https://doi.org/10.26749/rstpp.110.25

Papers and Proceedings of the Royal Society of Tasmania, Volume 110, 1976.

(ms. received 20.4.1975)

STRUCTURE AND METAMORPHISM OF THE Mc PARTLAN PASS - SENTINELS AREA

by S.J. Williams
Geological Survey of Western Australia, formerly
Geology Department, University of Tasmania

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

ABSTRACT

Low metamorphic grade Precambrian quartzites and phyllites of the Mc. Partlan Pass - Sentinels area have been subjected to polyphase deformation and polyphase metamorphism. The earliest recognizable folds are tight to isoclinal and they have a penetrative foliation, with syntectonic mineral growth parallel to their axial surface. F_2 folds, which are also tight to isoclinal and nearly coplanar with F_1, have an associated S_2 crenulation cleavage, with syntectonic mineral growth. The dominant folds in this area are of the third generation and they control the orientation of earlier structures. F_3 are tight to close, upright folds in phyllites, and are of more open style in quartzites. They have a moderate to steep north-westerly plunge. The S_3 cleavage may be a crenulation cleavage, a fracture cleavage, or a more isotropic foliation. D_4 structures occur sporadically throughout the area. Events D_1 to D_4 are of probable Precambrian age. The latest structures include two distinct sets of kink bands, which may have been produced during a Palaeozoic orogeny.

INTRODUCTION

This report is a summary of a B.Sc. Honours thesis submitted to the Geology Department, University of Tasmania in 1973. The aim of this work was to establish a structural and metamorphic sequence within complexly folded quartzites and phyllites in the Mc. Partlan Pass - Sentinels area of south-western Tasmania. The area under consideration is bounded by: longitude 146°09'E and 146°15'E and latitude 42°50'S and 42°54'S. Convenient access is provided by the Gordon River Road.

The area is mountainous with steep, sharp ridges separated by V-shaped valleys, or wide, flat, marshes. The morphology is directly related to the susceptibility of the underlying rocks to weathering and erosion. Topographic highs are formed in quartzites and topographic lows are in phyllite and micaceous quartzite. Poor outcrop of the latter rock types largely restricts their study to road cuttings.

The notation used herein to describe structures, or events and their temporal relationship is: D_n refers to deformation event n; F_n indicates folds associated with event D_n; and S_n and L_n refer, respectively, to any surface, or lineation, related to D_n. S_0 denotes the original bedding surface.

ROCK TYPES

The Precambrian metamorphic assemblage has been broadly divided into four major rock types: quartzites, micaceous quartzites: phyllites and a metaconglomerate unit. Two main types of quartzites can be distinguished. The first is a well-layered coarse-to medium-grained, saccharoidal orthoquartzite, which occurs in relatively thick units (approximately 500 metres) on the northern and western flanks of the Sentinels. The other is a flaggy, laminated variety which occurs in thinner units (maximum thickness about 30 metres) and crops out on the tops and flanks of the ridges north and south of Mc. Partlan Pass.

The micaceous quartzites are composed dominantly of quartz with varying amounts of muscovite (5%-30%) and locally chlorite as a minor component. They grade into purer quartzite at one extreme and into phyllite at the other extreme. The phyllites are mica rich, fine-to very fine-grained, grey to black,or light green rocks. They are extremely fissile. Some varieties are graphitic.

The metaconglomerate unit consist of a sequence of poorly-sorted metaconglomerates, micaceous quartzites and phyllites, which may contain pebbly bands and isolated pebbles. They occupy an area to the immediate north of the Sentinels (fig. 1) Their contact with the quartzite and micaceous quartzite of the Sentinels is not exposed, and is an uncomformity.

FIRST GENERATION STRUCTURES

F_1 Folds

The earliest recognizable structures in the area include folds with an earlier form surface, which in some cases can be shown to be bedding (S_0), from the presence of folded cross-bedding, and elsewhere is assumed to be S_0. Minor fold closures of the first generation are not commonly observed in the area as a whole. They are most easily recognized in purer quartzites, where overprinting by later structures is minimal. First folds are usually moderately to steeply inclined and the trend of their axial surface is dominantly controlled by major folds of the third generation. The plunge of F_1 hinges is highly variable, due to the combined effects of several phases of deformation. However, they commonly plunge moderate to steep SW.

F_1 folds are tight to isoclinal. Thicker psammitic layers have rounded hinge zones and are often flattened parallel in style. Thinner units have greater thickening in the hinge zone. In a folded sequence of layers with variable thickness there is usually a disharmonic relationship between the layers, with the thinner layers being more complexly folded. Where there is a considerable competence difference between folded layers, the limbs of the more competent layers are often attenuated, leading to boudinage.

Analysis of the vergence of minor F_1 has revealed only one major F_1 closure in the area, which occurs at the eastern end of the Sentinels. However, studies of this kind are hampered by the fact that minor F_1 folds are usually long-limbed isoclines, which give no indication of vergence, and other unrecognized major closures may be present.

The S_1 Foliation

S_1 is an axial surface foliation to folds of the first generation. It is well developed throughout the area, except in the thick quartzite units of the Sentinels, where it only occurs sporadically. The S_1 foliation is parallel to the boundaries between major lithological units and is probably parallel to the original bedding. However, S_1 is not a "bedding-foliation" as can be demonstrated by local survivals of folded and disrupted fragments of earlier layers (S_0). The near parallelism of S_1 and S_0 is due to the isoclinal nature of F_1 folds.

The expression of S_1 varies for different rock types. In flaggy laminated quartzites S_1 metamorphically differentiated layering consists of layers rich in quartz (1mm ro 4mm thick) separated by thin films of mica. In micaceous quartzites the differentiated mica layers are thicker (up to 4mm thick). Quartz-rich layers have a well developed mortar texture (plate 1a). In phyllites S_1 is a very penetrative slaty cleavage in which individual differentiated layers are not visible in hand specimen. The foliation is defined by the strong preferred alignment of tiny, interwoven mica flakes and fibres, with small, thin, elongate lenses and ribbons of quartz.

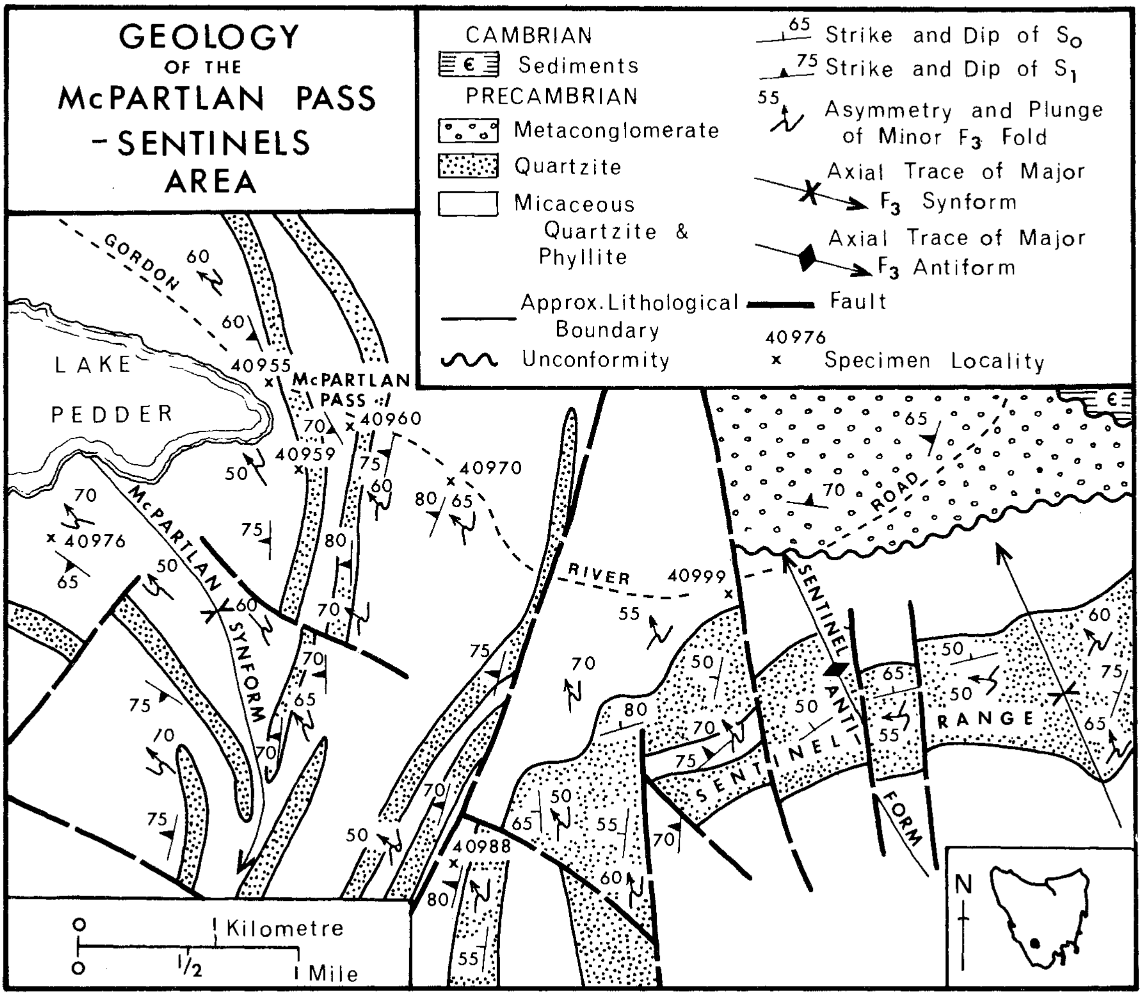

FIG. 1.- Rock types and structural elements of the McPartlan Pass - Sentinels area.

Progressive development of S_1 in quartzites

In the less deformed orthoquartzites of the Sentinels the S_1 surface, or later foliations, may be entirely absent. In this case the original sedimentary fabric, consisting of nearly spheroidal well-rounded, interpenetrating quartz grains with authigenic quartz overgrowths, is preserved intact. Deformation of this fabric during D_1 produced elongate ellipsoidal quartz grains the dimensional preferred orientation of which defines S_1. At this early stage of foliation development, the quartz grains are invariably undulose, they are commonly fractured and are occasionally disrupted. However, unlike the quartzites in which S_1 is intensely developed, these quartz grains show little or no granulation. Also, despite elongation of the grains, the authigenic quartz overgrowths are still preserved. Where S_1 is observable as a weak foliation microscopically, it is not usually visible in hand-specimen, even if a weak mica foliation is present. The slightly elongate quartz grains may be wrapped by a thin mica film, but at this stage the mica foliation is only coarsely anastomosing. As the quartz grains become more elongate the mica films become more finely anastomosing so that eventually they do define a good mesoscopic foliation.

In quartzites, of the same composition, from the ridges south of Mc. Partlan Pass the continuing sequence of progressively more intense S_1 development can be traced. The quartz grains become more elongate with strong undulosity and often deformation lamellae are present. They develop small "beards" of fibrous quartz, as well as granulated grain margins and a more disrupted appearance (plate 1). As S_1 becomes more intense in development the older grains are almost completely broken down and consist of isolated, highly deformed remnants set in matrix of finer-grained, granulated, re-crystallized quartz (plate 2). Thus the progressive development of S_1 in quartzites involves the conversion of a saccharoidal texture into a mortar texture.

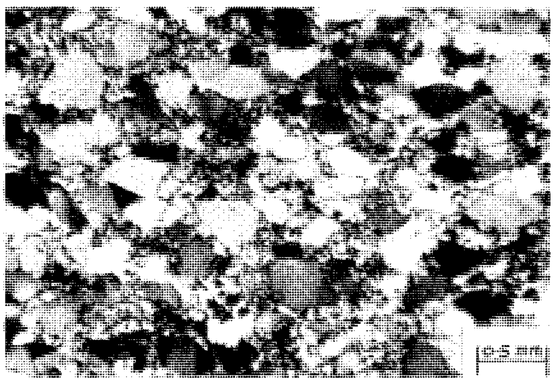

PLATE 1.- Quartzite with moderate S_1 development. The elongate quartz grains have sutured and granulated margins and fibrous quartz beards. They are surrounded by fine-grained, granulated quartz.

SECOND GENERATION STRUCTURES

Folds of the second generation are tight to isoclinal. They have many features in common with F_1 folds and are often difficult to distinguish from the latter in the field. Minor F_2 closures are somewhat sporadic in occurrence, but they are locally abundant around Mc.Partlan Pass. In phyllites F_2 closures are often obscured by an intense generated S_2 surface, and by over-printing of later cleavages, mainly S_3. Since their orientation depends on third and later generation folds, F_2 folds can be upright, steeply inclined, or reclined and their axial surfaces vary in strike from WNW to NNE with corresponding southerly to westerly dips. F_2 hinges are also variable in orientation, but they commonly plunge steeply to moderately WSW. Minor second folds do not usually give any sense of vergence, but where this is present they are, in all cases, asymmetric folds with an "S profile when viewed to the WSW down the axis. No major F_2 closures have been found in the area mapped.

In quartzites F_2 folds are distinguished from F_1 by microscopic analysis of the hinge area. Second folds have a penetrative, lenticular S_1 foliation as their form surface and this may be partially, or totally obliterated by a fairly penetrative, generated S_2 foliation, which cuts across S_1 at a high angle in the fold core. In phyllites and micaceous quartzites F_2 folds have a generated S_2 crenulation cleavage, which is at high angle to S_1 in the F_2 fold core (plate 3). Away from F_2 core zones, the S_2 surface can be observed as a spaced (1mm to 1cm) crenulation cleavage, at a low angle (15^o to 20^o) oblique to S_1. This produces a characteristic lenticular, diamond pattern in the rocks. However, in most phyllites, and in some micaceous quartzites, S_2 has been refracted into near alignment with S_1 and merely serves to accentuate the earlier penetrative foliation.

Lineations produced during D_2 include an L_2 crumple lineation, associated with S_2 crenulations, and an intersection lineation between S_1 and S_2. L_2 lineations are usually parallel to local F_2 hinges. These lineations are invarably cross-cut by a later, fine, crumple lineation (L_3). Micas which grow along the S_2 foliation surface are often crenulated or crinkled by the later S_3 cleavage (plate 3).

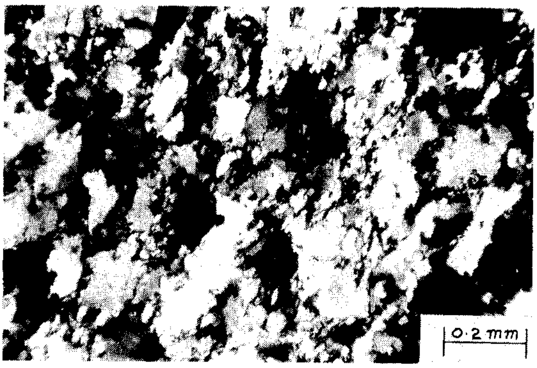

PLATE 2.- Strongly annealed quartz grains in a quartzite with an intense S_1 foliation developed.

THIRD GENERATION STRUCTURES

F_3 Folds

The third deformation event produced the dominant folds of this area. These folds exist on all scales, from microscopic crenulation up to macroscopic folds hundreds of metres in wavelength, and they control the orientation of the earlier surfaces, S_0, S_1 and S_2. Both F_1 and F_2 folds have been refolded by F_3 and the superposed interference patterns are Type 3 of Ramsay (1962).

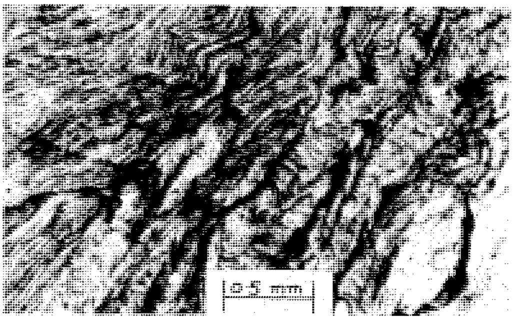

PLATE 3.- Differentiated S_2 crenulation cleavage from an F_2 fold core in phyllite. Twisted relics of S_1 exist between bands of S_2 mica. The latter have in turn been deformed by the development of S_3 crenulations.

Minor F_3 folds are generally steeply inclined to upright, with axial surfaces that strike NW and dip steeply SW. Their hinges usually plunge moderately to steeply WNW. The fold style is largely governed by lithology. In the well-laminated micaceous quartzites minor F_3 folds are often kink like, open to tight folds, with rounded, and sometimes angular, hinge zones. In the more competent, thickly-layered quartzites F_3 folds are usually open, parallel in style, except in areas of more intense deformation, such as the eastern end of the Sentinels, where they commonly have a flattened parallel profile. Where quartzite is inter-layered with less competent pelitic layers, the overall geometry is that of similar folds.

Folds of the types described above have been reported by Powell (1969) from the Gordon River Damsite, Bowen and Maclean (1971) from the Davey River and Boulter (1974) from the Frankland and Wilmot Ranges. Powell, Bowen and Maclean regard them as second generation structures, but Boulter and the present author regard them as third generation structures.

By analysis of the vergence of minor asymmetric F_3 folds (fig. 1) two major, third fold closures, each of which is composed of folds of various orders, have been determined. These are the Mc. Partlan Synform (statistical axis 77° to 260°) and the Sentinels Antiform (statistical axis 70° to 331°). Contoured stereoplots for each of these structures are given in figures 2a and 2b. Both major folds are more or less cylindrical and the difference in their statistical axes may be due to rotation about a major fault which separates them. Despite the overall near cylindrical nature of the major third folds, some minor F_3 folds show marked variability of plunge.

S_3 Cleavage

Associated with third folds is an axial surfaces cleavage, S_3, which varies in type according to: the rock type; the nature of the pre-existing surface; and the amount of local strain. In the quartzites of the Sentinels S_3 is often the first foliation to affect the original bedding, and its development varies from a weak, to fairly penetrative, lenticular foliation, or in some cases a distinct, spaced (1cm to 3cm) fracture.

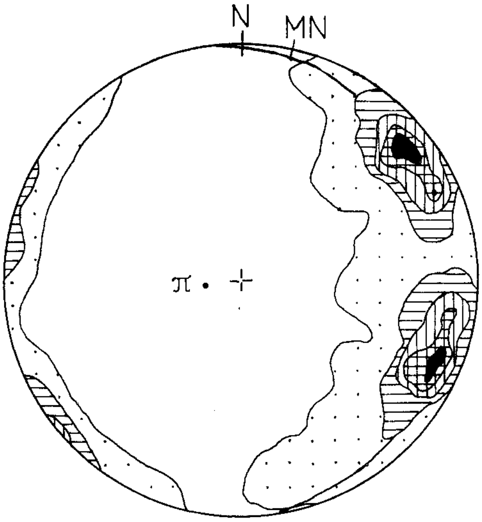

FIG. 2a - A contoured, equal-area, stereographic projection of the Mc. Partlan Synform using 215 poles to S_1. The contours are at 0 - 3 - 6 - 9 - 12%. The π axis is 77° to 260°.

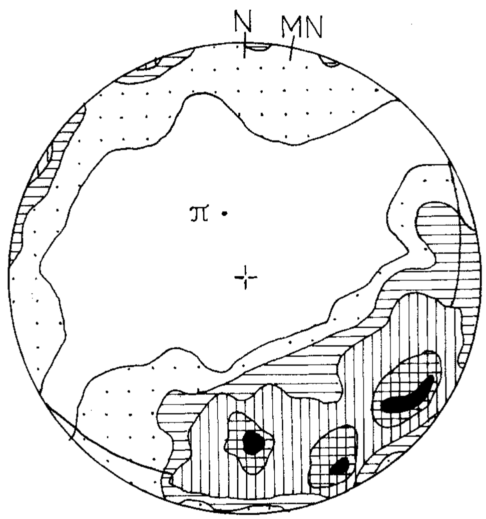

FIG. 2b.- A contoured, equal-area, stereographic projection of the Sentinels Antiform using 220 poles to S_1 and S_0. The contours are at 0 - 1 - 3 - 5 - 7%. The π axis is 77° to 331°.

In micaceous quartzites and phyllites, S_3 is a crenulation cleavage, with associated L_3 crumple lineations. The nature of the crenulation cleavage is somewhat variable. One type consists of a spaced fracture (up to 2cm) with, at one extreme, only slight crenulation of the microlithon to, at the other extreme, a tightly folded microlithon between the fractures. Alternatively, S_3 may be the axial surface to small, open to tight, crumple folds of wavelength 1mm to 2cm, which have no associated fracture. The most intense and most consistently developed S_3 occurs in phyllites. In the latter rocks differentiated crenulation cleavage (plate 4) is often developed and earlier foliations are difficult to recognize, due to their transposition into the S_3 direction.

LATER STRUCTURES

The S_3 cleavage has locally been folded by close F_4 minor folds with an associated weak crenulation cleavage of average orientation 296/68°N. F_4 folds are best developed in micaceous quartzite and phyllite on the SW limb of the Mc. Partlan Synform, but they occur sporadically in these rock types throughout the area. No F_4 folds have been observed in quartzites.

Later folds include F_5 kink bands, chevron kinks and conjugate kinks, and larger scale, open, concentric folds in more thickly layered rocks. The F_5 kinks have an average axial surface orientation of 250/70° SSE. A broad, open refold of the Mc. Partlan Synform has an axial surface with this orientation and is probably a major F_5 fold. Another, later, set of kink folds (F_6) has an average axial surface orientation of 008/60° E.

METAMORPHISM

The quartzite-phyllite assemblage of the Mc. Partlan Pass - Sentinels area is mineralogically relatively simple. In phyllites muscovite, a pale-green iron-rich variety, varies from 40% to 90% of the total rock. Chlorite is nearly always present, but is usually only a minor component ($\leqslant$ 10%). Some pyrite in minor to accessory amounts may alwo be present. The micaceous quartzites are composed of quartz (60% - 90%, muscovite (5% - 35%) and, in some cases, chlorite ($\leqslant$ 5%). Plagioclase, of composition An_4 to An_{12}, is sometimes present as a minor component ($\leqslant$ 5%). Accessory minerals include tourmaline, zircon, pyrite, microcline, apatite and rutile.

PLATE 4.-Differentiated S_3 crenulation cleavage in phyllite, with darker bands of mica growing parallel to the S_3 surface.

Chemical analyses of selected examples are shown on table 1. The analysed samples have been plotted on an A'KF facies diagram (fig. 3), which indicates the assemblage belongs to the lower greenschist facies of metamorphism (Turner and Verhoogen 1960, p.534). The possible range of conditions of metamorphism for this assemblage is: temperature 200°C to 350°C and pressure 10^2 MPa (1 Kb) to 9 x 10^2 MPa (9 Kb). The intense foliation, associated with early deformation in many rocks in this area, indicates that metamorphism took place under conditions of high stress. Although mineralogically simple, the pelitic rocks are texturally very complex. A study of crystallization with respect to various foliations (S_1, S_2 and S_3) indicates a relatively complex history of mineral paragenesis, This is summarized in figure 4. Most of the new mineral development occurred during D_1 and, to a lesser extent, during D_2 There was also a prominent static phase between D_1 and D_2, during which porphyroblasts of chlorite and albite grew over S_1 in rocks with suitable composition. In general only minor recrystallization accompanied the D_3 event and very little occurred after D_3.

Structure and Metamorphism of the McPartlan Pass-Sentinels area

There is no definite evidence from the present mineral assemblage as to when the metamorphic maximum was reached, if indeed there was such a climax. Some plagioclases have an oligoclase (An_{12}) composition which may indicate that the temperature did at some stage reach 350°C or higher. Some samples have idioblastic to subidioblastic chlorite flakes, which are post-S_1 but pre-S_2, and which appear to pseudomorph biotite flakes. It is possible that they formed from biotite during retrograde metamorphism, in which case the metamorphic maximum could be put at between D_1 and D_2, when biotite grade was reached. However this idea is speculative since no remnant biotites have been found.

The concept that retrograde metamorphism has occurred may be supported by the fact that the dominant muscovite in all specimens subject to X.R.D. analysis to 3T rather than 2M. Certainly, the multifoliated nature of many of these rocks would have made them particularly susceptible to retrograde effects, due to the ease of penetration, on all scales, of aqueous fluids.

TABLE 1

CHEMICAL ANALYSES OF PRECAMBRIAN METAMORPHIC ROCKS FROM THE MC PARTLAN PASS - SENTINELS AREA

	1	2	3	4	5	6	7
SiO_2	60.16	66.24	69.51	73.89	79.60	84.07	87.66
Al_2O_3	20.69	16.23	15.25	11.81	8.30	8.24	4.84
Fe_2O_3	0.00	1.66	1.24	0.71	0.18	0.00	0.24
FeO	2.60	1.88	2.62	1.02	2.25	0.51	2.10
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TiO_2	0.85	0.65	0.70	0.29	0.27	0.28	0.49
P_2O_5	0.07	0.03	0.00	0.05	0.01	0.02	0.01
CaO	0.01	0.01	0.01	0.03	0.01	0.00	0.01
MgO	4.85	1.47	1.42	4.22	5.20	1.14	1.40
Na_2O	0.52	0.25	0.40	0.30	0.11	0.82	0.25
K_2O	5.32	3.91	3.45	3.58	1.17	3.72	1.27
Ignition Loss	4.19	6.78	4.70	2.83	2.69	1.74	1.50
TOTAL	99.26	99.11	99.30	98.73	99.79	100.54	99.77

Chemical analyses of selected phyllites and micaceous quartzites from the Mc. Partlan Pass - Sentinels area. The numbers 1 to 7 refer respectively to specimens 40955, 40970, 40988, 40960, 40976, 40959, 40999, which are kept at the Geology Department, University of Tasmania.

DISCUSSION AND CONCLUSIONS

Inhomogeneous deformation is evident during D_1 since micaceous rocks have a penetrative S_1 foliation developed, but the thicker, more competent, quartzite sequences have no foliation, or only a weak foliation. The inhomogeneity of deformation may be due to local variations in the overall D_1 stress-field, but there seems to be no doubt that lithological differences have played a major role. F_1 axial surfaces were rotated into near alignment with those of F_2 due to the near isoclinal nature of the latter folds. F_2 folds are almost coplanar with the earlier folds.

The major period of metamorphism started with D_1 and continued until the end of D_2. Metamorphism was triggered by the onset of the first deformation event, during which micas were formed from pre-existing sedimentary minerals. Such reactions would have involved the release of volatiles, which would in turn affect the style of deformation by markedly increasing the creep rate (Holland and Lambert 1969). Following the D_2 event there was probably a considerable time gap before the onset of the third deformation event, which produced the dominant folds in the area, but which was accompanied by only minor crystallization.

Cambrian quartzose conglomerates, sandstones and siltstones (Corbett 1970), to the immediate east of the Precambrian metamorphic rocks discussed herein, have two distinct sets of folds developed, which can be correlated, on the basis of orientation, with F_5 and F_6. This indicates a Palaeozoic age for these events. The conglomerate beds, within the Cambrian sequence contain pebbles and cobbles of micaceous quartzite with S_3 crenulation cleavage and L_3 crumple lineations developed. These structures are not present in the bulk of the rock and so D_3, as well as the earlier D_1 and D_2 events, probably a Precambrian event. D_4 may be a late Precambrian, or early Palaeozoic event.

Corbett (1970) regarded the metaconglomerate unit as either Cambrian or Precambrian. This unit has been found to contain all the early structures, including S_1, S_2 and S_3, of the metamorphosed Precambrian rocks to the south and west. It is thus regarded as being Precambrian in age.

Events D_1 and D_4 can probably be correlated with D_1 to D_4 in the Frankland and Wilmot Ranges (Boulter 1974). Correlation of this sequence with published structural sequences from elsewhere in the Older Precambrian of Tasmania, can be found in Table 1 of Boulter (1974)

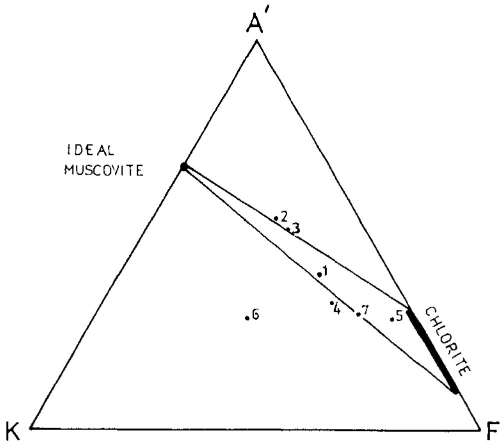

FIG. 3.- An A'KF facies diagram for selected phyllites and micaceous quartzites from the Mc. Partlan-Pass-Sentinels area.

$$A' = [Al_2O_3] + [Fe_2O_3] - ([Na_2O] + [K_2O] + [CaO])$$

$$K = [K_2O]$$

$$F = [FeO] + [MgO] + [MnO]$$

No specific corrections have been made. Muscovite and chlorite have not been analysed separately and their position on the plot has been taken from Turner and Verhoogen (1960, p.537) and Winkler (1967, p.61). The numbers refer to the same specimens as in Table 1.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the guidance and encouragement of Mr. C. Boulter and members of the staff of the Geology Department, University of Tasmania. Many helpful discussions were held with Mr. S. Cox, which were much appreciated. The co-operation of the Hydro-Electric Commission, and in particular the Mc. Partlan Pass engineer, Mr. S. Li, is gratefully acknowledge. I would also like to thank Mrs. K. Osbourne, who typed the

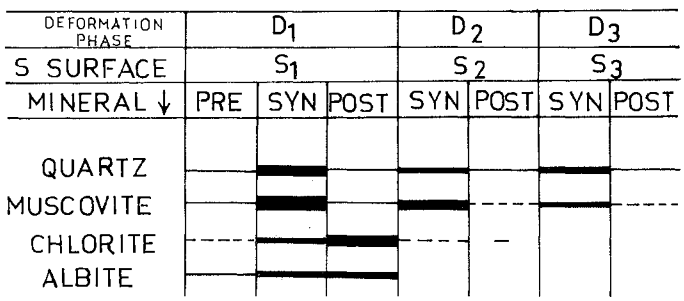

FIG. 4.-The chronological relationship between metamorphic crystallization and S-surfaces in pelitic rocks from the Mc. Partlan Pass-Sentinels area.

manuscript and Mr. R. Williams who assisted in the preparation of the illustrations.

REFERENCES

Boulter, C.A., 1974: Structural sequence in the metamorphosed Precambrian rocks of the Frankland and Wilmot Ranges, south-western Tasmania. *Pap. Proc. R. Soc. Tasm.*, 107, 105-115.

Bowen, E.A. and Maclean, C.J. 1971: Structure of the Precambrian rocks of the Davey River area, south-western Tasmania. *Pap. Proc. R. Soc. Tasm.*, 105, 97-104.

Corbett, K.D., 1970: Sedimentology of an upper Cambrian Flysch paralic seauence (Denison Group) of the Denison Range, southwest Tasmania. *Ph. D. Thesis, University of Tasmania*, 207pp. (unpublished).

Holland, J.G. and Lambert, R.St.J., 1969: Structural regimes and metamorphic facies. *Tectonophysics*, 7(3), 197-217.

Powell, C. McA., 1969: Polyphase folding in Precambrian low-grade metamorphic rocks, middle Gordon River, south-western Tasmania. *Pap. Proc. R. Soc. Tasm.*, 103, 47-51.

Ramsay, J.G. 1962: Interference patterns produced by the superposition of folds of similar type. *J. Geol.*, 70, 466-481.

Turner, F.J. and Verhoogen, J., 1960: IGNEOUS AND METAMORPHIC PETROLOGY. 2nd ed. McGraw Hill, New York., 694 pp.

Winkler, H.C.F., 1967. PETROGENESIS OF METAMORPHIC ROCKS. 2nd ed. Springer, Berlin, 218 pp.