

Tasmanian Geological Survey
Record 2014/01

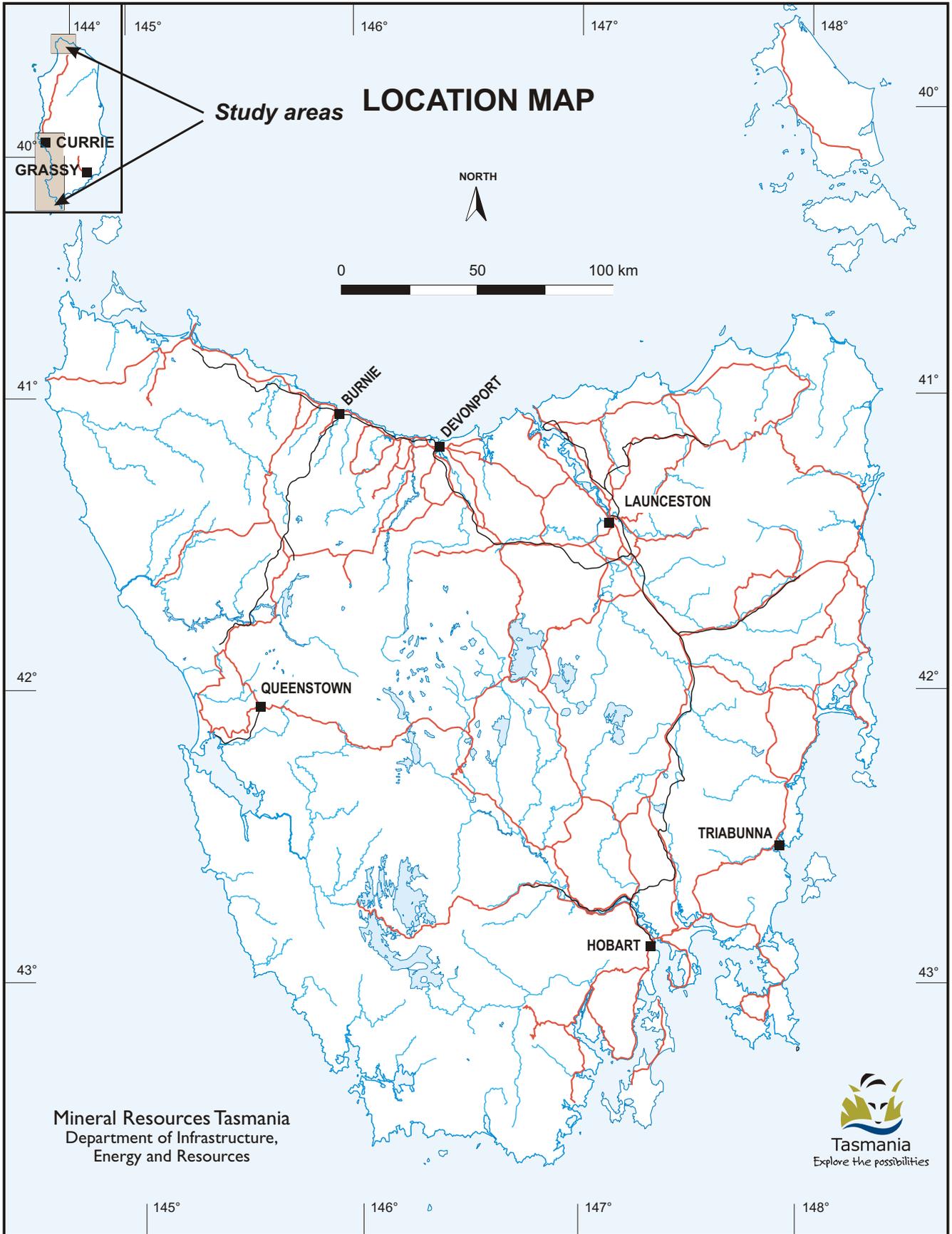
The Surprise Bay Formation (~1300 Ma) and related rocks of western King Island



Tasmanian Geological Survey
Record 2014/01

The Surprise Bay Formation (~1300 Ma) and related rocks of western King Island

by C. R. Calver and J. L. Everard



Mineral Resources Tasmania PO Box 56 Rosny Park Tasmania 7018

Phone: (03) 6165 4800 ● Fax: (03) 6233 8338

Email: info@mrt.tas.gov.au ● Internet: www.mrt.tas.gov.au

CONTENTS

Abstract	5
Introduction	5
Previous work	5
Age	5
Regional structure	7
Surprise Point to Stokes Point (Stokes 1:25 000 scale map sheet)	8
Stratigraphy	8
Metamorphism	10
Structure	10
Fitzmaurice Bay to Millers Bay (Pearshape 1:25 000 scale map sheet)	16
Stratigraphy	16
Structure and metamorphism	16
Currie coastal section (Currie 1:25 000 scale map sheet)	18
Stratigraphy	18
<i>Laminated siliceous siltstone (Lbll)</i>	18
<i>Fine-grained quartzose sandstone turbidite beds interbedded with cleaved mudstone/phyllite (LbIs)</i>	18
<i>Cleaved mudstone/phyllite with minor interbedded siliceous siltstone (LbIp)</i>	18
Intrusive rocks	18
<i>Cryogenian porphyry sills (Lgp)</i>	18
<i>Carboniferous feldspar porphyry dykes (Dgnsg)</i>	18
Metamorphism	20
Structure	20
Cape Wickham (Wickham 1:25 000 scale map sheet)	23
Stratigraphy	23
<i>Dominantly thin-bedded pelitic schist, contact metamorphosed (Lbpx)</i>	23
<i>Dominantly fine-grained quartzose sandstone, contact metamorphosed (Lbsx)</i>	23
Mafic intrusions	23
Minor granitic intrusions	25
Structure	25
Metamorphism	28
Discussion	32
References	33

Figures

1. Simplified geological map of King Island showing boundaries of completed 1:25 000 scale geological maps	6
2. Structural profiles looking along regional F_1 hinges, type section of Surprise Bay Formation	9
3. Equal-area stereoplots of poles to bedding and S_1 cleavage used in structural profiles A and B	10
4. Equal-area plot of bedding, F_1 and F_2 hinges, and calculated S_0/S_1 intersection lineations, Surprise Bay Formation, northern part of Pearshape map sheet	17
5. Equal-area plots of poles to bedding and S_1 cleavage, Currie inlier	20
6. D_2 and D_3 structural elements, Currie inlier	21
7. Geological map of coastal outcrop north of Yellow Rock Beach	25
8. Equal-area plot of poles to bedding, Cape Wickham area	26
9. Equal-area plot of D_2 structural elements, Cape Wickham area	26
10. Equal-area plot of D_3 structural elements, Cape Wickham area	27
11. Equal-area plot of D_5 structural elements	27

Plates

1.	Bedded sandstone, overlain by massive sandstone, 'lower sandy member', Surprise Bay Formation	11
2.	Plane-laminated siltstone with thin beds of ripple cross-laminated, load-casted fine-grained sandstone	11
3.	Plane-laminated siltstone, upper part of 'lower sandy member', west of Denbys Bay	11
4.	Thin-bedded fine-grained pelitic schist of 'middle pelitic member'	12
5.	Pelitic schist, with retrogressed andalusite and garnet, and plane-laminated to cross-laminated siltstone bed showing overturned facing, 'middle pelitic member', Surprise Bay	12
6.	Laminated pelitic schist with garnet and retrogressed ?andalusite, 'middle pelitic member'	12
7.	Internally stratified, porphyroblastic bed within pelitic siltstone of the 'middle pelitic member'	13
8.	Thick fine-grained sandstone turbidite beds, in predominant pelitic siltstone and schist, Gulchway	13
9.	Part of an ovoid concretion in fine-grained sandstone... ..	13
10.	Dark grey pelitic schist of the 'middle pelite member', with distinct thin, sharp-bounded black pelite beds ...	14
11.	Alternating schist and amphibole hornfels near Sealers Wall	14
12.	Tight synclinal F_1 closure marking the top of the type section of the Surprise Bay Formation	14
13.	Schist with foliation deflected about euhedral garnet porphyroblasts	15
14.	Schist with chlorite porphyroblast overgrowing S_1 foliation	15
15.	Schist with large retrogressed ?andalusite porphyroblast bounded by selvedge of coarse biotite, muscovite and minor garnet; S_1 deflected around porphyroblast	15
16.	Bed of cross-laminated quartz siltstone in grey phyllite, near Currie Harbour breakwater	19
17.	Rhythmically bedded muddy turbidites near Peerless Point	19
18.	Low-angle extensional faulting near Peerless Point... ..	21
19.	Domino boudinage indicating dextral shear in thin-bedded siltstone-shale, Netherby Point	22
20.	F_2 minor folds, north side of Currie Harbour	22
21.	Silty pelitic schist, Cape Farewell	24
22.	Thick, internally uniform, sharp-bounded very fine-grained sandstone bed, Yellow Rock Beach	24
23.	Two sharp-based, graded beds of fine-grained sandstone, younging to the right, Yellow Rock Beach	24
24.	Tight minor F_1 'Z' fold near Cape Farewell	28
25.	Minor gently south-plunging folds assigned to F_2	29
26.	Short, leucocratic veins associated with disharmonic folds, assigned to D_3	29
27.	Further examples of short veins and gentle disharmonic folds of D_3	29
28.	D_3 vein with well-developed flanking folds	30
29.	Recessively-weathered, broad, short veins associated with strong disharmonic folding	30
30.	Outcrop surface with multiple examples of crudely aligned short veins and gentle disharmonic folding	30
31.	D_4 fold; granite dyke intrudes parallel and just left of anticlinal axial plane	31
32.	Metamorphic ovoids in Surprise Bay Formation close to contact with the Cape Wickham Granite	31

While every care has been taken in the preparation of this report, no warranty is given as to the correctness of the information and no liability is accepted for any statement or opinion or for any error or omission. No reader should act or fail to act on the basis of any material contained herein. Readers should consult professional advisers. As a result the Crown in Right of the State of Tasmania and its employees, contractors and agents expressly disclaim all and any liability (including all liability from or attributable to any negligent or wrongful act or omission) to any persons whatsoever in respect of anything done or omitted to be done by any such person in reliance whether in whole or in part upon any of the material in this report.

Abstract

As the northernmost occurrence of Tasmanian Proterozoic basement, King Island occupies a key position in the geology of southeast Australia. The Surprise Bay Formation, a Mesoproterozoic, lower amphibolite-facies schist and metasediment sequence, makes up most of the western part of the island. It is at least three kilometres thick, with a protolith of turbiditic, fine-grained quartz sandstone and mudstone. A type section is designated at Surprise Bay. Regional, tight to isoclinal D_1 folds mainly plunge gently north or south and are overturned to the east. Peak regional metamorphism, together with D_1 , has been previously dated at ~1290 Ma. Near Currie, a penetrative foliation post-dates felsic porphyry sills dated at ~775 Ma. D_2 folds are approximately coaxial with F_1 and have subvertical axial surfaces. D_2 – D_4 near Cape Wickham are broadly coeval with intrusion of the Cape Wickham Granite (760–12 Ma). The Surprise Bay Formation correlates with the less deformed and lower grade, but otherwise very similar, Fraser Formation of eastern King Island. No correlatives are known away from King Island.

Introduction

Geological mapping, at 1:25 000 scale, of the southern half of King Island, and of the Cape Wickham map sheet in the far north, was undertaken by C. Calver and J. Everard between 2007 and 2012 (fig. 1). The geology of the Grassy and Naracoopa map sheets, in the southeast, was described by Calver (2012). The other completed maps (Stokes, Pearshape, Currie and Wickham) cover nearly all the known outcrop of the Surprise Bay Formation, which has received little systematic study to date. This report summarises the stratigraphy and structure of the Surprise Bay Formation in the light of the new mapping. Other aspects of the geology will be more fully dealt with in a later report.

All grid references in the text (and map grids) are GDA94 datum and are MGA co-ordinates in Zone 55, quoted in the form xxxxxx/yyyyyy, where the first six numbers are metres east and the last seven numbers are metres north.

Previous work

Rocks now referred to as the Surprise Bay Formation were first noted by Debenham (1910) and recorded as Precambrian quartzite, slate and schist by Waterhouse (1916). Gresham (1972) mapped the geology of the island as part of regional exploration by Geopeko Ltd, and recognised the ‘West Coast Metasediments’ as an older, higher-grade complex, with lower grade, inferentially younger Proterozoic rocks (now termed Fraser Formation) on the eastern part of the island.

Cox (1973, 1989) made a detailed study of the Cape Wickham area, and recorded five phases of deformation in the correlate of the Surprise Bay Formation there. Deformation was “in part broadly synchronous” (Cox, 1989, p.26) with the intrusion of the Cape Wickham Granite (760–12 Ma; Black, 1994).

Blackney (1982) studied the regional metamorphic mineral assemblages in the Surprise Bay area, which indicated temperatures of 470–580°C and pressures of one to three kilobars.

Turner *et al.* (1998) defined the Wickham Orogeny as the deformation in the Surprise Bay Formation at Cape Wickham (described by Cox, 1973, 1989) associated with the intrusion of the Cape Wickham Granite. The Wickham Orogeny was defined as encompassing “ D_1 together with the episode of granitic magmatism” (Turner *et al.*, 1998, p.801). A number of features on mainland Tasmania were linked to the Wickham Orogeny, among them the unconformity between the Rocky Cape Group and Togari Group in northwest Tasmania, and the deposition of the Oonah Formation.

Black *et al.* (2004) dated detrital zircons from a sample of Surprise Bay Formation and showed a range of ages, predominantly 1850–1350 Ma, the younger limit providing a maximum constraint on depositional age.

Berry *et al.* (2005) carried out chemical U-Th-Pb dating of metamorphic monazite in the Surprise Bay Formation in the Fitzmaurice Bay–Surprise Bay area. D_1 , encompassing regional isoclinal folding and prograde metamorphism, was shown to be 1287–18 Ma. They reinterpreted the Wickham Orogeny as a local deformation restricted to the contact aureole of the Cape Wickham Granite.

Calver (2012) gave a detailed account of the relatively weakly deformed Proterozoic basement rocks of eastern King Island, the Fraser Formation (Direen and Jago, 2008). Correlation of the Fraser and Surprise Bay formations was proposed on the basis of similarities in lithology and structural history.

Age

The depositional age of the Surprise Bay Formation is inferred to be mid-Mesoproterozoic, between c. 1350–50 Ma (the youngest detrital zircons recorded by Black *et al.*, 2004) and c. 1287–18 Ma (metamorphic monazite dated by Berry *et al.*, 2005). There are no known correlatives in Tasmania or southeastern Australia, although the Fraser Formation of eastern King Island appears to be a less deformed equivalent (Calver, 2012). Correlation is further discussed in the final section below.

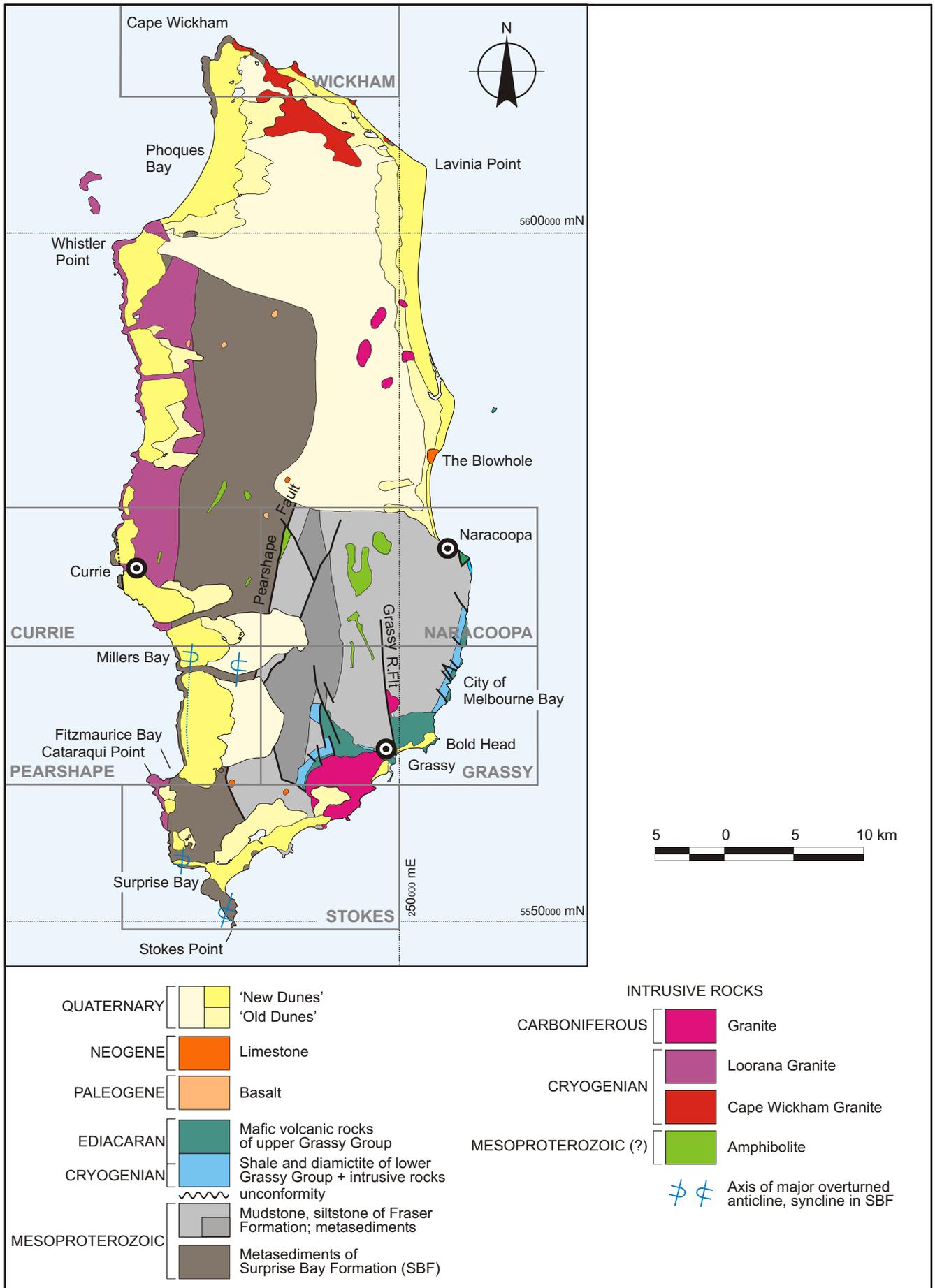


Figure 1

Simplified geological map of King Island with boundaries of completed 1:25 000 scale geological maps shown. Axes of major folds in Surprise Bay Formation indicated.

Regional structure

In simple terms, the Surprise Bay Formation is a north–south striking belt of isoclinally folded schist and metasandstone, 4–8 km wide, dipping steeply west, that extends the full length of King Island from Cape Wickham to Stokes Point. It is intruded by two Cryogenian granite bodies, the Loorana Granite (748 ± 2 Ma: Black *et al.*, 1997) to the west and the Cape Wickham Granite (760 ± 12 Ma, Turner *et al.*, 1998) to the northeast. The Loorana Granite is regionally concordant. A lower-grade (phyllitic-slaty) correlative of the Surprise Bay Formation is faulted against the western side of the Loorana Granite near Currie. The main belt of the Surprise Bay Formation is adjoined to the east by a weakly deformed correlative, the Fraser Formation, which underlies most of eastern King Island (Direen and Jago, 2008; Calver, 2012). The contact is an inferred fault (the Pearshape Fault, Calver, 2012). The tight to isoclinal F_1 folds in the Surprise Bay Formation plunge

gently north or south and face upwards. The granites were probably intruded into a recumbently folded sediment pile, as flat-lying laccoliths or thick sills. This could explain the much wider contact metamorphic zone at western (formerly upper) granite contacts (Cape Wickham) than eastern (formerly lower) granite contacts (Fitzmaurice Bay, Millers Bay). The F_1 fold axial surfaces and granite contacts may have rotated to their present steep west dip during the Cambrian Tyennan Orogeny.

The Surprise Bay Formation is almost entirely obscured inland by Quaternary sand and regolith, but the main schist belt is well exposed along three coastal outcrop tracts: Surprise Point–Stokes Point, Fitzmaurice Bay–Millers Bay, and Cape Wickham (fig. 1). The lower grade unit west of the Loorana Granite is well exposed along a fourth coastal tract near Currie. These four areas are described, from south to north, below.

Surprise Point to Stokes Point (Stokes 1:25 000 scale map sheet)

Stratigraphy

The longest across-strike exposure of the Surprise Bay Formation is between Surprise Point and Stokes Point in the southwest corner of King Island. Most of this section is a single overturned F_1 fold limb about 3.8 km thick, and this fold limb is defined here as the type section.

The type section is an overturned, steeply west-dipping (east-younging) section along the coast between an anticline near Conical Rock (234400/5554200) and a syncline one kilometre northwest of Stokes Point (237653/5550815). The primary (S_1) schistosity dips west at a shallower angle than bedding nearly everywhere in this section, and sedimentary structures confirm overturned (east-younging) bedding at many locations. Minor folds are rare. The total stratigraphic thickness is about 3800 m, but disruption of the section by undetected major faults cannot be ruled out. Three members can be recognised (fig. 2).

The stratigraphically lowest *lower sandy member* is about 1400 m thick. The stratigraphic base (and the base of the type section) is the anticline at 234386/5554188, about 175 m west of the mouth of Dromedary Creek. The lower part of this first member is predominantly thick-bedded, fine-grained quartzose sandstone, interbedded with lesser grey pelitic siltstone. Sandstone beds (many >1 m thick) are planar and continuous, with sharp bases and sharp or gradational tops. The beds are internally uniform (structureless) or faintly planar laminated. A few contain elongate ovoid bodies of dark grey hornfels with actinolite porphyroblasts, probably originally calcareous concretions. Continuous sandstone sections form massive prominent units up to 30 m thick (Plate 1). Thin sections (KE818B, KE830) show fine-grained (<0.25 mm) quartz sandstone, with a granoblastic texture and no detrital grain boundaries preserved, rare detrital feldspar and tourmaline, and 5–10% muscovite flakes aligned in a weakly anastomosing rough cleavage (S_1). There is an overall upward-finishing and upward-thinning through the member, with medium to thinly bedded, planar-bedded, very fine-grained sandstone and siltstone predominant in the upper part of the member, with lesser intercalated dark pelitic schist. The sandstone beds are frequently ripple cross laminated (Plate 2). In places, uniform planar-laminated, pale grey quartzose siltstone occurs as continuous units tens of metres thick (Plate 3), and resembles the type Fraser Formation (Direen and Jago, 2008; Calver, 2012). A slumped unit about 80 m thick is seen in the upper part of the lower sandy member (around 235570/5554100). This is predominantly massive, very fine-grained sandstone containing disorientated, slump-folded rafts of laminated pelitic siltstone.

The *middle pelitic member*, about 1400 m thick, is of grey pelitic schist. The rock is thin bedded or laminated (rarely thick bedded), with planar-parallel, continuous layering defined by paler, silty pelite alternating with darker, non-silty pelite layers (Plate 4). Metamorphic garnet (1 mm) and retrogressed andalusite (stubby columns up to 10–30 mm) are prominent on weathered surfaces in the lower

(western) half of the member (Plate 5), but retrogressed andalusite is absent in the upper half. Minor thin beds and laminae of quartzose siltstone and fine-grained sandstone are common; these are mostly planar and continuous, in some cases graded, and commonly lensing and cross laminated (Plate 4; Plate 5). Retrogressed andalusite porphyroblasts commonly preserve primary lamination (Plate 6). Rare, thin beds in the upper part of the middle pelitic member are rich in actinolite porphyroblasts (3 mm) and poikiloblastic (sieve-textured) garnet (2 mm), in a matrix of fine-grained granoblastic quartz and zoisite (thin section NI83). These actinolite hornfels beds may have been originally calcareous horizons or contained volcanoclastic material. Being internally stratified (Plate 7), they are unlikely to be metamorphosed thin sills. (Similar, much thicker, massive actinolite hornfels beds are seen in the upper member).

The *upper sandy member*, about 1100 m thick, consists of medium to thick beds of very fine-grained quartzose sandstone, interbedded with dark grey pelitic schist/phyllite. Lithologies and sedimentary structures are similar to the lower sandy member, although here sandstone is volumetrically subordinate (~30%). Sandstone beds are parallel, continuous, up to 1.5 m thick, and they tend to occur as groups or bundles totalling several metres to a few tens of metres thick (Plate 8). The sandstone beds tend to have sharp bases, and either sharp or gradational tops. They are generally internally structureless, in some cases with weak internal parallel lamination, and rarely partly cross laminated. Bouma CDE sequences are present. Some sandstone beds contain elongate ovoid concretions (Plate 9). These have calcitic cores, siliceous rims and amphibole-chlorite porphyroblasts that are absent from the surrounding rock. Pelitic intervals, some many metres thick, display thin to medium, planar continuous bedding. In places thin, sharply bounded black shale beds are preserved (Plate 10) that resemble the microbialite beds of the Fraser Formation (Calver, 2012).

Actinolite hornfels (Lbac): Near Sealers Wall, on the eastern side of Gulchway (237250/5551600), there is a ~50 m thick section within the upper sandy member. This contains about eight conformable units, each several metres thick, of a massive brown-weathering rock type resembling dolerite, interlayered with lesser grey schist (Plate 11). Most contacts with schist are sharp, but a few appear gradational over up to 0.5 metres. This rock type is essentially identical to 'amphibole hornfels' (Lfa) locally present in the Fraser Formation (Calver, 2012) and mentioned above as isolated beds in the middle pelitic member. As in the Fraser Formation occurrences, sparse, small (~50 mm) ellipsoidal siliceous concretions are present in the Gulchway units. Parts of the rock have incipient spheroidal weathering, a feature that led Blackney (1982) to (incorrectly) interpret the rocks as pillow lavas. Thin sections (e.g. KE310, KE311a) show plumose, often bowtie-shaped, aggregates of columnar to acicular pale green tremolite-actinolite, 2–4 mm long, in an abundant groundmass of fine-grained

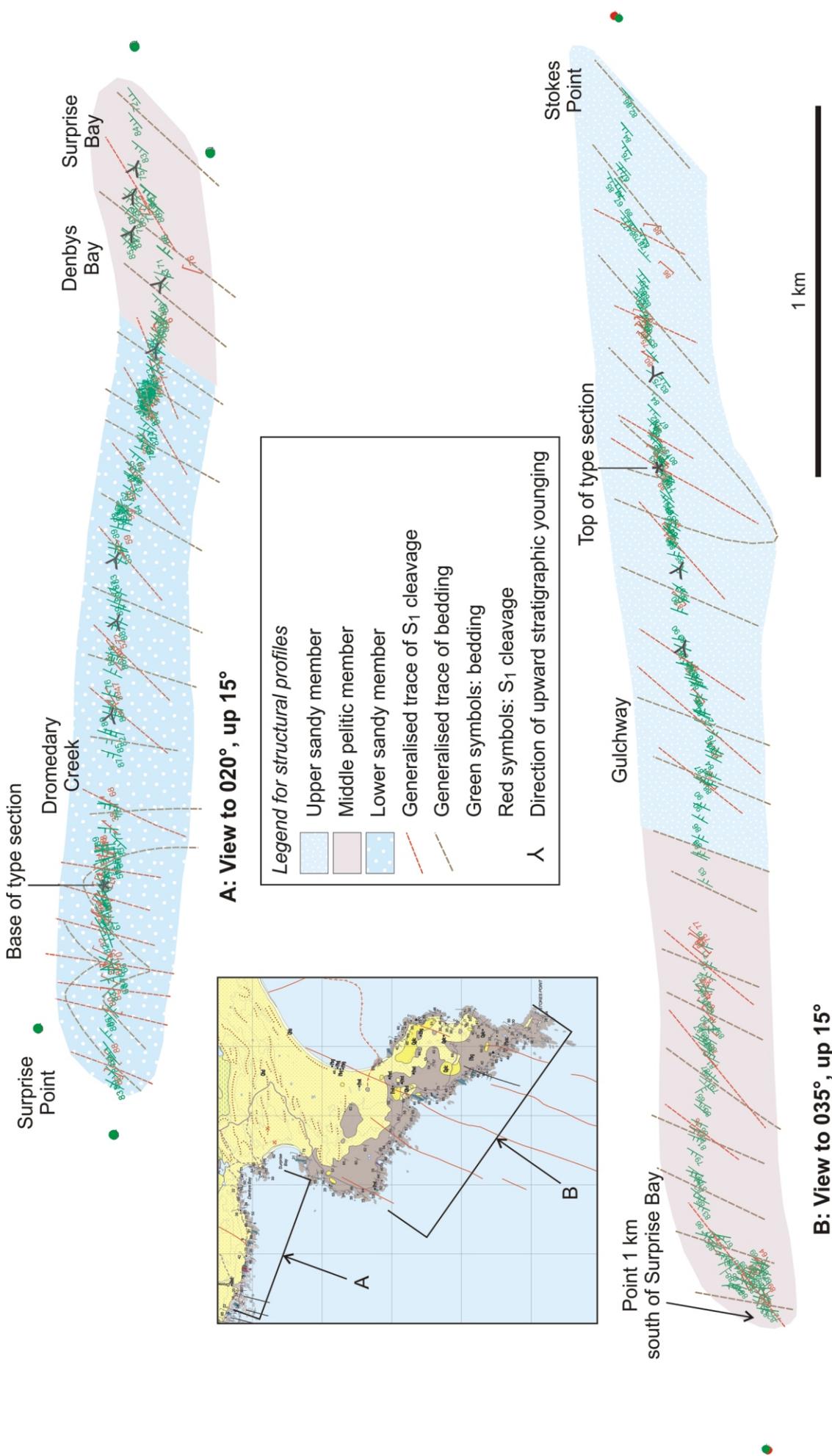


Figure 2
Structural profiles looking along regional F₁ hinges, type section of the Surprise Bay Formation in the Surprise Bay–Stokes Point area. Rotations done in Spheristat™.

(50 m) granoblastic quartz and biotite. Whole-rock analyses (KE310, KE311a) resemble mafic–intermediate igneous rocks (e.g. SiO₂ 56–59%, total iron oxide 10–11%, MgO 5–6%, Cr 105–140 ppm, Ni 56–76 ppm), and are very similar to the actinolite hornfels of the Fraser Formation. It is suggested that the protolith of these rocks was a pelitic sediment modified by the addition of fine-grained mafic volcanoclastic material. These rocks are shown on the Stokes map sheet with the symbol Lbac.

The top of the upper member (and of the type section) is the steeply overturned tight syncline at 237653/5550815 (Plate 12). A 50 m wide zone to the south contains further, open to tight F₁ folds, beyond which bedding predominantly dips to the west and is right-way-up. The folded zone thus corresponds to a regional, tight to isoclinal, F₁ synclinal closure, plunging subhorizontally and with a west-dipping axial surface. The regional west-younging major limb on Stokes Point has common minor F₁ folds (Stokes map sheet).

Metamorphism

Garnet is commonly present as subhedral to euhedral porphyroblasts 0.1–1 mm in size. The penetrative S₁ foliation wraps the garnet, and locally, chlorite occupies strain shadows adjacent to garnet porphyroblasts (Plate 13). In one sample, chlorite porphyroblasts that overgrow the S₁ foliation are present (Plate 14). Thus, garnet pre-dates D₁, and porphyroblastic chlorite post-dates D₁, as seen in the Fraser Formation (Calver, 2012). Large columnar (~10–40 mm) porphyroblasts, rounded to almost square in cross section, are locally abundant in pelitic schist, particularly the lower part of the middle pelitic member in the Denbys Bay–Teal Cove area (Plate 5, 6). In thin section, these are composed of undeformed, fine-grained sericite, quartz, muscovite and biotite, and the porphyroblasts are rimmed

by an undeformed selvage of coarse (0.5 mm) biotite and muscovite (Plate 15). The primary schistosity is strongly deflected around these porphyroblasts (Plate 15), whose original growth must therefore pre-date S₁, although retrogression apparently post-dates S₁. (However Berry *et al.* (2005, p.463) note that “porphyroblastic andalusite overgrows the foliation” in a sample from Surprise Bay). The penetrative S₁ schistosity in pelites is defined by a strong preferred orientation of muscovite and minor biotite.

An XRD of a sample from the interior of a concretion in the upper member, with dark greenish porphyroblasts in a fine-grained calcareous matrix, showed calcite, quartz, chlorite, plagioclase, amphibole and epidote (sample N181). Another XRD from a concretion in the lower member returned biotite, quartz, chlorite and minor sjogrenite (N185).

The actinolite hornfels are actinolite-quartz-biotite rocks; or actinolite-garnet-quartz-zoisite (N183). In KE343, the tremolite-actinolite porphyroblasts appear to pre-date the main foliation.

Structure

The main regional folds are tight to isoclinal F₁ folds with upright to west-dipping axial planes and subhorizontal NNE-trending hinges. The major anticlinal zone at Surprise Point and the synclinal zone one kilometre northwest of Stokes Point bound an overturned common limb about four kilometres wide (fig. 2). The statistical F₁ fold hinges plunge 15° SW (fig. 3) although locally, minor F₁ folds plunge more steeply (~40°) SW (235753/5554145). Later deformations have given rise to crenulation cleavages and minor folds in places without much affecting the regional D₁ structure. Retrogressed andalusite porphyroblasts display dextral rotation on subhorizontal outcrop surfaces at Denbys Bay (Plate 6).

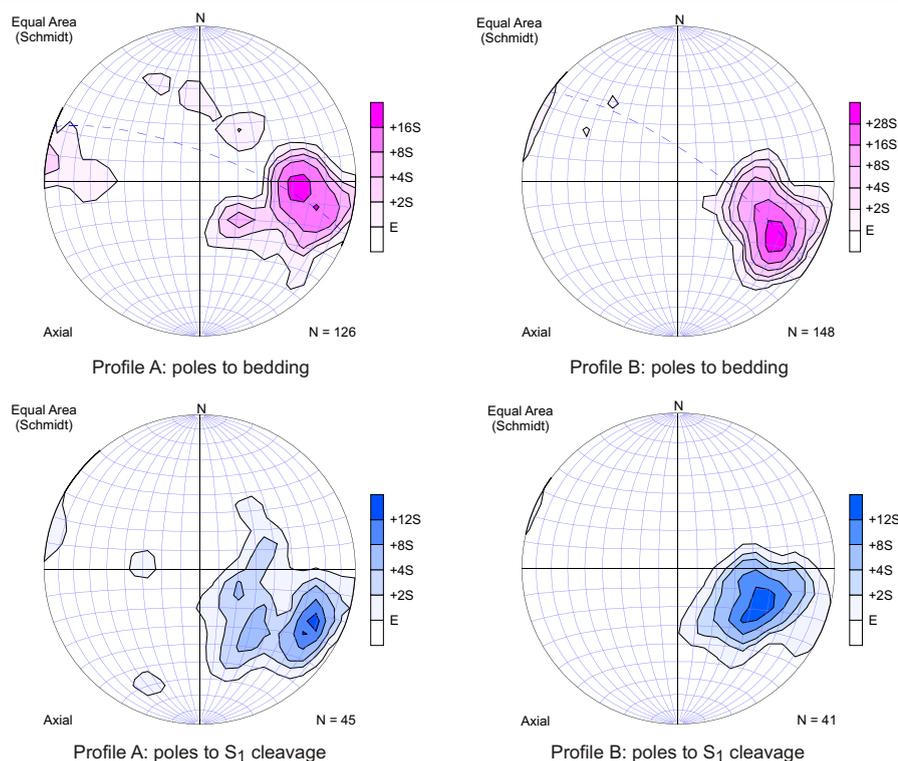


Figure 3
Equal-area stereoplots of poles to bedding and S₁ cleavage used in structural profiles A and B (Figure 2).



Plate 1

Bedded sandstone, overlain by massive sandstone, in the 'lower sandy member' of the Surprise Bay Formation, view looking south, west of Denbys Bay (234920/5554109).



Plate 2

Plane-laminated siltstone with thin beds of ripple-cross-laminated, load-casted fine-grained sandstone. Near top of 'lower sandy member' (235772/5554175).



Plate 3

Plane-laminated siltstone, upper part of 'lower sandy member', west of Denbys Bay (235186/5554037).



Plate 4

Thin-bedded fine-grained pelitic schist of 'middle pelitic member'. Note paler, silty, cross-laminated layers (236350/5552140).



Plate 5

Pelitic schist, with retrogressed andalusite (upper part of photo) and garnet, and plane-laminated to cross-laminated siltstone bed showing overturned facing; 'middle pelitic member'. Surprise Bay (236111/5553826).



Plate 6

Laminated pelitic schist with garnet (1 mm prominent grains) and retrogressed ?andalusite, 'middle pelitic member'. The retrogressed andalusites preserve the lamination and show dextral rotation. Denbys Bay (236267/5554042).



Plate 7

Internally stratified, porphyroblastic (actinolite + garnet) bed within pelitic siltstone of the middle pelitic member (236053/5552151).



Plate 8

'Bundle' of thick fine-grained sandstone turbidite beds, in predominant pelitic siltstone and schist, in 'upper sandy member', near Gulchway. Looking southwest (younging direction is to left) (237460/5551136).



Plate 9

Part of an ovoid concretion in fine-grained sandstone. Pen is sitting on remnant weathered core of amphibole calc-hornfels; note siliceous dark grey and pale grey rim zones speckled with amphibole porphyroblasts. (237455/5551135).



Plate 10

Dark grey pelitic schist of the 'middle pelite member', with distinct thin, sharp-bounded black pelite beds (arrowed) (237225/5551780).

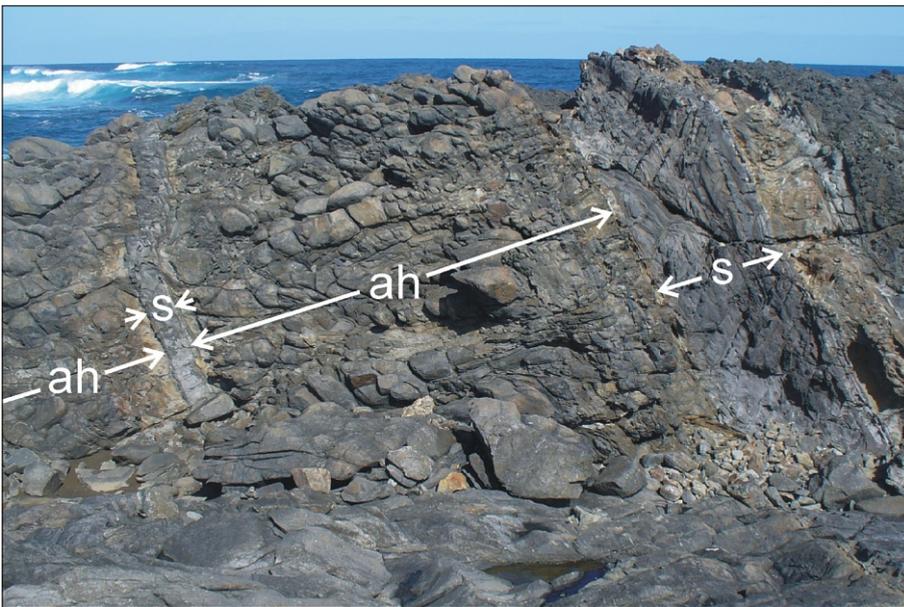


Plate 11

Alternating schist (s) and amphibole hornfels (ah) near Sealers Wall. The central hornfels unit is about seven metres thick (237246/5551580).

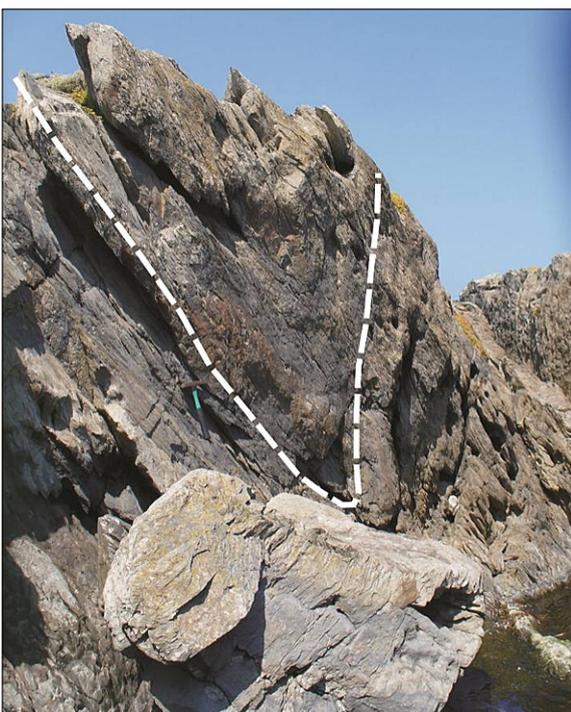


Plate 12

Tight synclinal F_1 closure at 237652/5550815, marking the top of the type section of the Surprise Bay Formation.

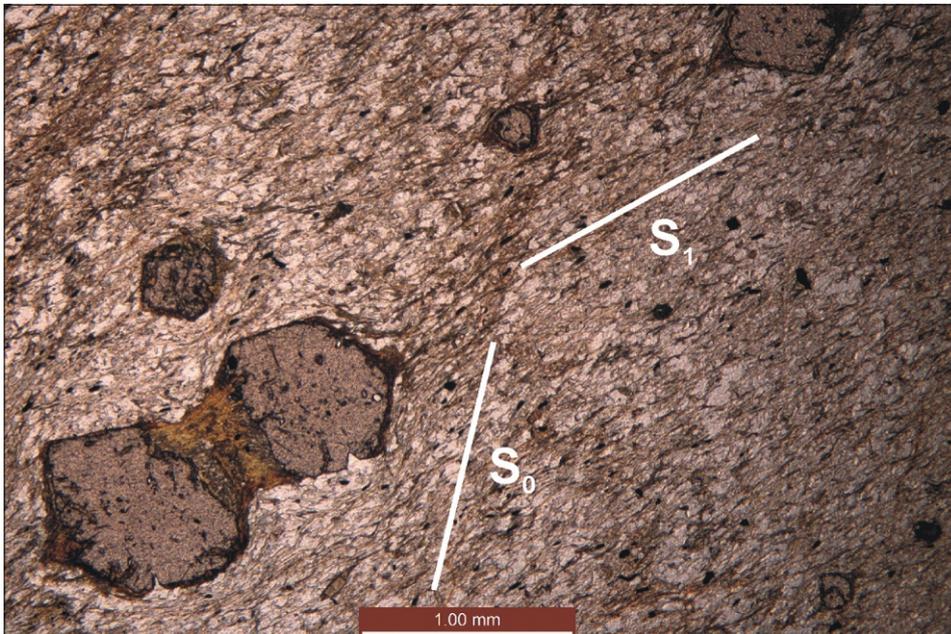


Plate 13

Schist with foliation deflected about euhedral garnet porphyroblasts; strain shadows of fine-grained chlorite. Sample KE607.



Plate 14

Schist, with chlorite porphyroblast overgrowing S₁ foliation. Sample KE429A.

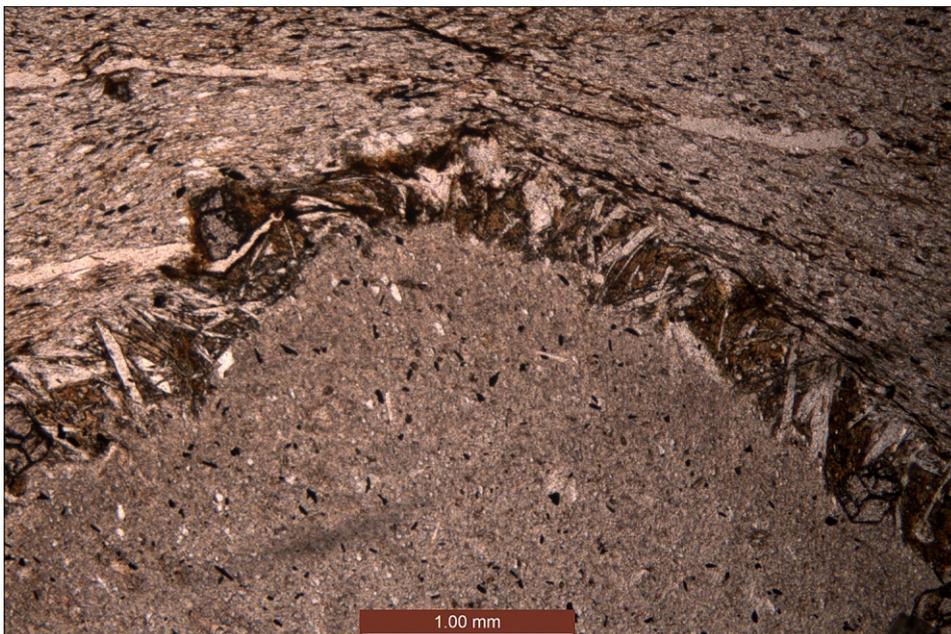


Plate 15

Schist with large retrogressed ?andalusite porphyroblast (lower part of image), bounded by selvage of coarse biotite, muscovite and minor garnet; S₁ deflected around porphyroblast. Sample KE521.

Fitzmaurice Bay to Millers Bay (Pearshape 1:25 000 scale map sheet)

The Surprise Bay Formation in the northern part of the Pearshape map sheet (Ettrick River–Millers Bay area) is described by Calver (2012), and that work is summarised here.

Along the west coast from Fitzmaurice Bay to Millers Bay the Surprise Bay Formation dips steeply west and is right-way-up. Inland, the Ettrick River provides an important cross-strike (east–west) section about five kilometres long. This section shows, 500 m inland, a major overturned F_1 isoclinal anticline, and three kilometres further east, a major isoclinal syncline. As on the Stokes map sheet, F_1 axial surfaces dip steeply west (see cross section on the Pearshape map sheet). These two regional folds are probably the same as those demarcating the type section, 15 km to the south on the Stokes map sheet (previous section). To the west, the west-younging, right-way-up Surprise Bay Formation of the coastal tract is intruded by the Loorana Granite at Fitzmaurice Bay and north of Millers Bay. Regionally, the granite contact appears to be concordant.

Stratigraphy

The Surprise Bay Formation consists of quartz-rich, fine-grained sandy turbidite beds alternating with metasilstone and pelitic schist. Sandier, thicker-bedded intervals alternate with thinner-bedded, more pelitic intervals, each metres to tens of metres thick. Amalgamated thick sandstone beds locally form packages 25 m or more in thickness, comprising resistant units such as those that form Ettrick Rock and the headlands north and south of Millers Bay. These sandy intervals are very similar to the lower sandy member of the type section. Individual sandstone beds within these units are up to 2.5 m thick. The finer grained intervals consist of parallel-laminated dark grey pelitic siltstone with starved ripples or lensing thin beds of fine-grained sandstone with cross lamination. Current directions shown by the cross lamination are approximately to the south.

In thin section, a massive quartzose sandstone (R15814) shows an interlocking granoblastic mosaic of fine-grained (0.1–0.25 mm) quartz (80%) with biotite, muscovite, K-feldspar, plagioclase and chlorite. Pelitic siltstone and pelitic schist show subequal quartz and muscovite, the latter as 0.25–0.5 mm long plates strongly aligned in the schistosity, with minor biotite (similarly aligned) and brown tourmaline. Garnet is subhedral to euhedral, and S_1 is deflected around garnet porphyroblasts (Figure 5 of Calver, 2012).

On the Pearshape map sheet, the Surprise Bay Formation has been differentiated into a sandstone-rich unit (Lbs) broadly similar to the lower sandy member of the type section, and a pelitic unit (Lbp) broadly similar to the middle pelite member, although no direct correlation is necessarily implied. Lbs includes the coastal exposures and most of the Ettrick River section, and the major F_1 anticline. Lbp occurs

in the easternmost part of the Ettrick River section, and includes the major F_1 syncline.

Structure and metamorphism

Boudinage: Coastal exposures of west-dipping and facing Surprise Bay Formation north of Millers Bay show boudinage of some sandstone beds. Strong refraction of S_1 around interboudin quartz gashes shows that the boudinage is pre- D_1 . Quartz gashes, rather than being perpendicular to bedding, are rotated anticlockwise and thereby signify an element of sinistral (top to south) shear during extension (Goscombe and Passchier, 2003). Most boudin necks plunge steeply southeast, at a high angle to the S_0/S_1 intersection, which plunges moderately north in this area (Figure 50 of Calver, 2012). Maximum extension direction shown by the boudinage was therefore approximately north–south. Minor extensional faulting subparallel to bedding, perhaps associated with the boudinage, is also present in this area.

D_1 : The Surprise Bay Formation is characterised by a strong schistose primary cleavage (S_1), which is well developed everywhere in this area except for some massive sandstones and recrystallised contact metamorphic rocks. S_1 is generally at a low angle or subparallel to bedding (reflecting tight to isoclinal F_1 folding), and is axial planar to uncommon, minor (outcrop scale) tight to isoclinal F_1 fold closures, and the two major regional F_1 folds. The few measured minor F_1 fold hinges and numerous calculated S_0/S_1 intersection lineations are subhorizontal to moderately north or south plunging (fig. 4).

Regional metamorphism associated with D_1 : Garnet, up to 1.5 mm, is locally present. The main schistosity, defined by platy muscovite and biotite, is deflected around the garnet porphyroblasts. Garnet is evidently pre-kinematic. Columnar porphyroblasts up to 10–50 mm in size, almost square in cross section, are locally abundant. They are entirely retrogressed to fine-grained muscovite, margarite and chlorite (XRD determination), but their morphology suggests they formed as andalusite. These porphyroblasts occur in pelitic schist but not sandstone. In places they show a preferred alignment in S_1 , and S_1 deflects around them, implying a pre or early D_1 age. The garnet and retrogressed andalusite show a disjunct regional distribution not obviously related to known granite distribution (Calver, 2012). These phases reflect low amphibolite facies metamorphism prior to or early in D_1 .

D_2 : A post- S_1 crenulation cleavage is locally present in the Surprise Bay Formation, with a similar (N–S) strike to S_1 , but a subvertical to steep easterly dip. Outcrop-scale, upright, open to tight F_2 folds, parallel in style, with strongly fanning S_2 , and plunging gently north, are seen on the coast at Dripping Wells (e.g. 234757/5566771; Figure 55 of Calver, 2012).

Cryogenian contact metamorphism: An intrusive contact of the Loorana Granite with west-dipping and facing Surprise Bay Formation is exposed at the southern end of Sandfly Beach

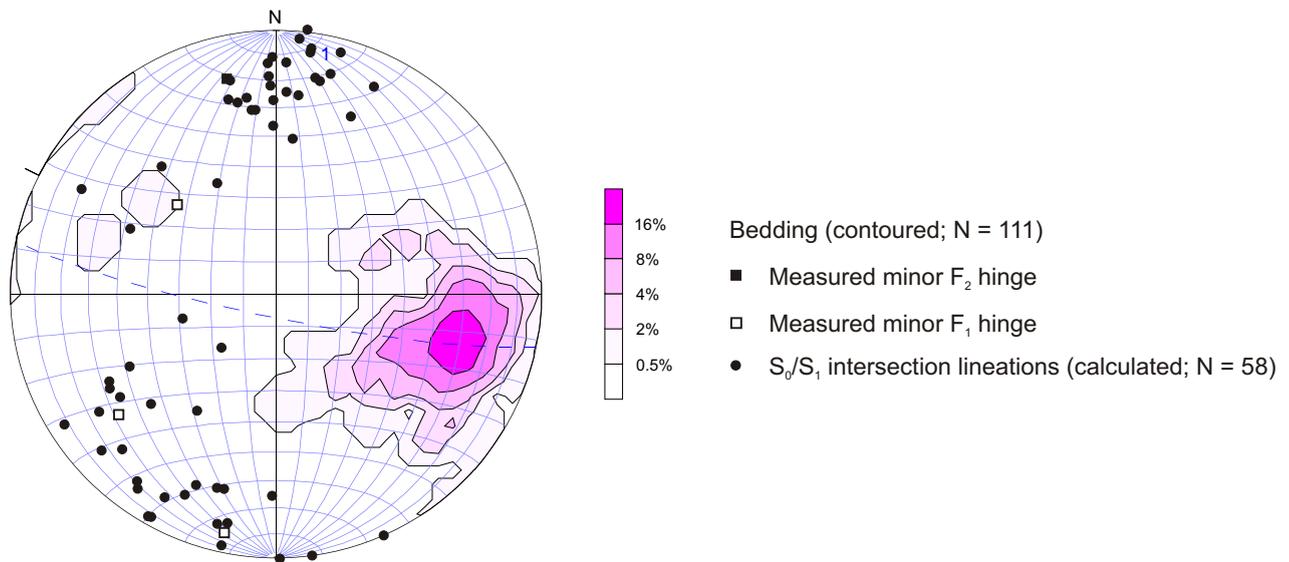


Figure 4
Equal-area plot of bedding, F_1 and F_2 hinges, and calculated S_0/S_1 intersection lineations, Surprise Bay Formation, northern part of Pearshape map sheet.

(northern edge of Pearshape map sheet). In outcrop, this contact is irregular, with rafts of metasediment in the granite, but regionally the contact appears to be conformable or nearly so (consistent with aeromagnetic trends), trending offshore to the south and reappearing on the south side of Fitzmaurice Bay. A contact metamorphosed zone about 100 m wide is present adjacent to the granite at the northern edge of the Pearshape map

sheet, marked by recrystallisation and the disappearance of S_1 and of small scale sedimentary structures such as planar and cross lamination, and the appearance of unaligned coarse (2 mm) poikiloblastic muscovite (e.g. thin section R15811), accompanied by thin veins and knots of microgranite and pegmatite.

Currie coastal section (Currie 1:25 000 scale map sheet)

Outcrop correlated with the Surprise Bay Formation extends along the coast from Netherby Point to Johnson Rock. This area is separated from the main belt of schist, to the east of the Loorana Granite, by a major fault and the granite itself. We refer here to this area as the 'Currie inlier' of the Surprise Bay Formation. Tectonometamorphic grade is relatively low in this inlier, with pelites being phyllite, slate or cleaved mudstone rather than schist, although garnet is locally present. By comparison, rare outcrop and float east of the Loorana Granite on the Currie map sheet is distinctly schistose. In the Currie inlier, there is a very similar range of protoliths and sedimentary facies to the type section, although no direct stratigraphic correlation can be made. Bedding mainly dips steeply west and is right-way-up. The faulted north-south contact with the Loorana Granite to the east (here named the Currie Fault) is exposed as a mylonite zone in several places. Continuity of outcrop along strike is interrupted by Currie Harbour and minor cross faults. Felsic porphyry sills in the Currie inlier have been dated at ~775 Ma (Calver *et al.*, 2013).

The lower grade is signified by a separate mnemonic for this area (Lbl: cleaved mudstone/phyllite with interbedded quartzose, fine-grained sandstone and siltstone). Some sub-units within this succession were mapped according to their predominant lithology.

Stratigraphy

Laminated siliceous siltstone (Lbll)

A unit of pale grey to grey-green, plane-laminated siliceous siltstone, 100–200 m thick, occurs at Netherby Point and on the north side of Burgess Bay. Probably the same unit reappears on the north side of Currie Harbour and continues along strike under cover to the south side of Dirty Bay, and at Johnson Rock. An identical lithology can be seen in the type section of the Surprise Bay Formation (Plate 3) and also in the type section of the Fraser Formation (Calver, 2012). The unit is rather monotonous in appearance, except for rare beds or lenses of dark grey, coarse-grained (3 mm) actinolite-garnet-quartz hornfels, probably originally calcareous beds or concretions. The top of this unit is marked in several places (Burgess Bay, Stingray Bay, Currie Harbour, Dirty Bay) by up to 10 m of thick-bedded pelitic siltstone with disseminated porphyroblasts 2 mm long of ?amphibole retrogressed to mica.

Fine-grained quartzose sandstone turbidite beds interbedded with cleaved mudstone/phyllite (Lblls)

Thin to thick (up to one metre) beds of very fine-grained sandstone are interbedded with a variable proportion of dark grey, thin-bedded pelite (the latter component identical to Lblp, below). Lblls overlies Lbll at Stingray Bay and north of Currie Harbour. The sandstone beds are turbidites, and Lblls is similar to (although of lower grade

than) Lbs (Pearshape sheet) and the lower and upper sandy members of the type section.

Cleaved mudstone/phyllite with minor interbedded siliceous siltstone (Lblp)

These rocks are grey, silty pelite or pelite, with a weak penetrative S_1 cleavage, and medium to thin, planar bedding. Groups or bundles of paler, planar siltstone laminae may be present, and there are rare thin beds or laminae of lensing quartz siltstone in which cross lamination and climbing-ripple lamination is well preserved (Plate 16). Well-developed regular rhythmic bedding is seen in an interval 10–20 m thick (229430/5577070) on Peerless Point. Each cycle consists of sharp-based pelitic siltstone, grading up into pale grey silty pelite, topped by a thin sharply-bounded layer of black shale, in total ~150 mm thick (Plate 17). These beds are interpreted as muddy turbidites, the black shale being the hemipelagic layer. Very similar beds are found in the Surprise Bay Formation correlate at Cape Wickham (see below) and in the Fraser Formation (e.g. Figure 12 of Calver, 2012).

Intrusive rocks

Cryogenian porphyry sills (Lgp)

About twelve quartz-feldspar porphyry sills, generally one to two metres thick, but ranging from 150 mm to 10 m thick, were noted within the Surprise Bay Formation between Netherby Point and Johnson Rock. These are more fully described by Calver *et al.* (2013), who dated two of them using LA-ICPMS U-Pb on zircon, at 776 ± 6 Ma and 772 ± 7 Ma. These felsic porphyry sills carry a strong foliation subparallel to their contacts that appears to correspond to the penetrative slaty cleavage in pelites in the enclosing sedimentary rocks. These sills appear to be restricted to the Currie inlier.

Carboniferous feldspar porphyry dykes (Dgnsg)

At 230728/5573780 (about 500 m southeast of Netherby Point), a subvertical, NNW-trending feldspar porphyry dyke about one metre wide intrudes the Loorana Granite. This dyke was dated by SHRIMP U-Pb on zircon at 350.4 ± 4.3 Ma (early Carboniferous) by Black *et al.* (1997), an age virtually identical to the Sandblow (Grassy) Granite of southeastern King Island. The dyke rock is pale grey with sparse feldspar phenocrysts up to 10 mm in size. In thin section (N130) the subhedral K-feldspar phenocrysts are zoned and variably altered, and there are rare rounded phenocrysts of quartz, in a more or less equigranular groundmass of feldspar, quartz and dark green chlorite.

A dyke very similar in width, orientation and outcrop aspect intrudes the Surprise Bay Formation in Burgess Bay, about 500 m to the northwest. It is possible that this is the same dyke, offset by movement on the Currie Fault. If so, about



Plate 16

Bed of cross-laminated quartz siltstone in grey phyllite, near Currie Harbour breakwater (230008/5575309). Upward in the photo is to the west.



Plate 17

Rhythmically bedded muddy turbidites, near Peerless Point (229430/5577070). Each cycle consists of yellowish siltstone, pale grey silty mudstone, and dark grey shale. Younging is to the left (west).

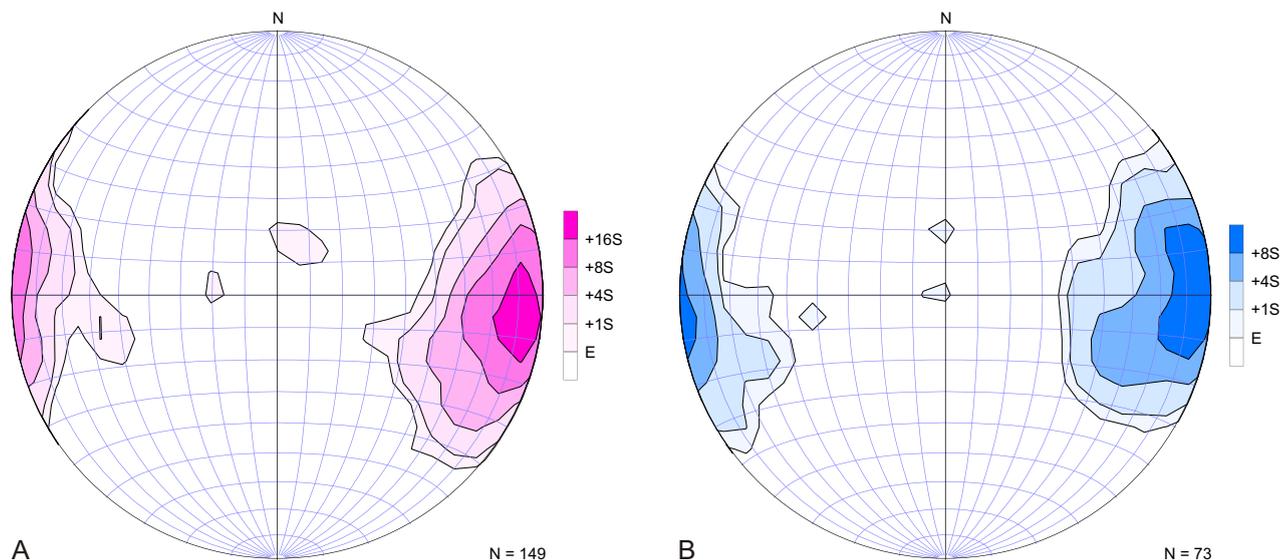


Figure 5
Equal-area plots of poles to (A) bedding; (B) S_1 cleavage, in the Currie inlier.

800 m of dextral movement on the fault, since the early Carboniferous, is implied.

Metamorphism

Pelitic lithologies in the Currie inlier appear to be of lower metamorphic grade than other areas of the Surprise Bay Formation. The much finer grain size (~50 μ m) of the muscovite comprising the main penetrative (local S_1) foliation means these rocks are better described as phyllite or slate, rather than the schist prevalent elsewhere. Biotite has not been found. No retrogressed andalusite porphyroblasts (common in other areas of the Surprise Bay Formation) were seen. Garnet is present as 1 mm subhedral porphyroblasts, wrapped by S_1 , in thin sections R17523 and R17534. Garnet was also seen as sparse (0.5 mm) small porphyroblasts in Lbll at Burgess Bay (230265/5574216).

Seen in Lbll, but also in other units, are minor thin to medium beds or lenses of dark grey hornfels with dark greenish, sheave-like aggregates (~2–4 mm), probably altered amphibole porphyroblasts, in a fine-grained siliceous matrix. These were probably originally impure calcareous beds or concretions. Thin section R17536 consists of 3 mm long plumes of actinolite, and lesser garnet, in a groundmass of fine-grained granoblastic quartz and sericite, with some patches of coarse quartz and zoisite. Similar actinolite porphyroblasts, aligned in S_1 , are disseminated through thick-bedded pelitic siltstone along the easternmost part of unit Lbll.

Structure

Bedding in the Currie coastal section mainly dips steeply west and is right-way-up (fig. 5). In areas near (i.e. within 200 m of) the Currie Fault, e.g. at the Currie Harbour breakwater and Dirty Bay, bedding swings around to dip steeply northwest. This may be due to drag on the fault, and suggests dextral fault movement.

The earliest cleavage is a penetrative foliation in pelites, and is subparallel to bedding, or steep and slightly anticlockwise of bedding such that the S_0/S_1 intersection plunges steeply north. The only F_1 closure seen, with the weak penetrative foliation in its axial plane, was a minor tight coupled fold with 'Z' asymmetry on a subhorizontal outcrop surface at 229957/5575329.

The Cryogenian porphyry sills carry a variably developed penetrative fabric sub-parallel to bedding, that appears to correlate with S_1 in the enclosing sedimentary rocks (Calver *et al.*, 2013). This puts a maximum age constraint on local D_1 that is at variance with the age of 1290 Ma determined by monazite dating in the Surprise Bay area (Berry *et al.*, 2005).

There are common, open to tight, upright minor folds that plunge gently south (fig. 6), and have an 'S' asymmetry looking south (Plate 18). Because of the fine grain size of the phyllites, the axial planar cleavage is often difficult to identify as a crenulation in the field. Thin sections (R17527, R17529, R17531, R17532) confirm the nature of the axial planar cleavage of these folds as a close-spaced (50 μ m) crenulation. This deformation is assigned to D_2 .

A shallow-dipping crenulation is seen in a few places between Currie Harbour and Burgess Bay. This cleavage dips <30° to the northwest or southeast (fig. 6). Similarly orientated axial planes of small open folds (a few centimetres wavelength) were seen at 229900/5575168. These features are assigned to D_3 . No evidence was seen to establish their age relative to D_2 .

Bedding-subparallel extensional faulting, of uncertain age relative to other structural elements, was noted in several places (Plate 19).

Currie Fault: This major NNW-trending fault separates the Currie inlier from the Loorana Granite. The fault post-dates the granite, and the lack of contact metamorphism in the inlier suggests significant movement. The fault zone is about 80 m wide at Netherby Point, and includes grey-green, fine-grained mylonite, with sheared lenses of granite,

metadolerite and schist. At Currie Harbour breakwater, the zone, including sheared granite and metasediments, is about 40 m wide and is mainly a pale grey mylonite. The mylonites lack obvious lineation, and the direction of movement cannot be readily discerned from outcrop or orientated thin sections. There are some indications of dextral movement; the apparent drag of bedding at the map scale mentioned

above; and the apparent dextral offset of about 800 m of a Carboniferous porphyry dyke across the fault (see below). Domino boudinage (Goscombe *et al.*, 2004) in the Surprise Bay Formation, 120 m west of the Currie Fault at Netherby Point, shows dextral shear (Plate 20).



Plate 18

F₂ minor folds, view looking south, on north side of Currie Harbour (229415/5576265).

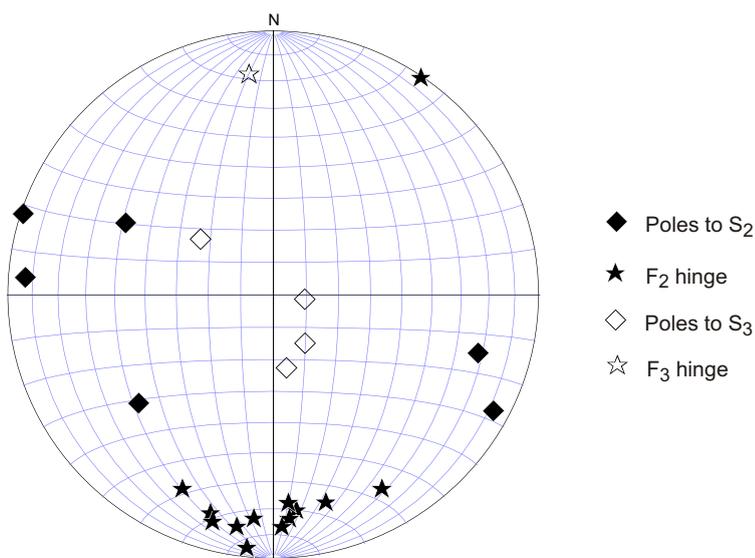


Figure 6

D₂ and D₃ structural elements, Currie inlier.



Plate 19

Low-angle extensional faulting near Peerless Point (229350/5576602). Up in the photo is to the east.



Plate 20

'Domino boudinage' (Goscombe et al., 2004), indicating dextral shear, in thin-bedded siltstone-shale, 120 m west of Currie Fault at Netherby Point (230354/5573971). Sub-horizontal outcrop surface; up in the photo is to the west.

Cape Wickham (Wickham 1:25 000 scale map sheet)

A correlative of the Surprise Bay Formation crops out along about eight kilometres of rocky coast from the northern end of Phoques Bay to just east of Cape Wickham. Dominantly schist and metasandstone, it has an intrusive contact with the Cape Wickham Granite to the east, and is contact metamorphosed throughout. Bedding for the most part dips steeply west, and is overturned. Sills and dykes, of mafic and granitic composition, are very common. A separate, one kilometre long tract of Surprise Bay Formation is found on the coast at Georges Rock, three kilometres east of Cape Wickham. This is enclosed by the Cape Wickham Granite, and may be a roof pendant (Cox, 1973). It has intrusive concordant contacts on either side. The structural history is complex and multi-phase, largely a result of an evolving stress field during intrusion of the Cape Wickham Granite. This area was the subject of a detailed study by Cox (1973), and to a large extent the discussion below builds on his work.

Granitic intrusive rocks include sheets, dykes, veins and irregular bodies of granite, microgranite and pegmatite. These are all thought to be more or less synchronous with intrusion of the Cape Wickham Granite. Mafic sheets and dykes of at least three different generations can be recognised. Timing of intrusion relative to the granite can generally be directly determined by cross-cutting relationships with minor granitic intrusive rocks. These rocks will be more fully described in a later report.

The southernmost 1.2 km of the main coastal tract lies south of the Wickham map, but is included in the discussion here. Its geology is shown in Figure 7.

Widespread sandy surficial deposits to the south of the Wickham map sheet mean that it is not clear whether the Surprise Bay Formation there links up to the south with the main schist belt east of the Loorana Granite (fig. 1). Gresham (1972) and Brown (1973) thought that the Cape Wickham and Loorana granites joined beneath the sand, based on sparse outcrop and shallow drilling. Two recent shallow holes drilled just inland of Phoques Bay (K1007 and K1008 of Hine and Smith, 2013) bottomed in schist, suggesting that the Surprise Bay Formation correlate outcropping on the coast on the Wickham map (north of Phoques Bay) extends along strike to the south to join up with sparse outcrop and drill hole intersections in the Yambacoona area, thereby separating the two granites. Parallel, crudely linear aeromagnetic anomalies, typical of the Surprise Bay Formation, occurring inland of Phoques Bay are consistent with this interpretation.

Stratigraphy

Alternating units dominated by either thin-bedded grey schist (Lbpx) or fine-grained metasandstone (Lbsx) have been differentiated, although no stratigraphic succession can be worked out because of faulting and deformation. Contact metamorphism has resulted in recrystallisation that overprints and partly obscures the primary foliation (S_1).

Dominantly thin-bedded pelitic schist, contact metamorphosed (Lbpx)

These rocks are mostly thin-bedded to laminated (banded), light grey to dark grey schist. Thin to medium beds of pale grey quartzose metasandstone are commonly a minor component. Packages of medium to thick beds of fine-grained quartzose sandstone are present in places. Boudinage of the sandstone beds is common (see *Structure* section). The schist is coarse-grained (micas 1–2 mm), probably a result of aggradational recrystallisation accompanying contact metamorphism, as they are distinctly coarser than schists in the Surprise Bay Formation distant from granite contacts (e.g. Surprise Bay area). There is a rough primary foliation sub-parallel to bedding. Recrystallisation also means that facing evidence, in the form of cross lamination, is only rarely preserved in some of the thin sandstone beds.

On Cape Farewell (between 236087/5613000 and 235992/5612545), the rock is a poorly-bedded to massive or thick-bedded, dark grey schist with common 'knots' of pegmatite and vein quartz. Much of the rock shows contact metamorphic (?) spots, 2–5 mm in size. Muddy turbidites can be recognised in places (Plate 21). These have silty, plane-laminated or cross-laminated basal parts, and thin dark grey pelagic shale interbeds. They show (together with cross lamination) that the beds here are overturned and younging east.

Dominantly fine-grained quartzose sandstone, contact metamorphosed (Lbsx)

Areas mapped as Lbsx are mainly quartzose siltstone and fine to very fine-grained sandstone, as medium to very thick beds, interbedded with lesser pelitic (schistose) lithologies. Individual sandstone beds are up to two metres, rarely five metres, thick (as at 236987/5613314), and internally structureless. Thick beds generally have sharp tops and bases (Plate 22); in places, grading is preserved in thin to medium beds (Plate 23). There are rare ellipsoidal concretions, ~0.5 m long, probably originally calcareous, of dark amphibole hornfels with pale siliceous rims, similar to those seen elsewhere in the Surprise Bay Formation.

Mafic intrusions

Amphibolite dykes (Laa) carry a weak S_1 foliation and are transected by minor granitic dykes in many cases. They may be up to 15 m wide (e.g. 237009/5613278).

Unfoliated fine-grained metadolerite dykes or sheets, that also pre-date the granite, are cut by minor granitic dykes or veins, e.g. at 236939/5612914 and 236178/5611749.

Unfoliated fine-grained mafic dykes that are post-granite (i.e. transect minor granite dykes) are up to 15 m wide (e.g. 236242/5610580) (Lmgf).

Feldspar phyric dolerite dykes with a north–south trend (Lmgf) occur, e.g. a 12 m wide dyke at Cape Farewell

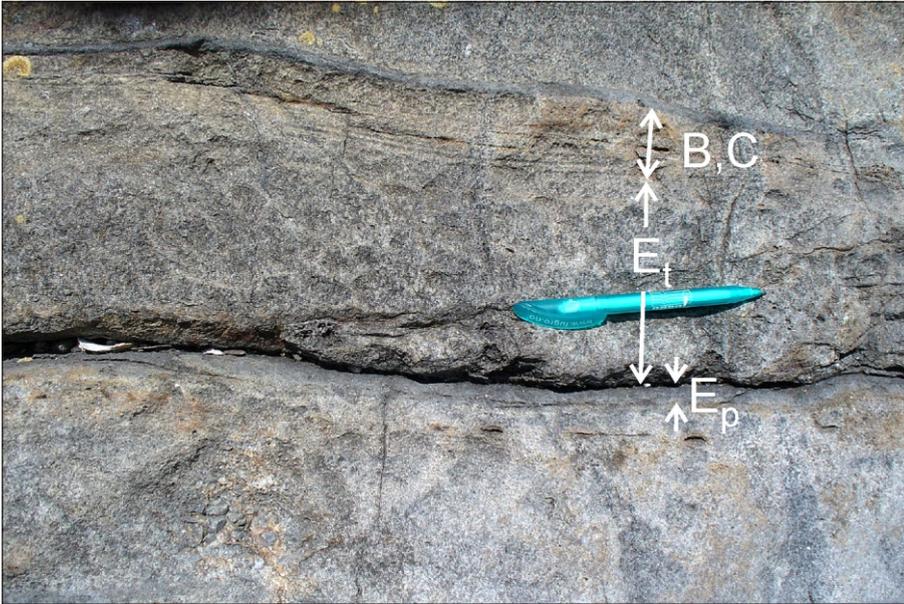


Plate 21

Silty pelitic schist; Bouma subdivisions of one muddy turbidite unit shown (B, C: metasilstone; E_t : turbiditic silty pelite; E_p : hemipelagic pelite). Younging direction is downwards in the photo (west is upward). Cape Farewell (235989/5612837).

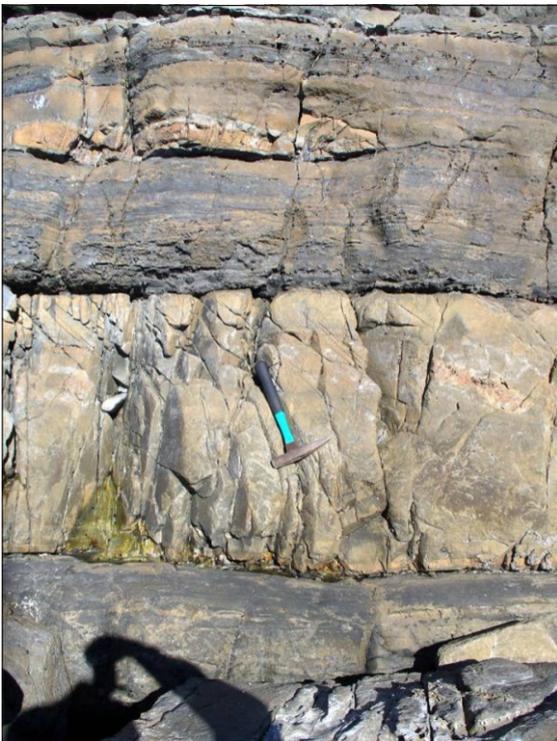


Plate 22

Thick, internally uniform, sharp-bounded very fine-grained sandstone bed. North of Yellow Rock Beach (236562/5609620).

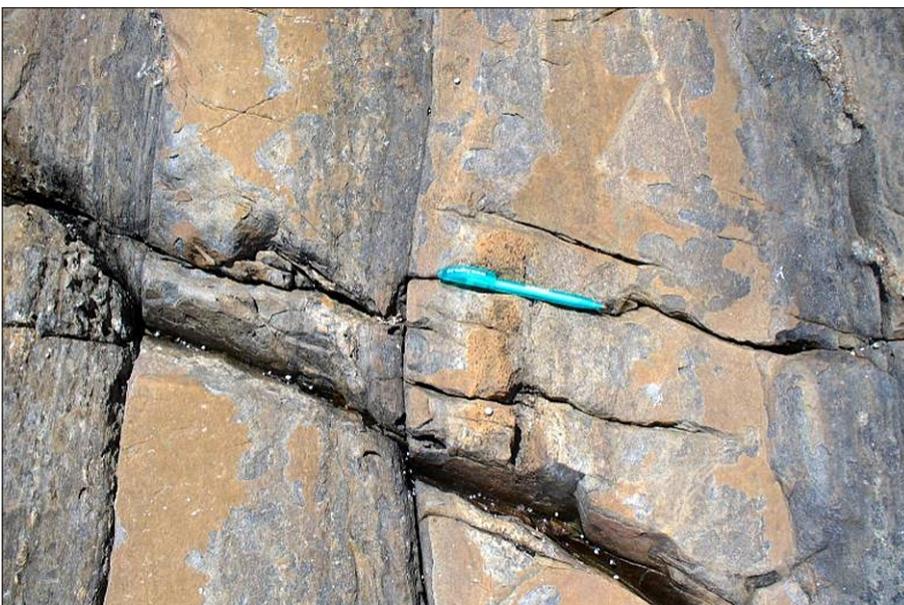


Plate 23

Two sharp-based, graded beds of fine-grained sandstone, younging to the right (west is to the left). North of Yellow Rock Beach (236586/5609964).

(236131/5613005) and at Cape Wickham (237784/5614430). Dykes similar in orientation and field appearance also occur in the Pearshape and Currie map sheet areas.

Minor granitic intrusions

A slightly transgressive granite sheet about 60 m wide and at least 400 m long intrudes Lbpx at The Springs (fig. 7). This sheet contains disorientated rafts of schist, up to five metres long, in several places. It is locally adjoined to the west by a 15 m wide sheet of amphibolite.

Elsewhere granitic intrusions are abundant in the Surprise Bay Formation, as dykes, sheets and irregular bodies 50 mm to several metres wide. Microgranite occurs as sills and sheets 50–100 mm wide, which are pygmatically folded in some cases.

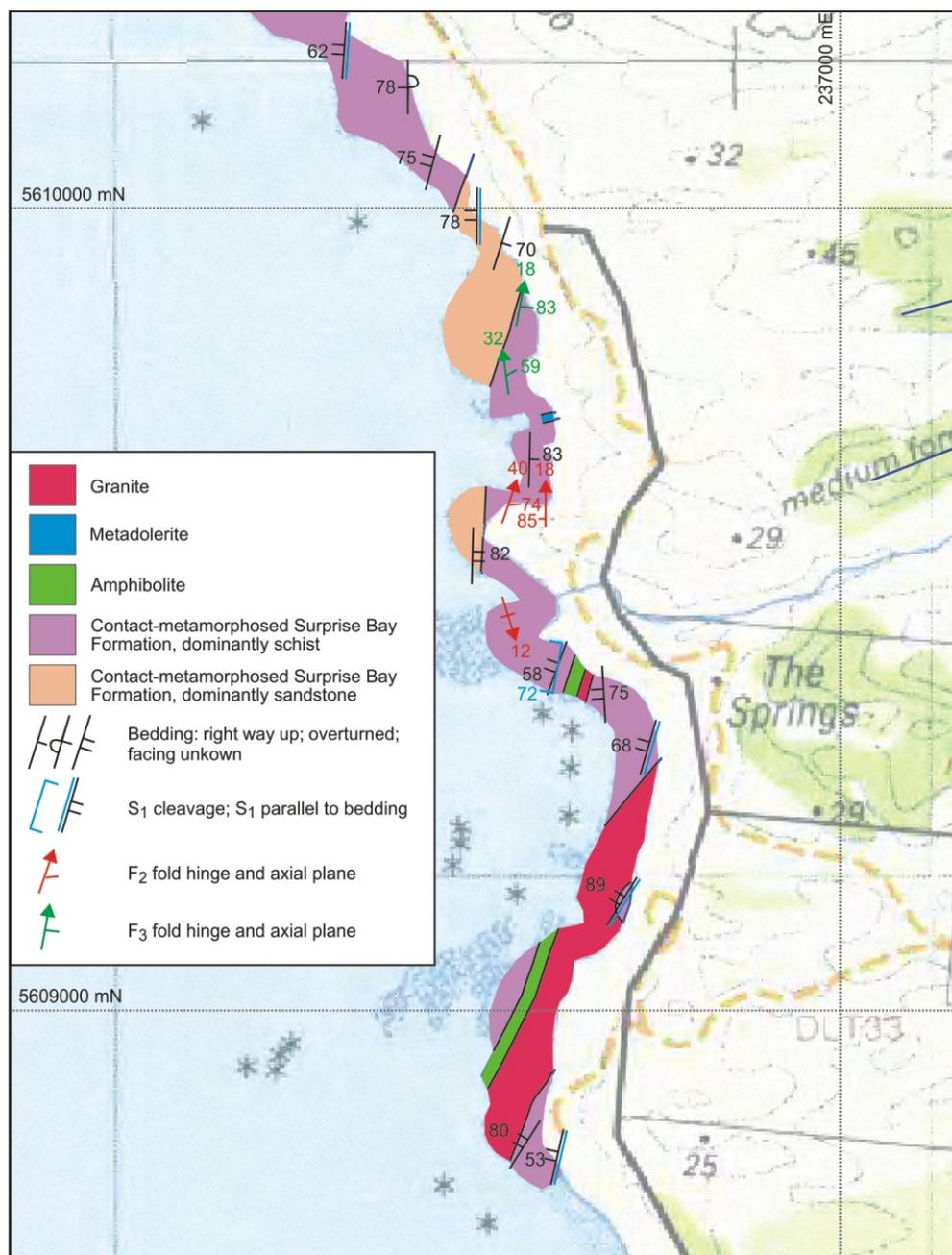


Figure 7

Geological map of coastal outcrop north of Yellow Rock Beach, on New Year 1:25 000 map sheet.

Many small knots of pegmatite may be sweat-out bodies or leucosomes, in some cases associated with extensional fracture, as shown for those associated with D_3 (below).

Structure

D_1 : Bedding in the Yellow Rock Beach–Cape Wickham outcrop tract dips predominantly steeply west (fig. 8) and youngs to the east (six observations). The primary foliation (coarse schistosity) is nearly everywhere subparallel to bedding, but is not obvious in many places because of contact metamorphic recrystallisation. The whole area presumably lies on the steeply overturned limb of a large scale isoclinal F_1 fold.

Minor F_1 fold closures were only seen at Cape Farewell (236188/5612996), where small tight parasitic F_1 folds, with the primary foliation in the axial plane, plunge south and have 'Z' vergence (looking south), and thus face upwards (Plate 24). At two locations (236593/5612773 and 236655/5609446), where bedding has steep west dips without younging evidence, what appears to be S_1 is slightly steeper than bedding, implying these outcrops could be west-younging narrow F_1 fold limbs, but no associated closures were seen.

Bedding in the Georges Rock inlier mostly dips steeply east or west. Only one facing determination could be made, from cross lamination at 239764/5613456, where bedding dips steeply east and is right-way-up. Forty metres to the southeast of that location, at 239798/5613431, a tight F_1 synform plunges gently north. Further southeast, for about 200 m, west-dipping bedding is associated with subparallel to more steeply west-dipping S_1 (implying west younging), until a gently north-plunging F_1 antiform is reached (at 239900/5613260). Further west, S_1 dips west more shallowly than bedding, implying an overturned east-facing F_1 limb at least 300 m wide. The overall D_1 structure of the central part of the Georges Rock inlier thus appears to

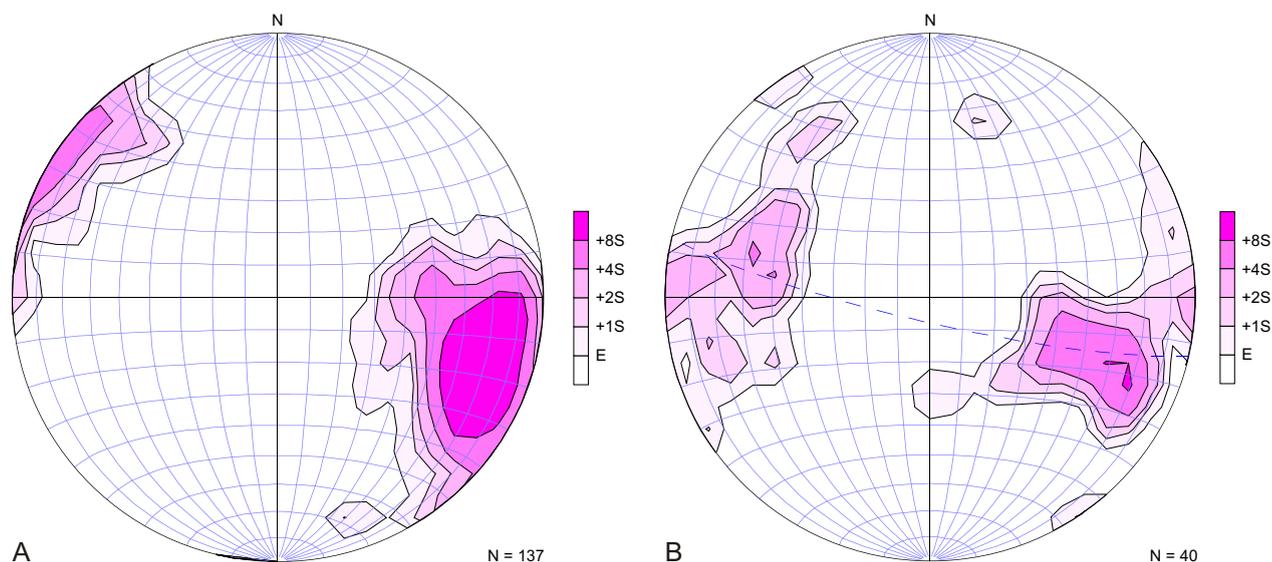


Figure 8
Equal-area plot of poles to bedding, Cape Wickham area.
 A: northern end of Yellow Rock Beach to Cape Wickham; B: Georges Rock inlier.

be a coupled tight syncline-anticline pair, upward-facing, plunging gently north.

D_1 pre-dates granite intrusion (Cox, 1973). Minor granitic intrusions, not significantly deformed, can be seen to cut across bedding and subparallel S_1 foliation in many places. Cox (1973) noted that granite intrusions in the Georges Rock inlier cut across F_1 folds without themselves being folded.

Post- D_1 boudinage: Symmetric boudinage of competent metasandstone beds was seen in several places. Tight neck folds involve both bedding and S_1 , implying a post- D_1 age, but temporal relationships with D_2 – D_5 are unknown. Boudin interspaces (and neck fold hinges) tend to plunge steeply northwest in steeply west-dipping bedding planes (4 out of 5 observations), a quite different orientation from the asymmetric foliation boudinage of D_3 (see below).

D_2 : D_2 – D_5 are spatially impersistent. This, and the absence of regionally penetrative foliations associated with these phases, makes correlation of structures across the area rather speculative. In large part the structural sequence set out here follows Cox (1973). At scattered localities there are upright, open to tight outcrop-scale folds that trend north to northeast, that fold bedding and S_1 schistosity (Plate 25). Hinges plunge gently north or south (fig. 9). Axial planar cleavage is often absent from these folds, but is seen in some localities as a coarse, patchy crenulation. These elements are grouped as D_2 mainly based on similar axial plane orientation, although more than one phase may be present. A thin pegmatite sheet is folded by F_2 at 236949/5613094. D_2 as recognised here appears to correspond predominantly to D_2 of Cox (1973), recognised as upright NE-trending folds that pre-date D_3 .

D_3 : D_3 , as used here, encompasses a curious group of structures that appear to be of predominantly extensional origin. The structures are found only at outcrop scale, in thinly banded schist (Lbpx). F_3 folds affecting bedding and the primary schistosity are disharmonic, generally lack axial

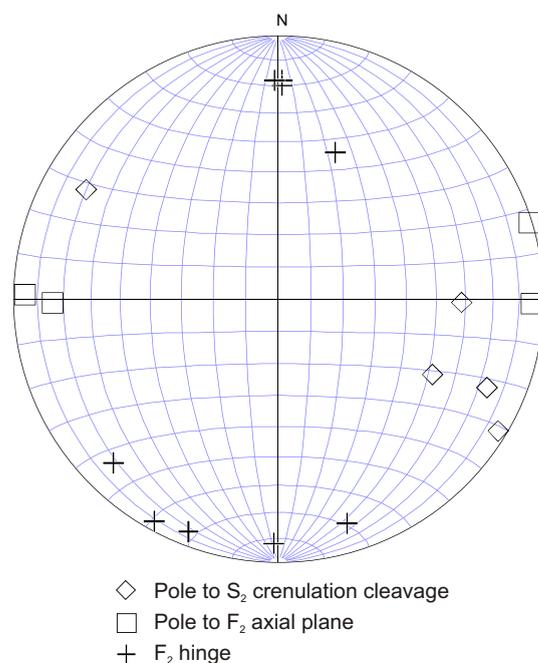


Figure 9
Equal-area plot of D_2 structural elements, Cape Wickham area.

plane cleavage, and have axial planes aligned with short vein segments, in a manner similar to the neck folds associated with boudin gashes (Plate 26, 27, 28). Viewed on outcrop surfaces approximately normal to the vein-bedding intersection, the veins are short (~50–150 mm) and inclined at 45–60° to bedding. The folds are more pronounced where associated with shorter, broader veins, an observation also consistent with boudinage (Plate 29). However the structures (veins + folds) differ from classical boudinage in that they appear more or less randomly distributed through the rock, and are not associated with any obvious compositionally discrete layers (Plate 30). As

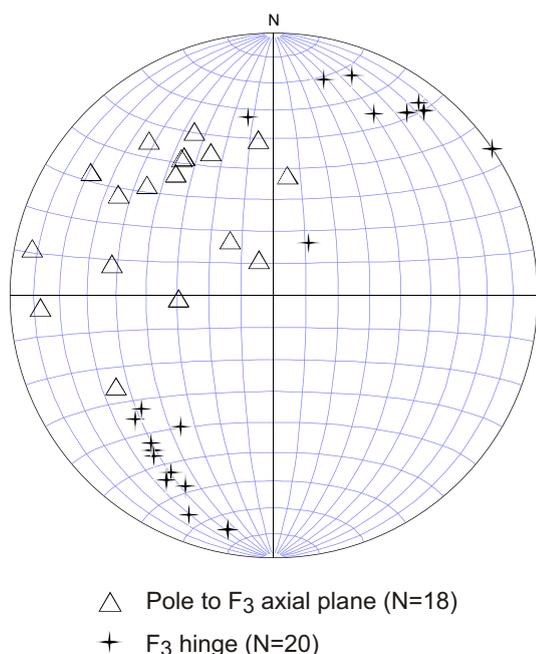


Figure 10
Equal-area plot of D₃ structural elements,
Cape Wickham area.

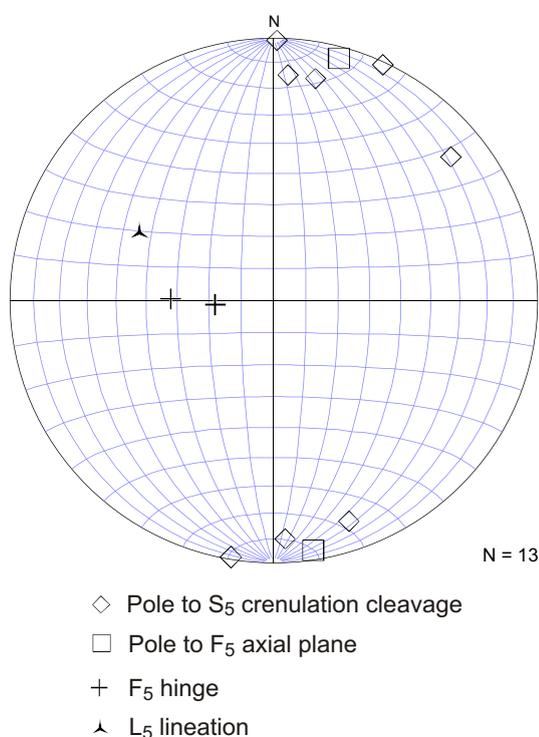


Figure 11
Equal-area plot of D₅ structural elements.

well as the neck folds immediately beyond the terminations of the veins, there are in most cases gentle 'flanking folds' (Passchier, 2001) on either side of them. Flanking fold closures on either side are generally opposed so that they form verging 'S' or 'Z' structures with the vein occupying the short limb. Layers in the schist may be slightly displaced from one side of a vein to the other. Displacement is antithetic (i.e. 'a-Type' flanking folds, Passchier, 2001; Plate 28). Viewed in the bedding plane, the veins are much longer, with a strong parallel alignment. They have an undeformed pegmatite-like fill of coarsely crystalline quartz, K-feldspar and (in some cases) tourmaline. The veins (and the axial surfaces of the neck folds, and flanking folds where present) dip fairly consistently to the southeast, in the area north of Victoria Cove, and dip to the east where seen in places between Cape Farewell and The Springs (fig. 10). The fold hinges (and the parallel vein-bedding intersections) plunge gently south in the area north of Victoria Cove (and have 'S' vergence, down plunge) and gently north elsewhere ('Z' vergence, down plunge). In rare cases, a weak patchy coarse crenulation cleavage is present, parallel to the axial plane of the neck folds (236887/5612968, 237141/5613549).

The D₃ structures are very similar to the 'foliation boudinage' of Platt and Vissers (1980), and imply extension in the direction of foliation (S₀ + S₁) of the banded schists. In this case, the extension direction was more or less vertical in the plane of the banding (predominantly steep west dipping). The angle between the overall banding (S₀ + S₁) in the schist and the D₃ structures (neck folds + veins) tends to be significantly less than 90°, indicating an element of non-coaxial shear (Platt and Vissers, 1980), in this case west-side-up. This is consistent with the vergence of the flanking folds. The veins imply brittle fracture and are filled by leucocratic minerals; the presence of tourmaline shows ambient fluid compositions were granitic, and a broadly syn-Wickham Granite age is implied for D₃. The D₃ structures indicated on the 1:25 000 scale geological map are F₃ axial planes; however it should be borne in mind that these are primarily (or entirely) extensional structures, rather than compressional folds. Rare axial planar cleavage may indicate a later compressional overprint.

D₃ as recognised here probably corresponds with D₃ of Cox (1973, 1989). Cox (1973, p.124) remarked that "...there is localised recrystallization and formation of granitic sweat-out structures in the hinges of some F₃ folds", although Cox seems not to have recognised the predominantly extensional nature of D₃.

D₄: D₄, as recognised by Cox (1973), comprises open, upright folds with northeast trends (similar to D₂), that overprint D₃ structures. One such fold could be positively identified in the course of this work (at 237133/5613401). This is an open coupled fold with a gently southwest plunging hinge, with easterly vergence, that can be seen to rotate D₃ structures (Plate 31). A fault along the synformal axial plane has been intruded by a granite dyke, suggesting that granitic intrusive activity continued after D₄.

D₅: Open, upright, approximately east-west trending folds are assigned to D₅ (fig. 11). Thin granitic sills are affected (236053/5612284, south of Cape Farewell). A weak, patchy

crenulation cleavage is locally present. Locally there is a down-dip lineation on steep west-dipping $S_0 + S_1$ surfaces, attributable to D_5 . On the north side of Cape Farewell, this is expressed in places as a weak alignment of retrogressed andalusite porphyroblasts. D_5 features occur around Cape Farewell, and about 500 m north of Victoria Cove. D_5 probably corresponds to the late, upright, open east-west trending fold phase of Cox (1973).

Metamorphism

Contact metamorphism has overprinted earlier regional fabrics in the Surprise Bay Formation throughout the Wickham map sheet area.

Coarse recrystallisation of micas and quartz in schist overprints the S_1 schistosity. A similar phenomenon is seen in the much narrower contact aureole east of the Loorana Granite at Millers Bay (Pearshape map; see above). In thin section (e.g. N171), these rocks show quartz, biotite, muscovite and microcline. In N171, microcline forms larger anhedral crystals (2 mm) poikilitically enclosing the other minerals (0.25–0.5 mm). Quartz grains are equant, unstrained, granoblastic in places, and all phases are apparently undeformed. The only vestige of S_1 (?) is a weak alignment of the micas.

Metamorphic spotting is locally present, such as in pelitic schist in the Cape Farewell area. Large ovoid 'mega-spots' (Plate 32) were seen near the granite contact on Cape Wickham (as far west as 237813/5614420), and just east of the granite sheet at the northern end of Yellow Rock Beach. XRD of a sample (N170) of a metamorphic ovoid at the latter locality showed muscovite, quartz, albite and chlorite.

Pseudomorphs of columnar porphyroblasts up to 30 mm long, probably originally andalusite, are locally abundant. XRD of samples of these porphyroblasts (N165 and N167) returned muscovite and minor chlorite. These are common in places distant from granite elsewhere on King Island (e.g. Surprise Bay, Ettrick River) where they also appear to pre-date S_1 , so are not necessarily here of contact metamorphic origin.

Dark greenish 2 mm porphyroblasts of probable amphibole are sparsely disseminated in some metasilstone layers (e.g. 236524/5612908, 236459/5612944). Rare, elongate-ovoid bodies of dark grey amphibole hornfels, with pale siliceous rims, are very similar to bodies elsewhere interpreted as calcareous concretions (see above; e.g. 236186/5613004).



Plate 24

Tight minor F_1 'Z' fold. West is upwards in the photo. Near Cape Farewell (236188/5612996).



Plate 25

Minor gently south-plunging folds assigned to F_2 . View looking north at 236595/5609500.



Plate 26

Short, leucocratic veins associated with disharmonic folds, assigned to D_3 (237175/5613518).

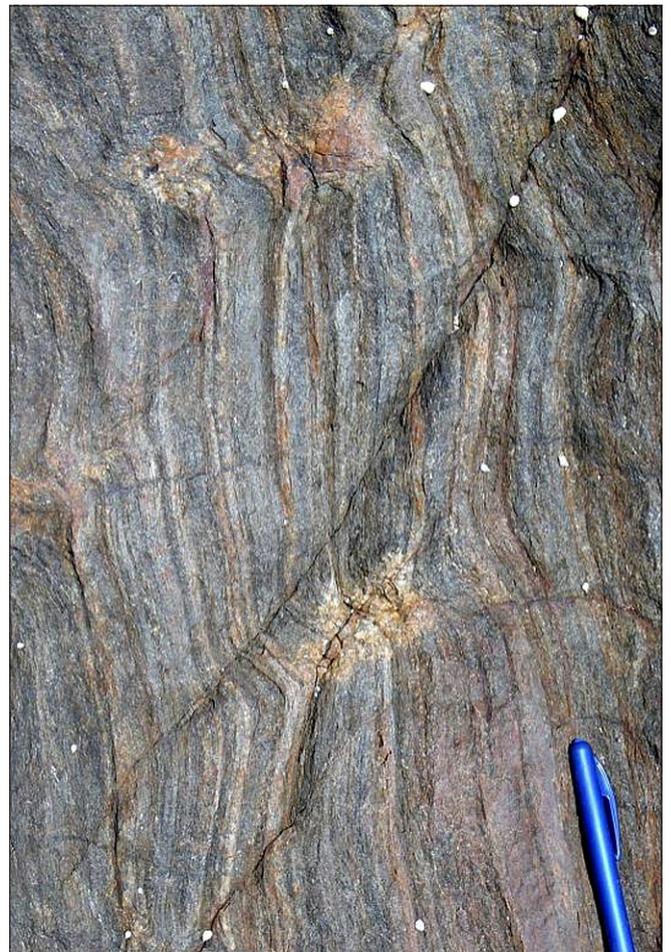


Plate 27

Further examples of short veins and gentle disharmonic folds of D_3 (237120/5613396).



Plate 28

D₃ vein with well-developed flanking folds (237120/5613396).



Plate 29

Recessively-weathered, broad, short veins associated with strong disharmonic folding (236497/5612910).

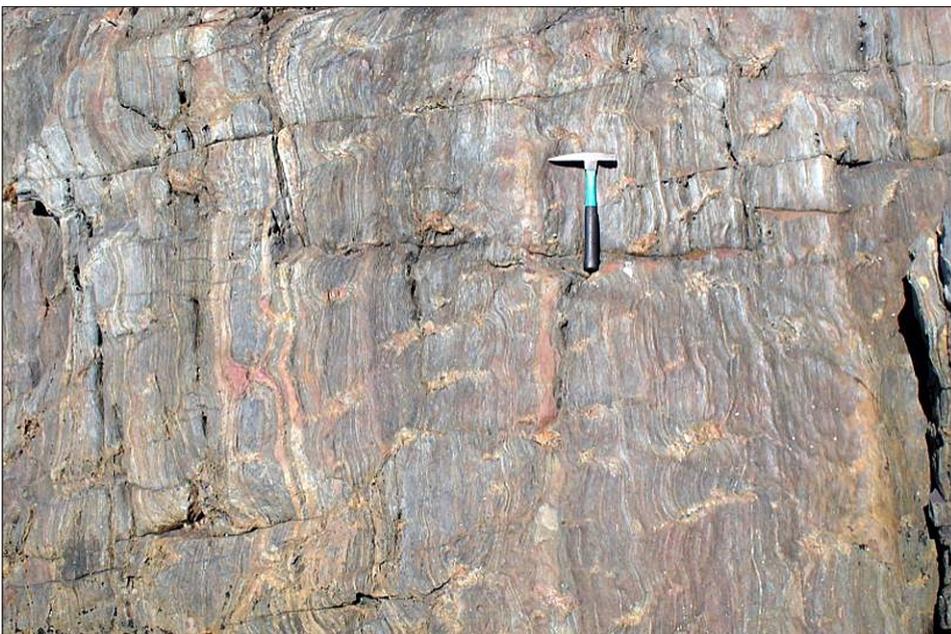


Plate 30

Outcrop surface with multiple examples of crudely aligned short veins and gentle disharmonic folding assigned to D₃ (237120/5613396).

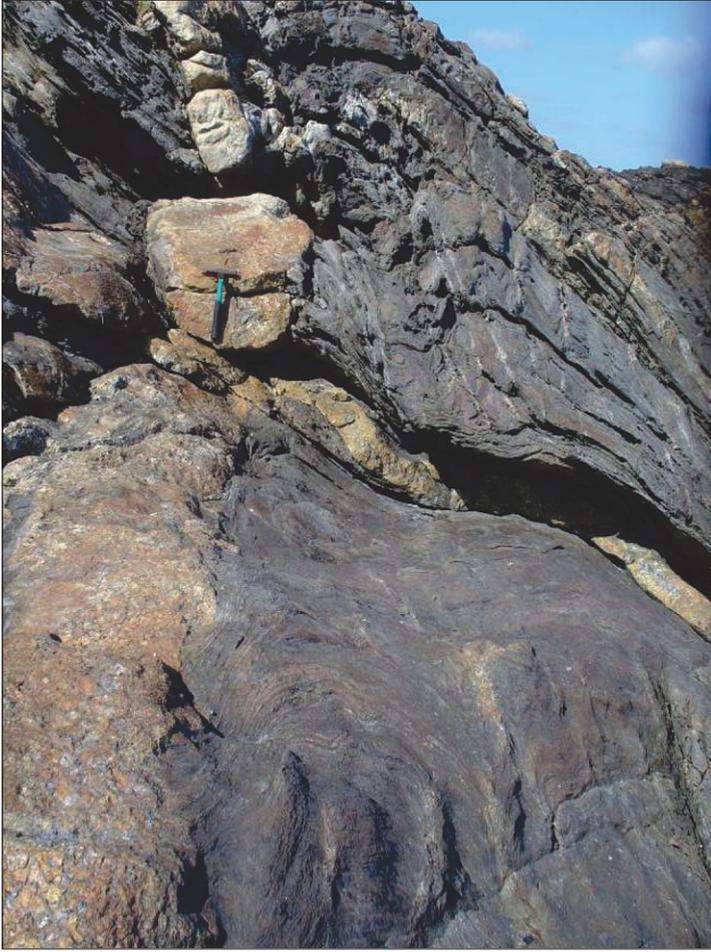


Plate 31

D₄ fold, looking south; granite dyke (on which hammer sits) intrudes parallel and just left of anticlinal axial plane (237133/5613401).



Plate 32

Metamorphic ovoids in Surprise Bay Formation close to contact with the Cape Wickham Granite (237813/5614420).

Discussion

The mapping confirms that one and the same metasedimentary succession is present throughout western King Island, and thus the Pearshape, Currie and Wickham outcrop areas described above are all correlated with the type Surprise Bay Formation on the Stokes map sheet. The succession is dominated by thick-bedded, fine-sandy (<0.25 mm) quartzose turbidites, and siltstone and pelite that are also at least in part turbidites. This distinctive sedimentary protolith also characterises the Fraser Formation of eastern King Island (Calver, 2012). Minor but distinctive amphibole hornfels are also present in both the Fraser and Surprise Bay formations. Correlation of the two formations is consistent with similarities in their detrital zircon age distributions (Black *et al.*, 2004).

The proposed correlation of the Fraser and Surprise Bay formations raises the issue of validity of the latter term, as the former has publication priority (Direen and Jago, 2008). However we favour retaining both names to reflect the regional westward increase in tectonometamorphic grade (as allowed under the current rules of lithostratigraphic nomenclature: Staines, 1985, p.100).

Presently available age constraints place the deposition of these rocks at between ~1400 Ma and ~1270 Ma (Black *et al.*, 2004; Berry *et al.*, 2005). Similar mid-Mesoproterozoic age constraints of approximately 1450 to 1330 Ma have recently been determined for the lower formations of the Rocky Cape Group of northwest Tasmania (Halpin *et al.*, in prep.). There are similarities in the age distributions of detrital zircon populations from the Rocky Cape Group and the Surprise Bay Formation/Fraser Formation (Black *et al.*, 2004; Halpin *et al.*, in prep.), but the predominant shallow-marine/shelfal facies of the lower Rocky Cape Group differs from the turbiditic Surprise Bay Formation, arguing against a direct correlation (Calver *et al.*, 2014). A correlation of the King Island rocks with the quartzose sandy turbidites of the Oonah Formation of western Tasmania could be considered on broad lithologic grounds, but the latter unit contains 1100 Ma detrital zircon (Black *et al.*, 2004), as does the Bowry Formation of the Arthur Metamorphic Complex in northwest Tasmania (Turner *et al.*, 1998).

Current ideas on basement structure underlying Bass Strait show King Island as part of a basement block that extends northeastwards under central Victoria. There, Proterozoic basement known as the Selwyn Block is inferred to underlie the Melbourne Zone (e.g. Cayley *et al.*, 2002). However limited basement exposures in central Victoria are

metabasites, rather than the predominant metasediments and granites of King Island.

D₁ can be correlated between the Stokes and Pearshape map areas, and probably along the (poorly exposed) main schist belt as far north as Cape Wickham. Going east, a penetrative slaty cleavage in the westernmost parts of the Fraser Formation can be correlated with D₁ in the Surprise Bay Formation. Further east in the Fraser Formation the effects of D₁ disappear (Calver, 2012). D₁ has been dated at c. 1290 Ma by Berry *et al.* (2005). It is suggested that F₁ folds in the Surprise Bay Formation (presently upward-facing) were originally recumbent and east-verging. The early penetrative cleavage in the Currie inlier post-dates the 775 Ma felsic sills there (Calver *et al.*, 2013). Like the eastern Fraser Formation, the effects of the 1290 Ma event seem to be absent in the Currie inlier. The problem of the relationships of the cleavages in the Currie inlier with those elsewhere deserves further study.

D₂ in the Surprise Bay Formation on the Pearshape map sheet was correlated with a crenulation cleavage and upright, north-south trending folds in the western part of the Fraser Formation (Calver, 2012). D₂ in the Fraser Formation was inferred to pre-date the late Cryogenian–Ediacaran Grassy Group. Post-D₁ events can only be tentatively correlated between the various inliers of Surprise Bay Formation.

D₂–D₄ in the Cape Wickham area are broadly coeval with granite intrusion at ~760 Ma, but are impersistent at a local scale. The concept of the ‘Wickham Orogeny’, as originally defined (“D₁ together with the episode of granitic magmatism”: Turner *et al.*, 1998, p.801), seems no longer valid as D₁ pre-dates the granites by 500 m.y. (Berry *et al.*, 2005), and the impersistent D₂–D₄ can be arguably attributed to strain accompanying intrusion.

The Cryogenian granites were probably intruded as flat-lying laccoliths or thick sills. The much wider contact metamorphic zone at a western granite contact (Cape Wickham) than the eastern contacts (observed at Fitzmaurice Bay, Millers Bay) suggests that the F₁ axial surfaces and granite were rotated to their present steep west dip some time after the Cryogenian, perhaps during the Cambrian Tyennan Orogeny.

The paleothermometry/barometry pioneered by Blackney (1982) in the south of the island should be extended to other areas, in order to define regional metamorphic gradients and conditions accompanying granite intrusion.

References

- BERRY, R. F.; HOLM, O. H.; STEELE, D. A. 2005. Chemical U-Th-Pb monazite dating and the Proterozoic history of King Island, southeast Australia. *Australian Journal of Earth Sciences* 52:461–471.
- BLACK, L. P. 1994. The significance of current and proposed SHRIMP dating. *Report Mineral Resources Tasmania* 1994/16.
- BLACK, L. P.; CALVER, C. R.; SEYMOUR, D. B.; REED, A. 2004. SHRIMP U-Pb detrital zircon ages from Proterozoic and Early Palaeozoic sandstones and their bearing on the early geological evolution of Tasmania. *Australian Journal of Earth Sciences* 51:885–900.
- BLACK, L. P.; SEYMOUR, D. B.; CORBETT, K. D.; COX, S. E.; STREIT, J. E.; BOTTRILL, R. S.; CALVER, C. R.; EVERARD, J. L.; GREEN, G. R.; MCCLENAGHAN, M. P.; PEMBERTON, J.; TAHERI, J.; TURNER, N. J. 1997. Dating Tasmania's oldest geological events. *Record Australian Geological Survey Organisation* 1997/15.
- BLACKNEY, P. C. J. 1982. *The petrology and conditions of metamorphism of the Fitzmaurice Bay to Stokes Point area, King Island*. B.Sc. (Hons) thesis, University of Tasmania.
- BROWN, S. G. 1973. *Final report on the mineral potential of Exploration Licence 4/69*. Geopeko Ltd Report KI/74/1 [TCR73-0984].
- CALVER, C. R. 2012. Explanatory report for the Grassy and Naracoopa geological map sheets. *Explanatory Report 1:25 000 Scale Digital Geological Map Series Mineral Resources Tasmania* 5.
- CALVER, C. R.; EVERARD, J. L.; MEFFRE, S. 2013. Felsic porphyry sills in Surprise Bay Formation near Currie, King Island, dated at ~775 Ma (LA-ICPMS, U-Pb on zircon). *Record Tasmanian Geological Survey* 2013/04.
- CALVER, C. R.; EVERARD, J. L.; BERRY, R. F.; BOTTRILL, R. S.; SEYMOUR, D. B. 2014. Chapter 3. Proterozoic Tasmania, in: CORBETT, K. D.; QUILTY, P.; CALVER, C. R. (ed.). *Geological evolution of Tasmania*. *Special Publication Geological Society of Australia* 24:33–94.
- CAYLEY, R. A.; TAYLOR, D. H.; VERG, A. H. M.; MOORE, D. H. 2002. Proterozoic–Early Palaeozoic rocks and the Tyennan Orogeny in central Victoria: The Selwyn Block and its tectonic implications. *Australian Journal of Earth Sciences* 49:225–254.
- COX, S. F. 1973. *The structure and petrology of the Cape Wickham area, King Island*. B.Sc. (Hons) Thesis, University of Tasmania.
- COX, S. F. 1989. Cape Wickham, in: BURRETT, C. F.; MARTIN, E. L. (ed.). *Geology and mineral resources of Tasmania*. *Special Publication Geological Society of Australia* 15:26–27.
- DEBENHAM, F. 1910. Notes on the Geology of King Island, Bass Strait. *Journal and Proceedings of the Royal Society of New South Wales* 44:560–575.
- DIREEN, N. G.; JAGO, J. B. 2008. The Cottons Breccia (Ediacaran) and its tectonostratigraphic context within the Grassy Group, King Island, Australia: A rift-related gravity slump deposit. *Precambrian Research* 165:1–14.
- GOSCOMBE, B. D.; PASSCHIER, C. W. 2003. Asymmetric boudins as shear sense indicators — an assessment from field data. *Journal of Structural Geology* 25:575–589.
- GOSCOMBE, B. D.; PASSCHIER, C. W.; HAND, M. 2004. Boudinage classification: end-member boudin types and modified boudin structures. *Journal of Structural Geology* 26:739–763.
- GRESHAM, J. J. 1972. *The regional geology of King Island*. Geopeko Limited [TCR72-0867].
- HALPIN, J. A.; JENSEN, T.; MCGOLDRICK, P.; MEFFRE, S.; BERRY, R. F.; EVERARD, J. L.; CALVER, C. R.; THOMPSON, J.; GOEMANN, K.; WHITTAKER, J. M. *in prep.* Authigenic monazite and detrital zircon dating from the Proterozoic Rocky Cape Group, Tasmania: links to the Belt-Purcell Supergroup, North America. *Precambrian Research*.
- HINE, R.; SMITH, P. 2013. *Annual report EL1/2012, 2 June 2012–1 June 2013, Yambacoona King Island Tasmania*. Iluka Resources Limited [TCR13-6673].
- LI, Z. X.; LI, X. H.; KINNY, P. D.; WANG, J.; ZHANG, S.; ZHOU, H. 2003. Geochronology of Neoproterozoic syn-rift magmatism in the Yangtze Craton, South China and correlations with other continents: evidence for a mantle superplume that broke up Rodinia. *Precambrian Research* 122:85–109.
- LI, Z. X. 2001. Understanding the Precambrian tectonic events in Tasmania: clues from South China, in: DAVIDSON, G.; PONGRATZ, J. (ed.). 2001: A structural odyssey. *Abstracts Geological Society of Australia* 64:110–111.
- PASSCHIER, C. W. 2001. Flanking structures. *Journal of Structural Geology* 23:951–962.
- PLATT, J. P.; VISSERS, R. L. M. 1980. Extensional structures in anisotropic rocks. *Journal of Structural Geology* 2:397–410.
- STAINES, H. R. E. 1985. Field geologist's guide to lithostratigraphic nomenclature in Australia. *Australian Journal of Earth Sciences* 32:83–106.
- TURNER, N. J.; BLACK, L. P.; KAMPERMAN, M. 1998. Dating of Neoproterozoic and Cambrian orogenies in Tasmania. *Australian Journal of Earth Sciences* 45:789–806.
- WATERHOUSE, L. L. 1916. Notes on geology of King Island. *Report Secretary of Mines Tasmania* 1915:88–93.

[17 March 2014]