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Summary of structural and stratigraphic observations on the Proterozoic/Eocambrian/Cambrian units of the Zeehan 1:50 000 Quadrangle

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INTRODUCTION

This report is a summary of structural and stratigraphic observations made on the Proterozoic and Eocambrian rocks in the Zeehan quadrangle. The report is based on an as yet incomplete analysis of a large number of structural/stratigraphic data collected during the 1:50 000 revision of the Zeehan 1:63 360 map sheet between 1989 and 1992. It is intended that the full data-set will be incorporated in joint publications with colleagues involved in this revision.

The Zeehan 1:63 360 map sheet has long been critical to the understanding of Tasmanian West Coast geology as it was here that the regional stratigraphy of the "Dundas Trough" became formalised in the mid-1950s to early 1960s. The revision of the map sheet has demonstrated extensive thrusting (fig. 1) affecting all pre-Late Devonian units with the concomitant requirement that areas thought previously to be of no economic potential must now be re-evaluated. This consideration also applies to units of lower Palaeozoic age beyond the borders of the revised Zeehan quadrangle as there is now clear geological field evidence, in addition to geophysical modelling, which supports the idea that thin-skinned tectonics has played a major role in the structural architecture of the Tasmanian West Coast mineral belt.

For the purposes of accreditation for the development of the concept of thin-skinned tectonics in the Precambrian and Palaeozoic sequences of Tasmania, thrusting was recognised in the field by Jennings and co-workers during the mid 1950s in the Round Mountain district (Jennings, 1958), by Burns in the Burnie-Devonport district (Burns, 1965), from geophysical modelling in the Forth region by Leaman in the early 1970s (Leaman, 1973), in the Point Hibbs region by Carey and Berry in 1983 (Carey and Berry, 1988), by Green in the Rosebery district (Green 1983, 1984), in the field in the Macquarie Harbour 1:50 000 quadrangle by McClenaghan in 1984 (McClenaghan and Findlay, 1989), through additional geophysical modelling (see Leaman (1986) and in the 1989-1992

revision of the Zeehan map sheet (see Findlay and Brown, 1992; Everard *et al.*, 1992).

This report follows the style of the current explanatory report series. The various units are described lithologically under *Stratigraphy* and their structural relationships are given under the heading *Structure*.

PRECAMBRIAN ROCKS

The Precambrian sequence is represented by the Oonah Formation to the west and north-west of Zeehan, and a sequence of dominantly quartzwacke sandstone, siltstone, pelite, and their schistose derivatives near Dundas (Dundas Inlier; Turner in Burrett and Martin, 1989). The Oonah Formation has been assigned a Precambrian age on the basis of its complex deformational history, its relationship to rocks of possible Eocambrian age, and whole-rock K-Ar radiometric ages of about 680-690 Ma (Adams *et al.*, 1985). The supposed Precambrian rocks of the Dundas area have been assigned a Precambrian age on the basis of one K-Ar whole rock age of 684 ± 10 Ma from a slate bed (Adams *et al.*, 1985).

Oonah Formation

The type locality of the Oonah Formation (mapped as unit Pou; Zeehan 1:50 000 quadrangle, Brown *et al.*, in press) is at Oonah Hill near Zeehan (see also Spry, 1964). The unit extends westward and northward from Oonah Hill to occupy approximately one quarter of the Zeehan 1:50 000 sheet area.

The Oonah Formation is structurally complex showing as many as six episodes of deformation and probably two episodes of intra-Devonian thrusting exclusive of post-Permian faulting. Other than within the thermal aureole of the Heemskirk Granite, in the study area metamorphism in the Oonah Formation is of low grade. In the east, the pelitic beds display a slaty cleavage and a sub-phyllitic appearance, whereas to the west (Reece Dam area; northern Granville Harbour) the rocks are strongly schistose and are of low greenschist facies grade.

The Oonah Formation is dominantly a quartzwacke sandstone/siliceous siltstone/pelite association also

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containing highly carbonaceous, sulphide-bearing slate beds. It also contains subordinate, highly vesicular pillow lavas of small areal extent and which, in places, form large boudins. Also present are carbonate beds which have acted as hosts for the Sn, Pb, Zn and Ag mineralisation derived from the Devonian Heemskirk Granite.

Within the Oonah Formation the sandstone beds range up to one metre in thickness. Siltstone/sandstone packets are common and range in thickness to 2–3 m. The formation is also notable for black, carbonaceous, commonly sulphurous, pelitic beds. Within these beds the thin siltstone/sandstone laminae are coherent and there also occur thin horizons of probably primary sulphide. No conglomeratic beds are known.

The eastern exposures of the formation contain cleaved vesicular pillow lavas up to 3–4 m in thickness and what appear to be massive but schistose probable lavas of similar thickness. Also present are thick sequences of carbonate which weather to an orange-red slippery clay; in drill core, the carbonates may contain lineated surfaces with the slippery feel of talc.

In the sandstone beds of the eastern part of the formation, the sand grains of the formation are recrystallised and corroded although the original grain shapes may still be recognised. The sandstone units show a variable amount of white mica ranging from an estimated 15% to about 40%; no systematic variations in mica content have been recognised.

The majority of the sedimentary structures appear to have been obliterated by deformation. However, graded bedding, ripples, and load casts are recognisable sporadically, but their common lack of preservation precludes mapping of the structural geology using solely sedimentological criteria.

Precambrian rocks of the Dundas area (Dundas Inlier)

These units have been correlated with the Oonah Formation because of their similar lithology and their structural and metamorphic complexity (see Blissett and Gulline, 1962; Turner, 1979; Turner *in* Burrett and Martin, 1989). Geochronological data, in the form of a single K-Ar whole rock age from a very low-grade slate bed (Adams *et al.*, 1985), may support this proposal.

The non-metamorphosed rocks consist of slate-grade quartzwacke sandstone, pelite and slate beds which also contain dark graphitic slates. The sequence passes apparently gradationally into a phyllite-dominated sequence including chloritic quartz-rich schist and dolomite horizons (Concert Schist; Blissett and Gulline, 1962). The transitional zone appears to be from only a few tens of metres wide to missing in the northern part of the inlier, in contrast to the central area where the transitional zone is 0.5 km wide. This suggests that faulting has cut out part of the transitional zone, although the proposed fault(s) have not been identified.

The Concert Schist contains numerous quartz 'sweats' which have been mined; the adits are short and were presumably unproductive. Much mining activity has been carried out in the ridge south of Comet Creek. Here the adits enter the calcareous beds overlying the

fault separating them from the rocks of the Dundas Inlier. This mine area is close to the recently productive South Comet Mine, in which the mineralisation (Zn-Pb-Sn) appears to be fault controlled and hosted in carbonate veins. The fault contact between the Dundas Inlier and the adjacent rocks may therefore also be prospective.

EOCAMBRIAN ROCKS

The Eocambrian rocks in the Zeehan quadrangle consist of the Success Creek Group and the Crimson Creek Formation. The rocks in the transitional zone between the two formations form the host for the Sn mineralisation at Renison, and therefore this sequence is of economic importance. The present study has led to modification of the stratigraphy of the Success Creek Group, and has revealed a more complex deformational history than thought previously.

Oonah Formation/Success Creek Group Boundary

Brown (1986) argued that in the Pieman River area the Success Creek Group overlies the Oonah Formation with an angular unconformity, and the top of the Oonah Formation here consisted of an "Upper" succession (unit Pom; Brown, 1986) containing units of, "...carbonate, sandstone, i.e. conglomerate, tuff and volcanoclastic lithicwacke interbedded with laminated siltstone and mudstone" (Brown, 1986, p. 15).

The present mapping has shown that this unit (Esru; Brown *et al.*, *in press*) is stratigraphically disjunctive; the unit consists predominantly of sheared black mudstone, including phacoids and lenses of the rock types described by Brown (1986). Of considerable significance is the occurrence in this unit of a boudinaged block of veined Oonah Formation sandstone beds at CP632769 in Misty Valley. The foliation in the surrounding sheared mudstone wraps round this boudin, and truncates a quartz vein within the block and orientated normal to the sandstone layers. This indicates a tectonic hiatus between the deposition and deformation of the Oonah Formation and the formation of the black mudstone unit.

On the south bank of the Pieman River, opposite the Misty Valley area, the sheared mudstone unit occupies the core of a faulted asymmetric NW-verging syncline within the Success Creek Group whereas in the north it lies adjacent to the quartzwacke-slate sequence of the Oonah Formation. Thus a faulted relationship is indicated between the Oonah Formation and the Success Creek Group.

The outcrops visited by Brown (1986) in the Pieman River are now flooded. The general regional complexity of the structure of the Oonah Formation is greater than that seen in most parts of the Success Creek Group, although this unit is more complex structurally than indicated previously. Secondly, in the Pieman River area, the quartz grains in the sandstones assigned to the Oonah Formation show greater corrosion and recrystallisation than do those in the adjacent sandstones assigned to the Success Creek Group. These differences in strain history can be used to argue for a major hiatus between deposition of the two units.

Success Creek Group

The Success Creek Group is divided into two parts. These are a lower dominantly quartz sandstone sequence (unit Eds; Brown *et al.*, in press) with siltstone and mudstone beds and an upper sequence (unit Esru; Brown *et al.*, in press) containing shallow marine to intertidal/lagoonal units. Brown (1986) has described local pebbly sandstone and conglomerate horizons and also reports thin tuffaceous horizons. In one thin section of a volcanoclastic fine-pebble conglomerate from these units, which occur in Misty Valley, (Brown, 1986, p. 15, 61) there is a clast containing chloritic pseudomorphs of pyroxene phenocrysts in a fine matrix. This clast does not contain chrome spinels.

Also present and previously not described in this unit are grey-green beds of volcanoclastic lithicwacke and siltstone. These beds contain chloritic pseudomorphs of detrital mafic mineral, together with clasts of devitrified glass and volcanic quartz displaying two or more crystal faces and embayments containing devitrified glass. Such units (Esf, Esruv) occur sporadically within the Success Creek Group (e.g. as at CP614743, Pieman River).

In the study area the sandstone beds of the lower part of the Success Creek Group (unit Esd) commonly display small-scale cross-bedding and also metre-scale cross-bedding in the rare large exposures. The sandstone beds are commonly rich in quartz grains (70–90%) which are generally rounded. Also present are tabular mud flakes (as large as 20 mm in some beds); detrital mica is found throughout.

The upper part of the Success Creek Group (unit Esru) is a sequence of well-sorted quartz sandstone beds, with grey siliceous siltstone units also containing interbeds of red to purple siltstone, thin red to pink chert horizons, chert pebble conglomerate, pink quartz-sandstone, green siltstone, dolomitic beds, and lithicwacke with mafic and felsic volcanic clasts. The sequence shows lateral facies variations, and the detailed stratigraphy of the mine sequence at Renison Bell may not hold throughout the mapped area.

The upper part of this sequence is notable for the persistent occurrence of one or more horizons (unit Esru on Zeehan 1:50 000 map) of black graphitic mudstone containing predominantly blocks and boudins of sandstone; other lithologies are also known in the Misty Valley region, as described above. This unit is invariably intensely sheared and contains cleavage surfaces which in places have been folded. In some places, it crosses bedding in the structurally underlying sequence at near right angles, although it may be concordant to the overlying beds into which it may grade. In the upper reaches of Crimson Creek (section 2, fig. 1) the unit has been mapped as separating structurally overlying Success Creek Group beds from structurally underlying units of the stratigraphically higher probably Cambrian unit Etl.

This black sheared mudstone has been described by Brown (1986, p. 25) as "...highly disturbed sedimentary rocks which show all degrees of deformation from soft-sediment slumping to sliding, resulting in places in a highly deformed mélangé ... [with] ... an over and under zone of boudinaged sandstone and blocks of undisrupted laminated

material in a schistose and brecciated siltstone-mudstone matrix". Brown described the unit as gradational with the Dalcoath Formation of the Renison Mine sequence. E. Williams (pers. comm., 1992) has indicated that near the Argent Dam, this unit grades into relatively undisturbed siltstone beds showing signs of soft-sediment deformation.

The section studied by Williams (unpublished data) is now covered by gorse. Wherever seen by the present author, this sheared black unit resembles closely the smashed black cataclasites seen along such major faults as the Federal-Bassett and Stanley River Faults, although in contrast to these structures, the unit Esru is folded by the deformation affecting the Success Creek Group and Crimson Creek Formation. It is therefore likely that unit Esru has acted as the locus for strain during an early episode of slumping and soft-sediment deformation and later tectonic strain preceding the folding of these two formations, as indicated in Brown (1986).

Crimson Creek Formation (unit Ecc)

Blissett and Gulline (1962) applied the term "Crimson Creek Formation" to an extensive sequence of volcanoclastic lithicwacke beds exposed north and west of Zeehan. In the region of Argent Flat [~CP590605] Blissett and Gulline (1962) mapped an enclave containing what they supposed to be Crimson Creek Formation rocks and a small area of fossiliferous volcanoclastic lithicwacke they termed "Dundas Group". The present mapping (Brown, pers. comm., 1991) has shown that there is no lithological or structural reason for distinguishing between these two units at this locality, and that the supposed Crimson Creek Formation here is best regarded as part of the Dundas Group. These rocks are now referred to as the Cambrian unit Etl, and in the region mapped by this author have been identified in the Cuni river region west of Tunnel Hill, and along parts of the Dunkley Tram where both Blissett and Gulline (1962) and Brown (1986) mapped the unit as Crimson Creek Formation.

The definition of the Crimson Creek Formation used here follows Brown (1986). In the northern Cuni River valley both the Crimson Creek Formation and the Success Creek Group are thought to be thrust over unit Etl; the Crimson Creek Formation forms Tunnel Hill east of Cuni River and the Success Creek Group forms the hills west of the northern part of the Cuni River (see also Figure 1 and *Structural Geology* section).

The Crimson Creek Formation consists of red-orange weathering medium-grained to fine-grained volcanoclastic lithicwacke sandstone beds which commonly display spheroidal weathering. The rock is green to dark green when fresh. The sandstone clasts are derived mainly from a mafic source and the unit contains much detrital pyroxene which has inevitably been chloritised; also present is a considerable amount of fine-grained iron oxide. Also present within the Crimson Creek formation are thin basaltic intercalations and rare carbonate horizons; the basaltic rocks have been described thoroughly by Brown (1986).

The boundary between the Crimson Creek Formation and the Success Creek Group is, as determined by

previous workers (see Brown 1986), transitional. The transition is rapid and is heralded by the onset of shallow marine/littoral sedimentation within the upper part of the Success Group (unit Esru) which produced dolomitic beds, dolomite-bearing red hematitic siltstone horizons some showing possible desiccation cracks, green siltstone, fine pebble conglomerates composed of chert clasts, and horizons displaying chert ooliths in a chert matrix.

Although the stratigraphy of the upper Success Creek Group has been formalised at the Renison Mine, the present mapping has suggested the possibility of rapid lateral facies changes. Thus, as indicated by Brown (1986) the best marker for determining the base of the Crimson Creek Formation is the first appearance of a continuous sequence of lithicwacke containing much mafic detritus.

CAMBRIAN ROCKS

Unit €tl

This new unit was first described by Brown (1991) who referred to it as unit €vs. It had been mapped previously by Blissett and Gulline (1962) as Crimson Creek Formation. Brown (1991) noted that lithicwacke samples from the Melba Flats drill hole and other adjacent localities contained detritus from an andesitic volcanic source and that the inter-bedded mudstones contained in excess of 50% carbon. Neither of these features were thought (Brown, 1991) consistent with assignment of the unit to the Crimson Creek Formation. Furthermore, this unit further south forms the Cambrian fossil enclaves (referred to by Blissett and Gulline (1962) as Dundas Group) within identical surrounding rocks they map as Crimson Creek Formation.

Unit €tl is a red-orange weathering, volcanoclastic lithicwacke resembling very closely in weathered outcrop rocks belonging to the Crimson Creek Formation. However it is characterised by a felsic detrital mineralogy and contains grey and dark grey graphitic mudstone intervals, some fine quartz sandstone beds as well as red hematitic siltstone beds. Also present in the upper Cuni River [CP667688] is an outcrop of a thin, massive, mafic probable lava. Silicified siltstone beds occur in the probable correlate of unit €tl in the mining exploration track at CP648700.

Unit €tl occupies the floor of the northern Cuni River valley where it appears overthrust by the Success Creek Group and Crimson Creek Formation; further north, in the upper regions of Crimson Creek [CP660721], the Success Creek Group is thrust over rocks mapped formerly (Brown, 1986) as Crimson Creek Formation but which is now correlated on a lithological basis with unit €tl; to the west, at CP646700, the correlate of unit €tl is overthrust by the Success Creek Group (see fig. 1, section 1).

The volcanoclastic lithicwacke, mapped formerly as Crimson Creek Formation by Blissett and Gulline (1962) in the southern part of the Dunkley Tram valley [CP176839] is correlated with unit €tl on the basis of lithology. Here this unit also contains a spherulitic felsic volcanic rock containing glass shards exposed in a costean at CP617682. It is not known whether this

horizon is a correlate of the Mt Read volcanic sequence to the east; note that the Westcott Argillite correlate (see later) also contains felsic volcanic detritus and andesitic lava.

In the southern Dunkley Tram valley area, the correlate of unit €tl appears to be faulted against the lower part of the Success Creek Group to the east and to be overthrust by the Oonah Formation to the west. Exposures are poor and the requisite faults have not been found.

Cambrian rocks of the Dundas region

These units were mapped extensively by A. V. Brown, as the author concentrated primarily on the boundary relationships and structural geology of the probable Proterozoic units of the Dundas inlier. The following comments reflect only local observations on the Cambrian units in this region and no attempt is made to discuss the Cambrian stratigraphy.

The units observed are those mapped in Brown *et al.* (in press) as units Erw and Erq where they are referred to as Westcott Argillite correlate (Erw) and the underlying Stitt Quartzite correlate (Erq).

The Stitt Quartzite correlate is a muscovitic quartz sandstone and wacke containing conglomeratic units. As seen by this author the conglomerate horizons are thin and contain rounded quartzitic pebbles of 30 mm diameter either in small clusters or as isolated pebbles; Brown *et al.* (in press) refer also to felsic volcanoclastic conglomerate beds formed as mass-flow deposits.

Also present in this unit are black carbonaceous mudstone units; where seen by the author these beds have acted as the locus for what appears to be considerable strain (e.g. at CP724616 near the South Comet Mine). Here the cleavage surfaces are lineated and shiny and this unit may mark the inferred fault contact with the overlying Westcott Argillite correlate.

Where seen by the author the Westcott Argillite correlate is a volcanoclastic lithicwacke which weathers to a colour and texture similar to both the Crimson Creek Formation and unit €tl. Where fresh it was recognised as a fine- to medium-grained volcanoclastic lithicwacke with intervals of disorganised volcanoclastic conglomerate beds which may represent mass flow deposits. Also present are red and black mudstone beds which Brown *et al.* (in press) recognise as dolomitic. Brown *et al.* (in press) note also felsic volcanoclastic conglomerate horizons, areas of andesitic lava, felsic volcanic detritus and shaly siltstone beds. In the headwaters of Concert and Comet Creeks there occurs a highly sheared black graphitic pelite associated with a zone of tight folding. Here this unit appears to separate the Stitt Quartzite correlate from the Westcott Argillite correlate and resembles unit Esru in its structural style. There is also an apparent resemblance between the Stitt Quartzite correlate and the Success Creek Group, and between the Westcott Argillite correlate and unit €tl; should these resemblances prove more than superficial then they are of major tectono-stratigraphic importance.

STRUCTURAL GEOLOGY

Thrusting; general comments

Thrust faulting (see fig. 1) plays a major role in the geological structure of the Zeehan map sheet area. Findlay and Brown (1992) have documented in detail the 10th Legion Thrust which juxtaposes the Precambrian Oonah Formation over Cambrian mafic lavas. C-S structures at the sole of this thrust indicate a south-easterly transport direction, which is supported by a reconnaissance study of quartz-fibre striations using the method of Etchecopar *et al.* (1981). In contrast, detailed work by Goscombe in Brown *et al.* (in press) (see also Everard *et al.*, 1992) in the coastal section south of Duck Creek, and as also seen by this author in the Piney Creek region, has shown that younger thrusting has also occurred. Goscombe (unpublished data) reports:

- high-angle thrusts related to monoclinial folds;
- the thrusts follow the axial planes of the folds;
- the reverse sense of movement is consistent with the vergence of the monoclines;
- the sense of shear is south-west over north-east (contrary to that of the 10th Legion Thrust);
- the thrusts are not folded by the folds affecting the Ordovician-Early Devonian sequence; the thrusts follow the 80–100° trend of the cleavage developed in the E-W trending Duck Creek syncline. The Duck Creek syncline has been described by Williams (1976) as due to late-stage Devonian folding, although Goscombe (unpublished data) has suggested that, from the outcrop pattern, the Duck Creek Syncline has been cross-folded by NW-trending folds. The NW-trending folds elsewhere in western Tasmania have been referred to as post-dating the east-west folds (Williams, 1976), and are the youngest folds reported here.

The author's continuing analysis of the quartz-fibre striations on faults in the central and north part of the map sheet indicates a north-east orientation for σ_1 , related to reverse faulting. This stress system is appropriate for the younger faults mapped by the author and by B. D. Goscombe and also coincides with the results of a similar preliminary analysis made by the author during revision of the 1:63360 Sheffield Quadrangle in the 1992/1993 Summer Season. That is, this later phase of thrusting (see Jennings, 1958; Brown *et al.*, in press) is of major regional importance as is the 10th Legion Thrust which displays an opposed sense of translation. These considerations are essential to the understanding of the regional stratigraphy and the concomitant development of exploration models in the Tasmanian west coast mineral belt.

The author also considers that the Success Creek Group east of, and the Crimson Creek Group at Tunnel Hill form part of an anticlinorial fault-bend fold overlying unit ϵ_{t1} (fig. 1, section 1). This explains the window of unit ϵ_{t1} in the northern part of Cuni River, and the smaller windows of the possible ϵ_{t1} correlate along the Dunkley Tram valley (fig. 1, section 2) and at CP648700. The author regards this thrust

development as probably synchronous with the 10th Legion Thrust.

Precambrian Rocks

Oonah Formation

The Oonah Formation is generally more complex structurally than the adjacent Eocambrian and Cambrian sequences, although six deformations have been identified adjacent to a deformed shear zone in the Success Creek Group (see later).

Three deformational events may be identified at many outcrops within the Oonah Formation, and analysis of outcrops along the Zeehan–Granville Harbour and Zeehan–Trial Harbour roads has indicated that as many as six cleavage-forming events have occurred. The first formed fabric (S_1) is related to isoclinal folding and boudinage, is invariably a weak to strongly-developed schistosity (equivalent in appearance to textural zone 2A of Bishop, 1972), and is oriented generally parallel to bedding. The subsequent cleavages are crenulation and spaced cleavages following north-east, north, west and WNW to north-west trends. Additional structural complexity is conferred by at least two generations of probably Devonian thrusting and possibly synchronous and younger steeply-dipping faults.

The sections below present outcrop data within the Oonah Formation along the Zeehan–Trial Harbour Road and along the highway from Zeehan to Piney Creek. These and additional data will be incorporated in work in preparation by the author and colleagues involved in the revision of the Zeehan map sheet.

Zeehan–Trial Harbour Road

The section between CP585614 and CP596617 (X and Y respectively in Figure 2) illustrates the complexity of structure which may be encountered in only a few hundred metres within the Oonah Formation. Such outcrop scale complexity is typical of the Oonah Formation. Given such local complexity, regional domain analyses, as are now traditional in areas of multiple deformation, may not be a useful approach to an understanding of the structure of the Oonah Formation. One major problem is that the various axial plane cleavages seen both in this section, and also in the low grade units as far west as Piney Creek, are remarkably similar morphologically and thus are difficult to correlate confidently between isolated outcrops.

Four fold generations are recognised in this section of road outcrop. D_1 folding is thought to have produced the phyllitic fabric in the pelitic beds and which is folded by the structures described above in the section; no D_1 folds are known here.

The D_2 structures appear to be represented by the small intrafolial folds seen at locality 4 (fig. 2) and it is thought that D_2 could well have been involved in overturning bedding. That is, D_2 could have involved recumbent or reclined isoclinal folding.

The correlates of the intrafolial folds at locality 4 are refolded by the reclined folds in insets 1 and 2 (fig. 2), which are thought to be D_3 structures.

D₄ is represented by the E-W trending upright warps as exemplified by those seen at locality 5 and shown in stereonet 5.

These conclusions are preliminary only and should not be regarded as firm, as the analysis is still in progress.

Zeehan to Piney Creek (Granville Harbour Road)

This road section was studied in detail as here occur the better exposed structures in the Oonah Formation. The field data are presented in a series of figures (fig. 3–9) with extended captions describing the detailed geology at each outcrop.

The structural geology is complex with six fold and cleavage-forming events being demonstrable. The D₁ event produced a weak schistosity in the sandstone horizons and a bedding-parallel slaty cleavage in the pelitic beds. This event was probably responsible for the flattening in the pelitic units and this has obliterated most sedimentary structures. Locally, the bedding is overturned indicating recumbent folding, but it is unlikely that geopotential indicators can be used on a systematic basis to map the major recumbent folds.

It is highly significant that the D₂–D₆ deformations can be attributed a Devonian age because of their trends and cleavage style. This leaves D₁ as the only representative of the Precambrian Penguin Orogeny. However, given the results of recent Ar-Ar and K-Ar dating (Turner *et al.*, 1992), which have yielded unequivocal evidence for a Cambro-Ordovician metamorphic event in the Precambrian sequence (see also Adams *et al.*, 1985), and also the interstate and international nature of the Ross-Delamerian orogeny (see Findlay, 1991 and Findlay *et al.*, 1991 for reviews), then it can be argued that D₁ could well be of Cambro-Ordovician age.

This being the case, it would follow that the Oonah Formation could be of Cambrian age, as are similar rocks in northern Victoria Land, Antarctica (Burrett and Findlay, 1984; Wright *et al.*, 1984; Findlay, 1987). The corollary to this is that given the tectonic break between the Success Creek Group and the Oonah Formation (Brown, 1986; see also this report) the Success Creek Group must be of latest Cambrian to Ordovician age, as must be the Crimson Creek Formation. Such a conclusion cuts across the correlation made on geochemical grounds between the basaltic rocks in the Crimson Creek Formation and basaltic rocks in the Smithton Trough. The basaltic rocks in the Smithton Trough, although yielding a Cambrian palaeopole (Delisle *et al.*, 1993) are correlated geochemically with dated Precambrian dolerite dykes in the Precambrian Rocky Cape Group.

The idea that the Oonah Formation is of Cambrian age conflicts with its lithological correlation with the Burnie Formation which contains syn-sedimentary dolerite dykes (Cooee Dolerite) dated at 725 Ma by the K-Ar method. It may be that this lithological correlation, made across some 80 km of discontinuous exposure of rocks of supposed Precambrian and known Palaeozoic age, is incorrect; the question of possible excess argon in the Cooee Dolerite also needs addressing.

Finally the recent revision of the Zeehan 1:50 000 sheet has confirmed that what at first had appeared as simple stratigraphic relationships are thrust-controlled and therefore previously-held conclusions about stratigraphic relations may be open to question. Indeed, as mentioned previously, there are superficial similarities between the Success Creek Group, Crimson Creek Formation and rocks adjacent to the Dundas Inlier; these similarities, as with those between the Oonah and Burnie Formations, are worthy of detailed and unbiased examination.

Probably Precambrian non-metamorphic rocks of the Dundas Inlier

The section of road between X and Y (fig. 10) illustrates the deceptively complex nature of the deformation within these non-metamorphosed rocks. According to a single whole-rock K-Ar slate age of 684 ± 10 Ma from a nearby outcrop (Adams *et al.*, 1985), these rocks are attributed a Precambrian age. The structural data for this section are given as an extended caption to Figure 10.

The early structural history involved production of a slaty cleavage and overturning of bedding; it is assumed and not proved that these were synchronous, and it is thought that this event might have involved large-scale recumbent folding.

Subsequent deformations have produced both recumbent (fig. 10, locality D) and upright chevron folds (fig. 10; localities B, C, E and F) the latter with steep N-trending axial surfaces. It is likely that the steeply S-plunging folds at G (the A_{PII} structures, fig. 10) have been refolded about the N-trending structures and a tentative correlation is made between these A_{PII} folds and the recumbent folds at locality D; this is not proved.

The tentative deformation history involves therefore:

- D₁; production of slaty cleavage and overturning of bedding during recumbent folding,
- D₂; production of structures now represented by the recumbent folds at locality and the A_{PII} folds at G (fig. 10),
- D₃; upright chevron folds with a predominantly westerly vergence,
- D₄; rotation of D₃ structures about a steep axis.

The outcrop contains thrusts and related fault-propagation folds. The age relations of these structures are uncertain.

Metamorphic rocks of the Dundas Inlier (Concert Schist)

These rocks contain two dominant metamorphic fabrics, a bedding-parallel schistosity (S₁) and a well-developed crenulation cleavage (S₂). Additional crenulation cleavages and finely-spaced cleavages occur locally (see also Turner, 1979) as do numerous kink-bands. The present study was unable to resolve the interrelationships of these post-S₂ structures.

Poles to bedding and S₁ for the Concert Schist (fig. 11, stereonet A) define principally a small circle about an E-W trend, as well as other diffuse partial girdles. This indicates complex deformation.

The dominant structures are those of the D₂ generation. In the Concert Creek region, D₂ produced a NE-verging anticlinorium whose steep northern limb contains a steeply plunging F₂ fold axis in the uniform S₂ axial plane crenulation cleavage; this may indicate simple shear on S₂ at this locality. The D₂ anticlinorium generally plunges shallowly north-west (fig. 11, stereonet B) and its axial plane fabric S₂ dips steeply NE-SW.

In contrast to the apparent simplicity of the structural geology in Concert Creek, in the Comet Creek region further south the structure is complex. In the ridge north of Comet Creek, (fig. 11, stereonet C) the L₂ crenulation lineation (Δ) appears rotated along a small circle girdle although a north-westerly trend still dominates. In this area poles to bedding and schistosity may be interpreted as defining three statistical fold axes which lie along this small circle. Additional post-S₂ crenulation lineations plunge variably; it is not known whether the four different orientations (south-west, steeply south-west, steeply south-east and steeply north-east) represent four different fold generations or whether these are the artefacts of the crossing of a twice-deformed S₁ fabric by no more than two post-S₂ crenulation cleavages.

The dominant NW-SW D₂ trend is evident also in Comet Creek (fig. 11, stereonet D) although here there is clear evidence for rotation of S₂ to an ENE-WSW orientation. Again, the L₂ crenulation lineation would fall on the small circle plotted in stereonet C.

Correlation of structures within the non-metamorphosed and metamorphosed rocks of the Dundas Inlier

There is no obvious correlation between the structures in the two suites, particularly so as neither S₁ nor S₂ have yet been recognised morphologically in the non-metamorphic rocks. There are some similarities between the structural geometries of the two suites, and these may indicate a correlation.

NW-plunging folds within a SW-dipping axial plane occur in the non-metamorphic rocks at the locality for stereonet C in Figure 10; here, they are indicated at β III which is the pole to great circle III.

The major similarities are:

- the plots of poles to bedding and S₁ in the Concert Schist resemble in complexity those in Figure 10.
- the F₂ trend in the Concert Schist (fig. 11, C and D) follows β III in stereonet C (fig. 10) and Δ II in stereonet E (fig. 10).
- there occur S-plunging folds in both regions (compare stereonet B, Figure 10 with stereonet C in Figure 11).
- the single N-plunging post-S₂ fold in the Concert Schist (stereonet C, fig. 11) has a steep N-striking axial plane but no axial plane fabric. Geometrically, it lies close to the N-plunging folds in stereonets C, E and D in Figure 10).

Neither S₁ nor S₂ have morphologically identical fabrics in the non-metamorphosed sequence. If the F₂ structures in the Concert Schist correlate with the β III folds in stereonet C (fig. 10), the S₂ surface would be

equivalent to the A_{PIII} surface in stereonet C (fig. 10): note here that the great circle to poles to bedding (III) in this diagram lies close to the poles to S₁ in the Concert Creek traverse (stereonet B, fig. 11). That is, the F₂ folds in the Concert Schist may correlate with the D₃ deformation in the non-metamorphic sequence. It is possible that the F₁ deformation in the Concert Schist would correlate with D₁ in the non-metamorphic sequence. As the D₂ deformation in the non-metamorphic rocks folds a slaty cleavage, this event is thought unlikely to correlate with F₁ in the metamorphic rocks.

Eocambrian rocks

Unit Esrui

This unit has the typical appearance of a fault rock. It is schistose, multiply cleaved, it displays C-S fabrics, contains symmetrical and asymmetrical phacoids (commonly of sandstone), it is stratigraphically disjunctive, and it contains broken quartz veins. A number of oriented samples were collected from this unit and similar fault rocks such as that marking the Federal Bassett Fault; these samples have not yet been slabbed and studied in thin section.

Brown (1986) and Williams (pers. comm., 1992) have remarked that in the Argent Dam region there is a gradation in this unit from a zone showing signs of soft-sediment deformation to a more intensely deformed zone, and therefore concluded that soft sediment deformation was important in the formation of this unit. The section discussed by Williams is now heavily overgrown with gorse and the author has not observed this supposed transition. Both Brown (1986) and Williams (pers. comm. 1992) have remarked that this unit could have been the locus for soft sediment deformation followed by later tectonic strain.

Unit Esrui displays evidence for multiple tectonic movements (fig. 12-13) which produced C-S fabrics and minor faults, boudinage and shearing of quartz veins. In some places structures showing opposed senses of movement lie adjacent each other.

In the sequence near Argent Dam [CP677705] and in exposures in the Pieman River region (area bounded by grid references CP620738, CP647747, CP640760 and CP630770) sinistral slip on the steeply-dipping fabric is predominant. However, less common structures (fig. 13) indicate a strain history involving dextral slip across the steep fabric. Unless it is argued that intense isoclinal folding has folded these structures, and for which there is no evidence in the other parts of the sequence, then multiple movements, involving strain partitioning to preserve the earlier-formed structures, must be the case. Such behaviour is consistent with that in complex mylonite zones elsewhere (Bell and Johnson, 1992).

Folding of Success Creek Group and Crimson Creek Formation

Brown (1986) remarked on the simplicity of folding within the Success Creek Group when compared to that seen in the Oonah Formation. However, folding in these units is more complex than thought previously.

The regional outcrop pattern between Tunnel Hill and the Pieman River is suggestive of the interference of

E-trending, NW-verging asymmetric folds and a folds with a north-west to northerly trend. In the Pieman River region [CP628742] the structure is dominated by a NW- to NNW-verging generally E-W trending syncline of Success Creek Group rocks containing in its core the upper part of the group and including unit Esrui. This structure is cross-folded about a NW to NNW trend to produce part of a Type 2 interference pattern whose eastern section is truncated by the regionally important Federal Bassett Fault.

These complexities are reflected in stereonet A, Figure 14, where there occurs a clearly defined small circle of poles to bedding, indicative of cross-folding. In this figure it is also possible to recognise the N and NW fold trends shown more clearly evident in stereo-net B from the area bounded by grid references CP681710, CP679718, CP670712 and CP665708.

Stereonet net C, Figure 14, exemplifies further the E-W fold trend. These data are from the Crimson Creek Formation of the Tunnel Hill region where again the mapped outcrop pattern is suggestive of interference folding.

Stereonet D, Figure 14, is from CP650718 where 6 deformations are mapped in rocks attributed to the Success Creek Group. The first generation folds produced isoclinal folding with an axial plane fabric that confers a phyllitic lustre to the pelitic interbeds. The F₂ folds in bedding (B₀) are upright weakly NW-verging folds and plunge close to the F₁ cleavage/bedding lineation (L₀). F₃ produced upright cross-warps of the F₂ axes and the F₃ folds are upright NW-plunging folds. Three crenulation lineations, seen in the phyllitic intervals, overprint these structures.

A six-fold deformation history has not been reported before from Success Creek Group rocks. This locality is adjacent to what is thought to be an important possible thrust fault which can be followed south from this locality, and it may be that some of the complexities seen at this locality are due to this faulting. Alternatively, a small thrust-slice of the Oonah Formation must occur at this locality; this has been tested by drilling and is not supported.

Cambrian sequences

The only structures studied in the Cambrian rocks are those adjacent to the Concert Schist. Although these were studied on a reconnaissance basis only, it is clear that the Cambrian sequences are faulted against the Concert Schist. It is also clear that the fold history of the Cambrian rocks is simpler than that of the probable Precambrian sequence (fig. 15). At the head of Concert Creek there occur W-verging folds which plunge to the north-west and south-east in a uniform axial surface (fig. 15, stereonet A). These folds occur in a dark pelitic sequence with thin silty laminae and may be disharmonic and multi-hinged. This sequence is broken by a major shear zone occupied by dark pelitic beds with siltstone intervals containing steeply-plunging sinistrally verging folds and structures showing complex cross-folding relations, as well as a C-S fabric indicating sinistral shear.

This shear zone lies within the Cambrian sequence east of a sequence of white quartzitic beds which

young west and contain dark pelitic intervals before passing to a coarse, possibly dolomitic, conglomerate.

The Cambrian rocks at the head and southern flank of Comet Creek show a similar structure. The beds here are folded predominantly about a N-S trend (fig. 15, stereonet B). The fold plunge appears to range from shallowly south to moderately steeply north in a uniform axial plane, and a weak axial plane cleavage is recognisable. As in Concert Creek, a black sheared unit separates a sandstone-pelite sequence from units containing coarse conglomeratic beds. As with Unit Esrui, this sheared unit contains sandstone phacoids and is schistose; the possibility of a correlation is intriguing but probably not useful as it would be a correlation of strain rather than stratigraphy.

Correlation of structures between the supposed Precambrian and Cambrian rocks of the Dundas region

The metamorphic rocks of the Dundas Inlier are dominated by the NW-trending F₂ structures. One post-F₂ N-plunging fold has been seen in the Concert Schist, and it is plausible that this could correlate with the N-trending folds in the Cambrian rocks of the Comet Creek region.

There is no obvious equivalent in the Cambrian rocks of either the S₁ or S₂ fabrics, and nor does there appear to be the complexity of deformation seen in the non-metamorphic supposedly Precambrian units. Despite this, the fault contacts between the Precambrian and Cambrian sequences are inferred (fig. 1, section 3) to be folded thrusts, and it is reasonable to suppose from this section that the F₂ deformation in the supposed Precambrian units have folded these thrusts. Clearly, there remains more to be done on the structural geology of the Cambrian sequence.

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[27 September 1993]

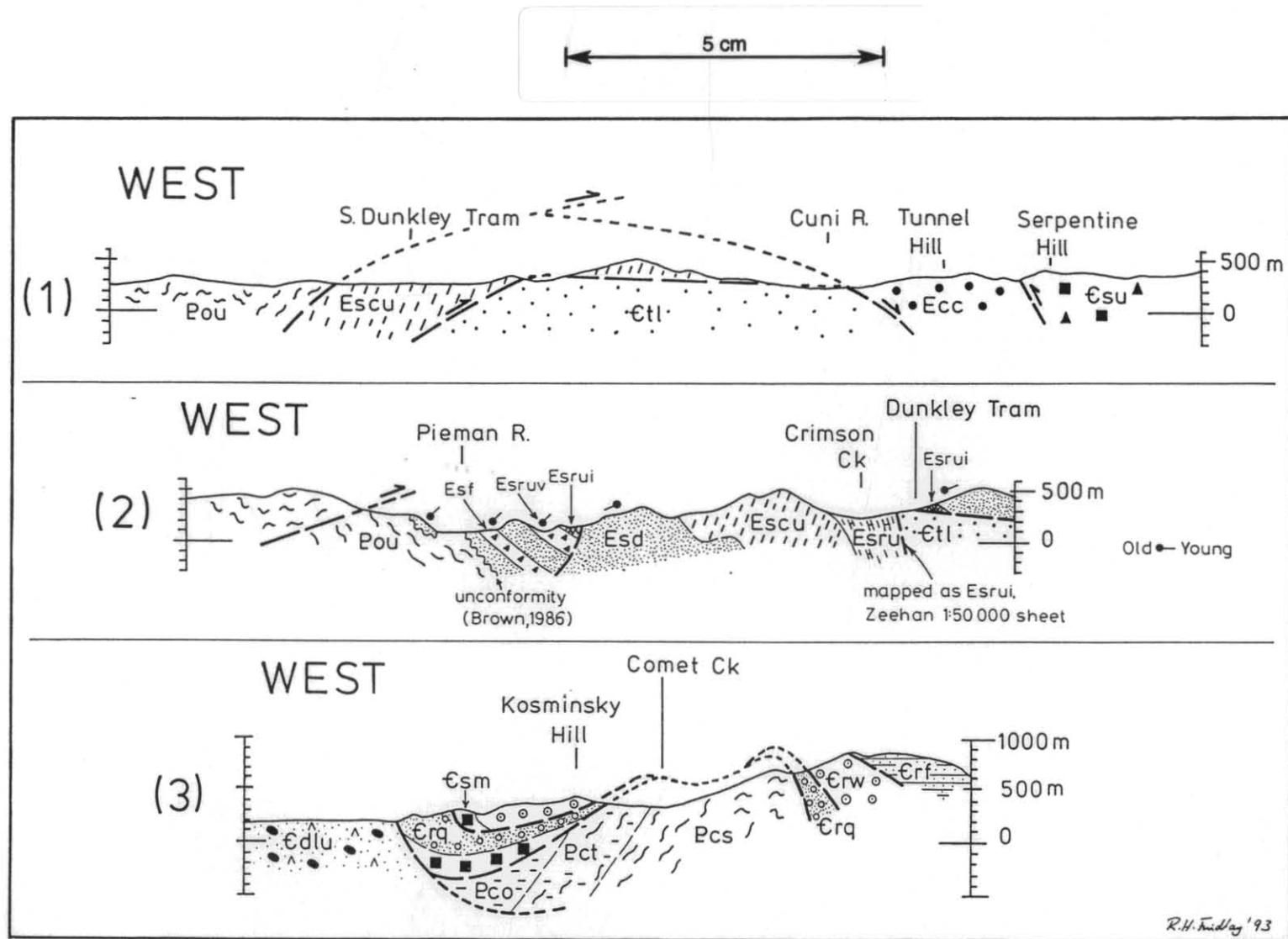


Figure 1. Cross-sections (horizontal scale = vertical scale) through three critical areas of the Zeehan 1:50 000 geological map sheet.

Section (1) South Dunkley Tram area to Serpentine Hill [CP620710-CP696670]. E_{su} - undivided Cambrian ultramafic rocks. E_{tl} - unit E_{tl} previously described by Brown (1991) as unit E_{vs}. E_{cc} - Crimson Creek Formation. E_{scu} - undivided Success Creek Group. P_{ou} - undivided Oonah Formation.

Section (2) Pieman River to Dunkley Tram [CP609765-CP714665] E_{tl} - unit E_{tl}. E_{srui} - black smashed rock (see text). E_{sr} - upper shallow-marine/littoral sequence of Success Creek Group. E_{scu} - undivided Success Creek Group. E_{sd} - quartz sandstone-dominated lower Success Creek Group. E_{sf} - volcanic lithicwacke in lower part of Success Creek Group. E_{sruv} - volcanoclastic lithicwacke in upper part of Success Creek Group.

Section (3) Section through the Dundas Inlier. E_{clu} - undivided Cambrian sequence. E_{sm} - Cambrian massive serpentinite. E_{rq} - Stitt Quartzite correlate. E_{rw} - Westcott Argillite correlate. E_{rf} - Cambrian laminated mudstone, siltstone and felsic volcanoclastic lithic and quartz wacke. P_{co} - ?correlate of Oonah Formation showing metamorphic transition (P_{ct}) into Concert Schist (P_{cs}).

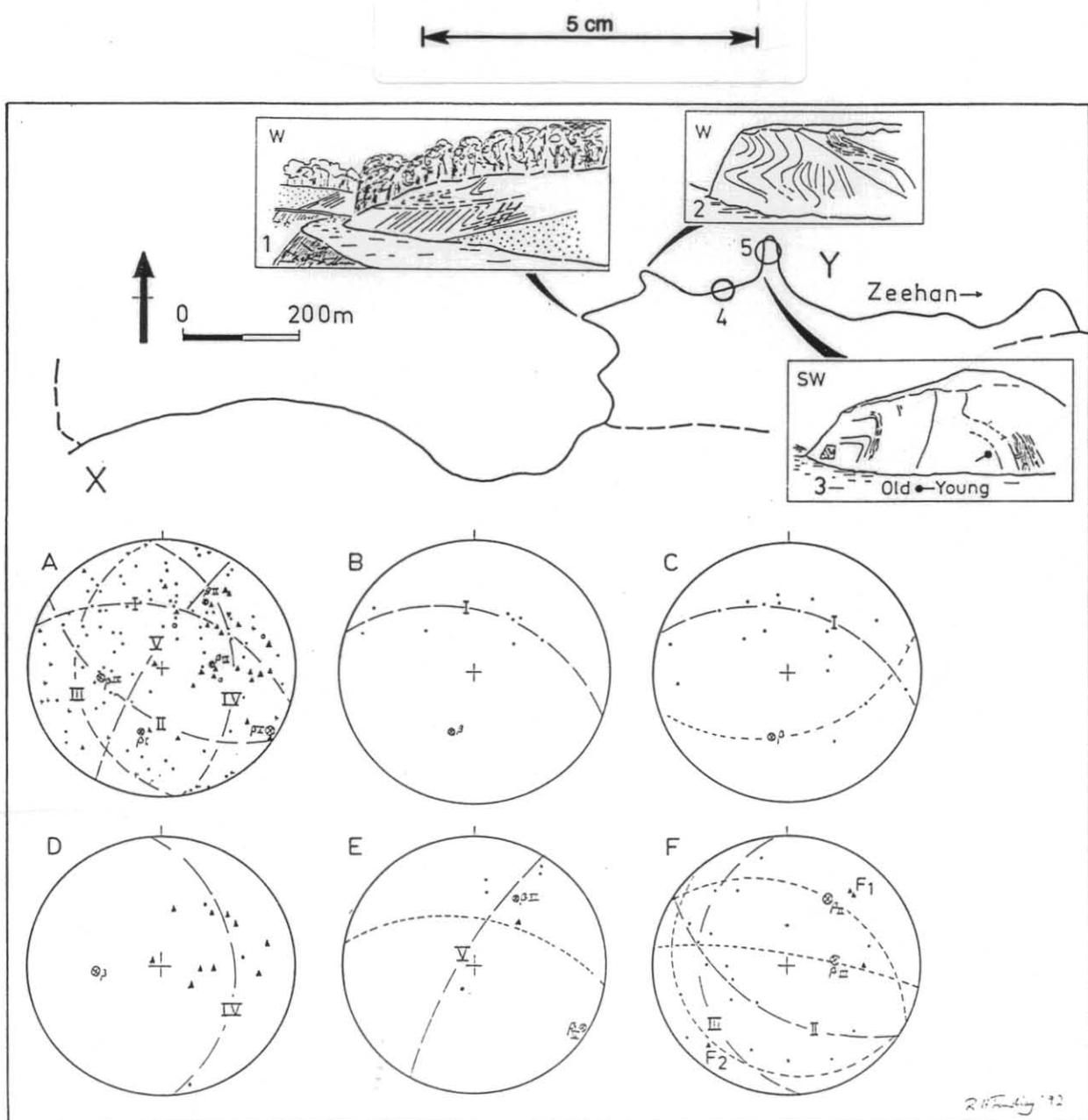


Figure 2. Details from the Zeehan-Trial Harbour Road, immediately west of Zeehan. The heavy line represents the road; the broken lines are 4WD tracks. Outcrop sketches shown in insets.

All stereonet are equal area, southern hemisphere projections. *Legend:* • – poles to bedding; light dashes, axial planes to folds; long dashes, great circle girdles or small circle girdles of poles to bedding; ▲ – measured fold axes.

Stereonet A shows all structural measurements made between X and Y in the figure. The great circles I-V represent bedding poles measured round specific fold hinges within the traverse; β I-V are the statistical axes to these measured folds, and are not numbered according to their relative age.

Inset 1 shows reclined folds overlying weathered volcanic rocks (dotted legend) and separated from them by a possible décollement. The folds above the supposed décollement possess a sheared limb overlain by a hinge. No axial plane fabric has been recognised and the folds are crossed by a later slaty cleavage (heavy dashes). Measurements around the folds below the décollement and in the vicinity of this structure indicate (stereonet B) that the fold axis plunges SSW at about 40°. Note that further west, volcanic rocks overlie this folded sequence of sandstone and pelite beds, whereas at this outcrop probably the same volcanic beds underlie the clastic rocks; this may well confirm large-scale recumbent folding.

Inset 2 shows folds of identical geometry to those in Inset 1 and here they fold a fabric sub-parallel to bedding. These structures are notably disharmonic and multi-hinged folds occur in the fold stack. The axial plane (short dashes) of these folds (stereonet C) tracks through the statistical fold axis (net B and β I in net A).

At the locality of inset 3 (stereonet D) occur numerous small folds and bedding is overturned. Cross-folding is observed, giving a broad scatter of fold axes in the eastern sector of stereonet D. Three bedding readings round one fold hinge define the great circle girdle IV and a W-trending axis β which corresponds to β IV in net A. These structures include folds wherein their shape changes rapidly in the fold stack from very tight single-hinged folds to multi-hinge "box" folds.

At locality 4 (stereonet E) occur folds of style similar to those at the localities of insets 1 and 2. However here, these structures plunge at a low angle south-east (β V, net E) and fold an apparently intrafolial fold whose axis (▲ – net E) is close to β III in net A. Here the axial plane (short dashed great circle) of this refolded structure dips at about 60° N.

At locality 5 (stereonet F) cross-folding is evident. The local F₂ folds plunge shallowly south-west in a shallowly SW-dipping axial plane. Poles to bedding appear to form a small circle distribution; these measurements are taken from around the hinge of a local F₁ fold refolded by the F₂ structure (great circle II, statistical axis β II) and probably post-F₂ upright E-trending warps (great circle III, β III) whose axis dip about 40° to the east.

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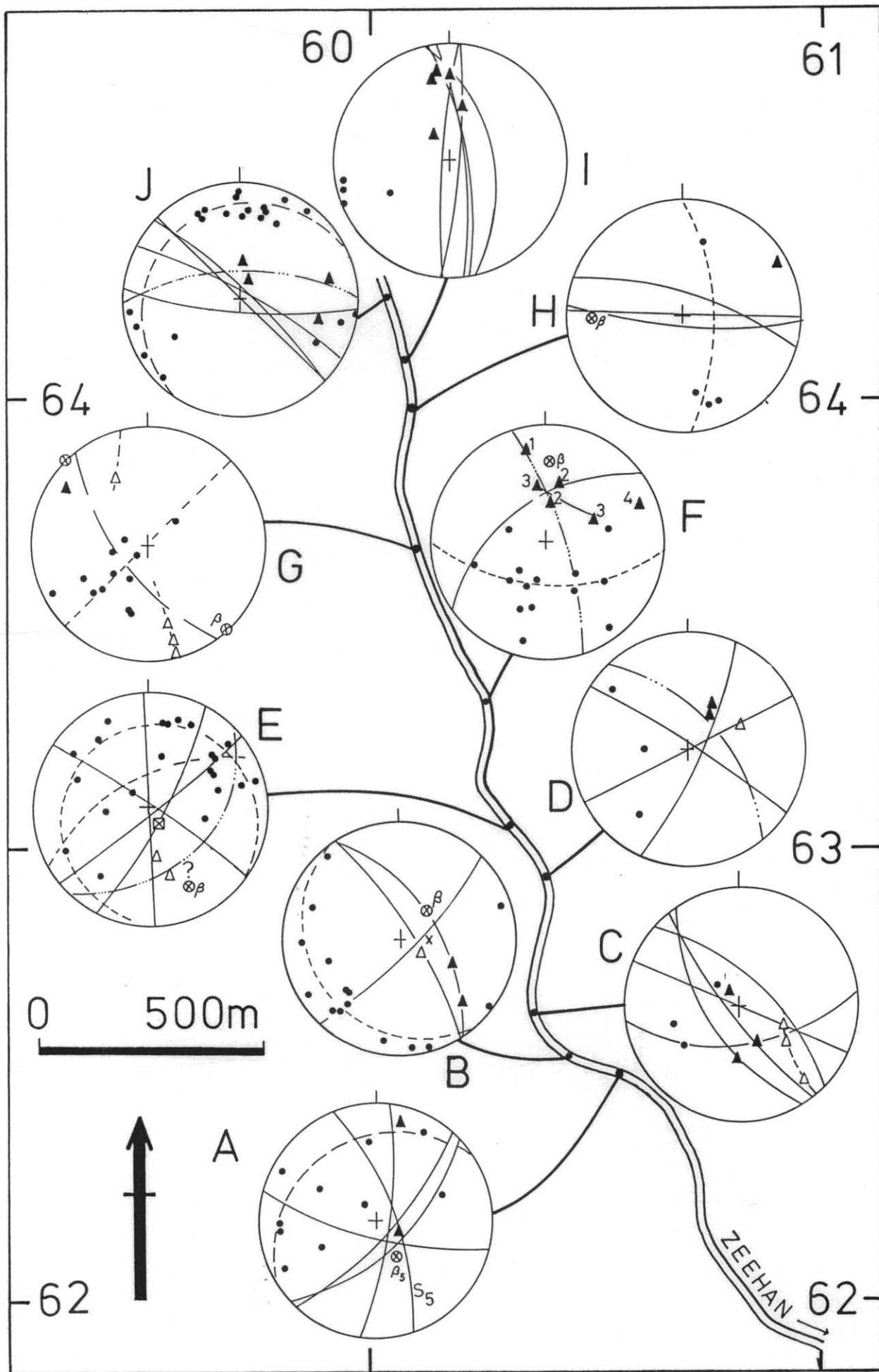


Figure 3 (part 1) Structural geometries in outcrops between Zeehan and the Permian unconformity near the Montana Mine. Key: ●, poles to bedding; triangles, fold axes (▲, locally younger; △, locally earlier); solid lines, axial plane cleavage; dashed line with three dots, measured axial plane; finely dashed line, construction lines showing great and small circles. All stereonet are equal-area, southern hemisphere projections and are referred to by letters A to J below.

Cross-references are made in this caption to sketches shown in Figures 4 and 5.

A – local probable S_5 axial surface, with bedding folded about a steep S-plunging statistical fold axis, β_5 . Also shown are N- and NE-trending older cleavages; there is also a bedding-parallel early schistosity. The two fold axes shown (▲) precede the local probable S_5 cleavage. The shallowly N-plunging fold has as its axial surface the N-striking cleavage and folds sub-coaxially a crenulation cleavage. The NE-trending cleavages are axial plane to the steeply-plunging fold coincidentally near β_5 .

B – poles to bedding define a steeply-plunging fold about a NE-trending axial plane slaty cleavage. The statistical fold axis lies reasonably close to the measured fold axis (△) and crenulation lineation (×); note that were a small circle plotted through the bedding poles, β would move towards (△). A later NW-striking cleavage overprints this structure and produces the crenulation shown as ▲.

C – Sole markings indicate that here bedding is upside down. NW- and E-trending cleavages are evident as are steeply and shallowly plunging folds. The NW-trending cleavage is correlated with S_5 in net A; it is axial plane to steeply plunging folds (▲) including one of sinistral vergence. Earlier folds (△) related to the E-W trending cleavage (probable S_4) appear folded along a small circle. **D** – See also Figure 4. The stereonet D shows the geometry of folding in Inset 1, Figure 4. The NW-trending correlate of the S_5 cleavage and associated steeply-plunging folds is evident. Also present is a NE-SW striking cleavage, correlatable with the NE-SW trending cleavage at A. The geometry of the thrusting here is shown in Figure 4(1).

E – See also Figure 4, (2). Poles to bedding define a possible small circle about a steeply-plunging cone axis (square with cross) and a great circle whose pole (β) plunges moderately south-east. The outcrop contains upright warps about a north-east trend and an earlier possible sheath fold whose axes plunge south in an axial plane dipping 45° to the south-east; the axes of this fold are plotted as (△). Also present is a N-trending spaced cleavage. The N- and NE-trending cleavages are correlatable with those in nets A, B and D.

F – See also Figure 4, (3). Here N and NE-trending cleavages cross the local S_1 schistosity as well as a recumbent fold which folds S_1 and a possible F_1 fold.

The south end of this outcrop contains the structures shown in Figure 4 (3), as well as structures a few metres north whose geometry is shown in net F. The outcrop contains upright N-trending folds as defined by poles to bedding which, measured around one such fold, indicates an axis plunging moderately north (β) in a steep axial plane; the measured fold axis is shown as the solid triangle 1. The folds at solid triangles 2 are conical dextral folds which fold a crenulation lineation which, near fold 1, plunges 46° to the north. These conical folds contain what appear to be primarily curved fold axes, as shown by the curved fold axis (linked solid triangles 3). The folds 2 and 3 are cross folded by an E-W trending fold (solid triangle 4).

G – Here the major structures are interpreted as E-verging step-folds which are cross-folded about a north-west trend equivalent to S_5 in net A. Poles to bedding around the cross-folds define a vertically-dipping girdle striking north-east. The steeply SW-dipping measured fold axial plane contains β and a shallowly NW-plunging fold axis (▲). The open triangles represent the axes of the refolded step folds.

H – Here occurs the structure illustrated in Figure 5. This E-trending N-verging structure folds overturned bedding. The bedding measurements around this fold define a W-plunging fold axis. The measured fold axis (▲) lies off the fold axial surface; it occurs in a pelitic band and may be an earlier structure.

I – Here occur a series of N-plunging folds (▲) with a consistently N-striking axial plane spaced cleavage. Bedding here dips dominantly east and is upright, and therefore a major recumbent fold hinge must intervene between H and I.

J – Here occur a series of faults breaking a sequence folded into shallowly to steeply plunging folds. Bedding measurements along the outcrop define a small circle of poles to bedding. The central part of the outcrop contains a syncline-anticline couple with faulting breaking the anticlinal hinge. The fold axes of this structure range from shallow to steep in an E-W trending axial surface which is highly oblique to the fault.

A broad shear zone containing intrafolial folds separates the eastern and western parts of the outcrop; in the west a spaced cleavage trends north-west following the trend of a fault in the east. This cleavage is folded by steeply plunging folds with a steep axial surface striking NNW; this NNW striking surface coincides with S_5 in stereonet A.

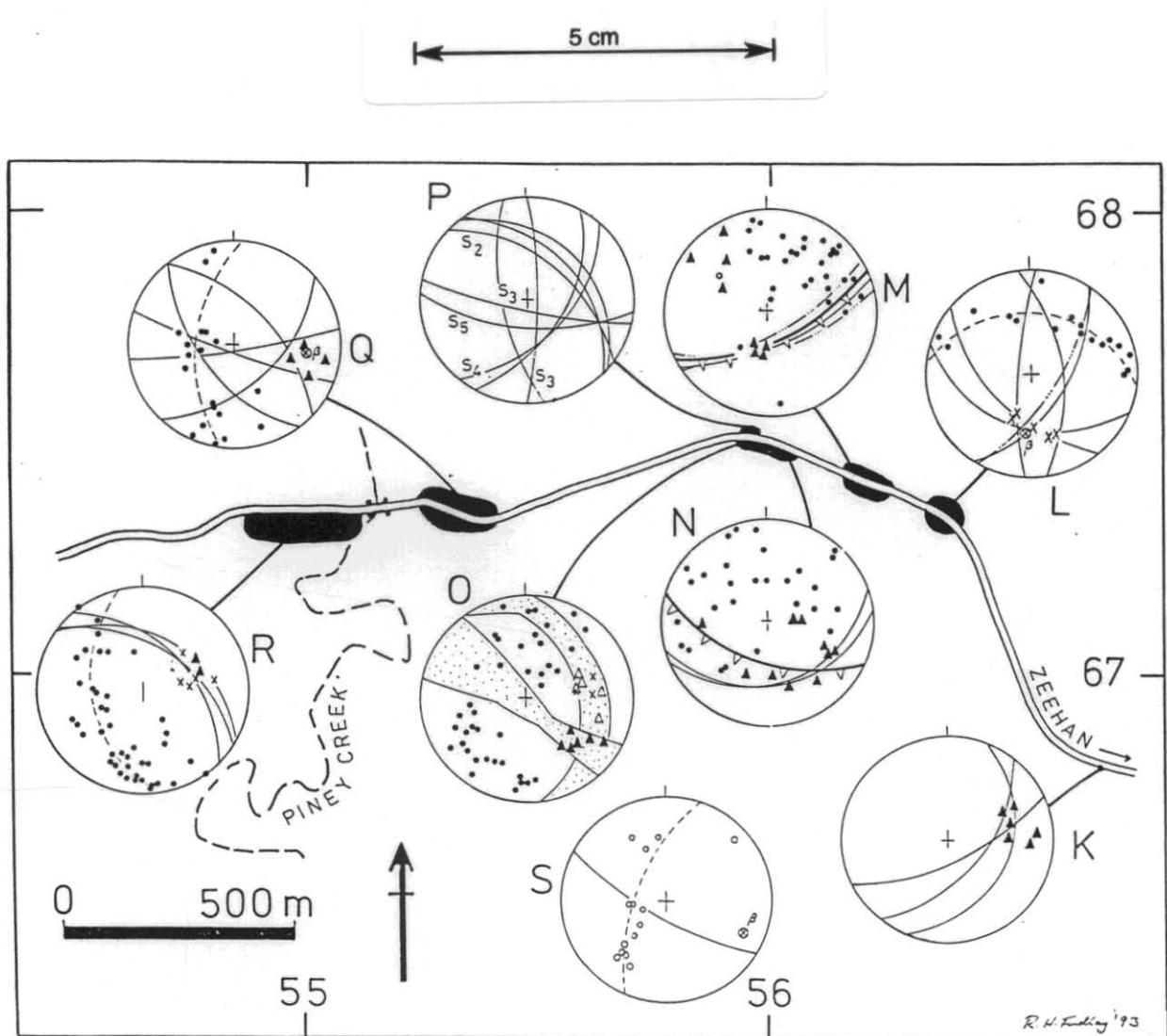


Figure 3, (part 2) Southern hemisphere equal-area stereonet showing structural geometries of outcrops between the north-western contact of the Permian tillite with the Oonah Formation and Piney Creek. Legend as for Figure 3, part 1. Cross-reference is made to Figures 6-9 and whose captions contain full details of their geometry.

K - E-plunging, NW-verging chevron folds with NE-striking axial plane cleavage fold overturned bedding and refold sub-coaxially isoclinal folds and contain a moderately SE-dipping slaty cleavage in pelitic beds. These folds also fold two crenulation lineations.

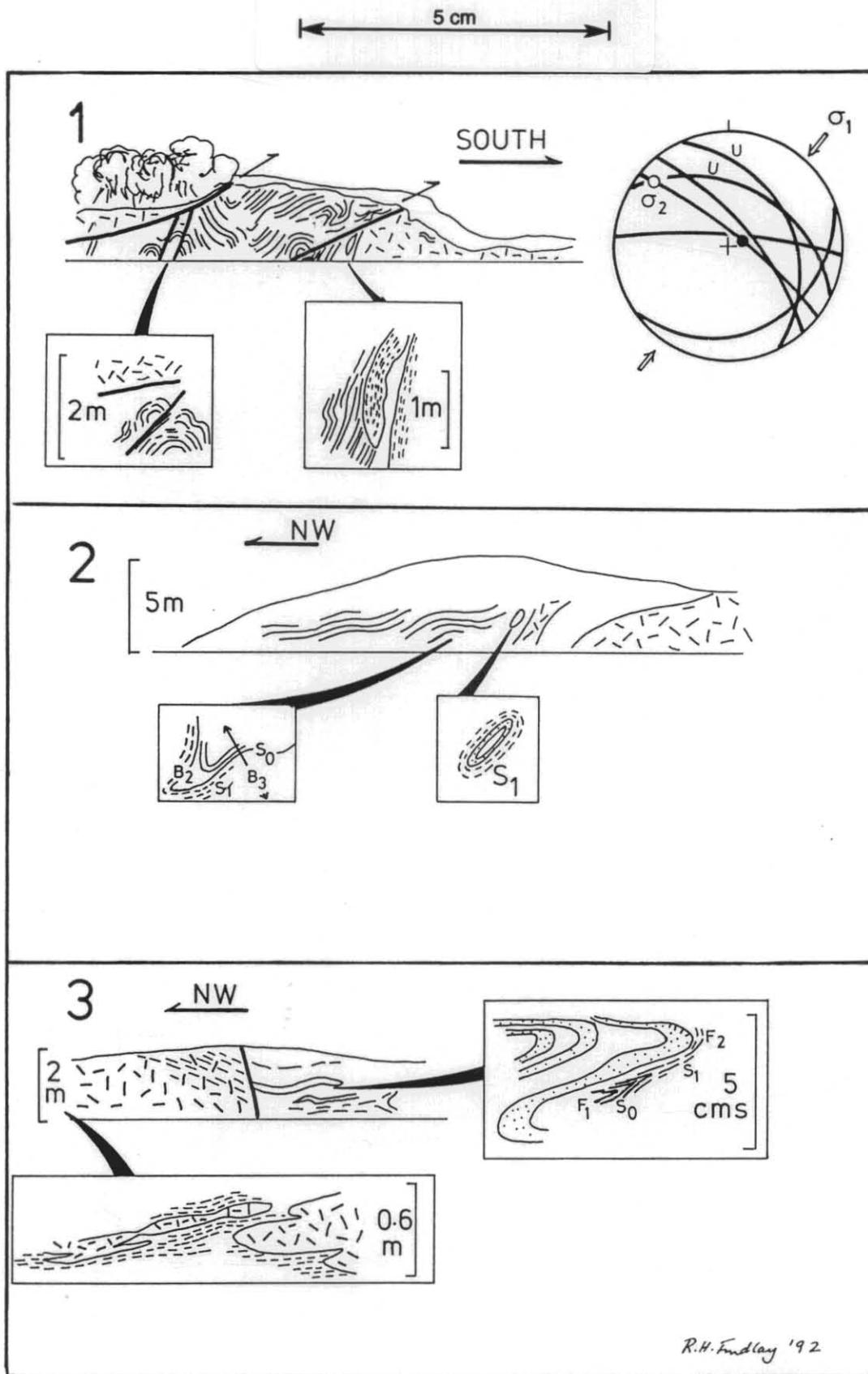
L - poles to bedding define a great circle whose statistical fold axis coincides with a S-plunging intersection lineation (\times). These lineations are the result of the intersection of bedding and the NE-trending cleavage which correlates with the cleavage in K, and they coincide with the statistical fold axis (β) derived from the great circle plot of poles to bedding. The change in orientation of the fold axes between the localities K and L is attributed to folding of bedding before the NE-trending deformation. Quartz fibres on bedding indicate flexural slip during folding.

M - See Figure 6. Stereonet M gives the overall geometries of this extensive outcrop (see also stereonet A in Figure 6).

N and **O** - (See also Figure 7). Stereonets O and P summarise the structural data at this outcrop. The dotted area in O encompasses the two dominant axial plane surfaces here. The latter folds follow the S_5 trend seen in stereonet A, Figure 3 (1).

P - Cleavage relations here are consistent with six deformations. S_1 (not shown) is a bedding-parallel weak schistosity overprinted by a textural zone 2A (Bishop, 1972) fabric in the sandstone beds. This is axial plane to reclined E-plunging folds here (see fig. 8) and at locality Q (fig. 9). S_3 is axial planar to minor folds in S_2 , and S_4 and S_5 are spaced to slaty cleavages. There is no indication of the late NW-trending cleavage (S_5 in stereonet A, fig. 3 (1)). If the S_5 at P correlates with the E-W trending local S_4 at stereonet A (fig. 3 (1)), then the NW-trending cleavage, S_4 cleavage at A would be the regional S_6 .

Q - This illustrates the geometry of the large reclined fold here. See Figure 9 (caption) for the explanation.



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Figure 4. Outcrop sketches for locality D [CP603632] (top, 1) in Figure 3, for locality E [CP602633] (centre, 2) in Figure 3 and for locality F [CP602637] (bottom, 3) in Figure 3.

Top, 1; shows thrust faulting and folding with some folds taking the form of thrust-ramp folds (left inset). Striated surface orientations shown in the stereonet indicate a north-east direction for σ_1 as seen by the author at Round Mountain. The sandstone/pelite sequence is thrust over a volcanic unit (right inset) and the S_1 schistosity parallel to the long axis of the boudins.

Centre, 2; shows three-phase refolding within the sandstone/pelite sequence (left inset) and a probable post- S_1 sheath fold in a thin volcanic layer (right inset).

Bottom, 3; a large boudin of the volcanic rocks occurs here with strain increasing towards the margin of the boudin. S_1 is parallel to the boudin axes (left inset). The right inset shows local F_2 reclined chevron folds verging S and refolding S_1 and an isoclinal F_1 fold.

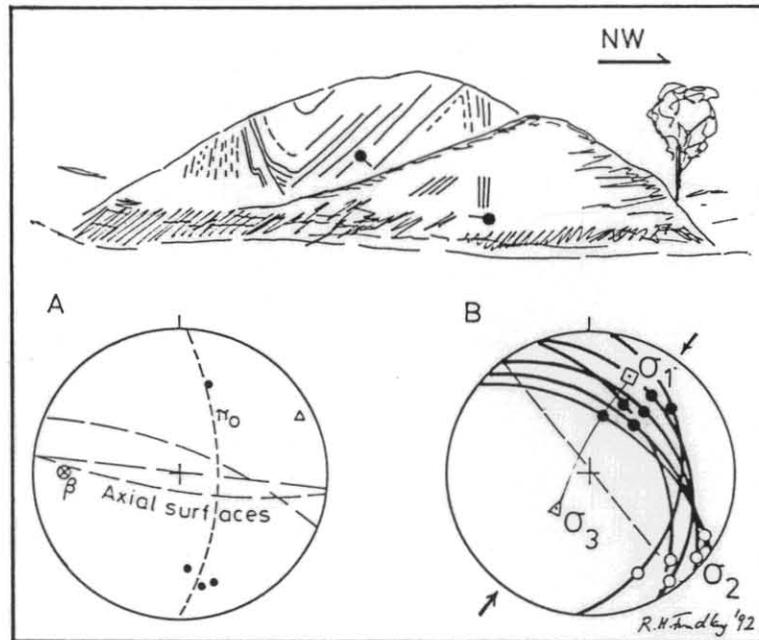


Figure 5. Outcrop sketch of locality H [CP601645] Here occurs a W-plunging syncline-anticline couple which folds overturned bedding and the S_1 schistosity. Stereonet A shows the geometry with bedding measured at four localities around the fold (● - poles to bedding) and the statistical fold axis β lying in the plane of three measured axial surfaces (long dashes). The open triangle (Δ) shows an earlier fold axis. Stereonet B shows a series of minor NE-dipping reverse faults which break this fold couple and striations on these faults indicate a NE-plunging principal stress similar to that seen in the Round Mountain district by the author.

Figure 6. Structure at M (CP561674). Here the outcrop is dominated by S-dipping bedding folded into reclined chevron folds and broken by faults including faults parallel to slightly oblique to bedding. Stereonets A-E show the structural geometry; insets 1 to 3 give an indication of the style of deformation; the lower diagram gives an interpretation of the 3D geometry. All stereonets are equal-area southern hemisphere projections. Legend: poles to bedding (●); fold axes (\blacktriangle); heavy lines are faults; broken lines (long dash) great circles for poles to bedding; broken lines (short dashes) axial surfaces.

Inset 1 reclined folds fold S_1 and develop limb faults and local collapse of fold hinges.

Inset 2 is indicative of layer-parallel slip during folding with the production of upright intrafolial folds above the plane of décollement. These reclined folds contain sandstone layers which are boudinaged and formed into multi-hinged folds with an axial plane cleavage in the pelitic layers.

Inset 3 shows what appears to be a thrust slicing through at a low angle the axial surface of a multi-hinged reclined fold.

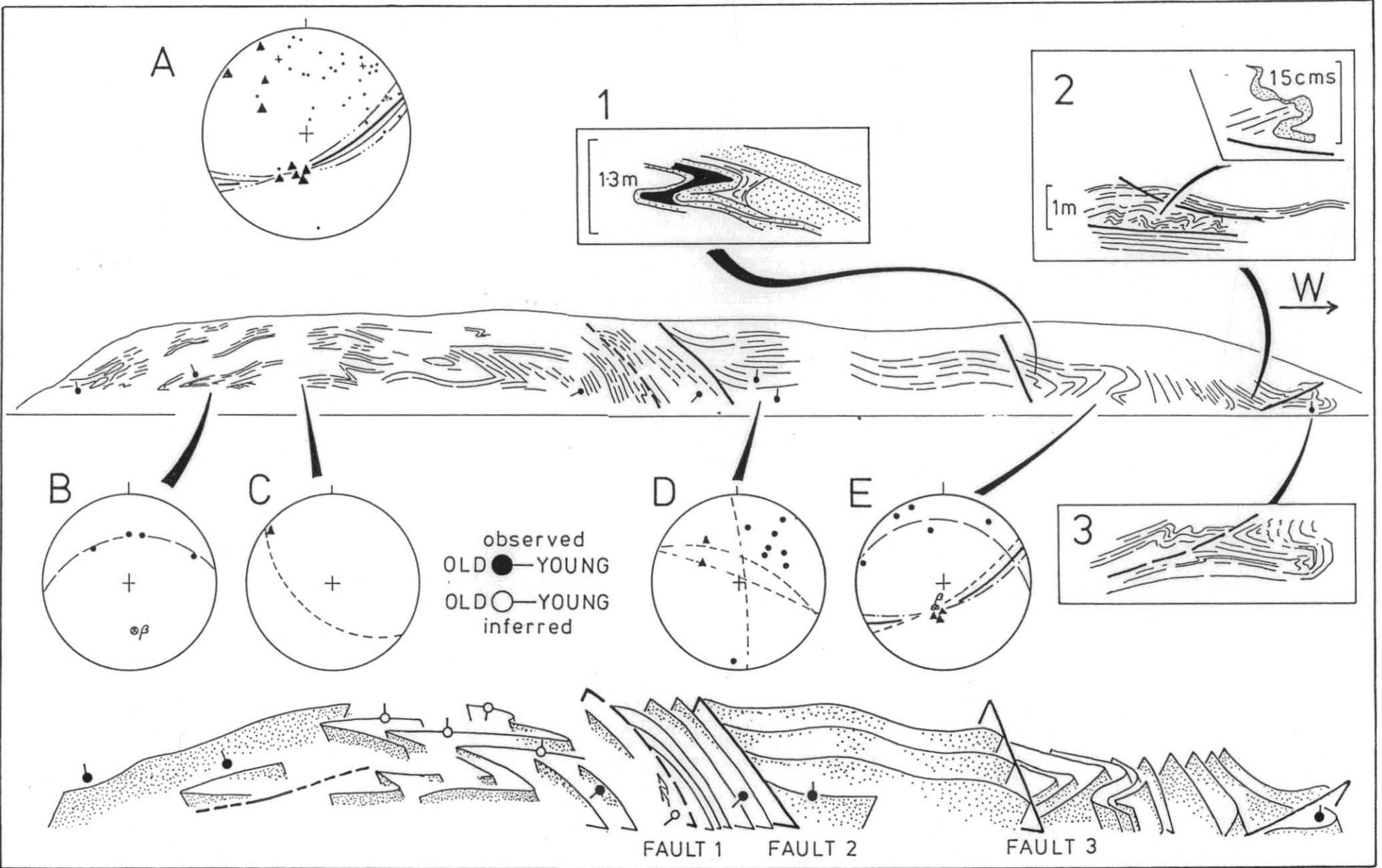
Stereonet A gives the overall outcrop geometry. The dominant folds (the reclined structures) plunge south in a steeply S-dipping axial surface which is followed by a weak schistosity in sandstone beds and crossed by a weak N-S trending, steeply-dipping spaced cleavage. Complexities in the deformation history are indicated by variations in orientation of the folds within this outcrop; some folds following a NW-trend are clearly evident.

Stereonet B gives the fold orientation at locality B. The statistical fold axis (β) in this figure also lies on the measured axial surface of reclined fold at locality at C whose axis plunges steeply north-west (see stereonet C).

Stereonet D shows two folds whose axes lie in a NE-dipping axial plane whose strike is close to that of the SW-dipping axial plane in C; these structures are cut by two poorly developed cleavages dipping west and north-west.

Stereonet E repeats the geometry of the folds at B although the plunge is steeper; here the folds are clearly associated with an axial plane cleavage; local limb thrusting occurs here (solid heavy line). In sum, the large reclined folds in this outcrop would appear to be rotated about an E-W axis producing S- and NW-plunging folds; they develop limb thrusts the regional significance of which is not certain. The reclined folds are also affected by warps on a N-S trend, are cut by two cleavages, and also by W-dipping faults (faults 1, 2 and 3).

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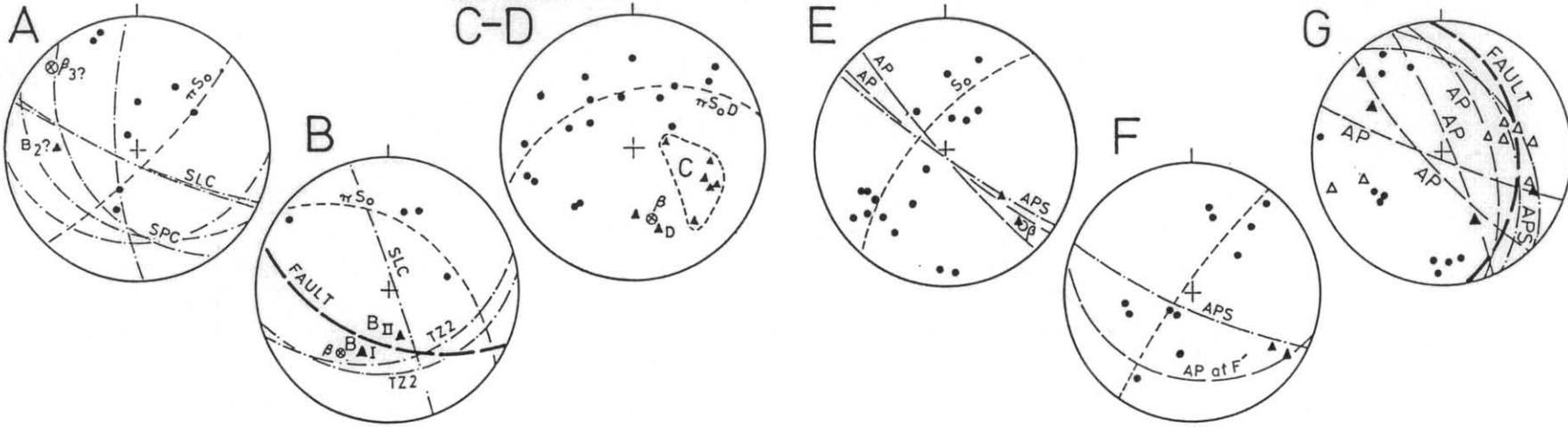
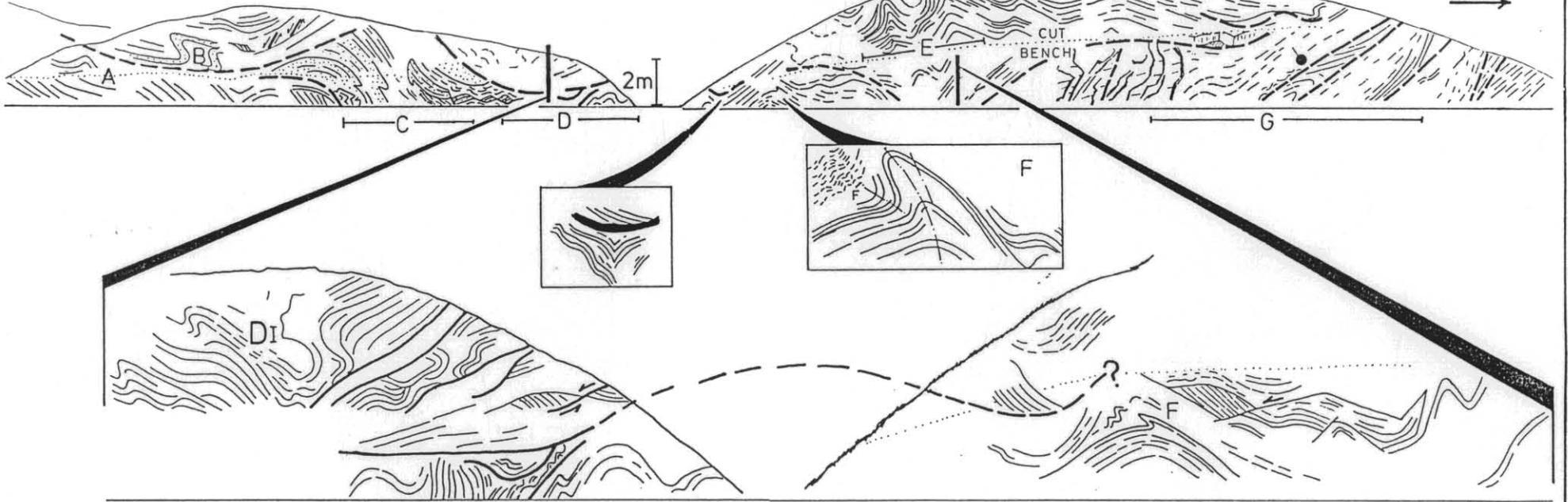
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5 cm

LOCALITY N

LOCALITY O

W



R.H. Fordley '92

Figure 7. This shows the complex structures at localities N and O [CP561675], with structural geometries at specific sites within this extensive outcrop being shown in stereonet A-G. The nets are equal-area southern hemisphere projection. *Legend:* poles to bedding (●); fold axes (▲ younger, △ older); short dashed great circles indicate best-fit great circle to bedding poles; heavy dashed great circles, faults; measured axial planes, great circles with long strokes; cleavages, great circles with long stroke and dot.

Simplistically the outcrop contains two or possibly three major sets of folds: an early phase of reclined structures such as those at CP561674 (locality M), upright N-S trending folds such as that at CP601645 and upright SE-plunging folds. The structural complexity is increased by the influence of numerous décollement surfaces and a possibly major shear zone at locality N. These décollements and shear zones may not be of a single age.

At site A, poles to bedding form a possible great circle girdle about a NW-trending shallowly-plunging axis β_3 ? (stereonet A). This fold does not possess an obvious axial plane fabric, although β_3 lies within one of three measured spaced cleavages (SPC, stereonet A). Also present is a fold, cut by this spaced cleavage and which develops an axial plane slaty cleavage (SLC); this fold plunges west and is indicated in stereonet A by the triangle B_2 ?

Stereonet B shows the geometry of the folded sandstone layers at site B. These folds are disharmonic with sheared limbs. Poles to bedding round this fold defines a S- to SW-plunging axis which lies in the axial plane schistosity of this fold; this schistosity (TZ2) is weakly developed in the sandstone beds, has a textural zone 2A fabric (Bishop, 1972) and here seems to be a local development only. The fold at B is underlain by a décollement oriented close to the textural zone 2A schistosity and which contains the fold axis (▲ I, stereonet B).

This fold is crossed by a steep NW-trending slaty cleavage (SLC) associated with a small fold (▲ II, stereonet B) which would appear therefore to be a structure younger than the obvious reclined fold. The region covered by C and D includes what appears to be a thick, folded shear zone containing small phacoids of schistose sandstone and large boudins of sandstone in a pelitic sequence. On the basis of the asymmetry of one phacoid in this shear zone, movement would have been to the west. This assumes that the shear zone is right way up and is not part of an overturned sequence as seen at CP601645. This broad shear zone appears to be early as it is cut by the décollement below fold B and is overlain by a similar décollement in the region of D.

Stereonet C-D shows the geometry of the structures in the region of C-D. Poles to bedding at D define a statistical fold axis plunging 40–50°S parallel to two measured fold hinges (▲ D). This trend is parallel to the local B_2 trend shown in stereonet B. However the folds in the shear zone at C (▲ C) show a range of plunges; these are derived principally from the zone of box folding on the eastern side of the early shear zone, they fold a bedding-parallel schistosity in the sandstone beds, and they do not possess an axial plane cleavage. The box-fold can be interpreted as part of a possible fault-bend fold over a décollement; the box-folding is presumably a response to space problems in the core of the supposed fault-bend fold.

The enlargement of the field sketch shows the complexity at D; note that the fold shapes drawn are an artefact of the exposure. For example at site D1 the folds plunge down the slope of the cut face, and the sketch here does not show the folds in their profile plane. Extensional faulting, such as that seen in the early shear zone at C is evident also both at D and at just west of the fold labelled F (locality O). The sense of fault movement at F is consistent with that on faults near fold B and may be related to E- or SE-directed translation; note that an opposite sense of shear seems the case from the extensional faults in the early shear zone at C.

Stereonet E shows the geometry at E where occur upright, NW-trending, disharmonic folds which plunge south-east and which contain a weak axial plane spaced cleavage. At locality F, these folds refold a structure correlated from its style with the reclined folds at B; a few metres west the upright SE-plunging folds fold a schistosity identical to the axial plane schistosity of fold (▲ I) at B.

Stereonet F gives the geometry of the structure shown in inset F. Poles to bedding plot in a great circle girdle about a shallowly SE-plunging axis which refolds an E-verging fold; the two triangles show the fold axis of the refolded fold. Geometrically this structure would seem more akin to the B_2 ? fold in stereonet A than to the reclined fold at B.

Stereonet G shows the geometry in the region of G. Here E-dipping faults follow closely the axial plane schistosity of the W-verging folds, and thus resemble the décollement below fold B. However, although the fold at B also develops an axial plane schistosity sub-parallel to the décollement, this fold verges east. One explanation is that folds B and G could be sheath-folds formed during movement on the décollement.

The solid triangles (▲) in stereonet G give the orientation of a set of upright structures which refold those shown by open triangles (△); these upright folds are of the same orientation and style as those shown in stereonet E and the upright folds at C. That is, they represent a post-thrust generation of NW-trending upright structures.

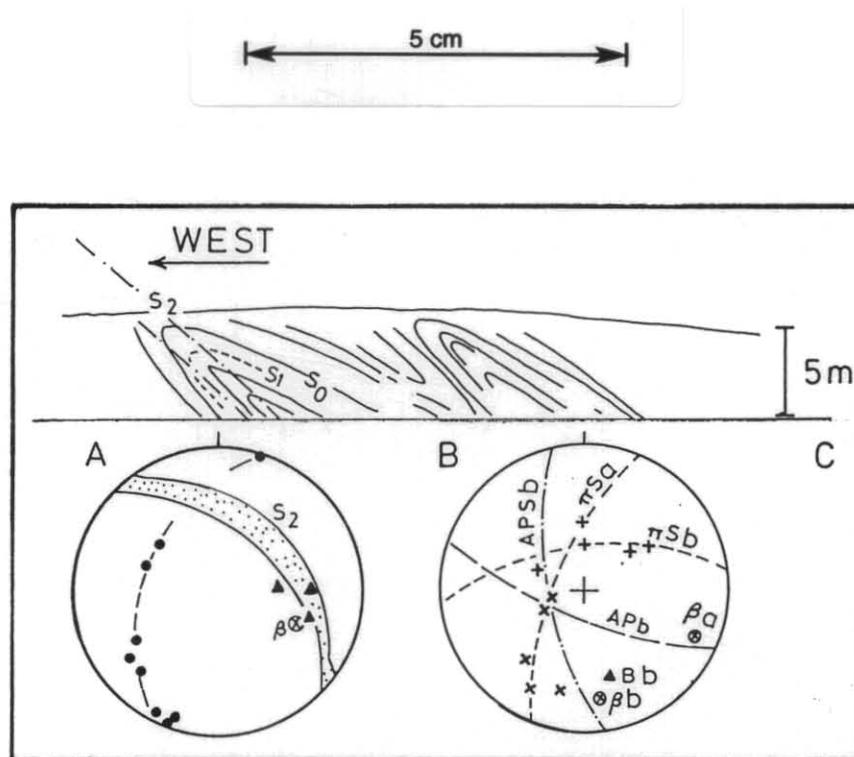


Figure 8. The geometry of the folds exposed at locality P [CP560676], a little west of locality O [CP561675]. All stereonet are equal-area southern hemisphere projections. *Legend:* ● - poles to bedding; + - poles to schistosity; short-dashed great circle, best-fit great circle to poles to bedding; + - schistosity; Δ , \blacktriangle - fold axes; long-dashes forming great circles, measured axial plane; long dashes broken by dots, measured schistosity; solid line great circles, slaty and spaced cleavages.

The near-isoclinal appearance of the folds is due to the obliquely cut face of the outcrop. The folds fold a schistosity; they plunge shallowly east (stereonet A) and possess an axial plane schistosity (S2 in figure) similar to that in the reclined folds at locality N [CP561675]. In this respect and their geometry they also resemble closely the large reclined fold at locality Q [CP554672] (fig. 9).

Stereonet B Figure 8 shows the structural geometry of the early schistosity (\times), which is folded by two sets of small folds. Great circle girdle ΠSa follows that for bedding in stereonet A and βa falls on the statistical and measured fold axis for the reclined E-plunging F2 folds shown in the sketch and stereo-net A; these possess the axial plane fabric S2 shown in stereonets A and B (fig. 3, part 2).

Great circle ΠSb indicates cross-folding about a S-plunging axis with a N-trending axial plane fabric APSb. This is the S3 surface in stereonet P, (fig. 3, part 2).

Stereonet C shows the geometry of a spaced and slaty cleavage within the pelite beds of this outcrop. The slaty cleavage (SLC) follows the axial plane of the F2 folds and it is cross-cut at a low angle by the spaced cleavage which here is not associated with folding.

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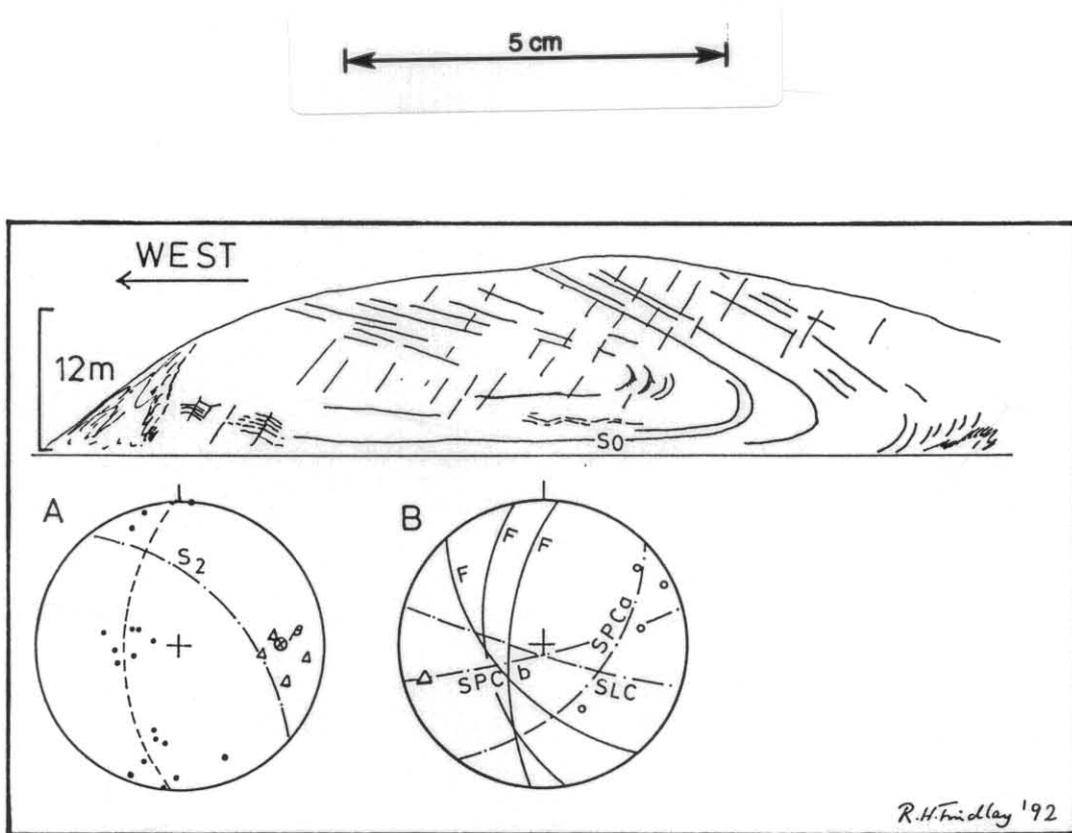
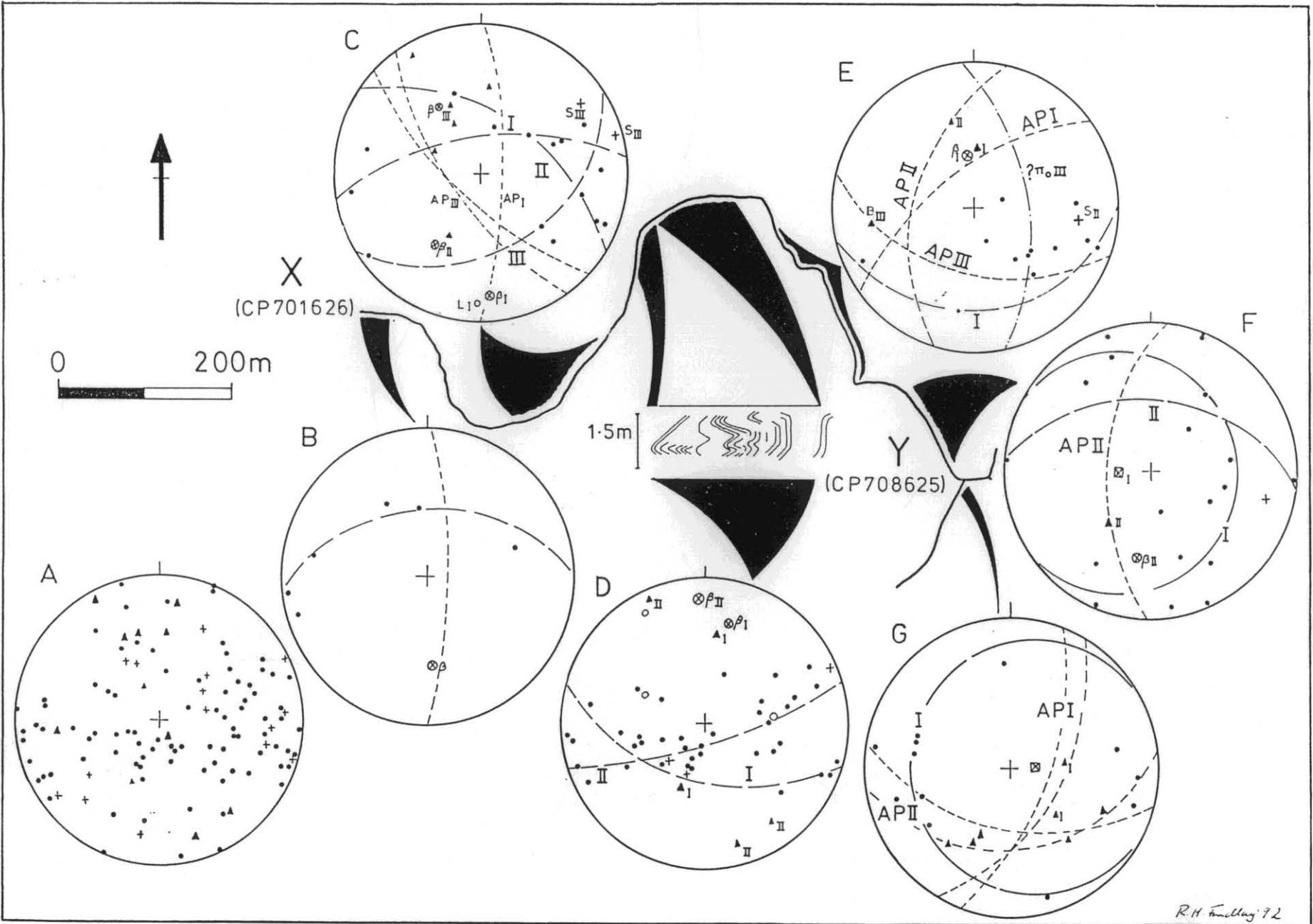


Figure 9. Structural geometry of large reclined fold near Piney Creek bridge, locality Q [CP554672]. Stereonets A and B are equal area southern hemisphere projections. *Legend:* poles to bedding (●) with best fit great circle girdle shown by light dashed line; cleavages are shown by the great circles formed of long strokes and dots; the solid great circles F are the prominent fractures shown in the outcrop sketch; O – crenulation lineations; ▲ – fold axes. *Stereonet A* illustrates the geometry of the reclined fold exposed on the northern side of the road. This fold can be correlated with the reclined folds at locality P. The fold in Figure 9 develops an axial plane fabric (S_2 in stereonet A) which correlates with the local S_2 fabric at locality P. The fold is cut by two spaced cleavages (SPCa, SPCb; stereonet B) as well as numerous W-dipping fractures whose range of orientations is shown by great circles F in stereonet B. Stereonet B also includes crenulation lineations measured at this locality and in the facing outcrop on the opposite side of the road. Also in this outcrop the S-dipping slaty cleavage (SLC, stereonet B) cuts two NE-trending crenulation lineations (net B) produced by the intersection of spaced cleavage SPCa with bedding; these crenulations are axial to NE-verging folds. The correlation between locality P and locality Q is: S_2 of Q correlates with S_2 of P; S_5 (fig. 3 (2)) and Apb (fig. 8, stereonet B) is the slaty cleavage SLC in Figure 9. The fractures F in stereonet B in Figure 9 follow the orientation of S_3 in stereonet P in Figure 3 (2) but a correlation is not proved. The spaced cleavage SPCb in Figure 9 stereonet B is probably the same surface as Apb in stereonet B in Figure 8 and could be the S_5 fabric shown in stereonet P in Figure 3 (2).

5 cm

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R.H. Furlong '72

Figure 10. Geometry of the non-metamorphic probably Precambrian rocks of the Dundas Inlier between CP709625 (Y) and CP701626 (X). All stereonet are equal-area southern-hemisphere projections. *Legend:* ● – poles to bedding; ▲ – fold axes; ○ – circles intersection lineation between the local first cleavage and bedding; great circles with long dashes, great circle to poles to bedding; great circles with short dashes, measured axial surfaces; + – cleavage surfaces.

Stereonet A summarises all bedding, cleavage, and fold axes measured in the traverse. Possible great circle girdles dip steeply south and also east at about 45° and/or north-east at about 45°, indicating multiple deformation.

Stereonet B contains readings collected from locality B around small, upright S-plunging, W-verging upright folds with transposed limbs; these occur close to the contact with ultramafic rocks immediately west of locality X. These folds step down to the west; they take the form of multi-hinged and singly-hinged chevron folds whose shape changes rapidly in the fold stack. The fold hinges are rounded to angular with inter-limb angles ranging between 40° and 70°. These upright folds dominate the traverse covered by *stereonet C* and involve overturned bedding in some instances; they may correlate with the F₂ structures in the Concert Schist (see text).

Poles to bedding in *stereonet C* produce three great circles (I, II, III) about statistical fold axes β_I , β_{II} , β_{III} . The folds develop an axial plane slaty cleavage measured at two localities, and the orientation of this is given by API and APIII. The change in orientation of the folds, from β_I to β_{III} occurs progressively westward suggesting warping about a later steep axis.

Stereonet D covers a zone of recumbent chevron style folds whose shape changes in the fold stack. These fold a weak slaty cleavage and are correlated with nearby reclined disharmonic folds in a small quarry 20–30 m to the east which fold overturned bedding and a slaty cleavage. *Stereonet D* shows bedding as measured around the recumbent folds and the measurements suggest two great circles I and II with corresponding statistical fold axes β_I and β_{II} which lie reasonably close to the shallowly SE- and NW-plunging fold axes (▲) shown. As with the upright folds at C, there has been rotation of the fold axes from ▲I to ▲II.

Stereonet E shows the structural geometry in the sector E. Here again bedding is overturned locally. Measurements around fold closures at E indicate three sets of folds here. Great circle I is composed of measurements around steeply-plunging NE-verging chevron folds folding a slaty cleavage which lies sub-parallel to bedding; these folds appear folded. The great circle APII represents the axial plane of a N- and S-closing chevron fold plunging steeply north-west, and which lies a few metres north-west of the locality of the fold API. This fold has a slaty cleavage parallel to the axial surface (+SII). APIII is derived from an intrafolial chevron fold which dies out upward as the axial surface curves into a décollement surface; this could be a fault-propagation fold related to thrusting.

Stereonet F shows the structural geometry in the sector F. Here a slaty cleavage is folded by reclined NE-verging folds. Measurements of bedding around the hinges of these folds fall on small circle I indicating a conical nature. Also present are S-plunging chevron folds whose bedding measurements fall on great circle II (note the similarity with folds at B and great circle API in net C, suggesting that these may be relatively late folds). At this locality also the bedding was overturned before folding.

Stereonet G gives the structural geometry at locality G. Two generations of folds occur here; their axial surfaces are given as API and APII, and the API fold axes are identified as ▲I. Here W- to NW-verging chevron folds (API) dominate the outcrop. The API folds have thickened hinges, thinned and boudinaged limbs and produce fold mullions; the pelitic intervals between the sandstone beds develop a weak slaty cleavage which produces a bedding-cleavage intersection parallel to the observed fold axes.

Also present are asymmetric steeply plunging E-W trending folds with a S-dipping axial plane (APII, short dashes, *stereonet G*). The E-W trending APII structures are of a smaller scale and have been seen only on the S-dipping limbs of the API folds; both sets of folds fold a slaty cleavage sub-parallel to bedding in the pelitic intervals. Cross-folding relationships between the API and APII folds are not obvious.

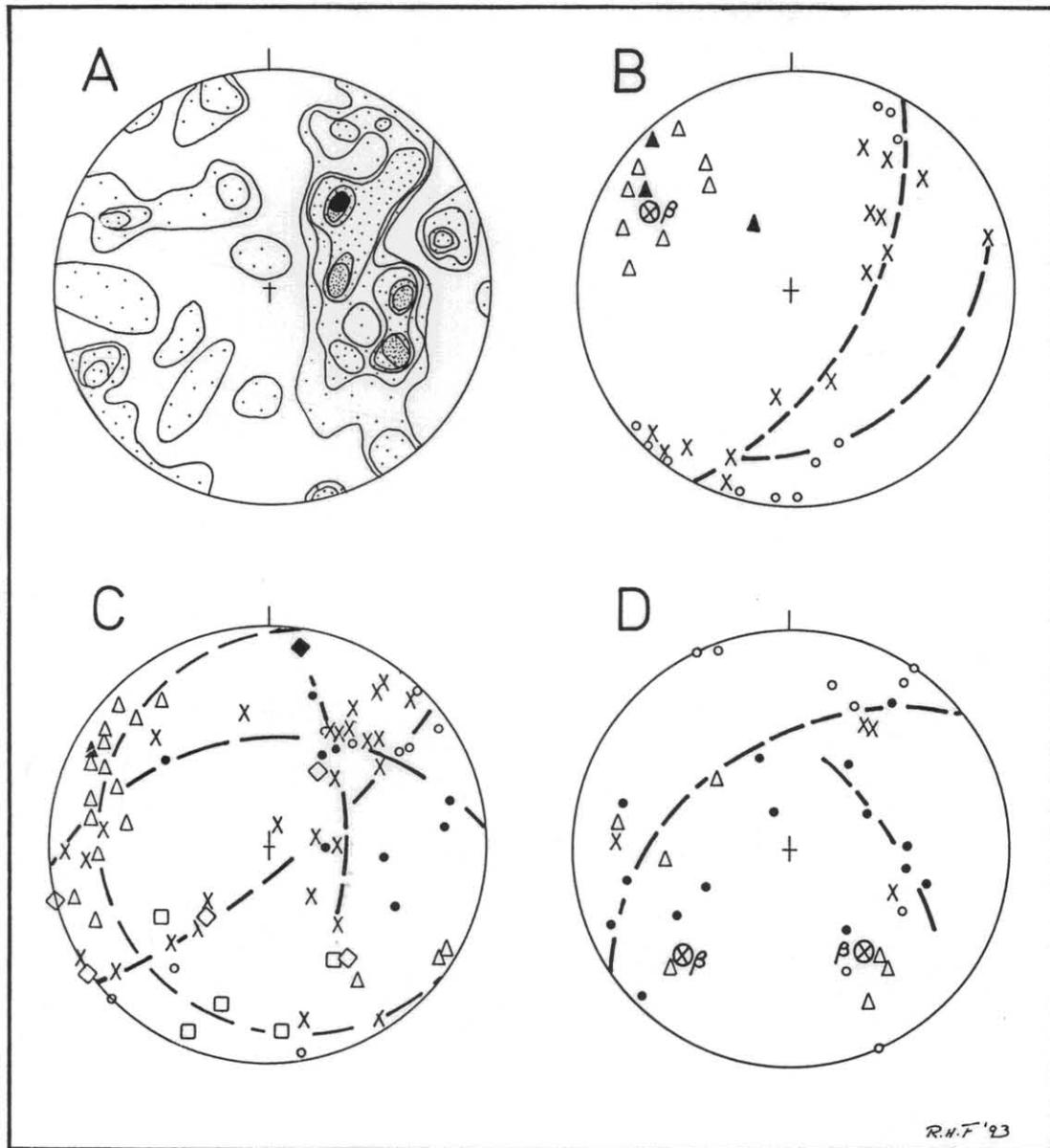
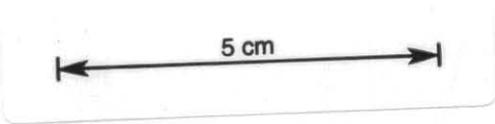


Figure 11. Structural data from the schistose rocks of the Dundas Inlier (Concert Schist). All nets equal-area, southern hemisphere projection.

Stereonet A – All bedding and S_1 (schistosity parallel to bedding) data plotted as poles. Contours at 1, 2, 3, 4, 5, 7 points per 1% area; 79 points.

Stereonet B – Concert Creek traverse. Bedding (●); S_1 (×); S_2 crenulation cleavage (○); L crenulation lineation (△); F_2 fold axis (B) folding S_0 and S_1 (▲). The S_2 crenulation cleavage follows the same trend as does the axial plane of the A_{PIII} folds in stereonets C and possibly E in Figure 10. Similarly, the F_2 axis lies close to β_{III} in stereonet C (fig. 10) and ▲II in stereonet E in Figure 10.

Stereonet C – Traverse along ridge north of Comet Creek. Legend: ● – bedding; × – S_1 ; ○ – S_2 ; ▲ – F_2 fold axis (B); △ – F_2 axial crenulation lineation (L); ◆ – post- S_2 fold axis; ◇ – post- S_2 crenulation lineation; □ – crenulation lineation of uncertain age.

Stereonet D – Traverse along Comet Creek. Legend as for net B.

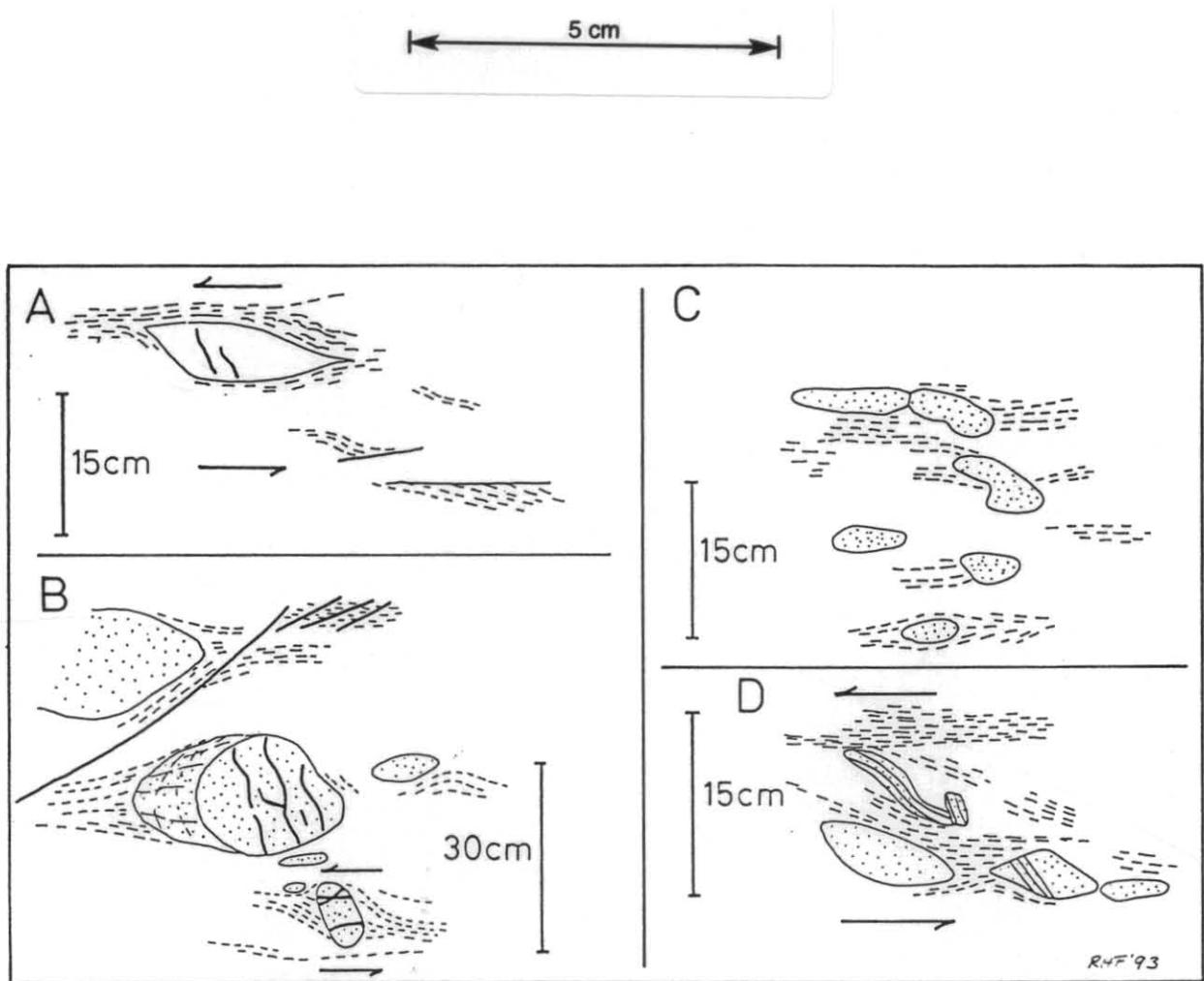


Figure 12. Field sketches of structures within unit Esrui near the Argent Dam. Stippled, sandstone; light dashes, schistosity in black pelitic matrix. View down dip to south-west. A, B, D indicate sinistral slip. C shows solely a flattening fabric.

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5 cm

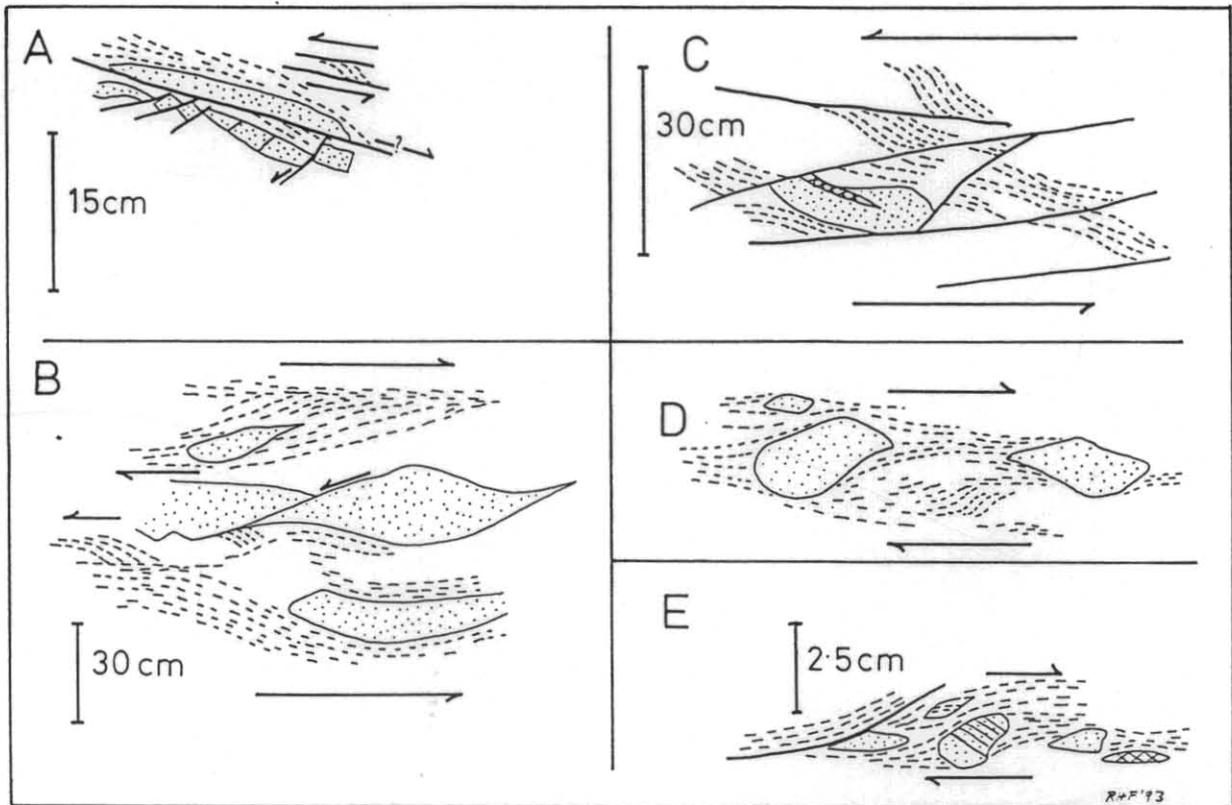


Figure 13. Structures in unit Esrui in the Pieman River area (A, B, D, E) and a black smashed rock of identical appearance between the Oonah Formation and Success Creek Group at CP623736. A and B are from CP636748 and contain evidence for both sinistral and dextral slip. C is from the contact between the Oonah Formation and Success Creek Group at CP623736 and indicates a sinistral slip component. D occurs nearby at CP637747 and contains a dextral C-S fabric. E is part of the black smashed unit extending 500 m west of Misty Valley, and occurs at CP635763 and shows a dextral slip.

5 cm

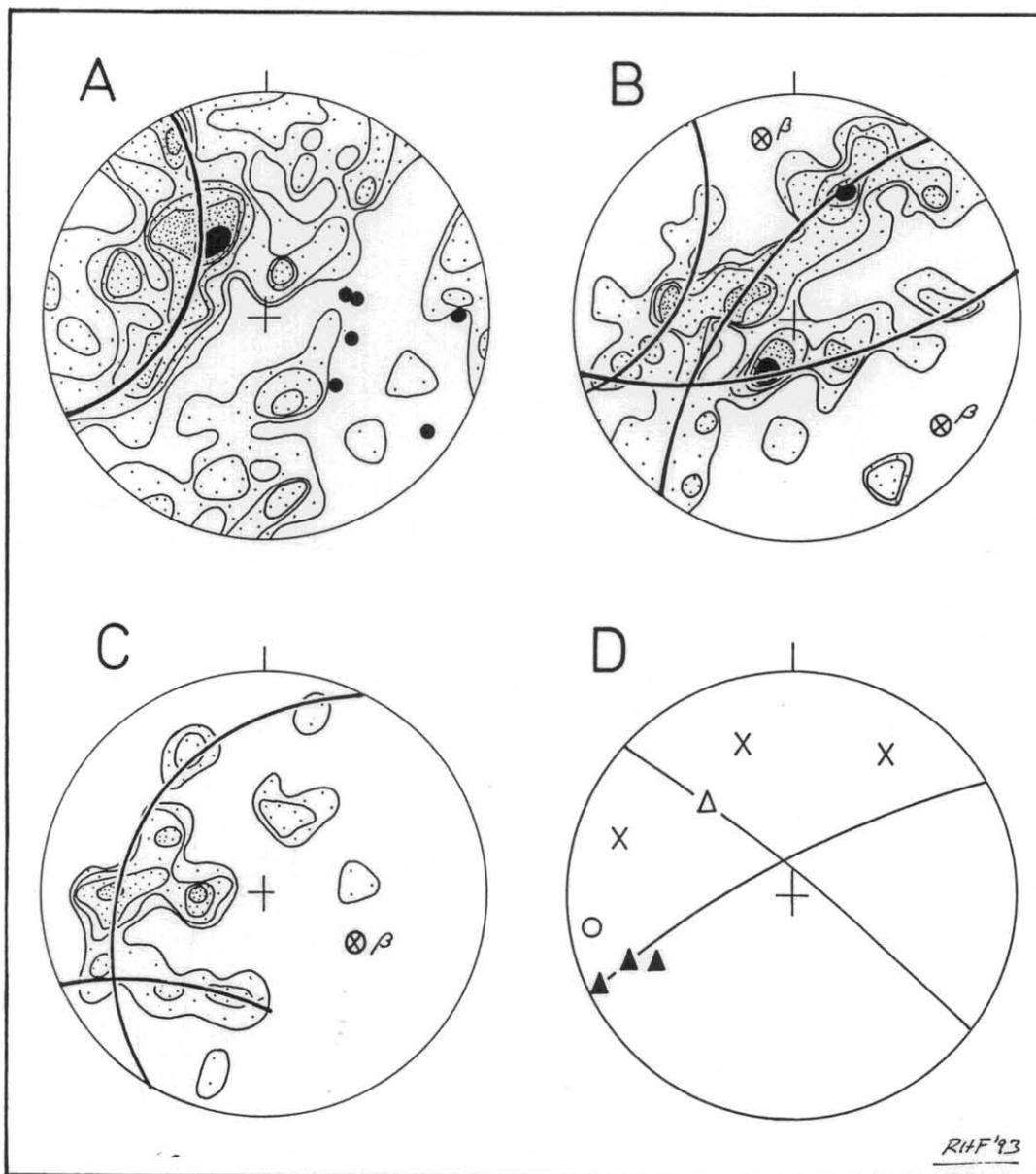


Figure 14. Structural data for Success Creek Group and Crimson Creek Formation; southern hemisphere equal-area projections.

Stereonet A. Poles to all bedding measurements in the Success Creek Group and the Crimson Creek Formation. Note small circle development in the north-west quadrant. Solid circles (●) are measured fold axes. 105 measurements; contours at 1, 2, 3, 4, 5 and 7 points per 1% area.

Stereonet B. Poles to bedding in the Success Creek Group in the Argent Dam region [CP681706–CP660717]. Note possible small circle development indicating cross-folding and NW- and SE-plunging statistical poles to the great circles to bedding. This may indicate doubly-plunging folds.

Stereonet C. Poles to bedding in the Cambrian unit ϵ 1 and Success Creek Group, Crimson Creek region between CP66472, CP660717, CP665720 and CP665729. The structure here is dominated by ESE-plunging folding, but the small circle in the south-west quadrant suggests cross-folding.

Stereonet D indicates multiple deformation in the Success Creek Group at CP650718. **Legend:** O – isoclinal F₁ fold axis with axial plane schistosity; ▲ – F₂ folds fold bedding and schistosity and possess axial plane cleavage; Δ – F₃ fold axis; X – fine crenulation lineations unrelated to these three deformations and occur in the pelitic units.