Tasmania Department of Mines—Report 1989/41

Fold related mesoscopic structures in the Mathinna beds: Field relationships compared with text-book relationships

by E. Williams

Abstract

The field relationships between folds and the genetically and/or geometrically associated mesoscopic structures of cleavage, joints and quartz veins in the Mathinna beds differ from the commonly accepted relationships presented in text books. Methods, which may be of importance in gold exploration, are given to predict localities of the maximum development of fold-related quartz veining in folded Mathinna beds which have been laterally buckled about steep axes.

INTRODUCTION

The Mathinna beds, of unknown thickness, consist of all the folded sedimentary sequences of eastern Tasmania older than the unconformably overlying rocks of the St Marys Porphyrite, which is dated 388±1 Ma (see Williams, 1989; Turner *et al.*, 1986). A dominantly lutite association has yielded graptolites of early Ordovician (Arenig) age west of Pipers River (Banks and Smith, 1968), whereas Early Devonian fossils have been recovered from the arenite-lutite associations elsewhere (e.g. Rickards and Banks, 1979). Diagnostic Silurian fossils have not been found (Banks and Baillie, 1989).

The Mathinna beds (e.g. Williams, 1959; Marshall, 1969; Turner *in* McClenaghan *et al.*, 1982) consist of conformable sequences of interbedded mudstone, siltstone and sandstone.

The mudstone comprises usually featureless layers of fine mica and quartz, and has the negative characteristics of sediment quietly deposited from normal dilute fluid suspensions. The only evidence of life that existed at the sites of deposition is the occasional presence of worm-like grooves on mud surfaces and rare graptolites.

The sandstone beds are generally some 0.25–0.5 m thick. They are usually poorly sorted and commonly graded from a coarser median size grade at the base to a finer laminated siltstone top. Chunks of mudstone often occur. Fragmented marine fossils have been recorded, together with the vascular plant *Hostimella.*

Current markings in the muds are usually preserved as casts on the soles of the sandstone and coarser siltstone layers. Small-scale current bedding is sometimes developed in the silty laminated tops of the graded beds. Occasionally the laminated sandstone displays convolute folds where deformation has resulted from liquefaction due to hydrostatic overpressures during water escapement.

Whereas mudstone has the negative characteristics of sediment formed by quiet deposition from dilute fluid suspensions, the sandstone layers have the characteristics of deposition from density currents which are usually turbid.

The Mathinna beds are everywhere folded, and in order to determine as best as possible rock distribution in three dimensions, the basic aim of mapping, data has to be collected at all localities on any structures which help in giving geometrical information on folds.

Many mesoscopic structures genetically and/or geometrically related to folding occur within the Mathinna beds. Obviously, if the geometrical relationships between the ubiquitous minor structures and the uncommonly observed folds are known, then these common structural features can be used to predict more accurately the three-dimensional distribution of the folded rock sequences. However, relationships can really only be established by fairly detailed local work on the best exposed outcrops. Awareness of the locally-derived knowledge of the relationships will, of course, lead to lesser errors in predictions than if the generalised relationships based on work abroad and presented in text books were accepted and applied to sparse data from poor exposures in bush-covered areas in NE Tasmania. Indeed, there are many possible pit-falls in applying information from text books and dealing with sparse data. Shortcomings in this approach will be illustrated by briefly considering, from a number of localities, cleavage, joints and veins developed in the Mathinna beds.

CLEAVAGE

Value of cleavage/bedding intersections

Primary cleavage, which is of layer-silicate films with grains of quartz and feldspar commonly showing beards of quartz and platy mineral fibres, is well developed in the Mathinna beds. This first-formed cleavage is associated with horizontal or gently plunging, usually SSW-trending folds of many orders of size. The folds are typically asymmetrical, long-limbed with narrow hinge zones, and their axial surfaces usually dip steeply to the south-west. In fold profiles the cleavage displays spectacular upwardly divergent fans in the sandstone layers, and convergent fans in the mudstone beds about the fold hinges, which are the zones of the maximum rate of change of curvature.

Although the cleavages are not exactly parallel to the traces of the axial surfaces in the profiles of the folds, they are named axial plane cleavages. Because of their systematic fanning about fold hinges, their line of intersection with bedding planes is commonly accepted in text books as approximately parallel to the fold hinge, and used to indicate the direction and plunge of the folds (e.g. Ramsay, 1967). Such information is very important in bush-covered regions where outcrop may be uncommon and fold hinges are rarely observed. However surprising results were obtained in testing the validity of these methods in excellent coastal exposures at Stony Head on the north coast to the north-east of Launceston.

At Stony Head (Williams, 1970) the bedding surface traces of cleavage of fans, with a spread of some 70° about fold hinges, strike up to 30° away from the fold hinge lines and vary in plunge by much more than 7° on the same hinge (fig. 1). This means that the cleavage of a fan centred on a fold hinge, in profile, is actually considerably twisted along the length of a hinge, and to take bedding/cleavage intersections as the fold direction in country of poor exposure could lead to considerable errors.

The sandstone cleavage at Stony Head is kinked and these structures can be used to indicate how cleavage fans are formed, which gives additional information about the reliability of bedding/cleavage intersections in determining distribution of folded rock types.

The kink bands are thin, lenticular, and monoclinal fold zones. There are four sets which belong to two conjugate systems. When the poles of each kink set are plotted with the corresponding undeformed cleavage surfaces on an equal area net (fig. 2), the variation in the dip of the undeformed cleavage is accompanied by systematic variations in the plot of the poles of the corresponding kink bands. Rotation about a single axis of all the undeformed cleavage to approximate parallelism is accompanied by rotation along small circles about the same single axis of the two pairs of conjugate sets with each set to a single maximum. Because of the remarkable simplicity of the pattern of the structural elements it has to be concluded that the development of the kink bands occurred when the cleavage was of uniform orientation throughout the sandstone layers. Rotation of the cleavage about an axis into fans spread the kink-band poles along small circles. The rotation obviously took place near to or about the pre-existing hinges, with folds becoming more tight by progressively greater squeezing or flattening within the inner zones of the hinges. Such flattening would result in some convergence of bedding/cleavage intersections with the hinge line. It can, therefore, be appreciated that a present-day variation of 30° between hinge line and bedding/cleavage intersections would have been even greater if the folds had not later tightened to a 70° fanning of the cleavage.

Characteristics of primary cleavage

Not only is the field relationship between fan cleavage and folds of the Mathinna beds exceptional by comparison with descriptions presented in text books, but so also is much of the first-formed cleavage itself.

Commonly, cleavage seams within the sandstone layers of the Mathinna beds appear to have a bimodal distribution of orientation, imparting a trapezoidal appearance to the fabric. In earlier text books the complimentary surfaces were known as shear cleavage (e.g. Hills, 1972). These cleavage structures are most clearly seen in the excellent outcrops on the foreshore at Bellingham on the north coast.

These primary cleavage structures at Bellingham are fanned or splayed about the fold hinges. However, the complementary surfaces may be modified in ways which do not appear to have been recorded. In the immediate vicinity of hinges at Bellingham the cleavage surface more nearly parallel to the axial surface is usually the dominant one and often crenulates the other — this relationship alternates from fold limb to fold limb, and must result from tightening of the folds during the same deformation phase. Obviously, if limited outcrop in bush-covered regions yielded a specimen with two similarly spaced cleavage surfaces but with one crenulating the other, then errors may be made in assessing the number of folding episodes in the deformational history required to determine the three-dimensional distribution of rock units.

So far only modifications to the complementary synchronous surfaces which make up shear cleavage have been described. However the primary cleavage at Bellingham does not consist of only two surfaces but three. The three well-developed surfaces appear to be contemporaneous, for they form a continuous system in the sandstone layers. The third surface, which does not appear to have been described in the literature, occurs in the lowermost and uppermost portions of the sandstone beds, and branches into the other two surfaces in the middle part of the layers. Surfaces of this third set are orientated parallel to the bisectrix of the other two cleavage surfaces (fig. 3). They are often occupied by mudstone wedges continuous with the adjacent mudstone layers above as well as below the sandstone beds. Unfortunately the third set of cleavage surfaces can be confused with sedimentary mudstone flames at the sole of the sandstone. Thus, if the occasional mudstone wedge in sandstone at the bed boundary is used alone in poor outcrop to determine the facing of the bed, then the conclusions may be wrong.

JOINTS

Evidently an empirical approach is required in using cleavage to determine the nature of the folds in the Mathinna beds. This type of approach is even more essential when examining such equally well-developed and ubiquitous minor structures as joint sets.

The common joints occurring within the Mathinna beds are smooth, straight cracks along which there is a lack of visible displacement. The joints, which may be confined to a bed or traverse a number of layers, occur in approximately parallel arrays constituting sets. The surfaces of joints of all the sets, where freshly exposed, show delicate plumose markings.

These are the types of joints which have been widely described and discussed in text books. Orientations of joint sets in folded rocks have received a great deal of attention, and have been commonly analysed in terms of the theory of Mohr, where joints may develop in conjugate sets parallel to the median stress direction and making an acute angle bisected by the largest stress direction, and as cracks orientated parallel to this largest stress and perpendicular to the smallest stress. In various studies reported in the literature orientations of joint sets with respect to folds have been plotted and, employing Mohr's theory, developments of local stress fields during folding determined. Such determinations have been summarised in Figure 4 (after fig. 88 of De Sitter, 1956), which is a stereographic representation of possible joints in an anticlinal structure. The orientations of the joint sets have been related to fold trends, but text books vary in their conclusions as to whether the joints formed at the onset of folding, formed continuously during folding, or in the latter part of a fold phase. Crucial to text-book analyses is the recognition and establishment of any conjugate joint sets which may be present.

Relationships between joint sets and folds in the Mathinna beds have been looked at in the excellent rock exposures near Rossarden (Williams, 1967). Attitudes of all naturally-occurring joint surfaces at each outcrop were determined.

The frequency of joints can be gauged in Figure 5, which also illustrates that whereas a majority of the fractures are terminated or deflected by bedding planes, there is no consistency in the terminations and deflections of joints of one set by those of another. Indeed, no consistent order in such relationships occurs in all the many localities examined, which indicates contemporaneity in the development of all the joints and the lack of any indication of conjugate pairs.

Equal-area plots of the poles of all of the joints at outcrops of beds of the dips specified (fig. 6) show concentrations in girdles at approximately right angles to the bedding, and such patterns have been confirmed where bedding could not be determined without chipping the outcrop to establish the layers of finer or coarser size of grain. In most cases equal-area plots have shown that a maximum occurs within the girdle distribution of the joint poles quite near the plot of the local fold axis, which was either measured directly or calculated from the intersection of bedding planes.

The characteristic pattern of joints in the folded Mathinna beds is of use in giving a general indication of the attitudes of bedding planes and fold trends in poor outcrops where such information is not easily obtained. However the usefulness of joint sets is limited, as not only is determination of conjugate pairs dubious, but also most pole-maxima of the fractures disappear into a continuous even density girdle when the equal-area plots of all the beds of different attitudes around a fold are added together. Thus the considerably more information obtained from joints about fold structures presented in some text books (e.g. De Sitter, 1956; Hobbs *et al.*, 1976) cannot be gleaned from the joints of the Mathinna beds.

Much has been written on the timing of joint development with respect to folding. However, with full regard of the conclusions presented in various text books (e.g. De Sitter, 1956), it appears to be self-evident that planar joints with feather-marked surfaces must be post-folding, for even in the simplest and least complicated type of folding, planes become curved, and the movements, albeit measured in microns, would obliterate the delicate surface markings. Nevertheless, the attitudes of the folded beds must have imparted considerable anisotropy, with most joints forming approximately perpendicular to bedding and a notable number forming at about right angles to the local fold axis.

The sets of planar joints in the Mathinna beds, then, were post-folding, and near Rossarden they can be shown to have developed prior to the deposition of the unconformably overlying flat-lying Permian beds, for representatives of all the Mathinna joint sets either form joint-bounded contacts with the basal Permian beds or had been sufficiently opened for the introduction of clastics as thin neptunian dykes. At another excellent rock exposure some 20 km to the south of Rossarden the Mathinna joint sets can be similarly shown to have been present during granite intrusion in late Devonian times (Williams, 1969).

Other discrepancies between relationships presented in text books and those encountered in the field become apparent in comparing the orientations of joints in the Mathinna beds with those of the planar fractures with feather markings in the overlying Permian. In the Permian rocks joint sets form a consistent regional pattern, and stresses responsible for their development must have operated in the underlying Mathinna beds. However no joint was observed crossing the unconformity, and Figure 7 shows that no joint set within the Mathinna beds has a similar orientation to those of the overlying Permian rocks. This finding is not unexpected, for experimental studies have shown that fractures with the characteristics of the joints described will be rotated from a theoretical position towards pre-existing anisotropic surfaces such as bedding, cleavage and joints (Jaegar, 1960). However whatever experimentally-determined constraints are used, they do not allow for failure to occur either along Mathinna bedding up to 18° from the expected position or along open joints up to 65° away. These results demonstrate that the anisotropic effects of pre-existing structures on joint formation are far greater than are generally accepted.

VEINS

The early structures of bedding, cleavage, and particularly joints in the folded Mathinna beds may later open and become the sites of quartz veins. However quartz veins may also occur independently of pre-existing anisotropic surfaces, forming systems which either may have been deformed together with bedding during folding, or else are undeformed and post-folding.

The quartz vein system which has created considerable interest is that of *en echelon* arrays. The veins may vary in size from microscopic to regional, and the vein pattern is universally used to determine the direction of relative displacement occurring during their formation. Where the veins are of economic significance it may well be very important to determine the movement pattern during the time of vein development as a guide in predicting the thickest vein formation, intersection of arrays etc. Unarguable movement indications are given where the veins develop sigmoidal characteristics, but these are not always present and are not determinable where regional-scale systems are mapped on the presence of quartz float in bush-covered terrain. In these cases the text-book rule (e.g. Hills, 1972) is that the acute angles enclosed between the veins and the median plane of the structures point in the direction of movement. However text books appear to have considered only *en echelon* vein systems which formed independent of any pre-existing surfaces, but these vein systems can also be developed on pre-existing anisotropic surfaces in such a way that the text-book movement rule is incorrect.

One of most common occurrences of openings along early structures is within kink bands. These bands are frequently noted as mesoscopic strucures, but they may vary in scale from microscopic to large systems of regional extent. Both microscopic and mesoscopic bands are very common in the Mathinna beds, and regional buckling about steep axes has been described (Turner *in* McClenaghan *et al.*, 1982; Turner *in* Turner and Calver, 1986) by the development of large-scale kink bands (Goscombe and Findlay, 1989).

Kink bands are formed during shortening by a style of folding which geometrically fundamentally differs from normal flexural folds. In a comparison of the fold styles starting at a plane of detachment (fig. 8), conjugate kink bands maintain the shortening from layer to layer by restricting interlayer slip to the bands themselves, which gradually die, whereas flexural folds result in progressively greater amounts of shortening, interlayer slip and fold height away from the décollement. In the Mathinna beds the normal flexural folds commonly develop about horizontal or gently-plunging axes where fold growth is impeded by only the superincumbent load under gravity. However it is evident that kink folding would be favoured over normal flexural folds in more confined environments, as in the shortening by buckling about vertical or steeply-plunging axes where comparatively lesser work is done during kinking in pushing the undeformed surrounding country rock aside than during normal flexural folding.

The general geometry of kink bands can be summarised by looking at the mesoscopic and microscopic characteristics of the kink bands developed at Stony Head (fig. 9). Here, the folia kinked are bounded by cleavage surfaces, and more often than not only one kink band of a conjugate pair is formed. Voids may be created at any pre-existing anisotropy within the kink bands during deformation, and are filled with quartz. *En echelon* quartz veins occur along cleavage surfaces where the angle ϕ is less than ϕk in the figure, and the thicknesses and attitudes of the veins are governed by the relative sizes of the angles (Anderson, 1964; Williams, 1970). Such dilation within a kink band, however, may also result in the opening of joints and the development of a quartz vein stockwork. Where ϕ is greater than ϕk the folia within the kink band are thinned, which in Figure 9 is accomplished by extensive solution with the development of stylolites.

In the comparison of *en echelon* kink veins and typical gash veins the movement patterns deduced differ for some of the orientations of the vein arrays (fig. 10). Such differences are obviously very important in, for example, predicting sites of greatest initial void development, and considerable errors can be made where the array types are confused. This is especially so in those instances where pre-existing anisotropic surfaces are not readily recognised in the more massive sequences, and the only evidence of partings is actually the *en echelon* veins themselves. However, as indicated earlier, where vein ends are curved no errors should occur, as the sigmoidal characteristics are the same with respect to shear sense for both vein systems (fig. 11).

On a regional scale, vein systems are commonly mapped in bush-covered terrains on the abundance of surface quartz float, and any sigmoidal characeristics which may have developed cannot usually be determined, despite the numerous records of extensive large quartz vein systems, particularly in the gold-bearing regions of the Mathinna beds. This, together with the recognition of buckling of the folded Mathinna beds around steep axes, strongly suggests that some of the *en echelon* vein systems may well have resulted from the opening of pre-existing surfaces, such as bedding. If this, indeed, is the origin of some of the vein arrays, then movement patterns determined by the text-book rule would be in error (fig. 12).

CONCLUSIONS

The geometrical relationships between mesoscopic structures and folding of the Mathinna beds can only be determined by local work of an empirical nature in localities with the best exposed outcrops. This approach will lead to lesser errors in predictions of the three dimensional distribution of the folded Mathinna beds and the associated quartz veins than if text-book presentations of relationships between structures are accepted as a guide to establishing the distribution of poorly-exposed rock units in bush-covered regions.

REFERENCES

ANDERSON, T. B. 1964. Kink-bands and related geological structures. *Nature* 202:272–274.

BANKS, M. R.; SMITH, E. A. 1968. A graptolite from the Mathinna Beds, North-eastern Tasmania. *Aust. J. Sci.* 31 (3): 118–119.

BANKS, M. R.; BAILLIE, P. W. 1989. Late Cambrian, *in:* BURRETT, C. F.; MARTIN, E. L. (ed.). Geology and mineral resources of Tasmania. *Spec. Publ. geol. Soc. Aust.* 15:182–237.

DE SITTER, L. U. 1956. *Structural geology.* McGraw Hill Book Company Inc. : New York.

GOSCOMBE B.; FINDLAY, R. H. 1989. Mega-kinking in Mathinna beds, north-east Tasmania. *Rep. Dep. Mines Tasm.* 1989/42.

HILLS, E. S. 1972. *Elements of structural geology.* Chapman and Hall Ltd.

HOBBS, B. E.; MEANS, W. D.; WILLIAMS P. F. 1976. *An outline of structural geology.* John Wiley and Sons.

JAEGAR, J. C. 1960. Shear failure of anisotropic rocks. *Geol. Mag.* 97:65–72.

MARSHALL, B. 1969. Geological Atlas one mile series. Zone 7 sheet 31 [8315N]. Pipers River. *Explan. Rep. geol. Surv. Tasm.*

MCCLENAGHAN, M. P.; TURNER, N. J.; BAILLIE, P. W.; *et al.* 1982. Geology of the Ringarooma–Boobyalla area. *Bull. geol. Surv. Tasm.* 61.

RAMSAY, J. G. 1967. *Folding and fracturing of rocks.* McGraw Hill.

RICKARDS, R. B.; BANKS, M. R. 1979. An Early Devonian monograptid from the Mathinna Beds, Tasmania. *Alcheringa* 3:307–311.

TURNER, N. J.; BLACK, L. P.; HIGGINS, N. C. 1986. The St Marys Porphyrite and related dykes—a Devonian intracaldera ignimbrite and its feeder. *Aust. J. Earth Sci.* 33:201–218.

TURNER, N. J.; CALVER, C. R. 1987. Geological Atlas 1:50 000 series. Sheet 44 [8514N]. St Marys. *Explan. Rep. geol. Surv. Tasm.*

WILLIAMS, E. 1959. The sedimentary structures of the Upper Scamander sequence and their significance. *Pap. Proc. R. Soc. Tasm.* 93:29–32.

WILLIAMS, E. 1967. Joint patterns at Dalrymple Hill, northeastern Tasmania. *Geol. Mag.* 104:240–252.

WILLIAMS, E. 1969. The repeated development of identical joint patterns, northeastern Tasmania. *Geol. Mag.* 106:362–369.

WILLIAMS, E. 1970. Kink-bands developed during folding of sandstone layers at Stony Head, Tasmania. *Tectonophysics* 10:433–457.

WILLIAMS, E. 1989. Summary and synthesis, *in:* BURRETT, C. F.; MARTIN, E. L. (ed.). Geology and mineral resources of Tasmania. *Spec. Publ. geol. Soc. Aust.* 15:468–499.

[17 November 1989]

FIGURES 1–8

Figure 1. Tracings of photographs (Stony Head).

(A) View south-east of fold profile with traces of cleavage in sandstone layers shown by thin lines.

(B) Folded sandstone (s) bed below mudstone (**md**) layers showing divergence between trace of axial surface (broken heavy line) and cleavage / bedding intersection (thin lines), with values given of direction and plunge.

Figure 2. Equal-area net plot of ranges of poles of kink bands (475 readings) and corresponding external cleavage. Position of rotated poles of kink-bands shown (K) when poles of corresponding external cleavage rotated to the position of the pole of the average nearest to axial surface of folds (C). Locality Stony Head.. See Williams (1970) for detailed diagrams.

. . . .	Range of poles of earlier conjugate kink-bands.
, , , , , , , , , , ,	Range of poles for later conjugate kink-bands.
~ ~ ~ ~ ~ ~	Range of poles of corresponding external cleavage.
- - - - - - - - - -	Average of cleavage surfaces nearest to axial surface of folds.

Figure 3. Thick (430 mm) sandstone layer with trimodal distribution of cleavage seams. Two seams in centre of layer, and third cleavage seam (T) in lowermost and uppermost portions of bed. Locality Bellingham. See text for further explanation.

Figure 4. After Figure 88 of De Sitter (1956), presenting stereographic plots of poles of possible joints in an anticline.

Figure 5. Traces of joints in Mathinna beds near Rossarden on a face perpendicular to bedding and sub-parallel to cleavage. Note deflections and terminations of joints at sandstone (s) and mudstone (m) boundaries, and against each other.

Figure 6. Contoured plots on equal-area net of poles of joints in Mathinna beds near Rossarden. Bedding poles indicated (B). Crosses are poles of cleavage and arrows are fold axes. Circles indicate poles of joints occupied by Permian neptunian dykes.

(a) Beds of dips 30°–45° W. 305 readings. Contour intervals: 0.3–1%, 1–3%, 3–6%, ≥6%
(b) Beds of dips 45°–65° W. 155 readings. Contour intervals: 0.6–1%, 1–3%, 3–6%, ≥6%
(c) Beds of dips 80°–82° E. 137 readings. Contour intervals: 0.7–1%, 1–3%, 3–6%, ≥6%
(d) Overturned beds of dips 60°–80° W. 141 readings. Contour intervals: 0.7–1%, 1–3%, 3–6%, ≥6%

Figure 7. Plots on equal-area net of poles of joints (contoured) and bedding (B) of Permian beds (top diagrams) and underlying Mathinna beds (bottom diagrams) at two localities (a, b) near Rossarden. In plots of Mathinna beds crosses are poles of cleavage, arrows are fold axes, and circles indicate joints occupied by Permian neptunian dykes. Tables give angular relationship in degrees between bedding, cleavage, and joints (1, 2 etc.) of ≥ 6% maxima of Mathinna beds with joints (I, II, III) of maxima of overlying Permian rocks.

Figure 8. Profile section giving comparison of deformation of layers by flexural folds and conjugate kink bands. Ends of undeformed layers small dashes; model of conjugate kink-bands solid line; model of flexural folds large dashes where not coincident with conjugate kink-band model. For further explanation see text.

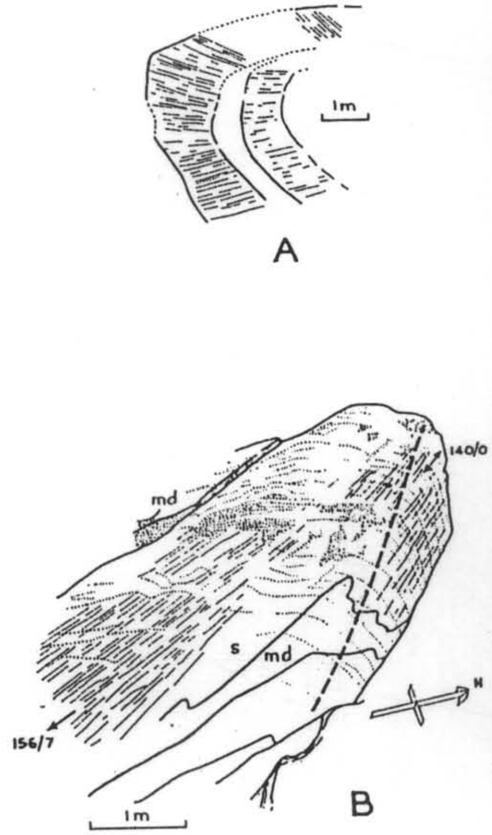


Figure 1.

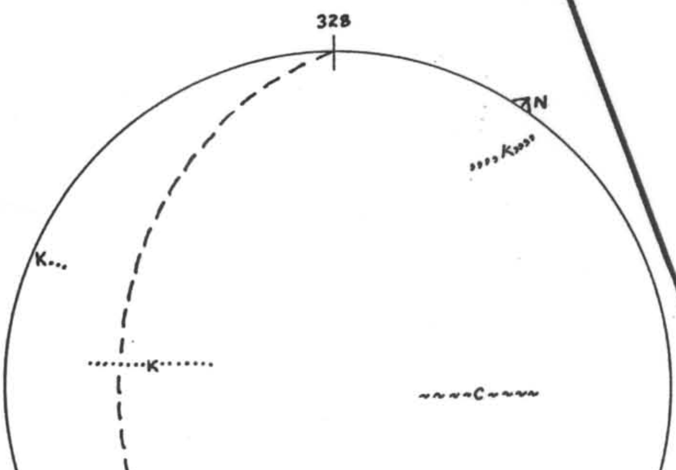


Figure 2.

5 cm

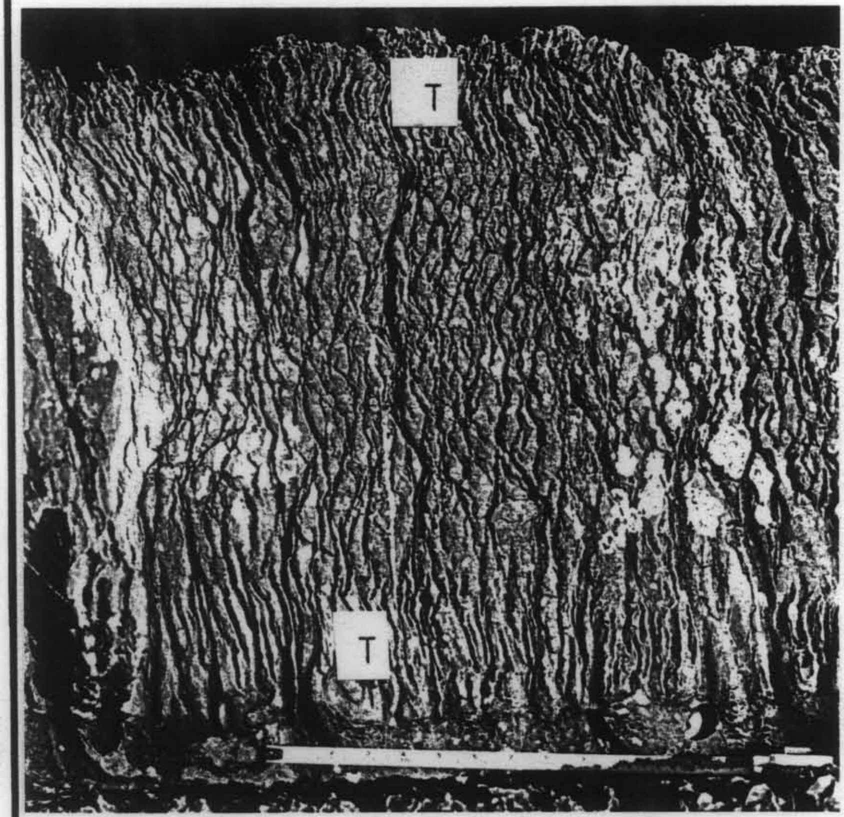


Figure 3.

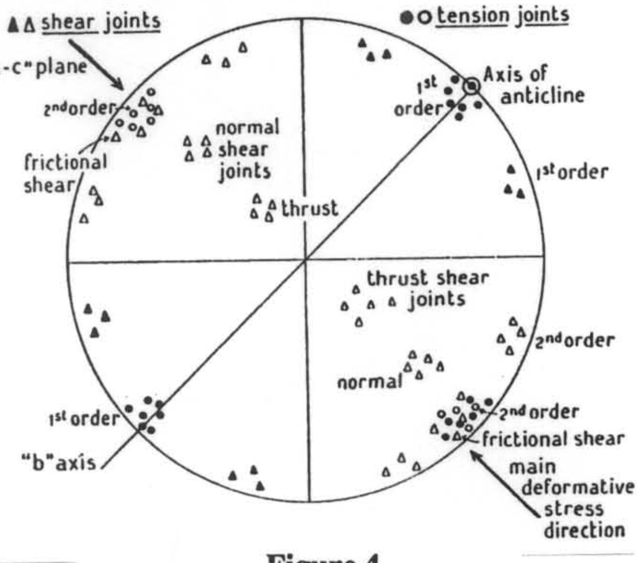


Figure 4.

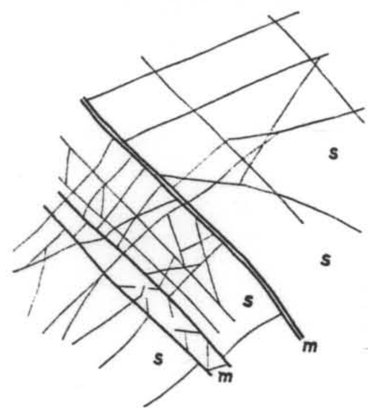


Figure 5.

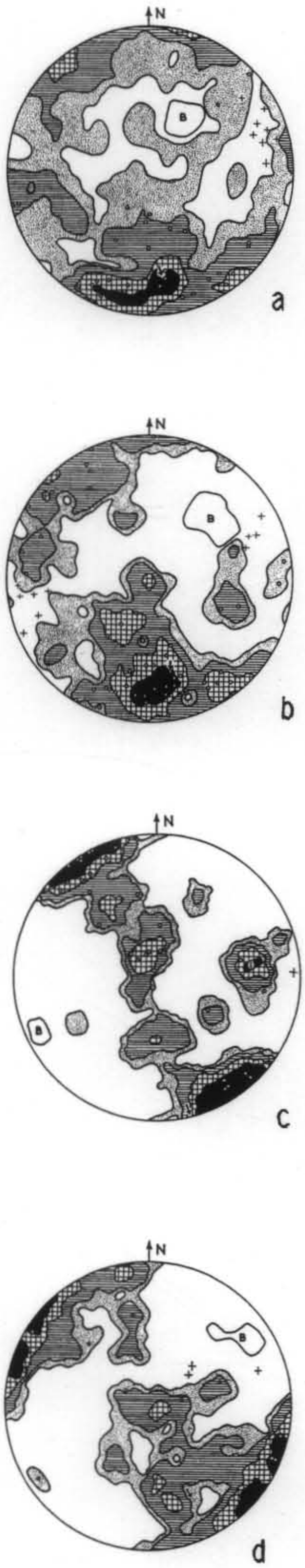
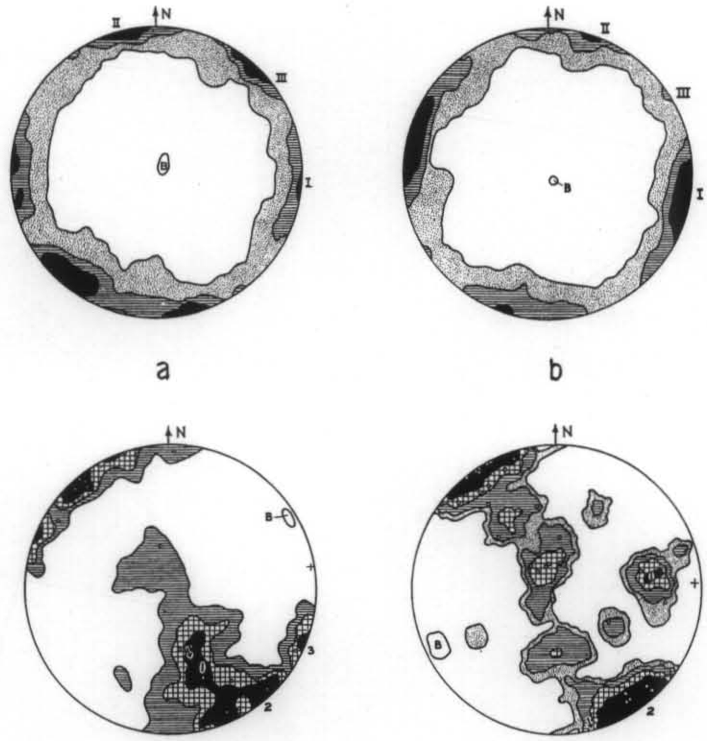


Figure 6.



	I	II	III
Bedding	33	70	18
1.	74	46	71
2.	56	21	65
3.	19	58	68
Cleavage	10	88	40

(*a*)

	I	II	III
Bedding	37	50	12
1.	38	71	42
2.	48	47	87
Cleavage	12	73	32

(*b*)

Figure 7.

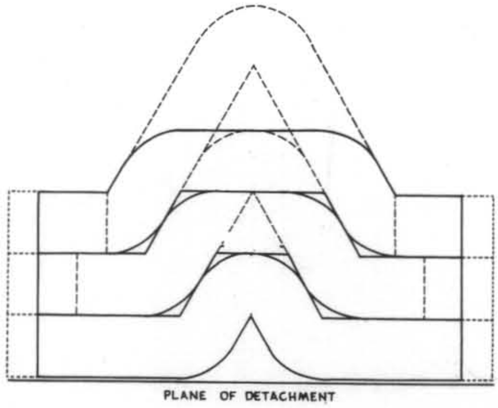
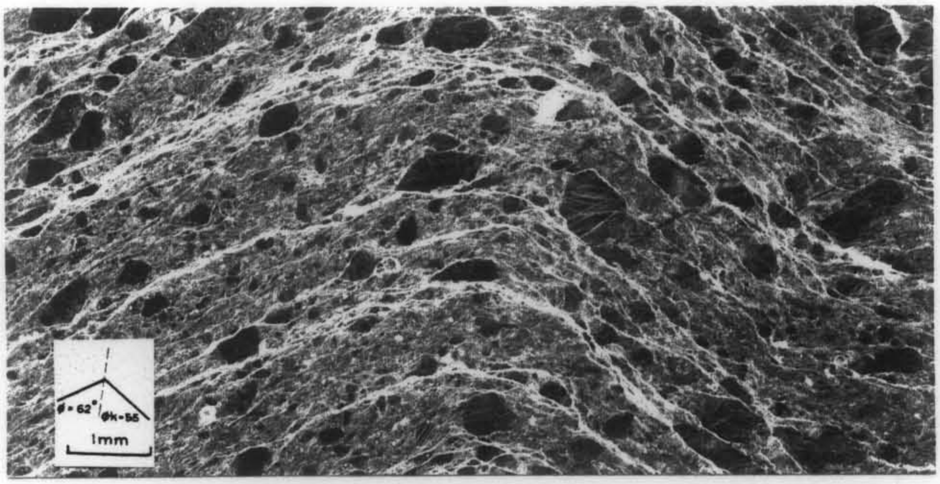
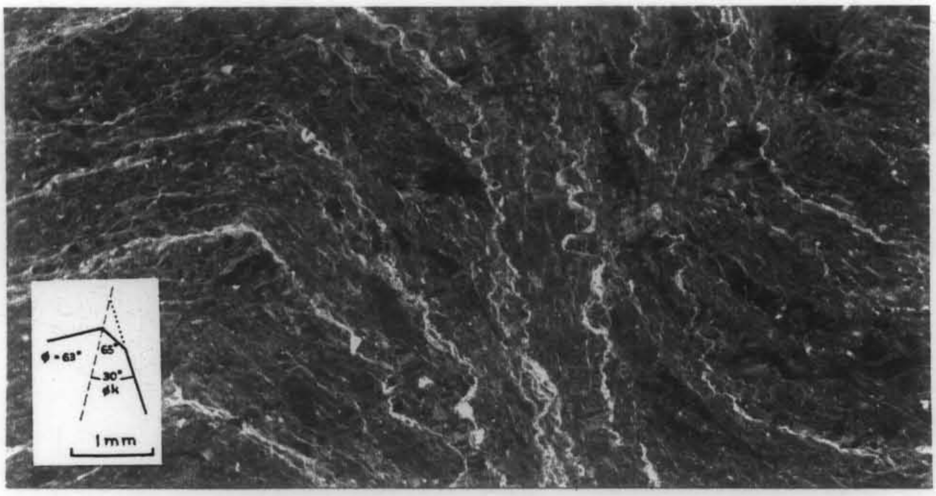


Figure 8.





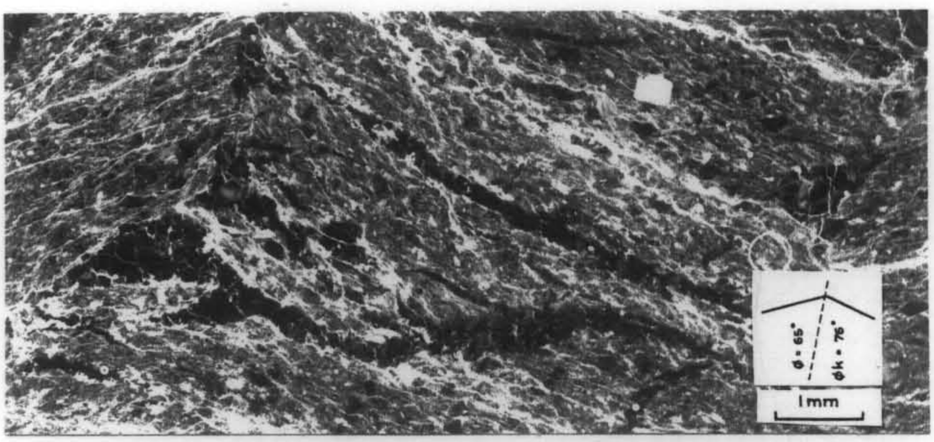


Figure 9. Photomicrographs (crossed polaroids) of kink bands at Stony Head. White ribbons are micaceous cleavage seams and black areas are quartz clastic grains and veins. Angles of external folia/kink band (f) and internal folia/kink band (fk) are shown.

Top—typical kink.

Middle—thinning of internal folia with extensive recrystallisation and stylolites.

Bottom—quartz veins parallel to cleavage within kink band.

5 cm

EN ECHELON VEINS

Text-book rule: the acute angle enclosed between gash veins and median plane of structures point in the direction of movement.

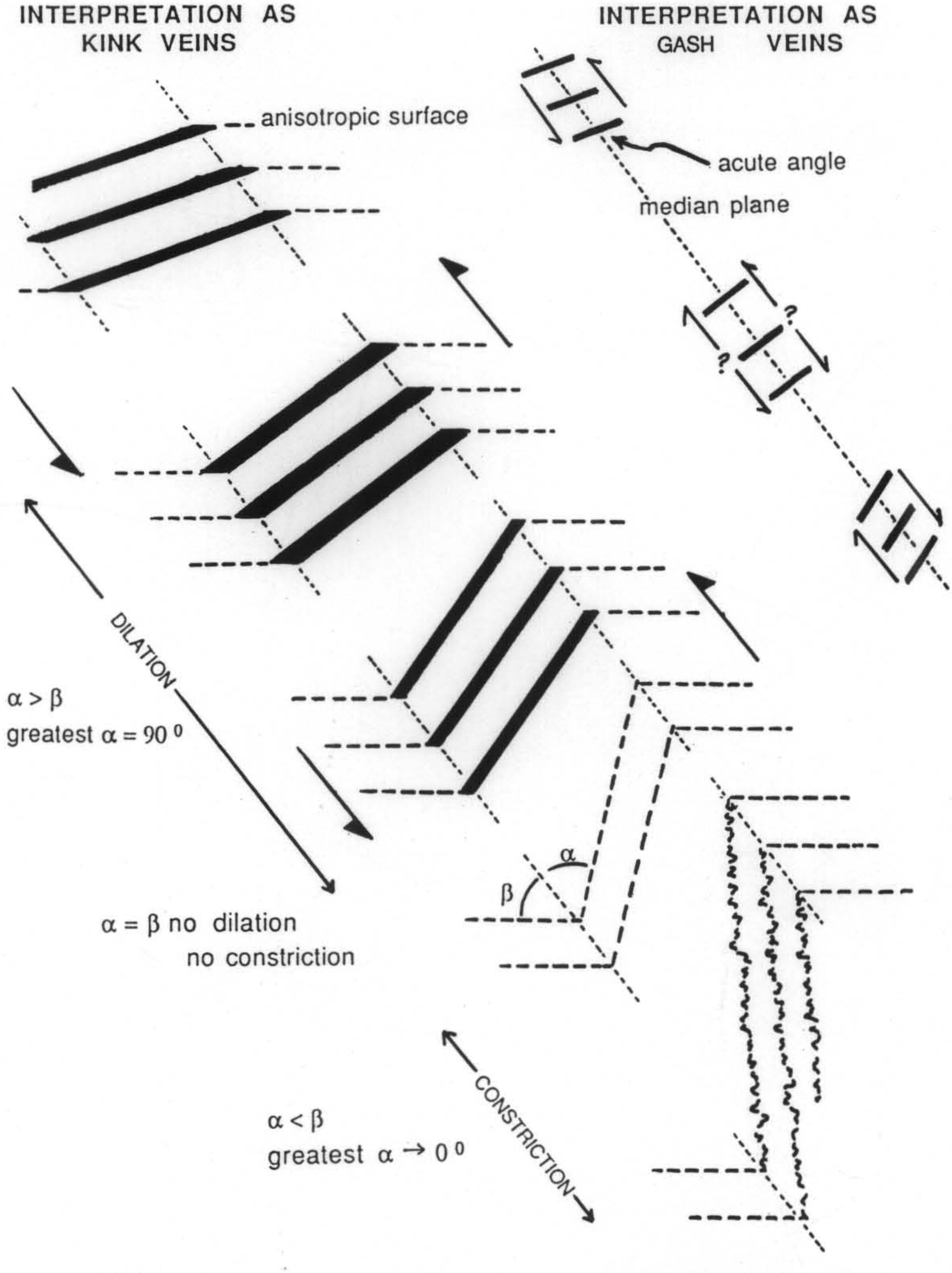


Figure 10. Comparison of movement patterns indicated by *en echelon* kink veins and typical gash veins.

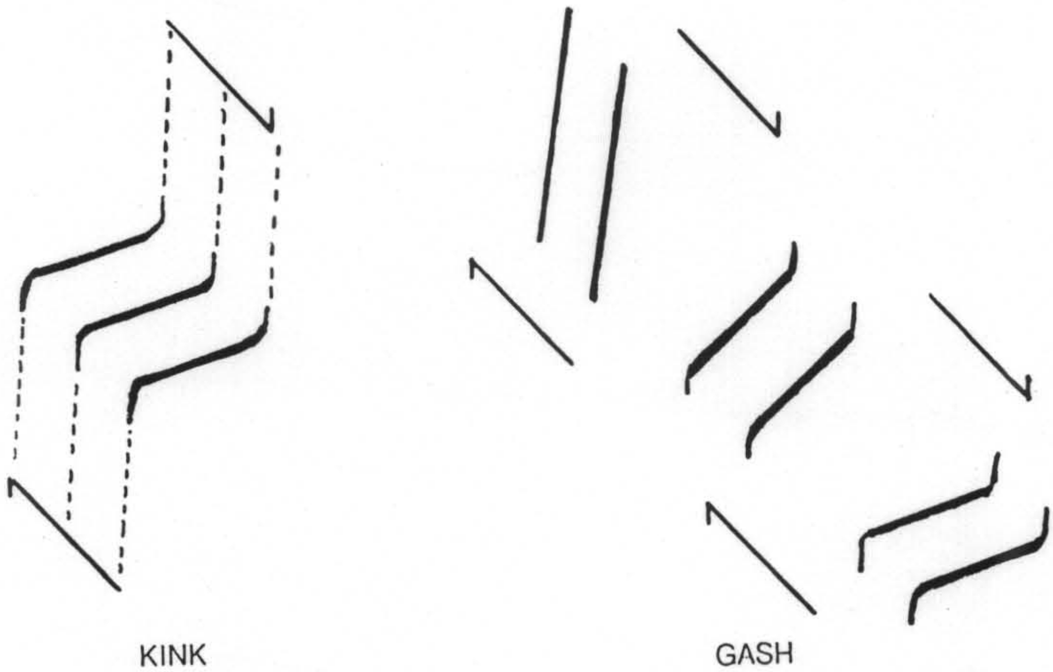


Figure 11. Sigmoidal characteristics for ends of veins of *en echelon* systems. See text for further comments.

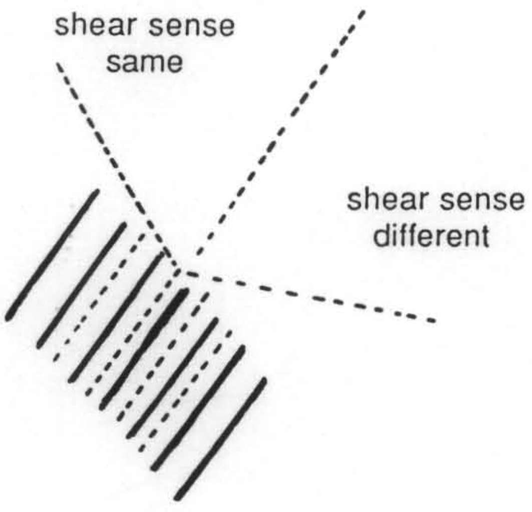


Figure 12. Comparison of shear sense of *en echelon* vein systems (kink *cf.* gash veins) if veins are parallel to anisotropic surface (e.g. bedding ----------), the trend of which is known outside the vein system.