magnification x 50) (c) felsic gneiss (orthopyroxene+biotite+quartz+plagioclase+ilmenite) (RPM 98–118, magnification x 50); (d) similar rock with C/S structures in granulite facies conditions (RPM 98–119, magnification x 50).

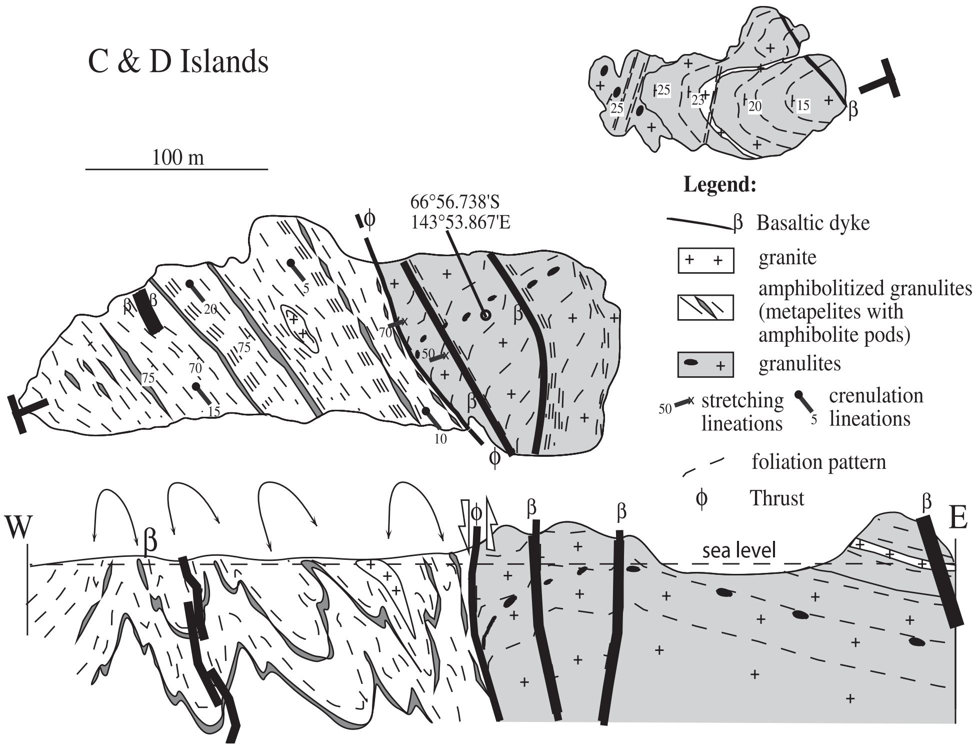

Fig. 4. Geological map (upper part) and cross-section (lower part) of islands C-D (ECB unit).

At the regional scale

The structural map of figure 6 presents a synthesis of the measurements of foliation plans and microstructures formed in the amphibolite facies. The foliation strike, as shown on the map, is the average of all foliation measurements calculated for each zone. At regional scale, the good coherence of foliations measurements enables to draw an interpreted pattern, which corresponds to the ductile strain field.

Main features of the strain field in the ECB:

(a) In the core of the ECB unit, the amphibolite grade foliation is relatively homogenous, striking NW-SE (from N135° to N155°).

(b) To the West, there is a very small obliquity of 15°, between the N170° striking, 1.7 Ga greenschist facies foliations at Cape Hunter and the N155° striking, amphibolite facies foliations at Cape Denison dated at 2.44 Ga, from syn-kinematic orthogneiss intrusions (Stüwe and Oliver, 1981; Monnier, 1995).

(c) To the East, the foliation trajectory becomes more N-S close to the MSZ. This inflexion suggests a passive rotation of the foliation due to the dextral motion of the MSZ. Therefore, the pattern of the foliation is in agreement with a younger age of the deformation on the MSZ (probably circa 1.7 Ga) relative to the main amphibolite-grade structuring of the ECB unit.

(d) The greenschist grade thrust of Cape Pigeon and islands C-D: its path, as proposed on figure 6 remains hypothetical at regional scale, because its extension to the NE of islands C-D and to the SW of Cape Pigeon remains unknown. However, this thrust is a remarkable structural feature, which seems to cross-cut all tectono-metamorphic structures, and should therefore be the latest structural event within the ECB unit.

Structural Analysis of the Cape Hunter Phyllites, (1.7 Ga)

The Cape Hunter phyllites (Fig. 1) are made of pelitic schists, with sedimentary layers strongly transposed into a subvertical N160–170°E schistosity underlined by greenschist grade minerals. The schistosity is axial plane of syn-metamorphic folds that display subvertical axes (76°S), and no preferential asymmetry (Fig. 7). Post-metamorphic deformation is featured by: (1) late folds of large wavelength, with subvertical axes, and (2) E-W kink-bands (best-calculated plane: N93, vertical), compatible with a dextral motion. Mineral lineations are rare; they are also steeply dipping towards the south.

From these observations, the deformation coeval with the main metamorphic event is not purely strike-slip shearing, despite the presence of subvertical folds. The subvertical lineations and foliations feature a context of strong horizontal shortening with a minor strike-slip component.

Discussion

From the above descriptions together with previous data (Stüwe and Oliver, 1981; Oliver and Fanning, 1997), it

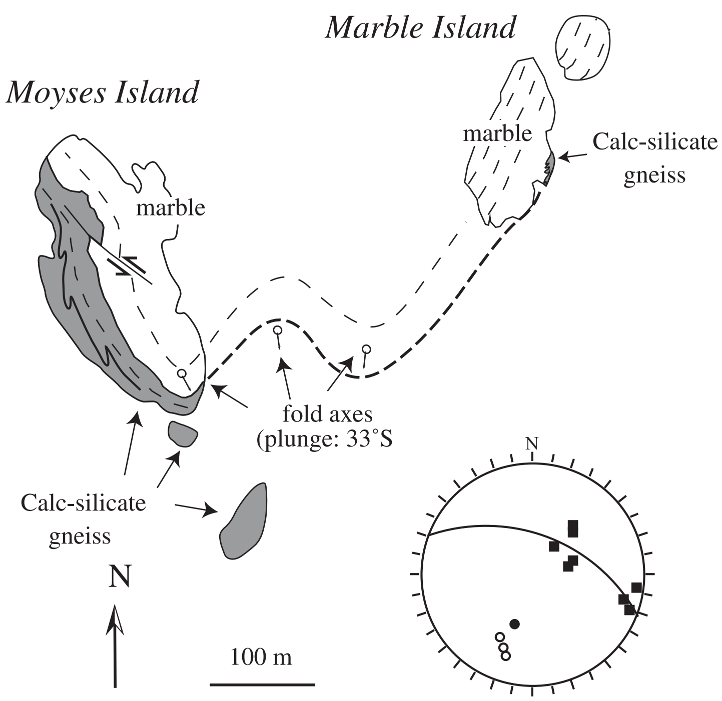

Fig. 5. Geological map of Marble (Moyes Islands) (ECB unit). Projection (Wulff diagram, lower hemisphere) of bedding/metamorphic foliation planes (black squares) and of axes of small-scale late-metamorphic folds (empty dot). Estimated axis of the hectometre scale fold (black dot, pole of the best-fitting great circle).

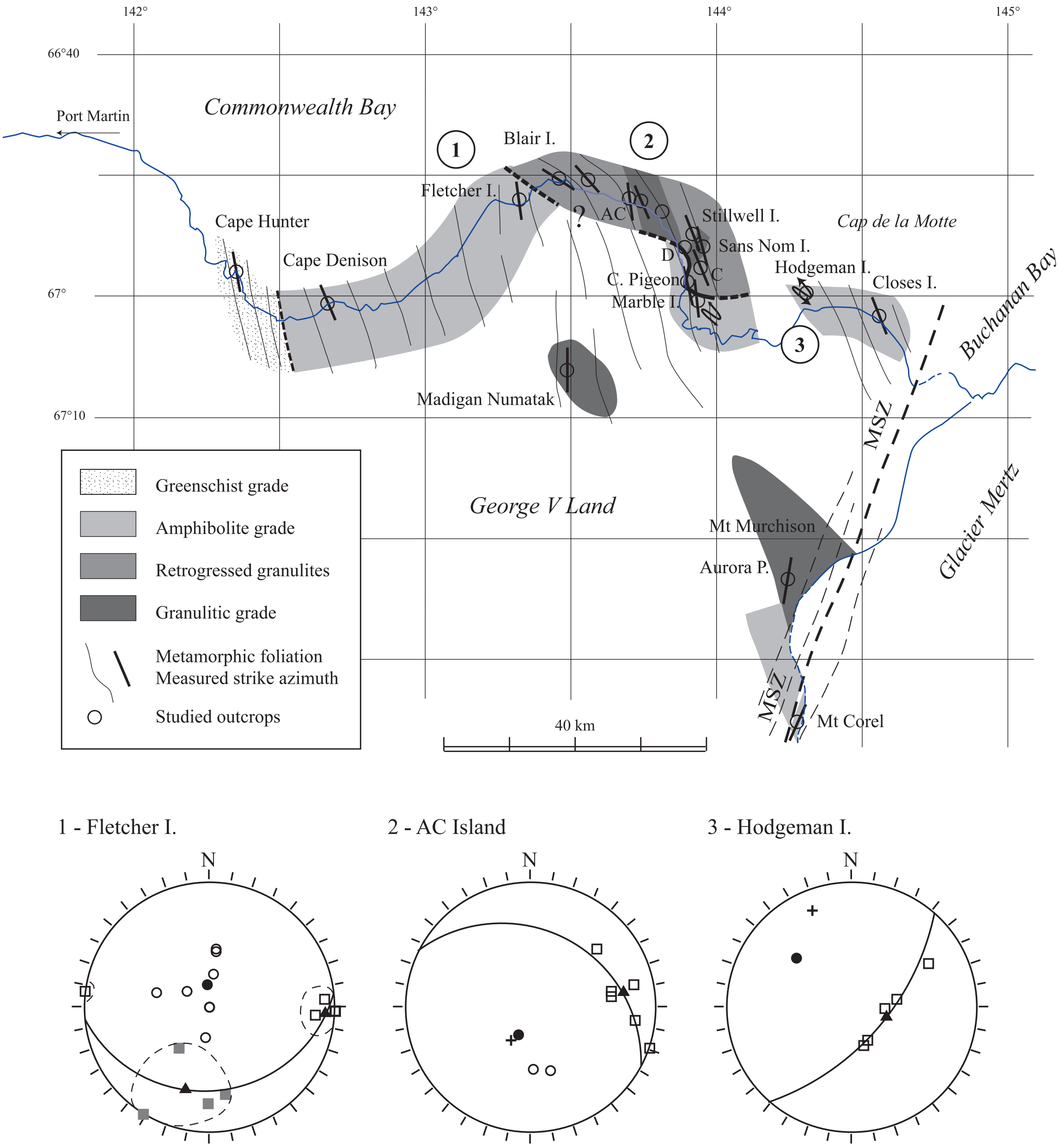

Fig. 6. Structural map of the Cape Hunter and ECB units (upper part) and structural data from 3 selected areas (1) Fletcher Isl., (2) A-C Isl., (3) Hodgeman Isl.. Projection (Wulff diagram, lower hemisphere) of amphibolite-grade metamorphic foliation planes (grey and empty squares), of stretching lineation (cross), of late-metamorphic fold axes (empty dots). For each set of measurements, the best great circle (circle fitting the distribution of the foliation poles) and its pole (black dot) are given in order to estimate axes of late metamorphic large-scale folds (respectively N27°E dipping S63 and. N131°E, NW29 at A-C Isl. and Hodgeman Isl.). Calculated best foliation plane (black triangle) used to draw foliation trends on map. Due to late refolding, data from Fletcher Isl-split in two sets of directions: around N120°E (grey squares) and around N-S (empty squares), the latter corresponding to the main foliation trend observed on the island.

appears that at least two tectonic events have occurred in the ECB unit. The Neoarchean event is featured by 2.5–2.42 Ga deformation coeval with amphibolite and granulite facies metamorphic conditions in the upper and the lowermost crust levels respectively, while the Paleoproterozoic event is witnessed by 1.7 Ga greenschist grade deformation in the Cape Hunter phyllites and possibly, in the eastern ECB unit.

The Neoarchean event is polyphased and featured by (Fig. 8):

1. A prior granulite-grade event with a flat metamorphic foliation. This granulite-grade event only affected the deeper parts of the ECB unit (lower crust), the mid to upper crust being subjected to amphibolite facies conditions.

2. Later, the uplift and retrogression of the granulites

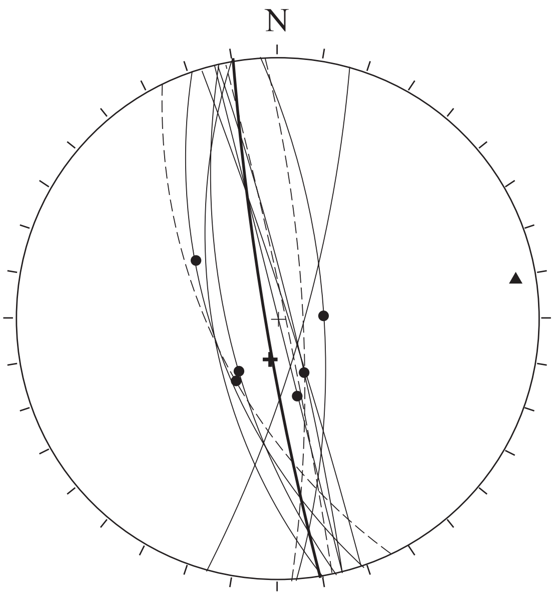

Fig. 7. Structural data of Cape Hunter phyllites (Wulff diagram lower hemisphere). Projection of bedding (dashed lines), metamorphic foliation (plain lines) and intersection lineation (black dots). Bold plain line and black triangle: respectively cyclographic trace and pole of the calculated foliation best plane (N170, dipping 85W). Bold cross: best line calculated for intersection lineations (N11, dipping 73S).

occurred during a NE-SW shortening. The granulites retrogression occurred on both sides of a NW-SE crustal-scale anticline. The amphibolite facies retrograde overprint is associated with steep shear zones, which can also account for the relative uplift of the granulite core. Fluid flow along these shear zones has to be invoked to induce amphibolite facies retrogression and related partial melting.

3. Top-to-the-East thrusting occurred in upper greenschist to lower amphibolite grade conditions during the Neoarchean event or the Paleoproterozoic event.

4. Clear Paleoproterozoic deformation occurred at the eastern and western limits of the ECB unit. In Cape Hunter, the structures result from strong E-W shortening and ductile vertical extrusion of metapelites at 1.7 Ga. These structures contradict the hypothesis of a strike-slip shear zone, but are rather in agreement with the convergence of two rigid blocks (Port Martin and ECB). In the Mertz Glacier area, probable Paleoproterozoic dextral shearing occurred (along the Mertz Shear Zone s. str.), likely correlated with the Kalinjala Shear Zone in South Australia, dated at 1.73 Ga (Kleindschmidt and Talarico, 2000).

Questions remain concerning the tectonics and metamorphic history of the Late Archean units (from Port Martin to Mertz Glacier):

1. What is the mechanism responsible for the exhumation of granulites (Neoarchean lower crust) and

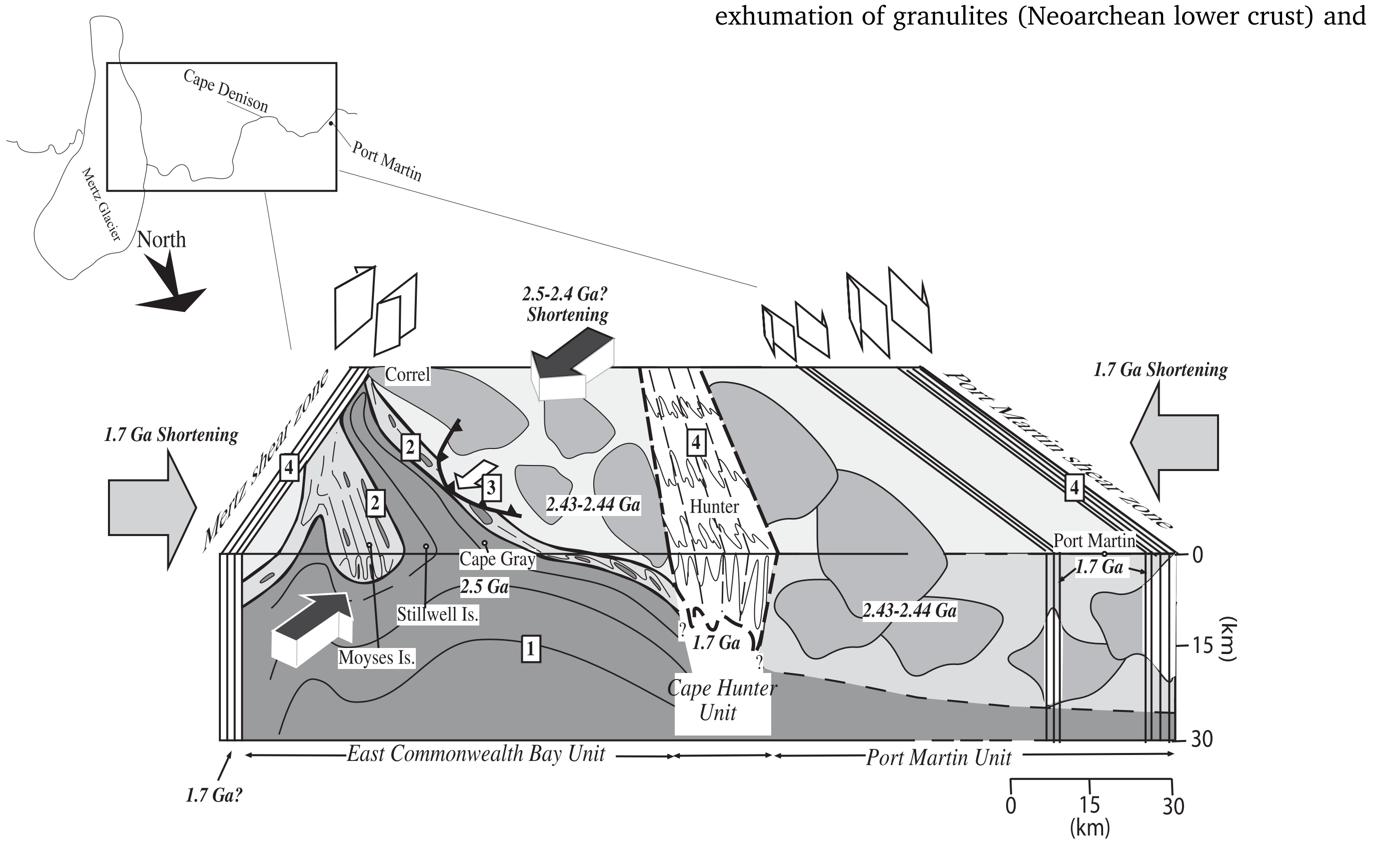

Fig. 8. Synthetic 3D bloc-diagram showing the proposed structural evolution of the Port Martin–ECB area. The numbers within squares relate to numbers quoted in the text.

their juxtapostion with amphibolite-grade gneiss (Neoarchean upper to mid crust)? The mechanism remains largely unexplained; in particular there are no direct indices for the presence of normal shear zones within the ECB unit. The almost vertical pattern of amphibolite foliation, at a regional scale, together with vertical stretching lineations pleads for a horizontal NE-SW shortening without any evidence of significant strike-slip shear zones such as the MSZ. Hydration, partial melting and amphibolite retrogression of granulites took place in vertical compressive shear zones, which are outlined by a subvertical foliation visible in the field. Finally, the later deformation event observed within the ECB unit is the lower amphibolite facies Cape Pigeon thrust, which is still compatible with NE-SW shortening.

2. Were tectonics and metamorphism responsible for the observed strain field achieved by 2.4 Ga?

There is still no evidence of pervasive 1.7 Ga deformations within the ECB. The Paleoproterozoic event seems to be confined to the limits of the Archean units, but this needs to be verified by Ar-Ar dating.

3. What is the significance of 1.7 Ga Cape Hunter phyllites?

Cape Hunter phyllites could represent a "flysch" series filling a marginal basin between two diverging tectonic blocks. They could also be a relict of upper crustal nappes (Ménot et al., 1995) but it is necessary to ask the question if the associated low-grade top-to-the-East Cape Pigeon thrust can be related to a mountain building nappe-thickening event at 1.7 Ga?

Acknowledgments

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