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SHEATH FOLDS IN PELITIC SCHISTS OF THE TIA COMPLEX, SOUTHERN NEW ENGLAND FOLD BELT, EASTERN AUSTRALIA

by

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(with 1 plate and 2 text-figures)

Abstract

Sheath folds in pelitic schists of the Tia complex of the Yarrowitch block are described. Multiple deformations and their kinematic interpretation in the complex are re-examined. Two major mesoscopic deformation cycles (D_1 and D_2) are identified. D_1 is associated with the formation of sheath folds and probably represents the earliest deformation in the region which occurred during high P/T metamorphism of 310-320 Ma. D_2 formed asymmetrical open～gentle fold with veins of biotite-quartz during the Tia granodiorite emplacement of 265 Ma. The sheath folds seem to have occurred along a nappe boundary between the Oxley and Brackendale metamorphics.

Introduction

Since the first description of sheath-like folds (Quinquis et al., 1978) and subsequent experimental studies on the formation of sheath folds (Cobbold and Quinquis, 1980), descriptions of sheath folds have been rapidly accumulated from regional metamorphic belts. In most cases a kinematic interpretation including simple shear component has been adopted for these belts (Henderson, 1981; Mattauer et al., 1983; Lacassin and Mattauer, 1985; Faure, 1985 etc.). Progressive deformation involving the formation of sheath folds has revised earlier interpretations using traditional chronological notation of structural elements such as S_1, S_2, etc. In many cases structure that can be separated into independent phases on geometric ground, are in fact recognized as belong to one continuous deformation process during progressive deformation with increasing shear strain (Gottachalk, 1990; Malavieille, 1987; Goscombe, 1991; Vollmer, 1988; Wallis, 1990). Thus, recognition of sheath folds in metamorphic belts gives new interpretations of the kinematics of regions showing multiple deformations that were formerly described in terms of a simple sequence of independent deformation phases. In this paper, the author describes mesoscopic scale sheath folds found in pelitic schists of the Tia complex in the western Yarrowitch block, southern New England Fold Belt and re-examines the deformation sequence in the complex.

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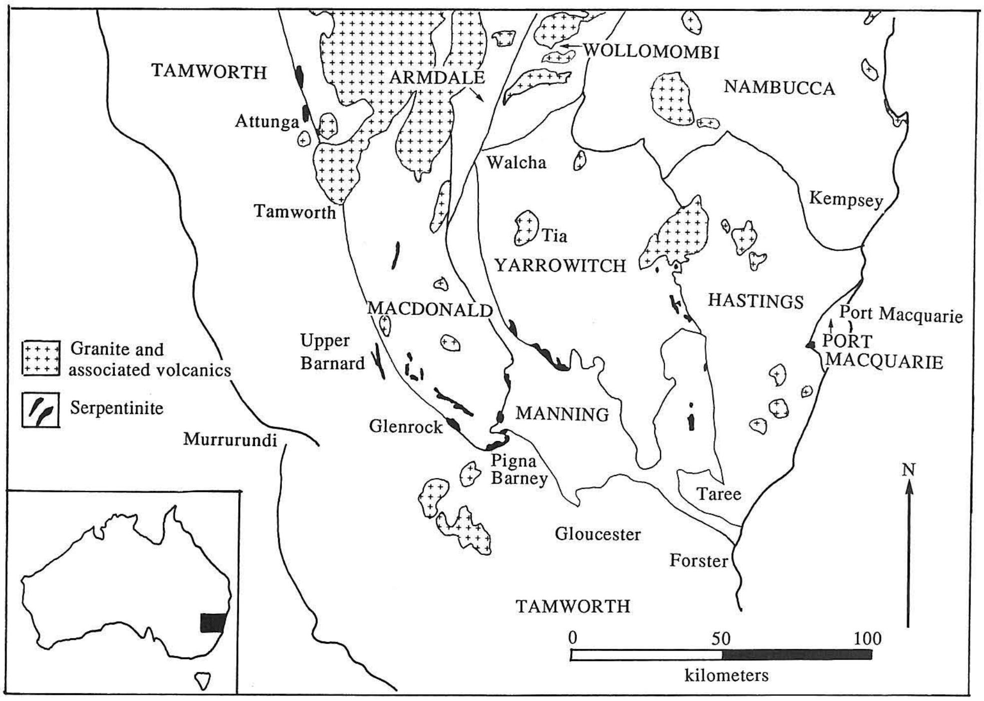
Outline of Geology

The southern part of the New England Fold Belt comprises a series of fault-bounded blocks made up of stratified Middle-Late Paleozoic rocks. Serpentinized ultramafic rocks are concentrated close to the boundaries of blocks and Permian and Triassic granites occur widely (Text-fig. 1). The Yarrowitch block is composed mainly of multiply deformed foliated regional metamorphic rocks and the western part of the metamorphic rocks was named the Tia complex (Gunthorpe, 1970) ; the central part of the Tia complex has been intruded by the Tia granodiorite. The metamorphic rocks of the Yarrowitch block were divided into two major units on the basis of lithology by Gunthorpe (1970), i. e. Oxley metamorphics (siliceous and mafic rocks predominate) and Brackendale metamorphics (pelitic rocks predominate). Both groups of metamorphic rocks have suffered thermal metamorphism at 265 Ma by the Tia granodiorite (Fukui et al., 1990). The southern Oxley metamorphics have suffered 310-320 Ma glaucophanitic metamorphism (Watanabe et al., 1988).

Mesoscopic structure of the Tia complex

Multiple deformation of the Tia complex was studied by Gunthorpe (1970) and



Text-fig. 1 Paleozoic structural blocks of the southern New England Fold Belt (modified from Leitch et al., 1990)

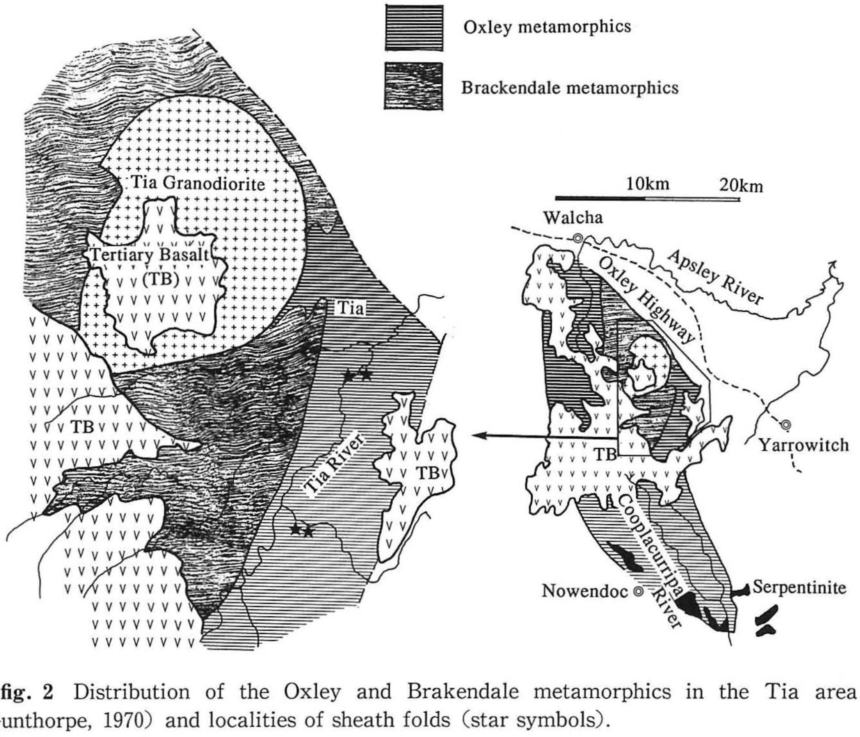
Morand (1982). They identified several deformation phases for the both Oxley and Brackendale metamorphics, and mentioned the difference of deformation sequences between them. In the area of Brackendale metamorphics, they did not identified the equivalent fold to the earliest fold in the Oxley metamorphic rocks. Hand (1989) studied the structure in the southern Oxley metamorphics and recognized six deformation phases including nappe formation. Watanabe and Naka (1988) studied structure of the metamorphic rocks and reported steeply plunging lineation in the southwestern and western marginal zones in the Oxley metamorphics. They also mentioned rotation of fold axes on the basis of their field observation and recognized only a few major deformation phases.

Subsequently, Watanabe et al. (1988) mentioned gently curved lineation and suggested occurrence of sheath folds.

Although multiple deformation in the Tia complex has been examined by some geologists mentioned above, it is still open to question due to its complicated folding geometry. Understanding the formation of sheath folds is one of the keys to solve the confusion concerning the multiple deformation.

Geometry of sheath folds of mesoscopic scale

Typical sheath folds (Plate 1) in biotite schists are found in a few localities along Tia river in the western margin of the Oxley metamorphics area (Text-fig.



Text-fig. 2 Distribution of the Oxley and Brakendale metamorphics in the Tia area (after Gunthorpe, 1970) and localities of sheath folds (star symbols).

2). In the area, main trend of foliation plane is approximately N-S to NE-SW and dips steeply to the east. Oblique cross-cutting cleavages and obliqlue lineations are common. At one locality involving sheath folds, main foliation strikes N30° E with steep dipping of 82° to the east. Two directional lineations, which are slightly oblique, are observed and predominant lineation (NE14°, plunging 80°) indicates the shear direction, though it may not be original situation, producing sheath folds (Plate 1a). In a cross-section parallel to the lineation (Plate 1b), S-plane (main foliation, see an arrow sign) involving isoclinal fold-axial plane is dislocated by asymmetric small fold. Along the axial plane cleavage (see a white line) of the amall fold, biotite-quartz veins are observed. Under the microscope, rotated refolding strucure is also observed. The structure is explained to be refolding of terminal nose during progressive stage as shown in Goscombe (1991, Fig. 9, b).

In a cross-section normal to the lineation (Plate 1c), eye structure proving sheath folds is rarely observed and is flattened due to pure shear component (vorticity, $0 < Wn < 1$). Fracture cleavages obliquely cross the foliation plane. This later cleavages are equivalent to the cleavages in Plate 1b. The duplication is considered to have formed appearance of complicated deformation and a flattenned sheath folds surface is gently bent as a tongue (Plate 1a).

Discussion

Biotite K-Ar ages of the Oxley metamorphics around the sheath folds localities are ca. 265 Ma (Fukui et al., 1990) and the ages become older southward (ca. 310-320 Ma ; Watanabe et al., 1988 ; Fukui et al., 1990). Biotite in the sheath folds occurs along cleavages by later deformation as described above ; therefore sheath folds are considered to be produced by earlier deformatin. Biotite has been produced by thermal effect of the Tia granodiorite partially showing gneissosity. So, later cleavages are considered to have been produced during the emplacement of the Tia granodiorite. As Gottschalk (1990) illustrates coaxial continuous deformation with sheath folds, sheath folds formation and oblique cleavage development can be produced by a continuous deformation (one cycle by Tobisch and Paterson, 1988). If it is non-coaxial, the sheath folds with later cross-cutting cleavages in the Tia complex can be formed. However, quartz grains in the biotite schist do not have a grain shape fabric in any direction. Contrarily they are roughly equidimensional with straight grain boundaries. This indicates that the primary elongate grain shape fabric has been obliterated by annealing due to the thermal effects of the Tia granodiorite.

The sheath folds were therefore formed during the deformation of the southern Oxley metamorphics, i. e., 310-320 Ma or before. The metamorphic temperature of the southern Oxley metamorphics is estimated to have been around 300℃ (Watanabe et al., 1988).

Thus the K-Ar ages indicate the maximum temperature if the deformation effect at lower temperature is negligible.

Typical sheath folds are only found in the Tia area. In the adjacent Brakendale metamorphic rocks, the earliest lineations trend N70°W, although the plunge is variable due to refolding. The lineation direction shows high angle obliquity to that of Oxley metamorphics. In cross sections parallel to lineation in pelitic and quartzose schists, isoclinal folds are often observed in the areas of both the Brackendale and Oxley metamorphics. This indicates that the both metamorphics suffered the earliest deformation. Along the western margin of the Oxley metamorphics, typical sheath folds with high angle plunges are indentified. The contrast with the earliest lineation direction and development of typical sheath folds in the Oxley metamorphics suggest that the boundary between two metamorphics, though it is not clearly defined, may be a nappe boundary. As shown in Plate 1c and d, the earliest deformation is not cylindrical, so the eye structure, characteristic of sheath folds, is flattened (see arrows). Moreover, the eye structures are rarely developed. The later deformation associated with cleavage may partly have destroyed the eye strucure. However, the main reason of the rare occurrence of sheath folds is considered to be a kinetics of the degree of non-coaxiality of deformation. In this case deformation is associated with a large shear strain, which is in harmony with a zone along a nappe or thrust sheet boundary forming sheath folds, or in more precise terms changing the line of the flow velocity (Ridley, 1986; Holdsworth, 1990). The shear strain (γ) is estimated to be over 10 on the basis of the equation $\alpha = \arctan \{B/C \cdot (\sqrt{\gamma^2+1})^{-1}\}$, here α is the intermarginal hinge angle and B/C is ellipticity of the sheath fold (Lacassin and Mattauer, 1985), although α can not be precisely determined.

The degree of vorticity will be discussed later in a separate paper.

Progressive deformation forming sheath folds makes a complicated deformed appearance. Taking the progressive deformation into account, only two major deformations (Cycles) are needed to account for the structures observed in the Tia complex.

Conclusions

Sheath folds in the Tia complex are described and two major deformation phases (CYCLE by Tobisch and Paterson, 1988) are indentified. The deformation which produced the sheath folds is as old as 310-320 Ma. The deformation style is non-coaxial with a large shear strain which locally produces typical sheath folds, suggesting a nappe boundary deformation.

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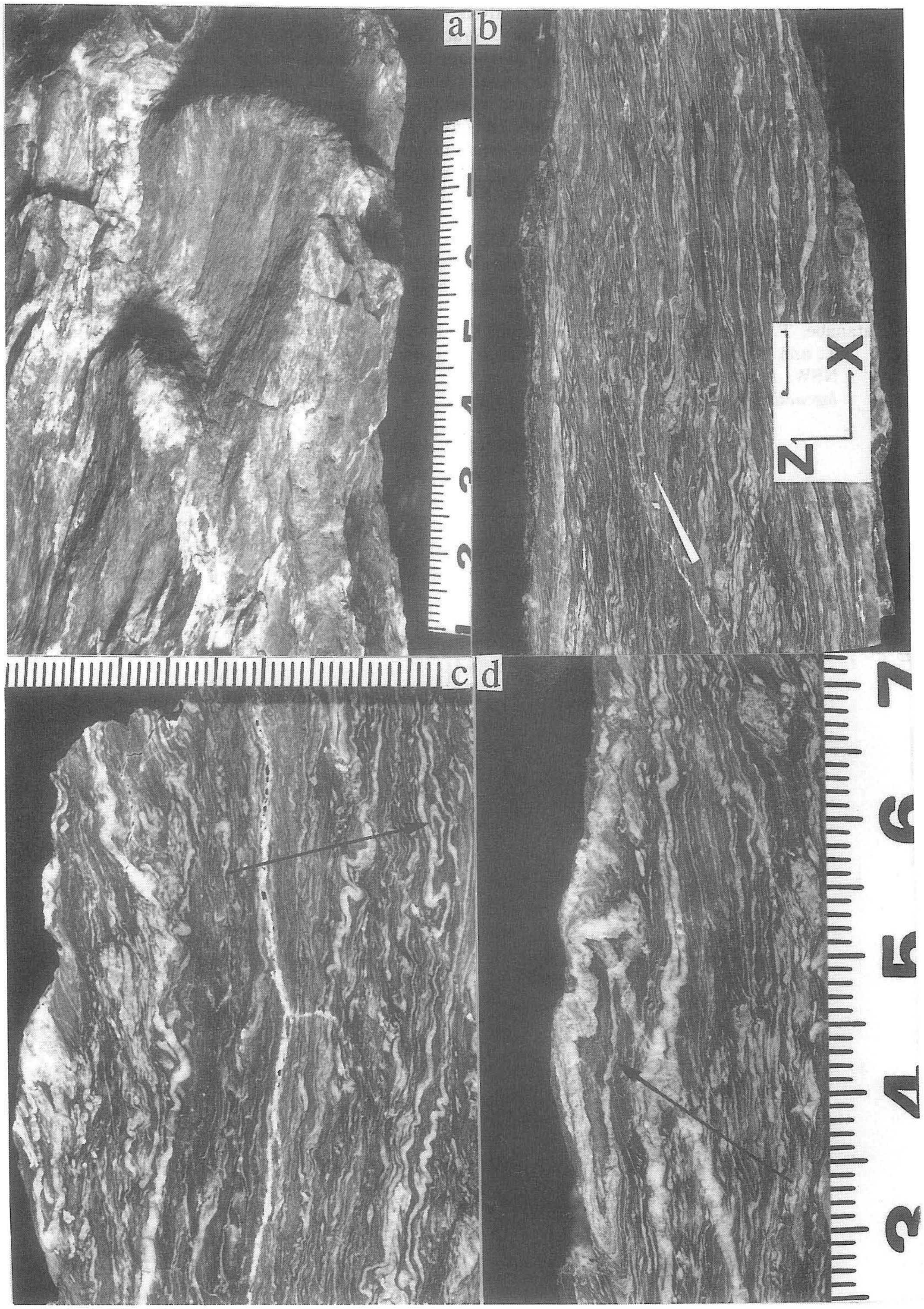
Explanation of Plate 1

a : Sheath folds in a hand-specimen of pelitic schist

b : A cross section parallel to elogated axes(X) of the sheath folds. an arrow is parallel to the axial plane cleavage of the earliest isoclinal folds. A while line is parallel to the later cross-cutting axial plane cleavage of small asymmetric folds. Scale is 1cm.

c & d : A cross section normal to elongated axes of the sheath folds. Arrows show flattened eye structures. (Photo by T. Hirama)

Plate 1



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