The Structure of the Blowhole Creek Area, Southern Adelaide Fold Belt, Fleurieu Peninsula, South Australia.

by

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ABSTRACT

The consideration of the Southern Adelaide fold Belt as a foreland fold and thrust belt has been proposed as a solution to stratigraphic problems related to both the dramatic change in style of sedimentation between the Cambrian Kanmantoo and Normanville Groups, and the unusual thickness of the.Kanmantoo Group.

It was proposed by Jenkins (1990) that the Kanmantoo group may be thickened by thrust stacking. Structural investigations by Steinhardt (1989) and this study have concentrated on finding evidence for the presence of such thrusts and measurement of any stratigraphic offsets.

Structural mapping along the south coast of the Fleurieu Peninsula of part of the Kanmantoo Group type section within the Blowhole Creek area has revealed at least one major complex thrust zone associated with the eastern most exposure of the Talisker Calc siltstone. Imbricate faulting within this zone displays unexpected normal sense stratigraphic offsets. This was observed at Blowhole Creek, in association with a previously unknown exposure of the Talisker Calc Siltstone. The Blowhole Creek section appears to be more highly deformed than previously described, a set of tight overturned folds being discovered as part of what was once thought to be the relatively undeformed limb of an overturned regional anticline. At least two major overturned anticlinal structures are present between Cooalinga Creek and Deep Creek Conservation Park, not the single anticline previously accepted.

Due to the lack of strain markers strain analysis was restricted to measurement of elongate phosphatic nodules within the Heatherdale Shale and shortening measurements of mesoscopic and microscopic folding. Rf/ϕ analysis revealed that the three dimensional shape of the strain ellipsoid varied on different limbs of the sampled regional anticline. The Rf/ϕ analysis also revealed that the amount of tectonic flattening does not significantly differ from one side of this structure to the other, hence any thinning of stratigraphic units on the overturned limbs of major fold structures must be due mostly to variations in original depositional thicknesses. Stratigraphic units were observed to thin towards the west, the Blowhole Creek Siltstone Member and the Campana Creek Member thinning to nothing on the western overturned limb of the regional anticline.

Restored sections revealed that the total shortening along a cross section of the whole Blowhole Creek area is in the order of 66 percent.

Studies of microscopic kinematic indicators revealed an east over west sense of shear for faults and shear zones within the Blowhole Creek area.

Late stage deformation has produced two sets of kinks within the Blowhole creek area. Two vein sets and a set of mafic dykes are also present.

NOMENCLATURE

ZX,YZ,XY	- Principal planes of finite strain.
Rzx,Ryz,Rxy	- Principal longitudinal strain ratio.
Rf	- Final deformed ellipse axial ratio in a principle plane.
Rs	- Finite strain axial ratio.
e_1, e_2, e_3	- Principal longitudinal strains.
Ri	- Initial undeformed particle axial ratio.
k	- Flinns k. A measure of deformation symmetry.
ε	- Shortening ratio.
lo	- Initial length (of a bedding plane for example) prior to shortening.
l1	- Final length after shortening.
α	- fold limb dip.
ϕ	- Angle between an isogon and the normal to the parallel tangents of the folded surfaces of a layer.

1.INTRODUCTION

1.1 General geology

With the exception of Permian glacial and Quaternary deposits the geology of the southern coast of Fleurieu Peninsula consists of the Cambrian Kanmantoo and Normanville Group sediments. The geology of the Blowhole Creek area is dominated by Kanmantoo Group sediments of the Carrickalinga Head Formation and Inman Hill Sub-Group, with minor exposures of Normanville Group rocks in the core of a regional anticline. A minor set of deformed mafic dykes are also present within the field area.

Generally one major deformational event is recognised for this area, this being the Delamerian Orogeny of Cambro-Ordovician age. A minor late stage kinking event may have ocurred during the waning stages of this deformation.

1.2 Previous investigations

Madigan (1925) was the first to investigate the south coast of Fleurieu Peninsula in any detail. He recognised outcrop of the Normanville Group "a mile to the east of Campbell Creek" which he correctly interpreted as the southern extremity of the "Delamere marble". Madigan (1925) considered both this marble, and later the associated phosphatic nodular phyllites, as being equivalent to similar rocks at Carrickalinga Head and elsewhere along the west coast of the Peninsula (Fig 1). Madigan (1925) dated these rocks as Cambrian in age .

Both Madigan (1925) and later Thomson (1969), failed to recognise the closure of a regional anticline, and hence (as recognised by Daily and Milnes, 1971) produced an incorrect stratigraphy and structure for the area.

Campana et al (1953), however, recognised that the Cambrian formations were "intensely dragged" and stated that they "remained observable up to Campbell Creek, where they show a stretched sharply overturned and sheared anticlinal fold."

Daily and Milnes (1971) considered the sequence along the south coast to be conformable, and repeated once by a major regional anticline overturned towards the northwest (Fig 2). They considered this anticline to be the major structural feature of the area, producing relatively simple fold repetition. They noted that "considerable tectonic thinning has ocurred on the western limb of a regional anticline" and invoked the presence of a fault to explain the absence of part of the section.

Fig 1. Map of the southern coast of Fleurieu Peninsula, after Madigan (1925).

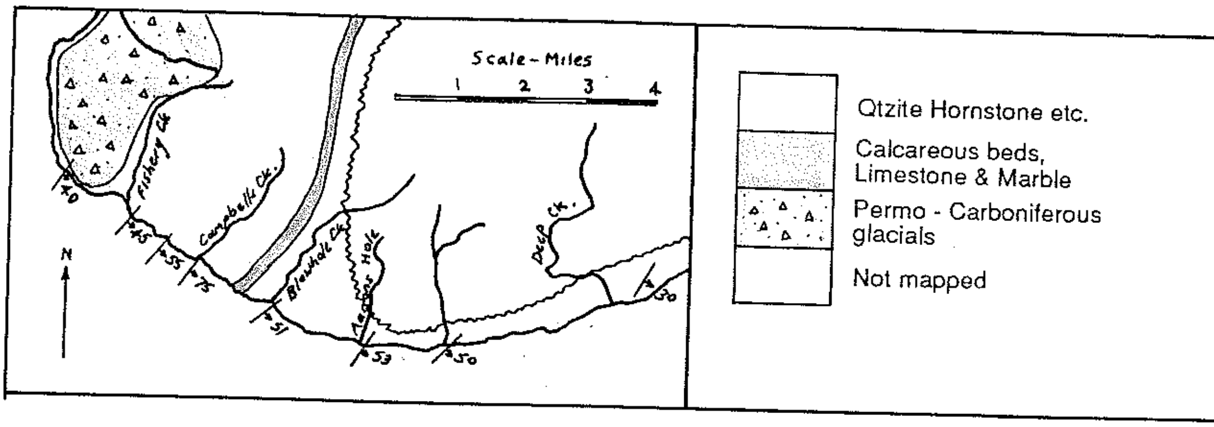
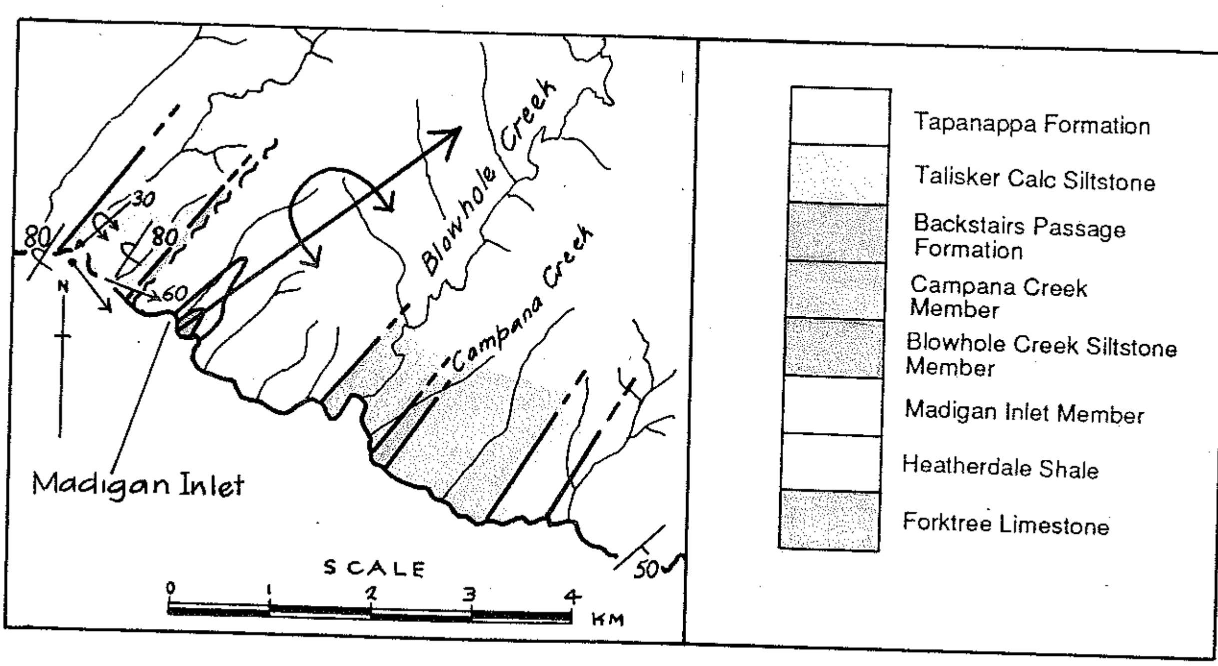


Fig 2. Map of the Blowhole Creek area, after Daily and Milnes (1971)



As a consequence of their investigations Daily and Milnes set the presently accepted stratigraphy for the area. Until this investigation, the structure of the area as determined by Daily and Milnes has been accepted as correct by later investigators, and the section on the eastern side of the regional anticline considered to be relatively undeformed, with the exception of minor folding. For example, minor folds are present within all units except for much of the Backstairs Passage Formation.

The first purely structural investigations of the south coast of Fleurieu Peninsula was carried out by Mancktelow (1981 & 1990) in the course of regional structural mapping. Mancktelow's investigations were mostly concerned with the regional change in fold axis orientation for the south west Fleurieu Peninsula, hence his work did not greatly improve upon the detailed structure as determined by Daily and Milnes for the local Blowhole Creek area.

Both Mancktelow and, Daily and Milnes recognised that the fold structures and the tectonic foliation in the Blowhole Creek area resulted from the deformation event during the Delamerian Orogeny.

Structural investigations of the southern Adelaide Fold Belt have been re-evaluated by Jenkins (1990). Jenkins considered that "the southern Adelaide Fold Belt in the Mount Lofty Ranges, Fleurieu Peninsula and Kangaroo Island comprises a section through a peripheral foreland thrust belt and a folded metamorphic complex" (Fig 3).

Also, Jenkins considered that the "extraordinary thickness" of the Cambrian Kanmantoo Group could be explained using his model by invoking thickening via thrust repetition. Recent structural investigations by Steinhardt (1989) (Fig 4) and this study have been dedicated towards finding evidence for the existence of these thrusts within the Kanmantoo section along the south coast of Fleurieu Peninsula.

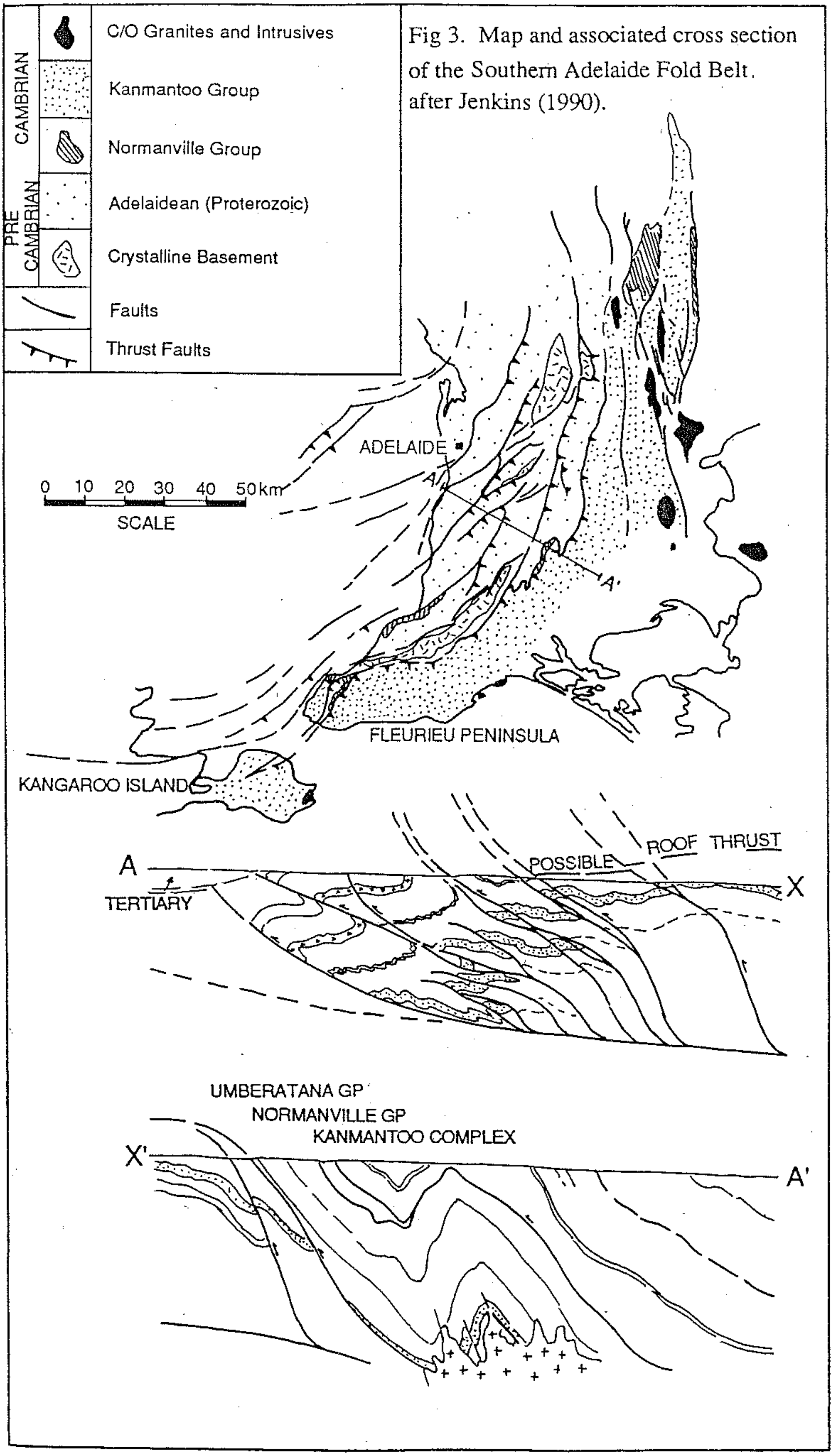
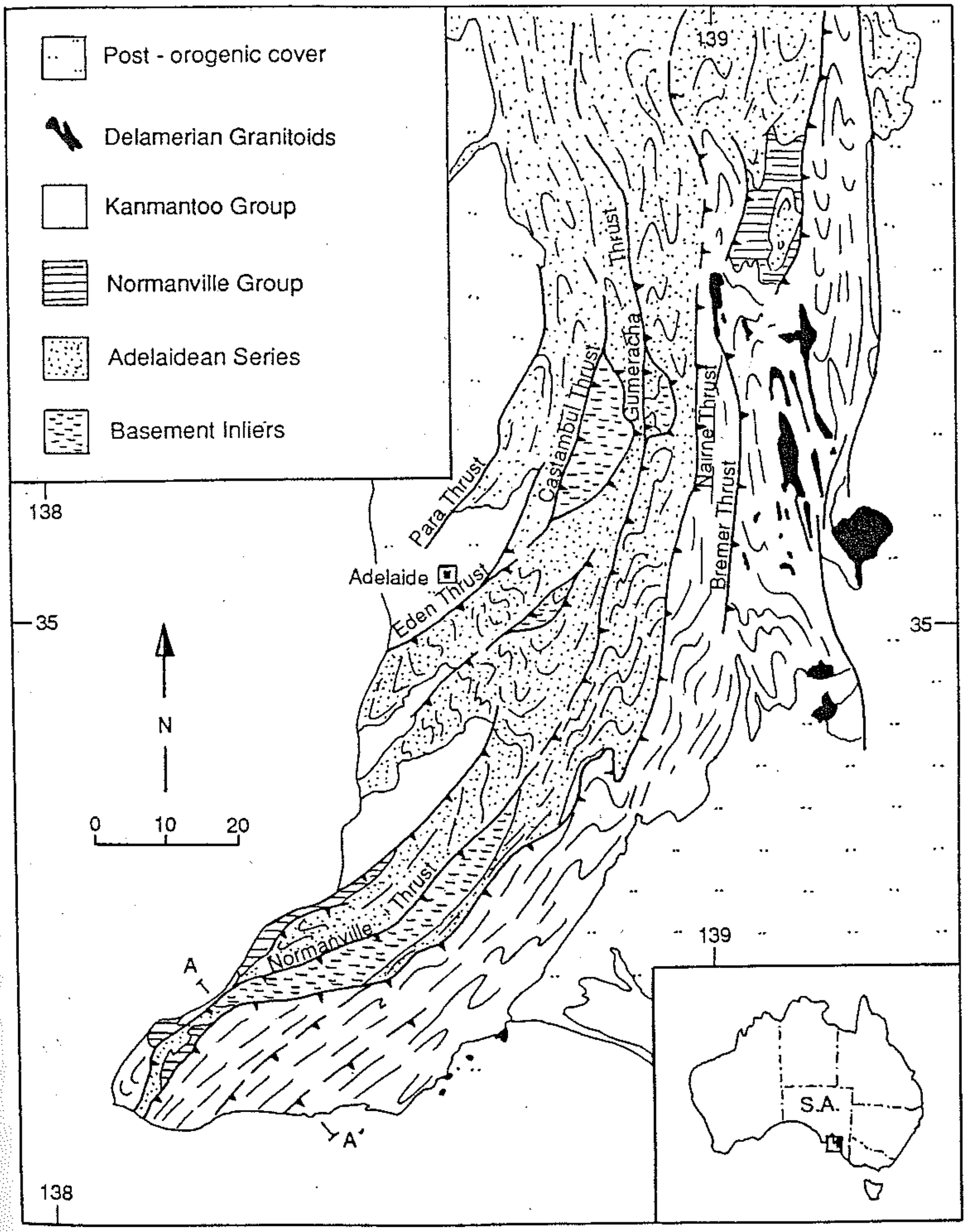
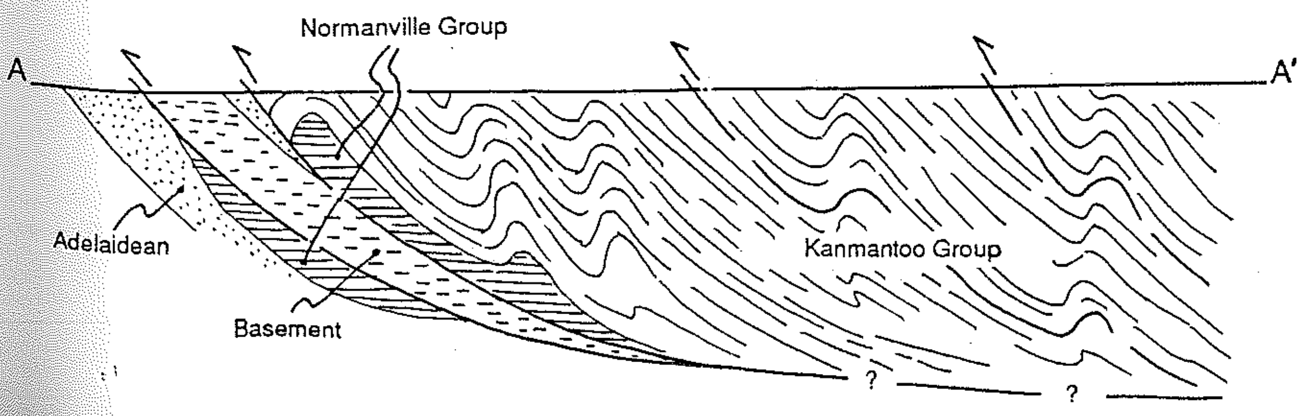


Fig 3. Map and associated cross section of the Southern Adelaide Fold Belt. after Jenkins (1990).

Fig 4. "Simplified geologic map of the Southern Adelaide Geosyncline" & section across the Southern Fleurieu Peninsula, after Steinhardt (1989).





1.3 Physiography

The morphology of the coastline between Madigan Inlet and Deep Creek consists of a line of wave cut platforms and coastal cliffs of 10 to 20 metres in height. The cliff line is broken in places by creeks which terminate in small sandy inlets. Outcrop exposure along the coastline is excellent, however the narrowness or absence of the wave cut platform often makes access difficult. Creeks arising from the pre-Tertiary peneplain surface produce variable outcrop (Plate 3A), the best being found on inside meander bends. Outcrop elsewhere is poor due to Quaternary scree and soil cover.

Due to pastoral activity, vegetation is generally restricted to grasses and isolated patches of eucalypts lining stream beds and on steep slopes. Dense scrub makes access in Deep Creek conservation park difficult.

2.STRUCTURAL MAPPING STRATEGY & TECHNIQUES

2.1 Mapping strategy

Structural and stratigraphic mapping was pursued on a 1:10 000 scale of the area between Madigan Inlet and the western edge of Deep Creek Conservation park.

The area designated for mapping was chosen for the following reasons;

1. Proximity to suspected thrust traces as predicted by Jenkins (1990). Mapping in this area is considered as part of structural mapping required throughout the Southern Adelaide fold Belt to validate his theories[1].

2. The stratigraphy of this section of coast consists of a number of easily distinguishable stratigraphic units as opposed to the majority of the south coast, which consists of large tracts of a smaller number of thick, monotonous units. The Talisker Calc Siltstone is present as an excellent marker horizon. Recognition of any thrust faults and related stratigraphic offsets or repetition may therefore be more easily determined in this locality.

3. The stratigraphy of this area consists of part of the type section for the Kanmantoo Group, hence any change in unit stratigraphic succession or thickness may have important implications elsewhere within the Group.

4. Mapping in this area was part of a twofold effort in which sections on both sides of the regional anticline were investigated, this being that of the normal eastern limb. Mapping of the overturned western limb was undertaken by Rogers (1991).

5. This area contains a length of rocky coast which presents excellent outcrop. The presence of numerous creeks was conducive to inland mapping.

6. Access in this area is generally good.

[1]. Jenkins' investigations were of a reconnaissance nature with little in the way of comprehensive supportive field work

Mapping of structures too small for adequate resolution on the 1: 10000 scale maps was achieved through the construction of structural sections (see structural sections sheet), on a scale varying from 1: 100 and 1: 50. These sections were measured with the aid of a tape measure and were to be taken as vertical sections on cliff faces or as horizontal sections on wave cut platforms. The latter type of section predominated, structural features being easier to see and better exposed on the wave cut platforms. Sections were taken in regions of interest, for shortening measurements, and for mapping in areas where the minor fold envelope made determination of the major structure difficult.

2.2 Structural mapping measurements & techniques

Three structural maps were produced. Bedding and cleavage orientations, lineation orientations and younging directions, and vein and kink orientations are displayed on separate maps (Maps 2 to 4). An extra map (Map 1) was produced as a locality map for samples and named structures.

Due to the highly deformed character of the Blowhole Creek area bedding measurements alone are insufficient to delineate major fold structures . Folds are tight and overturned towards the west, hence bedding almost always dips towards the east. In some units such as the Forktree Limestone, Heatherdale Shale, Blowhole Creek Siltstone Member and some parts of the Madigan Inlet Member, the presence of many minor folds made the taking of meaningful bedding measurements an impossibility. In these areas use was made of a combination of minor fold vergences, facing, and detailed structural sections to define the major structures.

Measurement of bedding within the Blowhole Creek Member was difficult since the cleavage is sufficiently well developed here to preclude the development of joint surfaces parallel to bedding. The most prominent bedding surfaces were to be found within the Madigan Inlet Member, the Campana Creek Member, and the Backstairs Passage Formation due to their well bedded sandstone lithologies.

Cleavage measurements were generally easily taken, although the rock often had to be broken to produce a suitable cleavage plane. Cleavage was most poorly developed within the Backstairs Passage Formation. Cleavage dips were always towards the southeast. In the Heatherdale Shale, due to prominent joint sets, rock faces formed sub parallel to cleavage making measurement of both cleavage and intersection lineations difficult.

Good intersection lineations were best found in those units with good cleavage faces on which the bedding trace could be seen. Such units included; the Heatherdale Shale, where bands of phosphatic nodules on cleavage planes (care had to be taken to avoid measuring on joint faces) defined the bedding trace, and the Blowhole Creek Siltstone Member, where the bedding trace was easily visible on the well developed cleavage planes. Intersection lineations were often observed to be folded with a wavelength of approximately one to two metres within the Blowhole Creek Siltstone Member (Plate 4B), indicating non-cylindricity of folding. This observation places doubt upon the significance of intersection lineation measurements taken within this member where outcrop is limited.

A strong mineral stretching lineation was observed on cleavage faces in areas proximal to suspected faulting and shearing, and to a lesser degree on cleavage faces within most phyllitic units. This observation enabled the orientation of the X axis of the strain ellipsoid for the area to be measured. Stretching lineations are well developed within the marble units and on veins.

Younging directions within the Blowhole Creek area were defined by observing facing relationships and minor fold vergences where sedimentary structures are not well developed.

Measurements were also taken of vein and kink orientations.

3. STRATIGRAPHY

The established stratigraphy of the area as set by Daily and Milnes was initially assumed to be at least chronologically correct . It was anticipated that this might change in the light of subsequent structural investigations, however this did not eventuate. The main result of structural mapping was mostly discovery of new outcrop of established units and change to previously estimated thicknesses of these units (Fig 5 - Stratigraphic Column).

3.1 The Normanville Group

This group, of early Cambrian age, is represented by its uppermost two units, the Forktree Limestone and the Heatherdale Shale found locally only in the core of the regional anticline.

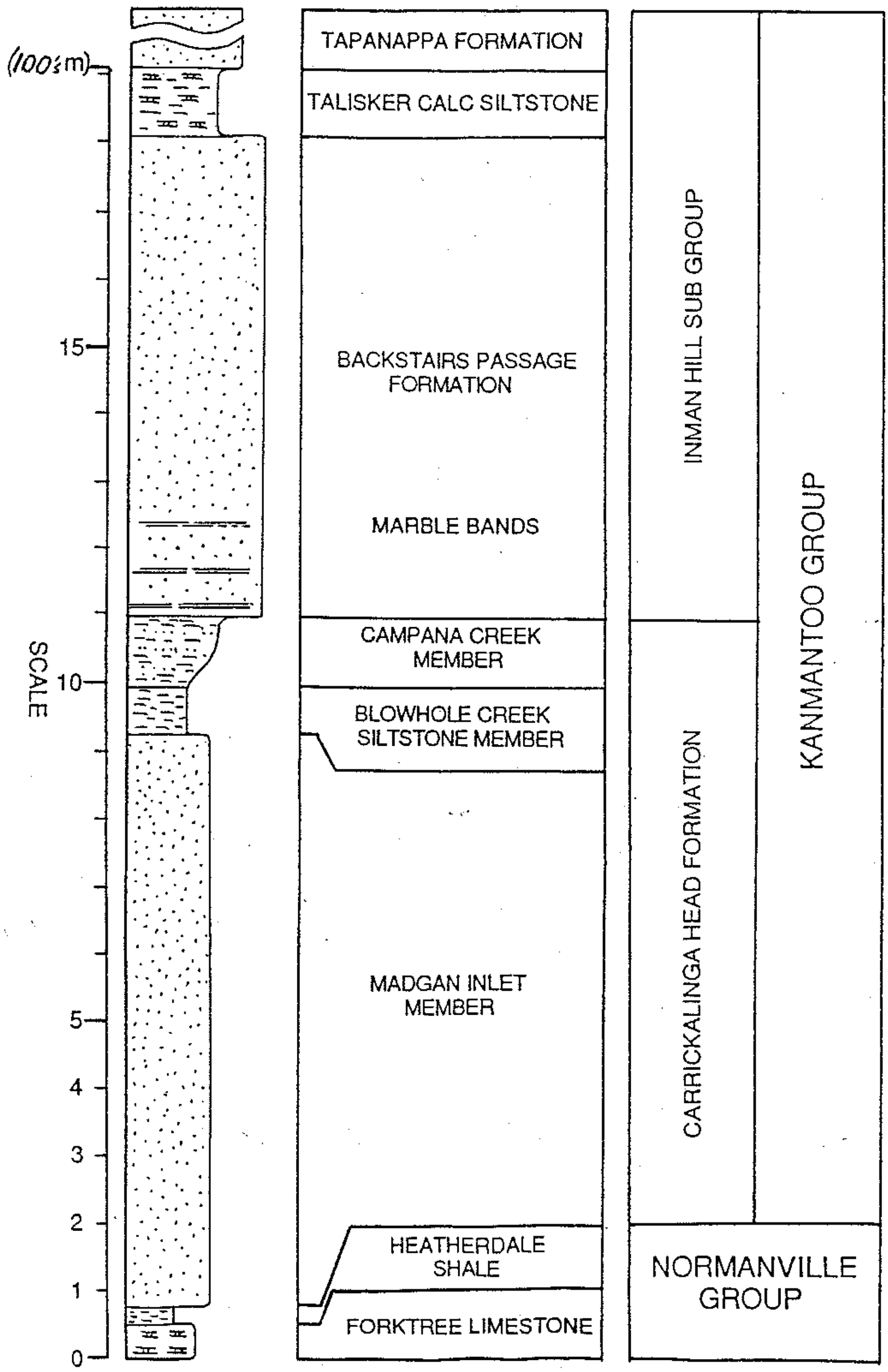
A. Forktree Limestone

This unit, called the Delamere Marble by Madigan, consists of a dark blue flaggy limestone, interbedded with thin (on the order of 1 to 0.5 cm) more deeply weathered layers. These layers define the fold structures within the rock and are probably more oxide or clay rich layers. This limestone is extensively deformed, displaying two scales of folding at outcrop scale (Plate 1B) and numerous boudinaged veins. Previous investigators have discovered fossil Hyolithids within this unit (Daily and Milnes, 1971).

B. Heatherdale Shale

The Heatherdale shale consists of a dark blue to black, well foliated slate or phyllite. The most prominent feature of this unit is the abundant black phosphatic nodules. These nodules have been elongated by the local strain field and make excellent strain markers. The nodules occur in bands approximating the bedding trace and provide a useful intersection lineation on cleavage planes. The Heatherdale Shale is considerably thinned on the overturned limb of the regional anticline. The NE-SW vein set prominent throughout the entire mapping area is also present within this unit. The contact between the Normanville Group and the Kanmantoo Group is sharp but lacks any evidence of a fault contact and hence is considered as conformable.

Fig 5. General stratigraphic column
Unit thicknesses are approximate and are taken from the normal limbs of overturned folds. Note that these thicknesses do not take into account small scale folding within separate units.



3.2 The Kanmantoo Group

The bulk of the rocks exposed within the mapping area consist of early Cambrian Kanmantoo Group sediments of the Carrickalinga Head Formation and the Inman Hill Sub Group. The units present within the mapping area represent part of the type section for the Kanmantoo Group.

A. Carrickalinga Head formation

This formation is comprised of three distinct members which are, from youngest to oldest;

1.Madigan Inlet Member

This appears to be the thickest of the three members and is comprised of a series of thin sandstone beds interspersed with phyllites (which appear to take up the majority of the deformation). Apart from simple shear of the phyllites this unit is relatively undeformed for the majority of its coastal outcrop length except at the eastern edge of its extent where it is folded. The NE-SW vein set is prominent within this unit. Deformed calc-silicate pods and lenticular layers are common within this unit. The contact between this and the overlying Blowhole Creek Formation is relatively sharp, but not directly visible due to scree and water cover. This is likely to be a fault contact as indicated by the intense deformation of both adjacent Members, especially the Blowhole Creek Siltstone Member.

2. Blowhole Creek Siltstone Member

This member consists entirely of grey laminated phyllites. An outcrop of sandstone in the middle of Blowhole Creek Beach was considered by Daily and Milnes (1971) to be a sandy unit within this member, but is now considered to be part of the overlying Campana Creek Member. This member is intensely deformed (especially within its western exposure) and displays tight asymmetric mesoscopic folding, overturned towards the west and plunging towards the northeast. Early, often intensely folded, mineralised vein sets and pods are prominent within this unit. The contact between this and the overlying Campana Creek Member is gradational over about one metre.

3. Campana Creek Member

The Campana Creek Member differs from the Blowhole Creek Member with the inclusion of many thin layers or stringers of sandstone within the phyllitic lithology characteristic of the latter member. Calc-silicate pods appear within this unit and have a shape characteristic of slumps (they differ from those in the Madigan Inlet Member). The NE-SW vein set is prominent within this member. The contact between the Carrickalinga Head Formation and the Backstairs Passage Formation is sharp and may be faulted.

B. Backstairs Passage Formation

The Backstairs Passage Formation is part of the Inman Hill Sub-Group and consists of a thick sequence of dominantly sandstone and minor interbedded siltstones. This sequence is essentially undeformed with the exception of a brecciated fault zone near its centre and folding and brecciation near the contact with the overlying sheared Talisker Calc Siltstone. This formation is also present inland along Blowhole Creek and here there are two thin marble members within the Backstairs Passage Formation. These marble bands may be an equivalent of the Tungkillo Marble Member previously only found further north of Tungkillo (Gatehouse & Jago, 1988).

C. Talisker Calc Siltstone

Where it outcrops on the coast at the eastern edge of the map this formation consists of a major, formation wide, shear zone. The rock is an extensively recrystallized marble of linear character, and displays boudinaged veins and shear related intrafolial folds. This unit is also found in outcrop in the vicinity of Blowhole Creek in the centre of the map area. That this outcrop had not been previously observed up until now may be due to the fact that it does not outcrop along the coastline. The rock here is a calc-phyllite with many small oxidised sulphide pods (each less than one millimetre in diameter) which is similar in character to that found inland on the overturned limb of the regional anticline to the west of the map area. These pods are elongated and have proven to be useful strain markers west of the map area, however within the map area itself they are poorly formed (probably due to higher strain) and could not be used as such .

D. Tapanappa Formation

This formation outcrops at the extreme east of the map area and may also be present inland in the vicinity of an anticline near Blowhole Creek. The Tapanappa Formation consists of a poorly sorted grey sandstone with thin phyllite interbeds.

4. STRUCTURAL GEOLOGY

The mapping area can be divided into six structural domains, each with a different style of deformation and displaying different structures to its neighbouring domains (Map 1). Each domain can also be dealt with separately with respect to stereoplot construction (Fig 6).

Domain I - The Coolinga Anticline

Domain I encloses the regional anticline as defined by Daily and Milnes. This domain is bounded on the west by the edge of the map and on the east by the Blowhole Creek Fault.

Folding in this area is best displayed in the Forktree Limestone where folding on three scales is observed. This includes the Cooalinga Anticline, folds on a scale of approximately one to two metres wavelength which are defined by an envelope of smaller folds of approximately one to two centimetres wavelength. (Plate 1B, Structural sections A and B) The regional anticline is overturned towards the west and plunges about 60 degrees ENE (Fig 6 - Stereonets).

It is evident from measured sections taken from Forktree Limestone on both sides of the regional anticline that the minor folds on the overturned limb are tighter than those on the normal limb (see also Strain Analysis chapter). Interlimb angles on the overturned limb are in the order of 20 to 30 degrees with the angle being 40 to 50 degrees on the normal limb. This result is not unexpected considering that the overturned limb of an overturned anticline usually displays more shortening than the normal limb. For example the Heatherdale Shale is considerably thinner on the overturned limb of the Cooalinga Anticline than on the normal limb.

Cleavage dips steeply towards the east in both the Forktree Limestone and the Heatherdale Shale. A down dip stretching lineation was measured on cleavage planes within these units.

The thick section of Madigan Inlet Member on the normal limb of the Cooalinga Anticline remains unfolded except for a series of smaller folds in the eastern edge of the domain, but apart from this the only deformation observed are minor shear zones defined by phyllitic layers (Plates 3G & 3H). These shear zones display a sinistral sense of shear, and are best documented by observing cross cutting veins.

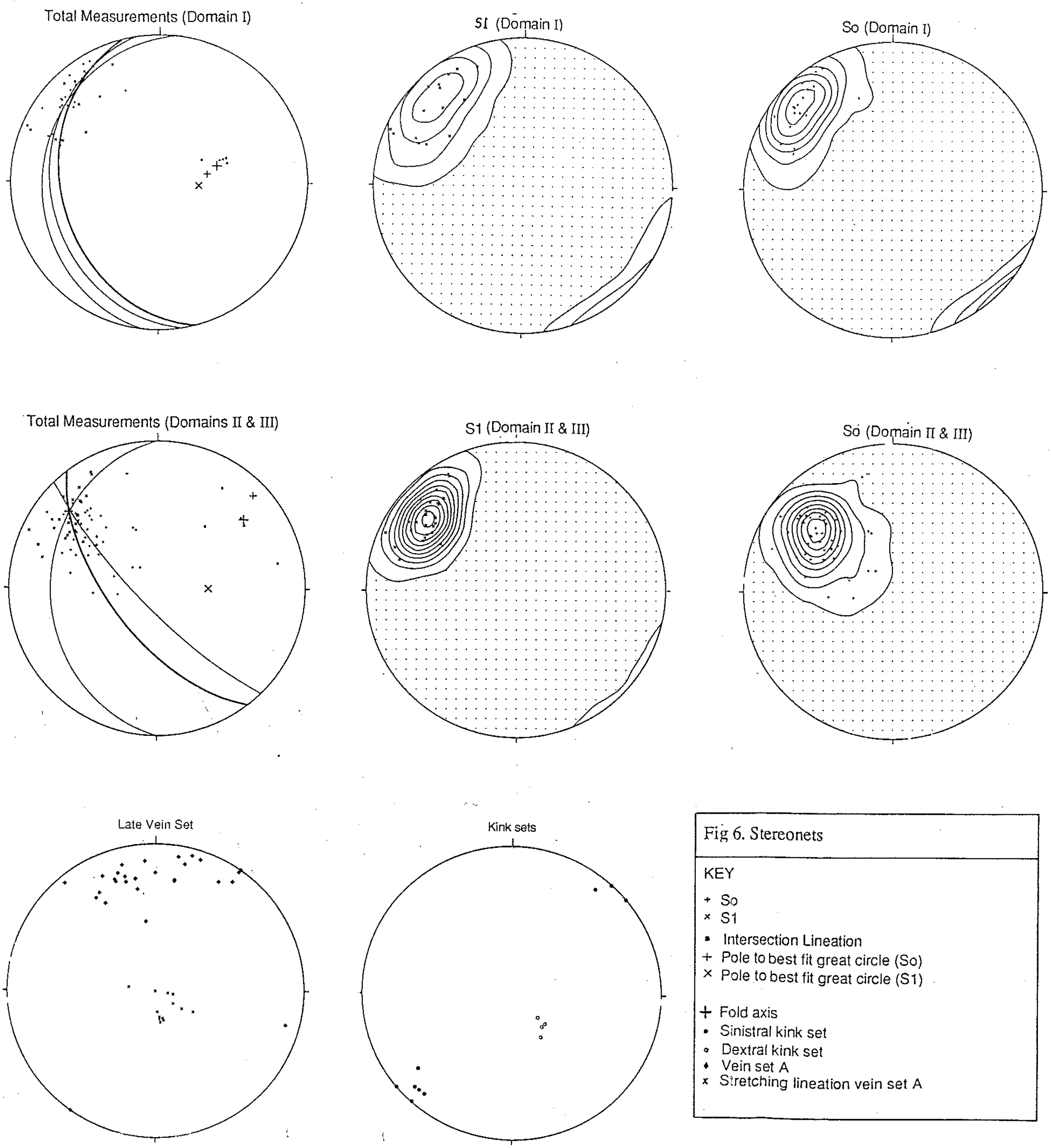


Fig 6. Stereonets

Within this domain, and most of the Madigan Inlet Member, deformed calc-silicate pods are common (Plate 1D). These pods are sometimes isolated but often appear to be the boudinaged remnants of formerly more continuous layers. The pods are orientated parallel to bedding with their edges plunging down dip parallel to the stretching lineation and hence the X axis of the strain ellipsoid.

Deformed slumps and occasional cross beds are the most common sedimentary structures within the Madigan Inlet Member.

The upper half of the Madigan Inlet Member is intensely folded. These folds plunge 45 degrees towards the northeast. A detailed structural section was measured through part of this zone to define the shape of these folds (see structural section C). Intense minor folding (Plate 3C) and minor faulting is characteristic of these structures.

The stratigraphic sequence within this domain is continuous and conformable up until the edge of the domain and the east limb of the regional anticline at the Blowhole Creek fault. Inland this sequence is composed of the Blowhole Creek Member, the Campana Creek Member, part of the Backstairs Passage Formation as well as the Madigan Inlet Member in a conformable eastward younging sequence that is cut off towards the south by the Blowhole Creek Fault. Faulting along the coast near the proposed trace of the Blowhole Creek fault appears to be extensive and was also observed by Gatehouse (Pers-comm 1991).

Domain II - The Blowhole Creek Imbricate Fan

The Blowhole Creek Imbricate Fan consists of what appears to be an extensional imbricate on the overturned limb of a previously undiscovered regional anticlinal structure. This fault bounded block contains the second of the two outcrops of the Talisker Calc Siltstone and the only layers of marble (Tungkillo Member Equivalent ?) in the mapping area.

The key outcrop in this area is found on an east-west oriented cliff face on an inside meander of Blowhole Creek (Plate 1A). As seen on Plate 1A there is an obvious anticlinal structure on this cliff face. The presence of this anticline, named the Blowhole Creek Anticline, has been confirmed by observing the change in facing direction across core of this structure. The core of this fold is composed of Backstairs Passage Formation and is overlain by the Talisker Calc Siltstone (Plate 1A).

The Talisker Calc Siltstone is bounded by two rock faces of Backstairs Passage Formation on the east and west limbs of the Blowhole Creek Anticline. Each of these rock faces is considered to parallel a fault trace. Hence this anticline forms a fault bounded block. The eastern most fault cuts off right way up, relatively shallow dipping Backstairs Passage Formation that overlies younger Talisker Calc Siltstone, resulting in thrust faulting as determined by an east over west stratigraphic offset. This, however, is the only fault within this domain that does not display an extensional sense of stratigraphic offset (Fig 7 - Cross section A - A').

The fault to the west, named here as the Blowhole Creek Fault, defines the easternmost extent of this domain. This fault seems to display an extensional stratigraphic offset.

Intersection lineations within this anticlinal zone are highly variable in plunge (Plate 4B), indicating non-cylindrical folding. On a larger scale the axis of the anticline itself experiences plunge reversals. Near the meander cliff face the plunge of the fold axis varies between southwesterly to nearly horizontal, whilst near the coast all intersection lineations indicate a fairly steep northeasterly plunge.

About 500 metres northeast of the meander cliff face the fold axis plunges shallowly northeast, which changes to a southwesterly plunge about one kilometre northeast. These plunge reversals allow Talisker Calc Siltstone to be present as the youngest unit within this domain, giving way to Backstairs Passage formation towards the northeast and eventually Madigan Inlet Member towards the southwest (Fig 7 - Cross section B - B'). This combination of faulting and fold character results in no outcrop of the Talisker Calc Siltstone at the coast.

Along Blowhole Creek, to the east of this fault block, a small extent of eastward younging Backstairs Passage Formation soon gives way to a steep zone of overturned, westward younging Backstairs Passage formation, characterised by the presence of at least four to five thin (1 to 2 metres thick) marble bands (Plate 1E.). A syncline has been inferred to explain the change in younging direction. The marble bands have been interpreted as two to three separate bands repeated once by faulting (only two bands of marble were found in the apparently conformable sequence in the north of Domain I.). All marble bands are younging towards the west and are considered to be on the eastern limbs of two synclines, the overturned limbs of which have been faulted out. A wedge of siltstone (either Blowhole Creek Siltstone Member, Campana Creek Member, or elements of both) separates the eastern limbs of what appears to be two separate synclines, the marble bands being visible on the eastern limbs of both structures. To the west of these synclines are the folds of the Campana Fold Domain.

Fig 7. Cross Sections A - A' & B B'.

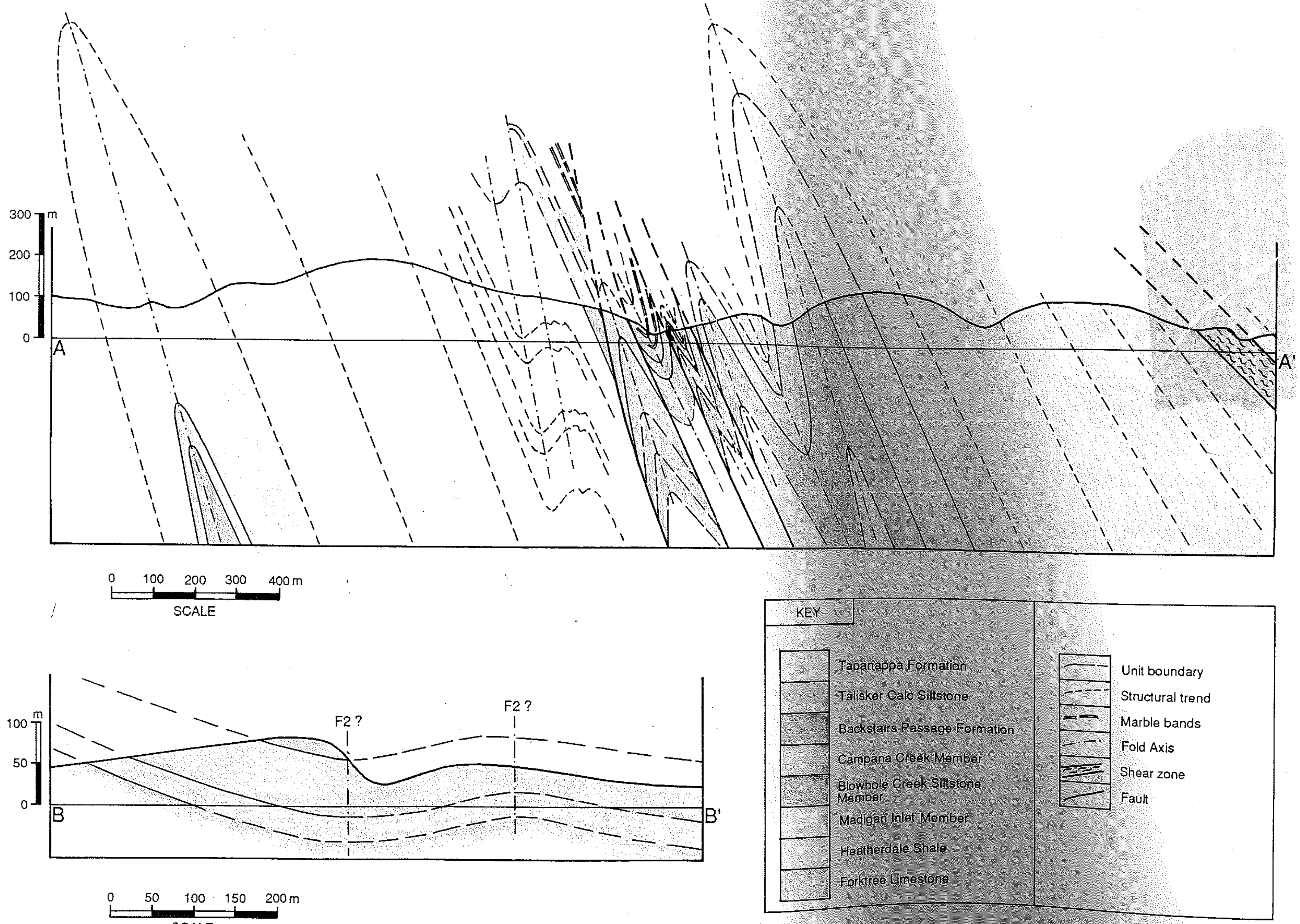
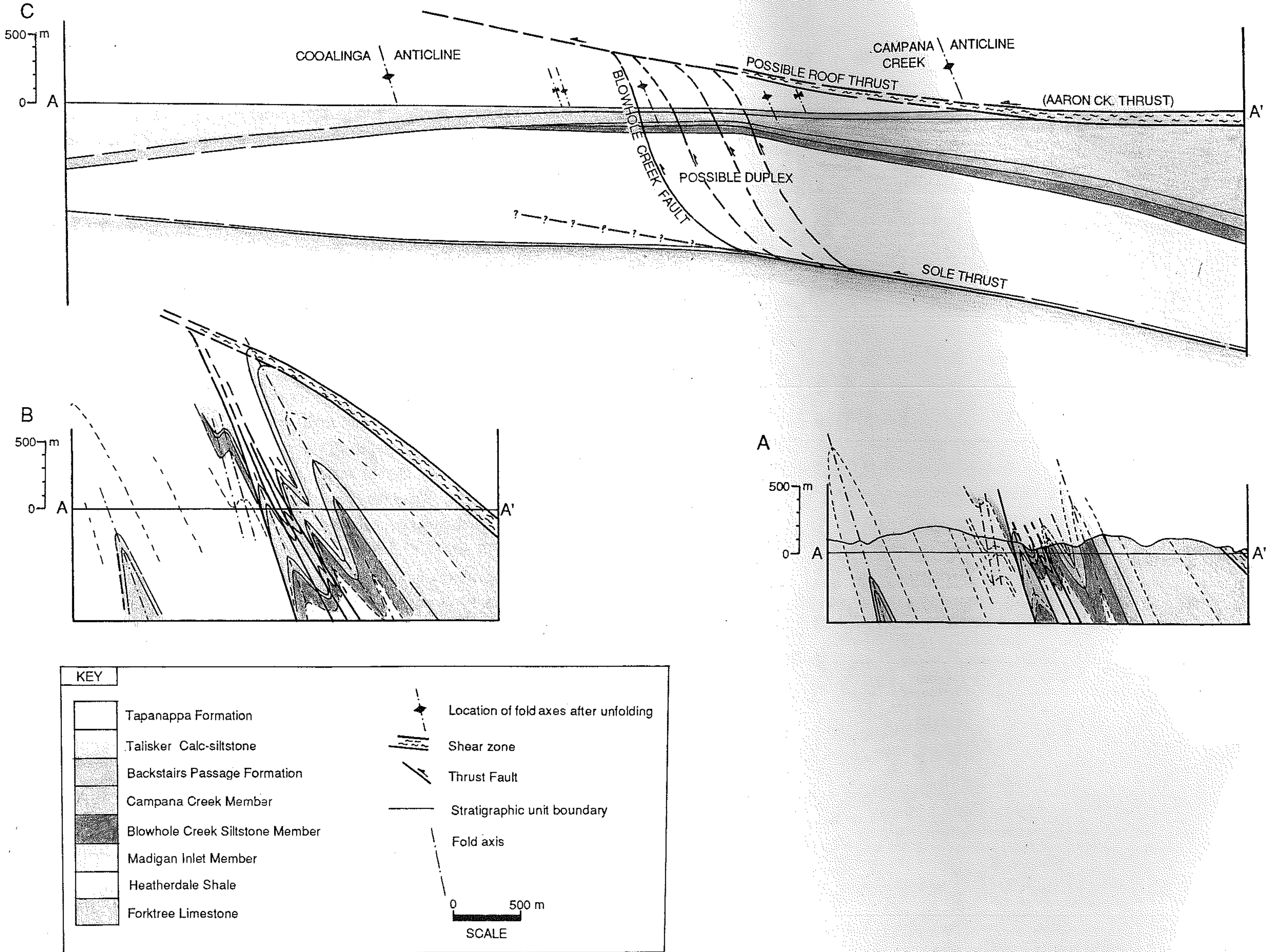


Fig 8. Restored cross sections of the Blowhole Creek area.
A - Cross section A - A' prior to restoration.
B - Interpreted cross section after restoration of displacement on imbricate faults.
C - Final restored section after unfolding. Note; unit thicknesses do not take into account small scale folding and shearing within separate units.



The Blowhole Creek Imbricate Domain presents a complex problem. The character of the structures within the zone are indicative of a thrust faulted, compressive terrain with tectonic transport towards the west, whilst the interpreted stratigraphic offsets which display a normal or extensional sense (see Fig 7 - cross sections). The orientation of these faults to each other is unusual. It can be observed that the faults to the east of the Blowhole Creek Fault appear to dip less steeply than the Blowhole Creek Fault, most unlike an extensional imbricate fan, but not unusual for a set of thrust produced duplexes (Fig 8C).

Structures such as the tight overturned folding of this domain and the adjoining Campana Creek Fold Domain indicate a compressive terrain, with kinematic indicators such as bookshelf structures, offset of boudinaged veins, and rotation of microscopic augens indicating that thrust movement should be expected on any faults. Despite these results the stratigraphic offsets within this domain consistently display an extensional sense of movement, regardless of interpretation of the maps and cross sections. Only the second most easterly fault appears to display a thrust indicative offset. Solutions to these problems are addressed further in the chapter 8.

Domain III - The Campana Creek Folds

This Domain is composed of a number of tight overturned folds consisting of Blowhole Creek Siltstone Member, Campana Creek Member and in the core of the folds, Backstairs Passage Formation. Of these units, only the Blowhole Creek Siltstone Member consistently outcrops at the coast, the Campana Creek Member doing so only once, and the Backstairs Passage Formation not at all (except in domain IV). Hence it is for this reason none of these folds were discovered by previous investigators who concentrated their mapping on the coastal strip of outcrop. It is evident that the Blowhole Creek Member is much thinner than any previous investigator may have thought, its greater thickness along the coast being due to fold repetition. Daily and Milnes (1971), who produced the currently accepted map for the area, did recognise the deformed nature of the Blowhole Creek Member and stated that "any thicknesses of formations and members computed can have no meaning because of ubiquitous small scale folding". They did not, however, recognise repetition due to large scale folding.

Along the coast the folds of this zone can be recognised using structural facing criteria since bedding always dips east due to the nature of the overturned folding in this domain. The fold axial traces can be defined by the change in facing direction. There is good evidence for the existence of a fault within this domain where it strikes the coastline, in the form of fault breccia rock and an abrupt change of facing direction across its trace.

All folds in this zone are tight, overturned towards the west and plunge shallowly towards the northeast. Minor folds are common along the coast and generally mirror the major folds in the area. Fold axes of minor folds can be measured directly on Blowhole Creek beach were they are present in the hinge of an overturned syncline (Plates 3C and 3E). These folds are within the Campana Creek Member and plunge shallowly towards the northeast.

The intersection lineation within this domain is often variable on outcrop scale (although not to the same extremes as within the previous zone), indicating non-cylindrical folding.

Domain IV - Backstairs Passage Formation

Bounded to the east by a major shear zone and to the west by a minor fault, this domain is an essentially undeformed zone composed entirely of Backstairs Passage Formation. The main expression of deformation in this domain is extensive fracturing and network veining in the vicinity of fault zones, especially near the shear zone bounding the eastern edge of the domain. Most of this domain consists of well bedded sediments striking into the sea and dipping eastward (Plate 3F), which are essentially undeformed except for late stage kinking. The steep eastward dipping rock faces make access along this section of coast difficult.

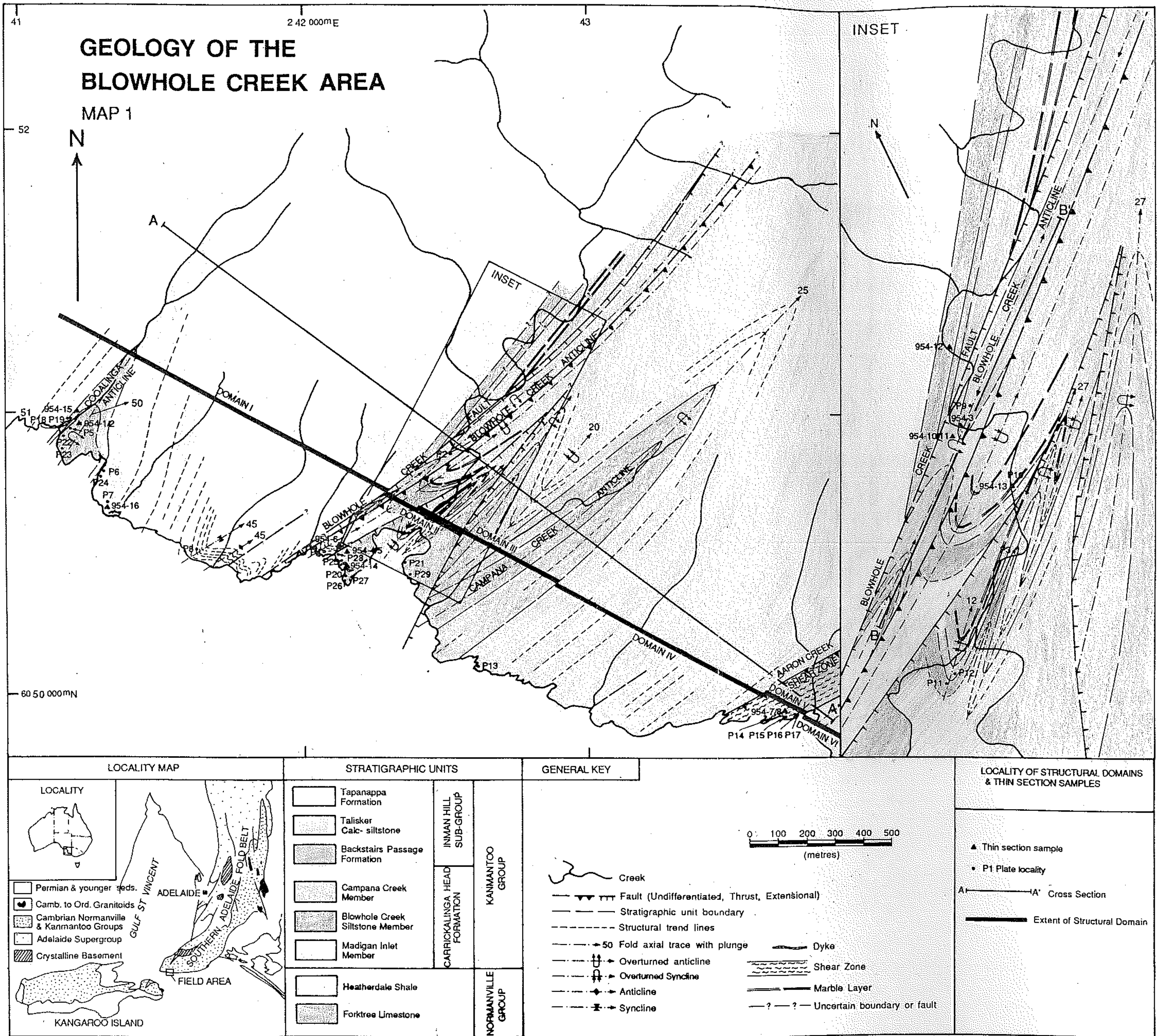
Domain V - The Talisker Calc Siltstone

This domain consists entirely of, and is bounded by the edges of the Talisker Calc Siltstone. This unit forms a major shear zone (named the Aaron Creek Shear Zone) which cuts the strike of the bounding Backstairs passage and Tapanappa Formations at an acute angle of 15 degrees, and dips 45 degrees towards the east. The Talisker Calc Siltstone within this shear zone bears little resemblance to that found in the middle of the map area, being composed mainly of linear bands of highly deformed, recrystallized marble. The rock is heavily veined, displays intrafolial folding, and possesses a prominent down dip stretching lineation. Veining varies from layer parallel, to low angle cross cutting, and some perpendicular to the foliation plane.

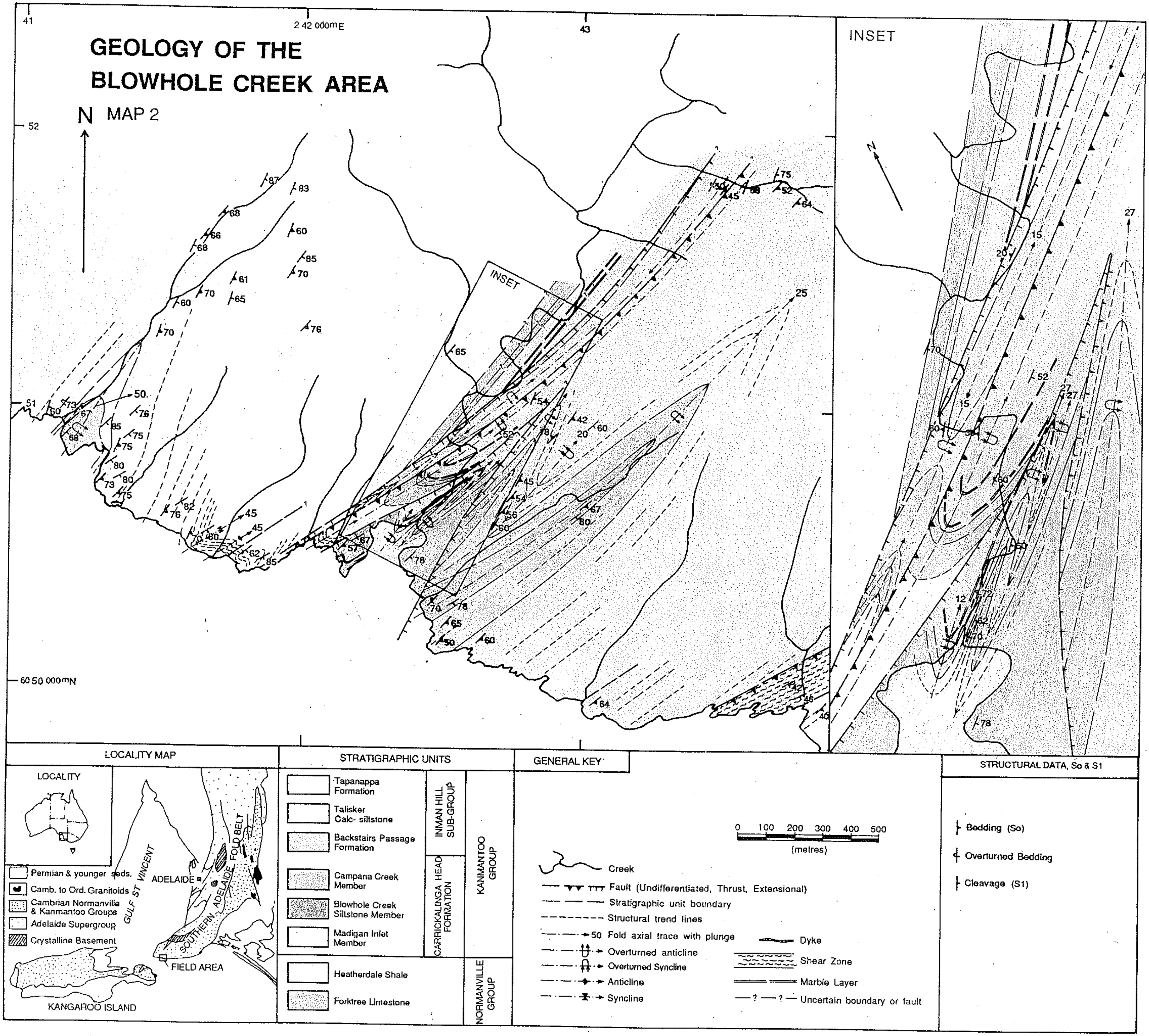
Most veins are boudinaged and often folded (Plates 1F and 1G). Large numbers of small mineralised pods are visible on foliation planes. The shear sense is defined by kinematic indicators such as deformed and rotated augen (Plates 4C and 4D), rotated vein boudins, and small scale folds with overturned limbs cut off by small scale thrusting. The shear sense is sinistral (when looking north) with an east over west sense of movement.

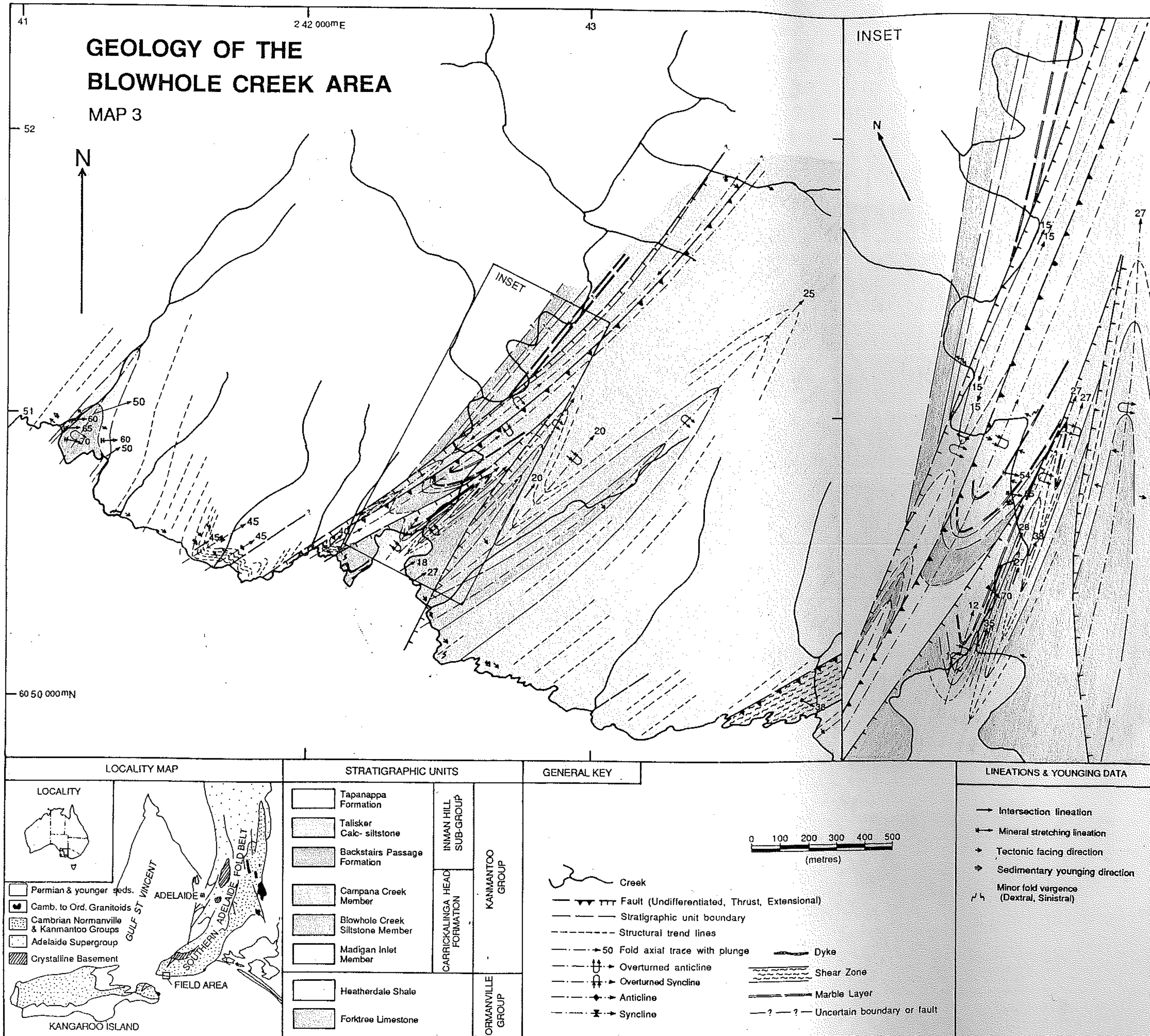
F). Domain VI - Tapanappa Formation

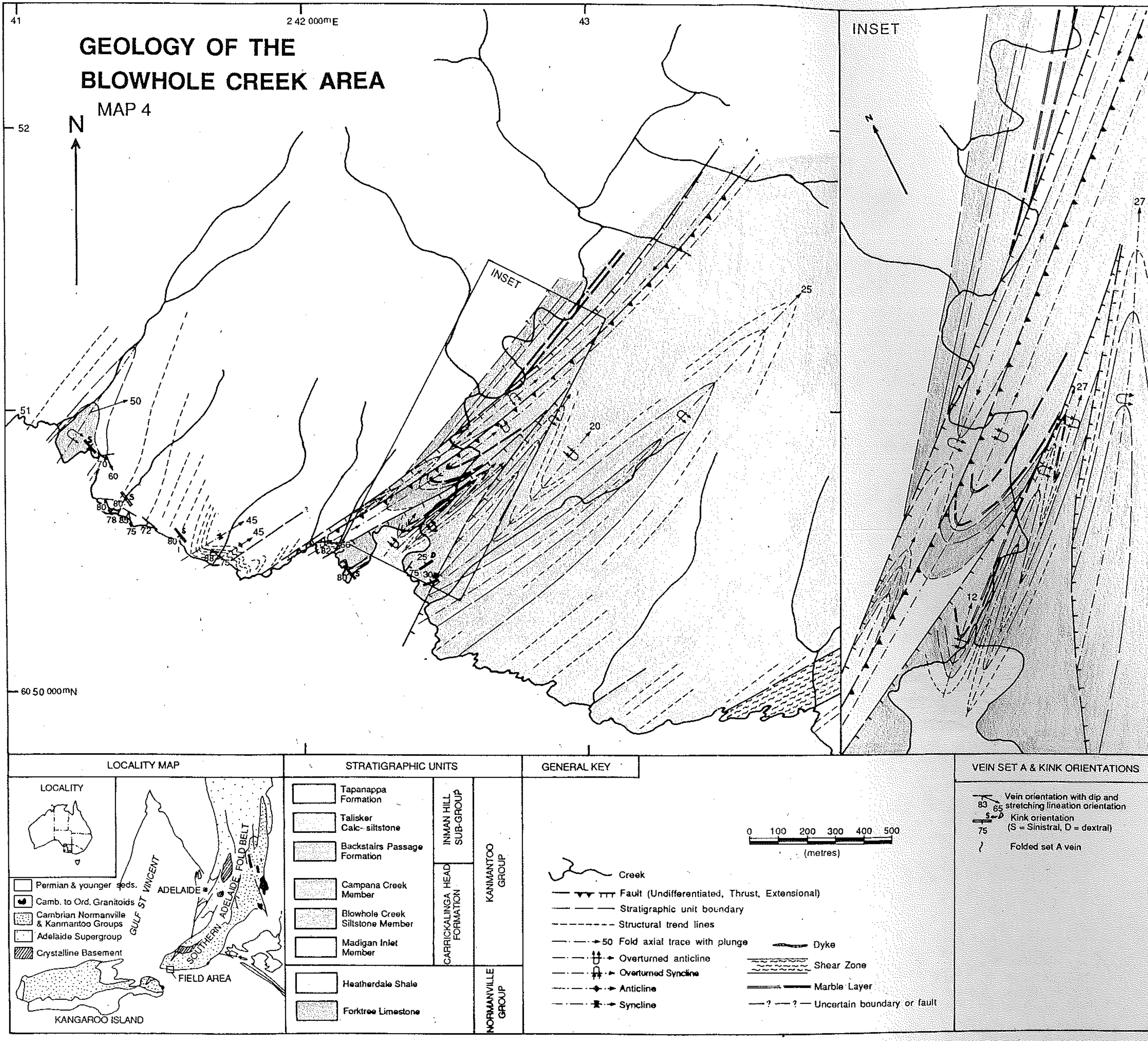
Only a small part of this domain, which consists entirely of a thick sequence of undeformed Tapanappa Formation, is present within the mapping area. The strike of the Tapanappa Formation close to domain V is not parallel to the strike of the shear zone itself.



GEOLOGY OF THE
BLOWHOLE CREEK AREA
MAP 1
N
41
2 42 000mE
43
52
51
60 50 000mN
A
A'
INSET
COOALINGA ANTICLINE
DOMAIN I
DOMAIN II
DOMAIN III
DOMAIN IV
DOMAIN V
DOMAIN VI
BLOWHOLE CREEK FAULT
BLOWHOLE CREEK ANTICLINE
BLOWHOLE CREEK
CAMPANA CREEK
ANTICLINE
AARON CREEK SHEAR ZONE
B
B'
954-15
954-12
954-16
954-14
954-13
954-3
954-10/11
954-7/8
P18 P19
P5
P22
P23
P6
P24
P7
P8
P20
P26
P27
P28
P21
P29
P13
P11
P12
P14 P15 P16 P17
50
45
20
25
27
12
43
LOCALITY MAP
LOCALITY
GULF ST VINCENT
ADELAIDE
SOUTHERN ADELAIDE FOLD BELT
FIELD AREA
KANGAROO ISLAND
Permian & younger seds.
Camb. to Ord. Granitoids
Cambrian Normanville & Kanmantoo Groups
Adelaide Supergroup
Crystalline Basement
STRATIGRAPHIC UNITS
Tapanappa Formation
Talisker Calc- siltstone
Backstairs Passage Formation
INMAN HILL SUB-GROUP
Campana Creek Member
Blowhole Creek Siltstone Member
Madigan Inlet Member
CARRICKALINGA HEAD FORMATION
KANMANTOO GROUP
Heatherdale Shale
Forktree Limestone
NORMANVILLE GROUP
GENERAL KEY
0 100 200 300 400 500
(metres)
Creek
Fault (Undifferentiated, Thrust, Extensional)
Stratigraphic unit boundary
Structural trend lines
Fold axial trace with plunge
Overturned anticline
Overturned Syncline
Anticline
Syncline
Dyke
Shear Zone
Marble Layer
Uncertain boundary or fault
LOCALITY OF STRUCTURAL DOMAINS & THIN SECTION SAMPLES
Thin section sample
P1 Plate locality
Cross Section
Extent of Structural Domain


GEOLOGY OF THE
BLOWHOLE CREEK AREA
N MAP 2
2 42 000mE
43
41
52
51
60 50 000mN
INSET
LOCALITY MAP
LOCALITY
Permian & younger seds.
Camb. to Ord. Granitoids
Cambrian Normanville & Kanmantoo Groups
Adelaide Supergroup
Crystalline Basement
ADELAIDE
GULF ST VINCENT
SOUTHERN ADELAIDE FOLD BELT
FIELD AREA
KANGAROO ISLAND
STRATIGRAPHIC UNITS
Tapanappa Formation
Talisker Calc- siltstone
Backstairs Passage Formation
Campana Creek Member
Blowhole Creek Siltstone Member
Madigan Inlet Member
Heatherdale Shale
Forktree Limestone
INMAN HILL SUB-GROUP
CARRICKALINGA HEAD FORMATION
KANMANTOO GROUP
NORMANVILLE GROUP
GENERAL KEY
0 100 200 300 400 500
(metres)
Creek
Fault (Undifferentiated, Thrust, Extensional)
Stratigraphic unit boundary
Structural trend lines
50 Fold axial trace with plunge
Overturned anticline
Overturned Syncline
Anticline
Syncline
Dyke
Shear Zone
Marble Layer
Uncertain boundary or fault
STRUCTURAL DATA, So & S1
Bedding (So)
Overturned Bedding
Cleavage (S1)


GEOLOGY OF THE
BLOWHOLE CREEK AREA
MAP 3
N
INSET
41
2 42 000mE
43
52
51
60 50 000mN
LOCALITY MAP
LOCALITY
Permian & younger seds.
Camb. to Ord. Granitoids
Cambrian Normanville & Kanmantoo Groups
Adelaide Supergroup
Crystalline Basement
GULF ST VINCENT
ADELAIDE
SOUTHERN ADELAIDE FOLD BELT
FIELD AREA
KANGAROO ISLAND
STRATIGRAPHIC UNITS
Tapanappa Formation
Talisker Calc- siltstone
Backstairs Passage Formation
Campana Creek Member
Blowhole Creek Siltstone Member
Madigan Inlet Member
Heatherdale Shale
Forktree Limestone
INMAN HILL SUB-GROUP
CARRICKALINGA HEAD FORMATION
KANMANTOO GROUP
NORMANVILLE GROUP
GENERAL KEY
0 100 200 300 400 500
(metres)
Creek
Fault (Undifferentiated, Thrust, Extensional)
Stratigraphic unit boundary
Structural trend lines
Fold axial trace with plunge
Overturned anticline
Overturned Syncline
Anticline
Syncline
Dyke
Shear Zone
Marble Layer
Uncertain boundary or fault
LINEATIONS & YOUNGING DATA
Intersection lineation
Mineral stretching lineation
Tectonic facing direction
Sedimentary younging direction
Minor fold vergence (Dextral, Sinistral)


GEOLOGY OF THE BLOWHOLE CREEK AREA
MAP 4
N
INSET
41
2 42 000mE
43
52
51
60 50 000mN
LOCALITY MAP
LOCALITY
Permian & younger seds.
Camb. to Ord. Granitoids
Cambrian Normanville & Kanmantoo Groups
Adelaide Supergroup
Crystalline Basement
GULF ST VINCENT
ADELAIDE
SOUTHERN ADELAIDE FOLD BELT
FIELD AREA
KANGAROO ISLAND
STRATIGRAPHIC UNITS
Tapanappa Formation
Talisker Calc-siltstone
Backstairs Passage Formation
INMAN HILL SUB-GROUP
Campana Creek Member
Blowhole Creek Siltstone Member
Madigan Inlet Member
CARRICKALINGA HEAD FORMATION
KANMANTOO GROUP
Heatherdale Shale
Forktree Limestone
NORMANVILLE GROUP
GENERAL KEY
0 100 200 300 400 500
(metres)
Creek
Fault (Undifferentiated, Thrust, Extensional)
Stratigraphic unit boundary
Structural trend lines
Fold axial trace with plunge
Overturned anticline
Overturned Syncline
Anticline
Syncline
Dyke
Shear Zone
Marble Layer
Uncertain boundary or fault
VEIN SET A & KINK ORIENTATIONS
Vein orientation with dip and stretching lineation orientation
Kink orientation (S = Sinistral, D = dextral)
Folded set A vein

5.STRAIN ANALYSIS

5.1 Aims

Strain analysis of suitable strain markers was undertaken in an effort to define the shape and orientation of the strain ellipsoid within the mapping area, and to quantify its change across any zones of internal deformation (shear).

Strain analysis of both sides of the overturned regional anticline was completed in an attempt to determine how much of the thinning on the overturned limb was due to tectonic shortening alone, as opposed to stratigraphic thinning. All units were found to thin towards the west (Fig 8C).

5.2 Nature of strain markers

As mentioned by Manktelow (1981), the south coast of Fleurieu Peninsula is lacking in good strain markers. Despite this view, two units have potential strain markers in sufficient numbers for a useful analysis. These units are the Heatherdale Shale which contains deformed phosphatic nodules, and the Talisker Calc Siltstone which contains small deformed pods of oxidised sulphides.

Both units are present within the mapping area, however the phosphatic nodules within the Heatherdale Shale proved to be the most useful strain markers (Plate 1D). These strain markers can be measured on both sides of the regional anticline, but due to the small outcrop area of the Heatherdale Shale, they only define the strain state for a small part of the mapping area.

The pods within the Talisker Calc Siltstone, although good strain markers further west, are poorly developed within the mapping area.

For strain analysis methods and technique descriptions see Appendix 2.

5.3 Results and discussion

1. Results of the RF/ϕ analysis.

The results of analysis of the Rf/ϕ plots for the XZ and YZ planes for samples on the overturned and normal limbs of the Cooalinga Anticline are shown in Table 1.

When plotted on a Flinn diagram (Fig 9) the three dimensional shape off the strain ellipsoid lies within the flattening field on the normal limb of the anticline and the the constrictional field on the overturned limb. This indicates that the nodules on the overturned limb have undergone type 4 general constrictional strain, whilst the nodules on the normal limb have undergone type 2 general flattening strain (Ramsay and Huber, 1983). Both the oblate strain ellipsoid on the overturned limb and the prolate strain ellipsoid on the normal limb are orientated with the X axis plunging 60 degrees towards 075.

The change in character of the strain ellipsoid from one limb of the anticline to another may be indicative of a change in deformational mechanisms. Shortening by folding only within a flattening field is probably the deformational mechanism characteristic of the normal limb of the anticline. Shearing within the Heatherdale Shale,as suggested by Daily and Milnes (1971), may account for the constrictional component of the strain ellipsoid as determined for the overturned limb of the anticline.

2. Removal of flattening strain from folded sections.

Removal of the flattening strain from folded sections of the the Forktree Limestone, as indicated by the XZ plane shape of the strain ellipsoid, revealed sections as in Fig 11B. These sections display open mesoscopic folding, with shortening required to produce this buckling being less than 10% of the removed flattening strain shortening as indicated by the strain markers in the Heatherdale Shale. This pre-flattening buckle shortening was not recorded by the Heatherdale Shale strain markers and may be accounted for by the following means;

1. The unaccounted for shortening may be indicative of the magnitude of the error incurred when measuring and analysing the strain markers (less than 10% error). The magnitude of the errors incurred during Rf/ϕ analysis were computed by the INSTRAIN program and recorded in Fig 10 are all above 10% (For each Rf/ϕ plot) hence the 10% shortening may easily be accounted for in this manner.

Fig 9. Flinn plot of k values from Rf/ϕ analysis of Heatherdale Shale strain markers.

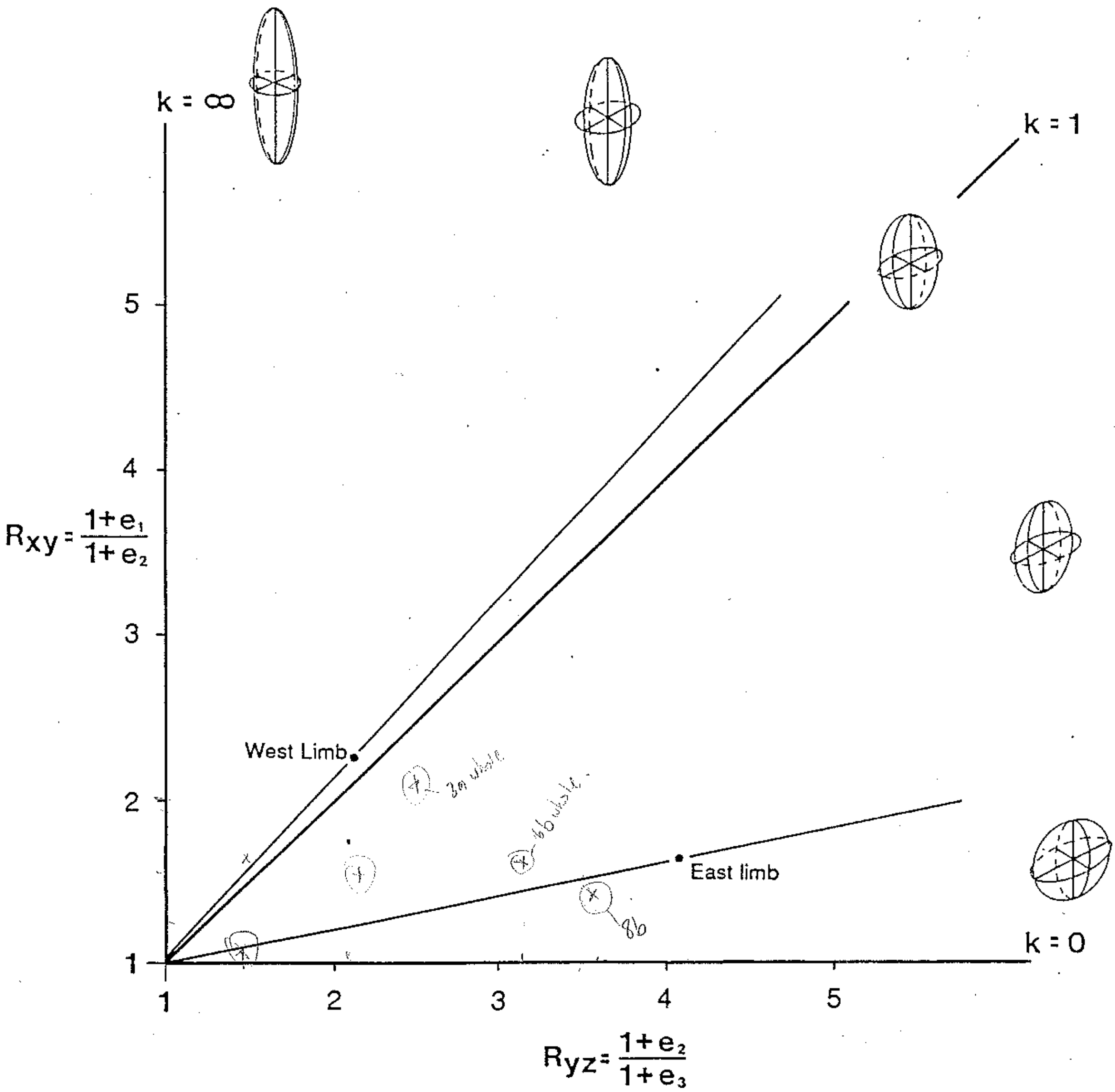
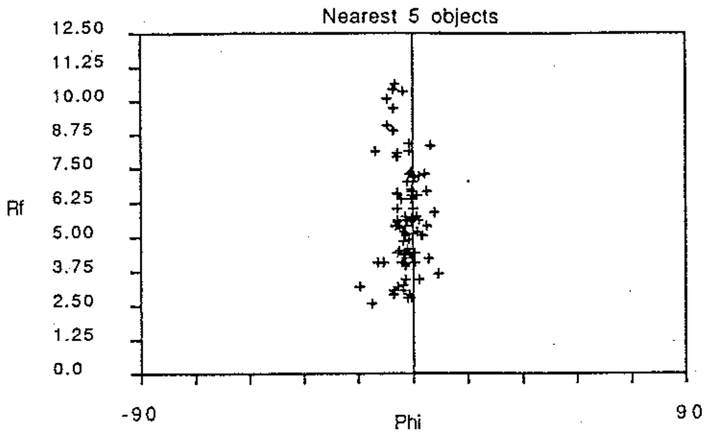


Fig 10. Rf/ϕplots (Plotted from INSTRAIN data sets) of phosphatic nodules in Heatherdale Shale.

East Limb - Cooalinga Anticline

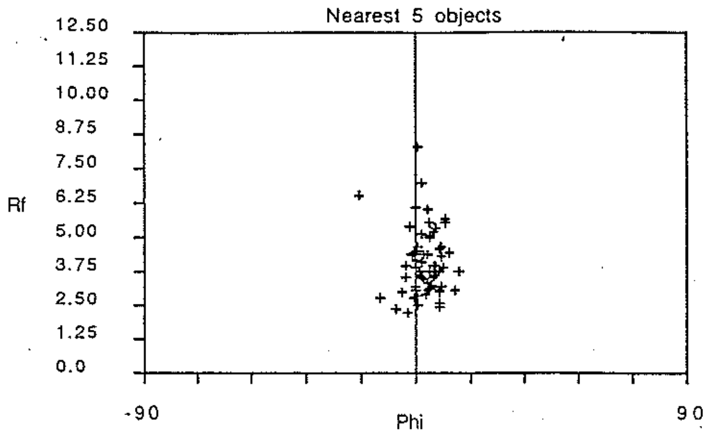


Ellipticity Range: 2.581 to 10.597

MEANS (+/- 1 STD)

Phi (degrees) : -2.314 +/- 4.260
X/Y (n = 86)
Arithmetic 5.634 +/- 1.932
Harmonic 5.025

Mean Object Ellipse: X/Y = 5.443 Phi = -4.73
Average error: 18.60 %
XZ plane



Ellipticity Range: 2.199 to 8.318

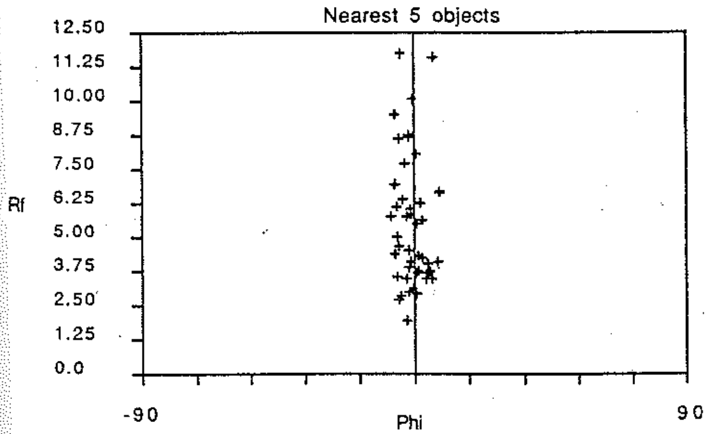
MEANS (+/- 1 STD)

Phi (degrees) : 3.084 +/- 5.426
X/Y (n = 62)
Arithmetic 4.062 +/- 1.216
Harmonic 3.753

Mean Object Ellipse: X/Y = 4.166 Phi = -1.21
Average error: 15.55 %
YZ plane

West Limb - Cooalinga Anticline

Rf/Phi Plot: Mean Object Ellipse



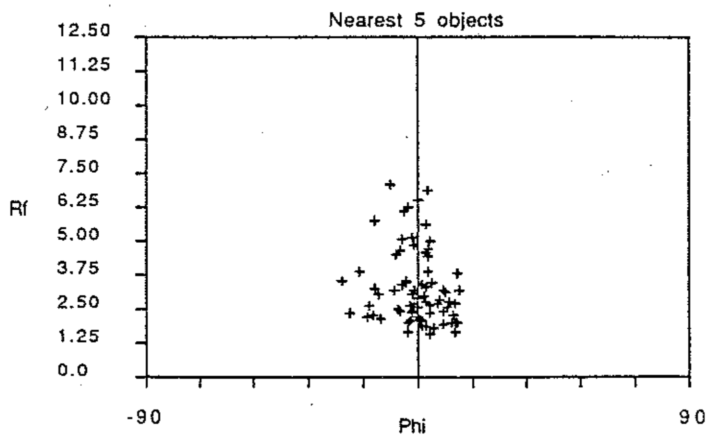
Ellipticity Range: 1.922 to 11.757

MEANS (+/- 1 STD)

Phi (degrees) : 0.766 +/- 4.135
X/Y (n = 46)
Arithmetic 5.421 +/- 2.372
Harmonic 4.588

Mean Object Ellipse: X/Y = 8.330 Phi = 0.71
Average error: 27.84 %
XZ plane

Rf/Phi Plot: Mean Object Ellipse



Ellipticity Range: 1.575 to 7.066

MEANS (+/- 1 STD)

Phi (degrees) : 0.590 +/- 8.517
X/Y (n = 76)
Arithmetic 3.240 +/- 1.323
Harmonic 2.832

Mean Object Ellipse: X/Y = 3.473 Phi = -5.07
Average error: 19.54 %
YZ plane

Table 1. Rf/Phi Calculations

	A	B	C	D	E	F
1	East Limb					
2	XZ	Rf max	10.6	Rs	5.23	
3		Rf min	2.58	Ri	2.03	
4	YZ	Rf max	7.5	Rs	4.06	
5		Rf min	2.19	Ri	1.85	
6						
7	e1	0.889	Rxy	1.29		
8	e2	0.466	Rxz	5.23		
9	e3	0.639 (-ve)	Ryz	4.06	k	0.094
10						
11	West Limb					
12	XZ	Rf max	11.76	Rs	4.75	
13		Rf min	1.92	Ri	2.47	
14	YZ	Rf max	7.07	Rs	2.12	
15		Rf min	1.58	Ri	3.34	
16						
17	e1	1.201	Rxy	2.24		
18	e2	0.019 (-ve)	Rxz	4.75		
19	e3	0.537 (-ve)	Ryz	3.34	k	1.113

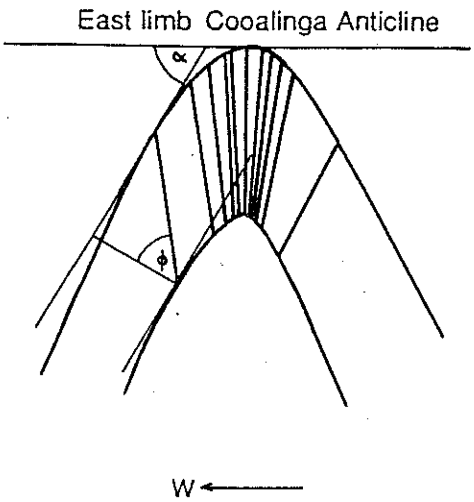
2. The strain markers may not have recorded the entire shortening history of the area (i.e. buckling prior to flattening of the strain markers). Strain markers such as clasts within a ductile matrix only provide a value equivalent to the minimum possible strain (Ramsay and Huber, 1983), some of the strain having being taken up during deformation of the matrix. Thus not all of the strain history has been recorded by the strain markers themselves. Extensive shortening via folding on a small scale (Fig 11D and Plate 1B) (these folds being present as an envelope to the mesoscopic folding) also does not appear to have been recorded by the strain markers.

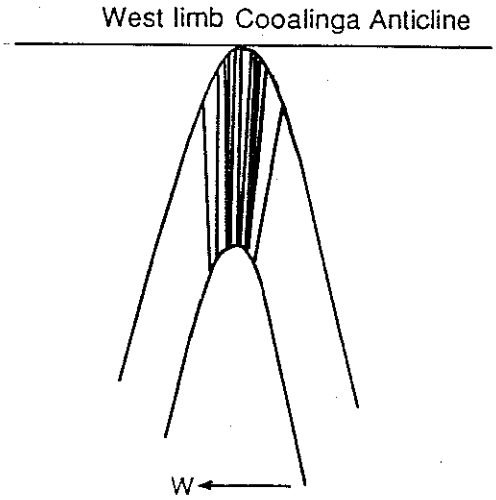
3. Comparison of results of Rf/ϕ and dip isogon techniques.

Analysis of the flattening values of the folded structural sections as determined by both the Rf/ϕ and dip isogon methods (Fig 15) has revealed that both methods achieved similar results for the normal limb of the Cooalinga Anticline. The dip isogon method appears to have confirmed the values obtained via the Rf/ϕ method as being accurate on this limb. On the overturned limb dip isogon analysis results in an value indicating higher flattening values than that indicated by Rf/ϕ analysis.

The folds on the overturned limb of the anticline are observed to have a shorter wavelength and are tighter than those on the normal limb. Ramsay (1967) stated that "the dominant wavelength is directly proportional to the thickness of a competent layer". It can be observed that the thickness of individual marble layers (as separated by the more weathered clay rich layers) on the overturned limb of the Cooalinga Anticline are thinner than the equivalent layers on the normal limb. Thus the wavelength of the folds may be expected to be shorter and the interlimb angle tighter on the overturned limb than on the normal limb. Hence, the flattening strain may be similar on both limbs, but the fold shape may vary. In conclusion, a comparison of flattening strains for both limbs using the dip isogon method may only have been accurate had the thicknesses of the competent layers and the viscosity contrast between layers been the same on both limbs.

Fig 15A. Measurement of α and $\alpha - \phi$ angles from dip isogon plots of minor folds from both limbs of Cooalinga Anticline (taken from structural sections A & B)





East Limb

α	ϕ	$\alpha - \phi$
20	15	5
30	23	7
40	31	9
50	40	10
60	35	25

West Limb

20	17	3
30	26	4
40	33	7
50	42	8
60	52	8

East Limb

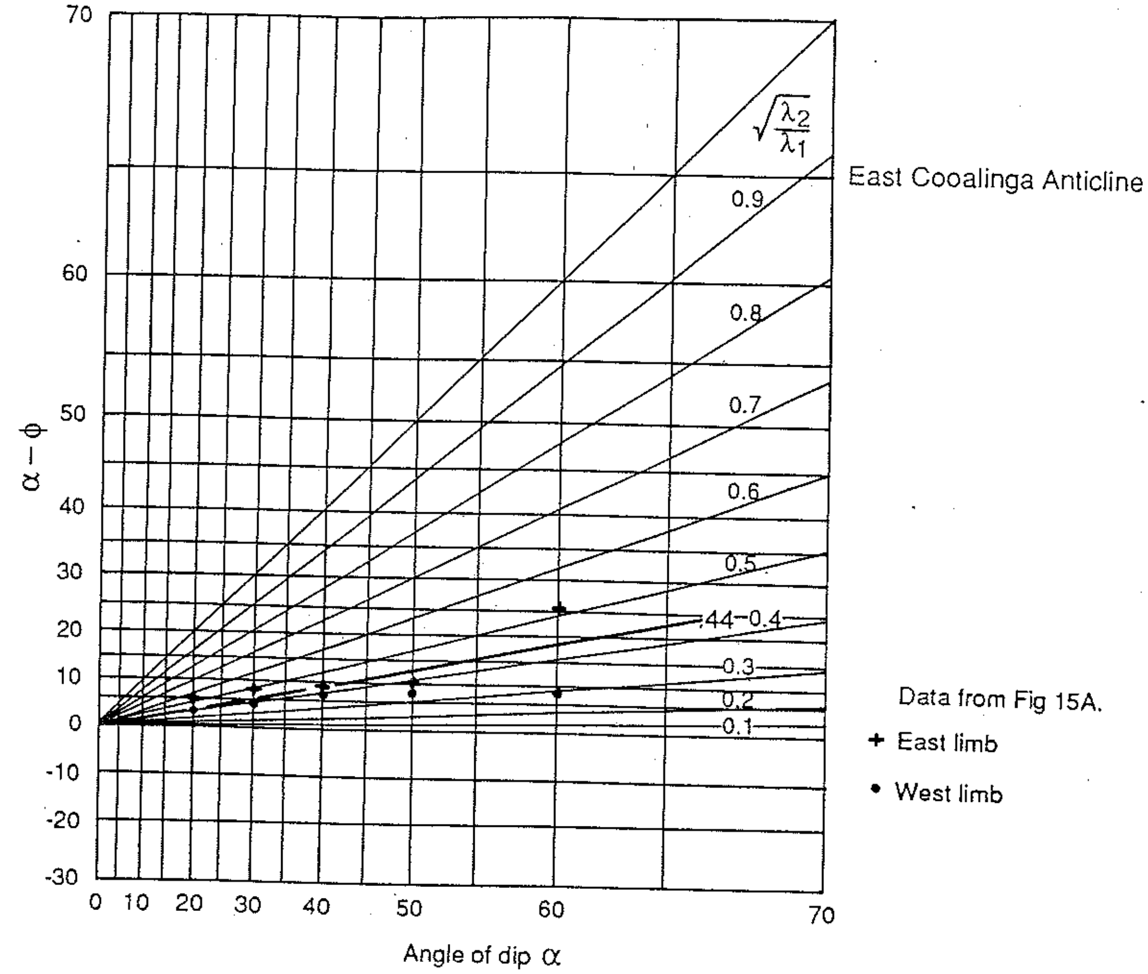
α	ϕ	$\alpha - \phi$
20	19	1
30	28	2
40	38	2
50	47	3
60	57	3
70	61	9

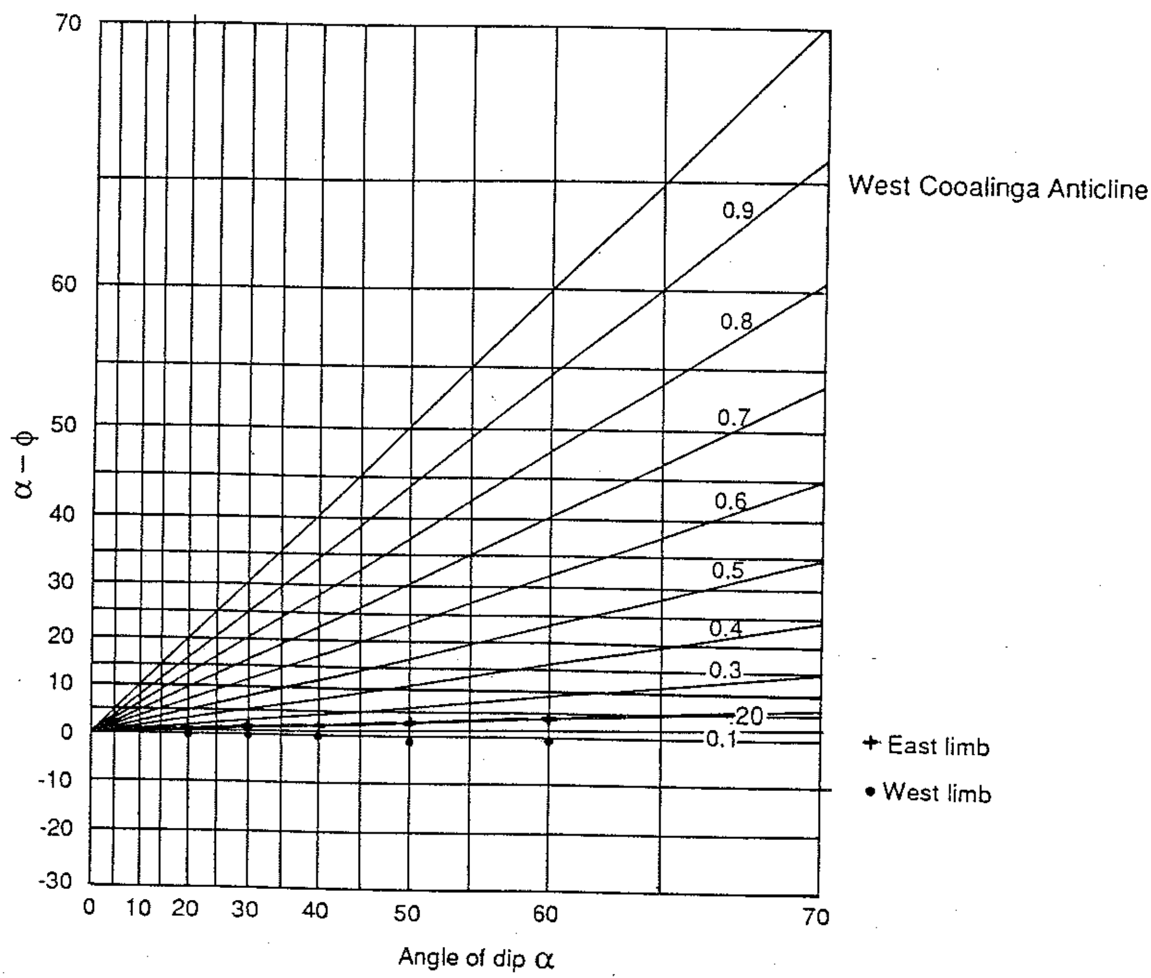
West Limb

20	20	0
30	30	0
40	40	0
50	51	-1
60	61	-1
70	69	1

RESULT (See Fig 15B)
East limb Cooalinga Anticline - Flattening Ratio = 0.43
(Hudleston Method)
East limb Cooalinga Anticline - Flattening Ratio = 0.1 to 0.2
(Hudleston Method)
West limb Cooalinga Anticline - Flattening Ratio = .46
(Rf/ϕ Method)
East limb Cooalinga Anticline - Flattening Ratio = .44
(Rf/ϕ Method)

Fig 15B. Graphs of the straight line relationship in the variation of $\alpha - \phi$ with α in flattened parallel folds for various amounts of flattening, after Hudleston 1973.





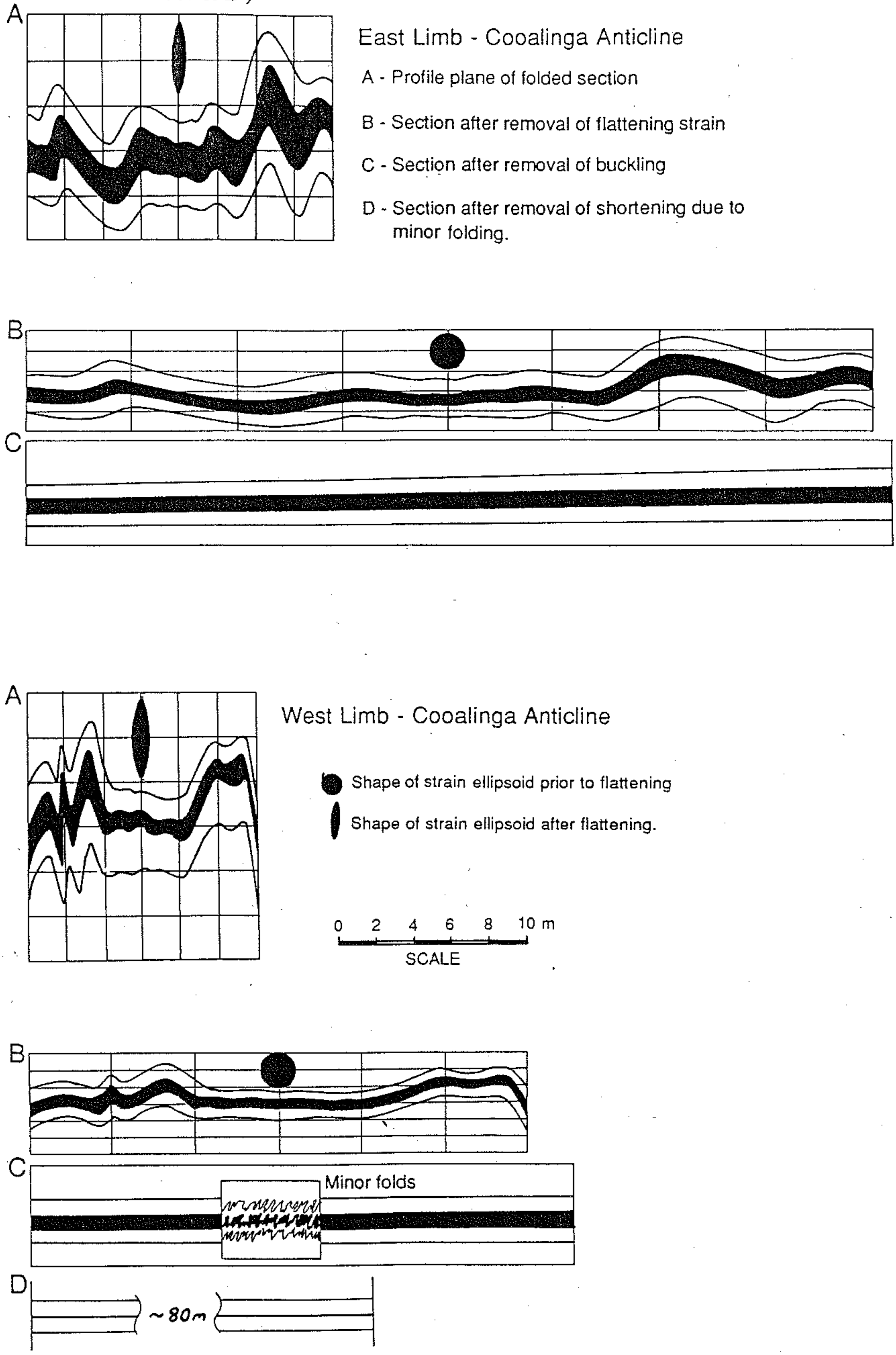
4. Discussion of Results

Comparison of the total shortening of the restored sections from both sides of the anticline (Fig 11C) reveals that the section on the normal limb displays approximately 14% more shortening than the overturned section. This is a comparison of the shortening as represented by the mesoscopic folds only, the shortening forming the small scale fold envelope being considered to be the same on both limbs of the major anticline.

Mechanisms such as imbricate shearing within units and volume loss during deformation may account for shortening missing on the overturned limb section. It was expected that the overturned limb would have experienced more shortening than the normal limb.

However, it is clear that there is no major difference in the amount of shortening on both limbs of the Cooalinga Anticline. If this result is considered to apply to other overturned structures within the Blowhole Creek area then it appears that thinning of stratigraphic units on either limb of fold structures is mostly a feature produced during deposition of that unit. For example the thinning of the westward younging sequence on the overturned limb of the Campana Creek Anticline must be primarily due to stratigraphic rather than tectonic processes. Although most units are internally deformed, the intensity of this deformation does not greatly change as its position relative to major fold structures changes, hence any thinning of units must be due to changes in their original pre-deformational thicknesses.

Fig 11. Removal of flattening strain (as determined from Heatherdale Shale strain markers) from selected lengths of folded Forktree Limestone structural sections. (structural sections A & B)



6. THIN SECTIONS

6.1 Analysis and localities

Thin sections were taken from most units within the map area in an effort to define the mineralogy and microstructures of each unit, the relationship between So and S1 on a microscopic scale, and to search for kinematic indicators near fault zones. Most thin sections were cut parallel to the XZ plane to facilitate discovery and analysis of kinematic indicators. Some were cut parallel to the YZ plane for comparison. Each slide was described and significant features photographed.

Samples and thin sections were taken from the following units (no of thin sections); Forktree Limestone (2), Heatherdale Shale (1), Madigan Inlet Member (2), Blowhole Creek Member (6), Talisker Calc Siltstone (4), Marble Band (1), Backstairs Passage Formation (1), and the mafic dyke (1). For sample localities see Map 1.

6.2 Mineralogy and microstructures

The mineralogy of the thin sections (with the exception of the calc silicate pod, the phosphatic nodules and the mafic dyke) was relatively simple, each section being composed of varying amounts of quartz, up to three types of phyllosilicates, hematite, and within the carbonate units, calcite.

Of the phyllosilicates, biotite was the most common followed by muscovite and chlorite. Chlorite, where present, developed larger crystals than the other two phyllosilicates.

Variation in the size of quartz crystals probably depends on the initial grain size when deposited. However, very few well rounded quartz grains were observed, indicating recrystallisation during deformation.

Varying quantities of hematite were found in most thin sections. Cubic pseudomorphs indicated that the hematite was an oxide after pyrite, the presence of this and related sulphides being not uncommon throughout the Kanmantoo Group, especially within the Talisker Calc Siltstone. The mobility of hematite has resulted of infilling of features such as pressure solution cleavage and fractures, and also formation of fringes of hematite about chlorite crystals within the pressure shadows of phosphatic nodules (within the Heatherdale Shale - Plate 5B). This hematite (and most other hematite) was probably emplaced when the rock came into contact with oxidising surface waters during its retrograde path.

All calcite grains observed seem to be the product of secondary recrystallisation, no primary detrietal or fossiliferous grains being observed. All carbonates within the field area resemble deformed impure marbles (Plates 5C and 5D).

Other minerals observed include; hornblende, present as part of the calc silicate pods within the Madigan Inlet Member, alkali feldspar, and other, opaque, igneous minerals as part of a deformed mafic dyke.

6.3 Fabric and textures

The main S1 fabric present in all specimens is a well developed mineral foliation defined by the preferred orientation of phyllosilicate minerals (Plates 5E and 5F). Within carbonate units S1 is manifested in the form of a pressure solution cleavage and preferred orientation of phyllosilicates. The S1 fabric is the only tectonic fabric present in any of the thin sections. Further to the east within the Kanmantoo Group F2 crenulations have been observed, however this is not the case within the Blowhole Creek area.

Bedding can often be observed as layers with greater abundances of quartz or phyllosilicates, and by increase in grain size of sandier layers (Plates 5E and 5F). Within the Forktree Limestone changes in abundance of hematite defines bedding layers.

6.4 Other microstructures and kinematic indicators

Minor folds are present in some of the thin sections, all having a well developed axial planar cleavage. These folds can also be observed in hand specimen.

Elongate phosphatic nodules are observed within the Heatherdale Shale and were used as strain markers (Plate 5A).

Microscopic kinematic indicators were found to be rare, but those observed displayed a sinistral sense of shear and hence an east over west sense of movement (Plates 5G and 5D). The kinematic indicator as seen in plate 5G displays σ type asymmetric pressure shadows and a sinistral sense of shear. This result is good evidence for the presence of thrust movements of faults within the area.

7. VEINS AND KINKS

7.1 Characteristics of different vein sets.

Two vein sets can be observed throughout the Blowhole Creek area. Both sets differ in orientation, age, and composition.

The younger, most prominent set (set A) is visible in all units, displays a relatively constant orientation throughout all units and is composed of quartz with little other mineralisation. This set is observed to cut the older second set (set B), this relationship being best observed within the Blowhole Creek Formation (Plate 2A). Set A generally strikes northeast and dips steeply towards the southwest.(Fig 6 - stereonets) Set A is relatively undeformed and may have been emplaced during the latter stages of the Delamerian Orogeny. Only in close proximity to faulting and in some extensively deformed units is set A intensely deformed. All set A veins display a prominent stretching lineation which plunges steeply southwest, almost parallel to the dip of the vein face.

Set B is observed to be older than set A by virtue of cross cutting relationships and its more intense deformation. Set B can also be distinguished from set A by its different compositional characteristics. Set B veins appear to be composed of an opaque mass of small separate quartz crystals whilst set A is composed of clear to translucent massive quartz. Set B is heavily mineralised with masses of chlorite, muscovite and other minerals.

Set B is always more intensely deformed than set A especially within the Blowhole Creek Formation. Set B commonly forms small en-echelon sets of numerous small veins that vary from 5 to 20 centimetres in length (Plate 2C), unlike set A where individual veins can be up to 5 metres in length and form parallel but not en-echelon sets. The edges of these sets can be measured, but since the set boundaries themselves are often folded, measurement of the orientation of set B veins is difficult.

7.2 Description of stratigraphy with respect to veining.

Set A is observed to be intensely boudinaged in the Forktree Limestone (Plate 2G), with some boudins having been rotated by movement along the encompassing S1 foliation planes (Plate 2H). Perhaps surprisingly, most major veins sets within this and most of the carbonate units throughout the area are composed of quartz rather than calcite. Set A is dominant within the Heatherdale Shale.

Within the Madigan Inlet Member set A is prominent and is observed to be relatively undeformed except for minor shear where individual veins cut silty beds (Plates 3G and 3H). These minor shear zones constitute the main effect of deformation of this part of the Madigan Inlet Member and are well defined by cross cutting set A veins (Fig 12). Set B is much less prominent within this unit, but is present in the form of small folded en-echelon sets with fold axes parallel to the set boundary. Small elongate horizontially orientated mineralised quartz pods are commonly observed on bedding planes within this unit.

The Blowhole Creek Siltstone Member is very heavily veined, especially with vein set B, which forms large pods (Plate 2B) and folded en-echelon sets (plate 2D). Here the fold axes are generally not parallel to the en-echelon set boundary, hence this boundary is itself folded. Bedding parallel veins with characteristics similar to set B veins are also present (Plate 2F). Set A is also present and towards the western boundary of this unit (near to an interpreted fault trace) veins belonging to this set are folded (Plate 2E). The degree of folding of set A veins decreases towards the east away from this boundary.

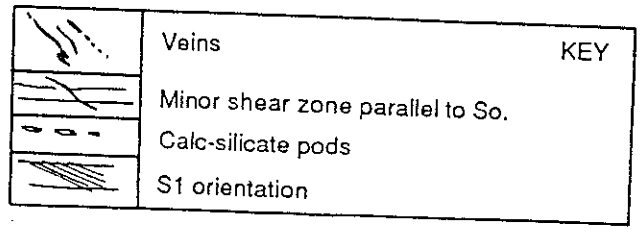
Vein set A is the most prominent set within the Campana creek Member, although set B is also well represented. Both sets are less intensely deformed then in the Blowhole Creek Siltstone Member.

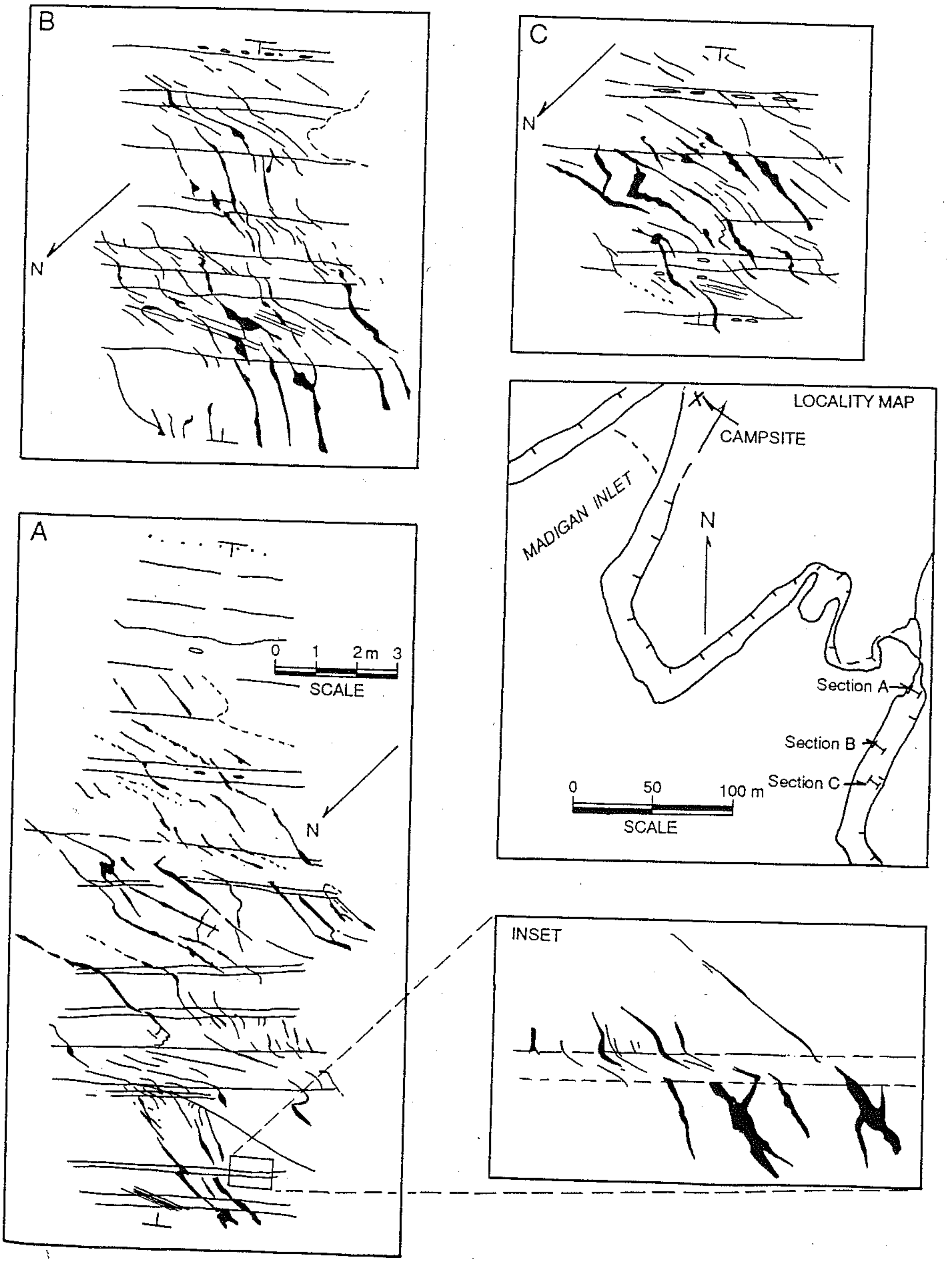
Although veining is not extensive in most of the the Backstairs Passage Formation, vein set A has been observed within this unit. Near a suspected fault an en-echelon set of set A veins was observed. Near the shear zone the Backstairs Passage Formation is penetrated by an extensive vein network.

Veining within the Shear zone (Talisker Calc Siltstone) veining is extensive and is often heavily boudinaged and folded. Small mineralised quartz pods similar to those seen within the Madigan inlet Member are commonly observed in large numbers on foliation planes.

Near fault zones inland along Blowhole Creek folded, boudinaged veins are common.

Fig 12.Sheared Set A veins within the Madigan Inlet Member





7.3 Significance of veining

As both vein sets were emplaced during different times within the Delamerian Orogeny they may represent strain markers that indicate the extent and intensity of deformation within the Blowhole Creek area that can be compared for two different times.

Vein set A is not intensively deformed and can be considered to have been emplaced during the waning stages of the Delamerian Orogeny. The orientation of the veins of this set do not appear to have been affected greatly by folding, their orientation being only slightly warped by major fold structures. These veins are only observed to be extensively deformed near and within shear zones or faults. This result indicates that deformation and resultant displacement along faults continued after folding ceased. For example; set A veins are observed to be folded at the western edge of the Blowhole Creek Member near a proposed fault trace, whist the same set is not folded some 20 metres east. It is possible that the deformation of these set A veins may have ocurred during extensional faulting after the major compressional event.

In contrast, vein set B is intensely deformed. These veins are often found to be bedding parallel and are folded the same as is bedding. Thus these veins may have been emplaced just prior to the major deformational event. The en-echelon set B veins may represent a different generation of veining to the bedding parallel set.

If both the set B(bedding parallel) and the set A veins could be dated, (perhaps via dating of the abundant phyllosilicate minerals present within each set) then it may be possible to bracket the period of deformation of the Blowhole Creek area

7.4. Kinks

Two sets of kinks can be observed within the Blowhole Creek area. The kinking deformation postdates the major F1 deformation of the region, both S0 and S1 being rotated within the kink band.

The two sets include; a sinistral set with kink plane dipping steeply towards the southwest and occasionally towards the northeast, and a dextral set with kink plane dipping shallowly northwest (Plate 4A) (Fig 6 - stereonets) Many joint surfaces throughout the area have orientations parallel to the planes of both sets, the most noticable being those associated with the shallower dipping of the two sets.

Despite having planes approximately perpendicular to each other, and with different shear senses the two kink orientations do not form a conjugate set. This is because the profile planes and kink axes of both sets have different orientations that are approximately perpendicular to each other. Hence I have concluded that each set formed independantly and at a different time to each other

During formation of the steep kink planes the direction of principal stress must have been approximately vertical, indicating that these kinks were not formed during a phase of compressional deformation. Since these kink planes are not observed to be folded they may have been formed after the main deformational event.

8.DISCUSSION

8.1 Structure

The previously accepted structure and stratigraphy of the Blowhole Creek region until this investigation was essentially that of Daily and Milnes (1971), this being a large overturned regional anticline (the Cooalinga Anticline), which repeats the type section of the Kanmantoo Group and upper elements of the Normanville Group on its overturned west limb. The limbs of this anticline were thought to be essentially undeformed with the exception of small scale folding within units. It is now evident that the section in this area is intensely faulted and folded, and displays a set of tight overturned folds independent of the major structure. There has been no evidence to suggest that the stratigraphy of Daily and Milnes (1971) is chronologically incorrect, however the the Blowhole Creek Siltstone Member appears to be thickened by fold repetition, and is much thinner than Daily and Milnes considered.

Daily and Milnes (1971) noted that two units, the Blowhole Creek Siltstone Member and the Campana Creek Member, along with much of the Backstairs Passage Formation was missing on the overturned limb of the Regional Anticline. They ascribed "the absence of much of the Carrickalinga Head Formation and the stratigraphically younger Backstairs Passage Formation as a result of faulting". However both Daily and Milnes (1971) and Rogers (1991) were unable to find conclusive evidence for such a fault. As a result of this investigation it is evident that the units in question thin stratigraphically towards the west (Fig 8C), and it is most likely that they thin out to almost nothing on the western limb of the Cooalinga Anticline. This interpretation is based on balanced and restored sections constructed across the whole of the Blowhole Creek area (Fig 8). It must be noted that whilst most units thin towards the west, the Talisker Calc Siltstone appears to thicken westward instead. This thickening has been attributed by Rogers (1991) to the development of a syn-sedimentary fault during deposition of this unit.

The discovery of a westward younging sequence inland along Blowhole Creek has resulted in the realisation that there are two large anticlinal structures within the Blowhole Creek region. These two structures are the Cooalinga Anticline to the west and the Campana Creek Anticline towards the east. The smaller folds that repeat the Blowhole Creek Siltstone Member are parasitic folds on the overturned limb of the Campana Creek Anticline.

These two structures are separated by the Blowhole Creek fault, with no well defined syncline between them. The western limb of the Campana Creek Anticline is cut by the faults of the Blowhole Creek Imbricate. Restoration of the displacement on these faults reveals the large Campana Creek Anticlinal Structure (Fig 8B).

8.2 Strain analysis

Finite strain analysis and shortening measurements have revealed that tectonic contraction on the overturned limbs of the major fold structures is not significantly greater than that on the normal limbs, hence the thinning of units towards the west is due mostly to stratigraphic rather than tectonic reasons. For example, the thinning of units on the overturned limb of the Campana Creek Anticline is not wholly a tectonic shortening feature. Strain analysis has also revealed that the normal limbs of folds have undergone type 4 general flattening strain (Ramsay & Huber (1983)) producing a strain ellipsoid of oblate shape as demonstrated by strain markers in the Blowhole Creek area. A constrictional strain component is indicative of the shear and thrust faulting deformational mechanisms characteristic of the overturned limbs of folds in the Blowhole Creek area.

Although the three dimensional shape of the strain ellipsoid varies from prolate to oblate across fold structures within the Blowhole Creek area, the two dimensional XZ plane shape does not vary greatly in shape. For example, on the overturned limb the flattening ratio as derived from the strain ellipsoid is a value of 0.46, whilst on the normal limb the value of the flattening ratio is 0.44. This result indicates that the amount of contraction parallel to the profile plane of structures would not vary greatly from one side of the anticline to the other, hence the conviction that the tectonic component of thinning of stratigraphic units on the western limbs of major structures is minimal.

The Blowhole Creek area has undergone about 66 percent shortening during the main fold producing deformation (Fig 8C). This values does not include shortening via small scale folding and faulting within separate units.

8.3 The Blowhole Creek imbricate fan

The displacements on most of the faults in this structural domain retain extensional offsets for any reasonable interpretation of this area. Explanations for these extensional offsets include;

1. Invoking a pop up structure or structures to explain the extensional offsets (Fig 14). This explanation involves rotation under increasing strain of the extensional side of the pop up to parallelism with the side displaying thrust displacement .

In this case the side displaying thrust displacement would be the first fault to the east of the Blowhole Creek Fault, which does in fact display thrust displacement, the Backstairs Passage Formation being thrust over older Talisker Calc Siltstone. Such an effect would produce tight folding between the faults involved, and this is observed within Domain II.

The main flaw in this theory is that it contains no explanation of the apparent extensional offset of the Blowhole creek fault. The pop up theory requires that the basal fault display a thrust sense. This is not the case if the most westerly fault of the imbricate, the Blowhole Creek Fault, is this basal fault.

2. An alternate and preferred theory assumes that these faults once displayed a thrust sense of displacement, that was overprinted by subsequent extensional reactivation (Fig 13C). Thus all of the contractional structures of the area were produced during thrusting, whilst the stratigraphic offsets on the faults were produced by later extensional movement. Extensional block faulting appears to be common within the Southern Adelaide Fold Belt, and many of these extensional faults parallel the proposed traces of earlier thrust faults. For example Steinhardt (1989) proposed the existence of thrust traces paralleling the Eden, Para, and Willunga extensional fault escarpments.

Assuming that all the observed faults in Domain II were thrusts, it is proposed that they form a duplex structure, with the Blowhole Creek Fault being the leading duplex thrust (Fig 8). It is also proposed that the Aaron Creek shear zone may have formed a roof thrust with which the duplex faults intersect. A suitable horizon for development of a basal sole thrust could be the Heatherdale shale.

8.4 Tectonic History

A proposed Tectonic history for the Blowhole Creek area may be as follows;

1. Deposition of a relatively flat lying sequence of Cambrian Kanmantoo and Normanville group sediments that thin towards the basin edge which lies to the west. Syn-sedimentary faulting during deposition of the Talisker Calc Siltstone resulted in thickening of this unit west of the Blowhole Creek area (Fig 8).

2. Beginning of thrust faulting during the early stages of the Delamerian Orogeny with tectonic transport towards the west. Development of a shallow roof thrust within the Talisker Calc Siltstone and sole thrust along the base of the Heatherdale shale. The sole thrust steepens and forms a ramp (the Blowhole Creek Fault) which intersects the roof thrust. Development of three imbricate faults behind the Blowhole Creek fault (Fig 8).

3. As strain increases the Cooalinga Anticline and the Campana Creek Anticline start to develop. The sole thrust may be folded parallel to the Campana Creek Anticline. The folding of this thrust may promote the development of offset along the imbricate faults. Continued formation of the Cooalinga Anticline may have resulted in the rotation of the roof thrust from its initial shallow angle to its present 45 degree slope (Fig 13A).

4. Extensional Block faulting along reactivated Blowhole Creek and other imbricate faults during an extensional period after the end of the Delamerian Orogeny (perhaps during the widespread Tertiary extensional block faulting event.) (Fig 13C).

Fig 13. Cartoon detailing possible evolution of the Blowhole Creek area along cross section A - A'.

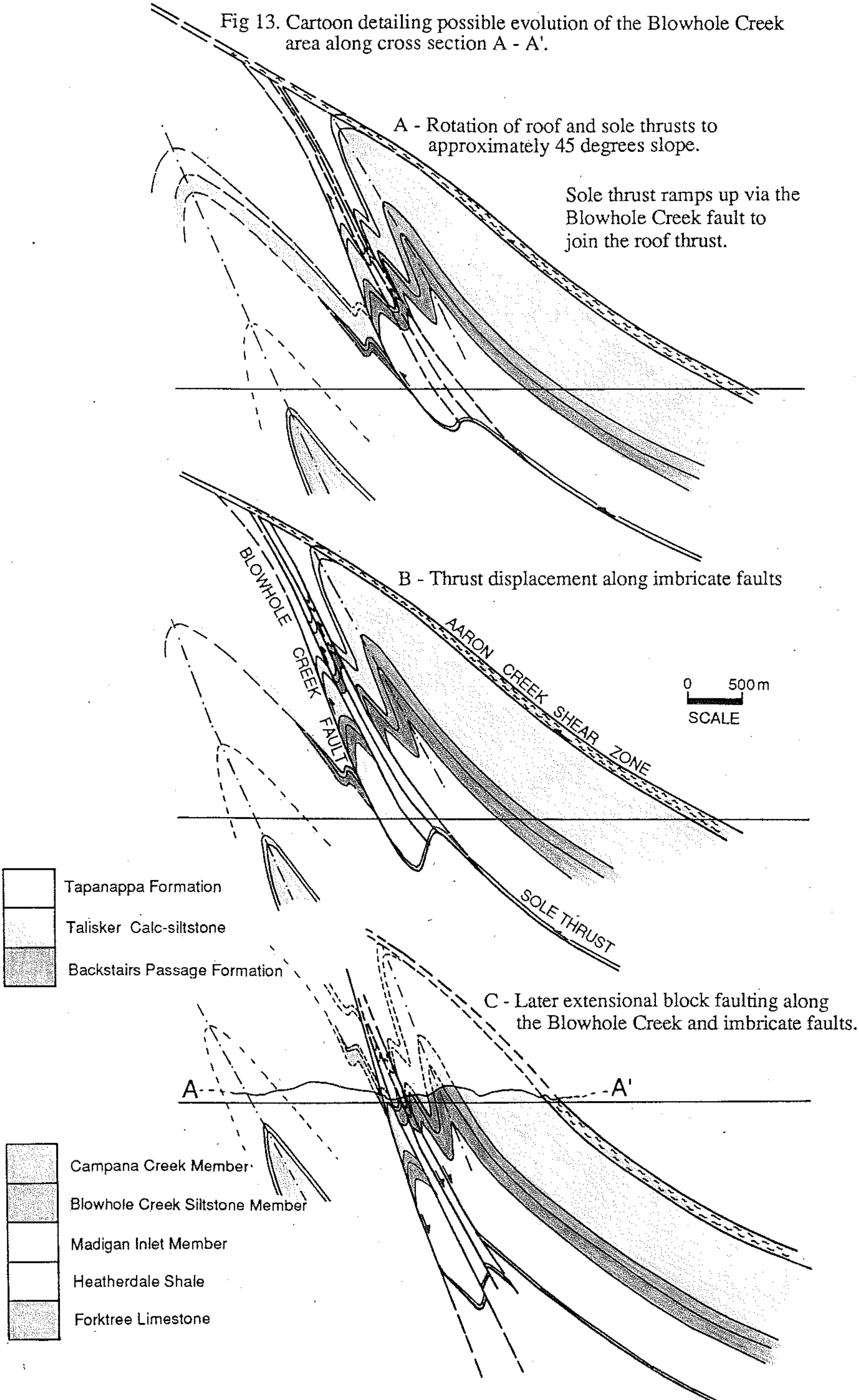
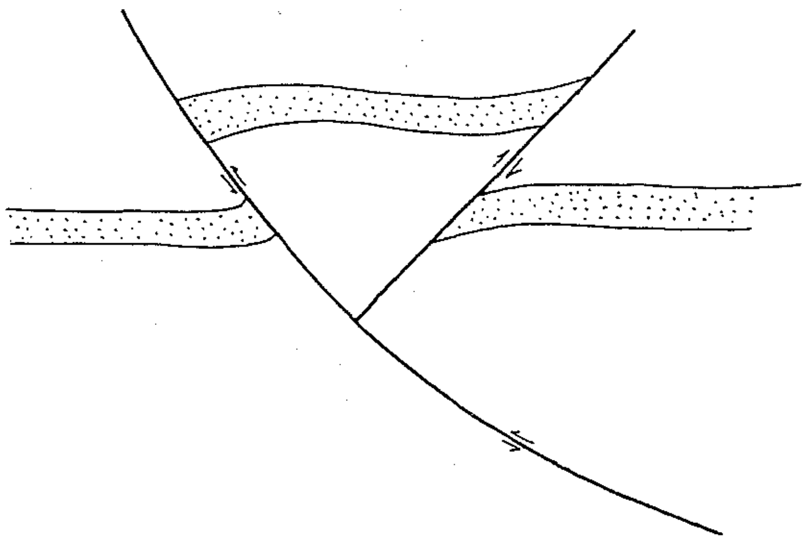
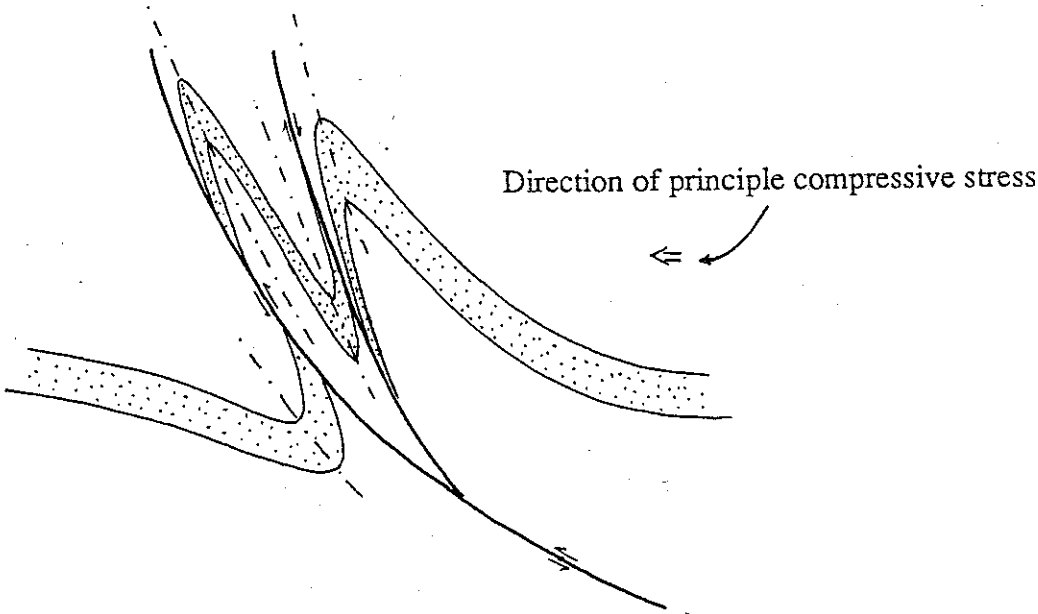


Fig14 Evolution of a pop up structure with increasing compressive strain. Note the near parallelism of both faults in B and the tight nature of folding within the Fault block.

A. development of pop up structure



B. Compressed pop up structure



9. CONCLUSION

The general structure of the Blowhole Creek Region consists of two large overturned anticlines bounded on both sides by fault or shear zones. This large scale structure of the Blowhole Creek area is considered to be typical of a thrust faulted terrain within a foreland fold and thrust belt. The tight overturned nature of smaller scale folds and kinematic indicators are evidence for a thrust faulted terrain with tectonic transport towards the west. Anomalous stratigraphic offsets indicating extensional movement along some faults may be explained via later extensional reactivation of earlier thrust faults.

From the cross sections of this area it can be observed that this section has been repeated and thus thickened by folding. If these folds are considered to have resulted from drag on underlying thrusts then the suggestion put forth by Jenkins (1990), that of repetition of the Kanmantoo Group via thrusting, holds true within the Blowhole Creek area.

In my opinion the main reason that earlier investigators of this region failed to recognise the existence of a westward younging sequence of the Kanmantoo Group at Blowhole Creek simply because of the nature of their mapping locale. All previous investigators restricted their mapping to the coastal strip of outcrop providing a limited two dimensional picture of the area and missing the vital exposures of Talisker Calc Siltstone and Backstairs Passage Formation found inland along Blowhole Creek. Due to the nature of faulting in the area these exposures do not extend to the coast. Hence I consider it important to map well inland to gain an understanding of the three dimensional characteristics of the structure of this and adjacent regions.

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APPENDIX 1.Thin section descriptions.

Sample #954-1/2 Forktree Limestone, cut parallel to the XZ and YZ planes.

Locality : From the overturned limb of the Cooalinga anticline.

Mineralogy : 90% recrystallised calcite, 10% hematite (after pyrite). Small pods of hematite are often fragmented and generally define layering. Calcite veins with large crystals in a randomly orientated fabric are common.

Fabric and textures: The main fabric is a prominent pressure solution cleavage. Hematite is present disseminated throughout this cleavage.

Microstructures : The slide displays tight microfolds, as defined by the hematite rich layers. In hand specimen and outcrop these layers are more intensely eroded than the purely calcite layers resulting in the folds being well defined.

Sample #954-15 Heatherdale Shale, cut parallel to the XZ plane (Plates 5A & 5B).

Locality : From the overturned limb of the Cooalinga anticline.

Mineralogy : Clasts - 30% black phosphatic nodules (composed of 80% clumps of black opaque mineral, 10% dark brown hematite oxide probably after pyrite.), Matrix - 60% fine grained phyllosilicates and quartz. (40% Qtz, 30% biotite, 10% muscovite, 5% chlorite, 5% hematite.)

Fabric and Textures : The main fabric is a cleavage defined by preferred orientation of phyllosilicate minerals which is deflected about elongate phosphatic nodules. Some chlorite crystals cross cut foliation. Chlorite is most abundant in pressure shadows at either end of phosphatic nodules, often associated with hematite (not deformed and may postdate main deformational event) which occupies a fringe surrounding individual and groups of chlorite crystals. Hematite is present in fractures within the matrix. Chlorite forms large crystals in isolated pods and in pressure shadows.

Microstructures : No microfolding is observed within this unit, the main structures being the elongated Phosphatic nodules.

Sample #954-6 Madigan Inlet Member, cut parallel to the XZ plane (Plate 4F).

Locality : Taken from the western limb of a syncline near the coastal exposure of the Madigan Inlet Member / Blowhole Creek Siltstone Member boundary.

Mineralogy : 50% quartz, 30% biotite, 15% muscovite, minor chlorite and hematite.

Fabric and Textures : A strong mineral foliation is defined by the preferred orientation of phyllosilicate minerals. Quartz displays undulose extinction, an occasional chlorite crystal cross cuts the foliation. Small Tabular pieces of hematite are disseminated throughout the sample.

Microstructures : The entire slide consists of a small fold, the dark So layers of which are composed of a higher abundance of biotite. Fold is of type Ic shape (Ramsey, 1967).

Sample #954-4/5 Blowhole Creek Siltstone Member, cut parallel to the YZ and XZ planes (Plate 4E).

Locality : Taken near the coastal boundary between the Blowhole Creek Siltstone and the Madigan Inlet Member.

Mineralogy : 60% quartz, 40% biotite with minor muscovite and hematite.

Fabric and Texture : The strong mineral foliation defined by preferred orientation of phyllosilicate minerals (strongest in silty layers). Quartz grains within the sandier layers are angular with well defined triple points, indicating that they have probably undergone some degree of recrystallisation. Rare biotite crystals cross cutting foliation are present only in sandier layers. Average crystal length is greater in sample parallel to YZ plane than in that parallel to XZ plane.

Microstructures : Micro folding is visible in both slides, but is better observed on the profile or XZ plane on slide #954-5. The fold structures are defined by So layering consisting of large quartz crystals with minor development of phyllosilicates.

Sample #954-12 Blowhole Creek Siltstone Member, cut parallel to XZ plane (Plate 4G).

Locality : Taken from an outcrop of Blowhole Creek Siltstone Member 10 m to the west of Blowhole Creek Fault

Mineralogy : 50% quartz, 20% biotite, 15% muscovite, 5% chlorite

Fabric and Textures : The rock contains pods or layers consisting primarily of quartz surrounded by a fine grained matrix of quartz and phyllosilicates. The matrix displays a strong mineral foliation, due to preferred orientation of phyllosilicate minerals.

Microstructures : Kinematic indicators such as rotated quartz pods indicate a sinistral sense of shear, with east over west sense of movement.

Sample #954-14 Backstairs Passage Formation, cut parallel to XZ plane.

Locality : Taken from the core of the Blowhole Creek Anticline on the overturned limb

Mineralogy : 70% quartz, 30% biotite and other phyllosilicates.

Fabric and Textures : The cleavage is defined by preferred orientation of phyllosilicates. A differentiate lamination is prominent and defined by phyllosilicate rich layers. In outcrop and hand specimen scale this lamination cuts, and could be mistaken for, bedding. As a result of its development So is almost obliterated.

Sample #954-13 Marble Band, cut parallel to XZ plane

Locality : Taken from the second marble band east of the Blowhole Creek Fault (within the Backstairs passage formation.).

Mineralogy : 60% twinned, recrystallised calcite, 40% biotite, minor muscovite and Quartz.

Texture and Fabric : The fabric consists of a mineral foliation defined by preferred orientation of phyllosilicates and pressure solution cleavage defined by calcite boundaries.

Sample #954-10/11 Talisker Calc Siltstone, cut parallel to XZ and YZ planes.

Locality : Both were taken from normal limb of Blowhole Creek Anticline.

Mineralogy : 60% calcite, 15% biotite, 15% quartz, 10% hematite.

Texture and Fabric : The main fabric is a well developed pressure solution cleavage. Elongate pods of hematite are common, they are often fractured and cubic pseudomorphs are not uncommon (hematite after pyrite). The pressure solution cleavage often infilled and defined by hematite.

Microstructures : The elongate oxide pods may be used as strain markers, however they are better developed and best suited for this purpose within the Talisker Calc Siltstone west of my field area.

Sample #954-7/8 Talisker Calc Siltstone, both samples cut parallel to XZ plane (Plates 5C and 5D).

Locality : Both were taken near the centre of a major shear zone in the far east of the field area.

Mineralogy : 60% recrystallised calcite, 20% biotite and minor muscovite, 15% quartz, 5% hematite.

Fabric and Textures : This layered rock consists of bands of coarsely crystalline recrystallised calcite, interlayered with bands of fine crystalline calcite and phyllosilicates. The foliation is defined by the preferred orientation of phyllosilicates and the effects of pressure solution on calcite boundaries is the dominant fabric of the fine grained bands. Within the coarse grained bands the calcite crystals are angular with well defined triple points, indicating recrystallisation during deformation. A considerable percent of the quartz content of this rock is associated with the coarser bands.

Microstructures : Despite being taken from a major shear zone there is a lack of good kinematic indicators within these two slides.

Sample #954-16 Calc silicate pod, cut parallel to the XY plane

Locality : Taken from a calc silicate pod about 40 metres southeast of the western boundary of the Madigan Inlet Member.

Mineralogy : 50% quartz, 40% hornblende, 5% hematite.

Fabric and textures : The fabric is largely defined by the preferred orientation of the hornblende crystals, although hornblende crystals that cross cut the fabric are not uncommon.

Sample #954-17 Mafic Dyke, cut parallel to the XZ plane

Locality : Taken from a folded dyke in the Blowhole Creek Siltstone Member west of Blowhole Creek Beach.

Mineralogy ; 50% amphibole (either hornblende or actinolite), 20% plagioclase, 20% quartz, minor biotite and opaques (probably hematite and magnetite)

Fabric and textures : The fabric is largely defined by the preferred orientation of the amphiboles.

APPENDIX 2. Strain Analysis Techniques

The Rf/ϕ technique

The strain on the phosphatic nodules within the Heatherdale Shale was measured using the Rf/ϕ technique (Ramsey & Huber (1983)) (Fig 10). The Rf/ϕ method, as developed by Ramsey (1967), allowed the effects of initial shape of strain markers to be distinguished from those effects due to tectonic strain. Ramsey (1967) demonstrated that the Rf/ϕ plot was a function of the strain ellipse shape and of the initial ellipticity of the strain markers. This method was applied to both the XZ and YZ surfaces in an attempt to measure the three dimensional characteristics of the strain ellipsoid. The Fry method (Ramsey and Huber (1983)) was attempted but was ineffective due to insufficient data points and was rejected in favour of the Rf/ϕ technique.

Samples of Heatherdale Shale were cut both parallel and perpendicular to the stretching lineation. Several parallel sets of these cuts were made to provide sufficient numbers of phosphatic nodules for measurement . These cuts were also perpendicular to the cleavage or foliation plane (and hence the XY surface). Thus both the XZ and YZ surfaces were exposed for measurement, the XY surface not being measured. Each surface was photocopied (the nodules are darker than the surrounding matrix), and the perimeter shape of each nodule was traced directly, resulting in minimal distortion of nodule shape.

Each traced shape was digitised using DIGITISE, a digitising program developed by Rockware Inc. for the Macintosh computer, and a Kurta digitiser tablet . Each ellipse was defined by digitising five points about its perimeter. The photocopy of each rock was aligned such that S1 was parallel to the horizontal axis of the digitising tablet, in order to provide S1 as a reference plane to the orientation of the long axis (ϕ axis) of each nodule. After initial digitising the data was reformatted into an XYZ coordinate file (this being the format required for INSTRAIN calculations). A normalised centre to centre Rf/ϕ plot was produced for each surface using INSTRAIN, a strain analysis program, also developed by Rockware Inc. for the Macintosh computer.

From these plots the ellipticity range was determined for each face. The ellipticity range was calculated automatically by the computer, however this result included anomalous points produced by oddly shaped nodules, which often had to be deleted by inspection.

From the Rf range Ri and Rs were calculated via the following equations (the graphical method of calculating Rs and Ri developed by Dunnet was not used due to the lack of suitable graphs to fit the INSTRAIN produced Rf/ϕ plots.) ;

For Max Ri greater than the strain Rs : $Ri = (Rf\ max\ \ Rf\ min)^{1/2}$ ..... Eqn 1.1

$Rs = (Rf\ max / Rf\ min)^{1/2}$ ... Eqn 1.2

For Max Ri less than the strain Rs : $Ri = (Rf\ max / Rf\ min)^{1/2}$ ..... Eqn 2.1

$Rs = (Rf\ max\ \ Rf\ min)^{1/2}$ .... Eqn 2.2

From these values the three principle stresses (e_1 e_2 e_3), Rxy and ultimately k were calculated via the following equations (note : Rs for the XZ plane = Rxz, etc.) :

$e_1 = (Rxz^2 / Ryz)^{1/3} - 1$ .... Eqn 3.1

$e_2 = (Ryz^2 / Rxz)^{1/3} - 1$ .... Eqn 3.2

$e_3 = (1 + e_2 / Ryz) - 1$ .... Eqn 3.3

$Rxy = 1 + e_1 / 1 + e_2$ .... Eqn 4.

$k = Rxy - 1 / Ryz - 1$ .... Eqn 5.

2. Removal of flattening strain from folded sections.

The shape of the two dimensional strain ellipsoid on the XZ plane was used to determine the amount of shortening along the Z axis, and elongation along the X axis (i.e the flattening strain) as recorded by the strain markers. These values were determined for both sides of the Cooalinga anticline for comparitive purposes.

The profile plane shapes of two folded sections (taken from part of structural sections recorded on both sides of Cooalinga anticline) were constructed using the graphical method (Fig 11). The sections were then unstrained graphically using the flattening strain values obtained from the strain ellipsoids and equation 6. The flattening strain shortening could then be compared with the shortening due to earlier buckling of the folded section. This result provided a way of determining how effective the strain markers have been in preserving the shortening history of the Cooalinga Anticline. This result also provided a test of the accuracy of the Rf/ϕ technique and the methods used to measure the strain markers.

$$\varepsilon = \frac{l1 - lo}{lo} \quad \text{........ Eqn 6.}$$

Measurement of folded bed lengths was acheived using the DIGITISE program polyline function.

3. Dip isogon analysis

A dip isogon study was carried out on selected folds from the two structural sections (Fig 15). The dip isogon method (Hudleston (1973)) was used to determine flattening values for these folded sections. The values for the α and ϕ angles were recorded for each dip isogon. Values for α and $\alpha - \phi$ were plotted against each other and the amount of flattening (strain ratio for the X and Z axes of the strain ellipsoid) was graphically determined as done by Hudleston (1973). This value for flattening could then be compared with the equivalent value as determined by analysis of the Heatherdale Shale strain markers and a comparison made between them.

Finally, a comparison of the shortening values as calculated on both limbs of the Cooalinga Anticline was made. Graphical methods were used to determine longitudinal shortening values for folded sections. This comparison was made to distiguish between the amount of thinning due to stratigraphic or depositional reasons, with that due to tectonic processes, on the overturned limbs of fold structures within the Blowhole Creek area.

PHOTOGRAPHIC PLATES

For localities of photographs see Map 1.(Locality numbers in brackets)

Plate 1.

A - View of Blowhole Creek Anticline on cliff face, looking south.(P9)

B - Two scales of folding within the Forktree Limestone.(P5)

C - Minor Folds within the Madigan Inlet Member.(P4)

D - Dark elongate phosphatic nodules within Heatherdale Shale. Upper face is cut parallel to the XZ plane and lower face is cut parallel to the YZ plane.(P18 &19)

E - Boudinaged specimen from a marble band.(P10)

F - Intrafolial folds within the Aaron Creek Shear Zone.(P15)

B - Boudinaged vein within the Aaron Creek Shear Zone.(P14)

Plate 2

A - Set A vein cross cutting a pod of set B veins.(P20)

B - Pod of set B veins within the Blowhole Creek Siltstone Member.(P25)

C - En-echelon set of set B veins.(P21)

D - Folded en-echelon set B veins within the Blowhole Creek Siltstone Member.(P26)

E - Folded set A veins near the western boundary of Blowhole Creek. (P28)

F - Bedding parallel set B vein within the Blowhole Creek Siltstone Member.(P27)

G - Rotated boudinaged veins within the Forktree Limestone.(P23)

H - Boudinaged veins within the Forktree Limestone.(P22)

Plate 1.

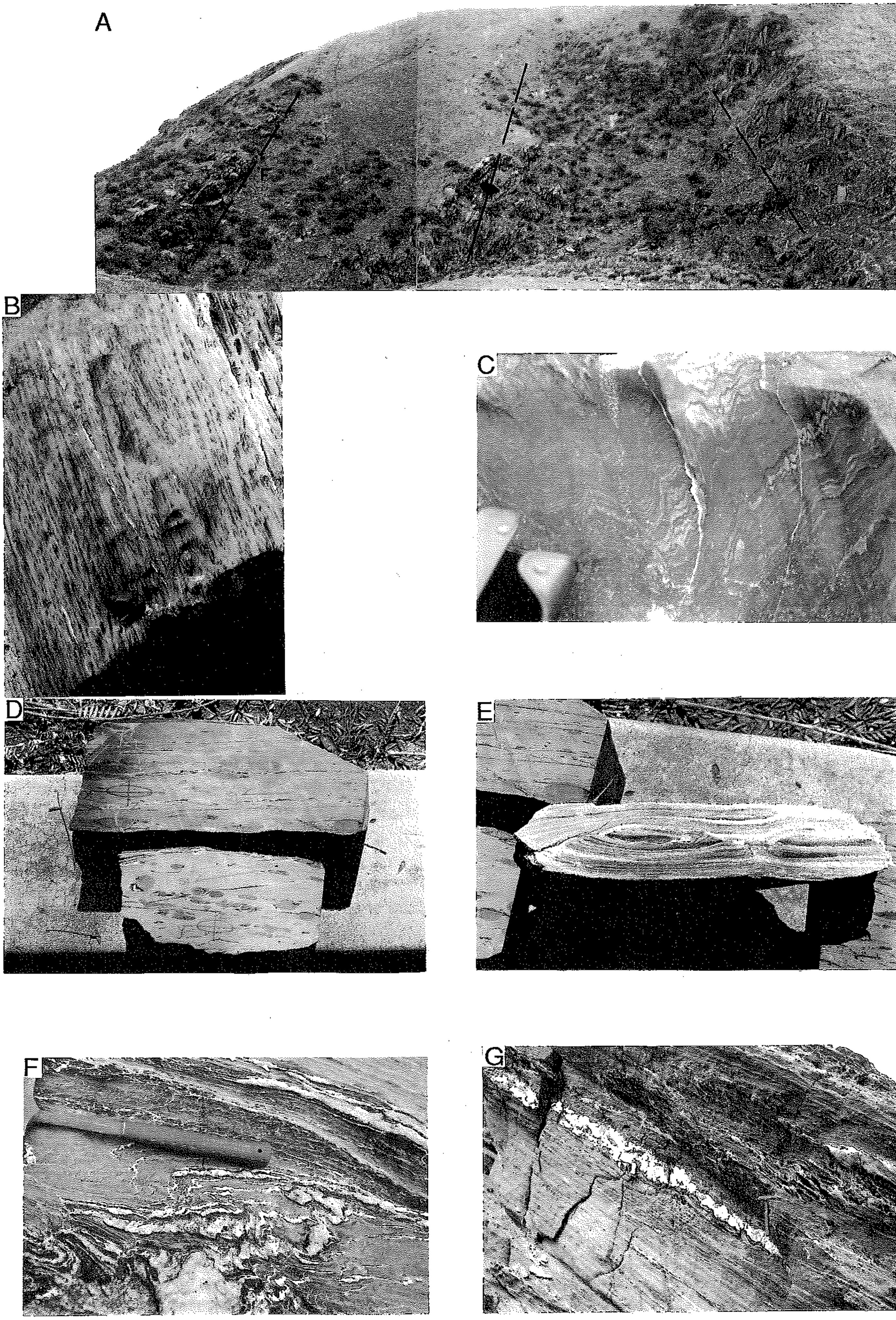


Plate 2.

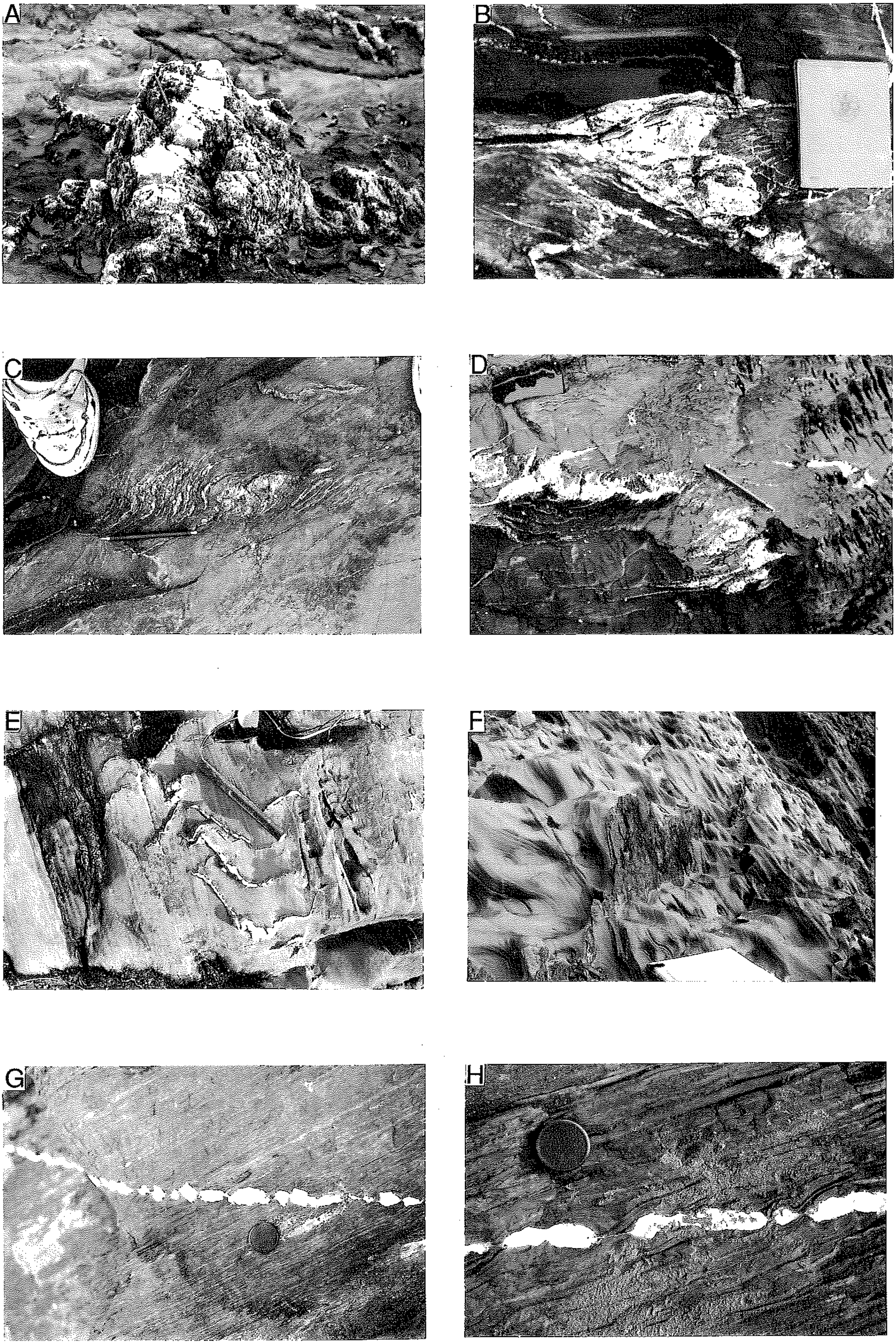


Plate 3

A.- View of Blowhole Creek, looking North.(P2)

B - Folded Campana Creek Member plunging northeast on Blowhole Creek. (P11)

C - Minor folds within the Madigan Inlet Member.(P8)

D - Elongate Calc-silicate pods within the Madigan Inlet Member.(P6)

E.- Minor fold and veins in the Campana Creek Member, Blowhole Creek Beach. (12)

F - Backstairs Passage formation, dipping eastward.(P13)

G - Sheared veins within the Madigan Inlet Member.(P24)

H - Minor bedding parallel shear zone within the Madigan Inlet Member.(P6)

Plate 4.

A.- Shallowly dipping kink planes.(P29)

B.- Shallowly folded intersection lineation in the Blowhole Creek Siltstone Formation. (P3)

C.- Sinistrally rotated asymmetric vein boudins or augens within the Aaron Creek Shear Zone.(P16)

D.- Sinistrally offset veins in the Aaron Creek Shear Zone.(P17)

Plate 3.

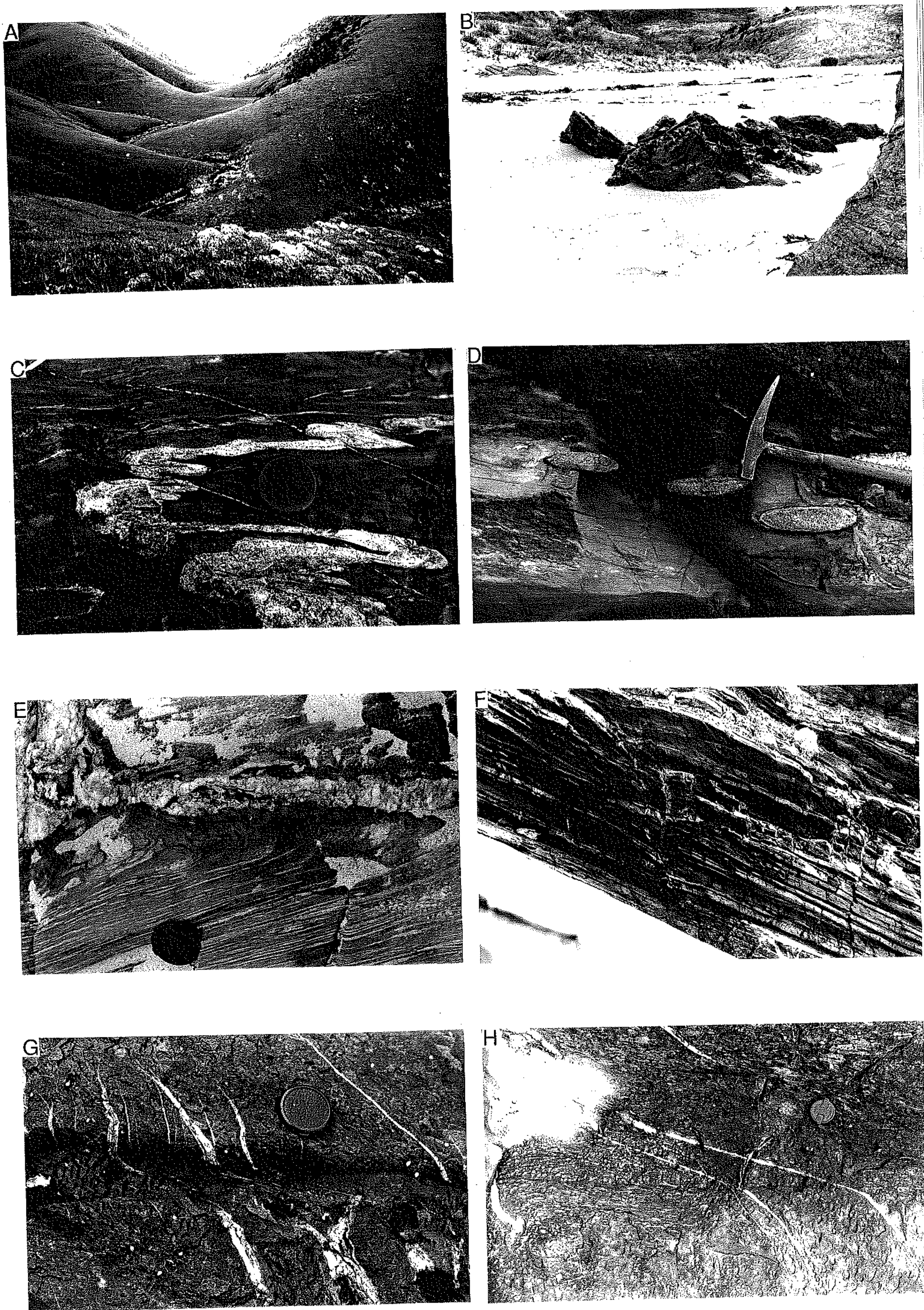


Plate 4.

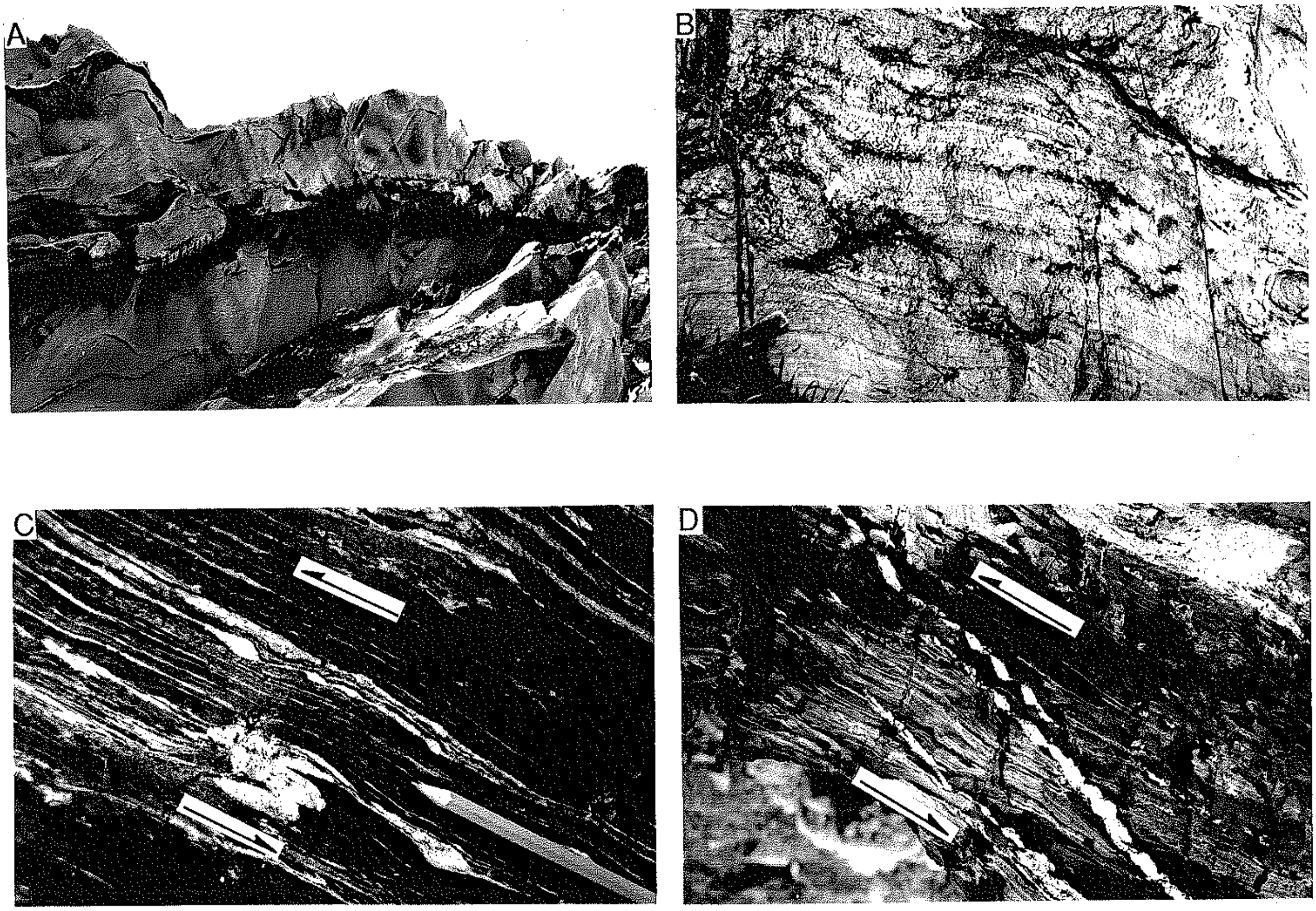


Plate 5.(Note: the bar scale on each photomicrograph is 1mm in length.)

A.- Thin section of Heatherdale Shale showing a dark deformed phosphatic nodule surrounded by a phyllosilicate (dominantly biotite) and quartz matrix. S1 foliation is defined by preferred orientation of phyllosilicates.

B.- Thin section of Heatherdale Shale showing a pressure shadow at one end of an elongate phosphatic nodule. The mineralogy of the pressure shadow consists of primarily chlorite and hematite.

C.- Thin section of Talisker calc Siltstone taken within the Aaron Creek Shear zone. This thin section is taken at one end of a boudinaged layer of coarsely crystalline calcite, hence the warping of the dominant foliation.

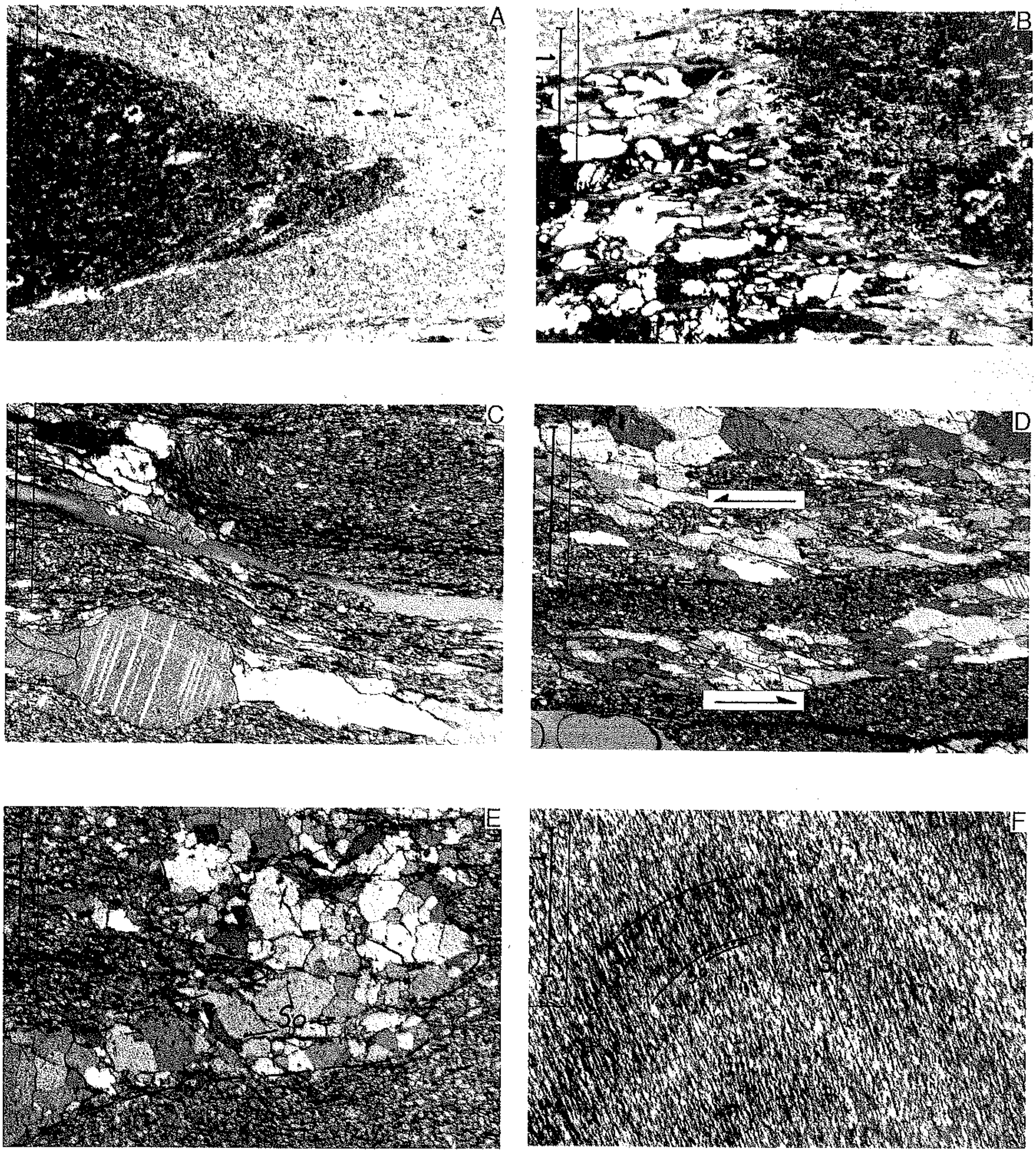
D.- As for plate 5C, note the interlayered bands of coarsely crystalline and fine calcite. The preferred orientation of the calcite crystals appears to cross cut the orientation of these bands at an acute angle of approximately 30 degrees. This feature may be considered as a kinematic indicator, in this case the shear sense being sinistral.

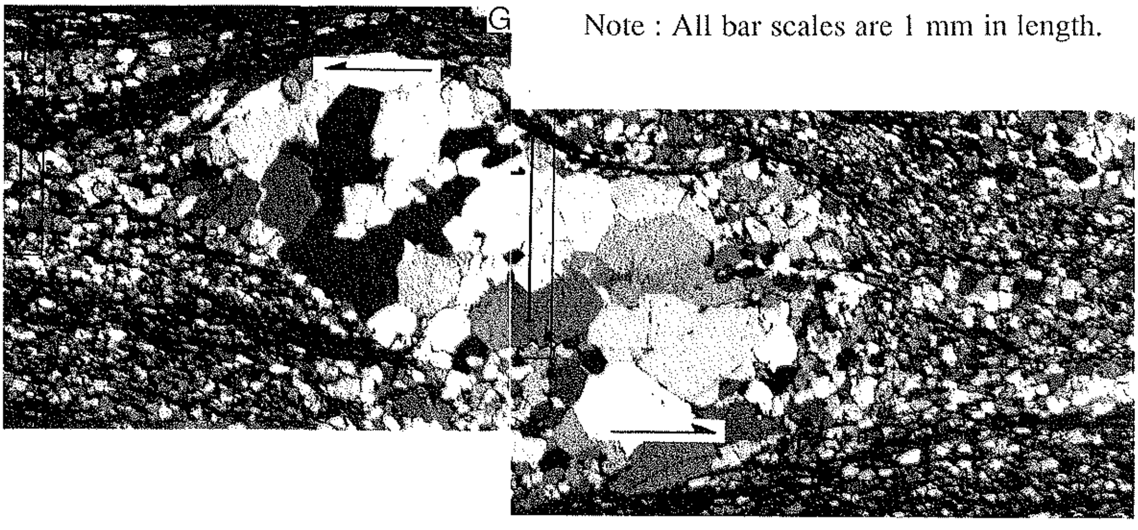
E.- Thin section of Blowhole Creek Siltstone Member taken near the western boundary of this unit. The coarsely crystalline quartz grains define So.

F.- Thin section of folded Madigan Inlet Member. So is defined by biotite rich layers. Preferred orientation of phyllosilicates defines S1.

G.- Thin section of Blowhole Creek Siltstone Member showing a rotated augen composed of coarsely crystalline quartz. This augen can be considered to be a σ type kinematic indicator defining a sinistral sense of shear.

Plate 5.





Note : All bar scales are 1 mm in length.