STRUCTURE AND TECTONIC HISTORY OF THE BRISBANE METAMORPHICS IN THE BRISBANE AREA

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(With 16 Figures)

(MS received 12 October 1977)

ABSTRACT

The Palaeozoic basement rocks of the Brisbane area have undergone three major deformations and a minor kinking episode. The central zone of Bunya Phyllite is dominated by a second-generation transposition layering whereas the flanking Neranleigh-Fernvale Beds are dominated by first-generation transposition structures.

The major structure previously described in the area, the Indooroopilly Anticline, is an apparent antiform formed in part by the intersection of dominant first- and second-generation structures and in part by a major third-generation feature. The complete geometry of the first-generation layering across the structure is suggested using vergence relationships but the stratigraphic relations and the structure of the stratigraphic boundaries are virtually impossible to deduce. Two possibilities are suggested and a major conclusion is that the Bunya Phyllite may be merely a unit within the Neranleigh-Fernvale Beds.

The first-generation deformation is a regional event whose effects can be traced north for some 500 km whereas the second- and third-generation structures are more restricted. There is evidence to suggest that all three generations may be related to the same tectonic event, possibly Carboniferous in age.

INTRODUCTION

A large part of the bedrock of the City of Brisbane consists of low-grade metasediments, some of which are strongly folded in outcrop and contain a complex system of intersecting and contorted quartz veins. The poor outcrop, deep weathering, and apparent complexity of these basement rocks, known as the Brisbane Metamorphics (Bryan & Jones, 1951), have impeded a detailed knowledge of the structure. The major comprehensive studies are by Denmead (1928); Bryan & Jones (1950, 1954), and Tucker (1967). The structural interpretation of each of these authors was based on the premise that the prominent cleavage in the rocks was parallel to stratigraphic bedding. That this is not so was recognized by Casey (1962), and Pethiyagoda (1976) showed that in some areas the cleavage is, in fact, a second-generation structure.

Bryan & Jones (1954) discussed in detail an east-west cross-section from west of Kenmore to Hamilton through the Brisbane city area (Fig. 1). It is this section, approximately 17 km long and 7 km wide, that is interpreted in this paper.

Local Geology and Previous Structural Interpretations

The Brisbane Metamorphics in this area consist of two major units: the relatively uniform, thinly-laminated cherts and phyllite of the Bunya Phyllite; and the more heterogeneous cherts, siltstones, arenites, and minor basic volcanics of the Neranleigh-Fernvale Beds. These are intruded by Triassic granitic rocks (the Enoggera Pluton) and acid dykes (the Indooroopilly Intrusives). This geology is shown in Figure 1 (from Houston & Tucker, 1965).

The Bunya Phyllite is a monotonous unit with a well-developed slaty cleavage or schistosity. It is heavily laced with quartz and fine-grained quartz-chlorite veins and these, together with the thin sedimentary chert laminations produce a pronounced unevenness to the fissility of the rock. Many of the various intersecting veins are contorted giving an appearance of great complexity. Ages ranging from Precambrian to Carboniferous have been suggested. The metamorphic grade is low green schist (quartz-albite-muscovite-chlorite).

The Neranleigh-Fernvale Beds are much more diverse and, in general, lack the contorted quartz veins and strong cleavage typical of the Bunya Phyllite. The metamorphic grade is low greenschist although somewhat lower than the Bunya Phyllite (E. Lohe, pers. comm.), and deformation, although present, is not as immediately obvious (in fact, Tucker (1967), in the latest comprehensive report on these rocks, maintains that the Neranleigh-
Fernvale Beds are undeformed and show no evidence of regional metamorphism. The major structure has been interpreted as an antiform (the Indooroopilly Anticline of Denmead, 1928) with the Bunya Phyllite separated from the flanking Neranleigh-Fernvale Beds by two steep normal faults, the Kenmore fault and the Normanby fault (Fig. 2, after Bryan & Jones, 1954).

Bryan & Jones (1951) divided the Bunya Phyllite into two parts: the St Lucia Polymetamorphics and 'Undefomed' Bunya Phyllite. They postulated a series of low-angle thrusts separating and within these units. Tucker (1967) rejected this division but maintained one thrust—the Hamilton Thrust (Fig. 2). Bryan & Jones (1954) further postulated a series of imbricate thrusts east of the Normanby fault to explain the apparent repetition of Bunya Phyllite within the Neranleigh-Fernvale Beds and repetition of a rock type termed the Hamilton Cataclasite (Bryan & Jones, 1951), presumed to be associated with the Hamilton Thrust.

**STRUCTURAL ANALYSIS**

The assumption of previous structural interpretations is that the observed layering is bedding and reflects the macroscopic stratigraphic structure. A cleavage is always parallel to the dominant layering in any outcrop of the Bunya Phyllite and this, plus the lenticular nature of the layering and the numerous intrafolial and rootless isoclinal folds, is a clear indication of its tectonic origin as recognized by Casey (1962) and Pethiyagoda (1976). E. Lohe (pers. comm.) has also recognized isoclinal folding as a general feature of the finer-grained rocks of the Neranleigh-Fernvale Beds. Thus the layering defining the Indooroopilly Anticline is a tectonic, axial-plane foliation indicating a much more complicated...
Fig. 2. Structural cross-section suggested by Bryan & Jones (1954). The D'Aguilar Batholith is an hypothetical, non-outcropping body.

Fig. 3. Trend-surface map of dominant layering in the Brisbane metamorphics. A broad antiformal structure is outlined but this is complicated by the fact that at any locality the dominant layering may be either a first-generation foliation ($S_1$) or a second-generation structure ($S_2$). The major lithological boundary between Bunya Phyllite and Neranleigh-Fernvale Beds corresponds, in part, to the Kenmore and Normanby Faults of previous interpretations.

structure than previously suggested. Continuous mappable horizons are absent but a trend-surface map of this layering is shown in Figure 3. A further complication is that three major generations of structures may be recognized and the dominant layering at any one locality may be parallel to either the first- or second-generation axial plane ($S_1$ or $S_2$).

The area may be divided into five major subareas on the basis of the type and orienta-
tion of the dominant layering at any locality (Fig. 4). These subareas will be described from west to east, which is also the direction of increasing complexity. The various fabric elements and their interrelationships will be defined and the orientations are presented in the stereograms of Figure 5.

**Subarea 1 (Neranleigh-Fernvale Beds)**

Layering in the Neranleigh-Fernvale rocks consists predominantly of bedding, although tight folding has virtually rotated bedding at all scales into the orientation of the axial planes (Fig. 6). Internal disruption of the sedimentary laminations to form a true transposition layering is apparent in some of the finer-grained units (Fig. 6c, d). In the bedded cherts, hinges of isoclinal folds are commonly obscured by boudinage, presenting an apparently uniform sequence to the observer (Fig. 6b).

A weak cleavage (parallel to the layering) is frequently present, but only locally can it be demonstrated to be actually in an axial-plane relationship. No evidence of any earlier deformation is present and the cleavage and the layering parallel to it represent a first-generation foliation ($S_1$).

These first-generation structures are overprinted by a set of minor open folds with subhorizontal axial planes (Fig. 7a). The intensity of these second-generation structures varies from negligible to fine crenulations, to folds with wavelengths up to 1 m.

The second-generation fold axes are subhorizontal and parallel to the first-generation axes except in a small part of the subarea at Kenmore where the $F_1$ axes are rotated into quite steep plunges.

**Subarea 2 (Bunya Phyllite)**

The tectonic nature of the dominant layering in the Bunya Phyllite is indicated by two main features: tight folds in quartz veins with the layering as axial plane; and small intrafolial folds and isolated hinges in the thin ($<\frac{1}{2}$ cm) chert layers themselves (Fig. 7c).

The axial-plane structure in the thin silty layers of these folds is generally a slaty cleavage, but locally, in outcrop, and somewhat more commonly in thin section, characteristics of a crenulation foliation are observed. There is a gradation between the two cleavage types and the crenulation end-member is generally most strongly developed in the outer hinge areas of folds in quartz veins or chert layers.
Fig. 5. Lower hemisphere, equal-area projections of the structural fabric elements in each of the sub-areas shown in Figure 4. $S_1$, $S_2$, and $S_3$ are respectively the first-, second-, and third-generation axial plane foliations. $L_{10}$, $L_{21}$, and $L_{32}$ are the intersection lineations of bedding ($S_0$) and $S_1$; $S_2$ and $S_1$; and $S_3$ and $S_2$, respectively. A similar convention is used for the kink bands, $S_k$ and the intersection lineations with $S_1$ and $S_2$ ($L_{S1}$, $L_{S12}$, respectively. Third-generation structures are found only in subarea 4. The contours are $S$, 10, 20% per 1% area except the $S_k$ diagram (2, 4, 6%). The number of data points is shown in the bottom left of each figure. Except in the transition zone of subarea 2 the separation of $S_1$ and $S_2$ as separate, measurable fabric elements is not possible at most outcrops of Bunya Phyllite (subareas 2, 3 and 4) owing to bulk rotation and local transposition (see text). The fabric element measured as $S_2$ is thus either a true $S_2$ orientation or a segment of $S_1$ subparallel to $S_2$ at any one locality.

In many outcrops the layering is undoubtedly just a first-generation transposition foliation rotated almost into the orientation of a second axial plane which, in these outcrops, is commonly only represented by planar quartz veins and very minor folds or crenulations (Fig. 7c). In other outcrops the main layering appears to be purely a second-generation transposition of the first-generation layer and associated quartz veins. The relative proportion of the dominant layering that is a new, second-generation transposition layering as opposed to that which is a larger-scale, bulk rota-
tion of the earlier first-generation layering is uncertain, but in any case the effect is to produce a layering in the rocks parallel or sub-parallel to a second-generation axial plane.

Thus the dominant, subhorizontal layering of subarea 2 is a second-generation axial plane foliation ($S_2$). Where $S_1$ can be observed as distinct from $S_2$ (Fig. 7d), the angular difference is generally small and the small number of data available suggest a constant vergence relationship (Pethiyagoda, 1976).

There is a sudden, but continuous, transition of the minor second-generation structures of subarea 1 into the more intense, dominant layering of subarea 2. In the transition zone the separate orientations of $S_1$ and $S_2$ are accentuated by the quartz veins parallel to each and tend to be at a somewhat larger angle to one another than farther into subarea 2 (Fig. 7b). It is common to find steeply dipping $S_1$ dominant layering side by side with sub-horizontal $S_2$-dominant layering in the same outcrop in this transition zone.

**Subarea 3 (Bunya Phyllite)**

Superimposed on both the first- and second-generation structures of subareas 1 and 2 are numerous kink bands (Fig. 8). Both isolated kinks and continuous kink structures occur and conjugate sets are common. These kinks increase in intensity near small fault zones or some of the acid dykes in this area.

The area of maximum intensity of kinking forms subarea 3 where their effect may be observed on the macroscopic geometry. Kink-band orientation is highly variable although some areas are dominated by a particular kink set. The major kink folds of subarea 3 are very gentle flexures with steeply dipping axial planes and axes plunging shallowly to the southsouthwest. These folds are accentuated on the map (Fig. 3) by the shallowly-plunging axes and are really quite minor structures in terms of the major geometry.

**Subarea 4 (Bunya Phyllite/Neranleigh-Fernvale)**

The dominant layering in the Bunya Phyllite changes rapidly in orientation from sub-horizontal in subarea 2 to steep, easterly dipping in subarea 4. The style of the layering also changes considerably. In part, the foliation is a true, second-generation crenulation foliation in which the earlier $S_1$ surface is easily recognizable (Fig. 9a). The microlithons defining the new layering are up to 1 cm wide and strongly enhanced by mineralogical differentiation (Fig. 9b). The new quartz-rich differentiation domains are very similar in appearance to the original thin cherty bands (even in thin
Fig. 7. Second-generation structures, subareas 1 and 2. (a) Open F2 fold and weak S2 developed in subarea 1. (b) Subhorizontal quartz veins parallel to S2 and axial planar to open folds in S1 which are also accentuated by quartz veins. Transition zone of subarea 2. (c) Transposition layering in Bunya Phyllite of subarea 2. The pen and the layering are subparallel to S2 although it is thought that most of the small-scale folds are actually remnants of the earlier F1 transposition. (d) Five metres from (c) and in the same orientation. The pen is parallel to S2 but the existence of an earlier layering containing small isoclinal folds is quite evident.

Fig. 8. Conjugate kink bands in subarea 3.

section). In outcrops where this style of layering dominates, close to isoclinal folds in the earlier S1 layering are commonly observed and the enveloping surface to these folds is generally at a high angle to the S2 layering (domain (a) of Fig. 10). That is, these represent hinge areas of somewhat larger F2 folds. In other outcrops there is no strong development of a new S2 layering and the dominant foliation observed is just the earlier S1 layering rotated almost into the S2 orientation (Fig. 9c, and domain (b) of Figure 10). The only manifestation of S2 in these outcrops is a minor crenulation foliation and prominent, regular quartz veins parallel to S2. The rotated S1 is consistently more steeply dipping to the east than S2 and the interpretation is that these outcrops form the limb areas of large F2 folds.

The two types of dominant layering occur within metres of one another, even in the same outcrop, and hence the internal structure of the Bunya Phyllites must be one of highly asymmetrical F2 folds in the S1 layering with wavelengths of several metres. The net effect must produce an enveloping surface to the S1 layering that is subvertical or even westerly dipping (Fig. 10).

As shown on Figure 4, these structural relationships and orientations persist in some places across the boundary into the Neranleigh-Fernvale lithologies. In the siltstones of this unit the quartz veins forming parallel to S2 tend to be much thinner, closer spaced, and more continuous than those in the Bunya Phyllite. Other relationships remain much the same.

Superimposed on the dominant second-generation foliation in this subarea is a group of pervasive, small open folds (Fig. 11a). Their orientation is relatively constant with an axial plane dipping about 40° to the west although a minor, but persistent, conjugate set occurs in a much shallower orientation (Fig. 11b). Other, more
Fig. 9. Second-generation structures in subarea 4. (a) $F_2$ folds in the earlier $S_1$ layering. (b) Mineralogical segregation of material into layers parallel to $S_2$. Subhorizontal remnants of the $S_1$ layering can be seen. (c) Transposition layering.

anomalous orientations are also found, and very near the eastern boundary of the subarea many different orientations may be observed in the same outcrop. In this latter case a low easterly-dipping orientation is common.

Locally, a crenulation foliation is developed as an axial plane structure and even when not obvious, its expression as a crenulation lineation on the $S_1$ or $S_2$ surface is very common. Somewhat less commonly developed are quartz veins parallel to the axial surface of the folds. These veins tend to be fairly lenticular and less extensive than earlier quartz veins.

These open folds are virtually absent from the western part of subarea 4 and increase in intensity towards the eastern margin. Maximum wavelengths of about 3 m have been observed. Their somewhat kink-like character and conjugate orientations are similar to the kinks observed in the subareas to the west. Although there is no mutual overprinting relationship between the two sets of structures, these post-$F_2$ folds of subarea 4 have much more in common with the first two generations of folds than with the kinks. The kinks have no axial-plane structure, do not develop axial plane quartz veins, have many different orientations of fold axes, and are spatially associated with high-level, brittle deformation features (faults, dykes). The late folds of subarea 4 not only have a relatively constant orientation of fold axes (even in conjugate sets) but these are subparallel to fold axes developed during the first two deformations (i.e. the three axial planes are coaxial—Fig. 14). In addition, the development of an axial-plane foliation and axial-plane quartz-veining is similar to the earlier deformations and hence the folds of subarea 4 are presumed to predate the kinks; these two separate sets of structures are defined as the $F_3$ and $F_4$ generations respectively.

The eastern margin of subarea 4 delimits the eastern extent of the $F_3$ folds.

Subarea 5 (Neranleigh-Fernvale)

Subarea 5 is entirely within the Neranleigh-Fernvale Beds. The lithology is much more varied than the Bunya Phyllite and consists of cherts, siltstones, arenites, and basic volcanics similar to subarea 1. The small-scale layering is generally bedding but,
as in subarea 1, isoclinal first-generation folds have rotated it into the subvertical orientation of \( S_1 \). True transposition is fairly common.

Whereas the rocks in subarea 4 contain three pervasive generations of structures, those near the boundary in subarea 5 contain only the dominant \( F_1 \) folds and foliations overprinted by a very weak second-generation set of structures. Near the boundary these \( F_2 \) structures form only very small folds and crenulations and commonly the only obvious manifestation of \( S_2 \) is as a series of thin, very regular, quartz veins parallel to the axial planes which dip shallowly to the east.

Fig. 10. Diagrammatic representation of the two types of outcrops found in subarea 4, particularly near the eastern boundary. In outcrop type (a) symmetrical folds in the \( S_1 \) surface and a differentiated \( S_2 \) crenulation foliation dominate. In outcrop type (b) the unfolded \( S_1 \) surface dominates but is in close orientation to the \( S_2 \) surface and with a constant vergence. Thus the mutual relationships of these two outcrop types indicate an enveloping surface or average orientation of \( S_1 \) that is very steeply dipping (shown by the heavy line).

Fig. 11. Third-generation folds in subarea 4. (a) Typical open, shallow, westerly-dipping \( F_3 \) structures. Quartz veins parallel to both \( S_1 \) (tightly folded) and \( S_2 \) can be seen. (b) Conjugate \( F_3 \) folds.

The size and intensity of the second-generation folds increases in the eastern half of the subarea up to an observed amplitude of 10 m. The fold tightness varies from open to tight and hinge shapes vary from angular to rounded. The degree of development of an axial-plane foliation is also variable and in some lithologies the crenulation foliation that is developed is strongly enhanced by mineralogical segregation (Fig. 12). The axial-plane quartz veins, noted above, which occur close to the western boundary, are absent in the eastern half of the subarea.

There is very intense development of the second-generation mesoscopic structures in a few outcrops. Where this occurs in a cherty siltstone lithologies, the transposition foliation produced is almost identical in appearance to the \( S_2 \) foliation in the Bunya Phyllites of subareas 2, 3, and 4. One of the most obvious outcrops of this nature is in the centre of the city (Turbot St) and the identification of this as Bunya Phyllite by Bryan & Jones (1954) formed the basis of their postulation of a series of imbricate thrusts bringing Bunya Phyllite up into the section.

A further factor in Bryan & Jones's (1954) postulation of thrusts controlling the geometry was their identification of cataclastic rocks in a formation they termed the Hamilton Cataclasites. In fact, these are fine to coarse psammites and psammo-
pelites that have been affected by both the \( F_1 \) and \( F_2 \) deformation. The axial-plane foliations produced by the two deformations are almost identical in both mesoscopic and microscopic appearance. The positive identification of an \( S_2 \) foliation in these rocks may be based solely on overprinting of folds and not on the style of the foliation. No cataclastic textures have been observed. The rocks have undergone partial recrystallization leaving large, strained, old grains surrounded by an aggregate of fine recrystallized grains. Brittle deformation features are absent and thus there seems no justification for the term 'Hamilton Cataclasite'.

Superimposed on the first two generations of structures are post-\( F_2 \) folds of varying orientation and intensity. They are mostly kink-like and probably could be grouped with the \( F_1 \) kinks in and around subarea 3.

**QUARTZ VEINING**

Complexly-folded and intersecting quartz veins are a characteristic feature of the Bunya Phyllite and similar lithologies within the Neranleigh-Fernvale. Veins are commonly observed parallel to \( S_1 \), \( S_2 \), and \( S_3 \) and show the appropriate overprinting relationships with one another (Fig. 13).

The veins parallel to \( S_1 \) are tightly folded and have the \( S_2 \) layering as axial-plane. The axes of these folded veins are relatively uniform in orientation and parallel the \( F_2 \) axes in the \( S_1 \) layering. That is, these veins must have been parallel to \( S_1 \) before the intense \( F_2 \) deformation.

Thus production of quartz veins subparallel to the axial planes is a characteristic of each of the first three generations of folds.

In the area around the Indooroopilly Intrusives (subareas 2 and 3), irregular pegma-
Fig. 14. Synoptic orientation plots of the main structural fabric-elements in the Brisbane area. Note that the third-generation structures ($S_3, L_3$) are only observed in subarea 4 (lower hemisphere equal-area projections with the number of data points and contour interval shown below each stereogram).

TITE VEINS are common. These are considered to be a late feature probably synchronous with $F_4$.

The $S_3$ foliation is a crenulation type and is accompanied by metamorphic differentiation to varying degrees. This produces quartz-rich layers parallel to $S_3$ and containing small amounts of phyllosilicates giving them a dark cherty appearance. These are the 'black quartz' layers referred to by previous authors (e.g. Bryan & Jones, 1954; Tucker, 1967).

TECTONIC HISTORY

The geometry of the area, as outlined, consists of three major generations of structures followed by minor to large-scale kinks. The geometry of the major structures is summarized in Figure 14. There are many similarities between the first three generations. The axial planes are almost coaxial such that $F_4$ fold axes in bedding, $F_2$ fold axes in the $S_2$ layering, and $F_3$ fold axes in the $S_2$ layering are subparallel. All three generations develop an axial-plane foliation although this is less marked in the $F_3$ folds. The development of quartz veins subparallel to the axial planes is common to all three generations although less intense in the $F_3$ structures. These similarities suggest that the first three generations are products of the same protracted deformation phase.

First-generation structures are characterized by isoclinal folding and widespread transposition. Such structures are a feature of the Neranleigh-Fernvale Beds and similar lithologies from at least the N.S.W. border (E. Lohe, pers. comm.) north for at least 500 km (personal observation). If these are all related structures then this event marks a major tectonic episode in the Palaeozoic history of southeast Queensland.

In contrast, the second- and third-generation structures are less intense and much more localized. South of Brisbane, minor, widespread, second-generation structures are found, but these only become of macroscopic importance at a few localities (E. Lohe, pers. comm.). Three generations of structures are found in phyllites and metavolcanics (the Rocksberg Greenstones) for about 50 km north of Brisbane. The metamorphic grade gradually rises rapidly northwards. Isolated fault blocks of blueschist (related to the Rocksberg Greenstones) containing three generations of structures are found a farther 75 km north. Thus the second- and third-generation structures represent a more localized tectonic episode than the first-generation.

The Enoggera granite provides an upper limit on the timing of the deformation. This intrusive and its aureole postdates the $F_2$ structures but it is spatially separated from areas of $F_3$ deformation. The $F_4$ kinks are spatially related to the area of high level Triassic intrusives but their relationship to the granite aureole is uncertain at this stage. It is inferred that the $F_1$, $F_2$, and $F_3$ structures predate the granite (Triassic, 219 m.y., Webb & McDougall, 1967) and the $F_4$ kinks are related to the intrusive activity. Carboniferous granodiorites described as syntectonic occur 150 km north of Brisbane (Hayden, 1971), and Green (1973) has suggested from radiometric dating that the last major episode of structural deformation and regional metamorphism was Late Carboniferous (ca 290 m.y.). Thus the deformation observed may be almost entirely associated with the Kanimblan Orogeny with only minimal effects of the Permian Hunter-Bowen Orogeny.

There have been suggestions that the intense small-scale folding characteristic of the Bunya
Phyllite is at least partly due to soft-sediment deformation. There is no evidence to support this. Most observed folds are either second- or third-generation structures; the first-generation structures have a well-developed axial-plane foliation, are accompanied by recrystallization, and contain abundant quartz veining subparallel to the axial planes.

**STRUCTURAL SYNTHESIS**

**Indooroopilly Anticline—western half**

It is now suggested that the western half of the Indooroopilly Anticline of Denmead (1928) is an apparent fold structure produced by the intersection of two dominant layerings of different generations. The steep western 'limb' is formed by $S_1$ and the 'crest' by the subhorizontal $S_2$. The constant vergence between these two foliations across sub-areas 1 and 2 indicates that there is no large-scale second-generation fold in this position, although a general rotation of $S_1$ towards the $S_2$ orientation is indicated. Exactly what the first-generation structure is in the stratigraphy is uncertain at this stage.

The western boundary of the Bunya Phyllites corresponds to the Kenmore fault of Bryan & Jones (1954). In this present study it has been regarded merely as a transition zone between the areas of first- and second-generation dominance and this does coincide in this section with a major lithologic boundary. At this stage, however, the postulation of such a fault is not required to explain the structure and there is no strong field evidence on which to base such a fault.

**Indooroopilly Anticline—eastern half**

The major change in orientation of the $S_2$ layering between subareas 2 and 4 defines the crest and eastern limb of the Indooroopilly 'Anticline'. The only post-$F_2$, mesoscopic structures that can be related to this major structure are the $F_3$ folds in the eastern half of subarea 4 and the $F_4$ kinks.

The orientation of the $F_3$ folds is consistent with the macroscopic fold structure in $S_2$ (Fig. 14) although mesoscopic $F_3$ folds are almost absent from the area of maximum curvature in $S_2$. Despite this it seems most likely that the major fold structure is part of a third-generation inclined fold with an axial plane dipping about 40° west and an axis plunging 10° to the southwest. Whether this major structure is simply part of a large monoclinal flexure or a large overturned fold is unknown but the former seems more likely.

**Boundary between subareas 4 and 5**

The nature of the boundary between subareas 4 and 5 is problematical. Previous workers (e.g., Bryan & Jones, 1954; Tucker, 1967) have regarded the lithological boundary between the Bunya Phyllite and the Neranleigh-Fernvale Beds as a structural discontinuity (the Normanby fault). However, it is clear that there are two boundaries; a lithologic boundary and a structural boundary (the subarea boundary) and these only coincide near one point in the area studied (Red Hill). Elsewhere there is no abrupt change in structures across the lithologic boundary and the structural boundary is farther to the east.

Structure-contour reconstruction indicates that the lithologic boundary is subvertical north of the river, which also seems to be the orientation of the enveloping surface to the folded $S_1$ layering observed in outcrop. South of the river, initial indications are that the lithologic boundary begins to veer westward across the dominant foliation ($S_2$) trend.

At Red Hill the structural boundary (here coinciding with the lithologic boundary) is quite abrupt. On the western side the rocks have a distinct phyllitic sheen and three penetrative generations of structures. On the eastern side, the siltstones show no strong phyllitic sheen and only contain two penetrative generations of structures (one of which is only weakly developed. Although the mean $S_1$ orientations are probably approximately parallel on either side of the boundary there is a marked change in the $S_2$ orientation from dips greater than 55° to dips less than 35° (and commonly less than 20°). This is accompanied by the marked change in style of $S_2$ previously described.

The structural boundary elsewhere is defined the same way but is more difficult to delineate owing to outcrop problems and the similarity of the lithologies on either side of the boundary.

Although there is no obvious brecciation or shearing it seems most likely that the boundary at Red Hill is a fault with east block down (lower grade, simpler structures). Whether the entire subarea boundary is a fault is problematical. The boundary marks the point at which there is an abrupt change in the orientation of $S_2$. This change is compatible with it being a major $F_3$, kink-like structure and as such the axial plane would dip to the southwest at about 35°. On the cross-sections, the boundary is tentatively shown as a fault along this axial plane. However, except at Red Hill, there is no other real evidence that a fault, equivalent to the Normanby fault, exists.

**Geometry**

The coaxial nature of the $F_1$, $F_2$, and $F_3$ axial planes leads to more or less parallel fold axes in each of the $S_0$, $S_1$, and $S_2$ surfaces (Fig. 14). Thus, complex three-dimensional refolded fold patterns are absent and a single cross-section is sufficient to characterize the structure (fold axes are subhorizontal).

The geometry of the observed dominant layering ($S_1$ or $S_2$) is shown in Figure 15a. The dominant steeply dipping $S_1$ layering in the west of the section passes through a transition zone into an area of dominant, shallowly dipping $S_2$ layering. Apart from minor, but large-scale kinks, near the intrusives the major structure in the dominant $S_2$ layering is a large kink-like flexure near the centre of the section. Faulting of unknown magnitude is associated with this major flexure but possibly this may only be a local feature. The eastern part of the section is again dominated by steeply
cross-section of observed geometry (excluding cover rocks)

Possible configuration of $S_1$

Fig. 15. Structural cross-sections corresponding to the same section presented by Bryan & Jones (1954)—see Fig. 2. (a) The geometry of the observed dominant layering. (b) The inferred geometry of the first generation foliation $S_1$.

dipping $S_1$ layering but $F_2$ folds increase in intensity towards the east. There seems to be no evidence for the thrust faults postulated in earlier sections (Bryan & Jones, 1954; Tucker, 1967).

The structure shown in Figure 15a is only the geometry of the obvious layering at any point. The region of $S_2$ dominance seems to be confined to the fine-grained Bunya Phyllite. Thus the macroscopic effect of $F_2$ may be much less intense than its mesoscopic effect. The broad geometry of the $S_1$ layering in the region of $S_2$ dominance can be inferred from the $S_1$/$S_2$ vergence relationships. In the west of the section the mean $S_1$ is at a high angle to $S_2$ which is only weakly developed. As $S_2$ becomes dominant (in subarea 2), the $S_1$ layering closely approaches the $S_2$ orientation but with a constant sense of vergence. In subarea 3 the mean $S_1$ is again at a high angle to $S_2$ and in the west of this subarea it begins to approach the $S_2$ orientation but with the opposite vergence to that observed in subarea 2. Thus the average geometry of the $S_1$ layering is interpreted as shown in Figure 15b.

The major lithologic boundaries are inferred to be most likely parallel to the $S_1$ geometry (macroscopic $F_1$ isoclinal folds and major boundaries parallel to $S_1$ are a feature of the Neranleigh-
Fernvale Beds in the area south of Brisbane (E. Lohe, pers. comm.). However, there are two possibilities for the structure of the major lithologic units depending on whether the eastern and western boundaries of the Bunya Phyllite are one and the same horizon (Fig. 16).

The alternatives are: (a)—the eastern and western boundaries of the Bunya Phyllite unit represent opposite sides of a strongly folded phyllite unit as shown in Figure 16a, or;

(b)—that the two mapped boundaries actually close with one another, which means that there must be a major $F_1$, isoclinal fold closure as shown in Figure 16b.

Detailed mapping of the boundary should provide an answer but poor outcrop and Mesozoic cover rocks have so far prevented this.

The first alternative seems somewhat simpler and more attractive. Note that internal transposition of this unit is complete at the mesoscopic scale and hence may also be effective at the macroscopic scale. Thus the thickness of the Bunya Phyllite unit shown in Figure 16a (ca 2000 m) is a maximum estimate for the stratigraphic thickness (assuming no macroscopic transposition) but it may have been considerably thinner owing to internal folding. Similarly, if there has been macroscopic transposition, no stratigraphic significance may be attached to the boundaries. It could be inferred that, if this alternative is correct, the Bunya Phyllite is merely a unit within the Neranleigh-Fernvale sequence.

The second alternative is more specific in its requirements but is by no means a remote possibility. It can more easily explain the absence, noted in previous studies, of the Bunya Phyllite lithology south of the river (the general antiformal structure plunges southward). It requires that the major lithologic boundaries cut across the $S_1$ layering and hence these boundaries would be true stratigraphic boundaries.

In this model the structure is a strongly refolded anticline in which the Bunya Phyllite stratigraphy underlies the Neranleigh-Fernvale Beds (at least in this section). That is, the presently accepted stratigraphic relationships are preserved. The thickness of the Bunya Phyllite is indeterminate.

CONCLUSIONS

The structure and tectonic history of the Brisbane ‘Metamorphics’ is somewhat more complex than previous studies have indicated. A regional deformation has produced widespread isoclinal folding and transposition. A series of two, more local deformations has refolded the earlier structures and has produced a new transposition layering in the unit known as the Bunya Phyllite.

The geometry of the various transposition layerings can be determined fairly confidently (Fig. 15a). The complete geometry of the first-generation foliation within the Bunya Phyllite may be inferred from vergence relationships but the number of data are not large (Fig. 15b). The geometry of the stratigraphy theoretically could be deduced from detailed mapping of major lithologic boundaries but this is fraught with difficulties in such areas of transposition. Partial solutions may be suggested at this stage (Fig. 16).

The Indooroopilly Anticline (Denmead, 1928) as defined by the observed layering is a composite structure in which the western limb and crest are defined by the intersection of two different generations of transposition layerings. The eastern limb is formed by a large, third-generation flexure in the second-generation layering. It may be inferred, however, that the ‘Indooroopilly Anticline’ does coincide with the crest of a large antiformal structure in the major lithologic units but this is a complex structure and its facing is problematic.

The exact stratigraphic position of the Bunya Phyllite is uncertain. It may stratigraphically underlie the Neranleigh-Fernvale sequence as generally accepted, but there is a strong possibility that it is merely one thin unit within the general Neranleigh-Fernvale sequence. A large part of its outcrop area is on the subhorizontal limb of a fold thus grossly exaggerating its outcrop width. There is no evidence to suggest that the two units are not conformable.

ACKNOWLEDGMENTS

I would like particularly to acknowledge two former students. Firstly, Mr Daya Pethiyagoda with whom I became interested in the problem and whose work on the central part of the Bunya Phyllites first established the importance of the second-generation deformation. Secondly, Mr Paul Donchak of the Queensland Geological Survey with whom I have spent many hours in discussion and in the field, debating the nature and importance of the eastern boundary of the Bunya Phyllite.

Finally, I must thank Mr Eric Lohe for the stimulating discussions we have had over the past few years concerning the structure of the region. Mr Lohe has suggested many new interpretations of the regional geology developed during his Ph.D. thesis work on the structure, stratigraphy, and sedimentology of the Neranleigh-Fernvale Beds in the Beenleigh Block, some 50 km south of Brisbane.
REFERENCES


HAYDEN, P., 1971: Metamorphism and geological evolution of the Stoney Creek area near Kilkivan, southeast Queensland. Univ. Qd Dept Geol., B.Sc.(Hons.) Thesis [unpubl.]


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