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STRUCTURAL SEQUENCE IN THE METAMORPHOSED PRECAMBRIAN ROCKS OF THE FRANKLAND AND WILMOT RANGES, SOUTHWESTERN TASMANIA.

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(with one table, four text-figures, eight plates)

ABSTRACT

Four groups of deformational events are recognised in the low grade Precambrian quartzite and phyllite of the Frankland and Wilmot Ranges. The rocks generally show the presence of a penetrative D_1 foliation with associated folding. D_3 folds are the most pronounced structures occurring on all scales in all lithologies and control the present attitude of the earliest foliation. Steeply inclined foliations are the rule. D_2 structures are variable; some inter-foliated quartzite/phyllite zones display strong F_2 and S_2 (a crenulation foliation) whereas these may be totally lacking in the same material, particularly to the south. The few mesoscopic F_2 folds in zones of massive quartzite layers involve localised rotation of S_1. D_4 structures only occur on a minor scale with little cleavage development. All D_{1-4} structures have been rotated by a major wrench system thought to have operated during the Cambrian which accounts for the swing of the main quartzite ridges from N/S to E/W.

INTRODUCTION

This report is by way of a summary of progress of a project which is aimed at studying the whole of the Frankland and Wilmot Ranges (fig. 1). The general purpose of the work is to serve as a link between studies of the central and southern portions of the Precambrian Tyennan Nucleus. To date, the Frankland Range, between Coronation Peak and Cleft Peak, and part of the excellent outcrop in the Hydro Electric Commission's workings at the Gordon River damsite have been mapped in detail. Extension of Powell's (1969) short study has revealed a more complex situation than previously realised and this has implication for recently proposed structural correlations. Also contrasting structural sequences within the metamorphosed Precambrian have proved of interest.

The deformational events have been ordered into groups in which minor structures have been related by their similarity, position with respect to other structures, and orientation. Within the first deformation event (D_1), which may involve several types of strain, the foliation generated is labelled S_1, the folds produced F_1 and the lineation L_1 (with qualification as to type).

Because of the marked structural contrasts between various lithological associations within the area it has been necessary to consider structures of each event in two groups. The main ridges, which form prominent topographic features, are virtually entirely composed of quartzite with very little phyllitic material. This has been termed assemblage A. Assemblage B is characterised by zones where phyllite becomes an important rock type, with consequent effect on deformation styles. Such a classification cannot be universally applied and is established only for the convenience of description.

As yet no pelitic rocks coarser than phyllite have been found. Metamorphic conditions of Lower Greenschist Facies grade are thought to have applied during the im-

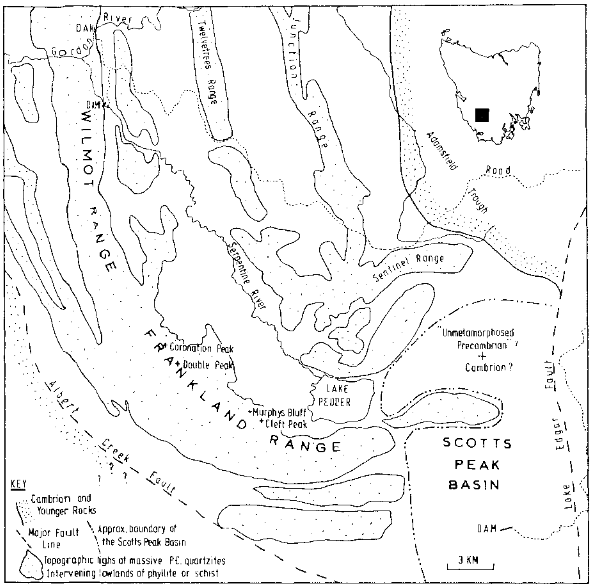

FIG. 1. - General location map of the region. In part after Corbett (1970).

portant deformation events of the area examined to date

D_1 STRUCTURES

Microscopically the S_1 surface in the quartzite layers is commonly a development of a mortar texture with fine, recrystallised quartz grains surrounding large, strained grains. The finer grains show varying degrees of dimensional preferred orientation to define S_1. A small proportion of mica is invariably present in the form of ribbons anastomosing around the large quartz grains generally aligned in the S_1 direction. The nature of the earliest surface in these rocks indicates conditions of low temperature and high stress operating during D_1.

In the field, S_1 can be a strong lenticular platyness parallel to a compositional layering though some bands of quartzite display no obvious "bedding foliation" in hand specimen. The differing expression of S_1 can be related to the microscopic texture; the extreme development is a granoblastic texture with somewhat elongate quartz grains with very few remnant large quartz grains while some examples have only a weakly developed mortar texture with widely spaced zones of granulation or have an apparently near original quartz grain fabric with little visible effect of deformation. The nature of the lattice preferred orientations associated with the various quartzite textures has yet to be investigated.

Minor folds (F_1) of a compositional surface (S_o) with S_1 as the axial plane foliation are well represented throughout the quartzite assemblage A. The majority of these folds are very tight to isoclinal with long limbs which give no indication of vergence (sense of climbing or closure) (see fig. 2, c and d). Some large mesoscopic folds with dihedral angles of about 35^o and considerable layer thickening in narrow hinge regions may belong to D_1 as a further style variant (plate A). Close examination however, of the known examples has unfortunately been restricted because of the nature of their outcrop.

The overall nature and geometry of the D_1 folds varies in a pattern which can be roughly correlated with size of the folded compositional layers (cf. upper and lower parts of fig. 2a). Thickly banded units have rounded hinge zones and geometries approximating those of parallel folds (IB) flattened less than 30% (Ramsay 1967). Thinly layered units show considerable thickness variations in the hinge zones of the D_1 folds indicating strong flattening. Boudinage of the layers is associated with these latter situations.

The orientation of the D_1 folds varies considerably due to rotation during D_2 and D_3, and a regional warping which produced the right angle change in trend of the massive quartzite ridges (see fig. 1). The Wilmot Range is oriented north/south whilst the eastern termination of the contiguous Frankland Range trends east/west. The gently plunging hinge lines show a similar change in direction being north/south in the north and east/west in the south. F_1 axial surfaces vary from recumbent to vertical as a result of near coaxial refolding.

S_1 in the phyllite layers is often obscured by later foliations and may only be preserved in the quartz rich hinge zones of crenulations in S_1. The microscopic expression of this foliation is a strong dimensional preferred orientation of quartz grains and mica flakes. The increase in the percentage of mica has probably guided the growth direction of the quartz grains. Few D_1 folds have been recorded in the phyllitic material and, where present, tend to be difficult to decipher due to strong over-printing by later events (see fig. 2e, f and plate B).

No major D_1 folds have been found and the effects of this obviously important deformation event, on the scale of the map, have yet to be determined. This might be achieved by the analysis of F_1 vergence but this has proved impossible to apply to date.

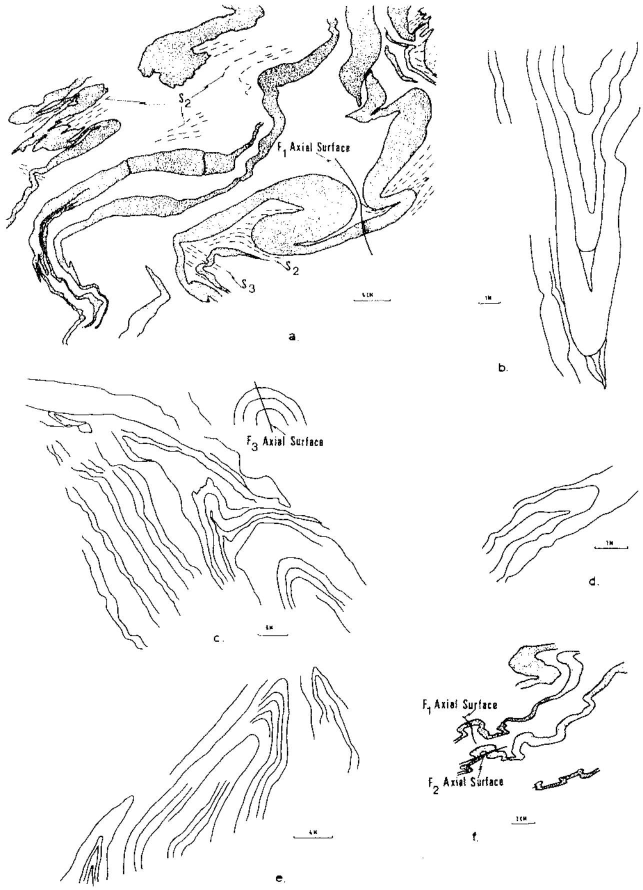

FIG. 2. - D_1 fold profiles from assemblage A material (b, c, d and e) and F_1/F_2 interference patterns in assemblage B (a and f from the Gordon Dam Quarry). Quartzite layers in stipple for a and f. b and e from the Serpentine Dam site and c and d from 500 m south-east of Double Peak.
All traced from photographs.

The form surface to the D_1 folds (S_0) has yet to be proved to be original bedding. Possible ripple mark structures have been noted and in many localities a compositional cross lamination occurs. Both may be tectonically produced and it is felt that most of the cross-bedding has such an origin. Many remnant fold closures are found between parallel compositional layers (plate C), and often adjacent layers give opposite senses of younging, if the cross-bedded structures are regarded as primary. They are also associated with a strong foliation (S_1) parallel to compositional layering (plate D). This is not to say that overall the presence of some original cross-bedding is totally discounted.

D_2 STRUCTURES

Within assemblage A the D_2 folds are somewhat rare but can be identified by the fact that they fold S_1 and are transected by S_3. Their characteristic feature is that S_1 has undergone rotation in discrete zones thus showing similarities with kink bands. The rotated limbs show layer thickness variations which can be related to the angle of external rotation and the angle between the kink plane and the external foliation

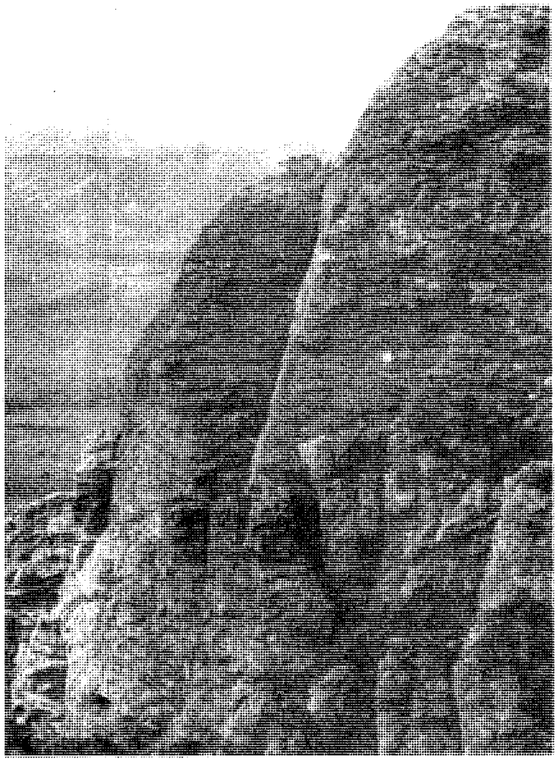

PLATE A. - Piles of recumbent folds which may be F_1 or a chevron variety of F_2. Murphy's Bluff.

(Anderson 1964). The illustrations depicting these folds show rotation of the short limb of the fold system arrested at various stages with resulting style differences (fig. 3 and plate E). Also all examples are negative according to the classification of Dewey (1969). These folds are considered to be essentially large scale examples of kink bands though no suggestion will be made at present as to their mode of origin.

Where the kink planes of D_2 folds, showing the same sense of rotation, converge (fig. 3f), or where kink planes are closely spaced (fig. 3g), near isoclinal folds are produced. These folds seen in isolated exposures may be easily mistaken for D_1 folds without detailed analysis of associated foliation and form surface.

As yet no conjugates have been found though zones of F_2 development are at scattered localities and rotation by F_3 makes it impossible to establish relative orientations.

One D_2 fold showed an associated weak mesoscopic foliation in the quartzite layers, but usually there is no obvious generated surface except for a well-spaced crenulation cleavage in thin micaceous quartzite horizons. This system of folds is to be subjected to petrofabric analysis in an attempt to elucidate their nature.

Most of the excellent road exposures in the Gordon Dam Site area are located in assemblage B material, where phyllite is an important rock type. Here D_2 folds are quite common. Again they are very tight to isoclinal showing signs of quite strong flattening (fig. 4). Rigorous geometric analysis of many of these folds is limited because the layers folded during D_2 had considerable thickness variation due to D_1 (see plate B). Such variations, to a certain extent, controlled the development of minor D_2 folds as the thinner parts of a layer were folded in preference to the thicker zones (cf. Powell 1969, p. 51 with reference to tectonic soft sediment deformation).

The S_2 surface in the phyllite layers of this area is a very well developed crenulation cleavage in which strong differentiation of quartz and micas during the crenulation process has led to a variably developed compositional layering parallel to S_2 (Rickard 1961) (see plate F). On the F_2 limbs this layering is virtually parallel to the folded quartzite bands. At F_2 hinges, S_2 and the associated metamorphic layering pass into the quartzite bands at a high angle.

D_2 fold hinges are fairly close to those of F_1 in orientation and similarly affected later deformations. F_2 axial surfaces tend to be approximately parallel to the gross lithological contacts between phyllite and quartzite layers and were rotated during D_3.

Despite the locally intense nature of S_2 at the northern end of the Wilmot Range, its development is quite variable, particularly to the south. In small pockets of assemblage B within the massive quartzite horizons it is almost entirely absent. An 800 m wide, steeply dipping zone of assemblage B material outcrops to the SW of Murphys Bluff, in which few D_2 folds are found and where F_3 is the dominant structure. Samples from within this zone either have no trace of S_2 (regional sense) or have a poor to moderately well defined S_2 surface variably overprinted by S_3 and S_4. Hence the second cleavage noted in a specimen may be a D_3 structure. The degree of quartz/mica segregation or transposition of S_1, associated with S_2, appears to be less severe than noted in the north of the area.

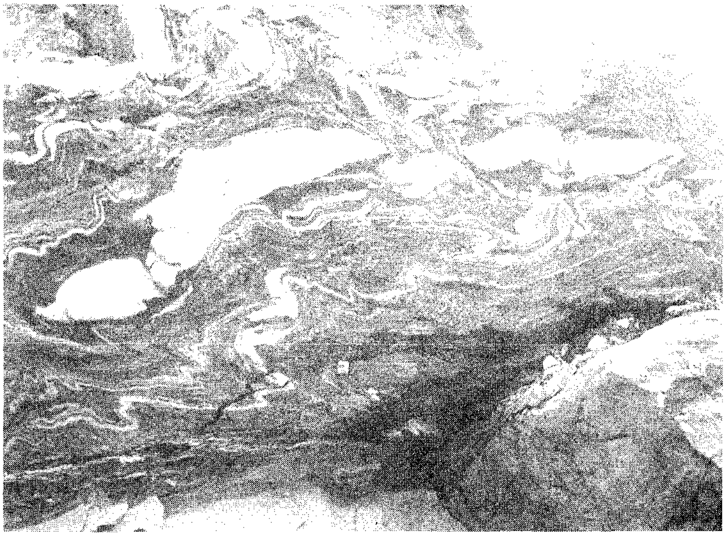

PLATE B. - $F_1/F_2/F_3$ interference. F_3 axial surface is inclined at about 35^{o} from left to right. Isoclinal F_2 fold a single F_1 on the right hand side. Gordon Dam quarry.

PLATE C. - Remnant D_1 fold closure between compositional layering. Serpentine Dam site.

The intensity of S_2 would seem to be more likely related to variation in development rather than complete transposition of S_1 during D_2 or obliteration of S_2 by S_3 and S_4, though this latter situation does create difficulties during microscopic examination.

D_3 STRUCTURES

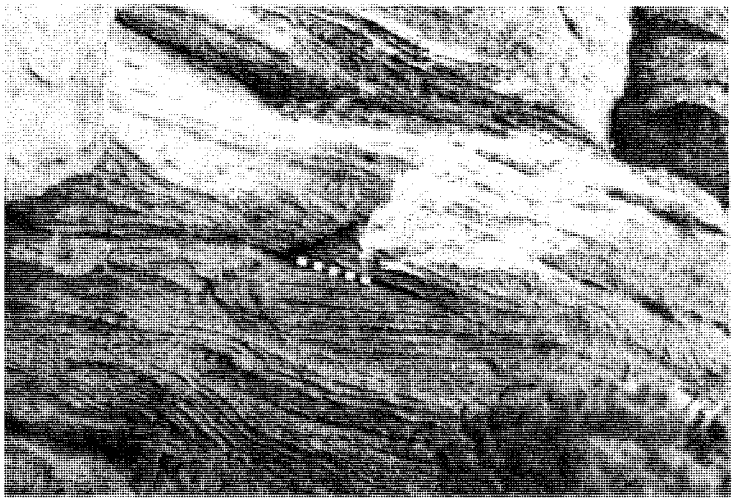

PLATE D. - Pseudo cross bedding in quartzite. Coronation Peak.

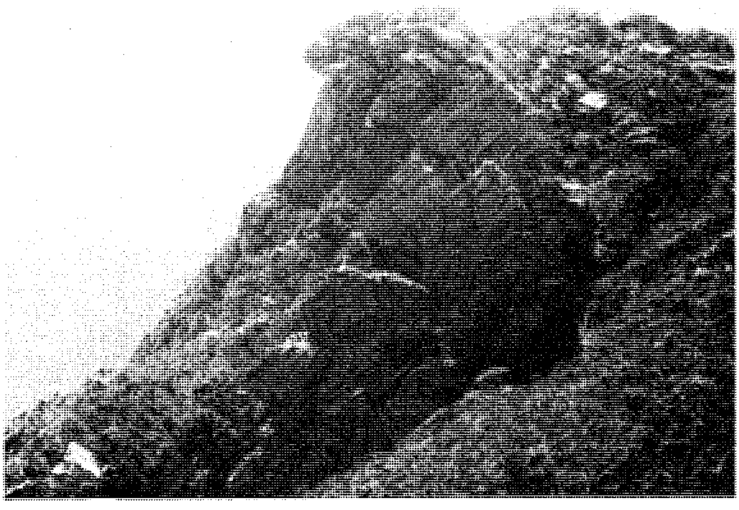

PLATE E. - Kink style F_2 in zones of massive quartzite layers. 2 km S.E. of Double Peak.

The third deformation event can be considered the dominant event in this region for several reasons. D_3 folds control the present attitude of the important S_1 surface and also can be shown to exist on the macroscopic scale by the analysis of vergence of minor, congruent folds. The S_3 surface is mesoscopically visible in almost every outcrop as a prominent plane of weakness though often widely spaced (see plate G). Along the crests of the quartzite ridges exposure is virtually continuous, thus changes in style orientation, etc. of folds within a particular event can be related to the many influencing factors with some success. Correlation of the various structures is also greatly aided by the constancy of certain attributes of D_3 structures, particularly the orientation of S_3 which in many respects can be used as reference point.

Folds of the third generation have, for the most part, upright or steeply inclined axial surfaces which strike N/S at the Gordon and gradually change orientation until they lie E/W at the southern end of the Frankland Range. The axial surfaces form convergent fans with respect to the major "antiformoria" whilst in assemblage B local inhomogeneity can produce axial surface dips of less than 40^{o}. F_3 hinges generally plunge at around 20^{o} but certain zones show considerable variation in the amount of plunge (see Maclean and Bowen 1971, p. 103). Individual hinges have an irregular wave form while lying in the same axial surface. Some hinge line variability may be due to interference with other phases but the exact cause is not yet resolved.

Profiles of D_3 folds vary from open to tight and are rarely isoclinal in thin pockets of assemblage B within the massive quartzite horizons. Parallel to slightly flattened parallel folds are found in quartzite layers and where interfoliated phyllite layers occur they show characteristics of class 3 folds (Ramsay 1967). Thus folds are propagated through multilayers of quartzite and phyllite in the manner reported by Powell (1969, p. 48). Typical F_3 profiles are shown in fig. 3f of Powell (1969) and fig. 6(a) of Maclean and Bowen (1971) and plate H of this paper.

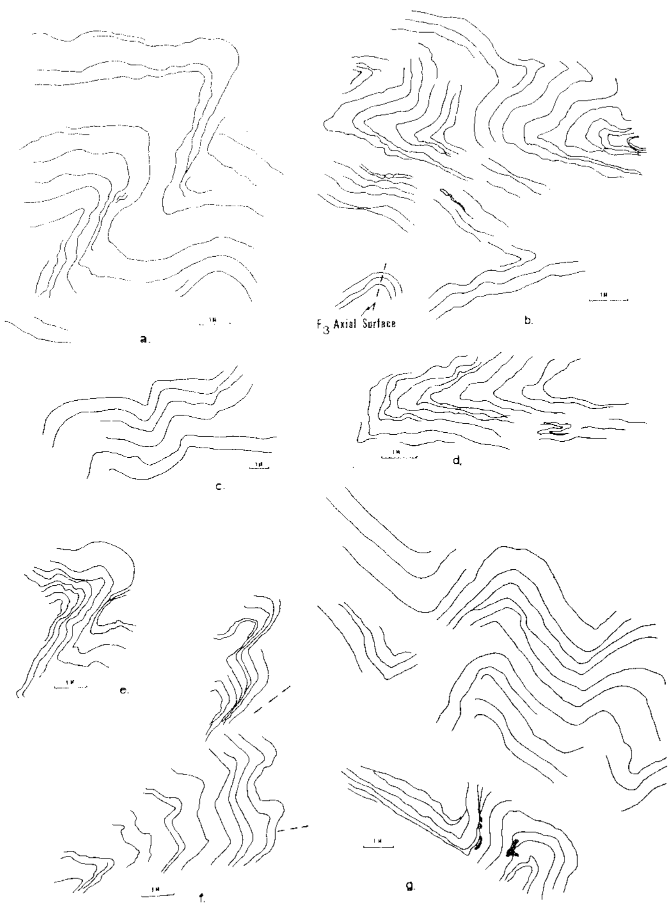

FIG. 3. - Variation of F_2 style in assemblage A. All found within a zone between 1 and 3 km southeast of Double Peak and are traced from photographs.

Within the quartz-ose phyllite layers the spaced S_3 cleavage has all the attributes of the Ausweichungsclivage (transposition foliation) figured by Whitten (1966, p. 182). In lithologies ranging from micaceous quartzite to phyllite, S_3 is a crenulation cleavage with a spacing approximately related to rock type. The spacing may be 1-2 cm in the micaceous quartzite but less than 1 mm in the phyllite. Within phyllite of assemblage B S_3 tends to show its greatest intensity, in a particular horizon, at an F_3 core and may be absent on the limbs (see fig. 4G). S_3 is rarely associated with marked new mineral growth, though a very crude layering can develop parallel to this surface in the phyllite.

On weathered faces of the massive quartzite layers S_3 is distinguished as a distinct grain at an angle to S_1. The S_1/S_3 intersection produces a lineation nearly parallel to the F_3 hinges and is a pronounced feature of the quartzite. The microscopic expression of S_3 in quartzite varies from a strong dimensional preferred orientation of quartz grains to a variably developed dimensional preferred orientation of some quartz grains in an S_1 mortar texture. Something of the nature of the latter case appears most common. Many large outcrops of quartzite show S_3 but have few or no D_3 folds and it would seem that the D_1 event, to a certain extent, welded the rocks so that they tended, later, to deform in a more isotropic manner (Fyson 1971 after Ramberg).

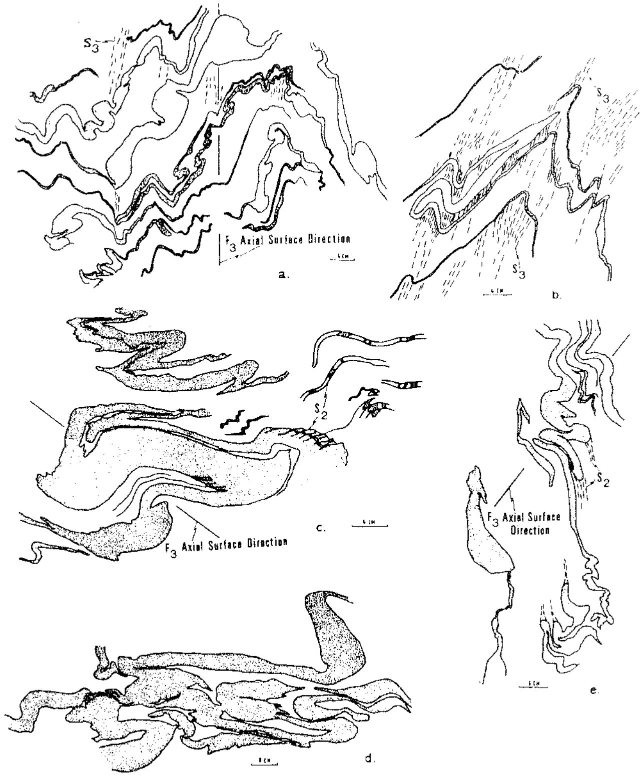

FIG. 4. - F_2 and F_2/F_3 interference in assemblage B material of the Gordon and Serpentine dam area. The density of S_3 in a and b indicates the variable development of this surface. d is largely the result of D_2 showing considerable thickening of quartzite layers; often metamorphic differentiation blurs the outline of these layers.

D_4 STRUCTURES

D_4 folds are very much restricted to the phyllite, thin quartzite layers of assemblage B, and some micaceous quartzite horizons. Many outcrops of these rock types on the main quartzite ridges show D_4 folds though no major structures of this phase are thought to exist. Wave lengths vary from a few cm to a few metres with the common form surface being S_3. F_4 hinges generally diverge by 20^o from the F_3 hinges and their axial surfaces dip at moderate angles (40-45^o) to the east in the Gordon Dam area. They follow as well the rotation of the main ridges and on the Frankland Range dip to the NE or NNE. A weak S_4 surface is occasionally produced axial planar to F_4.

The small scale G_3 folds of Powell (1969) are probably the equivalent of these folds on the bases of size, orientation and general nature.

KINK BANDS

Small scale kink bands occur in virtually all lithologies to differing degrees. The active surface varies from a platy S_1 to strong S_2, S_3 or even S_4 crenulation surfaces. Conjugates do occur and it is possible that several kink phases exist but more measurements are required before this can be demonstrated satisfactorily.

EVIDENCE FOR THE AGE OF D_{1-4}

Corbett (1970 p. 12, p. 17) has considered that the Adamsfield Trough was formed by the action of sinistral shearing and separation between the Precambrian Tyennan Geanticline and the Jubilee Block during the Cambrian. The marked swing of the quartzite ridges from N/S on the Wilmot Range to E/W on the Frankland Ranges has been attributed to this event. All the D_1 to D_4 structures show a gradual change in orientation related to their position on the ridge. The most feasible explanation is that these structures were rotated together by the Cambrian shear system. Such a regular change in direction of say S_3 or S_4 would be difficult to explain in terms of superposition with the ridges in their present orientation (i.e. post-Cambrian). With more data on the kink bands it may be possible to show their position with respect to this regional rotation.

D_{1-4} may well have formed as a climactic event in a very brief time span (cf. Dewey and Pankhurst 1970) though the intervals between the various events could be considerable.

CORRELATIONS AND CONCLUSIONS.

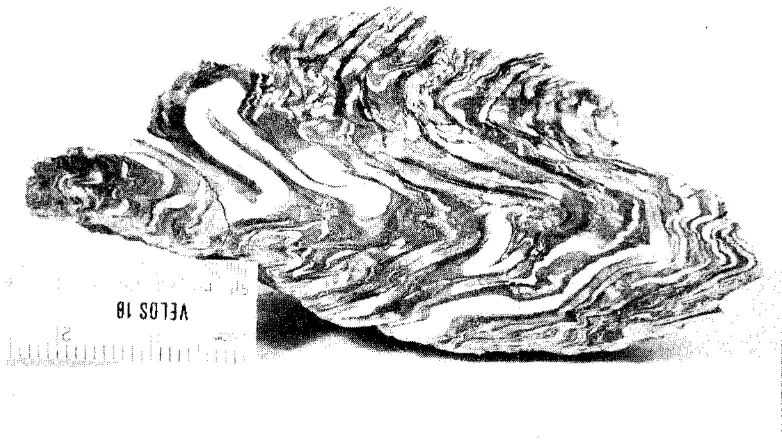

PLATE F. - S_2 crenulation foliation with differentiation of quartz and micas. S_2 folded during D_3. Gordon Dam quarry.

The present study indicates the presence of two important deformation events before Powell's (1969) G_2 phase. It is apparent that folds belonging to his G_1 can be separated into two groups (present paper D_1 and D_2) on the bases of differences in associated foliation, overprinting etc. Maclean and Bowen (1971, fig. 4) working in the Davey River area show examples of their F_1/F_2 phases commenting on the similarity with specimens collected from the Gordon River damsite. On the bases of orientation, associated foliation and general style, the F_2 of Maclean and Bowen (1971), G_2 of Powell (1969) and D_3 of this paper are regarded as equivalent events (see table 1). Maclean and Bowen (1971, p. 101) refer to the apparent complexity of their earliest deformation event and this may be explained, in part, by a variably developed deformation (equivalent to D_2 of this paper) between their F_1 + F_2.

TABLE 1

Frenchmans Cap Spry 1963	Port Davey Spry & Baker 1965	Frankland/ Wilmot Ranges this paper	Gordon R.Damsite Powell 1969	Davey River Bowen & Maclean 1971
F_1	F_1	D_1		F_1 in part equivalent to D_2, this paper
			G_1	
F_2	F_2	D_2		
F_3 (several events)	F_3 (several events)	D_3	G_2	F_2
		Upright to steeply inclined, gently plunging folds, trending N/S where unaffected by later events.		
		D_4	G_3	F_3(?)

Until more detailed structural field work is carried out in south-western Tasmania, all correlations of deformation events are highly speculative. One particularly difficult problem is the nature of the D_2 event which appears to become weaker in the

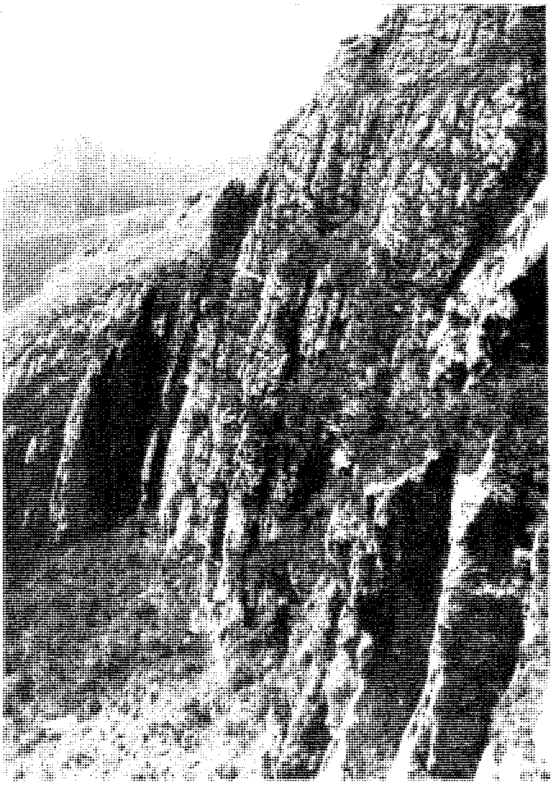

PLATE G. - Major planes of weakness along S_3 (vertical) in the quartzite. S_1 is gently inclined to the right. Between Double Peak and Coronation Peak.

Frankland Range and Davey River area but is associated with folds and a strongly differentiated crenulation cleavage at Port Davey (Spry and Baker 1965).

At the present stage of investigation it is considered probable that $F_1 + F_2$ of Spry (1963) can be equated with $D_1 + D_2$ of this paper and that the second phases of Maclean and Bowen and Powell are best related to part of Spry's F_3.

It appears that D_3 is a much more important event in the Strathgordon - Davey River region than around the higher grade metamorphic zones in the Tyennan Geanticline such as Frenchmans Cap and the Forth Nucleus. It is tempting to suggest that this represents a transition from an infrastructural regime to that more closely related to a suprastructural sequence in the manner of Fyson (1971). However, from the description of Spry and Baker (1965) at Port Davey it would seem that their schist-quartzite amphibolite assemblage shows little evidence for D_3 structures whereas within four miles the quartzite-phyllite assemblage has abundant D_3 folds. If these areas are not separated by major faults then the differences might best be explained in terms of residual temperate distributions and varying response of differing units to the same stresses, rather than by the mechanism of Fyson.

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PLATE H. - Typical F_3 in assemblage B near the Gordon Dam.

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