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SEDIMENTARY AND STRUCTURAL FEATURES OF THE BELL SHALE CORRELATE (EARLY DEVONIAN), STRAHAN QUADRANGLE, WESTERN TASMANIA

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Geological Survey of Tasmania

(with four text-figures and nine plates)

ABSTRACT

The sequence of interbedded mudstone, siltstone and very fine sandstone in the Strahan Quadrangle, correlated with the Bell Shale is at least 500 m thick. Two broad associations can be defined. The ratio of very fine sand to mud in the lower association is between 3:2 and 2:3 whereas in the upper association only occasional thin sandstone beds occur. Sedimentary structures such as lenticular bedding, symmetrical ripple marks and the lack of deep water sedimentary features suggest that deposition took place in shallow water. This is supported by palaeontological evidence. Some scouring and upward fining beds suggest that deposition from waning currents occurred sporadically within this environment.

The Bell Shale correlate has been folded during two phases. The first phase produced folds plunging between 30° and 90° NW and the second phase produced folds plunging shallowly WNW or ESE. Cleavage was developed only locally during each phase. Folds of both phases produced a primary axial surface cleavage and the second phase produced crenulation cleavage in some areas. The amplitude of folds produced during the first phase decreases towards the centre of the basin. The locus of strain during the second phase of deformation was along the Firewood Siding Fault. The existence and timing of these deformation events demonstrates the uniformity in orientation of Tabberabberan structures throughout north and western Tasmania.

INTRODUCTION

The most recent work on Eldon Group correlates is the systematic mapping by officers of the Geological Survey of Tasmania, within the Strahan 1:50000 quadrangle. This mapping has involved studies of a large basin containing correlates of the Bell Shale (fig. 1).

The Bell Shale is the uppermost formation of the Eldon Group as defined by Gill and Banks (1950) in the Zeehan area. Gill (in Banks 1962) considered the Bell Shale to be a shelf-type deposit, deposited in 'deeper, quieter waters'. Banks in Talent and Banks (1967) considered that deposition of the Bell Shale took place on a rather shallow, but deepening sea floor, in which turbidity currents were active during deposition of the lower parts of the formation. Recently Webby (1972) has advocated a 'Flysch-type' environment of deposition of the Bell Shale and its correlates. Present studies, however, suggest a shallow-water origin for the beds in the Strahan Quadrangle.

The basin of deposition of the Eldon Group in the Strahan Quadrangle has been folded during the Tabberabberan Orogeny, which is a major Devonian movement recorded throughout Tasmania. The events recorded within the Bell Shale correlate are discussed below in terms of the complexities of the Tabberabberan Orogeny and the relationship of these events to structures present elsewhere in Tasmania.

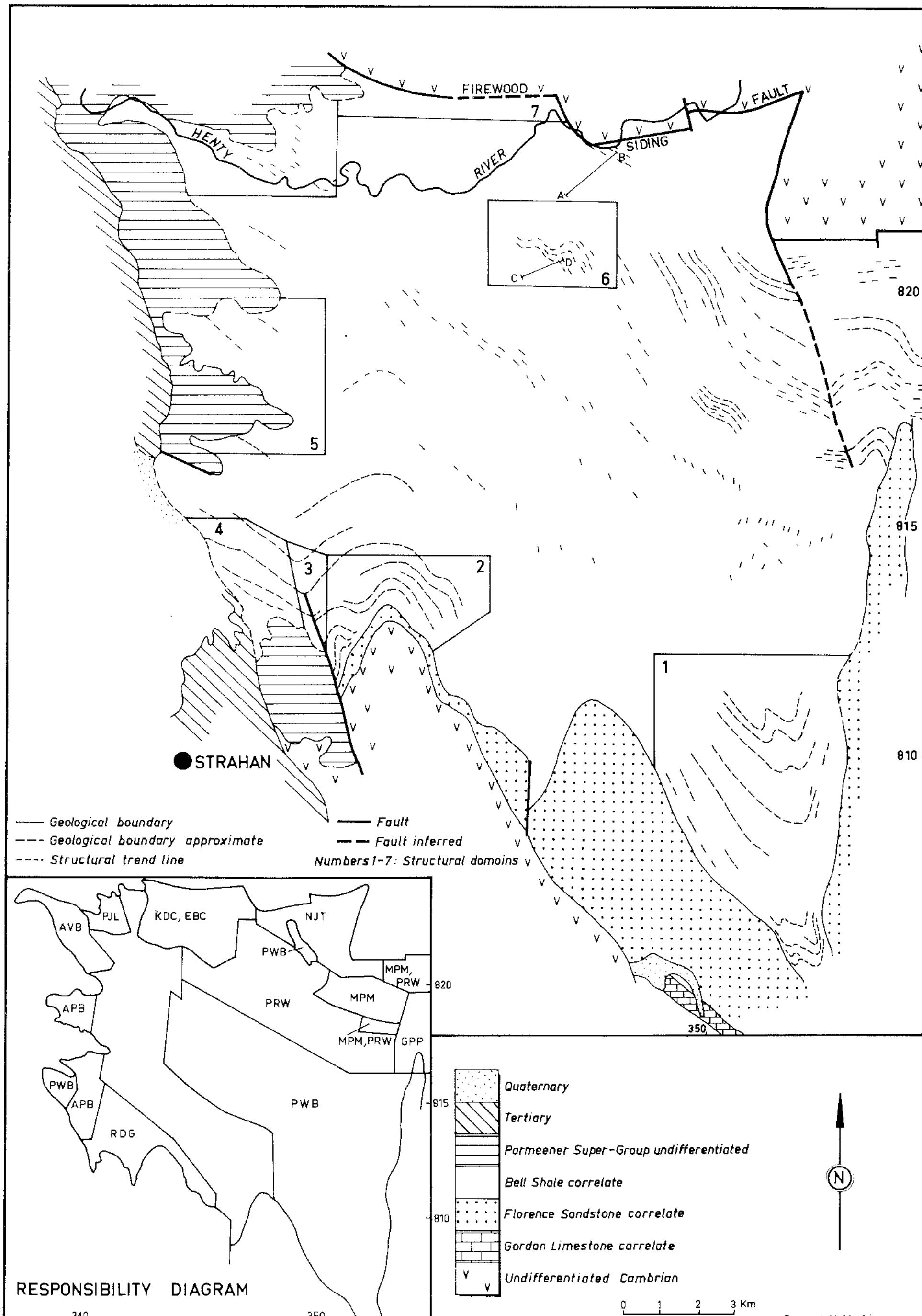

FIG. 1. - Geological Map of the Bell Shale correlate and environments. Responsibility diagram indicates areas mapped by P.W. Baillie (PWB), A.P. Bravo (APB), A.V. Brown (AVB), E.B. Corbett (EBC), K.D. Corbett (KDC), R.D. Gee (RDG), P.J. Legge (PJL), M.P. McClenaghan (MPM), G.P. Pike (GPP), N.J. Turner (NJT) and P.R. Williams (PRW).

SEDIMENTARY GEOLOGY

General

The Bell Shale correlate in the Strahan area is a sequence of very fine sandstone and mudstone, usually deficient in sand grade material above 0.15 mm in diameter. There exists a broad twofold division with the very fine sand occurring mainly within the lower part of the sequence. Total thickness is at least 500 m.

Immediately underlying the Bell Shale correlate is the correlate of the Florence Sandstone which consists of well-bedded and well-sorted sandstone and calcareous sandstone. Towards its top, the Florence Sandstone correlate contains mudstone beds which increase in frequency and thickness towards the top of the formation. The contact between the Florence Sandstone and Bell Shale correlates is gradational over at least 25 m. In this transition zone, beds of fine sandstone up to 80 cm thick may occur, although they are generally between 10 and 20 cm thick. These sandstone layers contain more clay grade material as matrix than the underlying Florence Sandstone correlate.

In the lower part of the Bell Shale correlate the proportion of sandstone to mudstone beds is between the ratios of 3:2 and 2:3. Thickness of individual beds rarely exceeds 20 cm which are generally between 5 and 10 cm thick.

In thin section (e.g. 72-69, 74-419, 74-425; numbers refer to Department of Mines collection) the very fine sandstone is well-sorted (So 1.2-1.4) and consists of angular to subrounded quartz grains with a medium sphericity. The average diameter of the grains is 0.12 mm, but they may occasionally reach a maximum of 0.25 mm (74-425). The quartz grains are of single crystals which occasionally show undulose extinction resulting from strain. Quartz overgrowths are occasionally observed. Detrital mica is ubiquitous. Other minerals identified in decreasing order of abundance are leucoxene, well-rounded green tourmaline and zircon. The green tourmaline and the presence of some strained quartz grains indicates that a metamorphic terrain formed part of the original source area. Clay matrix constitutes 10% of the rock. The matrix often contains carbonaceous material (e.g. 72-72).

The upper part of the Bell Shale correlate is dominantly a mudstone sequence. Beds of very fine sandstone are rare and are not more than 3 cm thick and usually much less. Pyrite is common, both disseminated and as nodules. A strong tectonic cleavage is usually present.

A broad twofold division has also been recognised in the fossil assemblages of the Bell Shale correlate. M.J. Clarke (pers. comm.) reports:-
"The faunas of the Bell Shale (like those of the underlying Florence Sandstone) are benthonic and essentially indicative of shallow water conditions. Diversity is moderate, but numbers of individuals are frequently prolific. Typical forms include the brachiopods *Isorthis*, *Leptostrophia*, *Maoristrophia*, *Plectodonta*, *Chonetes*, *Notanoplia*, *Atrypa*, *Meristella*, *Nucleospira*, *Australocoelia*, *Cyrtia*, *Eospirifer*, *Howellella*, *Hysterolites* and the trilobites *Cheirurus*, *Dalmanites*, *Gravicalymene*, *Proetus*, *Leonaspis* and *Trimerus (Trimerus)*. Crinoid debris (and other echinoderms), prolific *Tentaculites*, michelinoceratid nautiloids, loxonemid and straparollid gastropods, bryozoans, *Pleurodictyum*, *Favosites*, heliolitids and *'Lindstroemia'* occur at many horizons. Bivalve molluscs, *Chondrites*, worm and molluscan burrows, together with plant debris are common only at certain localities.

As noted by Gill (1950), a wide variety of almost mutually exclusive faunules replace one another in short distances both laterally and vertically, and presumably reflect slight variations in the substrate micro-environment. Despite this variation, only two broad faunal subdivisions are evident within the Bell Shale correlate. The fauna from the lower sandstone-mudstone sequence is characterised by *Trimerus (Trimerus) zeehanensis* Gill, *Australocoelia polyspera* (Gill), and *Meristella bellensis* Gill, whereas the upper mudstone fauna is characterised by *Chonetes*, *Maoristrophia spp.*,

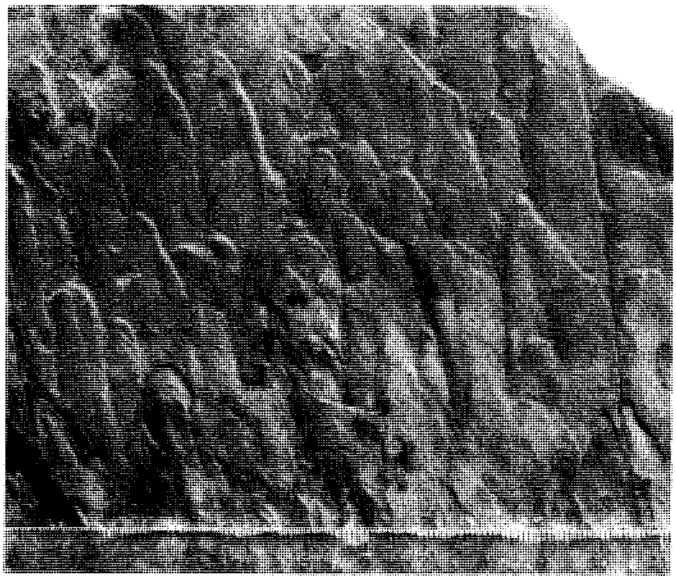

PLATE 1. - Shallow flute casts from the base of a mudstone bed.

Notanoplia pherista Gill and *Plectodonta bipartita* (Chapman). Most of the remaining fauna appears to be cosmopolitan. A similar sequence of faunas has been recognised in Victoria and elsewhere in eastern Australia in sequences of varying lithofacies (Talent 1965: in Talent and Banks 1968: Strusz 1971), so that the division appears to have real biostratigraphic significance and does not solely reflect lithological variation.

Modiola Phase faunas collected from the sandstone-mudstone sequence about 6 km NE of Strahan on the Strahan-Queenstown road are characterised by a profusion of the bivalves *Actinopteria*, *Ctenodonta*, *?Cyrtodonta*, *Glossites*, *?Grammysia*, *Leptodomus*, *Modiolopsis* and *Nuculites*, equally prolific *Tentaculites*, but rarer *Isorthis*, *Trimerus (Trimerus)*, crinoids and vascular plant debris".

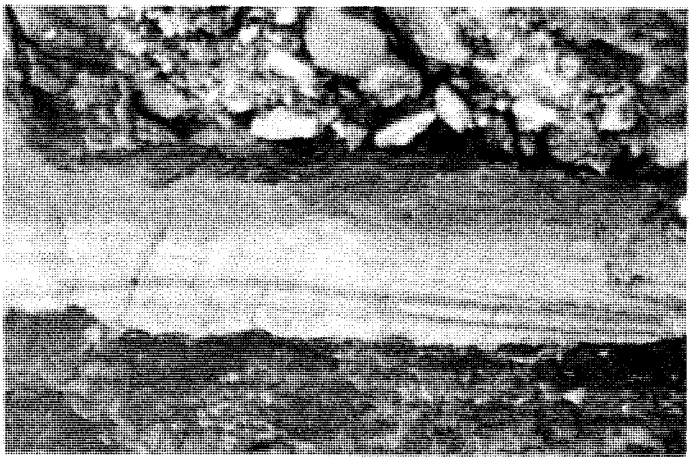

PLATE 2. - Laminated siltstone bed overlying a scoured mudstone bed. Note the grading of the siltstone unit. x 2/3.

The Modiola Phase fauna occurs in interbedded very fine sandstone (74-273) and micaceous siltstone (74-272). Specimen 74-273 is a grey-brown micaceous very fine sandstone that contains low sphericity, sub-angular to subrounded quartz grains of 0.08-0.12 mm diameter and rare heavy minerals in a clay matrix which constitutes 20% of the rock. The sandstone has an open framework but no grading is present. Specimen 74-272 is light grey in colour and contains 10% angular to subrounded quartz grains of maximum diameter 0.08 mm and abundant detrital mica in a clay matrix. The rock shows much bioturbation. In some of the very fine sandstone beds fragmented trilobites, bryozoans and thin-shelled bivalves occur in great abundance. There is no evidence to suggest that the fauna did not live

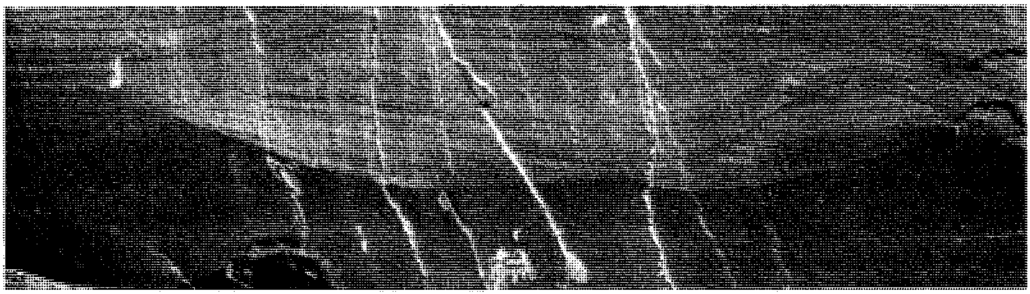

PLATE 3. - Scoured mudstone bed overlain by cross-bedded sandstone; ripple marks occur also.

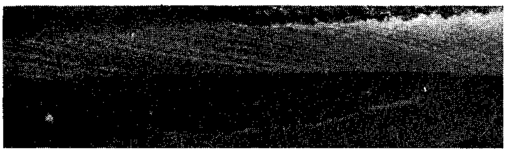

PLATE 4. - Non-erosional cross-bedded unit.

All plates
natural size

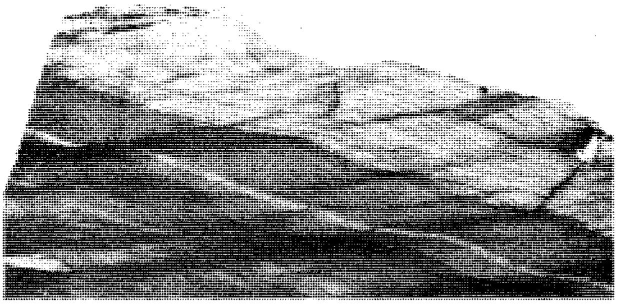

PLATE 5. - Gradational cross-bedded unit.

PLATE 6. - Worm burrows in very fine sandstone infilled with mud.

at the site at which they are now found buried.

Sedimentary Structures

Pre-depositional structures are largely confined to the upper mudstone sequence of the Bell Shale correlate. Shallow flute casts (plate 1) 2-3 cm long sometimes occur on the base of mudstone beds but are not obviously associated with coarser deposits. More commonly the tops of beds are scoured and have been overlain by plane laminated coarse silt which appears to grade into finer silt and mudstone (plate 2). These are not considered to be turbidites, but rather to result from deposition from waning currents. The lamination shows that initially current velocities were in the upper flow regime.

Plate 3 shows scouring of a mudstone bed by cross-bedded sand of the sandstone-mudstone sequence.

Syndepositional structures are much more common but are largely confined to the very fine sandstone layers of the sandstone-mudstone sequence. The sandstone beds very often show small scale trough bedding in sets of cross-bedded units that are generally grouped. The base of a cross-bedded unit may be erosional (plate 3), non-erosional (plate 4) or gradational (plate 5). Lithologically the cross-bedded units are generally homogenous. This type of cross-bedding is common in shallow water sequences (Conybeare and Crook 1968).

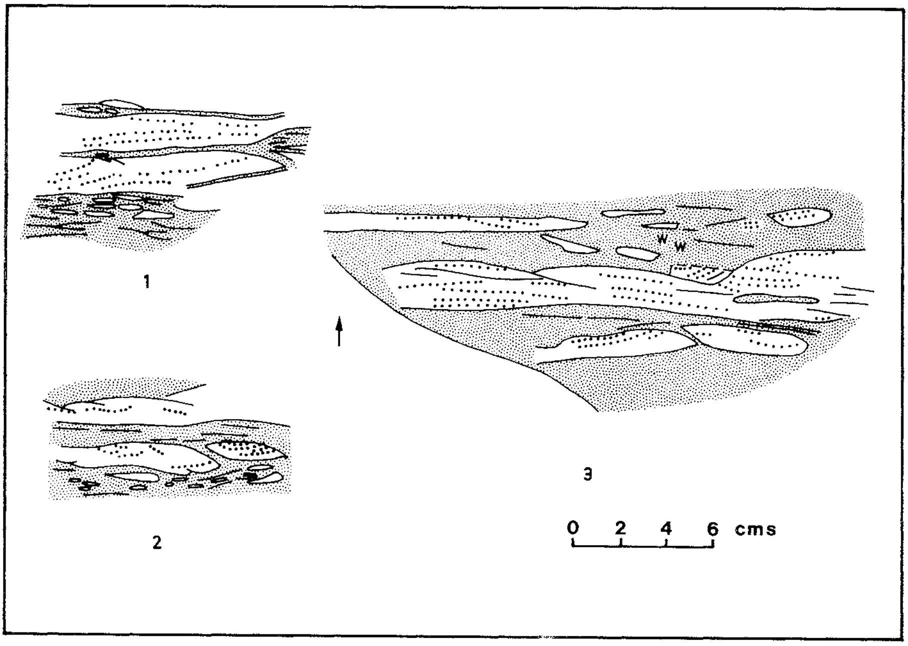

FIG. 2. - (a) Cross-bedded sandstone beds overlying lenticular sandstone bodies.
(b) Lenticular bedding, showing the cross-bedded nature of the sand units.
(c) Lenticular and continuous sand units showing cross-bedding.

Flaser or lenticular bedding also occurs in the lower part of the Bell Shale correlate (fig. 2a, 2b, 2c). Very fine-grained, often cross-stratified laminae of sand usually less than 2 cm thick are irregularly interbedded with silty mudstone.

Often the sand and silt are intimately mixed, apparently by reworking and "mottled" bedding results. This type of bedding forms in areas where a change takes place between slack and turbulent water.

Ripple marks occur on the top of sand beds in the sandstone-mudstone sequence though not commonly. They may be symmetrical (plate 2) or asymmetrical.

Post-depositional structures occasionally occur in the Bell Shale correlate. Bedding in very fine sandstone is often disturbed by the burrows of the worm *Chondrites* which have been infilled with mud (plate 6). Flame structures occur in the base of some very fine sandstone beds (plate 7) and pseudonodules occur rarely (plate 8). Soft sediment faults occur with displacement from 1 mm to 20 mm. The faults are both reverse and normal types. Bedding that has been disrupted by the formation of a tectonic cleavage also occurs (plate 9).

The bottoms and tops of the beds throughout the Bell Shale correlate are nearly always abrupt.

Summary

In summary it should be noted that whereas the term "shallow water" is open to subjective interpretation it is used here to indicate a near-shore, shelf environment. The lack of coarse sand, the large amount of detrital mica and the presence of carbonaceous material together with the limited development of a Modiola Phase fauna suggest that the Bell Shale correlate in the Strahan Quadrangle was deposited in a shallow water marine environment that was fed from a low relief distal source area. The form of depositional sedimentary structures suggests that the currents that transported material during deposition of much of the sandstone-mudstone sequence had a low velocity. Higher velocities, possibly in the upper flow regime, caused scouring and plane lamination in the upper mudstone sequence.

The presence of occasional scoured bases and the grading observed is not considered to be the result of turbidity currents but rather of waning currents.

The dominance of mudstone in the upper part of the sequence is due either to deposition in deeper water or a decrease in very fine sand grade material available from the source areas entering the basin.

Certainly the sedimentary and faunal evidence nowhere supports a "Flysch-type" environment as advocated by Webby (1972).

STRUCTURAL GEOLOGY

General

The overall structural pattern of the Bell Shale correlate is shown as trend lines and mapped fold hinges in figure 1. The trend lines are constructed from data on bedding plane orientation assuming that the folds are concentric in form.

The area has been divided into a number of domains which reflect areas mapped in sufficient detail to allow an interpretation of the structures present rather than homogeneous structural domains. They show the local variations in structural style across the basin. Domain boundaries are shown in figure 1.

The rocks in the southern part of the region show a general NNW trending fold system which folds the Bell Shale correlate together with the underlying Florence Quartzite correlate and the Cambrian System. The northern section of the basin is truncated by the Firewood Siding Fault (Blissett 1962). In the NW area of the basin the structural trend is WNW and the fold axes dip shallowly in marked contrast to the trend in the southern part of the basin. Regional mapping has also proved one major fault in the Bell Shale correlate, but the movement on it has not been established.

PLATE 7. - Flame structure. x $^{1}/3$.

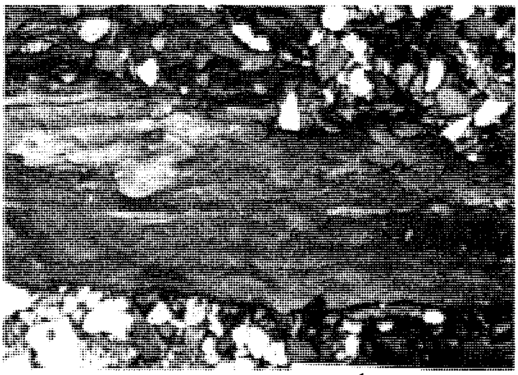

PLATE 8. - Pseudo-nodules. x $^{1}/3$.

PLATE 9. - Disrupted bedding exaggerated by a tectonic cleavage. Natural size.

Description of Folding

Domain 1. The folding in this region is on a steeply plunging hinge line. Figure 2a is a contoured equal area projection of poles to bedding, showing both limbs of the fold to be steeply dipping. The small number of shallow dips in the region are probably the result of EW faulting which is common in this area and on the west coast of Tasmania in general. The plot of cleavage poles (fig. 2b), shows that the cleavage dips 80° to 068°. This is parallel to the axial surface trace of the fold (fig. 1) and as the fold is plunging at 90° (fig. 2c) the map shows a profile section. Consequently the axial surface and the cleavage directions are coincident. On the western limb of this fold cleavage and bedding become more closely parallel. A large number of the bedding values in figure 2a are from this area, accounting for the small (10°) difference between the cleavage and bedding maxima. This fold reflects the NNW folding in the underlying rocks.

Domain 2. This area comprises the anticlinal region of a NNW trending anticline-syncline structure. The plunge of the folding in this area is 34° to 334° (fig. 2d). Few cleavages have been measured in this area (fig. 2e) but those measured suggest that the cleavage is approximately parallel to the steeply dipping fold axial surface.

Domain 3. The folding in domain 3 is nearly identical in plunge and direction of plunge to that in domain 2, plunging 40° to 340°. This suggests that the folding is homogeneous across the anticlinal region of the major structure. Figure 2f shows the equal area projection for bedding poles in this domain.

Domain 4. This forms the western limb of the NNW structure in the south of the region. Equal area projections of poles to bedding and cleavage are shown in figures 2g and 2h. The trend of cleavage has swung markedly westward, now trending 300°. The bedding is much more uniform away from the folds but shows a definite trend in spreading around a hinge plunging 6° to 110°. The cleavage is not disturbed by this trend and was probably formed by folds of this trend.

Figure 2i is an equal area projection of bedding poles from immediately north of domains 2 and 3, and shows a spread in the bedding on a hinge of 30° to 320°. This emphasizes the possible significance of fold hinge rotation during later folding, as this fold is a continuation of the folds of domains 2 and 3.

Towards the north and west of the sheet the structural elements differ in orientation from those in the south. Figure 3 shows a number of equal area projections of bedding and cleavage and bedding-cleavage intersection lineations. Figure 3a shows the latter for domain 5. The fold hinges are horizontal and trend at 300°, in marked contrast to the trends in previous domains. Bedding readings from the lower reaches of the Henty River show a similar orientation of the fold hinges, 6° to 290° (fig. 3b). A larger number of readings from domain 6 shows that bedding is folded around a hinge of 15° to 150° (fig. 3c). Bedding-cleavage intersections from the same region (fig. 3d) show a plunge of fold hinges of 0° to 330° but with a considerable spread of values lying in the axial surface direction. The axial surface of this folding is dipping 80° to 060°. The cleavage in these three regions is related to the shallowly plunging folds shown on the equal area plots and is essentially parallel to the axial surfaces of these folds.

Figures 3e, 3f, 3g and 3h show the data from the Henty River close to the Firewood Siding Fault and surrounding the Fault in the Bell Shale correlate. Figure 3e from domain 7 suggests folding on a vertical hinge. The other three diagrams show folding on a vertical hinge also, and it is believed that the structural trends in these regions is related to movement along fault zones.

Minor Structures

Prior to the major folding discussed above there occurred large open bends in the

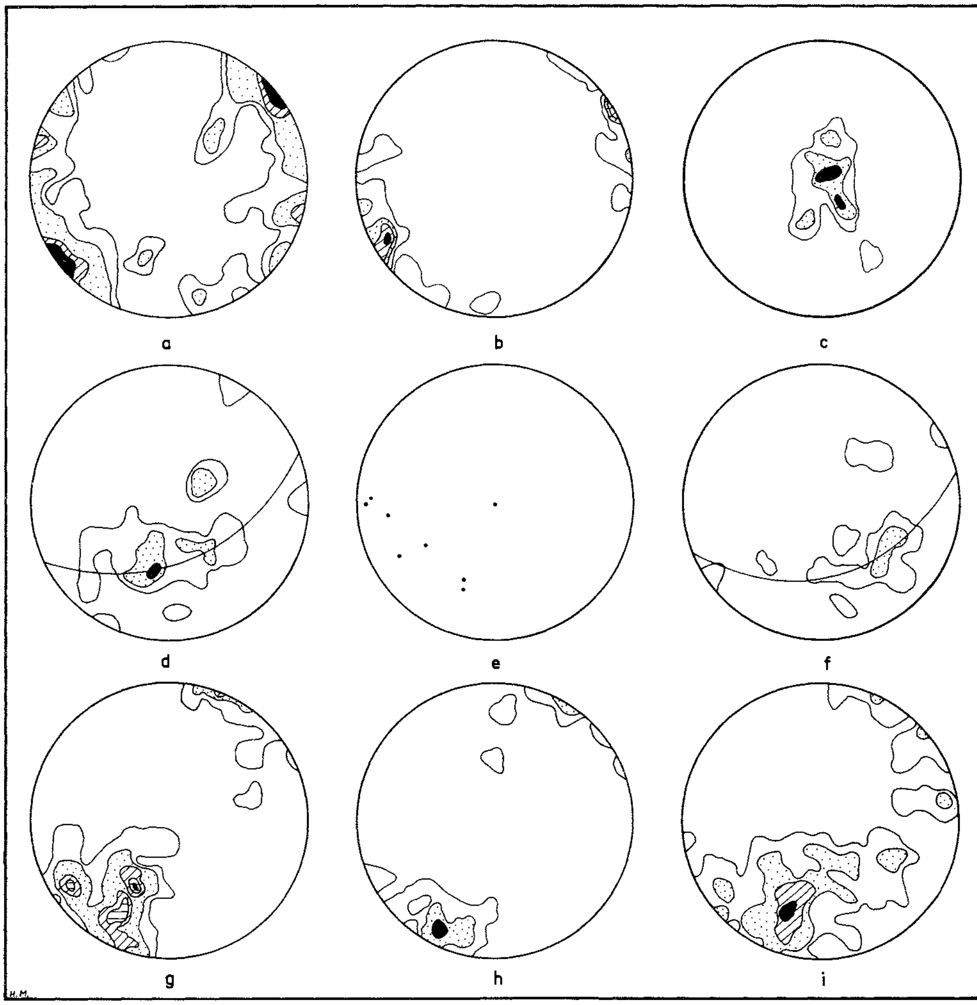

FIG. 3. - Contoured Equal Area Projections. Each point is representative of readings from a sequence of beds.

(a) Domain 1: Poles to bedding. 1, 2, 6 12% per 1% area, 13 points.
(b) Domain 1: Poles to cleavage. 2, 11, 20, 34% per 1% area, 22 points.
(c) Domain 1: Bedding-cleavage intersection lineations. 3, 9, 15% per 1% area, 17 points.
(d) Domain 2: Poles to bedding. 2, 5, 12% per 1% area, 29 points.
(e) Domain 2: Points represent poles to cleavage.
(f) Domain 3: Poles to bedding. 3, 9% per 1% area, 16 points.
(g) Domain 4: Poles to bedding. 1, 3, 8, 10, 12.5% per 1% area, 44 points.
(h) Domain 4: Poles to cleavage. 3, 12.5, 22.5% per 1% area, 20 points.
(i) North of domains 2 and 3: Poles to bedding. 0.5, 3, 6, 9% per 1% area, 96 points.

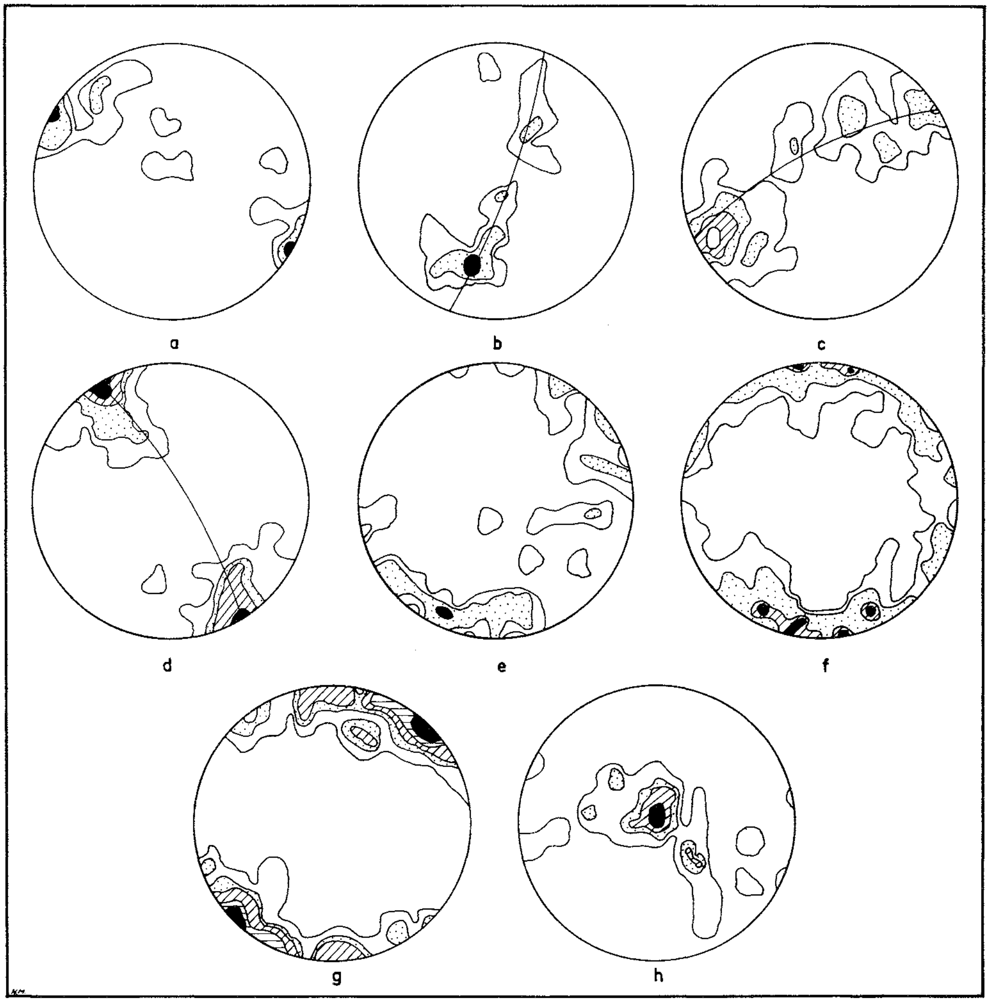

FIG. 4. - Contoured equal area projection. Each point is representative of readings from a sequence of beds.

(a) Bedding-cleavage intersections, domain 5: 3, 8, 19% per 1% area, 18 points.
(b) Bedding poles from lower Henty River: 2, 7, 15% per 1% area, 23 points.
(c) Bedding poles from domain 6: 0.5, 3, 8, 14% per 1% area, 90 points.
(d) Bedding-cleavage intersection from domain 6: 1, 4, 9% per 1% area, 38 points.
(f) Eastern edge of area, bedding poles: 0.5, 2, 6, 7% per 1% area, 111 points.
(g) Eastern edge of area, cleavage poles: 1, 2, 3, 8, 10% per 1% area, 73 points.
(h) Eastern edge of area, bedding-cleavage intersection lineations: 2, 5, 8, 14% per 1% area, 32 points.

bedding surfaces. Figure 4a shows the form of one of these warps as sketched in the field. Cleavage cross-cuts the structure. Following the major folding which caused the cleavage in the area east of the fault in the Bell Shale correlate, folding occurred which affected both bedding and cleavage (fig. 4b). This is a measured plan view of the folds. The plunge of these folds is steep and the axial surfaces strike NNE and dip steeply. Other folds which fold the cleavage occur in the Florence Quartzite correlate. In these folds the axial surface dips steeply and the plunge is WNW. A crenulation cleavage parallel to this direction was noted in the Bell Shale correlate adjacent to this area of folding. Figures 4c and 4d show the form of the shallowly plunging folds.

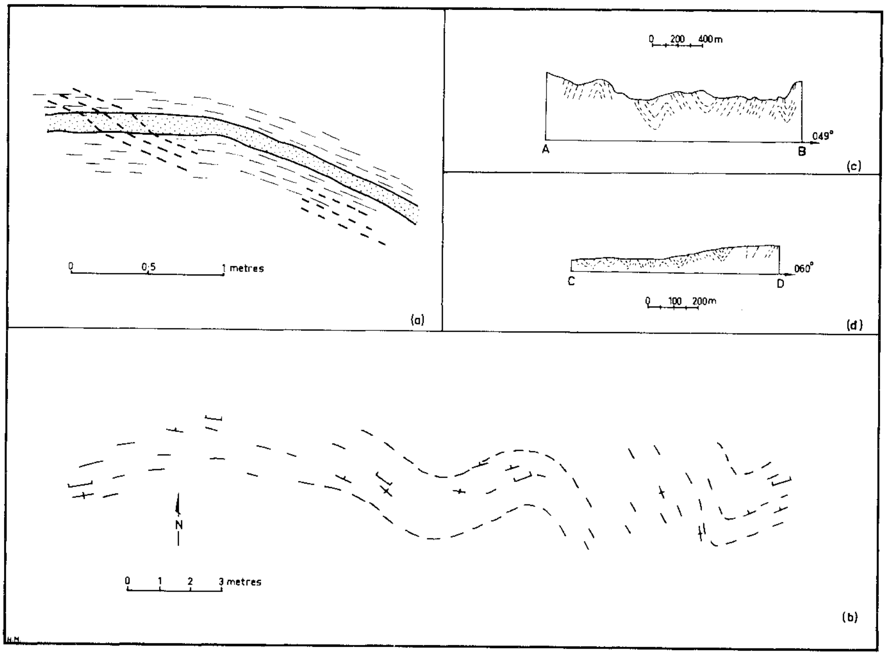

FIG. 5. - (a) Pre-cleavage fold from domain 6.
(b) Post cleavage folding - eastern edge of map.
(c) (d) Structural profiles of F2 folds. Location of sections A-B and C-D shown in fig. 1.

Microscopic Structures

Thin section examination of the morphology of the cleavage discussed above from folds on the two different trends showed that in general both sets of folds produced a primary cleavage. Pre-existing tectonic surfaces had not formed prior to the folding on either trend. The exception occurs in the regions SE from the fault in the Bell Shale correlate where the fold set trending WNW appears to have developed a crenulation cleavage. Crenulation cleavage does occur through the region but insufficient data are available to analyse its regional significance and it has been omitted from the previous descriptions.

Discussion

The best proposal to explain the data presented is that two phases of folding are developed in the Bell Shale correlate, both of which produced a primary tectonic cleavage but in separate domains. Where folding of the cleavage is observed on the eastern edge of the area a crenulation cleavage has formed which is parallel to the more westerly trending cleavage to the west of the area. The only alternative hypothesis is that the fold axial trend swings southward away from the northern area. The evidence of crenulation cleavage, folds folding the cleavage and the suggestion of a cross-fold trend in domain 4 indicates the first hypothesis. In addition the existence of two fold trends agrees with the regional fold pattern north of the basin (Blissett 1962) and the general pattern agrees well with other regions of northern Tasmania (Williams *et al.*, in press).

Solomon (1962) named the major structure being discussed the Dubbil-Barril synclinorium and considered there to be only one phase present, a phase related to the West Coast Range Anticlinorium (*op. cit.*). He also points out that probably superimposed on this trend in the Queenstown area is a W-NNW fold trend related to the Linda Fault Zone and other E-W fractures.

The fold set observed in the south of the region plunges between 30° and 90° to between 330° and 340°. The set in the west and north of the region plunges from $+6^{\circ}$ to -15° at between 280° and 330°. The two sets have not been observed to interfere in the areas which have been mapped, and consequently the age relationship between them is unclear. The folded cleavage (fig. 4b) suggests that at least locally the more northerly trend was later than the more westerly trend. However, this fold occurs in the fault-disturbed zone and has suffered body rotation during faulting; this effect can also be seen in the folds from domain 7 (see above). In the north western section of the basin there is clear evidence that the more westerly folds produced the primary cleavage and in the south of the area evidence that the northerly folds produced the primary cleavage.

It is suggested that the NW trending folds belong to the earlier phase, folding the underlying Cambrian to Siluro-Devonian rocks. These folds died out in the large area of incompetent rocks, movement being taken up by readjustment of the basin sediments by bedding plane slip and possibly faulting.

The Bell Shale correlate, which is Early Devonian in age (Banks in Spry and Banks 1962) is the uppermost unit of the Eldon Group and the Tabberabberan Orogeny occurred before the Late Middle Devonian (Balme 1960; Williams *et al.*, in press). The rocks must therefore have been close to the surface, as no evidence exists for rapid subsidence during deposition. In this situation the fold style will, in general, be more open, allowing the suggested readjustments. The plunge of these folds was, as a consequence, determined by basin irregularities and in particular the thinning of the Florence Sandstone correlate to the east.

The southern margin of the basin at this stage formed a true structural basin. The second major phase was on a WNW trend which formed a second synclinal system causing the upturning of the southern edge of the basin to form vertically plunging folds.

The intensity of the second deformation was variable, the locus of strain being along the Firewood Siding Fault zone. This zone is a continuation of major Tabberabberan structures from the Precambrian rocks at Raglan Range (Gee 1963) and through the Queenstown area. These structures are normally considered the result of the second Tabberabberan deformation phase found elsewhere in Tasmania (Williams *et al.*, in press).

Blissett (1962) has mapped structures (e.g. "Little Henty Syncline") around Zeehan and N of the Firewood Siding Fault which comprise folds trending NW and folds trending EW or ESE. Blissett (*op. cit.*) assumed that this pattern was produced by a single folding event and that the major compression was NE-SW producing NW trending folds which were warped towards the E by compression from the W.

From the mapping at Strahan the importance of the WNW trend is emphasized as this is the major and first cleavage producing phase close to the Firewood Siding Fault. Major transport perpendicular to this direction is thus implied. From the work of Gee (1963) and that of one of the authors (P. Williams) on Mt. McCall this event is known to be the major phase of Tabberabberan movement affecting the Tyennan nucleus, and is a major phase affecting Palaeozoic rocks in NW Tasmania (Williams *et al.*, in press). In addition it gives a clear explanation for the outcrop pattern of the Eldon Group on the Zeehan Map Sheet (Blissett 1962). The authors do not see a ready explanation of this structure in a single fold phase.

The overall Tabberabberan structures can be understood in terms of a first compressional phase in a SW-NE direction followed by compression from a SSW-NNE direction. This produced refolded folds in the Zeehan area. As the locus of strain was along the Firewood Siding Fault the deformation reduced in intensity both N and S from that line, explaining the lack of interference of structure in the southern part of the area.

Thus the structure of the Bell Shale in the Strahan Quadrangle gives a much clearer insight into Tabberabberan structures in western Tasmania. The multiplicity of Tabberabberan trends and the effects of major faults on the loci of strain during folding is an important consideration in understanding Tabberabberan structure and consequently, pre-Tabberabberan structure.

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