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A re-evaluation of the structural significance of the Boat Harbour Fault, northwestern Tasmania

by D. B. Seymour

Abstract

The Boat Harbour Fault is an east-west trending, major wrench fault which post-dates regional D_1 folds and associated cleavage in the ?Mesoproterozoic Rocky Cape Group in northwestern Tasmania. Re-evaluation of the fault's structural relationships indicates that the ~8 km net dextral offset previously inferred by Gee (1967*a*, 1971) over the eastern half of the fault trace is essentially correct, but D_2 structures locally developed adjacent to the fault may not be associated with the main movement as Gee (*ibid*.) concluded. The inference by Lennox *et al.* (1982) of a westward continuation of the fault, based on local clockwise rotation of D_1 regional structures, is reinforced in this study but with a minor shift in position of the fault trace. Current knowledge of relative age relationships indicates that the fault post-dates the Smithton Synclinorium and the metamorphic belt known as the Arthur Lineament, yet it apparently offsets neither of these structures. Accommodation of these relationships may require a complex transfer fault geometry, with dextral wrench movement on the Boat Harbour Fault absorbed on coeval east-directed thrusts in the Rocky Cape Group between the Smithton Synclinorium and the Arthur Lineament.

INTRODUCTION

As part of the National Geoscience Mapping Accord TASGO Project, a sub-project was initiated to re-evaluate the structural significance of the Boat Harbour Fault in northwestern Tasmania. This major wrench fault was recognised in past regional mapping programmes, but its demonstrated offset has been difficult to reconcile with current knowledge of its age relative to adjacent major structures not affected by the fault. The brief re-evaluation presented herein includes a review and re-analysis of existing data, re-examination of some key outcrops, and an analysis of new mesoscopic structural data.

Six field days were devoted to field examination of outcrops and collection of new structural data. Several computer software packages were used in processing of new and existing data: mesoscopic structural analysis was assisted by the structural map-making, domain recognition, and statistical analysis routines of SpheriStat 2.1 (Pangaea Scientific); regional aeromagnetic images were optimised using ER Mapper 5.2; and ArcInfo geological coverages from the Mineral Resources Tasmania GIS system were overlain on the geophysical images and exported for use in figures using ArcView 3.0. Grid co-ordinates quoted in the text and figures are AMG, and all quoted azimuths are relative to AMG Grid North.

REGIONAL SETTING

The Boat Harbour Fault is an east-trending, regional-scale dextral wrench fault in northwestern Tasmania. It transects the northern part of a northeast-trending belt of deformed ?Mesoproterozoic shelf-facies clastic sedimentary rocks of the Rocky Cape Group. This belt lies between the Smithton Synclinorium (most of which is occupied by the Neoproterozoic Togari Group, a folded sequence of clastic, carbonate and mafic volcanic rocks unconformably overlying the Rocky Cape Group) and the Arthur Lineament, a narrow

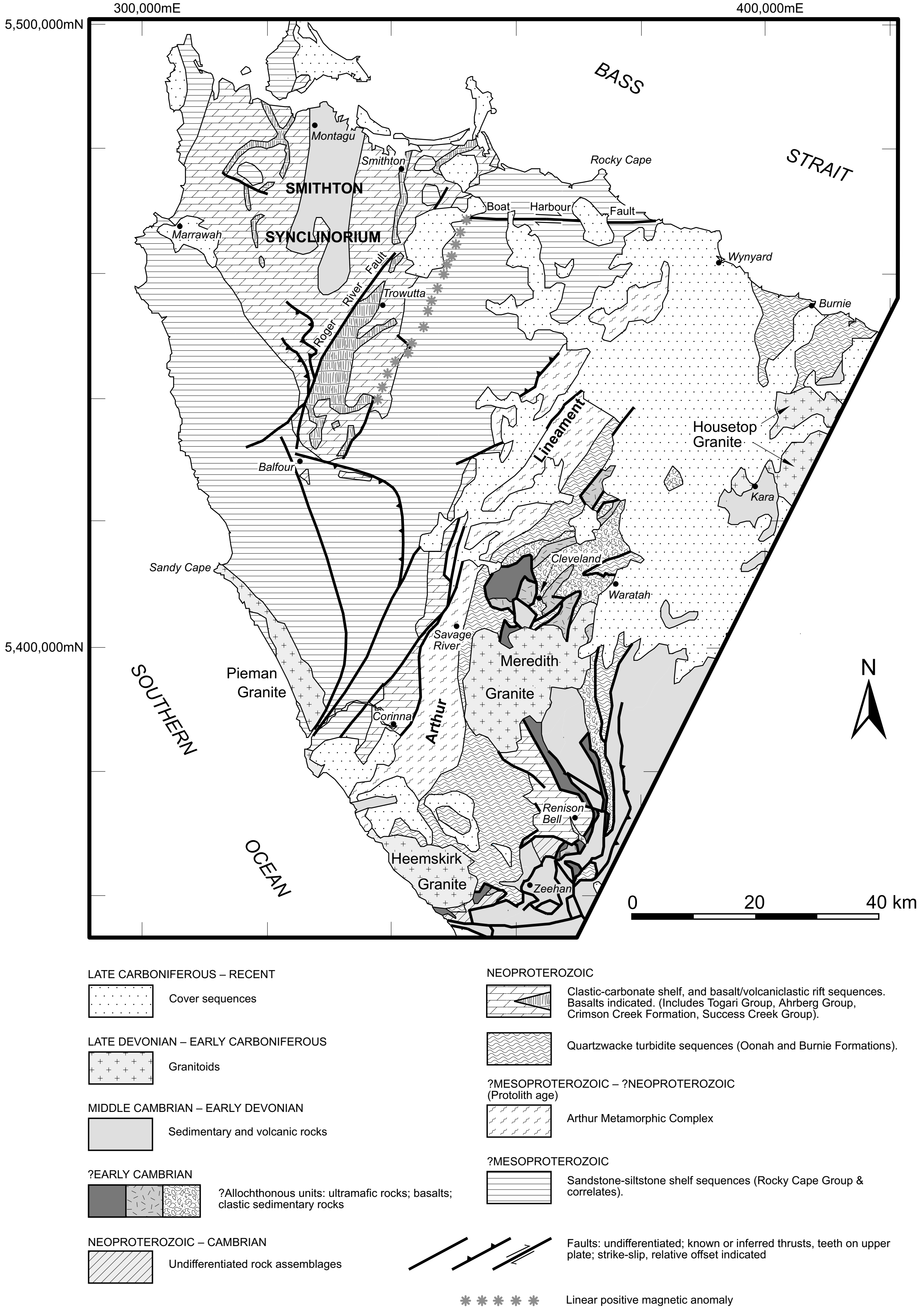


Figure 1

Regional geology of northwestern Tasmania, after Seymour and Calver (1995), with additional information from McClenaghan and Seymour (1996), and Everard et al. *(in press).*

northeast-trending metamorphic belt consisting of Proterozoic sedimentary and mafic volcanic rocks deformed and metamorphosed at c. 500 Ma (Turner, 1993) (fig. 1). A horizontal dextral offset of some 8 km has been inferred over at least part of the trace of the Boat Harbour Fault (see below), but its integration into a regional structural framework has been enigmatic because the fault appears to offset neither the eastern margin of the Smithton Synclinorium nor the western margin of the Arthur Lineament. An unresolved contradiction has existed because the Boat Harbour Fault apparently post-dates folds and cleavage associated with the regional D_1 deformation of the Rocky Cape Group, yet this deformation is demonstrably synchronous with metamorphism at c. 500 Ma in the Arthur Lineament, and by implication also affected the Neoproterozoic sequences of the Smithton Synclinorium (see below).

The first significant work on the Boat Harbour Fault was carried out by Gee (1967*a*, 1971). Major quartzite units which form large-scale folds in the Rocky Cape Group north and south of the eastern half of the Boat Harbour Fault trace were used as marker horizons to infer a dextral net horizontal offset of approximately eight kilometres. Gee (1967*a*) also inferred a relatively minor component of vertical south-side-up offset of about 150 metres. Gee (1967*a*, 1971) pointed out that north-trending structures within the Smithton Synclinorium are apparently not affected by the Boat Harbour Fault. The fault crops out on the shore platform at Western Bay immediately west of Boat Harbour (fig. 2), and Gee (*ibid*.) carried out detailed structural work at this locality, which is re-examined here.

Over the western half of its trace the fault is inferred only, on the basis of regional and detailed structural mapping by Lennox *et al.* (1982) and Lennox *in* Brown (1989). This evidence is re-examined here.

The main regional deformation of the Rocky Cape Group, and synchronous deformation and metamorphism in the Arthur Lineament, were assigned by Gee (1967*b*) to the Penguin Orogeny, an event he believed could be shown to have also affected the Togari Group. However, a contrary view published by Williams (1976), and adhered to in Brown (1989) and Williams (1989), is that the main deformation of the Rocky Cape Group predates the unconformity at the base of the Togari Group. Several lines of evidence now indicate that the interpretation of Gee (1967*b*) is the correct one:

- West of the Arthur Lineament, the Rocky Cape Group is intruded by a swarm of northeast-trending dolerite dykes, a few of which also intrude the Togari Group in the Smithton Synclinorium. Brown (1989) and Crawford and Berry (1992) suggested that some of these dykes are co-magmatic with basalt in the Togari Group. Brown (1989) identified four geochemically distinct groups of dolerite dykes west of the Arthur Lineament, one group of which (the massive tholeiitic variety) he interpreted as feeders for tholeiitic basalts in what is now known (Everard *et al.*, 1996) as the Spinks Creek Volcanics of the Togari Group. Two samples assigned by Brown (1989) to this group of dykes yielded K-Ar radiometric ages of 600 ± 8 and 588 ± 8 Ma respectively. However, analyses of further samples of generally massive tholeiitic dykes from the area between the Arthur and Rapid Rivers (J. L. Everard, pers. comm., 1997) indicate that they are geochemically distinct from the Togari Group basalts, having for example generally higher SiO_2 and K_2O contents, and perhaps more importantly, different ratios of immobile incompatible elements (e.g. lower Ti/Zr). This suggests that the tholeiitic dykes and basalts are not directly co-magmatic, although they *could* represent different phases of the same episode of volcanism.
- Despite the element of doubt about the significance of the dolerite dyke ages, a Neoproterozoic age for the Togari Group has been independently confirmed by C and Sr isotope chemostratigraphic studies of the Togari Group carbonate sequences (Calver, in press).
- Regional geological mapping by Turner *et al.* (1991) demonstrated that the main metamorphism (and synchronous deformation) in the Arthur Lineament also affected the Ahrberg Group, a lithostratigraphic correlate of the Togari Group in the Corinna area adjacent to the southwestern margin of the Arthur Lineament (fig. 1). Correlation of the Ahrberg and Togari Groups has also been independently confirmed by C and Sr isotope chemostratigraphy (Calver, 1996).
- In the northern part of the Arthur Lineament, relationships recognised by Gee (1967*a*, 1971), and reinforced by the work of Everard *et al.* (1996), show that the regional D_1 structural event in the Rocky Cape Group exhibits a transition by way of increasing strain and metamorphic grade eastward into the Arthur Lineament, where it is apparently synchronous with the main metamorphism.
- A concordant group of K-Ar radiometric ages from prograde metamorphic hornblende in the Bowry Formation of the Arthur Lineament indicates that the main metamorphism occurred at 500 ± 10 Ma, i.e. in the Middle to Late Cambrian (Turner, 1993).

As the weight of evidence now favours a post-Togari Group age for the main tectonothermal event, the objectives of this re-examination of the problem of the Boat Harbour Fault were threefold:

- To revisit the type area and compare it with that part of the fault trace where its presence had been inferred rather than proven.

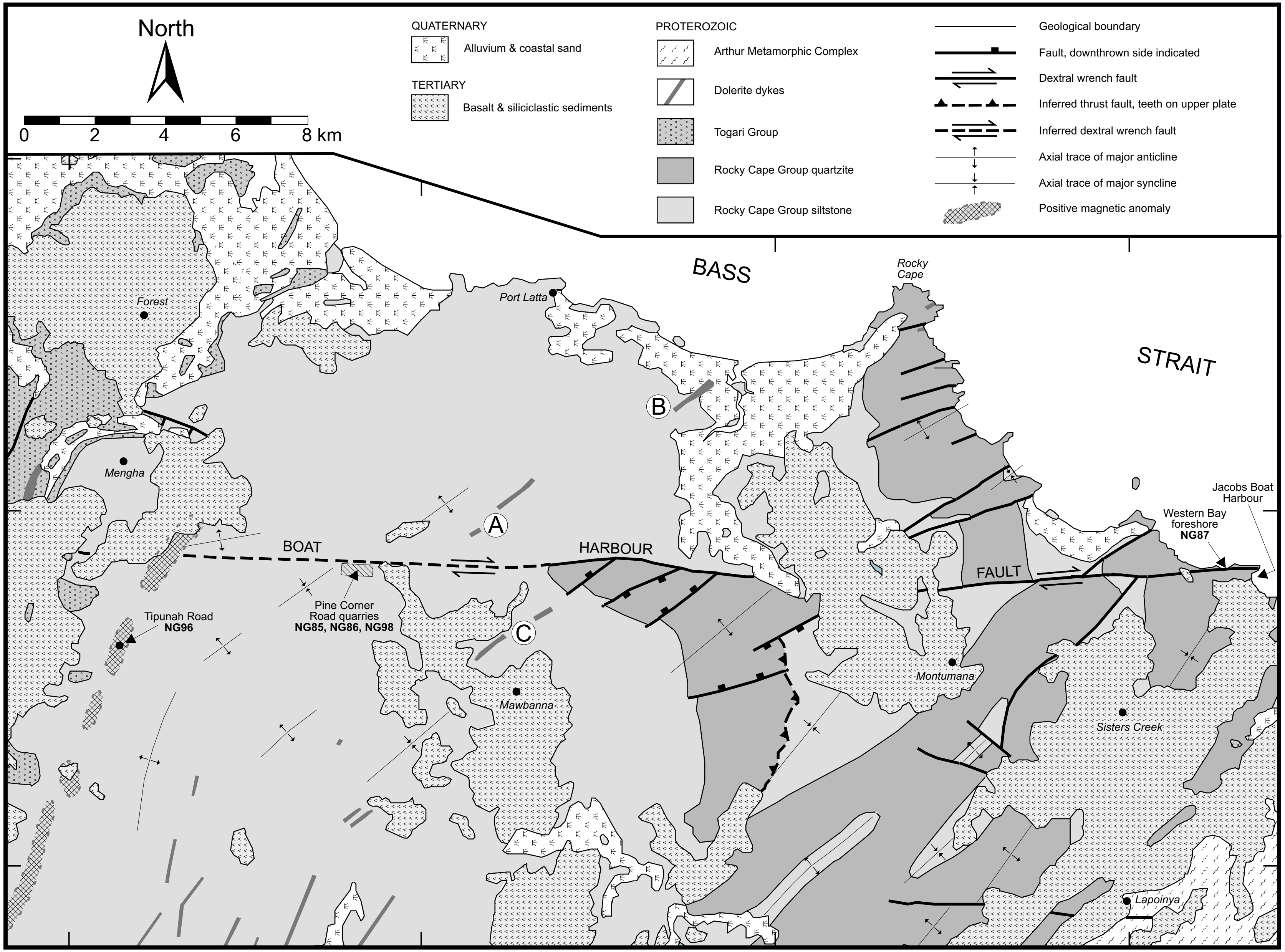


Figure 2. *Regional geological setting of the Boat Harbour Fault. Geology after Calver* et al. *(1995), with some re-mapping by D. B. Seymour.*

- To assess possible fault geometries which may permit the known dextral offset on the Boat Harbour Fault, but at the same time are consistent with lack of offset of the Smithton Synclinorium and the Arthur Lineament.
- To assess the possible interaction of the Boat Harbour Fault with other known or inferred regional-scale faults in northwestern Tasmania.

TYPE LOCALITY — BOAT HARBOUR

Previous work

As part of a major structural and stratigraphic study in northwestern Tasmania, Gee (1967*a*, 1971) carried out detailed mapping of mesoscopic structures associated with the Boat Harbour Fault in foreshore exposures at Western Bay immediately west of Jacobs Boat Harbour on the Bass Strait coast (fig. 2). The actual fault plane was observed in a number of places, but no slickensides were recorded. Complex refolding of D_1 structures, an event believed to be associated with the main movement on the fault, was observed in an unnamed "siltstone" unit apparently lying stratigraphically above the Jacob Quartzite (the uppermost defined unit of the Rocky Cape Group). These locally-developed D_2 structures fell into two style groups:

- *En echelon*, doubly-plunging anticlines and domes with axial plane cleavage of "strain-slip" type. These structures refold pre-existing minor folds and slaty cleavage related to the D_1 regional deformation.
- A set of small-scale vertical shear planes trending WNW, "expressed as axial planes of angular chevron folds in the siltstone and small sinistral transcurrent faults in the quartzite".

Re-assessment

As they represent the best approach to a 'type locality' for the Boat Harbour Fault, the coastal outcrops described by Gee (1967*a*, 1971) were re-examined in this study. The unnamed "siltstone" unit, which Gee described above the Jacob Quartzite, actually consists of interbedded quartzite and pelite (in about 1:1 proportion overall), the quartzite being more thinly bedded than that in the Jacob Quartzite but otherwise showing similar characteristics. Attention was focused on a 200 × 80 m outcrop area of this unnamed unit. This area is only fully visible at low tide and abuts the southern side of the Boat Harbour Fault, which locally has an overall trend of 082°. Figure 3 is a detailed structural sketch map based on the original map of Gee (1967*a*, 1971), but with additional mesoscopic structural data overlain.

The area of interest was divided into five structural domains, the boundaries of which partially coincide with previously mapped faults. The main objective was to more precisely define the geometry of D_2 mesoscopic structures, orientations of which are shown in stereographic form in Figure 4. D_2 mesoscopic folds were generally identified on the basis of observed refolding of the penetrative S_1 cleavage, but in some quartzite-dominated parts of the outcrop, separation of D_1 and D_2 structures was difficult. Patchy development of an S_2 axial plane cleavage was observed in pelitic lithologies in places, particularly near the cores of D_2 folds. S_2 is a close-spaced, somewhat differentiated crenulation cleavage, and is equivalent to the foliation described by Gee (1967*a*, 1971) as "strain-slip" cleavage.

Domain A

The best exposures of the actual surface of the Boat Harbour Fault occur in Domain A (fig. 3). On the northern side of the fault there is virtually 100% outcrop of the Jacob Quartzite from low water mark up to the fault surface, but to the south, exposure of the unnamed quartzite-pelite unit close to the fault is poor. Within two metres of the fault the Jacob Quartzite shows considerable evidence of brittle deformation, including close-spaced jointing mostly sub-parallel to the fault surface, and brecciation. In some places there are shallow, 10 cm wide, sub-horizontal grooves on the fault surface, but as Gee (1967*a*, 1971) reported, fine striations are not evident. The fault surface is plastered with a very thin pale cream-coloured siliceous film.

Domain A differs from the other domains in showing a high angle between the trends of D_1 and D_2 structures, which consequently were relatively easy to differentiate. Open rounded and chevron folds in bedded quartzite in the southwestern corner of Domain A plunge moderately to the ENE and have steep SSE-dipping axial surfaces; these folds do not appear to affect S_1 penetrative cleavage and are almost certainly of the D_1 generation. F_2 fold axial planes dip steeply to the southwest, and most F_2 hingelines plunge at moderate to steep angles to the WNW (fig. 4). However, two F_2 folds have reclined geometry, with the hingelines plunging steeply down the dip of the axial surfaces. Steep S_2 crenulation cleavage trending 305° was recorded at one point.

Domain B

All of the mesoscopic structures in Domain B are of the D_2 generation. F_2 folds are chevron-style in thin-bedded quartzite, and large open structures in thick-bedded quartzite. F_2 axial surfaces are steep and show a range in strike between west and northwest, and most F_2 hingelines plunge west to northwest at between 25° and vertical (fig. 4). Reclined geometry was recorded in one F_2 fold.

Domain C

Domain C shows some geometric similarities to Domain B, differing mainly in the shallower west to northwest plunges of most F_2 folds (fig. 4). Steep S_2 crenulation cleavage recorded at one point has a westerly strike. Bedding traces shown on the detailed map in Gee (1967*a*, 1971), and included in Figure 4 herein, suggest that the F_2 folds have conjugate geometry in part, and field observations in the current study support this. Such geometry may partially explain the variation in plunge direction of the F_2 folds. At the southeastern corner of Domain C an elongate dome in thin-bedded quartzite is a result of double plunge in a mesoscopic F_2 anticline (fig. 3); the axial surface twists through this structure in such a way that the hingelines at each end of the domal core have plunge directions which are slightly clockwise from the axial surface trace.

Domain D

Upright SE to SSE-plunging F_1 fold closures are present near the southern margin of Domain D (fig. 3), but otherwise the area is dominated by F_2 mesoscopic folds. D_2 structures in Domain D show a slightly more regular pattern than in Domains A–C. F_2 folds vary from small, open to fairly tight chevrons in thin-bedded pelite, to open larger-scale folds in quartzite. Elongate F_2 domes are present near the centre of the domain. Steep F_2 axial surfaces mostly range in strike from northwest to west, but there is a tendency to cluster around an azimuth of 305°. F_2 hingeline orientations range from shallow southeast plunges to moderate northwest plunges, but show a statistical tendency towards a girdle pattern clustered around a vertical plane striking 305° (fig. 4). Near the centre of Domain D, Gee (1967*a*, 1971) recorded vertical S_2 crenulation cleavage nearly parallel to this direction.

Domain E

Near the western end of Domain E, an assemblage of mostly thin-bedded quartzite with subordinate pelite shows mesoscopic folds of both F_1 generation (identified by penetrative axial plane cleavage) and F_2 generation (folding the penetrative cleavage and with axial plane crenulation cleavage). The two fold generations are almost coaxial here, with shallow southeast plunges. The rest of Domain E is mostly dominated by F_2 mesoscopic folds, which statistically show a geometric pattern similar to that present in Domain D, but perhaps somewhat better defined (fig. 4). Steep F_2 axial surface orientations are more tightly clustered, around the same preferred 305° azimuth noted in Domain D, and F_2 hingelines show a correspondingly similar girdle pattern defined by a vertical plane with this azimuth. A number of S_2 crenulation cleavage orientations were recorded, and appear to be statistically linked to the pattern of F_2 axial surface orientations (fig. 4).

Overall pattern and significance of D_2 structures

When all of the D_2 structural data are considered together (fig. 4), the fairly regular geometry of D_2 structures in Domains D and E appears to also be the statistically preferred D_2 pattern for the whole area. The composite stereogram shows a spread in F_2 axial surface azimuths from ~NW–SE to E–W. Cluster analysis of the distribution of poles to F_2 axial surfaces shows a main cluster corresponding to a plane striking 305° and dipping southwest at 86°, and the distribution of F_2 hingelines shows a moderately developed girdle pattern centred on this plane (fig. 4).

This re-analysis of the geometry of the D_2 structures shows that the F_2 fold hingelines and axial surfaces are statistically aligned at an angle of about 43° oblique to (and clockwise from) the local trend of the Boat Harbour Fault trace. As Gee (1967*a*, 1971) noted, the largest-scale F_2 mesoscopic folds present are anticlines with undulating hingelines, and with axial surface traces which tend to be arranged in an *en echelon* fashion with intervening synclines apparently faulted out in part (see fig. 3).

The localised distribution of these D_2 structures seems to leave little doubt that their development is linked to movement on the Boat Harbour Fault. However, if it is assumed that the local principal compressional stress direction during their formation was oriented approximately normal to the axial surface orientations, it seems necessary that any synchronous shear movement on the Boat Harbour Fault would have to have been a horizontal *sinistral* movement, opposite to that implied by the overall net offset on the fault. This suggests that the net offset may be a result of multiple movements, and that the D_2 structures at this locality may not have developed during the main dextral wrench movement on the fault. A possible alternative explanation is that during the main dextral wrench movement, a localised compressional stress field may have developed south of the fault and normal to the contact between the unnamed quartzite-pelite unit and the underlying Jacob Quartzite to the southwest (fig. 3). Such a local stress field could conceivably have resulted from a competence contrast between the two rock units.

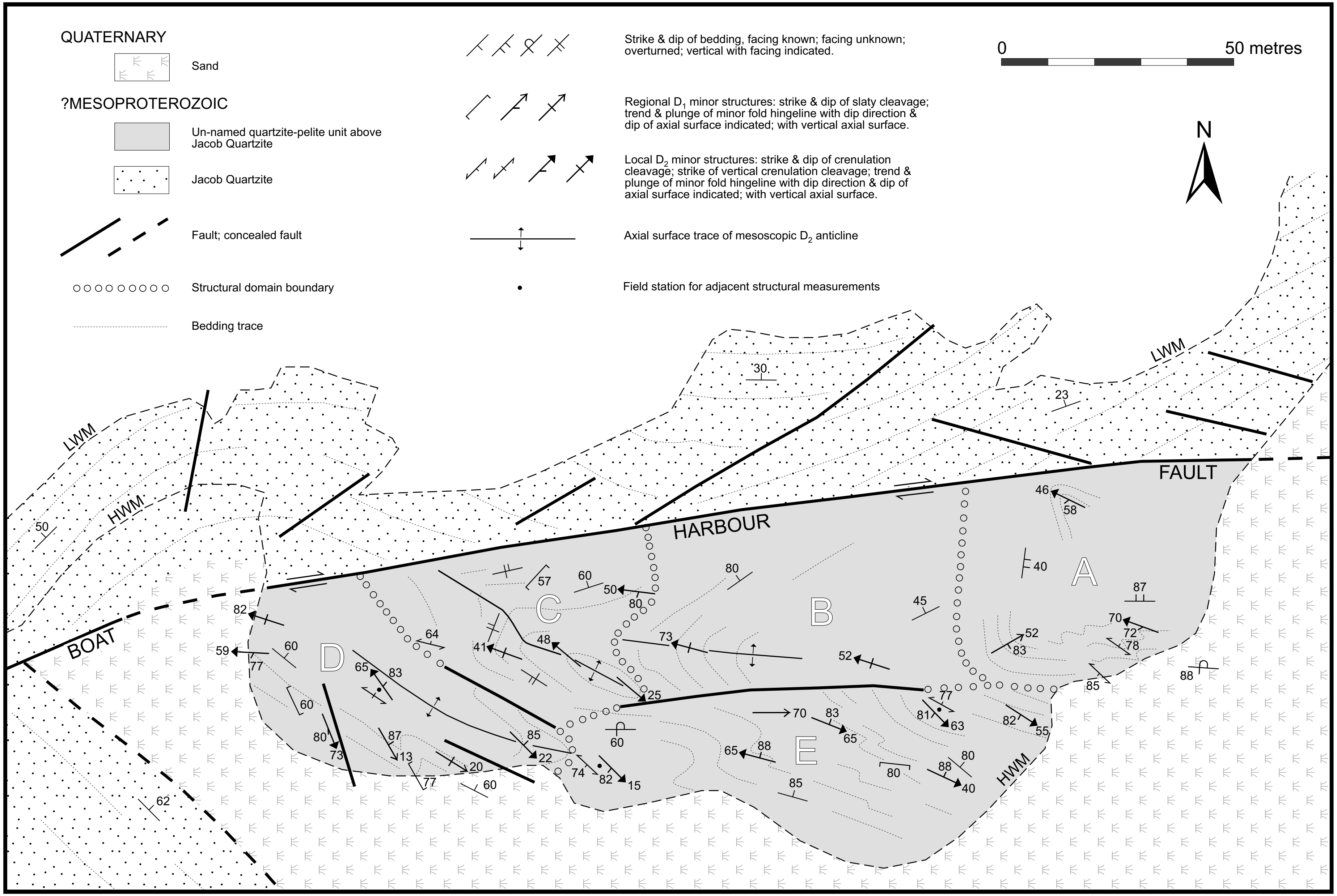


Figure 3. *Detailed geological map, based on Gee (1967a) with additional structural data by D. B. Seymour (this study), of mesoscopic structures associated with the Boat Harbour Fault, in an unnamed quartzite-siltstone unit above the Jacob Quartzite at Western Bay, west of Jacobs Boat Harbour.*

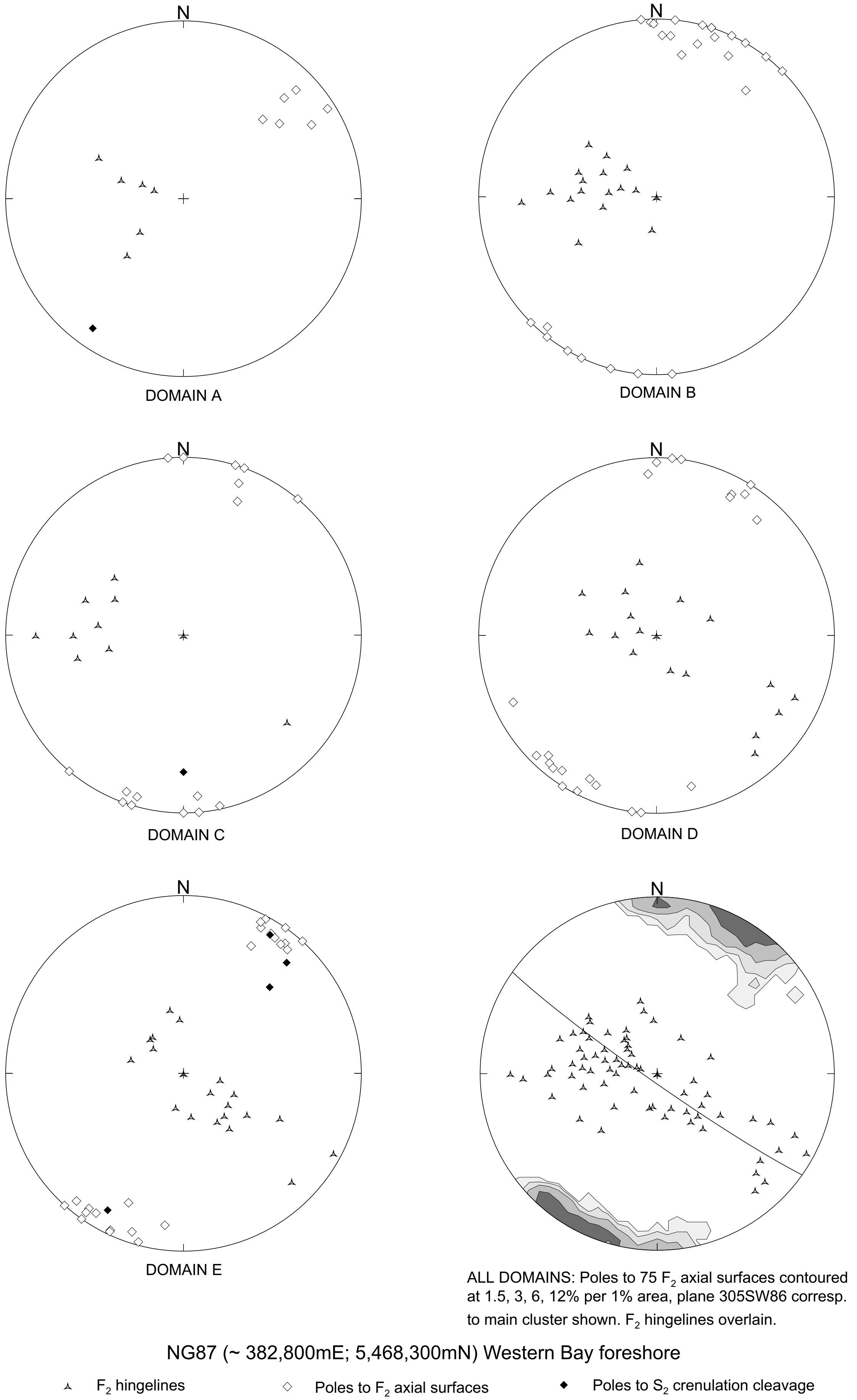


Figure 4

Lower hemisphere equal area stereograms of orientations of D_2 mesoscopic structures associated with the Boat Harbour Fault, in an unnamed quartzite-siltstone unit above the Jacob Quartzite at Western Bay, west of Jacobs Boat Harbour.

PINE CORNER ROAD AREA

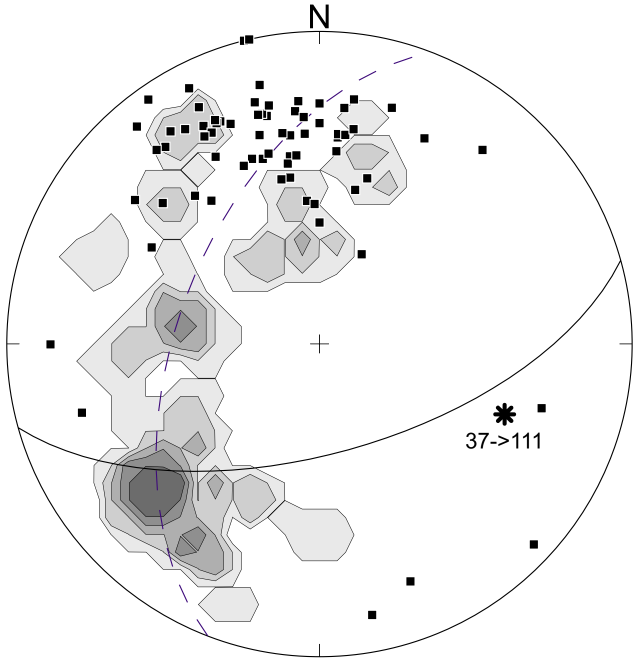
Previous work

During 1:50 000 scale regional geological mapping by Lennox *et al.* (1982), mesoscopic structures in the Rocky Cape Group adjoining the western half of the inferred trace of the Boat Harbour Fault were mapped in detail (fig. 2). The presence of the Boat Harbour Fault was demonstrated some five kilometres northeast of Mawbanna (fig. 2) by truncation of the northwestern limb of a large northeast-plunging anticline in the Detention Subgroup, an orthoquartzite-dominated unit of the Rocky Cape Group. Marker horizons are rare in the Cowrie Siltstone (which is the oldest unit in the Rocky Cape Group in this area) west of this point, and Lennox *et al.* (1982) and Lennox (*in* Brown, 1989) inferred the westward continuation of the Boat Harbour Fault from indirect evidence:

- Clockwise deflection of the axial surface traces of some of the main D_1 regional folds close to the inferred fault trace, particularly apparent in an anticlinal axis some 3½ km southeast of Mengha (fig. 2). This deflection is also apparent in the pattern of D_1 axial plane cleavages. There is also a regional clockwise rotation of D_1 fold trends apparent over an interval from about 10 km south of the Boat Harbour Fault to about 8 km north of it (roughly the area covered by fig. 2), but it is unclear whether this regional rotation is related to the fault. Lennox (*in* Brown, 1989) implied that this regional swing in D_1 fold trends was present prior to further, more local rotations caused by displacement on the Boat Harbour Fault.
- Lack of continuity in minor folding across the inferred trace of the Boat Harbour Fault in the Pine Corner Road area (fig. 2); this was attributed to wrench displacement on the fault.
- The presence, in a quarry in Cowrie Siltstone on the southern side of Pine Corner Road a short distance south of the inferred trace of the Boat Harbour Fault, of approximately east-trending mesoscopic folds and associated cleavage, interpreted as being due to drag associated with wrench displacement on the fault.

Structural data from the Pine Corner Road quarry were not discussed in detail by Lennox (*in* Brown, 1989), but a detailed map and stereograms were included in the report. The original field data of Lennox are still accessible and were re-analysed in the current study (fig. 5). Several points are evident from re-examination of these data:

- Bedding data outline an open, upright or steeply inclined mesoscopic fold, which according to Lennox (*in* Brown, 1989) has a statistical fold axis plunging 50° to 106°. Re-analysis of the original bedding data during the present study yielded a revised statistical fold axis plunging 37° to 111° (fig. 5).
- According to Lennox (*in* Brown, 1989) the fold is "transected by two foliations and is associated with a rare and poorly developed axial plane foliation". The original cleavage data were replotted in the current study, selecting all measurements except those specifically identified as "local" or "S_2". A cluster analysis applied to these data shows a moderately developed cluster of cleavage orientations centred on an attitude of 074.5°S61.3° (fig. 5). Furthermore, the statistical fold axis derived from bedding data lies within 7° of this preferred cleavage orientation. It is therefore reasonable to conclude that most of the cleavage is axial plane cleavage associated with the main folding, and that statistically the fold is only slightly transected by its associated cleavage. The deviation between the average strike of cleavage and the trend of the statistical fold axis, evident on the detailed map in Lennox (*in* Brown, 1989), is a geometric consequence of southward dip of the axial surface of the main fold.
- The detailed map in Lennox (*in* Brown, 1989) indicates that at two locations in the quarry,



NG69 (~ 358,530mE; 5,468,330mN) Pine Corner Road quarry
Data from P. G. Lennox (*in* Brown, 1989)

68 poles to bedding contoured at 1.5, 3, 4.5, 6, 7.5% per 1% area. Overlain data points and great circles as below.

■ Poles to cleavage. Solid great circle is preferred orientation of cleavage derived from cluster analysis of pole distribution.

✱ E_1 eigenvector of distribution of bedding poles. Corresponding principal plane shown by dashed great circle.

Figure 5

Lower hemisphere equal-area stereogram of replotted original structural data of P. G. Lennox (in Brown, 1989), from a quarry in Cowrie Siltstone at Station NG69, Pine Corner Road area.

locally developed steep S_2 cleavages striking 071° and 112° respectively were observed apparently overprinting the regional S_1 penetrative cleavage. Only brief discussion of this appears in the text, but the "local foliation" is described as a "spaced, differentiated sericite fabric", which probably refers to micro-domainal development of a preferred orientation of very fine-grained white mica.

The interpretation of these structures is left somewhat unclear by the brief explanatory text in Lennox (*in* Brown, 1989). However, re-examination of the original data indicates that the main mesoscopic fold in bedding, and most of the cleavage recorded in the quarry, are regional D_1 structures which have undergone significant clockwise rotation, which it appears reasonable to attribute to drag associated with dextral wrench movement on the Boat Harbour Fault.

Re-assessment

Because of the importance of the Pine Corner Road area to interpretation of the Boat Harbour Fault, a number of small quarries in Cowrie Siltstone in the area were re-examined in detail.

Station NG69 (358 530 mE; 5 468 340 mN)

This quarry, which lies about 130 m south of the inferred trace of the Boat Harbour Fault shown on the regional map of Lennox *et al*. (1982), was previously mapped in detail by Lennox (*in* Brown, 1989). The quality of bedrock exposures has deteriorated considerably due to weathering in the 18 years since the original fieldwork. However, most of the outcrops mapped in the previous work are still accessible, and a new detailed combined topometric and structural survey with minimum station spacing of less than one metre was carried out, using a Topolite distance-measuring device and Brunton compass. Linking each structural measurement to an accurate survey point made it possible to separately analyse bedding, cleavage, minor fold, and cleavage/bedding intersection data, both spatially and stereographically (fig. 6–9).

Domain analysis

Compilation of the new data identified a significant feature which had been missed in the previous work, namely a steeply southwest-dipping, northwest-trending 1.5 m thick shear zone which transects the central part of the quarry (fig. 6–9). Analysis using Spheristat 2.1 indicated that this shear zone separates the quarry into two distinct structural domains, which are particularly apparent in the bedding and minor fold hingeline data (fig. 6, 8).

A combined plot of all of the new structural data yields a pattern similar to that derived from re-analysis of the total original data of Lennox (*in* Brown, 1989) (fig. 10). Poles to bedding are distributed in a girdle pattern (statistically a moderately developed girdle with cluster), which is somewhat better defined than that shown by the previous data. The statistical fold axis lies within 8° of that derived from the previous data, and 5° away from the statistically preferred cleavage orientation. In the new survey no sign was found of the locally developed later foliations recorded by Lennox (*ibid*.), possibly due to the poorer state of the exposures. Perhaps because of this, a tighter cluster of cleavage orientations is present in the new data (fig. 10), and it can probably be reasonably concluded that all or nearly all of the new cleavage measurements are of regional S_1. Hingelines of minor folds in bedding, and cleavage/bedding intersections, show a considerable spread in orientations, which is reduced somewhat when considered on a domainal basis (see below).

Domain A

Poles to bedding from Domain A (the part of the quarry northeast of the shear zone) show a moderately developed girdle on the stereogram (fig. 10), indicating a statistical fold axis plunging 51° to 171°. It is also apparent from visual inspection of the detailed structural map (fig. 6) that, in Domain A, a significant part of the northern limb of the main D_1 mesoscopic fold in the quarry has been affected by approximately upright refolding on this trend. The Domain A stereogram also shows hingelines of minor folds in bedding distributed in a rather diffuse cluster around the statistical fold axis, suggesting that these minor folds are related to the refolding. This post-D_1 refolding event was not recognised in the previous work, and it may be Devonian in age (see further discussion below).

Domain B

Domain B, southwest of the shear zone, appears to be dominated by the main regional D_1 fold closure in the quarry (fig. 6). Poles to bedding show a much better-defined girdle distribution than on the all-data stereogram (fig. 10). The statistical fold axis plunges 37° to 106°, and lies 9° away from the plane of preferred orientation of cleavage (derived from cluster analysis). Minor fold hingelines form a moderately tight group (fig. 10), centred on an orientation of 30° to 119°, some 13° clockwise in trend away from the statistical fold axis, and 7° shallower in plunge. Cleavage/bedding intersections form a fairly loose group which is generally oriented anticlockwise in trend from both the statistical fold axis and the minor fold hingelines, reflecting the fact that the fold is slightly transected by its associated cleavage. Nonetheless most of the structural geometry in Domain B can be attributed to regional D_1, the only perceptible effect of the later refolding affecting Domain A perhaps being the slight spread in azimuths of cleavage (fig. 7, 10).

Station NG86 (358 200 mE; 5 468 430 mN)

This quarry is located on the northern side of Pine Corner Road, less than 100 m south of the inferred trace of the Boat Harbour Fault shown on the regional map (Lennox *et al*., 1982). The latter map shows some approximately east-trending, steeply south-dipping cleavages in the vicinity of this quarry, but the locality was not described in detail by Lennox (*in* Brown, 1989).

Much of the lower (southern) part of the quarry is dominated by phyllitic pelite with common quartz veining and disseminated quartz-pyrite mineralisation. Thin ribbon-like quartz veins sub-parallel to the foliation are common. The foliation may have been enhanced and intensified by a component of ductile shear. Its attitude seems to vary systematically through the quarry, and a stereogram of poles to the foliation (fig. 11) shows a girdle distribution which indicates that the variation is due to later refolding about a statistical axis plunging 43° to 204°. Significantly, this axis is close in orientation to a faint crumple lineation which overprints the main foliation at one point in the quarry (fig. 11). Cluster analysis of the girdle distribution indicates that it contains a slight cluster of poles corresponding to a foliation attitude of about 099°S44°, which may indicate the common orientation prior to refolding.

Station NG98 (358 030 mE; 5 468 450 mN)

This quarry is also situated on the northern side of Pine Corner Road, some 170 m west of NG86 and less than 100 m south of the inferred trace of the Boat Harbour Fault. Most of the quarry is occupied by a superficial gravel veneer, but there are scattered small exposures of light grey-brown weathering, fine-grained pelite showing a strongly but finely developed penetrative cleavage, not as well developed as the phyllitic foliation at NG86. A moderate amount of quartz veining is present, but again not as much as at NG86.

The cleavage varies systematically in attitude, and the stereogram (fig. 11) shows poles to cleavage forming a moderately developed girdle indicating refolding about a statistical axis plunging 51° to 206°. Crumple lineations and hingelines of minor folds overprinting the penetrative cleavage were measured at five localities within the quarry, and four of these show orientations reasonably close to the statistical axis of refolding (fig. 11). The girdle of poles to cleavage contains a noticeable cluster (also confirmed by cluster analysis) corresponding to a cleavage orientation of about 090°S54°, and this may have been the common orientation of S_1 cleavage prior to refolding. The axis of refolding is sufficiently close to that recorded at NG86 to confidently be assigned to the same generation.

Station NG85 (357 780 mE; 5 468 080 mN)

This is a new, previously unmapped quarry, situated 400 m south of the inferred trace of the Boat Harbour Fault and 750 m west of the quarry mapped by Lennox (*in* Brown, 1989). Bedrock exposure is of cleaved and folded, thin-bedded plane-laminated siltstone of the Cowrie Siltstone.

The folding is monoclinal, with northward bedding dips predominating, and the fold asymmetry is 'Z' viewed down the gentle easterly plunge. The cleavage is well developed and appears to be axial planar to the folds, an observation supported by the stereogram (fig. 11). Poles to bedding form a moderately developed partial girdle on the stereogram, indicating a statistical fold axis plunging 12° to 078°, and cleavage/bedding intersections are closely grouped around this axis (fig. 11). Poles to cleavage form a tight cluster indicating a preferred cleavage orientation of 073°S58°.

It is reasonable to conclude from this very coherent pattern that only regional D_1 mesoscopic structures are present in this quarry. However, within a distance of 4 km north and 7 km south of the Pine Corner Road quarries (but away from the immediate vicinity of the inferred trace of the Boat Harbour Fault), major D_1 folds show a consistent axial trend of about 055° (based on the regional mapping of Lennox *et al*., 1982). The D_1 structures in this quarry have been bodily rotated in the horizontal about 20° clockwise from this trend, and as the rotation is less than that present in the quarries closer to the inferred fault trace, it is reasonable to conclude that the body rotation was created by drag due to dextral wrench movement on the Boat Harbour Fault.

Summary of the Pine Corner Road area

Re-analysis of mesoscopic structures in the Cowrie Siltstone in the Pine Corner Road quarries has yielded the following conclusions:

- South of the previously inferred trace of the Boat Harbour Fault, regional D_1 folds and associated axial cleavage are progressively rotated in a horizontal clockwise sense with increasing proximity to the inferred fault. The regional mapping of Lennox *et al.* (1982) shows a similar clockwise rotation of D_1 structures north of the inferred fault some 4 km west of the Pine Corner Road area.
- In the quarries closest to the inferred fault trace, the regional S_1 cleavage has been rotated into a generally east-striking, steeply south-dipping orientation. In at least one of these quarries, S_1 has been intensified into a phyllitic foliation which may have been influenced by a component of ductile shear.
- A northwest-striking, steeply southwest-dipping ductile shear zone in one of the quarries post-dates regional D_1 folds. Its sense of shear is unproven, but its orientation allows for the possibility that it is a conjugate sinistral wrench which developed during the main dextral movement on the Boat Harbour Fault.

- The rotated regional D_1 structures have been overprinted by open, approximately upright minor folds with axial trends of about 170° and 205° respectively at separate locations. These may be all of the same, possibly Devonian, generation.

These results lend strong support to the actual presence of the Boat Harbour Fault over most of that part of its trace which was previously inferred by Lennox *et al*. (1982). The remaining part of this study focuses on the western extremity of the inferred fault trace, where it approaches the eastern margin of the Smithton Synclinorium.

TIPUNAH ROAD

The mapping of Lennox *et al*. (1982) indicated horizontal clockwise rotation of regional D_1 mesoscopic structures adjacent to the inferred trace of the Boat Harbour Fault, between the Pine Corner Road quarries and a point some five kilometres to the west, just east of where the fault trace becomes obscured by Tertiary basalt cover (fig. 2). West of this point there was no specific evidence to support the inferred presence of the fault in the Cowrie Siltstone close to the eastern margin of the Smithton Synclinorium.

The Tipunah Road Anomaly

New regional aeromagnetic data (Mackey *et al*., 1995), which have become available since the mapping of Lennox *et al*. (1982), show a slightly discontinuous, narrow but very distinct, linear positive magnetic anomaly (referred to herein as the Tipunah Road Anomaly) which extends ~33 km on a trend of 026° from ~15 km northeast of Balfour, to a point close to where the western part of the inferred Boat Harbour Fault trace first passes beneath Tertiary cover (fig. 1, 2, 12). The anomaly characteristics imply a shallow source. The southern end of this anomaly connects with the northern end of a previously mapped, similarly trending steep fault at the southeastern margin of the Smithton Synclinorium (Everard *et al*., 1996; fig. 1 herein), and the fact that the anomaly transects both Togari Group sequences in the Smithton Synclinorium and Cowrie Siltstone of the Rocky Cape Group (fig. 2) implies that it is not stratigraphically related. Furthermore, it is unlikely to be dyke-related, as a number of mapped Proterozoic dolerite dykes intruding the Cowrie Siltstone to the southeast and south (Lennox *et al*., 1982; Everard *et al*., 1996) all show more diffuse and generally more subdued associated magnetic signatures (fig. 12). Together, these observations imply that the anomaly is structurally related, and its relatively sharp and well-defined nature may indicate that it represents the signature of magnetic mineral concentrations along a fault zone.

A ground check of Tipunah Road where it crosses one of the discontinuous segments of the anomaly (Station NG96, fig. 2) found rather poor outcrop. At this locality low road cuts expose very weathered Cowrie Siltstone with quartz veining and copious float of angular white vein quartz in the derived soil. Vein orientations vary between ~042°SE83° and ~017°W80°. Some of the vein quartz, when broken open, shows minor patchy orange-brown to reddish-brown staining, which may indicate the original presence of ferruginous minerals. No evidence was found at the locality of anything suggestive of the presence of a dolerite dyke, which even when deeply weathered in this region typically show up as zones of red-orange clay, commonly containing rounded float of fresh or weathered dolerite. A typical dolerite dyke exposure occurs on Tipunah Road 1.3 km southeast of Station NG96 (Lennox *et al*., 1982, and confirmed in this study).

East of the Tipunah Road Anomaly, in the Smithton and Trowutta map quadrangles, outcropping dolerite dykes intruding the Cowrie Siltstone were commonly encountered in the numerous detailed geological traverses completed for the 1:50 000 scale mapping program (Lennox *et al*., 1982; Everard *et al*., 1996). Despite the thorough mapping, which involved traverses of most roads, tracks and watercourses, a dolerite dyke coincident with the Tipunah Road Anomaly was suggested at only one locality (343 350 mE; 5 448 950 mN) on Milkshakes Road in the Trowutta Quadrangle, just inside the southern margin of Figure 12 herein. At this locality, a ~30 m thick zone of red coarse-textured clay is approximately parallel to and within 30 m of a pair of one metre wide, steep fault zones (attitudes 040°SE78°, 035°SE75°) in the Cowrie Siltstone (field observations by D. B. Seymour, *in* Everard *et al*., 1996). At the time it was thought that this red clay zone could represent very weathered dolerite, although no sign of remnant dolerite cores was found. A dyke origin for the red clay is made less likely by the following observations by J. L. Everard (pers. comm., 1997) at other magnetic high points on the Tipunah Road Anomaly:

- At 344 850 mE; 5 450 750 mN, at the end of Milkshakes 4 Road just south of the Arthur River, float was found of a weathered orange-red rock with high magnetic susceptibility ($\leq 11 \times 10^{-3}$ SI), a value lying between that of typical Tertiary basalt ($\sim 2.5 \times 10^{-3}$ SI) and typical Togari Group basalt ($\sim 20\text{–}50 \times 10^{-3}$ SI), but much higher than the susceptibility of typical Cowrie Siltstone ($\sim 0.1 \times 10^{-3}$ SI) and typical dolerite dykes in the area ($\sim 0.5 \times 10^{-3}$ SI). The orange-red rock was thought to be a limonitic alteration product. Typical weathered white-grey-green float of Cowrie Siltstone also occurs nearby.

- At ~346 000 mE; 5 454 000 mN, on Tayatea 3 Road, strongly magnetic and deeply weathered orange-red float was thought to represent limonitic alteration of Cowrie Siltstone.

The Trowutta mapping also indicated the presence of mesoscopic, steeply southeast-dipping fault zones coincident with and parallel to the trend of the Tipunah Road Anomaly at two localities: near 345 650 mE; 5 453 700 mN on Tayatea Road, and 347 150 mE; 5 456 300 mN on Wedge Plains Road.

The available aeromagnetic and ground data thus support a structural rather than igneous intrusive origin for the Tipunah Road Anomaly.

The aeromagnetic data show no exact equivalent of the terminated Tipunah Road Anomaly north of the Boat Harbour Fault at a position corresponding to the previously inferred eight kilometre net dextral offset on the fault. However, in the vicinity of this position a broad, diffuse linear positive magnetic anomaly trends ~057° from just north of the fault to the Bass Strait coast, and is apparently coincident with two previously mapped, almost colinear dolerite dyke segments (fig. 12; dykes A and B on fig. 2). The characteristics of this anomaly are quite different to the Tipunah Road Anomaly, and imply a significant contribution from a deeper source. If the dolerite dykes coincident with the anomaly are its only source, these dykes may expand at depth into broader bodies.

The termination of this anomaly near the Boat Harbour Fault may be more than coincidence. However, the only similar dyke-coincident anomaly south of the fault is offset ~5 km in a *sinistral* sense and is not an exact match in characteristics (dyke C, fig. 2; compare with fig. 12). On the other hand, dykes A and B have similar major and trace-element chemistry to dyke C (A. V. Brown, pers. comm. 1997), and a match may be implied which would suggest a ~5 km sinistral offset during a movement which post-dated the main dextral wrench movement on the Boat Harbour Fault. Based on the dyke evidence alone this may seem unlikely, but as discussed above a late sinistral wrench movement is independently implied by D_2 structures near Jacobs Boat Harbour.

Discussion

If the suggested origin of the Tipunah Road Anomaly is correct, one possible structural geometry places a major east-directed thrust fault coincident with the anomaly and connecting with the Boat Harbour Fault in a transfer-fault arrangement, which would be one way of disposing of the dextral wrench offset on the Boat Harbour Fault east of the point where it would otherwise intersect the Smithton Synclinorium. The Tipunah Road Anomaly terminates abruptly just north of the previously inferred trace of the Boat Harbour Fault (fig. 2), which would therefore need to be shifted northward a little over one kilometre (fig. 12) for this geometry to be viable.

The suggested thrust fault may interact with other major structures in the region (fig. 1). Recent interpretation of new, detailed, airborne geophysical datasets covering poorly-mapped areas of the Rocky Cape Group south of the Smithton Synclinorium (McClenaghan and Seymour, 1996), inferred the existence of a number of previously unrecognised regional-scale faults. One of these is an arcuate structure defining the eastern boundary of a large D-shaped structural domain lying southeast of Balfour (fig. 1), and which is provisionally interpreted as a major east-directed thrust fault. A thrust fault coinciding with the Tipunah Road Anomaly may intersect the northern part of this arcuate structure, and may be coeval with it.

It may not be necessary to absorb all of the wrench offset on the Boat Harbour Fault on one thrust fault, as other east-directed thrusts may occur in the Rocky Cape Group south of the western half of the Boat Harbour Fault trace. Map relationships shown by Lennox *et al.* (1982) imply the presence of a shallowly west-dipping thrust contact between quartzitic and pelitic formations in the Rocky Cape Group eight kilometres east of Mawbanna (Turner, 1980) (fig. 2). A recent detailed aeromagnetic survey south of the area covered by Figure 12 (McClenaghan and Seymour, 1996) shows, in greater detail, the magnetic anomalies associated with dolerite dykes intruding the Rocky Cape Group east of the Tipunah Road Anomaly. These anomalies show a pattern of intersecting trends which may be interpreted as being caused by a fault parallel with and some seven kilometres east of the Tipunah Road Anomaly (fig. 13).

The interaction of the Boat Harbour Fault with the Arthur Lineament is more difficult to assess because the structures intersect offshore in Bass Strait. The most recent compilation of onshore and offshore regional aeromagnetic data (Mackey *et al.*, 1995) shows that the major positive magnetic anomaly associated with the Arthur Lineament becomes progressively broader and more diffuse as it approaches the coast from the south, and becomes less distinct after it crosses the coast. Nonetheless the data appear to indicate that the Arthur Lineament extends without major offset some 22 km into Bass Strait, albeit with a gradual regional swing in overall trend from ~023° near Savage River to ~056° in its offshore segment. If the impression gained from the aeromagnetic data is correct, then in order to avoid offset of the Arthur Lineament, it would be necessary for the Boat Harbour Fault to link in a further transfer-fault arrangement with another, east-directed thrust or series of thrusts located at or west of the northwestern margin of the offshore part of the Arthur Lineament. Some 35 km to the southwest, east or southeast-directed thrusting at the western margin of the Arthur Lineament has been inferred from geophysical interpretation (Leaman *et al.*, 1994), and a similar inference was independently made by Everard *et al.* (1996) based on surface structural data collected during regional mapping.

CONCLUSIONS

The main results of this re-examination of the problem of the Boat Harbour Fault are:

- The overall geometry of the fault over the eastern part of its trace as described by Gee (1967*a*, 1971) is essentially correct, although it is difficult to be precise about the total net offset on the fault.
- Second-generation mesoscopic structures which are locally developed in a quartzite/pelite unit adjacent to the fault immediately west of Boat Harbour, and which Gee (1967*a*, 1971) attributed to the main dextral wrench movement on the fault, are enigmatic. Their localised development indicates association with the fault, but it is difficult to visualise how their geometry could have been produced by the same overall stress field responsible for a major dextral wrench movement on the fault. They may have developed during such a movement in response to local ductility contrasts between their host unit and the underlying Jacob Quartzite, or alternatively during a separate, later sinistral wrench movement on the fault.
- Re-examination of mesoscopic structures previously attributed to the fault in the Pine Corner Road area supports the westward extension of the fault trace previously inferred by Lennox *et al.* (1982) and Lennox (*in* Brown, 1989), albeit in a slightly different position. Significant clockwise rotation of pre-existing regional D_1 mesoscopic structures is attributed to dextral wrench movement on the Boat Harbour Fault. The rotated D_1 structures are overprinted by later minor upright folds which may be Devonian in age.
- Regional age relationships indicate that the Boat Harbour Fault post-dates the Neoproterozoic Togari Group, which forms most of the Smithton Synclinorium. This necessitates disposing of all of the offset on the fault somewhere east of the eastern margin of the Smithton Synclinorium. This may be achieved if the fault is linked in a transfer-fault relationship with one (or several) NNE-trending, east-directed thrust faults, and a possible location for at least one such fault has been suggested here.
- It may be necessary to invoke a similar wrench-thrust transfer geometry near the intersection of the Boat Harbour Fault with the western margin of the Arthur Lineament.

To prevent the offset on the Boat Harbour Fault from affecting the major structural units adjoining the Rocky Cape Group requires a structural geometry of sufficient complexity to perhaps cast some doubt on its validity. However, the only alternative explanation is one or more serious flaws in current knowledge of the age relationships between the Togari Group, the main metamorphism in the Arthur Lineament, and the regional D_1 folding event in the Rocky Cape Group. Within this triad, the relationship between the latter two components is possibly the least well-constrained, and may be worthy of further investigation. Other indicators for further work are as follows:

- The precise origin of the Tipunah Road Anomaly remains enigmatic, and geochemical sampling of weathered rock exposures on the line of the anomaly would be a useful basis for further research.
- The structural database of Lennox *et al.* (1982) remains incompletely interpreted, particularly in the absence of an explanation for east-trending folds which appear to be domainally developed in the Rocky Cape Group up to at least five kilometres away from the Boat Harbour Fault. Further re-analysis of this dataset is one avenue for further work on the structural history of the region.
- Structural data derived from successive regional mapping projects (Lennox *et al.*, 1982; Seymour and Baillie, 1992; Everard *et al.*, 1996; McClenaghan *et al.*, in press; Everard *et al.*, in press) indicate that the Smithton Synclinorium is as structurally complex as much of the Rocky Cape Group, and delineation of the structural history which lead to this complexity is needed to fully clarify the significance of the Boat Harbour Fault.
- Beyond the immediate scope of the Boat Harbour Fault problem (although bearing on it), the systematic geochemistry of the dolerite dyke swarm and the Togari Group basalts, and their relationships (if any) to each other, also remains an important subject for further research.

In the first major work on the Boat Harbour Fault, Gee (1967*a*, 1971) concluded that the fault may emerge, following further mapping, as one of the major fault structures in northwestern Tasmania. This conclusion appears to be substantiated by the later mapping of Lennox *et al.* (1982) and Lennox (*in* Brown, 1989), and reinforced by the re-examination of the problem presented here. Opinion on the geometric relationship of the Boat Harbour Fault with other regional structures may undergo further modification, but any tectonic framework proposed in the future must accommodate this major wrench fault.

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[14 August 1997]

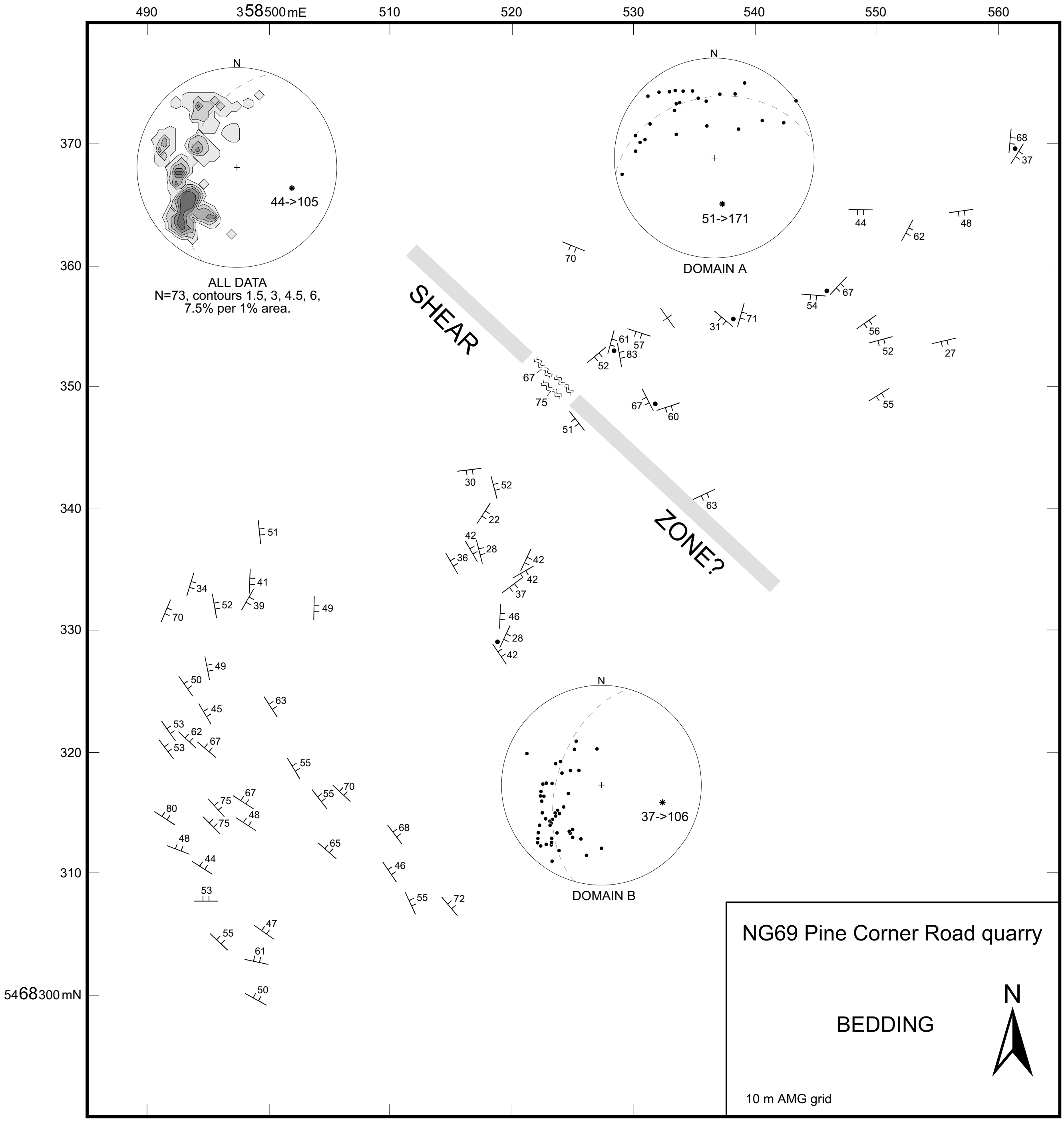


Figure 6

Detailed structural map and lower hemisphere equal-area polar stereograms of bedding orientations in a quarry in Cowrie Siltstone at Station NG69, Pine Corner Road area.

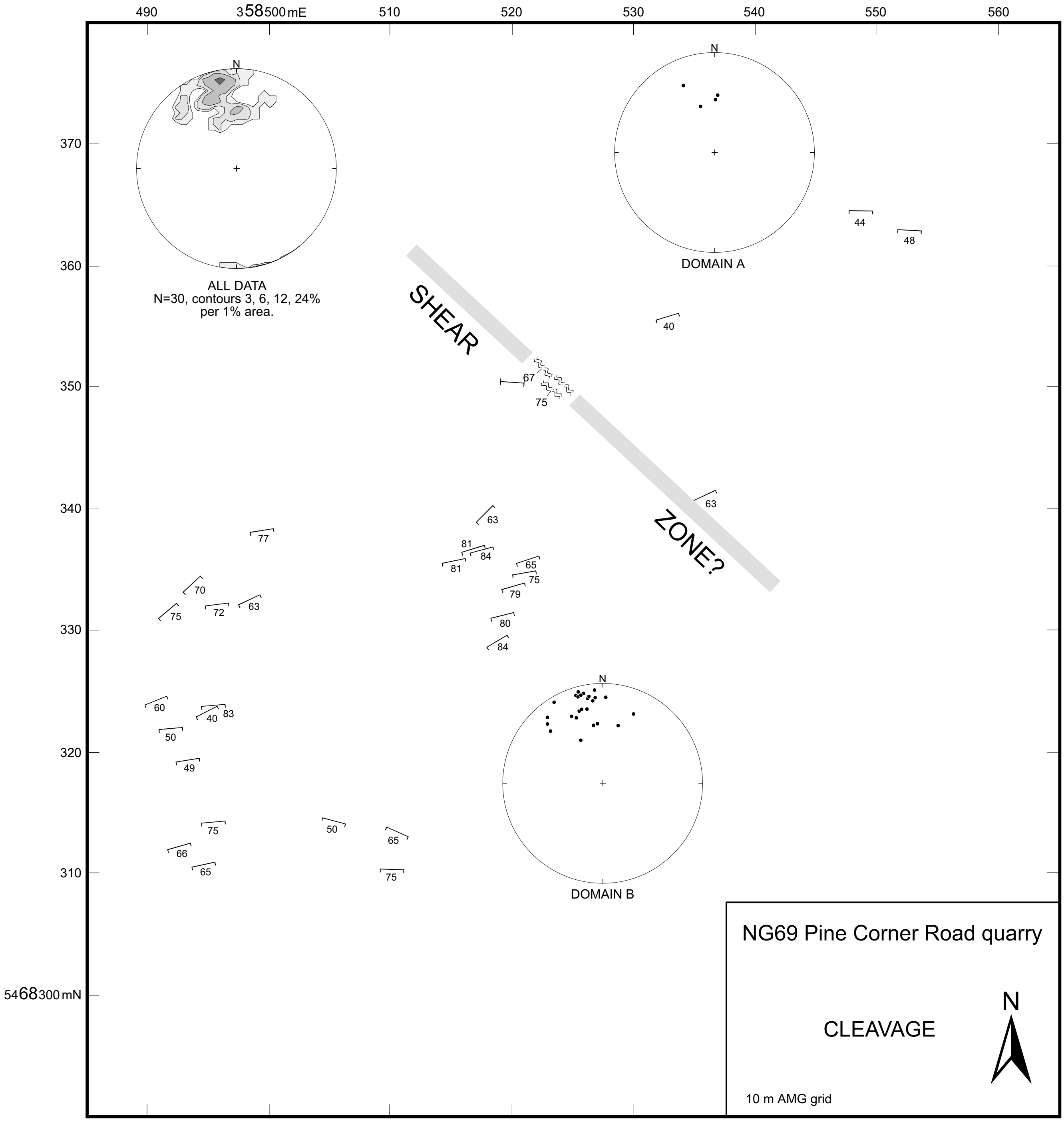


Figure 7

Detailed structural map and lower hemisphere equal-area polar stereograms of cleavage orientations in a quarry in Cowrie Siltstone at Station NG69, Pine Corner Road area.

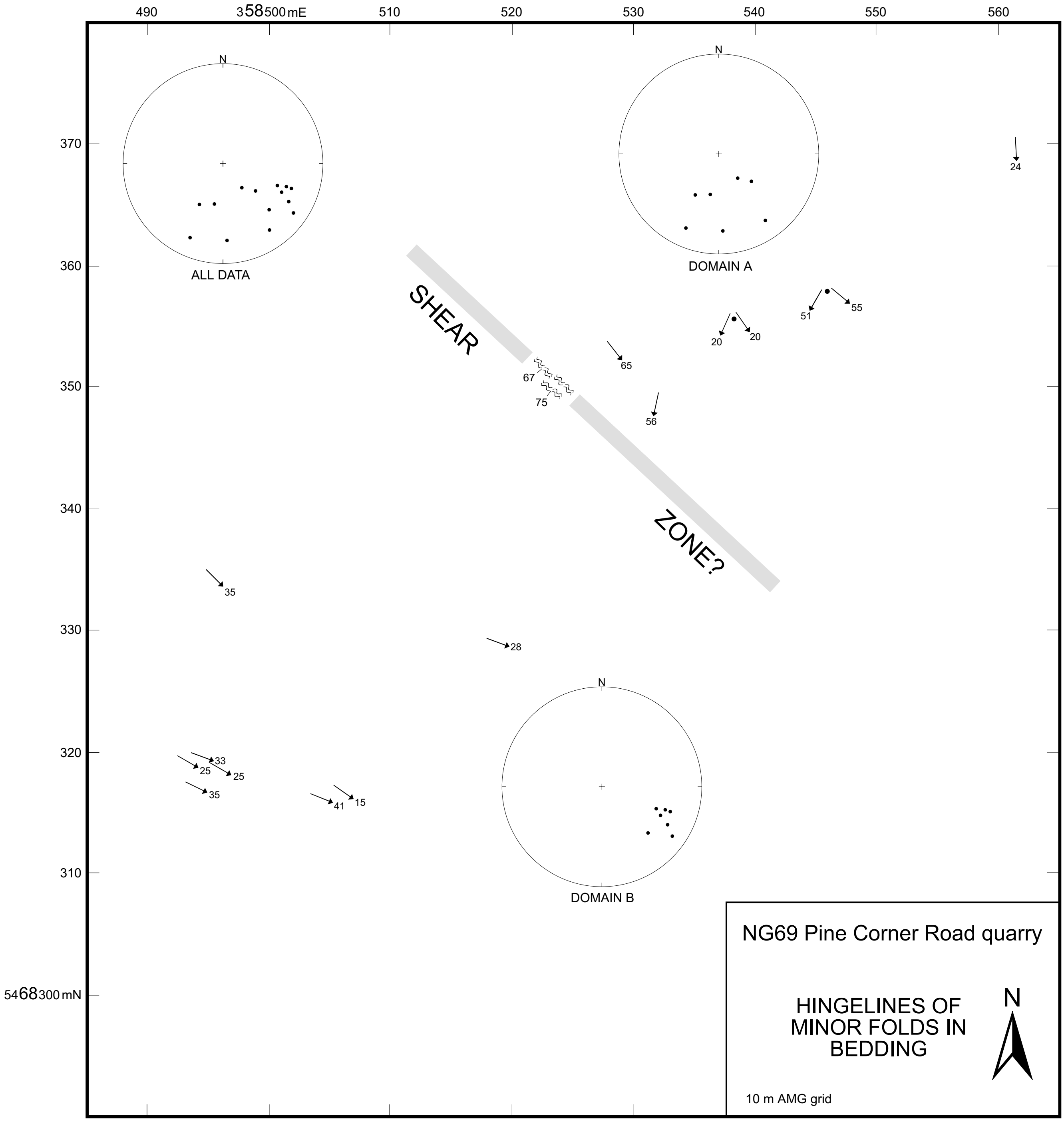


Figure 8

Detailed structural map and lower hemisphere equal-area stereograms of hingeline orientations of minor folds in bedding, in a quarry in Cowrie Siltstone at Station NG69, Pine Corner Road area.

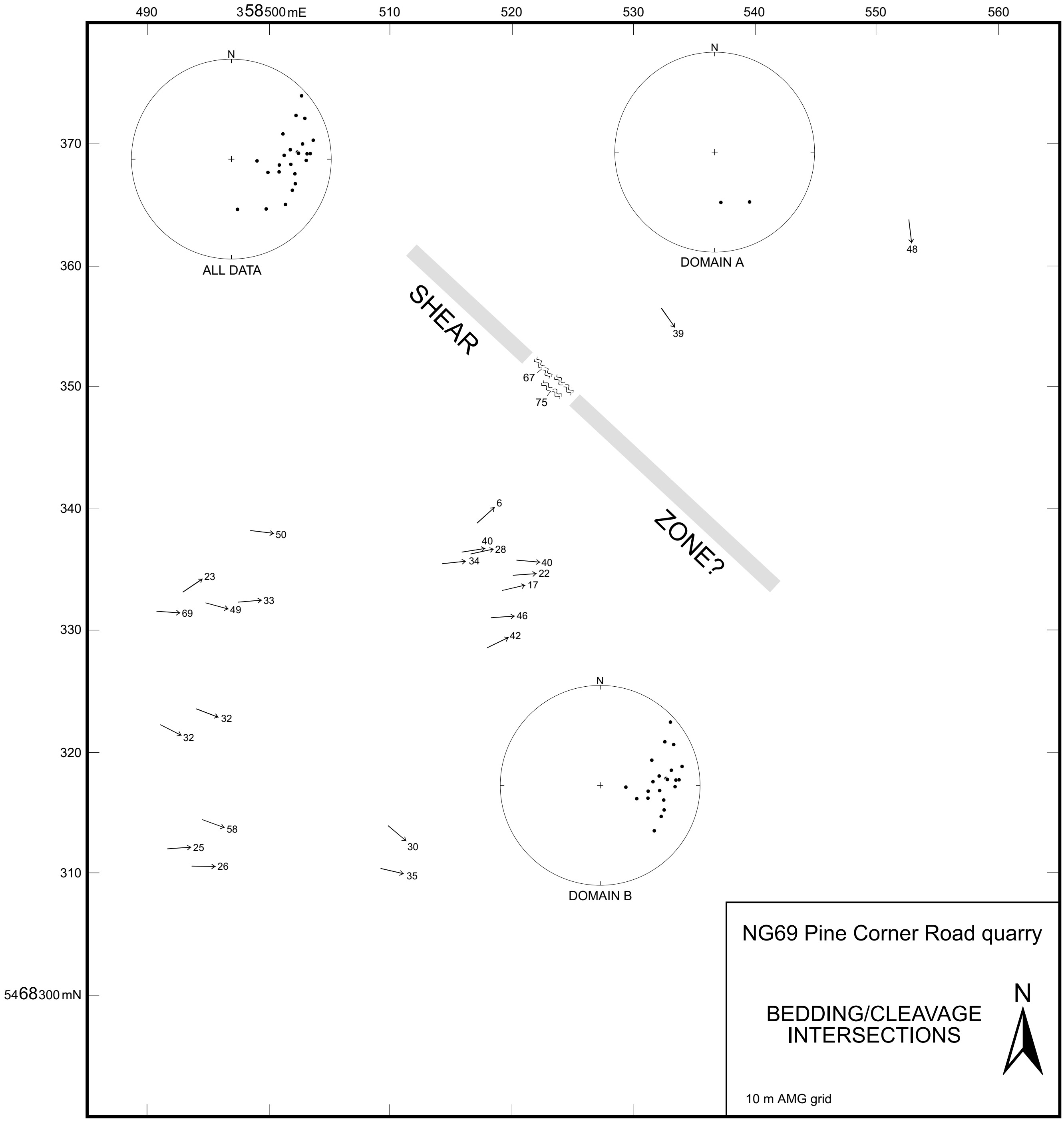
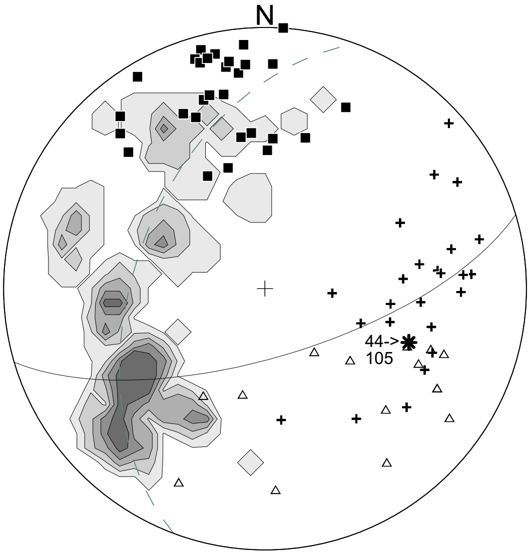
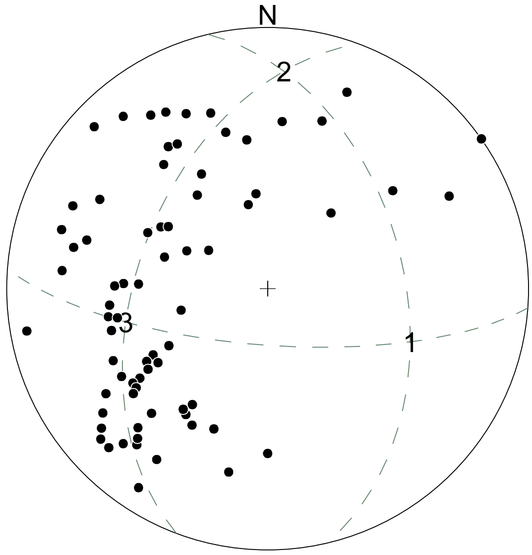


Figure 9

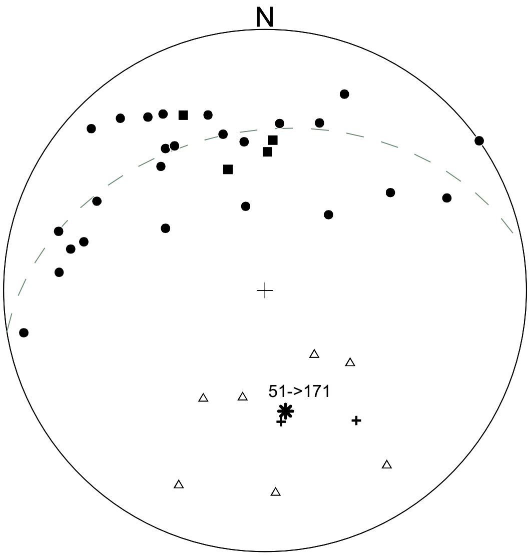
Detailed structural map and lower hemisphere equal-area stereograms of orientations of bedding/cleavage intersections in a quarry in Cowrie Siltstone at Station NG69, Pine Corner Road area.



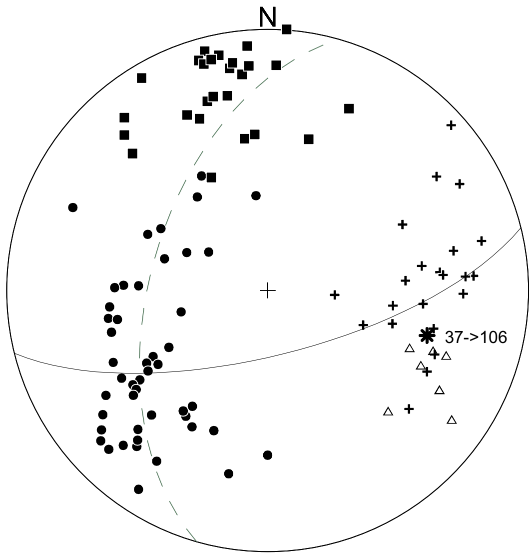
ALL DATA
73 poles to bedding contoured at 1.5, 3, 4.5, 6, 7.5% per 1% area. Overlain data points as per legend. Dashed great circle — best fit to bedding poles. Solid great circle — preferred orientation of cleavage derived from cluster analysis.



ALL DATA
Poles to bedding; principal planes and eigenvectors shown.



DOMAIN A
Dashed great circle — best fit to bedding poles.



DOMAIN B
Dashed great circle — best fit to bedding poles. Solid great circle — preferred orientation of cleavage derived from cluster analysis.

NG69 (~358 530 mE; 5 468 330 mN) Pine Corner Road quarry

- ● Poles to bedding
- ■ Poles to cleavage
- + Bedding/cleavage intersections
- △ Hingelines of minor folds in bedding
- ✱ E_1 eigenvector of distribution of bedding poles (corresponding principal plane shown by dashed great circle)

Figure 10

Lower hemisphere equal-area stereograms of orientation data from a quarry in Cowrie Siltstone at Station NG69, Pine Corner Road area.

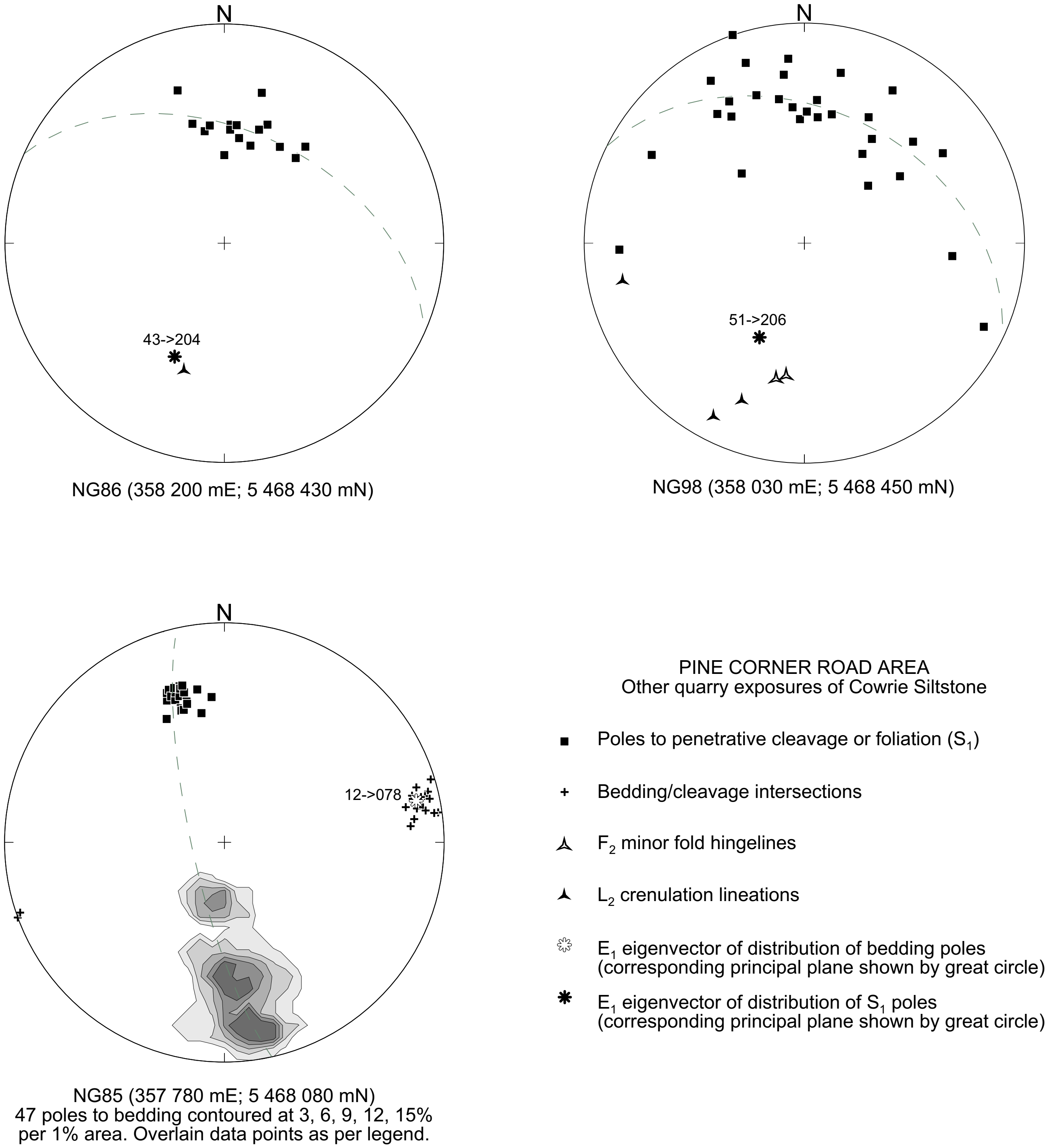
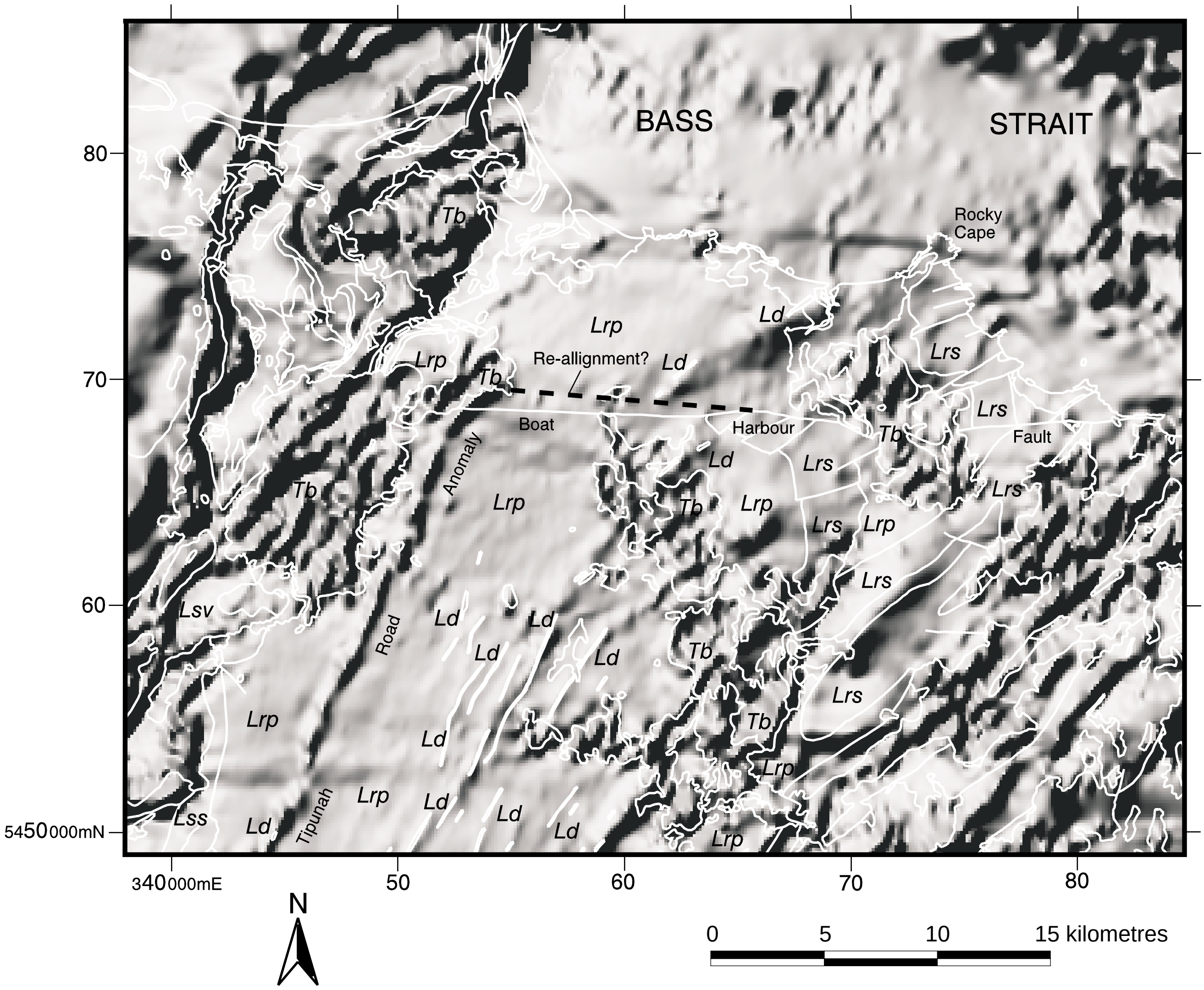


Figure 11

Lower hemisphere equal-area stereograms of orientation data from quarries in Cowrie Siltstone at Stations NG85, NG86 & NG98, Pine Corner Road area.



Key to labelled units:

TERTIARY

Tb	Basalt & related pyroclastic rocks

NEOPROTEROZOIC (Togari Group)

Lsv	Rift sequence, including volcaniclastic turbidites and mafic volcanic rocks
Lss	Shallow marine shelf-facies dolomite, chert, shale and diamictite

?MESOPROTEROZOIC (Rocky Cape Group)

Lrs	Orthoquartzite sequences (Lrs)
Lrp	Mudstone-siltstone sequences with minor carbonate rocks (Lrp)

PROTEROZOIC Intrusive Rocks

Ld	Dolerite dykes

Figure 12

Grey-scale image of Total Magnetic Intensity (illumination at 45° elevation from the northwest) for the region surrounding the Boat Harbour Fault (Mackey et al.*, 1995). 1:250 000 scale digital geological coverage (Calver* et al.*, 1995) overlain in white, and some rock units are labelled.*

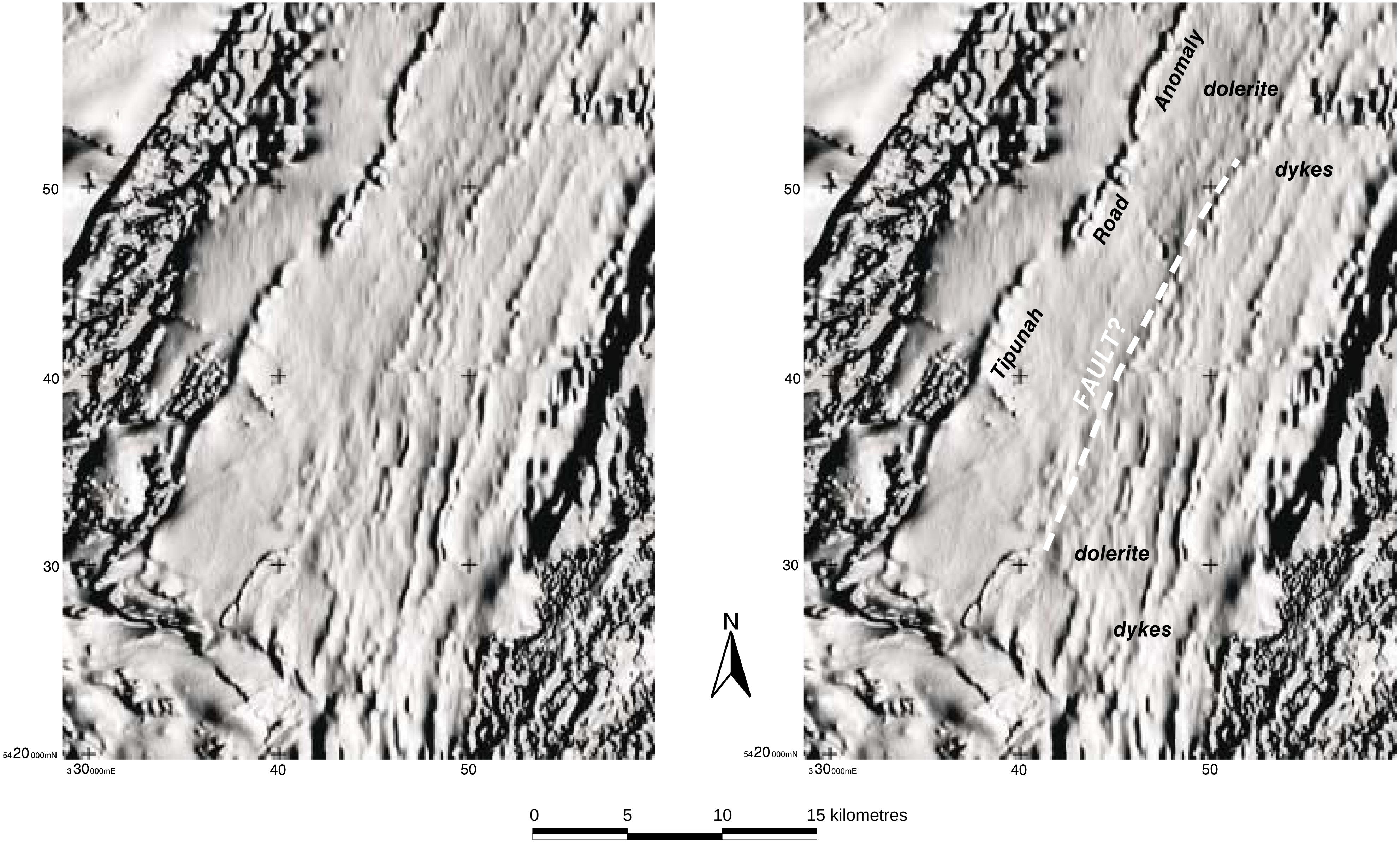


Figure 13. *Grey-scale image of Total Magnetic Intensity (illumination at 45° from the east) for area south of Figure 12. Part of April 1996 Northwest Forests Airborne Geophysical Survey, Tasmania. Annotated image shows a possible fault inferred from a pattern of intersecting linear anomalies associated with dolerite dykes intruding the Rocky Cape Group.*