CHAPTER THREE

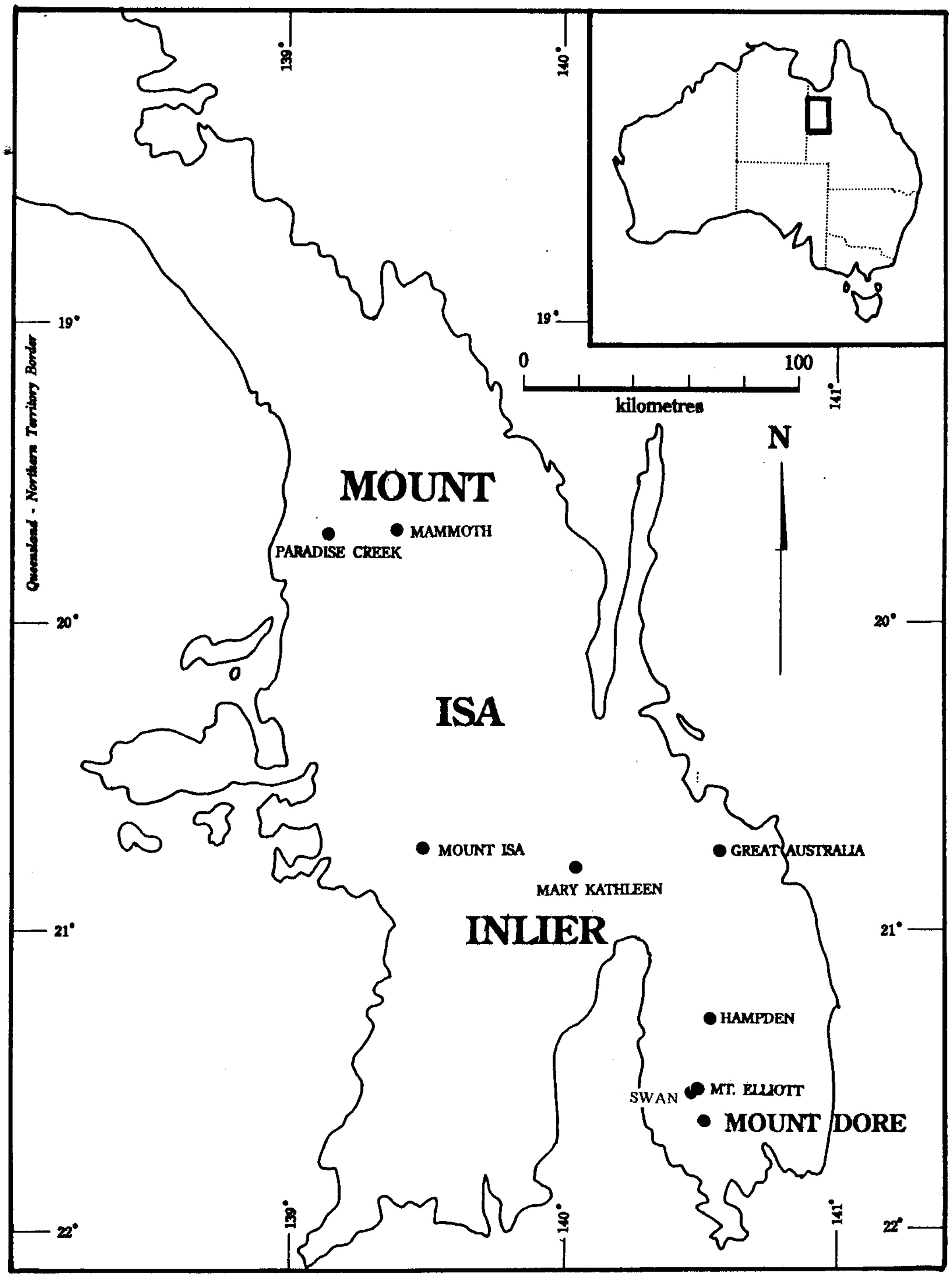
DEFORMATION HISTORY

3.1 INTRODUCTION

Recent petrogenetic models for breccia-hosted copper deposits in the western Mount Isa Inlier (Figure 3.1) relate the mineralizing event to regional deformation and syntectonic hydrothermal activity (*e.g.* Mount Isa Mine: Swager, 1983; Perkins, 1984; Bell *et al.*, 1988; Mammoth group of deposits: van Dijk, 1991). Structural studies in this part of the inlier interpret a post-depositional tectonic history where early large-scale thrusting along a proposed north-south axis has generated a pile of superimposed, right-way-up sheets and imbricate structures, which were then overprinted by two phases of regionally penetrative folding and cleavage development, at greenschist facies metamorphic grade (Bell, 1983; Winsor, 1983, 1986; Bell *et al.*, 1988). Within this framework Mount Isa and related breccia-hosted copper mineralisation was introduced during the third deformation event (D_3; terminology after Bell and Duncan, 1978), into locally dilational structural traps produced where favourable geometric interaction between the two earlier deformation events has occurred (Swager, 1983; Perkins, 1984).

Breccia-hosted copper deposits in the Kuridala-Selwyn region (Figure 3.1) also show strong structural controls (*e.g.* Hampden: Sullivan, 1953a; Mount Elliott: Sullivan, 1953b; Dimo, 1975; SWAN: Nyvlt, 1980; Mount Dore: Ophel, 1975), and Laing (1983) went as far as suggesting that formation of the Mount Dore deposit is directly analogous to that at Mount Isa. Until recently, however, the tectonic history for the region south of Cloncurry was poorly documented, and consequently little understood. Without such information, mineral deposits cannot be placed into context with the tectonic history, nor will patterns in the regional metallogeny become evident.

FIGURE 3.1: Locations of some important breccia-hosted copper deposits in the Mount Isa Inlier.



The aim of this phase of the study was therefore to expand the understanding of the regional deformation history of the Kuridala-Selwyn region, by documenting the characteristics and timing of different generations of structures. Metamorphism accompanying these events is touched on in only a very cursory manner, drawing largely on the work of previous investigators (see below), and general observations made during the present study.

3.2 PREVIOUS INVESTIGATIONS

3.2.1 Deformation history

The first recorded structural analyses in the Kuridala-Selwyn region were those of Honman (1938) and Broadhurst (1938). These workers interpreted one major folding event along north-south axes, overprinted by roughly east-west "cross-folding" (invoked to account for reversals in plunge direction in major folds), and at least one major, later episode of faulting. The first structural analysis across the entire Mount Isa Inlier was that of Carter *et al.* (1961), who recognized regionally extensive, generally north-trending, open to tight folds, and at least one other locally important fold set at a high angle to the main one. They also interpreted several episodes of later faulting, producing largely steep to vertical, conjugate strike-slip faults, but also creating reverse and normal dip-slip faults.

Blake *et al.* (1983) described two generations of folding in the Selwyn region. The earliest corresponds to first-generation structures described by earlier workers. The second generation occurs as more open, roughly coaxial folds. Donchak *et al.* (1983) recognized similar structures in the Kuridala region, but proposed an earlier, nappe-style of deformation to explain the juxtaposition of Mount Norna Quartzite against the Staveley Formation. The distribution of rock types and strain patterns around and to the south of Selwyn led Leishman (1983) and Nisbet (1983) to identify three deformation events, including an early nappe style. Laing (pers. commum., 1984) also proposed the existence of a possible early nappe-style of deformation in the eastern Mount Isa Inlier, by analogy with Proterozoic terranes elsewhere in eastern Australia (*e.g.* Broken Hill Block; Georgetown Block).

Nisbet (1983) identified a mylonitic fabric and extensive transposition of layering in ironstones adjacent to the eastern margin of the Gin Creek Block (Figure 1.2), and was able to discern two foliations. Leishman (1983) proposed that shear zones are present in pelitic rocks adjacent to these ironstones. Ransom (1986) suggested that this high strain zone is a north-striking corridor between the Gin Creek Block and the Maronan Supergroup, forming by sinistral shearing and flattening during northwest shortening after the main folding event. Switzer (1987) subsequently showed the fabric to be part of a layer-parallel shear zone (the Starra Shear) up to one kilometre thick, containing the Starra Ironstones, and extending into the Gin Creek Block. He mapped it around a major antiform related to the main folding episode, and microstructural studies by him and White (1989) confirmed it to have formed before the folding. The Starra Shear is interpreted to be a crustal-scale, originally subhorizontal detachment fault (Switzer, 1987).

3.2.2 Metamorphic history

Devlin (1980) and Nisbet *et al.* (1983) recorded prograde mineral assemblages in metapelites and metabasites at Mount Cobalt (Figure 3.1) that indicate amphibolite facies conditions. These workers also recognized a zone of metasomatism, restricted to a shear zone encompassing the boundary between metapelites and metabasites, and characterised by replacement of prograde mineral assemblages with albite, scapolite, biotite and tourmaline. Shearing and metasomatism were interpreted to have occurred simultaneously, during or after D_2, but before significant temperature decrease. K, Cl, CO_2 and B were added, and Ca and Na removed during this event, probably by metamorphic fluids selectively channelled through the shear zone. The Co (± W,Cu,Ni,Au,REE) mineralization at Mount Cobalt was interpreted to have also formed during this event.

The most detailed study of regional metamorphism in the Kuridala-Selwyn region is that of Jaques *et al.* (1982). They dealt with the whole southeastern part of the Mount Isa Inlier, and determined broad pressure and temperature constraints on the prograde phase of metamorphism for this region. Using mineral assemblages in pelitic rocks they identified three broad prograde metamorphic "zones":

Zone A: low-grade (biotite) zone, corresponding to upper greenschist-lower amphibolite facies grade; dominantly in the Staveley Formation;

Zone B: andalusite-almandine-staurolite zone, of amphibolite facies grade; incorporates all the remainder of the Kuridala-Selwyn region; and

Zone C: sillimanite + K-feldspar zone (upper amphibolite facies grade); largely along the southeastern extremities of the Mount Isa Inlier.

They interpreted peak metamorphism to have occurred during the event then regarded as D_1, but now identified as D_2. In the Kuridala-Selwyn region they obtained maximum temperatures of 550 to 600°C in the Maronan Supergroup, and 450 to 550°C in the Staveley Formation. Maximum pressures were estimated to be between 300 and 400 MPa. Jaques *et al.* (1982) noted that prograde mineral assemblages indicated a medium-pressure facies series. They did not report any syntectonic metasomatism.

Microstructural studies relating the growth of metamorphic minerals to the evolution of the structure have been performed locally in and around the ironstones at Starra (Switzer, 1987; White, 1989). Switzer (1987) observed a steep metamorphic gradient across the Starra Shear, and subsequently revised the zone boundaries of Jaques *et al.* (1982) to be parallel to, and strongly telescoped across the Starra Shear. He showed that the Double Crossing Metamorphics underwent higher grade (sillimanite zone) metamorphism than was previously recognized, and suggested this unit reached peak grade earlier in the thermal history. White (1989) did detailed microstructural studies specifically within the Western Ironstone, and confirmed that these lithologies formed late during D_2. Both he and Switzer (1987) recognized a late

D_2 metasomatic event, of which ironstone formation was a part, involving introduction of K, Si and B (as tourmaline), and at least local redistribution of Fe.

3.3 STRUCTURE IN THE KURIDALA-SELWYN REGION

3.3.1 Rationale

Three major ductile and at least one major brittle (faulting) events are now recognized in the Kuridala-Selwyn region. Other minor events are apparent, but these do not affect the overall regional geometry. Details are obscured in many instances by alluvial cover, deep weathering, or dissection by faults. The sequence and styles of events are nonetheless regarded to be correct.

This study has identified another large, layer-parallel high strain zone (herein named the Selwyn Shear) to the east of the Starra Shear, located around the boundary between the Staveley Formation and the Maronan Supergroup (Figure 3.2). It also formed prior to folding, as shown by evidence preserved in the macro- and microscopic features of the fold structures. The (interpreted) D_2 event will therefore be described first, and the evidence leading to the interpretation of an earlier event documented. The characteristics of the deformation events are summarised in Table 3.1.

3.3.2 D_2 - Regional north-south folding

The dominant structures in the Kuridala-Selwyn region are slightly reclined, tight to isoclinal folds. Axial planes are rarely directly observed, instead being located using fold vergence changes and reversals in stratigraphic sequence. Orientations of large-scale axial planes and fold axes are believed to be similar to those of small-scale folds of the same generation, or to the associated foliation and bedding-cleavage intersection lineation, respectively. Regional folds are thus interpreted to have steeply east-dipping, north- to north-northeast-striking axial planes, and both north- and south-

TABLE 3.1: Characteristics of main deformation events recognized in the Kuridala-Selywn region.

DEFORMATION EVENT	STYLE	PRESERVATION AT MESO- TO MICRO-SCALE	ORIENTATION
D_1	layer-parallel shear zones up to 2000 metres thick, along and around contact between major stratigraphic units	phacoidal mélange; inclusion trails in syn-metamorphic porphyroblasts; strain shadows and zones of incomplete S_2 crenulation reactivation in schistose matrix	bedding-parallel; generally steeply east-dipping, folded around D_2 structures; originally subhorizontal
D_2	tight to isoclinal, inclined folds; wavelength varies from several thousand metres to several centimetres, depending on competency of host rocks	pervasive, differentiated to slaty foliation; main fabric developed in rocks (other than bedding)	steeply east-northeast to east-southeast dipping axial planes
D_3	open rounded folds with wavelength of tens to hundreds of metres (depending on competency of rock type), occurring in bands up to 1000 metres wide, separated by several thousand metres; causes local reorientation of steeply dipping bedding and S_2 foliation to shallow orientations	angular to rounded crenulations with wavelengths of several mm developed in S_2 foliations; also development of late (retrogressive) metamorphic minerals such as biotite parallel to foliations	north-northwest striking, subvertical axial planes; variably north to south, generally shallowly plunging fold axes
D_4	narrow bands (less than a few tens of metres?) of crenulations developed locally in the Starra Shear in strongly foliated chloritic schists between ironstones of the Staveley Formation and Double Crossing Metamorphics	local development of open crenulations with wavelengths of a few tens of mm, or less	S_4 foliation dips shallowly to moderately to the southwest, and L^2_4 intersection lineation plunges similarly
D_5	major late-tectonic, layering and foliation sub-parallel fault zones; *e.g.* Mount Dore Fault Zone, Hampden Fault Zone, Answer Fault	marked by localized breccias, and extensive alteration in places (mainly quartz); sites of breccia-hosted base±precious metal mineralization	steeply to moderately east-northeast to east-southeast dipping; sub-parallel with regional "grain" of the rock

plunging fold axes, with a slight predominance of the former (Figures 3.2, 3.3, 3.4).

The scale of folding ranges from megascopic to microscopic, and is strongly dependent on the lithologies in which it is developed. Rocks in the eastern part of the region are mainly coarse-grained, thickly bedded quartzofeldspathic and siliciclastic psammites of the Llewellyn Creek Formation and New Hope Arkose. The megascopic structures here have wavelengths of between one and two kilometres, and small-scale folds are generally not developed. Typical examples are the Mort River Syncline and New Hope Anticline. Lithologies towards the western extremity of the Soldiers Cap Group become progressively finer-grained and more pelitic. The wavelengths of megascopic structures decrease to less than one kilometre, although at Kuridala the Hampden Syncline is somewhat larger. Small-scale, intraformational folds with well-developed axial-plane foliations become more abundant, particularly in the very fine-grained pelites and carbonaceous slates of the Toole Creek Volcanics. Micro- and meso-scale folds are less common in Staveley Formation lithologies, but megascopic structures are present, and these have wavelengths of at least one kilometre (*e.g.* Belgium Syncline west of Mount Elliott).

Where unequivocal younging evidence is available, these folds are demonstrably upward-facing[1]. D_1 structures therefore do not manifest themselves in large-scale overturning of stratigraphy. Their existence is clearly demonstrated, however, using macroscopic and microscopic evidence.

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[1] The *facing* of a fold is defined as the component of the younging direction on either limb measured parallel to the fold axial plane, and perpendicular to the fold axis. When this vector points above the horizontal, a fold is said to be *upward-facing*. If it points below the horizontal, the fold is *downward-facing*. The younging direction is only parallel to the facing in the unique case of bedding lying in the axial plane of the fold.

FIGURE 3.2: Map showing the interpreted distribution of major regional structures in the Kuridala-Selwyn region. Interpretations in the Gin Creek Block (dominated by Double Crossing Metamorphics and Belgium Granite) are those of Switzer (1987). Regional structure in the Limestone Creek area, and the region south of Mount Elliott is interpreted from mapping during this study. Structures north of Mount Elliott are interpreted from mapping by the AGSO (see, for example Donchak *et al.*, 1983), and on extrapolation of interpretations from this study.


KEY TO GEOLOGICAL SYMBOLS
D2 fault
geological contact; observed, inferred
quartzite marker unit (meta-arenite or mylonite)
bedding or S2 foliation trends
D1 shear zone
F antiform, synform
F antiform, synform
late tectonic fault; observed, inferred
coincident F2 axial plane and late fault
bedding; younging known dipping, vertical, overturned
bedding; younging unknown dipping, vertical
S2 orientation; dipping, vertical
S3 orientation; dipping, vertical
S4 orientation; dipping, vertical
L1 1 mineral lineation
L2 2 mineral lineation
L2 0 intersection lineation
L3 0,2 intersection lineation
younging (stem points up-sequence)
mine or prospect
KEY TO LITHOLOGICAL UNITS
Late to post-tectonic granitoids
Amphibolite (metadolerite or metabasalt)
MARY KATHLEEN GROUP
Pkg Agate Downs Siltstone
Pks Staveley Formation
Pka Answer Slate
Pmm Mitakoodi Quartzite
MARONAN SUPERGROUP
Pon/Pot Undifferentiated Toole Creek Volcanics and Mount Norna Quartzite
Pot Toole Creek Volcanics
Pon Mount Norna Quartzite
Pol Llewellyn Creek Formation
Poh New Hope Arkose
Plm Double Crossing Metamorphics
0 5 kilometres
N
CLONCURRY
CLONCURRY FOLD BELT
KURIDALA
SELWYN
0 10 km
140°25'
140°30'
140°20'
21°15'
21°20'
21°25'
21°30'
21°35'
21°40'
21°45'
21°50'
WIMBERU GRANITE
SILVER PHANTOM Ag
SHEAR
STRAIGHT EIGHT FAULT
MOUNT TRACEY FAULT
ZONE
HAMPDEN Cu,Au
HAMPDEN CONSOLS Cu,Au
HAMPDEN Q Cu,Au
KURIDALA
HAMPDEN SYNCLINE
HAMPDEN FAULT
KURIDALA
SQUIRREL HILLS GRANITE
TWIGGIE VOUS Cu
TIP TOP Cu
LABOUR VICTORY Cu,Au
SELWYN
ANSWER FAULT
SELWYN
SELWYN
MT. ELLIOTT Cu,Au
SWAN Cu,Au
LIMESTONE CREEK Au,Cu
BELGIUM SYNCLINE
SHEAR
LADY ELLA Cu
BELGIUM Cu
MOUNT DORE GRANITE
ZONE
STARRA SHEAR
ANTIFORM
BELGIUM GRANITE
ANSWER FAULT
ANSWER Cu
MT. DORE Cu, Ag
MARILYN Cu
STARRA Au,Cu
MARIPOSA U
NEW HOPE W
SYNCLINE
ANTICLINE
RIVER
MOUNT COBALT Co,W
NEW HOPE
MORT
MOUNT
STUART Cu
MOUNT THOMAS Pb,Zn
YELLOW WATERHOLE GRANITE
Pmm
Pka
Pks
Pkg
Pon
Pot
Pon/Pot
Pol
Poh
Plm

FIGURE 3.3: Polar and contoured polar equal area stereoplots of foliation data. (a,b) Poles to bedding (S_0); (c,d) Poles to S_2; (e,f) Poles to S_3.

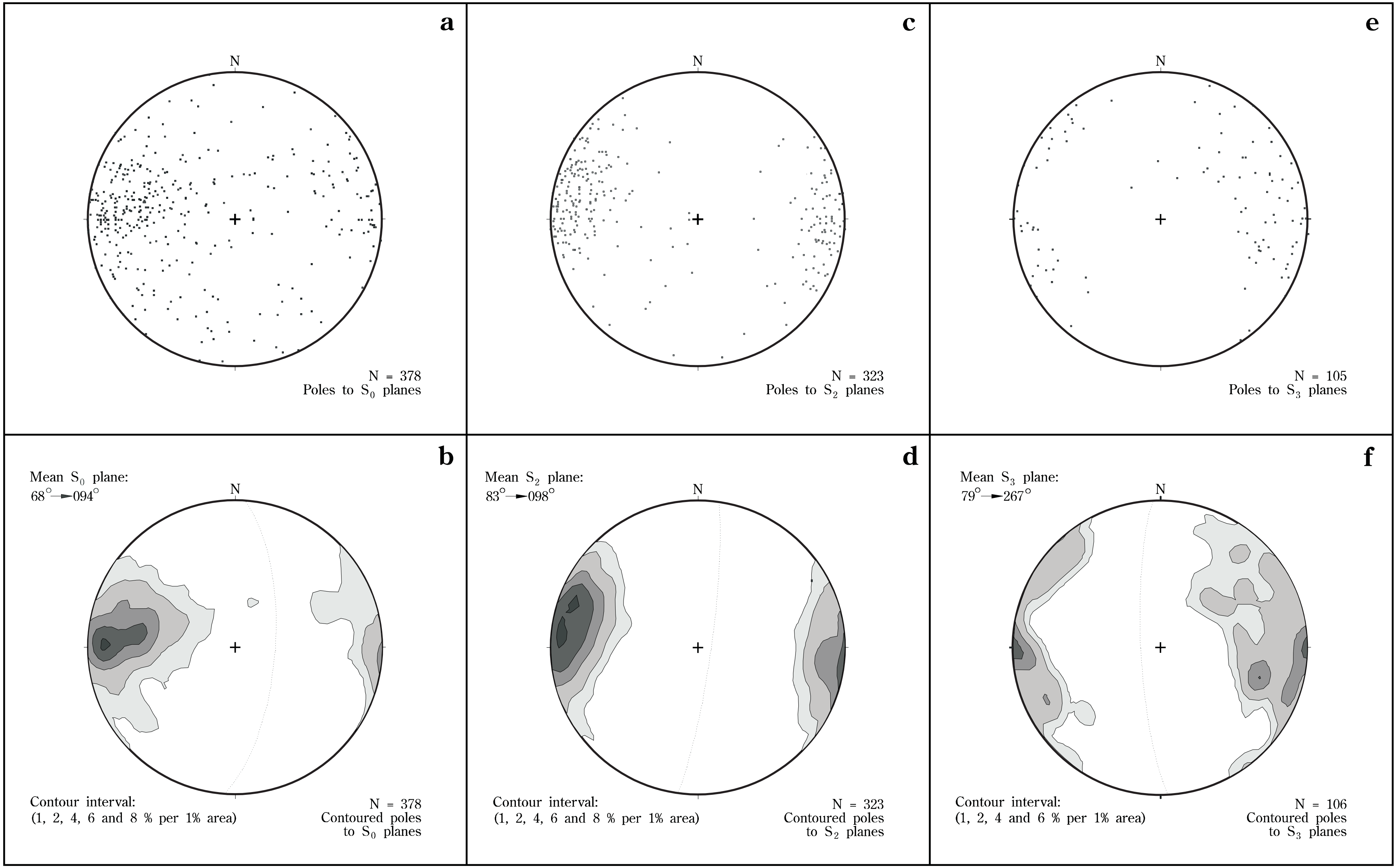
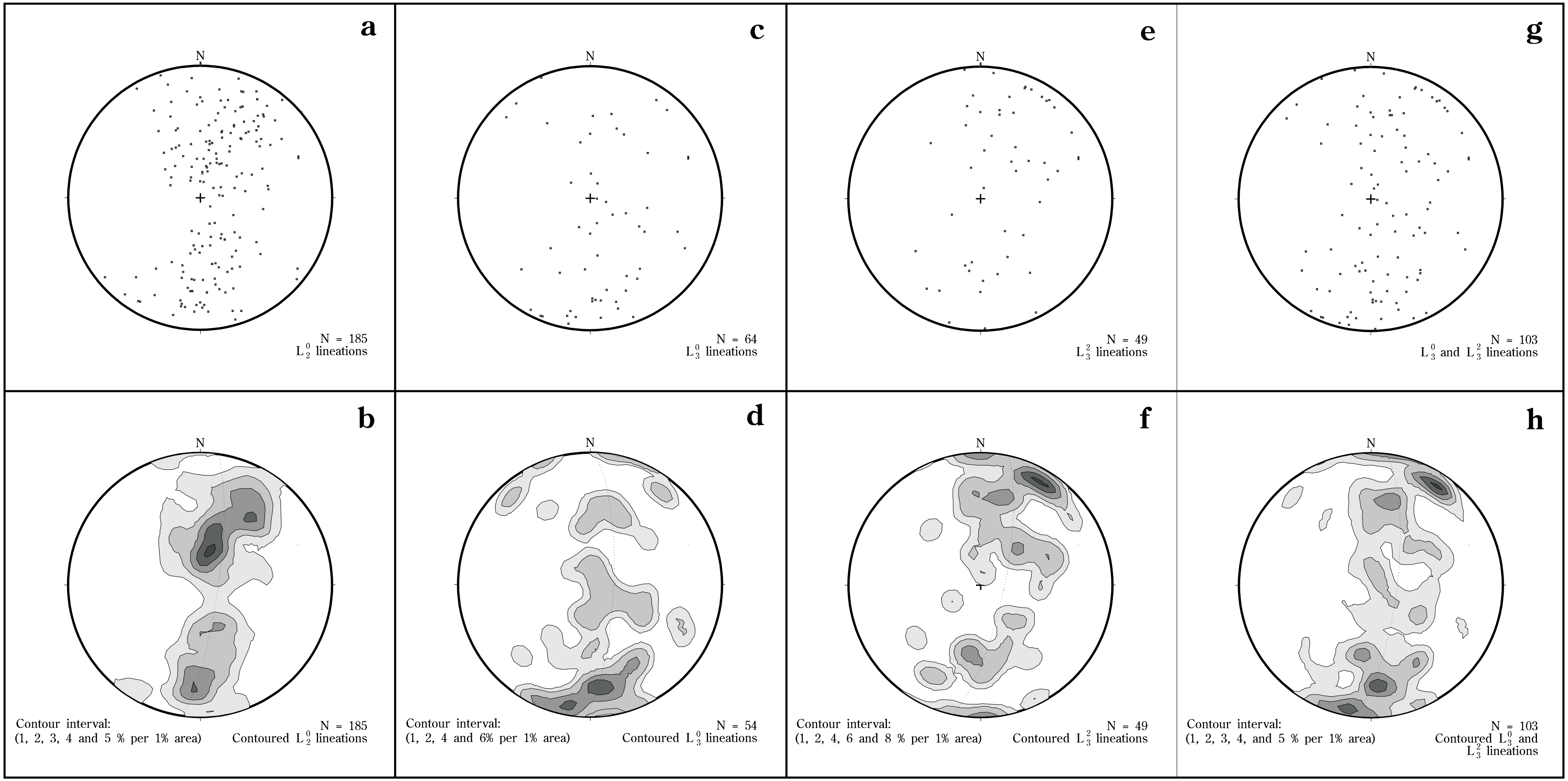

a
N
N = 378
Poles to S0 planes
c
N
N = 323
Poles to S2 planes
e
N
N = 105
Poles to S3 planes
b
Mean S0 plane:
68° → 094°
N
Contour interval:
(1, 2, 4, 6 and 8 % per 1% area)
N = 378
Contoured poles
to S0 planes
d
Mean S2 plane:
83° → 098°
N
Contour interval:
(1, 2, 4, 6 and 8 % per 1% area)
N = 323
Contoured poles
to S2 planes
f
Mean S3 plane:
79° → 267°
N
Contour interval:
(1, 2, 4 and 6 % per 1% area)
N = 106
Contoured poles
to S3 planes

FIGURE 3.4: Linear and contoured linear equal area stereoplots of lineation data. (a,b) L_2^0 intersection lineations; (c,d) L_3^0 intersection lineations; (e,f) L_3^2 intersection lineations; (g,h) combined L_3^0 and L_3^2 intersection lineations.


a
N
N = 185
L_2^0 lineations
b
N
Contour interval:
(1, 2, 3, 4 and 5 % per 1% area)
N = 185
Contoured L_2^0 lineations
c
N
N = 64
L_3^0 lineations
d
N
Contour interval:
(1, 2, 4 and 6% per 1% area)
N = 54
Contoured L_3^0 lineations
e
N
N = 49
L_3^2 lineations
f
N
Contour interval:
(1, 2, 4, 6 and 8 % per 1% area)
N = 49
Contoured L_3^2 lineations
g
N
N = 103
L_3^0 and L_3^2 lineations
h
N
Contour interval:
(1, 2, 3, 4, and 5 % per 1% area)
N = 103
Contoured L_3^0 and L_3^2 lineations

Macrostructural evidence

Macrostructural evidence that the major folds in the region are at earliest D_2 in age is by itself inconclusive, yet strongly suggestive. It comes from analogy with structural styles further west, from the distribution of strain throughout the region, and from anomalous contact relationships.

The dominant folds and their associated fabrics in the Kuridala-Selwyn region have a style and orientation similar to D_2 structures identified by Bell (1983) and Winsor (1983, 1986) in the western part of the Mount Isa Inlier, suggesting they developed during the same deformation event.

"Corridors" of high strain at least one kilometre thick have been identified, wherein an intense mylonitic schistosity is present and bedding is generally obliterated or strongly transposed (Figure 3.2, 3.5). The Starra Shear identified by Switzer (1987) is one of these. This structure is folded around the Gin Creek Antiform, and is now known to extend into the Limestone Creek region. Metabasalts and adjacent metasediments of the Staveley Formation within this shear zone are strongly foliated.

The other major high strain zone, herein termed the Selwyn Shear, occurs around the boundary between the Soldiers Cap Group and Staveley Formation. The distinctive ridge-forming quartzite along this boundary in the Selwyn region is finely banded along much of its length, with a strong, down-dip mineral streaking developed in the banding. The banding in the quartzite is defined by alternating layers generally less than 1 mm wide of fine (≤ 0.03 mm) and relatively coarse (0.3 mm) crystalline quartz, with minor muscovite and, in the more carbonaceous units, dark graphitic(?) material (Figure 3.5a-d). Transposition of the layers is occasionally observed. This texture is probably originally mylonitic, although extensive recrystallization has occurred. The quartzite is repeated about the Mariposa Anticline and Pyramid Syncline.

FIGURE 3.5: Field and microscopic characteristics of the Selwyn Shear: (a) strongly silicified mylonitic carbonaceous slate, with an intense down-dip streaking, interpreted to be (reactivated?) L^1_1; view looking approximately southwest; geology hammer for scale (centre) is 32 cm long (location: 54K VA466975); (b) close-up view of a foliation surface at the site in (a), showing intense mineral streaking (labelled L^m_m); view looking west; lens cap diameter is 55 mm; (c) photomicrograph the typical textural characteristics of the quartzite along the boundary between the Soldiers Cap Group and Staveley Formation; alternating bands of coarse and fine granoblastic quartz suggest an annealed mylonitic fabric; section is cut parallel to L^m_m and perpendicular to S_m; sample JCU-29868 (location: 54K VB473177); crossed nicols (XPL); (d) similar texture in siliceous (silicified?) carbonaceous slate, showing "wispy" nature of carbonaceous material; similar section orientation to (a); sample JCU-29859 (location: 54K VB480188); plane polarized light (PPL); (e) transposed layering in Staveley Formation lithologies caught in the Selwyn Shear; lens cap diameter is 55 mm (location: 54K VA455956); (f) outcrop charactersitics of the phacoidal mélange in the Selwyn Shear; lens cap diameter is 55 mm (location: 54K VB435225); (g) photomicrograph of the fabric in the phacoidal mélange; section orientation as per (c) and (d); sample JCU-29840 (location: as per (f)); PPL.

FIGURE 3.5: