Structural setting of the Late Archean terrains in the Commonwealth Bay area (143-145°E), Terre Adélie Craton, East Antarctica.

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Abstract

Lithological and structural maps from the East Commonwealth Bay Unit (ECB; Terre Adélie and Georges V land, Antarctica) are presented with a summary of the main structural and metamorphic data obtained in the area. The ECB unit is structured during the Late Archean – Lower Proterozoic (at 2.4-2.5 Ga), with (i) granulite metamorphism at 9 - 6 kbar and 850 $\pm$ 50 °C of lower-mid crust and amphibolite metamorphism (P $\leq$ 5 kbar, T $\leq$ 750°C) of the upper crustal levels. (ii) The lower crustal granulites are uplifted, and suffered local partial melting and then retrogression into the amphibolite facies at 550 $\pm$ 50°C $-$ 5 kbar. Granulites are extruded in the core of a crustal-scale anticlinal fold, granulites being retrogressed only on the rims of the anticline. Crustal-scale folding, along with other structural features results from intense NE-SW shortening, that prevailed during the Late Archean orogenic cycle. Strike-slip and extensive motions are only minor in that process. (iii), Top-to-the-East thrusting and nappe piling has (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 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 .

Keywords: Antarctica, Archean, Paleoproterozoic, Granulites, extrusion.

Introduction

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

(i)   The main Paleoproterozoic- tectonic unit is located to the west of Terre Adélie (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 at a regional scale (Monnier, 1995; Pelletier, 2001; Pelletier et al., 2002). This tectonometamorphic event has been dated at 1.7 Ga by U-Pb on zircons and at 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 Late Archean domain but contacts are not observed. It consists of fine-grained metapelites that recrystallized in greenschist facies conditions (500°C, 4-5 Kb) at 1.7 Ga (U-Pb on zircon; Oliver and Fanning, 1997).

(ii)   The Late Archean units, to the East of Terre Adélie (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; Peucat et al., in progress). To the East, from Cape Denison to Mertz Glacier, granulitic conditions have been recorded with subsequent retrogression in amphibolite facies conditions (Stillwell, 1918; Stüwe and Oliver, 1981; Ménot et al., 1999; Pelletier, 2001; Oliver and Fanning, 2002). Such an evolution, from granulitic to amphibolitic conditions, is

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supposed to be bracketed between 2.5 Ga (initial granulitic 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 Late Archean tectonic units are still poorly known and the most striking structures that have been described are the vertical shear zones (Stüwe and Oliver, 1981; Kleinschmidt and Talarico, 2000; Monnier, 1995; Pelletier, 2001) that are commonly considered as strike-slip limits of assembled terranes (Ménot et al., 1995; Monnier et al., 1996; Ménot et al., 1999). 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 is now documented in the Paleoproterozoic units, by Monnier et al. (1996), Pelletier et al. (2002) and Peucat et al. (1999); still little is known about the geology (structures, lithologies) of the Archean units. In particular, there has been no structural study at the scale of the Archean domain, and subsequently, the significance of foliations / lineations within units, and relationships between units of different ages remains speculative.

This paper deals with the geology of the Archean eastern domain, integrating field works of the GEOLETA project during austral summers 1998 and 2003 in the East Commonwealth Bay from 142°E to 144.50°E (ECB unit; Ménot et al., 1999), for which still no cartographic document has 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 it is bounded to the 1.7 Ga Cape Hunter phyllites (Oliver and Fanning, 1997). An inventory and a brief discussion of the various lithologies and of the metamorphic evolution of this area will be presented, followed by a synthesis of the structural data. These new data will lead to a proposition of a geodynamic reconstitution at the scale of the Late Archean domain.

Lithologies

Seven main lithologies have been distinguished in the ECB unit (Figs. 2 & 3):

a-   Felsic gneiss with Orthopyroxene + Quartz + Biotite (± Plagioclase ± K-feldspar ± Ilmenite ± Garnet);

b-   Aluminous gneiss 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 (monzo-granodiorites);

f-   Marbles and quartzites;

g-   Aluminous gneiss with Biotite ± Hornblende.

These lithologies form part of two distinct crustal sections: a deep seated one (a to d) characterized by early HT granulitic assemblages. In certain lithologies (c and d), those higher temperature assemblages are retrogressed into the amphibolite facies. In the lithologies (e to g), metamorphic assemblages are representative of an uppermost crustal section without any granulite facies imprint (Fig. 2 & 6).

These two groups of lithologies, from lower and higher crust levels respectively, are found into 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.

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Metamorphism

P-T conditions of metamorphism

In the deep crustal rocks (a-d), the co-stability of granulite grade assemblages (a), (b) et (c) and complementary thermo-barometric estimates detailed in Pelletier (2001) yield Pressure-Temperature (P-T) conditions of P = 9 - 6 Kb and T = 800 ± 50 °C for the metamorphic peak and retromorphosis into the amphibolite facies at 550 ± 50 °C – 5 Kbar.

Other lithologies (e-g) representing the Late Archean mid- to upper crust do not present any granulite grade relics. Further, their mineralogical composition is similar to those observed more to the west, into the Late Archean unit of Port Martin. Mineral assemblages suggest peak metamorphic conditions in the amphibolite facies such as described by Monnier (1995) in the Port Martin area, at 550 ± 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 (Ménot et al., 1999; Peucat et al., in progress). Consequently, an apparently "purely Archean" domain (ECB) is bounded by the 1.7 Ga metapelitic unit to West (Cape Hunter; Oliver and Fanning, 1997) and by the Mertz Glacier shear zone(s). An age of 1.7 Ga is assumed for the formation of the shear zones found in the area of Mertz (Kleinschmidt and Talarico, 2000), although a younger (post-Ordovician ?) age cannot be formally ruled out because Paleozoic rocks are found to the East of Mertz Glacier (Fanning et al., 2002).

Structural analysis of the ECB (2.4 Ga) unit

At local scale

The main structural features are:

- The **metamorphic foliation**, defined by (i) amphibolite or (ii) granulite facies minerals. On some outcrops, one can see the superposition of these two foliations, with 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 observed.

In contrast, the amphibolite facies foliation is subvertical. Centimeter to meter-scale shear bands are observed in association with the amphibolitic foliation, but they bear very variable sense of shear, with both strike-slip and thrust components.

(iii)   Syn-metamorphic to post- metamorphic **folds**, of centimeter to hectometer scale.

In the core of the granulite-grade zone, no folds are observed. In the amphibolite-grade zones, folds are frequent, striking N150°E with sub-horizontal axes and subvertical axial planes (e. g., Fig. 4) . These feature intense NE-SW shortening at the time of the amphibolite retrogression.

To the East of the ECB, in Marble and Hodgeman islands (Fig. 5), our measurements reveal post-metamorphic hectometer-scale folds with steeply dipping axes (N29°E SW 46° at Marble Island, part of the Moyses Islands and N132°E NW 29° at Hodgeman Island). These steep folds are in agreement with a strike-slip component or reactivation close to the MSZ,

- The **stretching lineation** is rarely clearly evidenced, by the "boudinage" of amphibolite facies pods. Where it can be evidenced it is always vertical, and 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 senses are observed, 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; Ménot pers. obs.), it seems that the eastern rim of the ECB unit is at least partly a dextral shear zone. Though, 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 meter-thick low-temperature mylonites. Biotite-bearing C-S fish and quartz rubans indicate greenschist 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 puts in contact amphibolite facies (s.s.) metasediments over orthogneisses with amphibolitised granulite relics.

At regional scale

The structural map of figure 6 presents a synthesis of the measurements of microstructures formed in the amphibolite facies, mainly measurements of the foliation. The foliation strike as shown on the map is the average of foliation measurements calculated for each zone. At

regional scale, the good coherence of foliations measurements allows 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° à N155°).

b- To the West, there is a very small obliquity of 15°, between the N170° strike of foliations at Cape Hunter (1.7 Ga fabric) and the N155° strike of foliations at Cape Denison (2.44 Ga amphibolite facies foliation dated by 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 later deformation on the MSZ (probably at 1.7 Ga) than 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 the tectono-metamorphic structures, and should therefore be the later structural event within the ECB unit.

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. Initial lithological alternations are still clearly distinguishable, and also N170°E

subvertical. The schistosity is axial plane of syn-metamorphic folds, which have subvertical axes (76°S), and do not show any preferential asymmetry (Fig. 7). Post metamorphic deformation is featured by: (1) late subvertical folds of large wave-length, 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 very 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 and previous data from (Stüwe and Oliver, 1981; Oliver and Fanning, 1997), it appears that at least two tectonic events have structured the ECB unit. The Late Archean event is featured by 2.4 - 2.5 Ga deformation coeval with amphibolite and granulite facies metamorphic conditions, while the Paleoproterozoic event is featured by 1.7 Ga greenschist grade deformation in the Cape Hunter phyllites and possibly, in the eastern ECB unit.

The Late Archean event is 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 (mid-to-lower crust).

2   Later, a regional amphibolite-grade event occurred, together with the uplift and retrogression of the deeper granulites in a NE-SW shortening context. The granulites retrogression has occurred on both sides of an NW-SE crustal-scale anticline. The amphibolite facies retrograde overprint is associated to 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 explain the hydrous conditions that prevailed during partial melting and amphibolite facies retrogression.

3   Top-to-the-East thrusting occurred in upper greenschist grade conditions during the Late Archean event or the Paleoproterozoic event.

4   Clear Paleoproterozoic deformation occurred at the East and West 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 blocs (Port Martin and ECB). In the Mertz Glacier area, probable Paleoproterozoic dextral shearing occurred (the proper Mertz shear zone), which could be correlated to 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 (Late Archean lower crust) and their superposition with amphibolite grade gneiss (Late Archean 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 foliations, at regional scale, together with vertical stretching lineations pleads for an horizontal NE-SW shortening context without any evidence of great strike-slip shear zones such as the MSZ at this stage. Hydration, partial melting and amphibolite retrogression of granulites rather takes place in vertical compressive shear zones, which are outlined by a subvertical foliation in the field. Finally, the later deformation event observed within the ECB

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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 deformation within the ECB. The Paleoproterozoic event seems to be confined to the limits of the Archean units, but this needs to be checked 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: allochtonous or autochtonous (Ménot et al., 1995) ? Following this last hypothesis, is the low-grade top-to-the-East Cape Pigeon thrust associated to a mountain building nappe-thickening event at 1.7 Ga ?

Acknowledgements

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Figures
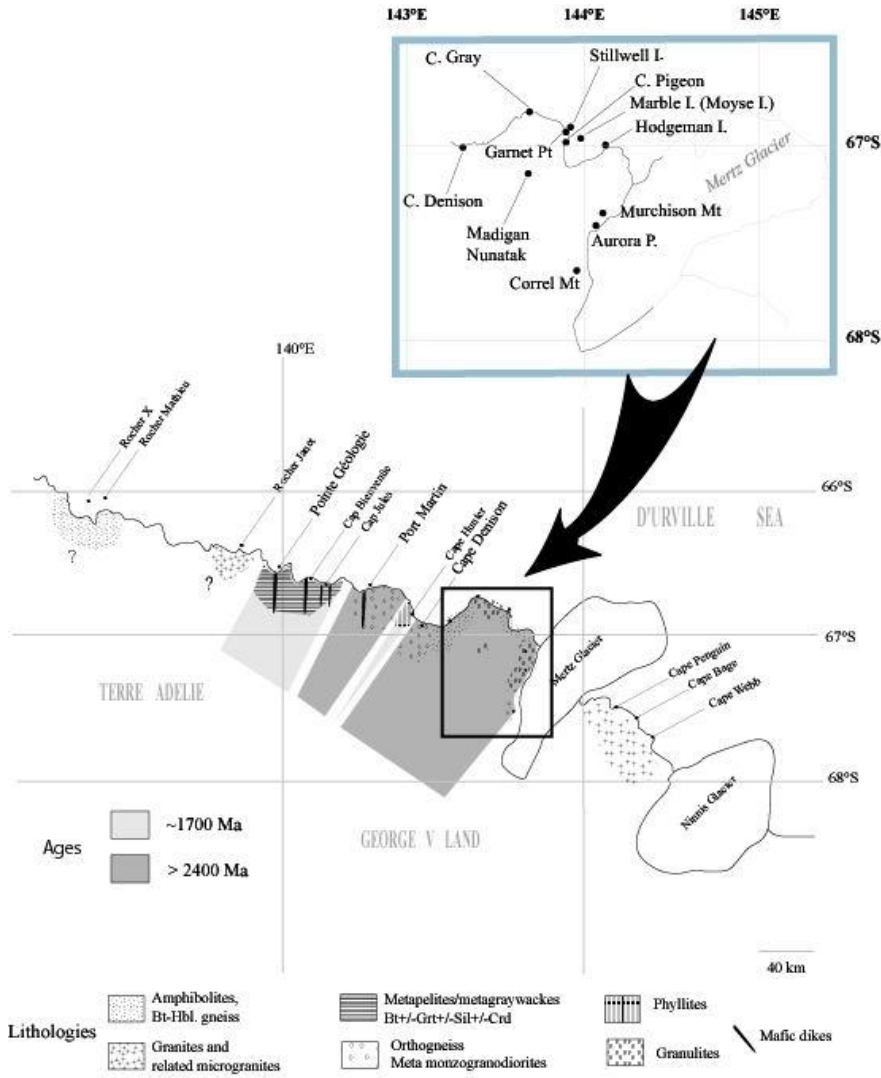
Fig. 1. General geological map of Terre Adélie Craton, with the location of the studied area.
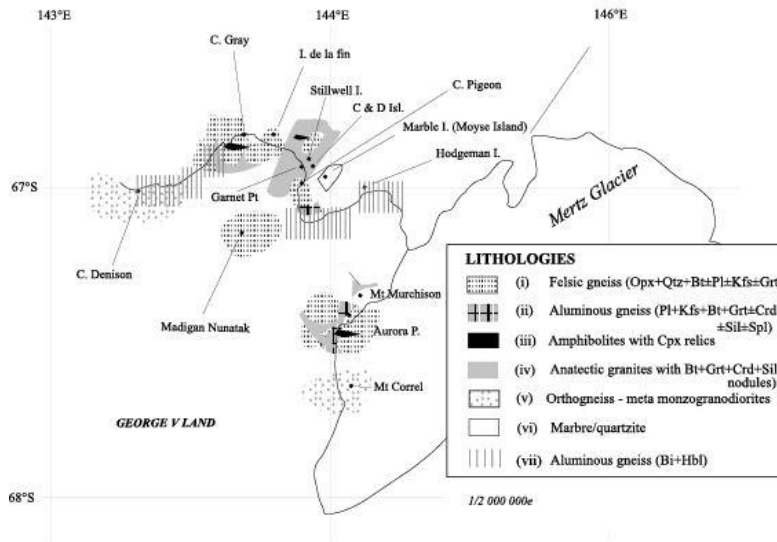
Fig. 2. Lithological map of the East commonwealth Bay units.

Fig. 3. Thin sections pictures of fresh granulites:

a – felsic gneiss with Garnet coronas (Orthopyroxene + Biotite + Garnet +Plagioclase + Quartz ± Ilmenite) , b- similar rock with mylonitic foliation in granulite facies conditions

c – felsic gneiss (Orthopyroxene + Biotite +Quartz + Plagioclase + Ilmenite) ; d – similar rock with S/C structures in granulite facies conditions.

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C & D Islands

100 m

N

66°56.738'S
143°53.867'E

Legend:

β Basaltic dyke

φ Thrust

Migmatised zone

+ + granite

Retrogressed granuli
facies rocks (amphib
facies aluminous gne
with mafic pods)

granulites

W

β φ β β β E
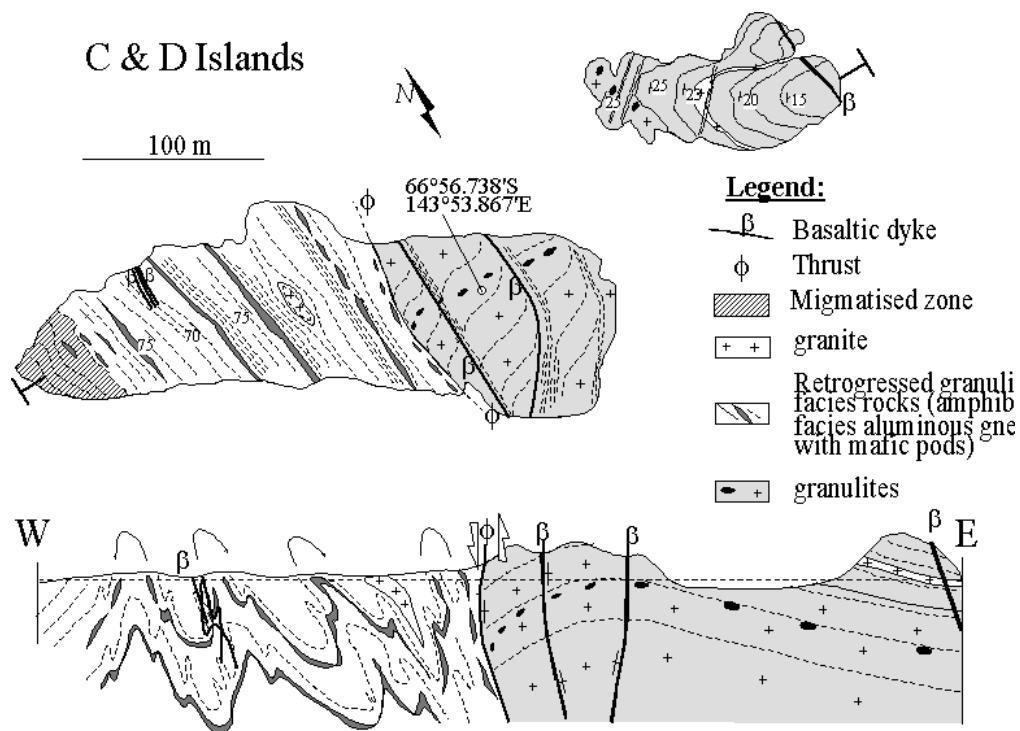
Fig. 4, Ménot et al.

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

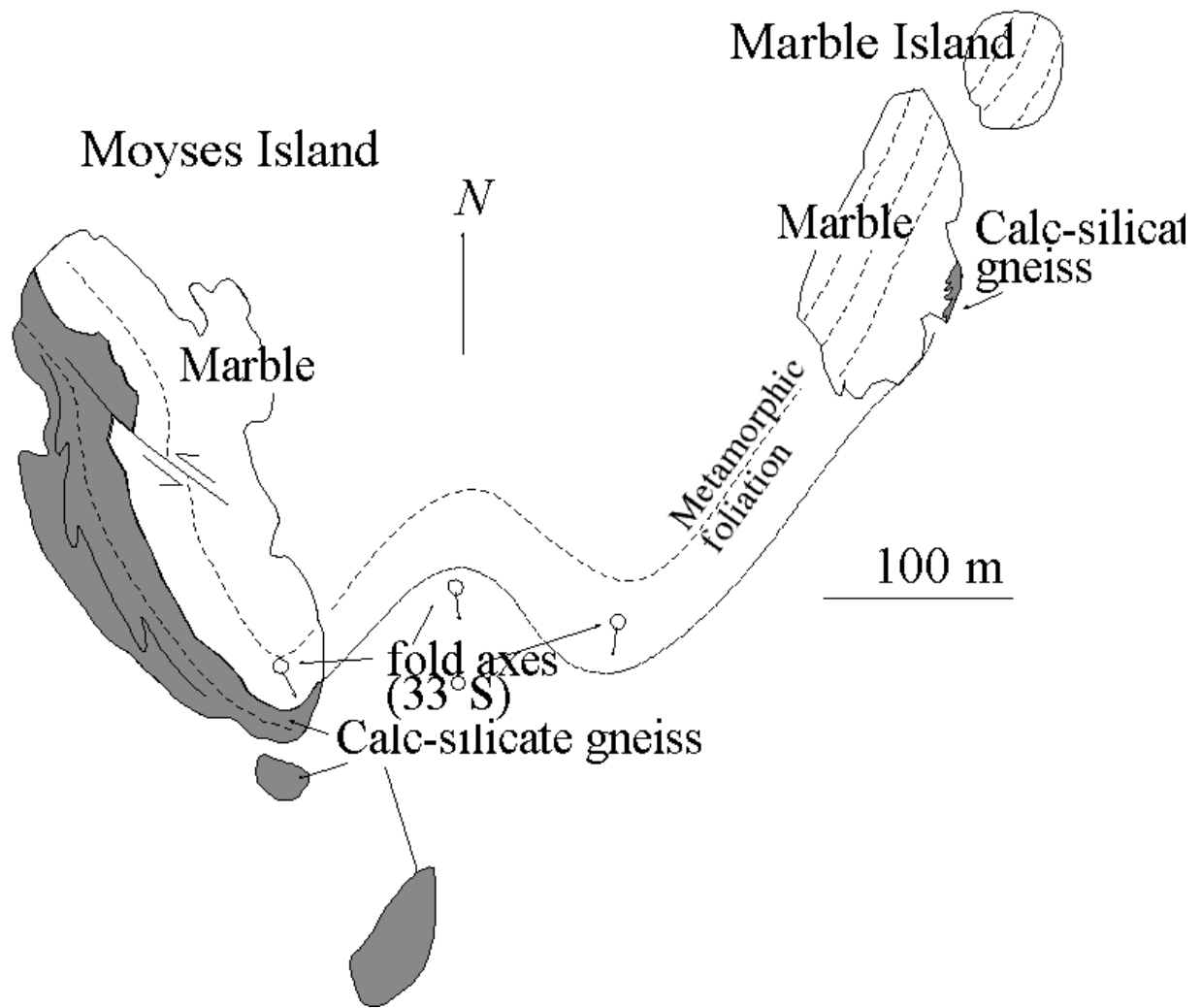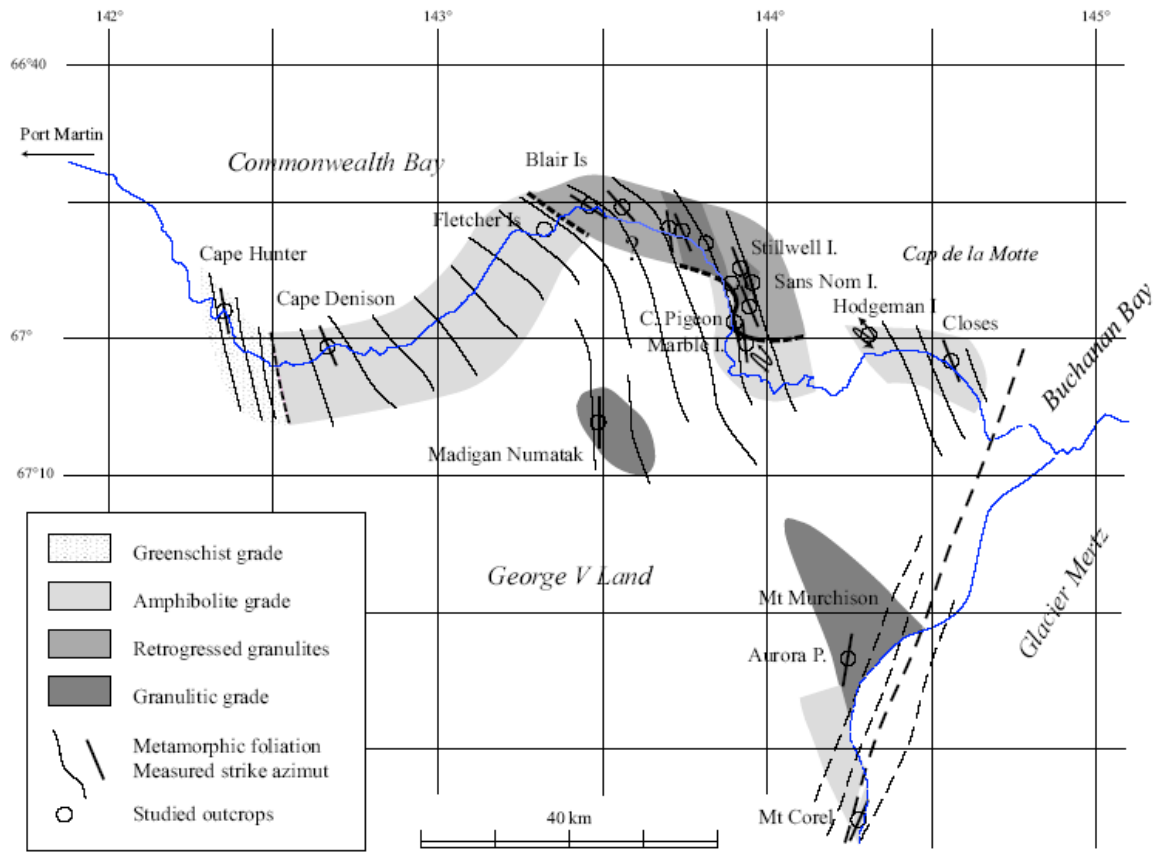Fig. 5. Geological map of Marble (Moyses group) and Hodgeman islands, (East Commonwealth Bay unit).

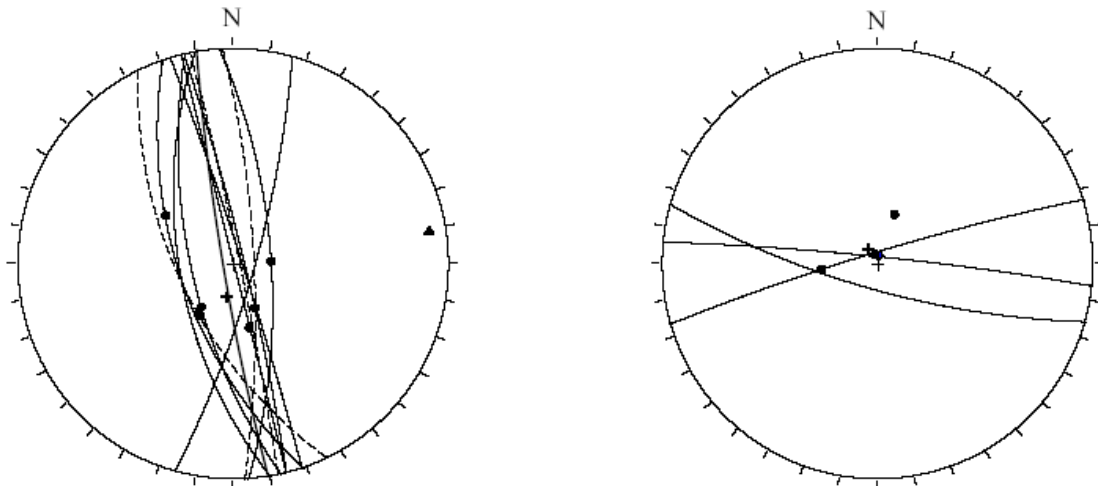Fig. 6. Structural map of the Cape Hunter and East commonwealth Bay units.

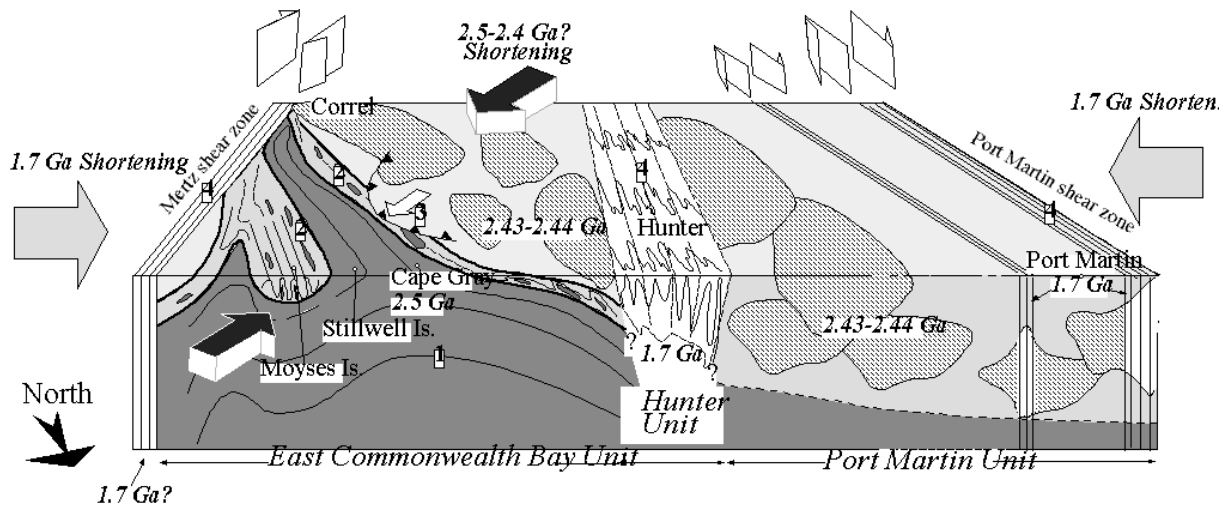Fig. 7. Structural data of Cape Hunter phyllites (Wulff Canvas in lower hemisphere).

Fig. 8. Synthetic bloc-diagram showing the proposed structural evolution of the Port Martin –
East Commonwealth Bay area. The numbers within squares relate to numbers quoted in the
discussion.