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Subduction complex melange of the Wandilla terrane, Palaeozoic New England Orogen, central Queensland, Australia

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Abstract—Devonian and Carboniferous rocks of the northern New England Orogen developed in a forearc setting in which the Wandilla terrane was part of the subduction complex. The Wandilla terrane shows three episodes of deformation. The first was associated with accretionary processes and formed lenticular and mud-seam melange. Lenticular melange was derived from interbedded greywacke and mudstone, bedded chert and greenstone and shows progressive bedding-parallel extension with pinch-and-swell and boudinage. It is characterized by an alternation between zones of semi-coherent beds and zones with total bed disruption. Mud-seam melange formed from thick-bedded greywacke units and is characterized by abundant mud injection features and scalloped greywacke contacts indicative of deformation of unconsolidated sediment and mobilization of overpressured mud. Both melange types formed at shallow structural levels in offscraped and imbricated successions. Lenticular melange resulted from stratal extension whereas mud-seam rocks were produced by the injection of overpressured mud into massive sands. The second and third deformations post-dated formation of the subduction complex and gave rise to a variably developed cleavage (S_2) and steeply dipping strike-slip faults, respectively.

INTRODUCTION

SUBDUCTION complexes are characterized by imbricate fault systems containing either intensely disrupted oceanic lithologies in tectonic melanges or relatively coherent folded marine successions (Karig 1982). In exposed ancient subduction complexes it appears that deformation has occurred during lithification of strata, especially in melanges containing disrupted slabs and lenticles in a predominantly mudstone matrix (e.g. Cowan 1985, Lash 1985, Agar 1988). This accords with offshore studies of active subduction zones, involving mainly drilling (Moore 1986, Behrmann *et al.* 1988), seismic reflection profiling (e.g. Moore & Shipley 1988) and other techniques such as three-dimensional sonar data (e.g. Ogawa 1985), that all demonstrate the role of early deformation associated with offscraping at the toe of the subduction complex.

In ancient uplifted subduction complexes an additional complexity is introduced by the extent that post-accretion deformation overprints and obscures the early accretionary structures (Knipe & Needham 1986). In this paper we describe the nature and structural succession found in melange of the Wandilla terrane, the subduction complex of the Devonian–Carboniferous arc–forearc system in the northern part of the New England Orogen (Fig. 1) (Murray *et al.* 1987, Fergusson *et al.* 1988). The basic melange fabrics formed at an early stage as a result of disruption by imbricate thrusting accompanied by mud injection and dewatering during offscraping. Later structures, in particular a moderately dipping cleavage and late-stage faults, have variously modified these rocks and partly obscured their early history.

REGIONAL SETTING

In the Rockhampton–Gladstone region of central Queensland the northern New England Orogen consists of the Yarrol terrane, the Marlborough terrane, the Wandilla terrane and the Shoalwater terrane (Fig. 1) (Fergusson *et al.* 1988). The Connors and Auburn Arches, located at the western margin of the Yarrol terrane, consist of Carboniferous silicic plutonic rocks and poorly documented silicic volcanics that are part of a magmatic arc (Murray *et al.* 1987). The Yarrol terrane comprises Devonian to Permian sedimentary and vol-

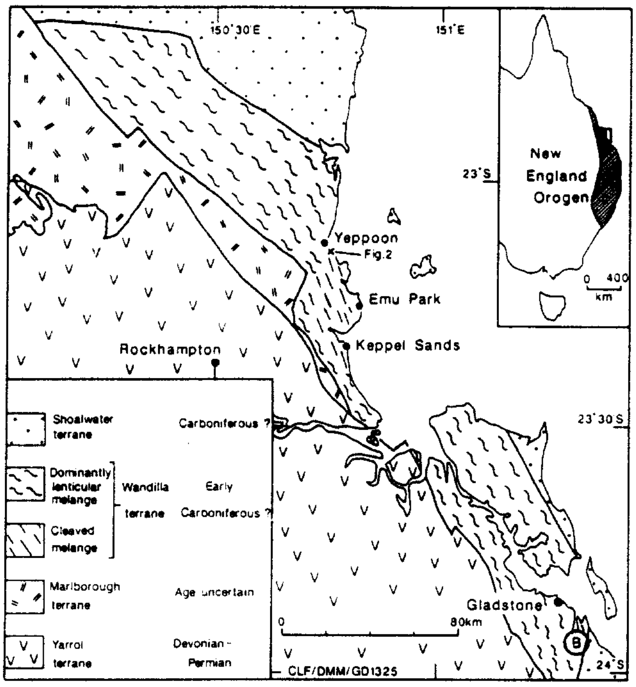

Fig. 1. Location of the Wandilla terrane within the northern New England Orogen (inset map) showing structural trends and extent of lenticular and cleaved melange (B—Boyne River diversion, see text). See Fergusson *et al.* (1988) for structural data and cross-sections of the Yeppoon and Gladstone districts.

canic successions which were deposited in a forearc basin and subsequently intruded by mafic to silicic plutons of Late Palaeozoic and Early Mesozoic age. The forearc basic strata consist of early to Middle Devonian andesitic volcaniclastics and limestone, Late Devonian andesitic volcanics and volcaniclastics, Early Carboniferous shallow marine clastic strata derived from an andesitic to silicic volcanic arc and interlayered with oolitic limestones, passing eastwards into deeper marine rocks, and Late Carboniferous marine clastics. Scattered units of Permian conglomerate, sandstone, mudstone and silicic volcanics unconformably overlie older successions. The contact between the Yarrol and Wandilla terranes is a major fault marked by discontinuous serpentinite bodies and a zone of extensive undated ultramafic and metamorphic thrust sheets grouped as the Marlborough terrane.

From west to east the Wandilla terrane consists of three units: greenstones of the Balnagowan Volcanic Member, the Doonside Formation containing chert, mudstone and greenstone, and the Wandilla Formation which forms the bulk of the terrane and consists of greywacke, mudstone, chert, tuff and greenstone (Kirkegaard *et al.* 1970, Willmont *et al.* 1986). The Wandilla terrane, in contrast to the Yarrol terrane, almost completely lacks fossils and is largely a tectonic melange. The Shoalwater terrane consists of a variably metamorphosed Palaeozoic succession of quartzose turbidite sandstone and mudstone. It has a history of polydeformation and is dominated by relatively coherent strata in contrast to the much more disrupted Wandilla terrane.

Both the Wandilla and Shoalwater terranes are regarded as part of a subduction complex with forearc basin and arc development in the Yarrol terrane (Murray *et al.* 1987). We consider that the Wandilla and Yarrol terranes were linked because of the similar distinctive oolith-bearing greywackes present in both terranes (Fleming *et al.* 1975).

STRUCTURE OF THE WANDILLA TERRANE

We have examined the Wandilla terrane over a strike-length of 350 km with a special regard for structures within the greywacke and mudstone dominated Wandilla Formation. Utilizing the excellent 1 : 250,000 geological maps of the region (Kirkegaard *et al.* 1970) we have conducted regional reconnaissance with detailed analysis in the areas of best exposure on coastal headlands (e.g. Fig. 2) and along numerous roads and creeks. The Wandilla Formation is dominated by two types of melange, lenticular and cleaved, which generally result from distinct deformations. The distribution of these melange types is shown on Fig. 1. Coherent strata are much more common adjacent to the Shoalwater terrane than elsewhere in the Wandilla terrane. The structure of the Shoalwater terrane and adjacent parts of the Wandilla terrane will be described in detail elsewhere (Fergusson *et al.* in preparation).

D_1 *structures*

The first deformation (D_1) was associated with widespread disruption which produced lenticular melange and far less abundant mud-seam melange.

Lenticular melange is characterized by a pervasive lenticular fabric that in restricted exposures could be mistaken for undisrupted bedding. It is developed in alternating greywacke–mudstone, tuff–mudstone units, chert and greenstone–chert units. Lenticular melange is widely reported in the literature and has the essential features of melanges described by Hsü (1973) and types I, II and IV melange of Cowan (1985).

There is a complete gradation between undisrupted strata and units with phacoid-in-matrix fabric in which the stratification has been completely destroyed (Fig. 3). Packets of coherent beds alternate with variably disrupted stata (see Fig. 7 of Bell 1987). Incipiently deformed beds show widespread pinch-and-swell which becomes more common and is associated with boudinage in more disrupted units (Fig. 3b). Most pull-apart features have developed by bedding-parallel extension achieved by plastic thinning and fracturing of competent beds. Plastic behaviour has probably been accommodated by grain-boundary sliding in either unlithified or lithified strata. At most places the extent of consolidation during melange formation is difficult to determine (e.g. Agar 1988), although our bias is that most of the material was lithified prior to deformation. This is because: (i) lenticular melange is identical to localized

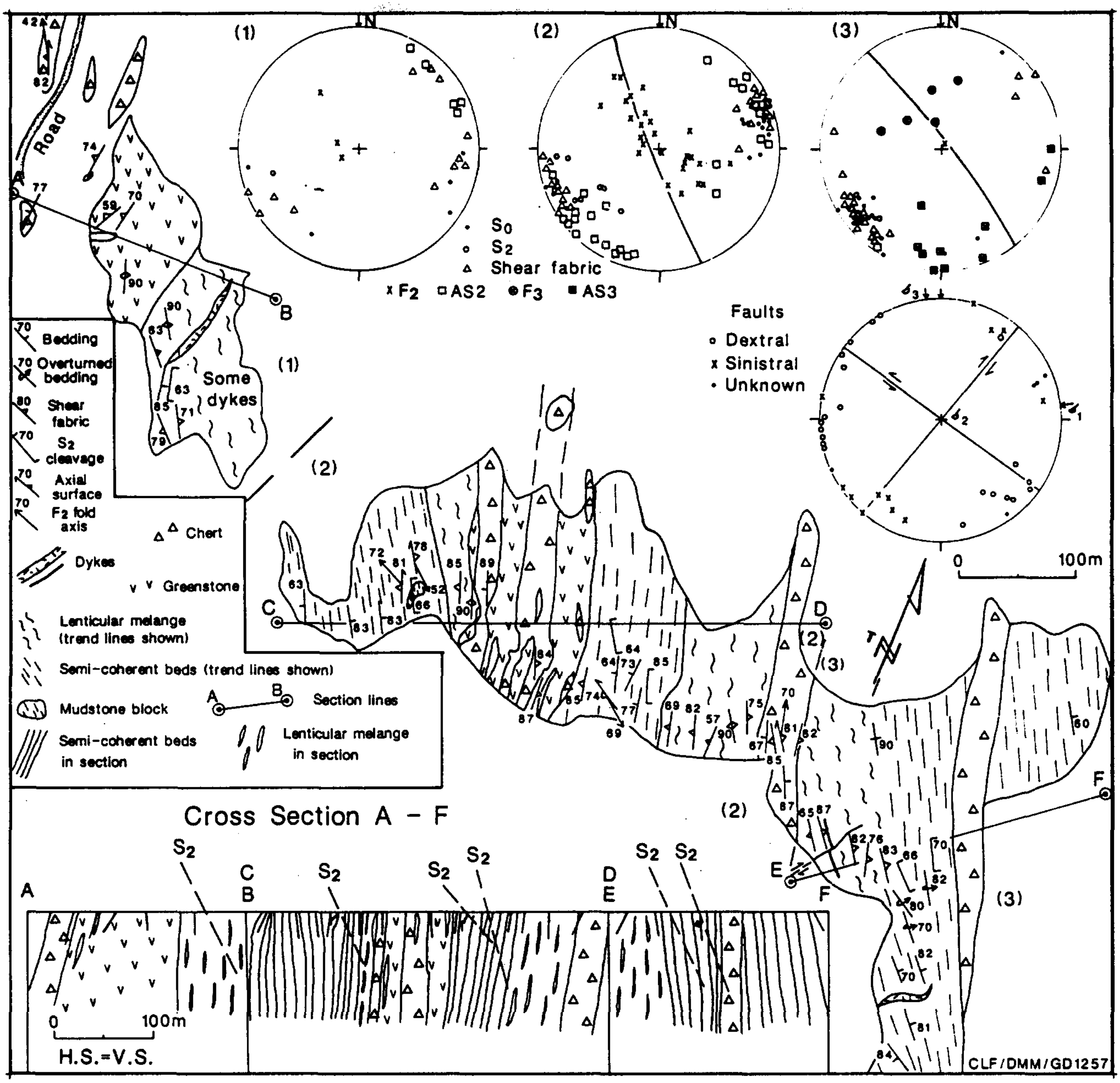

Fig. 2. Detailed map and cross-section of typical lenticular melange exposed along headlands at Wave Point to the south of Yeppoon (see Fig. 1 for location). Relationships here are particularly clear because of the weak post-melange deformation. Note that contacts between lithologies are all early faults. Equal-area stereographic projections, for the three domains marked on the map, show the orientation of poles to bedding (S_0), scaly fabric (S_f), S_2 cleavage, axial surfaces of F_2 and F_3 folds (AS2 and AS3, respectively), and F_2 and F_3 fold axes. Great circles in stereograms 2 and 3 show the average orientations of S_2 cleavage. The stereogram for the faults shows data from the whole map area with the great circles representing the average orientation of the sinistral and dextral fault sets.

melange that occurs along late-stage faults (see below); and (ii) in one example at Wave Point (Figs. 2 and 4a) a boudin of siliceous tuff preserves a soft-sediment slump fold indicating deformation of unconsolidated material prior to lithification and subsequent brittle and plastic extension.

As is being increasingly recognized in melange terranes (Needham 1987) both symmetric and asymmetric pull-apart structures occur in the Wandilla terrane. The best exposures are flat coastal headlands resulting in a bias towards detecting asymmetry, and therefore movement sense, in plan view. It is clear from vertical exposures that extension has been in all directions perpendicular to the layering (i.e. pure flattening or axially symmetric shortening). The only type of asymmetry widely encountered in the Wandilla terrane is the Type 2B asymmetrical pull-apart of Hanmer (1986), which resembles geometries described by Needham (1987) (see also Platt & Vissers 1980). Such asymmetric pull-aparts have formed by back-rotation during offset along shear zones in pinched areas (Fig. 4b). The shear zones are interpreted by Needham (1987) as Riedel shears with the same sense of shear as the main shear plane defined by the orientation of shear fabric in the matrix and symmetric pull-aparts. Indicators of dextral shear are widespread throughout the Wandilla terrane but sinistral asymmetric boudinage has also been recorded. Because of this no consistent shear sense is recognized for the whole terrane.

Small-scale injections of mudstone into greywacke phacoids are commonplace in lenticular melange of the Wandilla terrane as has been reported elsewhere (e.g. Korsch 1982, Lash 1987), and this indicates that mud was present at the time of deformation.

Mudstone and greenstone matrices within the lenticular melanges have a scaly fabric (S_f) parallel to symmetrical lenticles. Scaly fabric is best preserved within inland exposures where weathering has accentuated primary anastomosing fractures, splitting the rock into many small chips with polished faces and steeply pitching striations. In the coastal exposures the scaly mudstone is preferentially degraded and in many places the fabric is difficult to distinguish from spaced cleavage. Greenstones contain a less pervasive scaly fabric which in thin section consists of many chlorite-filled microfaults, arranged in an irregular network with most veins crudely sub-parallel and cut by thicker carbonate veins. Overall the fabric is parallel to symmetric boudins, which are dominant in this lithology. Scaly fabric in both the mudstone and greenstone developed by brittle deformation (see Moore 1986).

Abundant faults cut the lenticular melange, commonly forming contacts between different rock-types, and these are responsible for the overall imbricate repetition of rock-types in the Wandilla terrane. Such faults are mainly parallel to the gross orientation of lenticles but locally truncate trends at the margins of fault slices (Fig. 2). Detailed mapping of selected areas indicates that the spacing between faults is commonly 10–200 m. Many bedding-parallel faults amongst the mass of poorly to well developed lenticular melange remain undetected. Contacts between rock-types are sharp, except for greenstone–chert lenticular melanges, which consist of fragments of chert and more resistant greenstone up to several metres in length embedded in a greenstone matrix indicative of pervasive mixing. Outcrops with mixed chert, greenstone, tuff and greywacke in a mudstone matrix, reported from many melange terranes (e.g. Fergusson 1984, Bell 1987), have not been found in the Wandilla terrane.

In common with other melange terranes, trains of small-scale folds abound in cherts and are much less common in greywacke–mudstone units. They are typically developed in intervals up to 2 m in thickness where the strata are more coherent. Most folds are tight to isoclinal with shallow to steep plunges and steep axial planes parallel to local structural trends. Some exposures show sporadic early folds contorted by the dominant tight folds. Many folds have highly asymmetric profiles and thickened hinges that indicate substantial plastic behaviour, reflecting a lack of lithification at the time of deformation (cf. Brueckner *et al.* 1987). In areas dominated by chert, with no interbedded mudstone, contacts between the chert layers are strongly anastomosing and appear in thin section to be stylolites similar to those reported by Brueckner *et al.* (1987). The distinctive structural state of chert reflects its variable rheological behaviour due to a long-continued process of lithification and diagenesis accompanying deformation.

At Gladstone (Fig. 1) mudstone and greenstone matrix is more highly strained than elsewhere in lenticular melange and contains a slaty cleavage (S_1). This region coincides with a higher, probably lower greenschist facies, metamorphic grade in contrast to the remainder of the lenticular melange in the Wandilla terrane, which is typically prehnite–pumpellyite facies (Fergusson *et al.* in preparation). These rocks resemble the cleaved melange developed during the second deformation (see below) except in the orientation of the cleavage, which is parallel to adjacent steeply dipping N-trending lenticular melange. In contrast, nearby D_2 cleaved melange at the Boyne River diversion is flat-lying (Fig. 1, locality B, see also Fergusson *et al.* 1988). In addition to slaty cleavage there are also tight to isoclinal upright folds with S_1 developed as an axial planar structure. Such folds have no consistent vergence and have as a form-surface the lenticular melange fabric. Clearly the first deformation is a multi-phase event with lenticular melange forming first and postdated by higher-strain fabrics including cleavage and folds in tracts of higher metamorphic grade.

Mud-seam melange occurs in greywacke-dominated zones up to 50 m in thickness in which bedding has been largely obliterated and mudstone injections up to 1 m in width are widespread. Many of the seams have irregular flame shaped margins which lack a consistent orientation (Fig. 4c). Greywacke forms bulbous masses with irregular contacts. Internally these greywackes are either structureless or contain abundant criss-crossing planar seams of mudstone less than 0.5 cm in width formed by mud injection. Cutting both the irregular greywacke–mudstone contacts and the more uniform thin mud seams are randomly oriented quartz and carbonate veins. Thus the overall structure records deformation accompanying lithification in three stages: (i) massive disruption by mobilization of mudstone and greywacke layers with the loss of stratification and other sedimentary structures; (ii) lithification of greywackes and brittle fracturing enabling partly fluidized mud to penetrate along fractures; and (iii) lithification of all mud accompanied by build up of fluid pressures to enable brittle fracture to form mineral-filled veins (Norris & Henley 1976).

Mud-seam melange occurs in the greywacke-rich portion of the Wandilla terrane and it is likely that it was restricted to rapidly deposited, poorly stratified water-rich greywacke-dominant successions that underwent massive liquefaction and soft sediment disruption. The lack of any obvious imposed anisotropy is unusual for any deformation process, including either tectonism or soft sediment slumping. The mud-seam melange demonstrates that deformation of unlithified materials was at least locally important.

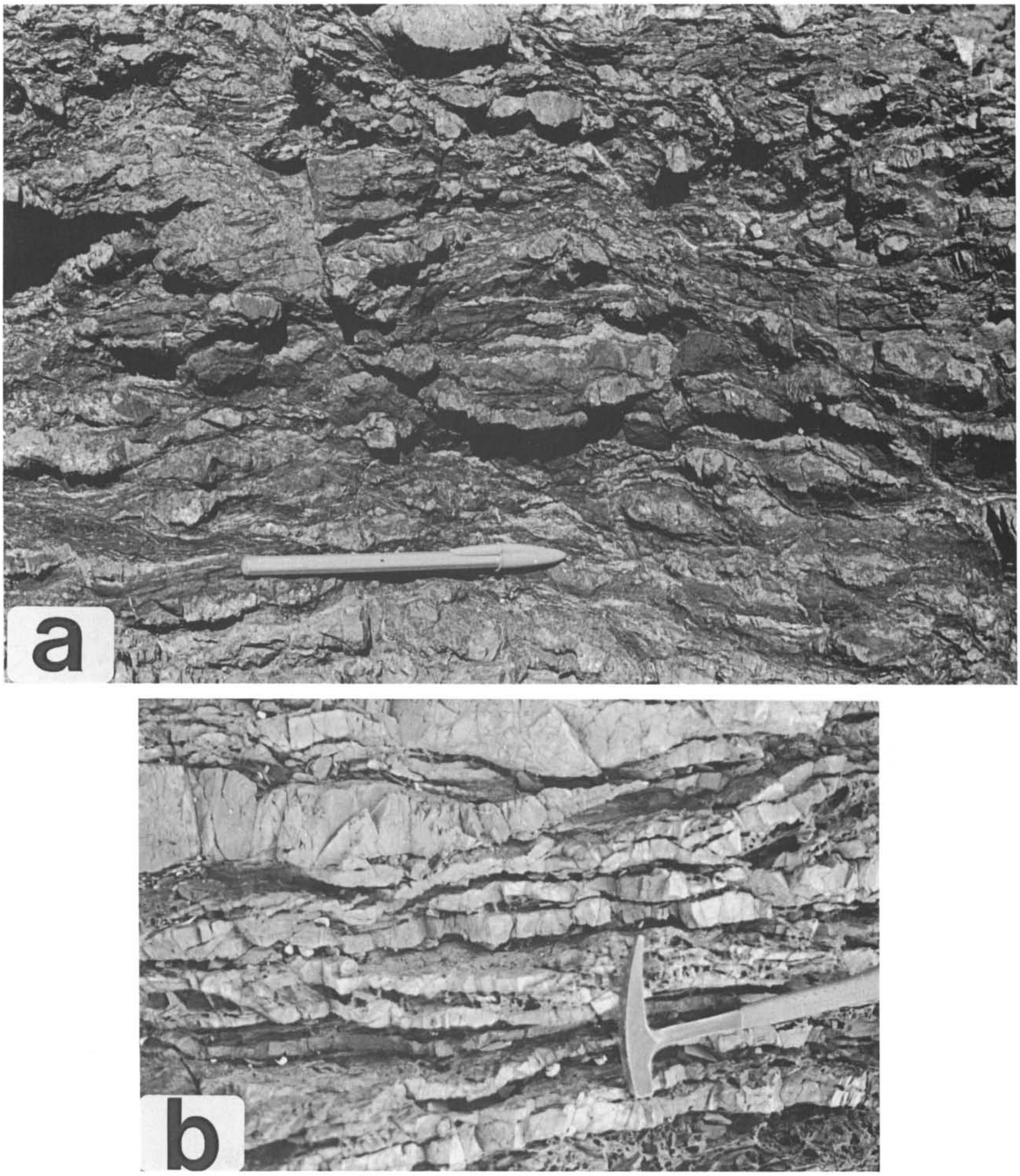

Fig. 3. (a) Lenticular melange with strongly necked terminations (lenticles) contained in a sheared matrix. Clearly this rock was derived from an initially stratified succession. (b) Lenticular layering developed in more coherent interbedded greywacke and mudstone at Wave Point.

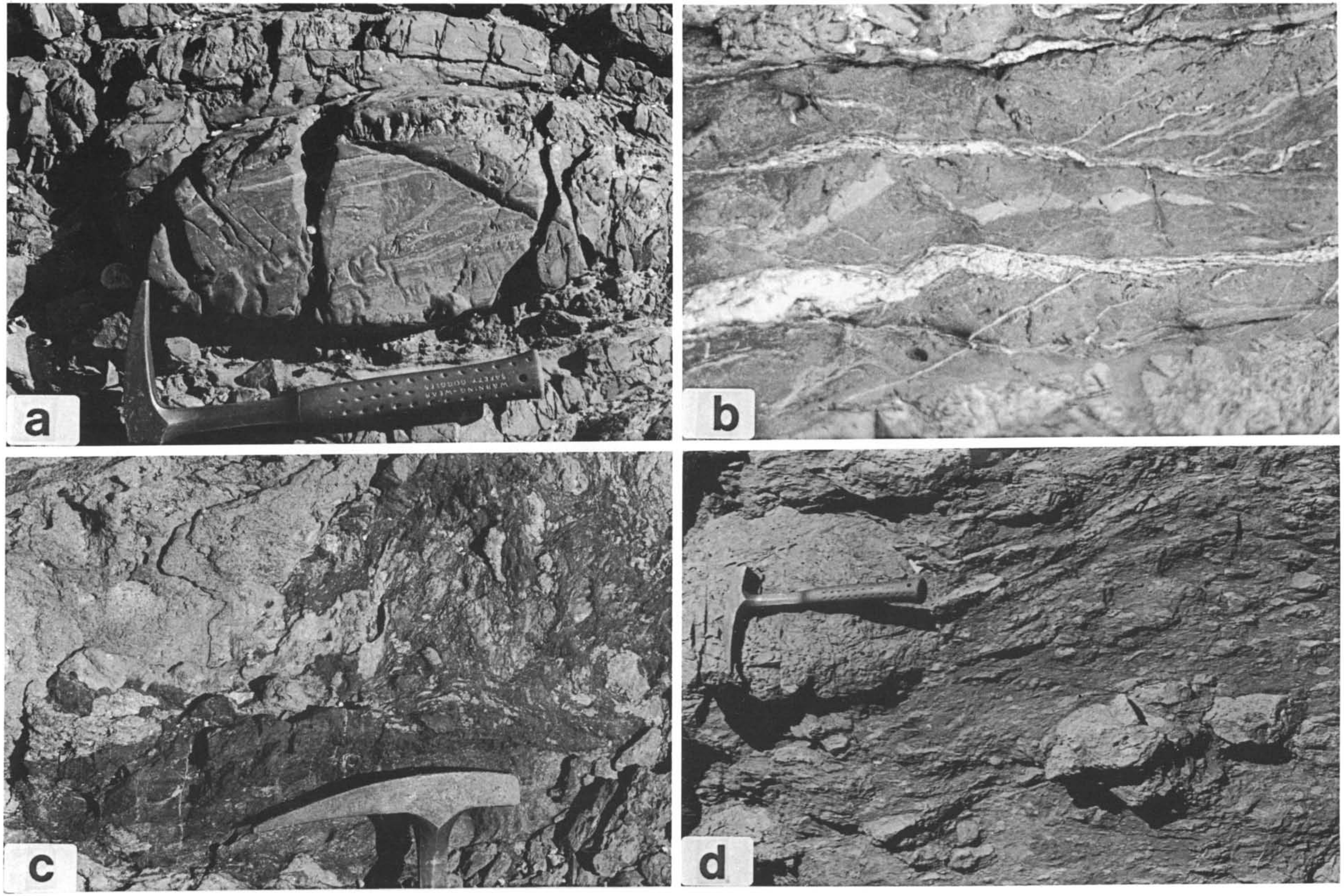

Fig. 4. (a) Fragment of siliceous tuff containing internal lamination with an early soft sediment slump fold. (b) Layer-parallel extension of a thin tuff layer (1 cm thick) accommodated by dextral shears with back-rotation of the bed fragments at Wave Point. (c) Irregular flame-like contact between mudstone and greywacke in a mud-seam melange at Tanby Point (located 2 km north of Emu Park on Fig. 1). (d) Cleaved melange viewed looking down onto the *XY* plane with fragments of greywacke stretched out in the cleavage plane.

D_2 *structures*

In many areas of the Wandilla terrane pod-in-matrix fabrics are modified by a well-developed cleavage and associated folds, elongation lineations, intersection lineations and mineral-fibre coated fault surfaces. In areas of intense deformation fabrics resemble those of a stretched pebble conglomerate (Fig. 4d). Lenticle layering overprinted by cleavage, and folds with lenticle layering as a form surface and cleavage as an axial planar structure, demonstrate that the cleavage was imposed on a pre-existing lenticular fabric. Where the earlier lenticular melange fabric is not transposed parallel to S_2 the S_f–S_2 angle typically implies an antiform to the east relationship with S_f dipping more steeply than S_2. In areas weakly affected by this deformation, a spaced cleavage is sporadically developed. For example at Wave Point spaced cleavage in mudstones dips eastwards more shallowly than nearly vertical bedding and/or shear fabric (Fig. 2). This cleavage is axial planar to close to tight asymmetric folds in the lenticular melange.

D_2 structures are extensively developed in an area of 100 km^2 around Emu Park and Keppel Sands (Fig. 1). Throughout this area there is a pervasive slaty cleavage dipping moderately east with a down-dip stretching lineation formed from elongation of mainly small greywacke lenticles. F_2 folds with axial planar S_2 slaty cleavage are uncommon and are tight with reclined hinges. They are difficult to distinguish from strongly appressed flame structures in the mud-seam melange.

Further south at Boyne River (locality B on Fig. 1) a shallowly dipping S_2 slaty cleavage is strongly developed and is the dominant feature of the rocks. A prominent lineation is developed at the intersection of the cleavage with lenticles. No overprinting is seen between this cleavage and the S_1 cleavage further north at Gladstone. S_f scaly fabrics were destroyed under the metamorphic conditions associated with the new mineral growth during the D_2 deformation and as a result the only trace of the D_1 deformation is the intersection lineation between S_2 and S_f. At one locality (GR 283443 Calliope 1 : 100,000 Topographic Sheet) a stretched sand-grain fabric has been found parallel to the lineation.

D_3 *structures*

In many exposures there is abundant disruption by steeply dipping faults orientated at 30–45° to the lenticular layering and scaly cleavage of the mudstones. These are strike-slip structures with offsets and fault-related flexures indicating that they formed by compression perpendicular to the lenticular fabric (Fig. 2, see stereogram showing the orientation of late faults). Mineral infillings along these faults indicate their undoubted tectonic origin, relatively late in the deformation history. In some such faults 10–30 cm wide shear zones contain lenticular melange, developed amongst more coherent host rocks. These structures have accentuated the degree of disruption in the melange.

Fault breccias abound in the chert units and form anastomosing networks that cut across the autoclastic melange fabric and sometimes occupy as much as 50% of the chert units. They are clearly associated with the late-stage faults. They consist of angular fragments of chert contained in a poorly sorted Fe–Mn stained matrix that has no scaly fabric but is irregularly fractured. Internally the chert clasts also have irregular fractures and overall the rock has the appearance of a high-level fault breccia and has clearly formed by *in situ* brecciation of cherty lenticular melange.

Locally in the Emu Park area the D_2 slaty cleavage is affected by kinks and open folds with a steep N–S axial planar crenulation cleavage and an incipient crenulation lineation. In the Boyne River diversion area the D_2 slaty cleavage is folded by a set of open upright N–S folds with an axial planar crenulation cleavage. The folds verge east and cause the decrease in dip of cleavage adjacent to the terrane boundary.

DISCUSSION

Offscraping and accretion

Until recently the principal mechanism of growth of subduction complexes was thought to be by offscraping at the toe of the trench slope (Karig & Sharman 1975). Now it is argued that growth may also be by underplating or subcretion (Platt *et al.* 1985). In uplifted subduction complexes distinction between underplating and offscraping is possible where the former occurs at depth with a characteristic higher grade of metamorphism and a dominantly ductile, as opposed to brittle, deformation history (e.g. Sample & Moore 1987). Many components in uplifted subduction complexes, however, do not show evidence of deep burial and are dominated by rocks deformed at shallow structural levels, thus making distinction between offscraping and underplating problematic (e.g. Agar 1988).

In the Wandilla terrane the only evidence for a deeper structural level occurs in the Gladstone area where the local folding of scaly foliation with S_1 as an axial planar cleavage demonstrates progressive formation of melange under gradually increasing (although always modest) temperatures and pressures. It is possible that these rocks were underplated at some depth below the subduction complex (Fig. 5). For the lenticular melange that makes up the bulk of the Wandilla terrane, however, it is not possible to demonstrate any connection with underplating and an offscraping mechanism of accretion is favoured (Fig. 5).

Offscraping is seen as responsible for the lithologic content of the Wandilla terrane, which formed from imbrication and disruption of a trench floor and fill succession with greenstone at the base, overlain by chert which in turn is overlain by thickening and coarsening upwards turbidites. The association of highly deformed chert and greenstone marks the base of the offscraped units, and is common in many melanges that have been interpreted as parts of subduction complexes. In con-

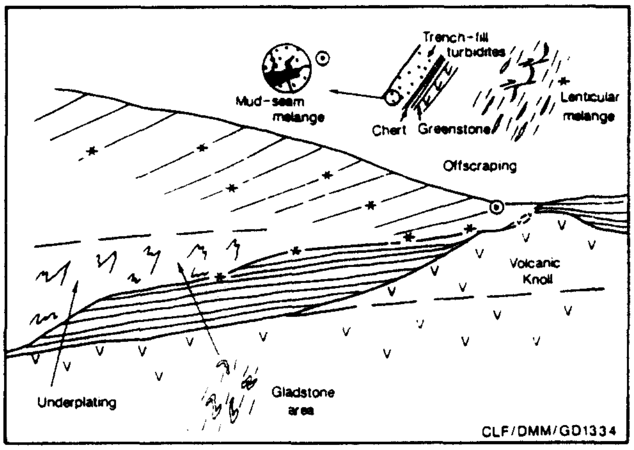

Fig. 5. Proposed origin for lenticular melanges, mud-seam melanges and D_1 cleaved melanges of the Gladstone area in the Wandilla terrane (in part after fig. 15 of Sample & Moore 1987, and incorporating a volcanic knoll as imaged by Davey *et al.* 1986 in the Hikurangi margin off the North Island of New Zealand). Lenticular melange (as shown in Fig. 2) is regarded as forming at relatively shallow levels due to offscraping at the toe of the subduction complex (*—mark location). It also develops along the main basal detachment below the subduction complex and throughout the mass of offscraped material under the lower trench slope (as shown by the asterisks). In contrast mud-seam melange developed only at the toe of the subduction complex where water-charged sediments are thrust directly under older imbricate slices (⊙—marks location). Underplating produces D_1 cleavage and folds imposed on lenticular layering. The pre-melange stratigraphy shown in an offscraped slice (see Cawood 1982 and Fergusson 1984) implies that considerable topographic features in the form of volcanic knolls must have been added to the subduction complex.

trast, most seismic sections of active subduction zones show that igneous basement is not incorporated within the offscraped material (e.g. Moore & Shipley 1988). Davey *et al.* (1986), however, have imaged a volcanic knoll entering the Hikurangi margin off the North Island of New Zealand and we interpret the presence of seamounts and their subsequent decapitation as essential for the development of lenticular melange in the Wandilla terrane (Fig. 5). The seemingly randomly oriented shear directions indicated by the asymmetric boudins suggest that offscraping and accretion involved complex shuffling of stacked sheets rather than undirectional shear parallel to the convergence vector.

Genesis of lenticular melange

In common with most other melange types the primary cause of lenticular melange was extension and ultimately rupture of stratification (Bell 1987). Axially symmetric extension was the dominant process but was locally modified by the imposition of a shear component to produce asymmetric boudinage. Extension was accommodated in the more competent rocks by plastic flow in narrow shear zones, which developed as Riedel shears to the main slip planes along the scaly foliation, and subsequently underwent brittle failure due to larger strains. As described by Platt & Vissers (1980) the extensional fractures delineating the 'ends' of the individual boudins curve into the cleavage–scaly foliation in the less competent matrix. Variation in the degree of disruption indicate that extensional shear was inhomogeneously distributed, perhaps as function of proximity to the surface of detachment from the subducting slab. The deformation invariably shown by greenstones is accounted for by this mechanism (Fig. 5).

Contrary to the views of Moore & Byrne (1987) who suggested that disruptive processes in subduction complexes result from the progressive strengthening of sheared rocks, we stress the importance of competency contrasts arising from stratification. In the Wandilla lenticular melange there is very little evidence (rare clastic dykes and mud injection) that suggests disruption occurred before lithification of the sediment pile. After lithification the marked contrast in competence between sandstone and mudstone exerted a major control over the nature of the lenticular melange (see Lister & Williams 1983, p. 21).

Genesis of mud-seam melange

The Wandilla mud-seam melange provides a new perspective on early deformational processes involved in melange formation. It resulted from hydraulic injection of overpressured mud layers into more competent but low-strength sandstone. Imbricate thrust stacking of unconsolidated sediments as occurs in accretionary subduction complexes is probably critical to formation of this type of melange. Stratal packets underthrust at the accretionary toe insert water-charged sediments into the base of the subduction complex (Fig. 5). Load-induced dewatering, possibly enhanced by shear on thrust soles (Bray & Karig 1985), caused fluid pressures in excess of lithostatic pressures in rocks higher in the complex, decreasing their effective strength and causing liquefaction in the more clay-rich mudstones. The mobile mud injected into the adjacent sands.

In a recent paper Pickering *et al.* (1988) described mud injections in melange from SW Japan that have many of the characteristics of the Wandilla mud-seam melange. However, they emphasized the role of mud diapirism in disrupting basalt–limestone–chert associations, presumably as a result of the rise of mud from an underlying thrust slice. In the Wandilla rocks there is no evidence for movement of mud other than within the same slice, and mud injection has never affected chert–greenstone units.

Modification of melange fabric by later deformation

Overprinting of pre-existing melange structure by S_2 slaty cleavage has had several effects, the most noteworthy of which has been the distortion of originally axially symmetric lenticular melange into triaxial pseudoconglomerate. The D_2 deformation represents a substantially younger event in the history of the New England Orogen that post-dated formation of the subduction complex. Fault displacement of lenticular layering is widespread and has contributed significantly to the broken appearance of the melange. Of particular importance in this regard is the presence of many fractures that intersect lenticular layering at a high angle and have been responsible for compression perpendicular to the direction of this layering. These fractures cut the S_2 cleavage and therefore arose late in the deformation history of the Wandilla terrane.

Overview

There is no evidence that the melanges of the Wandilla terrane formed by gravity driven, surficial mass-flow. The absence of exotic, extra-formational blocks, the gradational development of lenticular melange from coherent strata and the regional development of this lithology argue against debris-flow mixing. The pervasive distribution of this melange, the oblate ellipsoid fabric, and the rarity of soft-sediment folds precludes slumping. Many of these characters also conflict with formation of such melange by mud diapirism (cf. Williams *et al.* 1984). We conclude that melange in the Wandilla terrane has formed principally by offscraping at the toe of a subduction complex and that later deformation has enhanced the extent of disruption.

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