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The structural and metamorphic geology of the Ebagoola 1:250 000 sheet (SD54–12), Coen Inlier, Cape York Peninsula
Record 1992/67

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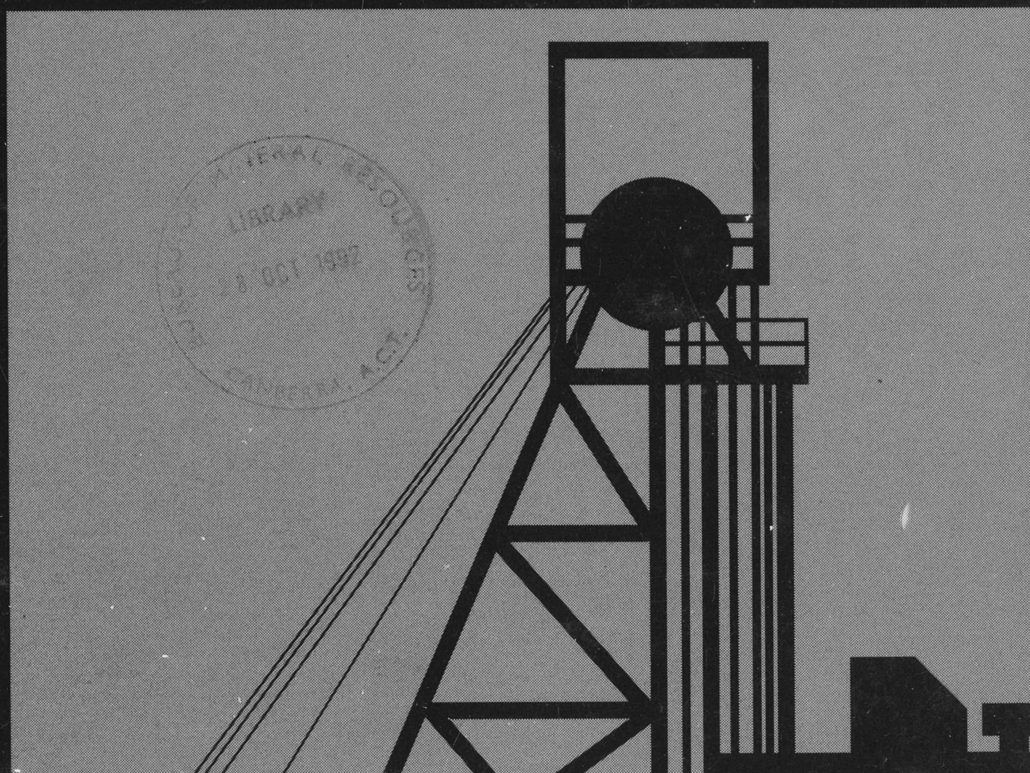

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R S Blewett

MINERALS AND LAND USE PROGRAM
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Minerals and Land Use Program

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister for Resources: The Hon. Alan Griffiths
Secretary: G.L. Miller

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION
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ABSTRACT

In the Ebagoola 1:250 000 sheet area (EBAGOOLA) four phases of penetrative, regional deformation for the Coen Inlier have been recognised. In the model described, the Coen Inlier is a Proterozoic belt dominated by early Devonian transpressional orogenesis which extends 110 km west from the Palmerville Fault Zone. There are number of major groups of metamorphic rocks:– the Holroyd Group comprising the Lukin and Kalkah Structural Domains, the Edward River Metamorphic Group, the Coen Metamorphic Group and the Newberry Metamorphic Group. The Coen Metamorphic Group is separated from the Holroyd Group and the Newberry Metamorphic Group by Siluro-Devonian granites of the Cape York Peninsula Batholith (CYPB).

D1 structures are widespread but difficult to recognise in the metamorphics. These structures were probably upright and E-W trending; the age of this deformation and associated metamorphism can only at present be established as earlier than Devonian.

The second phase or D2 event (Coen Orogeny) was the climax of deformation and metamorphism which was associated with the emplacement of the Siluro-Devonian CYPB. The NNW-trending D2 fabric and subsequent shearing dominate the distribution of rock types and the orientation of meso and macroscopic structures throughout EBAGOOLA, and most of the Coen Inlier. Major shearing subparallel to the NNW-trending D2 strike occurred along the margins of the CYPB during its emplacement, and this shearing (principally sinistral oblique-slip) continued after solidification of the batholith along the Coen, Ebagoola and Lukin River Shear Zones. These shear zones are of low metamorphic grade (biotite) and they overprint the CYPB.

D3 structures are widespread and include mesoscopic folding and associated crenulation of earlier fabrics. F3 folds are tight, trend N-S, dip steeply and have steep N, and less common S-plunges. The S3 crenulation is characterised by retrogressive muscovite and biotite growth and is generally more obvious in hand specimen than the S2 crenulation of S1. D3 structures overprint the S-C mylonites of the major shear zones.

D4 structures are seen as NE to E-trending folds with associated weak crenulation foliations. Most D4 structures are meso-scale, but macro-scale folding does occur.

EBAGOOLA provides a window across a Proterozoic margin that was reworked during the Devonian Coen Orogeny along a transpressive margin, or mobile belt.

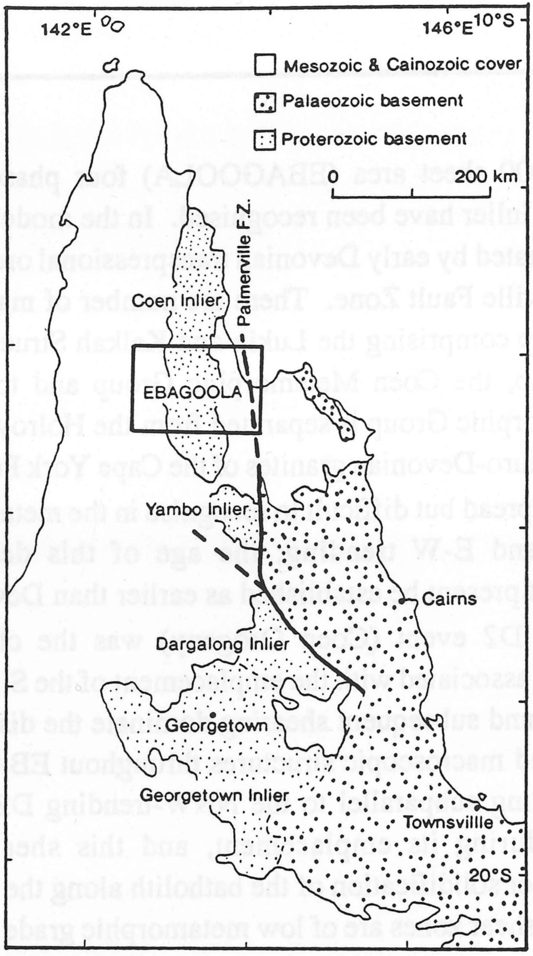


Figure 1. The four Proterozoic Inliers in North Queensland. The Ebagoola 1:250 000 sheet (EBAGOOLA) is outlined.

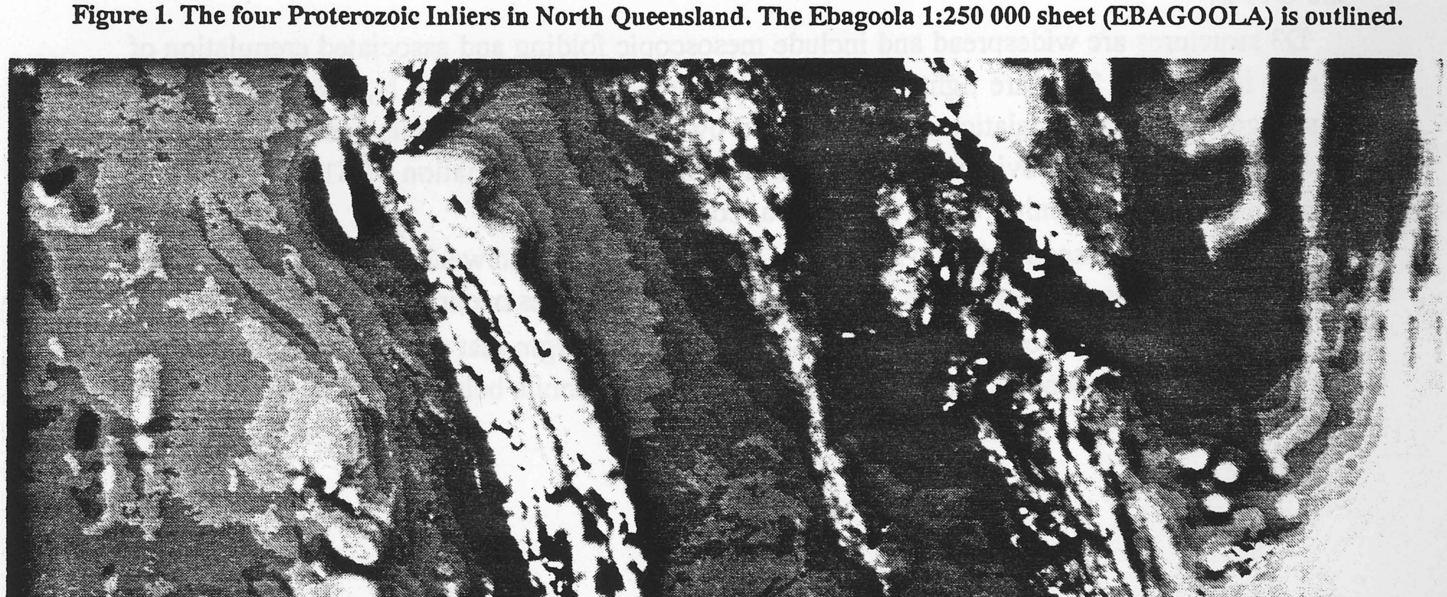


Figure 2. Easterly illumination of the total magnetic intensity (TMI) for EBAGOOLA.

INTRODUCTION

The Ebagoola 1:250 000 sheet area (EBAGOOLA) lies in Cape York Peninsula, north Queensland between latitudes 14°S and 15°S (Fig. 1) with COEN to the north and HANN RIVER to the south also covering large parts of the Coen Inlier. The terrain ranges from sea level to 450 m above sea level. Access is provided by the main Peninsula Developmental Road, an all-weather gravel road that links Cairns (some 500 km SSE) with Weipa (255 km NW) and the tip of Cape York Peninsula. Coen airport, 20 km north of Coen town, is served by regular flights from Cairns.

Other access is provided by minor station tracks that lead off the Peninsula Developmental Road and by a limited number of very rough and largely overgrown exploration tracks. The bush, ranges from rain forest to open scrub, is generally too dense to drive cross-country and most traverses were done on foot. A track map for the Coen Inlier is given by Trail and Blewett (1991).

In the centre of EBAGOOLA, the metamorphic rocks (particularly schist and quartzite) form the high ground and narrow NNW-trending ridges that are bevelled at around 400 m (Pain & Wilford, 1992), while the granites occupy the poorly exposed low relief regions between the ridges. The Great Dividing Range (Pain & Wilford, 1992) runs roughly north-south; bounding the eastern third of EBAGOOLA. East of this is a wide coastal plain that is covered by alluvium and sediments of the Laura Basin (see Pain & Wilford, 1992). The western quarter of EBAGOOLA comprises Mesozoic sedimentary rocks of the Carpentaria Basin which have low topographic relief except for a few mesas (see Pain & Wilford, 1992).

Most of the geological mapping was compiled on 1:50 000 scale colour aerial photography flown in 1991. The most northerly 15 km of EBAGOOLA, due to poor flying weather, were not flown in 1991. The geology of this area was compiled upon 1:84 000 scale RC9 (panchromatic) photography. Some 1:20 000 scale, colour photography over the NE part of the Ebagoola 1:100 000 sheet was also used. Royal Australian Survey Corps topographical maps of the 1:100 000 series for the Ebagoola, Strathburn, Strathmay, Princess Charlotte Bay, Marina Plains and Kalkah (7569, 7469, 7468, 7669, 7659 and 7568) sheets were used as base maps. Site positioning was by the Pro Nav Global Positioning System (GPS) using hand-held and vehicle-mounted receivers.

The four Proterozoic (?) Inliers in north east Queensland from south to north are the Georgetown, Dargalong, Yambo and Coen Inliers (Fig. 1). The metamorphic and igneous rocks of EBAGOOLA occupy the southern central part of the Coen Inlier (Fig. 1). The Coen Inlier was thought by many (cf. Henderson 1980; Withnall et al., 1980; Bain et al., 1990) to be the northern extension of the largely Proterozoic Georgetown Province to the south (Fig. 1), but this has recently been questioned by Blewett & von Gnielinski (1991a) on structural grounds, and consideration of other data sets gathered in 1991 (see BMR Research Newsletter 16) has reinforced these doubts.

The exposed part of the Coen Province is elongated north-south, and is over 270 km long and up to 50 km wide. The concealed eastern margin is defined by the extension or splay of the Palmerville Fault Zone (Wellman, 1992) and is covered by sediments of the Laura Basin, while the western margin becomes progressively less affected by the Palaeozoic reworking for a distance of about 110 km (Wellman, 1992), and forms the basement to the Carpentaria Basin. The Palmerville Fault Zone defines a "fundamental" structure (de Keyser, 1963) as it separates Proterozoic metamorphics and Palaeozoic granites to the west, from the Palaeozoic Hodgkinson Province to the east. A major structure running in a NW direction as a splay of the Palmerville

Fault Zone, separates the Coen and Yambo Inliers from the Georgetown and Dargalong Inliers (Wellman, 1992). This also reflects a change in Palaeozoic granitoids from predominantly S-type in the north to I-type in the south.

Most of the structural data outlined in this report result from a study of the metamorphic rocks of EBAGOOLA. Data on various stereographic projections (shown later) was derived from field work by Richard Blewett and Dave Trail (AGSO) and Friedrich von Gnielinski (GSQ). The metamorphic rocks crop out in three principal, NNW-oriented belts that are separated by granites of the Cape York Peninsula Batholith or CYPB (Willmott et al., 1973; Mackenzie & Knutson, 1992).

The metamorphic rocks of EBAGOOLA were first described in detail by Trail et al., (1968), who divided them into the Holroyd and Dargalong Metamorphics to the west and east respectively. The Holroyd Metamorphics were subdivided into the Kalkah-type, Lukin-type, Pollappa-type and Pretender-type schists and the Dargalong Metamorphics into the Arkara-type gneiss and the Pombete-type schist (Trail et al., 1968). These subdivisions were not published in the final BMR Bulletin (Willmott et al., 1973) except as a figure (cf. Willmott et al., 1973 - Fig. 41) nor in the first edition EBAGOOLA geological map (Whitaker & Gibson, 1977a). The name Dargalong Metamorphics was maintained in the Yambo Inlier to the south (Fig. 1), but they were renamed the Coen Metamorphics (Willmott et al., 1973) for the rocks in the east of EBAGOOLA.

The distribution of rock types in EBAGOOLA is well illustrated by the total magnetic intensity (TMI) image (Fig. 2). The image shows the Palmerville Fault Zone as a broad band of low amplitude, N-S trending features; the metamorphic rocks as zones of high magnetic relief with a prominent NNW-trending fabric; and the CYPB granites between as areas of low magnetic relief. Ring structures of ?Carboniferous acid igneous rock are found in the SW (Fig. 2).

Figure 3 is a simplified map of the basement geology showing the distribution of major rock types and groups as well as structural domains.

STRATIGRAPHY

The stratigraphy of the metamorphic rocks has been redefined and is described by Blewett et al. (1992), and the Cape York Peninsula Batholith (CYPB) is described by Mackenzie & Knutson (1992).

The name Holroyd Metamorphics is replaced by Holroyd Group and the Coen Metamorphics are restricted to the central pendant of metamorphic rock in EBAGOOLA as the Coen Metamorphic Group. The Edward River Metamorphic Group and the Newberry Metamorphic Group are new names that are defined by Blewett et al. (1992).

The Edward River Metamorphic Group is poorly exposed on the western edge of the outcropping part of the Coen Inlier. They were formerly included in the Holroyd Metamorphics (Willmott et al., 1973). The group is divided into three domains based on their geophysical character (Wellman, 1992), with the eastern domain being subdivided into two formations.

The Holroyd Group is divided into two structural domains — the Lukin and Kalkah Structural Domains. Nine formations totalling not less than 10 km of section have been defined in the Lukin Structural Domain and these have been correlated with their more deformed and metamorphosed variants in the Kalkah Structural Domain. The Kalkah Structural Domain is

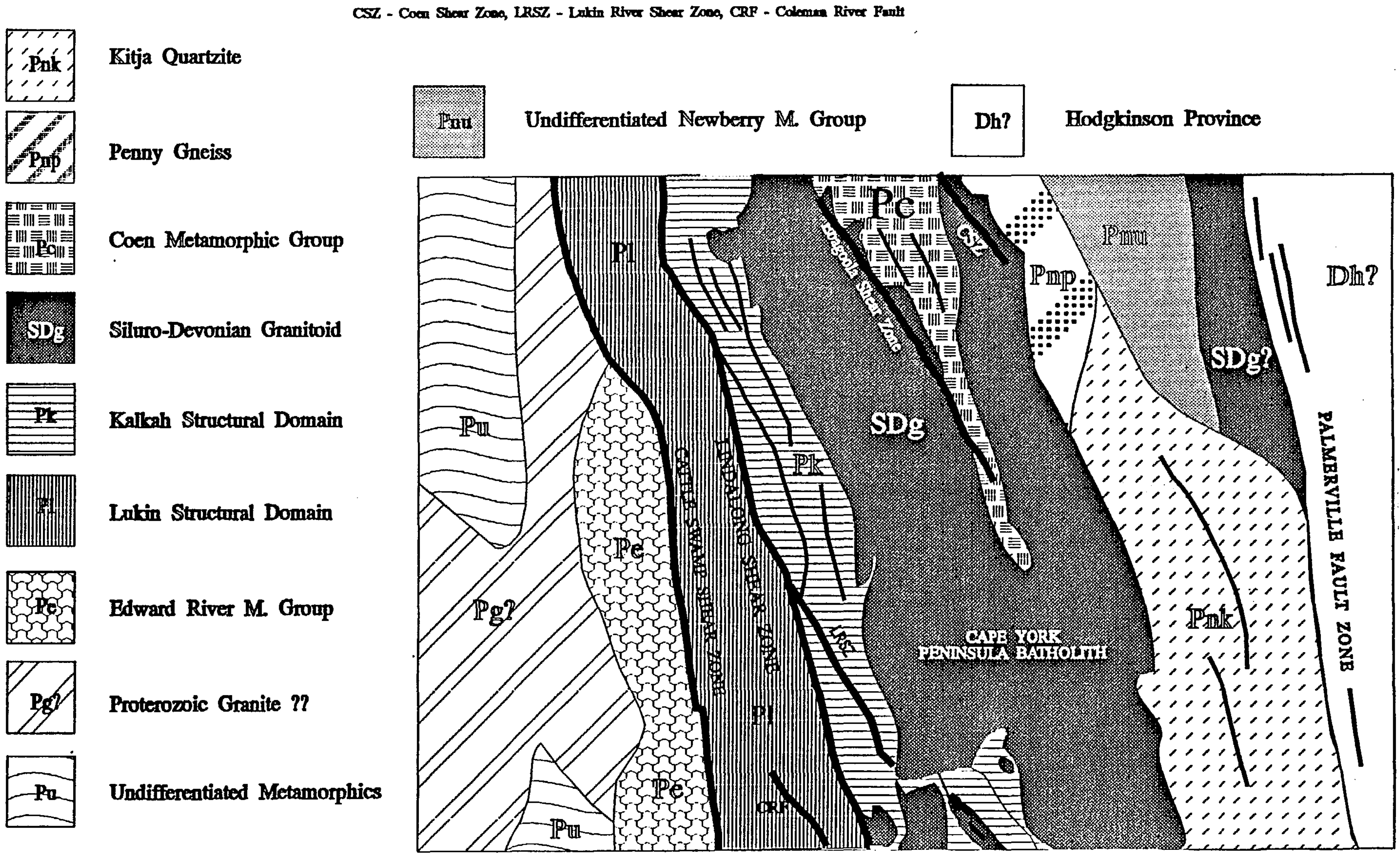


Figure 3. Schematic distribution of major rock groups in EBAGOOLA.

divided into four shear zone (D2b&c) bounded subdomains which repeat elements of the stratigraphy.

The Coen Metamorphic Group is restricted to the central belt of metamorphic rocks in EBAGOOLA. This belt is the type area of "Coen Metamorphics" that was originally defined by Willmott et al. (1973). The group is divided into four units of formation status.

The Newberry Metamorphic Group crops out in the east of EBAGOOLA, they were originally correlated with the Dargalong Metamorphics of the Yambo Inlier by Trail et al. (1968), but were subsequently included with the Coen Metamorphics of Willmott et al. (1973). The distribution of the Groups and "Metamorphics" for EBAGOOLA is shown in Figure 3.

STRUCTURAL GEOLOGY

Four phases of penetrative, regional deformation have been recognised in EBAGOOLA (Fig. 4). In the model described below, the area is a Proterozoic belt dominated by Siluro-Devonian transpressional orogenesis that extended 110 km west from the Palmerville Fault Zone (Wellman, 1992). Figure 4 is a simplified, 2D fabric-element sketch combined with a a simplified interpretation of the TMI image that can be used as a reference guide to the structural geology.

The first phase of deformation was minor and occurred before the emplacement of the Siluro-Devonian CYPB. The D2 phase was the climax of deformation and metamorphism which was associated with the emplacement of the CYPB at about 407 Ma. (Black et al., 1992). The NNW-trending D2 fabric and subsequent faults determine the distribution of rock types and the orientation of meso and macroscopic structures throughout the sheet, and most of the Coen Inlier. Major shearing subparallel to the NNW-trending D2 strike occurred along the margins of the CYPB during its emplacement, and this shearing (principally sinistral oblique-slip) continued after solidification of the batholith. The magnetic and structural character of the various rock types was used to define a number of fault-bounded structural subdomains. The distribution of the domains is shown in the various stereoplots for each phase of deformation; they include the Coleman (incorporating the Lukin Structural Domain), Pollappa (incorporating most of the Kalkah Structural Domain), Lucy (incorporating the eastern Subdomain 4 of the Kalkah Structural Domain), Crystal Vale (incorporating the northern part of the Kalkah Structural Domain), Coen (incorporating the Coen Metamorphic Group) and the Lilyvale Structural Subdomain which incorporates the Newberry Metamorphic Group.

First Deformation (D1)

D1 structures are widespread but difficult to recognise in the metamorphic units. D1 structures were probably upright and E-W trending (as seen by D1 sheet dips or enveloping surfaces); the age of deformation is not known. Figure 5 is a stereoplot of D1 structural elements, the NNW D2 overprint is apparent.

F1 Folding

D1 structures are best seen in the lower grade, and least deformed units of the Lukin Structural Domain in the west of the Holroyd Group. Here the style of deformation is one of tight to isoclinal, variably plunging F1 folds with an axial planar S1 slaty cleavage. Fine examples of F1 folding may be found in the low-grade Newirie Formation north of Astrea Holdings Homestead. Here,

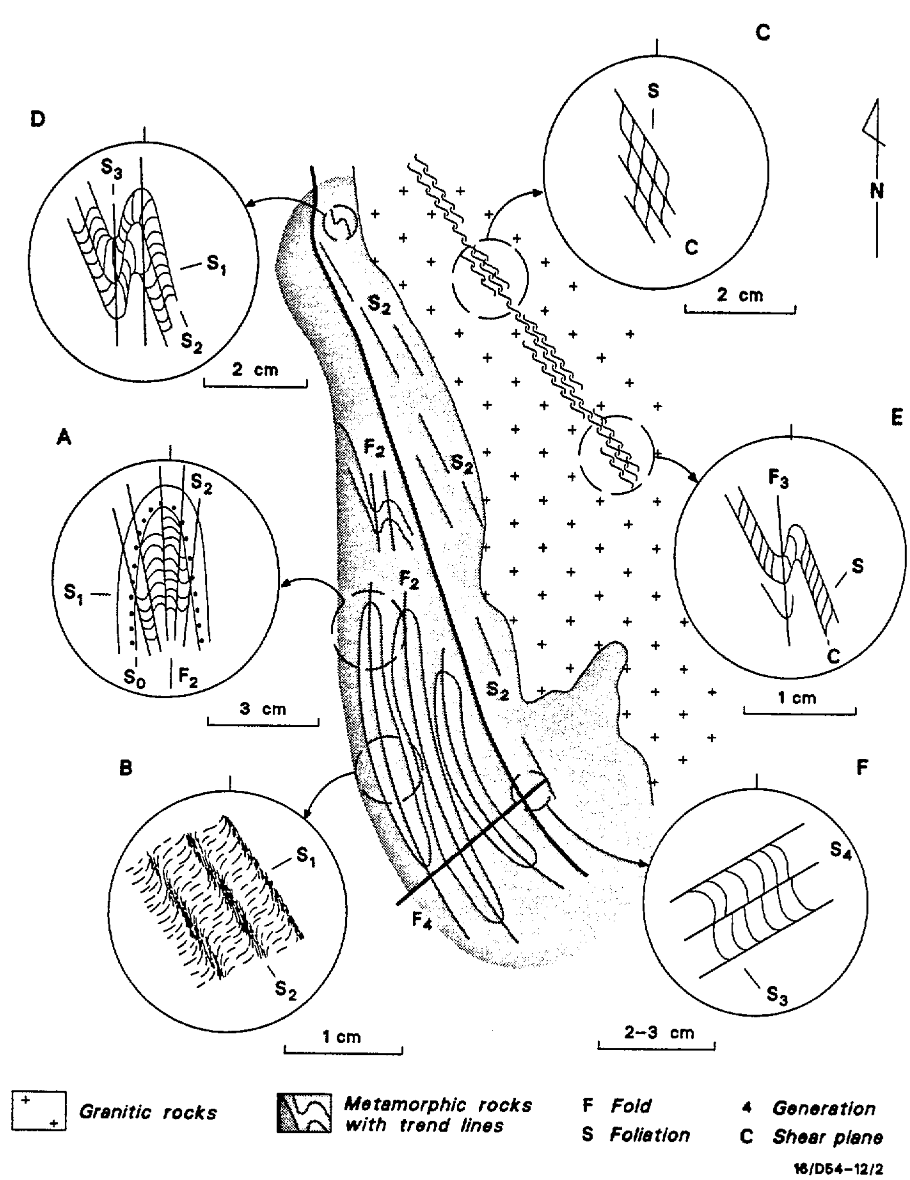


Figure 4. Simplified fabric element sketch of the structural geology of EBAGOOLA. The diagram provides a summary of the deformation history. A – F2 fold closure with axial planar cleavage; B – S2 as a NNW trending crenulation cleavage; C – S-C composite fabrics in mylonitic granites; D – S3 as a coarse, asymmetric N-trending crenulation cleavage; E – F3 folding of S-C mylonites; F – broad, open ENE-trending crenulation by F4.

thin inter-bedded slate and sandy slate are mesoscopically isoclinally folded with axial planar S1 slaty cleavages and hinges that plunge moderately to steeply to the east (91834287). The high metamorphic grade units of the Kalkah Structural Domain and Coen Metamorphic Group to the east suffered intense D2 transposition which obliterated D1 structures.

Some isoclinal F1 folds suffered varying amounts of limb transposition. Locally, F1 folds have a sheath-like geometry indicating that transposition, which is generally considered a D2 or later feature, may be in part a D1 effect. The relationship between the F1 fold axes and L1 lineations is poorly constrained, because not enough have been successfully located.

F1 fold closures are generally difficult to recognize, this is due to their isoclinal nature, transposition, their very high amplitude to wavelength ratios, together with the intensity of overprinting by later generations of deformation. In the gneissic units, especially the Lochs and

Penny Gneiss, fold closures are identified by having the above style, and by the presence of melanosome phyllosilicates aligned parallel to the F1 axial surface (Fig. 6b).

S1 Foliations and Layering

S1 is commonly visible in the Q-domains (quartz) of the S2 crenulation foliation, while rare isoclinal F1 fold closures occur as part of complex fold interference patterns in the gneissic units (Fig. 6b). In other areas of less D2 interference, especially to the west in the Lukin Structural Domain, S1 is clearly visible around hinge zones of tight F2 microfolds. In the low grade slates, or in regions where bedding is visible, the S1 surface is sub-parallel to bedding.

The enveloping surface seen where S1 is little deformed by D2 suggests that it was a steeply dipping, E-W to ENE-WSW trending schistosity prior to being folded by F2. Type II and III fold interference patterns (Ramsay, 1967), coupled with the relatively gentle F2 fold plunge, also indicate that F1 folds were originally shallow plunging and possibly recumbent. The stereonet of S1 shows a scatter, but generally indicates a steeply ENE-dipping foliation (Fig. 5).

Boudinage of leucosome layers and granitoid pods within gneiss and migmatite is common, with discontinuous quartzo-feldspathic layers smeared out and defining the gneissic layering and foliation (S1). Many of these boudins are overprinted by F2 folds.

Second Deformation (D2) — COEN OROGENY (new name)

The abundant and widespread NNW-trending, steeply dipping D2 structures dominate the fabric of the entire sheet area and characterise the climax tectono-thermal event in the Coen Inlier as the Coen Orogeny. D2 structures are associated with climax metamorphism M2, and D2 is therefore pre to syn the Siluro-Devonian emplacement of the CYPB.

Although D2 accompanied granite emplacement in the broad sense (as a product of the thermal pulse that generated the granites), numerous observations show that individual intrusions cross-cut the S2 surface (Fig. 6d). The solid-state foliations (i.e. foliated and mylonitic) in the granite are therefore considered to be D2c surfaces, and are slightly later than the main D2 (a&b) deformation in the progressive development of the Coen Orogeny. D2 and M2 are used in general terms to describe the Coen Orogeny as a whole, while the additional suffixes refer to particular periods of deformation within an evolving deformational event. The suffix "a" is pre-CYPB, "b" is syn-CYPB, while "c" is post-CYPB.

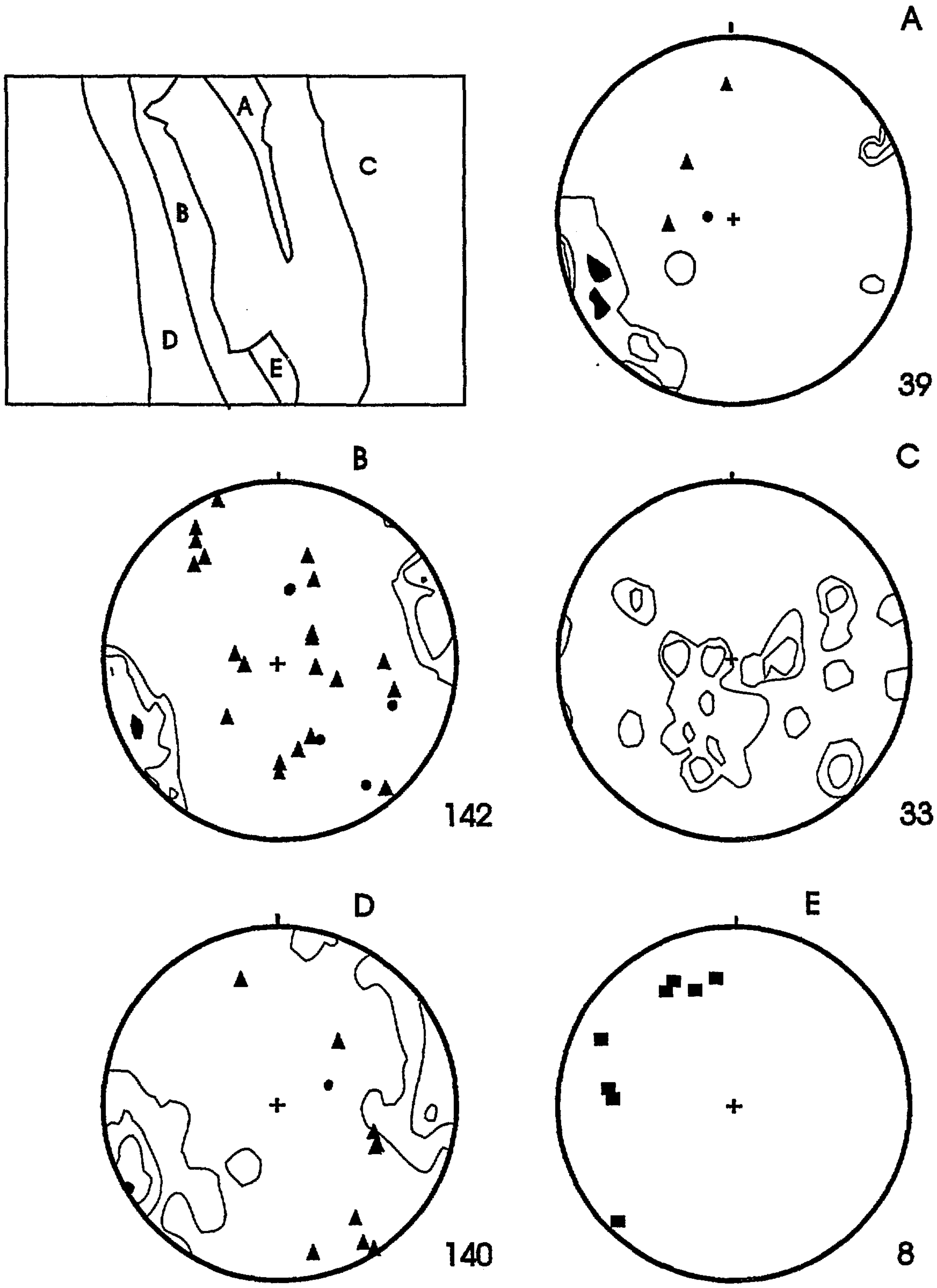
D2a structures are dominated by gently to sub-horizontally NNW-plunging, isoclinal folds with an axial planar S2a schistosity that dips subvertically. The gentle F2a fold plunge and subvertical axial surfaces suggest coaxial deformation at least during fold and foliation development in EBAGOOLA (Fig. 7). D2b structures are NNW-trending, steeply dipping shear zones that are subparallel to, but overprint S2a and probably some of the granites of the CYPB. D2c structures are post the CYPB granites and are steeply dipping and trend NW-SE.

F2a Folds

All F2a folds in the Coen Metamorphic Group are mesoscopic, while F2a folds with kilometre wavelengths occur in the south and west of the Holroyd Group. This general absence of macroscopic folding in the Coen Metamorphic Group could be attributed to the lack of competence contrasts coupled with the intensity of subsequent shearing and/or transposition. The degree of transposition of D2 fabrics and frequency of ductile shear zones increases eastwards towards the Palmerville Fault Zone.

Figure 5
Lower hemisphere equal area stereographic projection of D1 structural elements. Domains A=Coen, B=Pollappa, C=Lilyvale D=Coleman, E=Lucy.

▲ F1 fold axes ■ poles to S1 ● L1 lineations



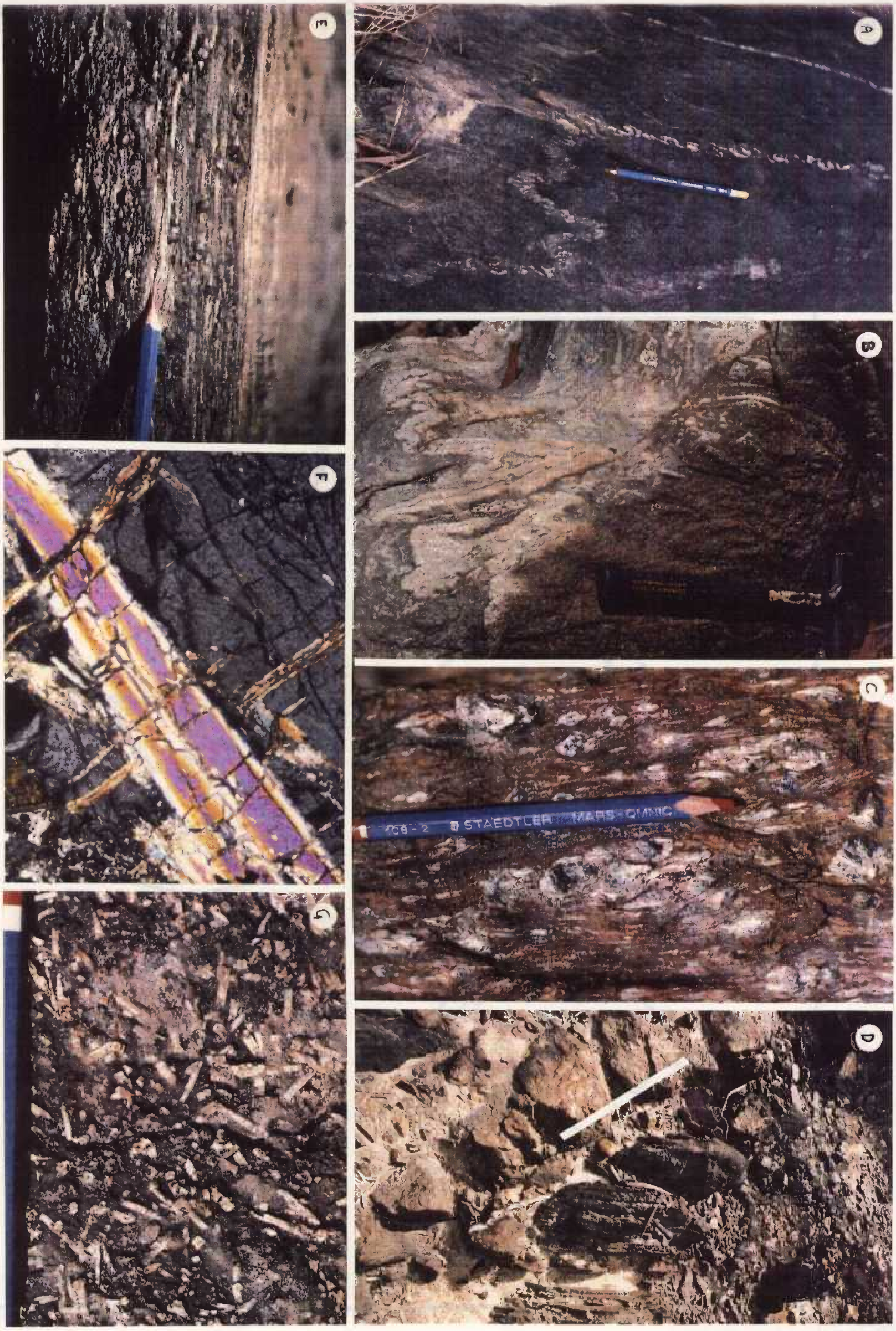

A
B
C
D
E
F
G
STAEDTLER MARS-OMNIC

Figure 6. (opposite page) Plates of mesoscale structures in EBAGOOLA. A) F2 ptygmatic folds in the Strathburn Formation (Pkt) of the Kalkah Structural Domain. B) F1/F2 fold interference in Lochs Gneiss (Coen Metamorphic Group). C) S2 schistosity and andalusite porphyroblasts in the Strathburn Formation (Pki) of the Kalkah Structural Domain. D) S2 schistosity cross-cut by the CYPB (Warner Granite) with contact parallel to white bar. S2 is parallel to the angle of view, the granite contact runs bottom right to top left, with pale-coloured granite to the left (west). E) Asymmetric pressure shadows from sinistral shear on garnet porphyroblasts in Strathburn Formation (Pki) of the Kalkah Structural Domain. F) Cross polarized photomicrograph of high birefringent sillimanite intergrown with andalusite (darker colured) in the Astrea Formation (Pko) of the Kalkah Structural Domain. Field of view 1mm. G) Chiastolite in hornfels of Astrea Formation (Pko) of the Kalkah Structural Domain adjacent to the Lindalong Granite.

F2a folds have steeply dipping axial surfaces, and axial planar S2a foliations that generally trend NNW and have gentle plunges (Fig. 7). The folds are upward facing, although only a few younging directions were observed, and only in the Lukin Structural Domain.

The macroscopic fold trains of the Carew Greenstone and surrounding stratigraphy in the southern Lukin Structural Domain have a slight sense of westward overturning. This sense of overturning, coupled with faulting of syncline/anticline pairs was interpreted by Willmott et al. (1973) as related to west-directed thrusting. These were the only folds shown on the Ebagoola 1:250 000 geological map of Whitaker & Gibson (1977a), and they are clearly visible on the TMI image (Fig. 2). These folds are periclinal with shallow north and south plunging hinges. The Dinah Formation forms the core to these folds and is the lowest stratigraphic level exposed in EBAGOOLA, and probably the Lukin Structural Domain as a whole (i.e. as it extends south into HANN RIVER). This is because the folds begin to plunge to the south at the southern margin of EBAGOOLA and consequently expose progressively higher levels of the Holroyd Group southwards.

Spectacular macroscopic F2 folds are also found in subdomain 2 of the Kalkah Structural Domain. Here, the very thick bedded and competent quartzite of the Gorge Quartzite (Pkp) defines subhorizontal N-plunging F2 antiforms with shear zones transecting the complementary synforms. These shear zones form the NNW to N-trending magnetic troughs typical of the "early" or D2b shear zones that dominate the Kalkah Structural Domain. The Gorge Quartzite is also folded into a macroscopic F2a synform with the Strathburn Formation cropping out in the core. This fold is visible on the aeromagnetic image (Fig. 2) and may be an extension of the large folds to the south that are defined by the Carew Greenstone (discussed above).

In the gneiss outcrops, F2a folds are tight to isoclinal or even ptygmatic (Fig. 6a), they trend NNW to N and overprint isoclinal, variably oriented F1 folds with Type II and III patterns (Ramsay, 1967).

S2a Foliations

S2a is a widespread, steeply ENE-dipping foliation (Fig. 7), and in almost all schists it defines the schistosity (Fig. 6c, d, e). The trend of S2a in the metamorphic rocks is essentially sub-parallel to the solid-state foliation in the granites of the CYPB (see later). The solid-state foliation in the CYPB tends to increase in intensity towards the margins of the batholith and develops into a D2c S-C mylonite (see later).

The S2a foliation is commonly seen as a penetrative schistosity (typically 0.1 mm spacing) with occasional gently plunging lineations, or as an intense crenulation foliation with preserved S1 closures. In the more competent units, S2a may occur as a spaced fracture cleavage and yet interbedded schist is penetrated by S2a as a crenulation cleavage or schistosity. With increasing metamorphic grade and intensity of D2, the competent quartzite units like the Gorge Quartzite (Pkp) begin to take on a rudimentary schistosity with S2a defined by muscovite and biotite between strongly recrystallized quartz. In lower grade units like the Sugarbag Creek Formation, S2a refracts from the more argillaceous units (where S2a is at a low angle to bedding) into a more steeply dipping foliation. S2a also becomes wider spaced in the more competent beds.

In areas of intense D2b non-coaxial deformation, S2a is seen as a crenulated cleavage in the strain shadows of large porphyroblasts such as andalusite or garnet, while the rest of the rock comprises a decrenulated S2 schistosity. These fabrics are interpreted as "quarter folds" that result from non-coaxial bulk flow being perturbed by stiff inclusions (cf. Hanmer & Passchier, 1991). Most porphyroblasts are largely retrogressed (during M3) and the preservation of fossil crenulations in growing porphyroblasts is very rare. Some garnet-hematite-quartz porphyroblasts preserve a symmetrical curving S2a surface that "rotated" through 90°. These may indicate the rotation of porphyroblasts during D2 (Hanmer & Passchier, 1991) or the overgrowth of early stages of crenulation development (cf. Bell & Hayward, 1991).

Prograde metamorphic minerals are associated with S2a, which envelopes porphyroblasts of andalusite and intergrown sillimanite. Graphite is a common mineral in the schist varieties of the Astrea Formation (Pko) and Strathburn Formation (Pki); it is parallel to and in a sense defines S2a. The schistosity is principally defined by fine muscovite and sometimes biotite as the P-domain (phyllosilicate). Q-domains (quartz) or microlithons are made up of quartz which is generally strained, together with fine-grained mica.

The intersection of S2a with S0 and/or S1 commonly results in a steeply plunging lineation (Fig. 7). The plunge is variable due to the axial instability associated with subparallel striking foliations – small changes in one surface can result in large swings in the intersection lineation. These lineations are generally crinkle-like in the more phyllitic (pelitic) rocks while they are defined by the alignment of biotite in the more schistose units. The M2 porphyroblasts (especially andalusite) are generally, but not invariably, poorly aligned. However, these porphyroblasts lie within the S2a surface resulting in an S-tectonite.

Shear Zones

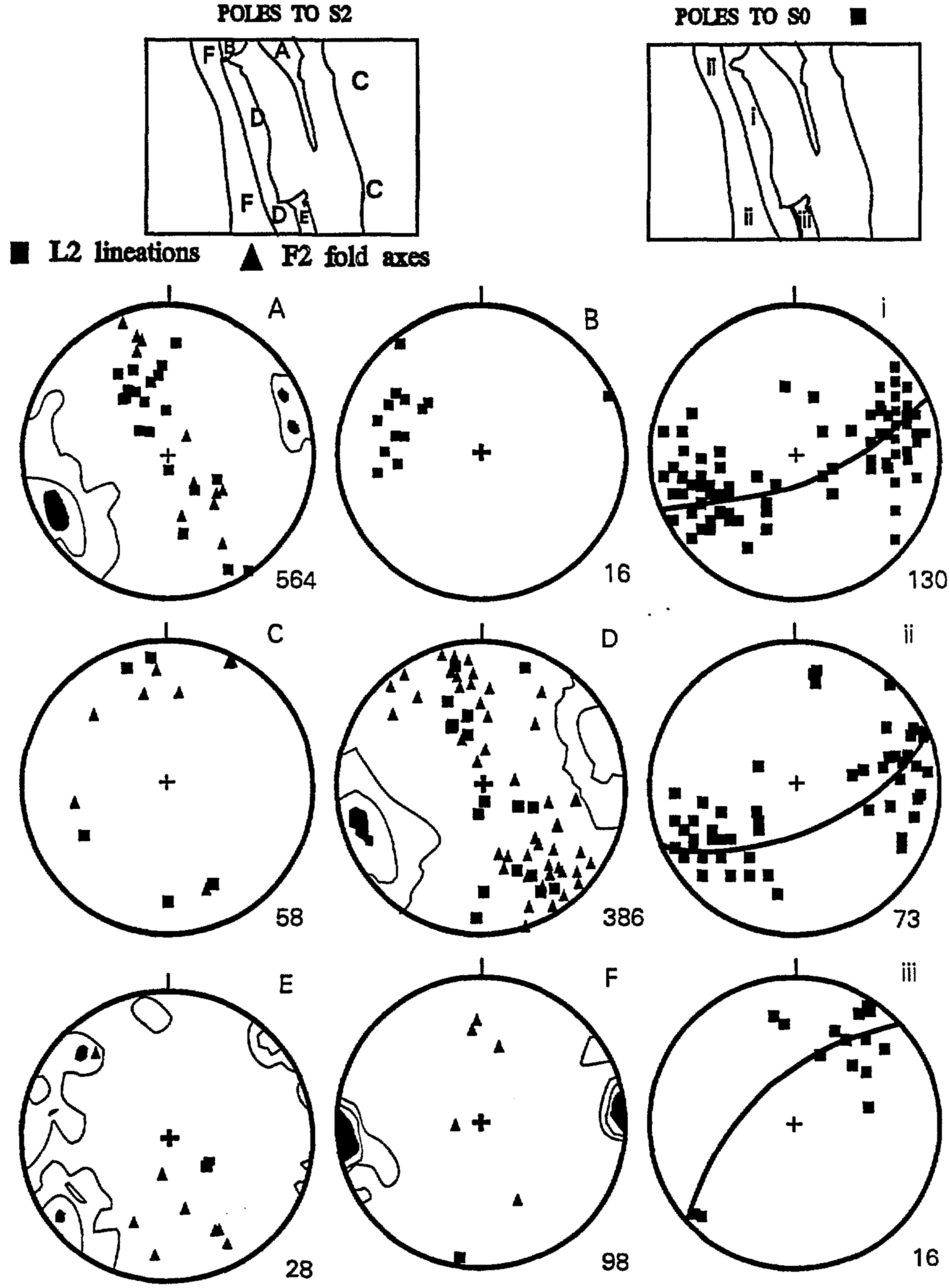
D2b "Early" Shear Zones

The Kalkah Structural Domain of the Holroyd Group have been intensely sheared, probably during the later stages of D2. Many of the shear zones have been reactivated, and are extensions of the mylonite zones found in thin granitic slices within the Kalkah Structural Domain (e.g. near Dingo Creek and Lukin River). Many of the D2b shear zones form the contacts of the metamorphic units; this is especially so in the Kalkah Structural Domain, and Edward River and Coen Metamorphic Group.

Some of the early shear zones are cross-cut by granites of the CYPB – examples can be found at Dead Horse and Opera Creeks, 6 km west of Glen Garland Homestead. Another example is found at Lagoon Creek in the north east of the Strathburn 1:100 000 sheet area, where a westward protruding "apophysis" of Siluro/Devonian granite transects the NNW-trending Kalkah Structural Domain and associated shear zones.

The majority of NNW to N-trending faults in the Lukin Structural Domain are probably D2b in age; for example, the Coleman River Fault (Fig. 3) which has a 7 km horizontal offset of the Carew Greenstone. The NNW-trending fault that transects the syncline between the western and central macroscopic anticlines of the Carew Greenstone is probably D2b in age.

Figure 7
Lower hemisphere equal area projections of D2 structural elements. Contours are % per 1% of area - poles to S2. Domains A=Coen, B=Crystal Vale, C=Lilyvale, D&I=Pollappa, E&II=Lucy, F&III=Coleman.



The "early" shear zones are visible on the aeromagnetic data as linear troughs or lows; many stretch for tens of kilometres and trend more northerly than the regional NNW-oriented strike. They are commonly expressed as shear planes subparallel to the S2 schistosity, and therefore generally only visible where they cross-cut S2. Along the Coleman River where the Strathburn Formation (Pki) crops out, a number of shear planes are highlighted by the boudinage of quartz veins that are parallel to S2. Other "early" shear zones that may have been reactivated are common around the Curlew Ranges NW of Glen Garland Homestead, where there is an anomalous amount of surface quartz.

A number of major D2b shear zones overprint F2 folds or juxtapose differing M2 metamorphic grades. The N-S trending Cattle Swamp Shear Zone (Fig. 3) separates the Edward River Metamorphic Group from the Holroyd Group (Lukin Structural Domain). It is poorly exposed and only really visible as a change in magnetic susceptibility, although foliated granitic gneiss does crop out along the headwaters of the Edward River (see Blewett et al., 1992). The Lindalong Shear Zone juxtaposes the mid-amphibolite facies Kalkah Structural Domain with the largely greenschist facies Lukin Structural Domain. No kinematic indicators have been located, but these post-D2a shear zones are interpreted to have strike-slip components of shear, with transport up to the NNW bringing the Kalkah Structural Domain over the Lukin Structural Domain. The S2a schistosity dips steeply to the east along the Kalkah Structural Domain hangingwall. The Gorge Fault (Fig. 3) trends NNW, dips steeply and transects the Gorge Quartzite, and removes the complementary anticline to the N-plunging syncline whose core is defined by the outcrop of Strathburn Formation. This fault cuts down the structural section northwards by juxtaposing successively higher levels of the Strathburn Formation against the Strathmay Formation. The Sugarbag Creek Fault separates Subdomain 3 from Subdomain 4 of the Kalkah Structural Domain. The S2 schistosity is deformed along the trace of the fault, and slip has occurred sub-parallel to S2 with acutely intersecting shear planes or ramps.

The aeromagnetic data over the Coen Metamorphic Group is more difficult to interpret. The D2b shear zones are less continuous (on the TMI images) and the contrast between them and the surrounding metamorphic rocks is less than in the Kalkah Structural Domain (Fig. 2). The D2b shear zones trend in a more northerly orientation than the more obvious D2c Coen and Ebagoola Shear Zones (Fig. 3). The Stewart River Fault separates the biotite-bearing Yarraden Schist from the mostly biotite free Goolha-Goolha Schist. The kinematics of these D2b shear zones is unknown, they are probably similar to those found in the Kalkah Structural Domain to the west and described above.

D2c Shear Zones

Mylonites of the D2c shear zones are the most easily recognised in the field, especially where they intersect the granites. Spectacular S-C composite fabrics are found along these shear zones, all seeming to indicate a significant component of sinistral shear. The D2c shear zones tend to be NNW-oriented (Fig. 8) and they locally cross cut the earlier and more N-trending D2b shear zones. A fine example of this angular discordance is where the Lukin River Shear Zone cuts the D2b shear zones of the Kalkah Structural Domain around, and to the NE, of the Lukin River.

Sub-parallel to and yet overprinting the D2 structures are major shear zones which have important spatial links with gold mineralization, these are the Coen and Ebagoola Shear Zones.

These shear zones are of low metamorphic grade (biotite) and they overprint the 407 Ma. granites (pooled ages) of the CYPB (Fig. 9a, b). Some movements on the Coen and Ebagoola

Figure 8
Lower hemisphere equal area projections of poles to mylonite and solid-state foliations. Contours are % per 1% of area. CSZ=Coen Shear Zone, ESZ=Ebagoola Shear Zone, LRSZ=Lukin River Shear Zone.

▲ Stretching lineations Lm

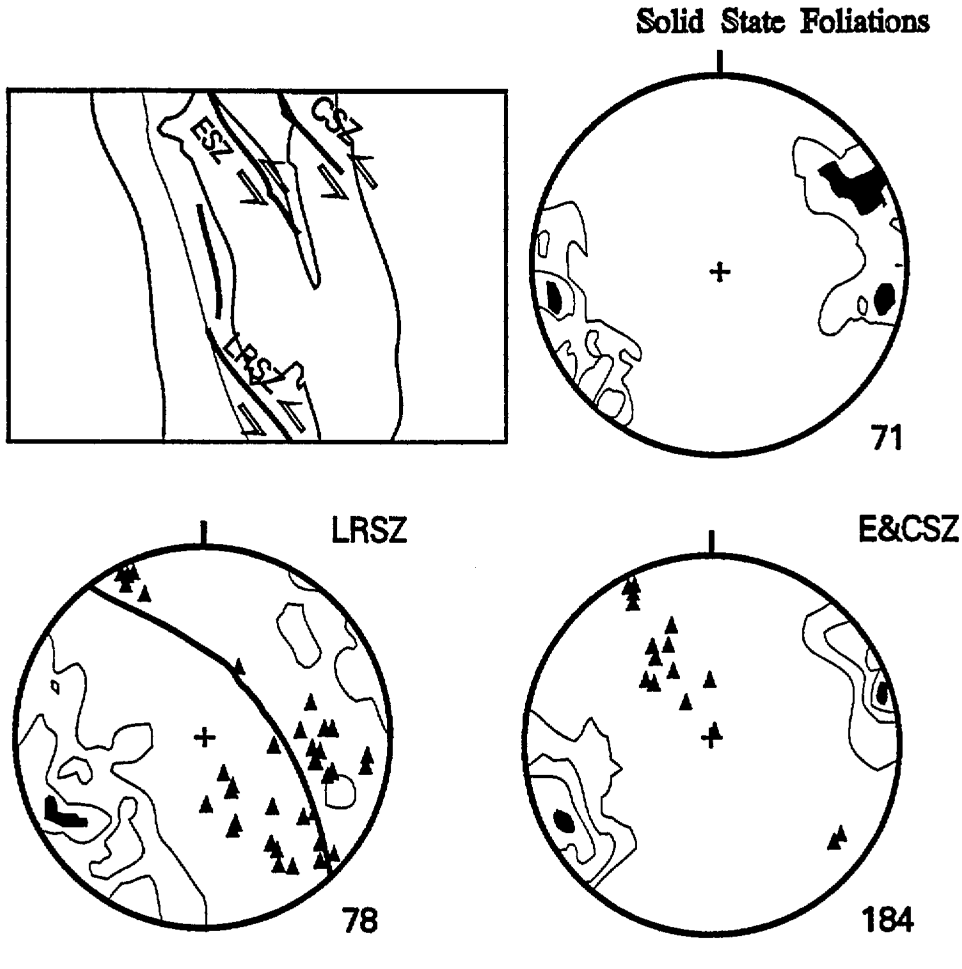


Figure 9. (opposite page) A) S-C-C' mylonites from the Lukin River Shear Zone (D2c) indicating sinistral shear. B) Photomicrograph of a typical; S-C mylonite with "mica-fish". C) Chloritoid replacing andalusite/sericite in the Gorge Quartzite (Pku) of the Kalkah Structural Domain. D) Coarse S3 crenulation of S2 schistosity in the Yarraden Schist (Coen Metamorphic Group). Note steep plunges of F3 folds - view horizontal. E) Fine S3 crenulation in Newirie Formation (Pkb) of the Kalkah Structural Domain. Note N-S orientation of crenulation hinge lines. F) S1, S2, S3 foliations. S1 is the fine foliation defined by biotite within the quartz domain. S2 is defined by muscovite running bottom left to top right. S3 is the warping of the S1 and S2 running top to bottom in the frame. Note no mineral growth along S3. Sample from the Strathburn Formation (Pki) (Kalkah Structural Domain). Frame width 1mm. G) Gently NE-plunging F4 folds in the Newirie Formation (Lukin Structural Domain).

Shear Zones deform rhyolite dykes, which on regional considerations, could be Carboniferous in age.

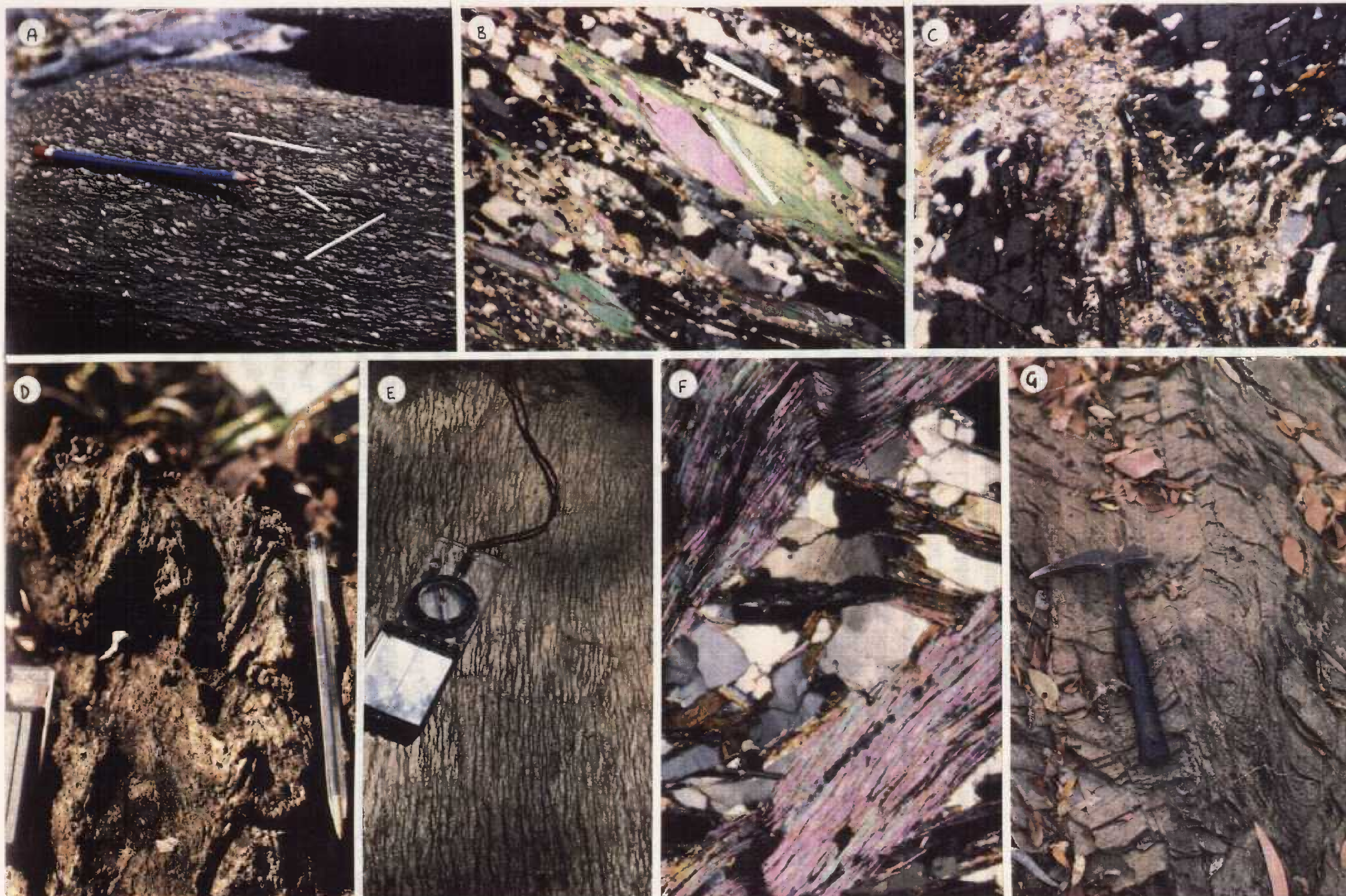
Coen Shear Zone (CSZ) — This is a NNW-trending, rectilinear ductile shear zone that partly juxtapose the Coen Metamorphic Group with the CYPB. The shear sense has been determined in the well developed S-C and C-C' mylonites as sinistral, west-block-up, along stretching lineations plunging steeply at 65° (Fig. 8).

Major shear zones form discrete belts of intense deformation in NNW-SSE trending en-échelon zones. Well developed mylonites with kinematic indicators including S-C fabrics occur in narrow high-strain zones up to tens of metres in width within the shear zones. The kinematic indicators point to a west-over-east sense of shear along stretching lineations that plunge moderately to steeply NW. The overall shear sense is oblique-slip and numerous kinematic indicators point to a very strong sinistral shear associated with the mylonite. Mylonites occur predominantly in the granites, hence the porphyroblasts are quartz or more commonly feldspar and are generally of the sigma-type (Passchier & Simpson, 1986). Locally, vein quartz within mylonites is folded and transposed consistent with the shear sense determined from the S-C fabrics. In places, quartz veins also overprint mylonites demonstrating a number of vein generations. The Coen Shear Zone dips steeply on average ENE or 86° to 067 (Fig. 8). Stretching lineations with associated mylonite plunge NNW (average 65° to 333) close to the calculated average mylonite surface (Fig. 8). The Lm lineation or stretching lineation is defined by elongate quartz and aligned biotite. Strong L-S tectonites are visible within mylonitized rhyolite dykes that occur with the major shear zones.

Mylonites also occur in the metamorphics, with well developed S-C fabrics and asymmetrical quartz/feldspar augen in the Penny Gneiss along the Coen Shear Zone suggest sinistral west-over-east movements. The gneissic layering is the locus of shearing, with occasional strong rodding of the leucosome layers. Thin graphitic shears also occur within the metamorphics, some of which have associated gold mineralization.

In the Coen Shear Zone silicification is widespread and diffuse, and not necessarily restricted to vein material. A generation of black to smoky quartz veins are fairly common in areas along and adjacent to the Coen Shear Zone. S-C fabrics are not common in the Coen Shear Zone and the mylonites are characterised by flattened and ribboned quartz. Brittle fractures are common along, and adjacent to, the Coen Shear Zone. Strongly foliated and lineated rhyolite is commonly associated with the Coen Shear Zone, especially at the Hanging Rock and Homeward Bound mines near the town of Coen.

Along the extension of the Coen Shear Zone at the Archer River in COEN, the mylonite is clearly overprinted by a N-S trending S3 crenulation cleavage with an S-shaped asymmetry viewed north. This crenulation of 'SM1' is itself strongly transposed into a second generation of mylonitization with a sinistral sense of shear. The S-shaped asymmetry and steep plunge of


A
B
C
D
E
F
G

F3 folds suggests maintenance of the sinistral shearing with a reduction of the dip-slip movement. This also points to progressive deformation, where foliations formed and were deformed in an active shear zone.

Ebagoola Shear Zone (ESZ) — This is less than 100 km long, and like the Coen Shear Zone is subvertical with a NNW trend (Fig. 8). The Ebagoola Shear Zone is an anastomosing zone of ductile shear several kilometres wide that contains discrete zones of high strain tens of metres wide. It is visible as a series of lineaments on aerial photographs and Landsat, and is well defined on the aeromagnetic images (Fig. 2). The Ebagoola Shear Zone is well exposed in the granites around Tadpole Creek in the north of the Ebagoola 1:100 000 sheet, where it contains very thin slivers of highly attenuated schist. Ribbons of the Ebagoola Granite (Mackenzie & Knutson, 1992) are distributed along the Ebagoola Shear Zone. It is probably thin slivers of metamorphics along the length of the shear zone that result in the higher magnetic response compared to the CYPB which the shear zone essentially cuts. In the south near Mount Ryan, the Ebagoola Shear Zone forms the eastern contact of the Mount Ryan Quartzite with the Lochs Gneiss and Yarraden Schist. There is no significant horizontal offset of the Coen Metamorphic Group by the Ebagoola Shear Zone.

Many of the old workings in the Hamilton Goldfield occur along the Ebagoola Shear Zone, especially adjacent to the sheared contact between the Coen Metamorphic Group and the CYPB.

The Ebagoola Shear Zone has rare outcrops of highly deformed rhyolite similar to that found along the Coen Shear Zone, for example 10 km north of the Holroyd River. Quartz veins do crop out along the Ebagoola Shear Zone, especially between Mt Lee Bryce and the Hamilton Goldfield, but silicification is less than along the Coen Shear Zone.

The Ebagoola Shear Zone dips steeply towards ENE (86° to 067), and has stretching lineations with associated mylonite that plunge to the NNW or on average 65° to 333 (Fig. 8). The stretching lineation, like the one found along the Coen Shear Zone, is defined by elongate quartz and aligned biotite.

Lukin River and associated shear zones of the Kalkah Structural Domain — The Kalkah Structural Domain, and plutons of the CYPB within the metamorphics, are highly deformed by a large number of NNW-trending, anastomosing shear zones. The Kalkah Structural Domain is separated from the Lukin Structural Domain by the Lindalong Shear Zone (Fig. 3), which is a D2c shear zone juxtaposing mid amphibolite facies rocks against greenschist facies rocks. Parallel to the Lindalong Shear Zone are a number of unnamed shear zones that separate the stratigraphic units of the Kalkah Structural Domain. Many of these shear zones have a large number of quartz blows; some of which are foliated and/or lineated. Good examples of lineated quartz veins may be found in the granites along the Lucy Swamp Shear Zone. These lineations are parallel to the stretching lineation of the mylonitized granite. Further veining overprints the mylonitic foliation, so there are a number of generations of quartz veining. The Lukin River Shear Zone (Fig 3c) or LRSZ (Blewett & von Gnielinski, 1991b) is well exposed near Eighteen Mile Lagoon on the Lukin River in the Kalkah 1:100 000 sheet area. The Lukin River Shear Zone is a complex, anastomosing zone of ductile shear up to 2 km wide within a sheared pod of Barwon Granite. The shear zones dip steeply to the ENE, while the shear sense is consistently sinistral (Fig. 9a, b) oblique-slip with well developed gentle SE-plunging stretching lineations (on average 36° to 122) indicating transport up to the NNW (Fig. 8). Kinematic indicators are common and include S-C and C-C' composite fabrics (Fig. 9a), mica fish (Fig. 9b) and tiling structures. The stretching lineations at the crossing of the Lukin River (just east of Eighteen

Mile Lagoon on the Kalkah 1:100 000 sheet area) are subhorizontal, with 5° plunges towards the south east. Here, the mylonite approaches an ultramylonite in textural terms, and is the most intense example located in EBAGOOLA. Significant grain size reduction has occurred in this area.

The Lukin River Shear Zone extends SSE as the boundary between the Carysfort Formation (Pke) and the Strathburn Formation (Pki) and is cross cut by a late-stage tongue of the Barwon Granite. The Lucy Swamp Shear Zone is the southern extension and good examples of mylonitized Warner Granite (Mackenzie & Knutson, 1992) may be found just west of Glen Garland. The Lucy Swamp Shear Zone is developed over 2 km across strike, it dips steeply and has a gentle to moderate SE-plunging stretching lineation. The granites here are coarser grained and more porphyritic. The development of the C-plane (shear) and associated grain size reduction is not as intense as the example further north at the Lukin River. A number of quartz veins overprint the mylonitic fabric.

The shear zone dips steeply to the ENE and the stretching lineations plunge gently to locally steeply south or east respectively (Fig. 8), the geometry is one of oblique thrusting towards the NNW, with the Kalkah Structural Domain as the hangingwall above the footwall Lukin Structural Domain.

In the central part of the Kalkah Structural Domain, a spectacular strike-slip duplex has truncated the synforms of a series of macroscopic F2 antiforms, and horse-tail splays also occur. These may have been D2b shear zones that were later reactivated as splays of the Lukin River Shear Zone. Some of the shear zones have individual strike lengths of over 50 kilometres. Individual mylonite zones are up to 1 km wide; a good example occurs in the porphyritic Warner Granite near Bob's Yard south of Glen Garland.

The timing of shearing is problematical. The ductile shearing event may have begun while the CYPB was in a magmatic state as phenocrysts are commonly flow aligned parallel to the ductile shear zones and the age of shearing is approximately Siluro-Devonian. However, some granites overprint the shear zones (Fig. 6d) while other (similar looking) ones are overprinted by them (as above). At this stage no dates on the CYPB differ significantly from the "pooled" 407 Ma. ages so far obtained (see Black et al., 1992). It can be established that the shear zones overprint some of the Siluro-Devonian granites, transect F2a folds, and deform the S2a schistosity (utilizing the strong anisotropy). However, the tongues of granite north of Glen Garland (Dead Horse Creek) and in the north of EBAGOOLA around Lagoon Creek, transect the shear zones of the Kalkah Structural Domain and indicate that reactivation of D2b shear zones during D2c was not uniform.

In summary, the shear zones followed folding and metamorphism of the metasediments; they were probably active during emplacement of the "earliest" phases of the CYPB, and partly controlled its emplacement. Deformation continued on some shear zones, while others were not reactivated and were overprinted by later pulses of the CYPB.

Other Shear Zones — The porphyritic Lankelly Granite (Mackenzie & Knutson, 1992) provides useful indicators of shearing. Quartz ribbons are commonly associated with the 'rotation' of porphyroblasts with the development of asymmetric pressure shadows (Hanmer & Passchier, 1991). Foliation spacing in the granite varies from millimetre scale to tens of metres. The spacing reflects discrete shear surfaces and/or zones of flattening, phenocryst rotation, quartz ribboning and mica alignment. Phenocryst alignment in the Lankelly Granite is generally oriented NW-SE about steeply dipping planes, suggesting a link between flow alignment and some stage of shear-zone development. In horizontal sections of granite pavement, the obliquity of phenocrysts to shear planes is almost invariably clockwise. These tiling structures (Hanmer & Passchier, 1991) suggest a sinistral component of shear upon them. Broken feldspar grains also confirm the sinistral sense of movement (Blewett & von Gnielinski, 1991a).

In other areas, a weak solid-state (non-mylonitic) foliation is developed; it is principally NNW-trending and dips steeply WNW. Locally, phenocryst alignment in the Lankelly Granite (Mackenzie & Knutson, 1992) is not parallel to the plane defined by 2-3 cm long quartz ribbons. The quartz ribboned surface represents an L-S tectonite oriented N-S, with phenocryst alignment rotated 25° clockwise relative to the surface. In the more equigranular granodiorite bodies of Flyspeck-type, the foliations are commonly defined by alignment of biotite and hornblende grains.

Third Deformation (D3)

D3 structures are widespread and include mesoscopic folding and associated crenulation of earlier fabrics. F3 folds are tight, trend N-S, have steeply dipping limbs and plunge N, and less commonly S (Fig. 9d, e, f). The S3 crenulation is characterised by retrogressive muscovite and biotite growth and is generally more obvious in hand specimen than the S2 crenulation of S1. D3 structures overprint the S-C mylonites of the major shear zones indicating that D3 is younger than 407 Ma. Blewett & von Gnielinski (1991b) reported that S3 crenulations overprinting S-C mylonites of the Archer River Shear Zone (extension of the Coen Shear Zone) are themselves overprinted by a further phase of ductile shearing. Movement along the shear zone at Archer River (in COEN) continued after the intrusion of the Permian granitoids exposed there, but no further evidence for this was found in EBAGOOLA.

F3 Folds

F3 folds are generally tight and asymmetric with chevron-like hinge zones; they are mostly S-shaped viewed down plunge to the north, and the associated axial surface trends almost N-S. The resultant orientation of S2 is NNW-SSE (Fig. 9d). In some areas, Z- asymmetric F3 folds occur, giving rise to a more northerly trend for S1 and a NNW-trend to S2. This change in F3 plunge is seen in the scatter of the hinges. The average F3 fold plunge is towards the north (Fig. 10). Figure 10 shows that the orientation of D3 structures is generally invariant across EBAGOOLA and that the region was essentially welded into a single structural domain before this period in the tectonic evolution.

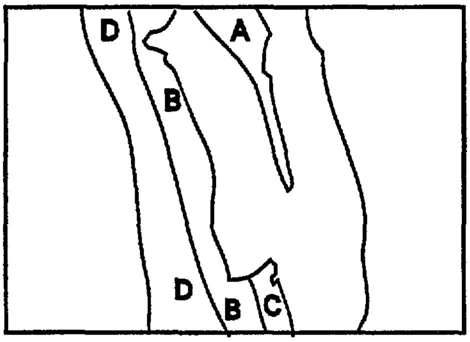
Visible F3 folds are invariably mesoscopic in scale. There are no macroscopic F3 fold closures; however, some localities have an anomalous flat lying S2 schistosity (commonly without an S3 overprint). These regions (e.g. in the Coleman River Gneiss north west of Glen Garland Homestead) may be the hinge zones of macroscopic F3 folds. The absence in these areas of a mesoscopic S3 foliation or associated parasitic F3 folds is enigmatic.

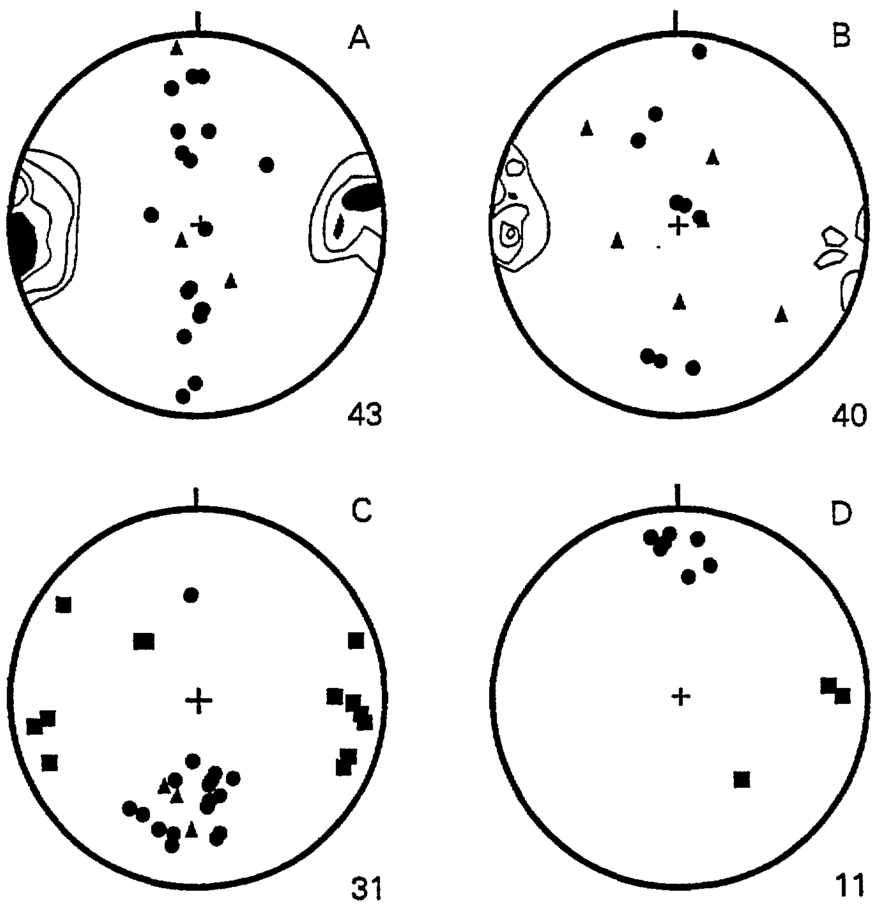
D3 structures overprint the sillimanite and garnet that lie within the S2 surface. No M3 metamorphic marker minerals have been identified; however, chlorite is common and muscovite pseudomorphs after sillimanite may be related to D3. In places the L2 lineation as defined by sillimanite needles is rotated parallel to L3.

The contact of the CYPB with the metamorphics is locally folded about N-S oriented F3 fold axes. A pegmatite intrusions from the Lankelly Granite into a diorite xenolith along the Stewart River (Ebagoola 1:100 000 sheet) are folded by N-trending F3 folds.

Figure 10
Lower hemisphere equal area projections of D3 structural elements. Contours are % per 1% area of poles to S3. Domains are A=Coen, B=Pollappa, C=Lucy, D=Coleman

▲ Fold axes ■ poles to S3 ● L3 lineations





S3 Foliations

The S3 surface generally trends N-S and dips steeply (Fig. 10) and is patchily developed across all structural domains of the basement. It ranges from a coarse, asymmetric, spaced crenulation cleavage to a fine millimetre-scale crenulation cleavage (Fig. 9e). F3 folding is not always apparent in regions where S3 foliations are present. In thin section, S3 crenulations tend to be angular with fractured mica (Fig. 9f). In some cases muscovite and biotite growth along S3 is recorded.

Fourth Deformation (D4)

D4 structures are seen as NE to E-trending folds with associated weak crenulation foliations (Fig. 9g). Kink bands in argillaceous units are also considered to be D4. Macro-scale folding east of Glen Garland in the Strathburn Formation (Pkj) may be F4, as well as the E-W oriented folding of the Lindalong Shear Zone in the headwaters of Lindalong Creek in the Kalkah 1:100 000 sheet area.

D4 structures are not well represented in the Coen Metamorphic Group and do little to deform the D2 structural trends. There are some S4 crenulation foliations (Fig. 11), but more commonly E to NE-trending open to tight folding of gneissic layering and S2 is recorded. There are no macroscopic F4 folds in the Coen Metamorphic Group. F4 folds occasionally occur as E to ENE and NE-trending open crenulations or monoclinal kinks. The best examples of F4 folding are found in the low-grade Newirie Formation just north of Astrea Holdings Homestead (91834360). Here, F4 folds have curvilinear hinge lines that plunge moderately to steeply and variably to NNE or NE (Fig. 11). These are open folds with kink-like or chevron hinge zones.

The fabric element sketch (Fig. 4) provides a summary of the typical mesoscale features of the deformation chronology outlined in this record.

The Palmerville Fault

The Palmerville Fault was called a "fundamental" structure in north Queensland by de Keyser (1963) as it was considered to coincide with the Tasman Line (Hill, 1951), which separates the Precambrian craton to the west from the Tasman "Geosyncline" to the east.

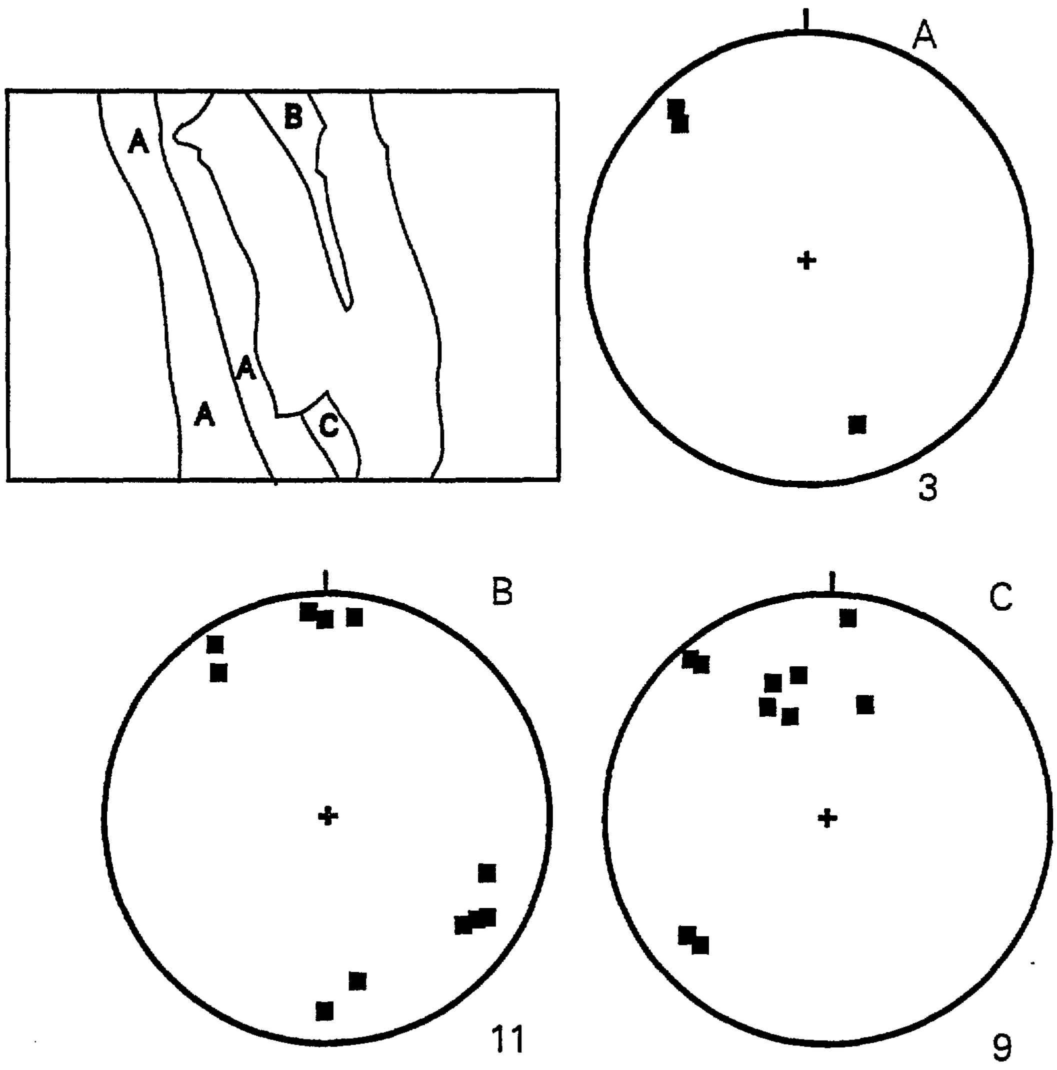
The Palmerville Fault has a weak surface expression in EBAGOOLA where the youngest movements (down throw to the west) are clearly visible on the radiometrics, where an older, deeply weathered alluvial surface is adjacent to more recent alluvium associated (see Pain & Wilford, 1992) with the Five and Fifteen Mile Creeks. A series of melon holes (swamps) occur on the footwall side (east) and the passage of Saltwater Creek has been superimposed upon the last movement of the fault.

The magnetic response of the Palmerville Fault shows that it is a zone of deformation with a series of broad wavelength anomalies up to 8 km wide, extending in a northerly direction from the SE corner of EBAGOOLA through Princess Charlotte Bay to the NE corner of the sheet (Wellman, 1992).

It is not possible to study the pre-recent movements of the Palmerville Fault Zone in EBAGOOLA. In the most recent detailed study of the Palmerville Fault south of EBAGOOLA, Shaw et al. (1987) concluded that the major movement was west-directed thrusting. They could not rule out that the kinematics of the fault were complex, nor that oblique-slip movements had not occurred.

Figure 11
Lower hemisphere equal area stereographic projection of poles to S4. Note scarcity of D4 elements.
Domains A=Coleman, B=Coen, C=Lucy

■ Poles to S4



Other Faults

An unexposed short wavelength, high amplitude, linear magnetic anomaly trends N-S in the Newberry Metamorphic Group (Fig. 3). This feature is interpreted as a fault, however the kinematics are unknown.

The airborne magnetics show a number of NE-trending fractures without any discernible offset along them. They are subparallel to the dyke swarm in the central part of the Kalkah 1:100 000 sheet area (Fig. 2). The dykes have not been dated, but because many are altered, they are thought to be pre-Mesozoic.

METAMORPHISM

The metamorphic grade is mid to upper amphibolite facies throughout the Coen and Newberry Metamorphic Groups, with sillimanite, garnet and rare andalusite and kyanite as metamorphic marker minerals. The presence of migmatite in the Coen River area of COEN suggest higher grades.

Rock types in the Holroyd Group range from indurated sediment to sillimanite schist and gneiss. In the higher grade Kalkah Structural Domain the dominant lithologies are andalusite-mica schist, quartzite and lesser gneiss. Generally, the metamorphic grade is lower in the Holroyd Group compared to the Coen Metamorphic Group, with the greatest range found in the central belt and least in the Lukin Structural Domain of the Holroyd Group (Blewett et al., 1992). There are extensive greenstone bands in the Lukin Structural Domain and disaggregated metadolerite in the Kalkah Structural Domain of the Holroyd Group. The Coen Metamorphic Group is predominantly sillimanite-mica schist gradational into gneiss with minor quartzite.

The Holroyd Group ranges from sub greenschist to mid to upper amphibolite facies, while the Coen Metamorphic Group is entirely mid to upper amphibolite facies.

M1 Metamorphism

The intensity of the Coen Orogeny means that little is known about the pre-Coen (D2) deformation and early metamorphic history of the Coen Inlier. In the least deformed units of the Lukin Structural Domain, indurated sediments and slates show that M1 facies were as low as sub-greenschist. Some slates have biotite along S1 surfaces (Fig. f), indicating local attainment of biotite grade during the metamorphic climax.

The M1 metamorphic history is unknown outside the Lukin Structural Domain where the M2 overprint is the lowest.

M2 Metamorphism

In EBAGOOLA it is clear that there was a spatial and temporal link between Siluro-Devonian granites of the CYPB and the climax (Coen Orogeny) deformation and metamorphism. Willmott et al., (1973) first suggested that the CYPB was responsible for the thermal climax of metamorphism. The highest metamorphic grades (M2) are essentially linked to proximity to the CYPB and possibly to the eastern edge of the zone of Palaeozoic reworking (Wellman, 1992). The common minerals formed during M2 metamorphism include sillimanite, andalusite, garnet, biotite, tourmaline, graphite and muscovite. Less common are staurolite and kyanite. The mineralogy indicates that EBAGOOLA represents a high temperature / low pressure regime (Fig.

6f), with a thermal source that was provided by, or more likely resulted in the generation of the CYPB. There was only rare and restricted development of moderate to high pressure.

The CYPB has a broad regional aureole, and this is well displayed in the Kalkah Structural Domain by the change from mainly andalusite bearing schist into mainly sillimanite bearing schist towards the contact with the CYPB towards the east. The Coen Metamorphic Group which lies to the east of the Holroyd Group is mainly sillimanite-bearing and also contains more gneiss and migmatite. Similar "regional contact" or large-scale type contact aureoles have been described in the Connemara region of Ireland (Leake, 1970) and also in north Queensland (Withnall, 1984). The contact effects at Connemara are visible up to 15 km from the heat source and occur in an area of 230 km^2 (Leake, 1970). The thickness of the "regional contact" aureole in EBAGOOLA appears to be large because the metamorphic isograds (at least in the Kalkah Structural Domain) dip gently to the west, and the current level of exposure results in an oblique section.

The regional aureole and almost total absence of hornfels in the metasediments, suggests that the emplacement of the CYPB into the Proterozoic margin took place at depths where high-temperature amphibolite-facies metamorphism occurs.

The only record of hornfels is found in a series of thin skins of Astrea Formation (Pko) on the top of low hills in the Warner Granite (Mackenzie & Knutson, 1992) south of Glen Garland Homestead. The gravity data show that the Glen Garland region is shallowly underlain by the CYPB (Wellman, 1992), and that the metamorphic rocks in this area are the roof pendants of the batholith. The hornfelsed schist is deep red to purple in colour and comprises andalusite (chiastolite), tourmaline, hematite, quartz and sericite (Fig. 6g). The foliation is poorly developed and surprisingly the magnetic susceptibility is low to moderate (7 SI units).

Migmatites occur locally as relatively narrow zones within the Coen Metamorphic Group. The presence of local migmatites may indicate different host rock as migmatization can occur in upper amphibolite facies.

M2 Minerals

Kyanite is recorded in the south of the Coen Metamorphic Group in the Lochs Gneiss as waxy blue blades 8-10 cm long and 0.5 cm wide, pitching steeply within the gneissic foliation. It is pseudomorphed by muscovite. Kyanite in the Holroyd Group was found at one site (91834068a) on the Lukin River north of Cockers Knob in the Kalkah 1:100 000 sheet area. The kyanite porphyroblasts are waxy-blue blades up to 3 cm long, that are randomly oriented within the S2 foliation and are largely retrogressed to muscovite/sericite. The rare presence of kyanite indicates local regions of higher pressure than the more common low-pressure andalusite to sillimanite transition.

Sillimanite is widespread in the Coen Metamorphic Group and in higher grade units of the Kalkah Structural Domain. It commonly forms bunches of porphyroblasts generally 1-2 cm long, overprinted by the S3 crenulation cleavage and contained by or defining the S2 schistosity. The acicular habit occasionally shows a strongly preferred orientation (L2). Sillimanite is generally pseudomorphed by retrograde muscovite in bunches several centimetres long and little fresh sillimanite is visible in thin section. Some thin sections reveal intergrown sillimanite and andalusite (Fig. 6f), for example in the Astrea Formation (Pko) (91834111a). Such intergrowth indicates a temperature close to the aluminium-silicate transition. This variety of prograde P-T path has been inferred for other low-pressure metamorphic terrains, for example Broken Hill

(Phillips & Wall, 1984) and New Mexico (Vernon, 1987). Sillimanite needles may also be aligned parallel to and together with muscovite, define the S2 surface. Sillimanite is also seen as fibrolite bunches.

Garnet is unevenly distributed and locally may constitute up to 20% of a gneiss. Garnet porphyroblasts range from millimetre scale to 2 cm in diameter. Garnet locally overgrows the gneissic (melanosome/leucosome) layering which indicates that the gneissic layering existed before D2. The gneissic variety of the Strathburn Formation (Pkt) in Dingo Creek (91834179) is a quartz dominated gneiss that has little feldspar and probably had an interbedded psammite/pelite protolith, so it is not surprising that garnet overgrows the gneissic layering (i.e. original bedding). As the layering in the gneiss was originally bedding, the overgrowth by M2 garnet does not require the formation of an orthogneissic layering before D2 (i.e. it does not imply high metamorphic grades during D1). Extensional shear bands (D2c) and S3 crenulations overprint M2 garnets locally. Garnets in the schist of the Strathburn Formation (Pki) and Gorge Quartzite (Pku) along the Coleman River, have well developed strain shadows (Fig. 6e), with quartz and mica beards developed as asymmetric tails. Such asymmetry is interpreted as a result of sinistral shearing.

Andalusite is very common in the Kalkah Structural Domain (Fig. 6f), is uncommon in the Lukin Structural Domain and rare in the Coen Metamorphic Group. Much of the original aluminium silicate is retrogressed to sericite, but the porphyroblast shapes, commonly with chiastolite crosses, are well preserved (Fig. 6c, g). Porphyroblasts may be up to 8 cm long, they are generally tabular and 2-3 cm in length (Fig. 6c). Most andalusite porphyroblasts are not aligned or are weakly so, and they may preserve S2 as a crenulation surface in their strain shadows, while the matrix is a decrenulated schistosity.

Cordierite is widespread in the Kalkah Structural Domain, but is almost totally replaced by sericite. It occurs as ovoid porphyroblasts up to 0.5 mm in diameter, and is commonly associated with andalusite and or sillimanite.

Staurolite was first reported in the "Holroyd Metamorphics" by Trail et al. (1968). In this study, staurolite was found to be restricted to the schistose beds of the Gorge Quartzite (Pku) located in the Kalkah Structural Domain (e.g. 91834218). Some staurolite porphyroblasts show straight inclusion trails of quartz, others are intergrown with andalusite. Chloritoid prisms up to 1 mm and randomly oriented together with sericite are the products of staurolite retrogression during M3.

Muscovite and biotite generally define the S2 schistosity. Most schists are fine-grained with a foliation spacing up to 0.5 mm thick (Fig. 9f). Muscovite (sericite) also is the dominant retrogressive mineral (M3)

Graphite is a relatively common mineral in the schists of the Kalkah Structural Domain where it defines S2 as laths less than 1 mm long and may comprise 20% of the rock. Graphite is also common in the Lukin Structural Domain, some of which is little metamorphosed. Hematite and limonite are widespread but generally occur in small amounts (1-2%), and cause much of the reddening of the exposed metamorphic rocks.

Inclusion trails in porphyroblasts are not common. The large amount of retrogression has probably obliterated much of the earlier textural information. In some localities of the Strathburn Formation (Pki) (e.g. QFG0014), porphyroblasts of garnet/hematite/quartz show curved inclusion trails of quartz that are symmetrically disposed about their centres. The inclusion trails appear to be continuous with the S2 schistosity outside of the porphyroblast, no internal truncations were noted, so that rotation of these porphyroblasts may have occurred during growth and foliation development. In general, however, inclusion trails are absent and when present they are straight (see Bell & Hayward, 1991).

Accessory minerals include zircon, tourmaline, topaz, allanite and abundant opaques.

M3 Metamorphism

Metamorphism during D3 was largely retrogressive and probably responsible for the muscovite pseudomorphs after sillimanite, chloritoid and sericite after staurolite (Fig. 9c), sericite after andalusite with sericite, tremolite-actinolite after sillimanite(?), and chlorite after biotite. In sample 91834163 from the Strathburn Formation (Pki), a porphyroblast retrogressed to sericite contains abundant, fine needles of tremolite-actinolite.

DISCUSSION

Table 1 shows a simplified geological evolution of EBAGOOLA.

General features of EBAGOOLA geophysics

The detailed airborne radiometrics and magnetics were essential mapping data sets in the determination of the structure and distribution of the rock types across EBAGOOLA. Analysis of the regional data sets are also necessary for a complete study (e.g. BMR regional gravity).

Wellman (1992) used the relationship between the geological contacts at the surface and the inflexion of the gravity anomaly residual to estimate the direction of dip of the granite/ metamorphic contact at depth. The dip value is calculated using density contrasts. Along the eastern edge of the CYPB, the gravity inflexion and the surface contact are coincident which indicates that the contact is essentially vertical. The contact of the CYPB with the Kalkah Structural Domain has a westward shift in gravity inflexion from the surface contact. This indicates that the granite dips westward under the metamorphics (see Fig. 12).

A number of simplified cross sections are shown in Figure 12, and they illustrate some major features of the geology at depth that have been inferred from structural observations and geophysical interpretation:

- the Palmerville Fault Zone is vertical and at depth it may become listric and dip towards to the west (Shaw et al., 1987);
- granite underlies the Coen Metamorphic Group and the contact becomes more shallow towards the south;
- the eastern edge of the CYPB has a vertical contact with the Newberry Metamorphic Group south of the Penny Gneiss region;
- the CYPB dips at moderate angles westward under the Kalkah Structural Domain, with shear zones (e.g., LRSZ) bringing pods of granite into higher levels;
- the Palaeozoic granites extend as far west as the Kalkah Structural Domain in EBAGOOLA (they are present in the Lukin Structural Domain in HANN RIVER);
- the Lindalong Shear Zone dips steeply to the east and is overprinted by the CYPB;

Table 1. Geological evolution of the Ebagoola 1:250 000 sheet.

DEFORMATION	METAMORPHISM		ORIENTATION		HISTORY	TIMING
D0	?		?		Deposition of turbidites, shallow water clastics lesser limestone and intrusion of basic sills.	?
D1	PROGRADE	GREENSCHIST		THE COEN OROGENY	Regional deformation - folding and faulting.	> 400 My
D2a		U. AMPHIBOLITE			Climax deformation, isoclinal folding, prograde to upper amphibolite facies metamorphism. Reworking of Proterozoic margin decreasing westwards.	> 407 my
					Cape York Peninsula Batholith	Ca. 407 My
D2b	RETROGRADE				Ductile shearing - sinistral oblique about steeply dipping shear zones	< 407 My
D2c					Rhyolite dykes -Carboniferous ?	
D3		GREENSCHIST			N-S oriented folding and crenulation, limited macroscale elements.	
D4					Minor folding and crenulation.	> 285 My
					Permian (?) intrusions	285 My
					Uplift, erosion and Mesozoic sedimentation.	
					Basalt flows	
					Minor faulting - normal sense.	to Quaternary

RSB

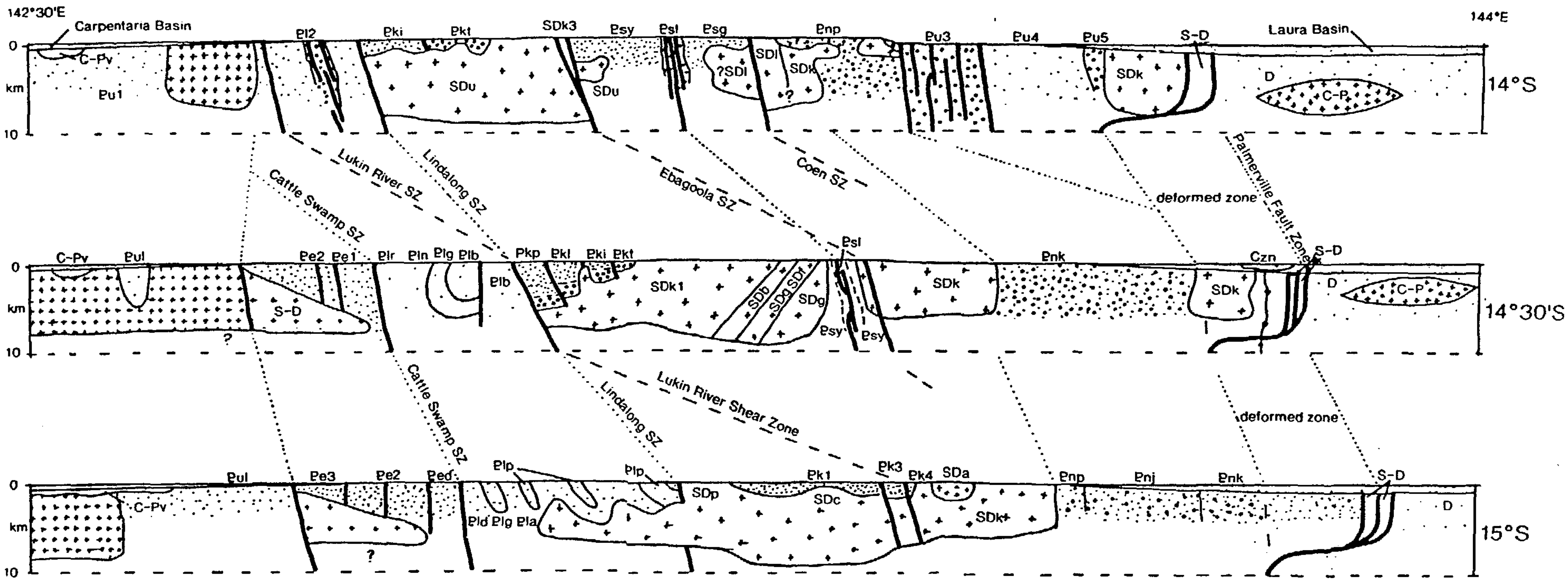


FIGURE 12
Schematic sections across EBAGOOLA showing the major structural elements and rock type distribution (from Wellman, 1992).

- the Cattle Swamp Shear Zone dips steeply to the east;

- Proterozoic granites may occur in the far west of the sheet area – reworking by the Coen Orogeny extended about 110 km west of the Palmerville Fault Zone.

The Palaeozoic Reworking of a ?Proterozoic Margin and the Emplacement of the CYPB in a mid Palaeozoic Sinistral Shear Zone

EBAGOOLA is dominated by a NNW-trending, steeply dipping structural grain defined by subparallel S0, S1, S2 and mylonitic foliations, shear zones and to a lesser extent gneissic layering. Low-angle to recumbent axial surfaces (F1 and F2) are occasionally found, but these are probably only local in extent. Poor exposure and the prevalence of horizontal, two-dimensional outcrops mean that near-horizontal surfaces are under-represented and may be more common than observed. Original sedimentary layering is almost completely lost in the Coen Metamorphic Group, in contrast to the lower grade Lukin Structural Domain to the west, where sedimentary structures are common (Blewett et al., 1992).

Wellman (1992) proposed a model of "reworking" for EBAGOOLA in which he envisaged that the previous margin of the Proterozoic is modified in the Siluro-Devonian by deformation, metamorphism and intrusion. The effects on this margin are reduced towards the west for a distance up to 110 km, after which they are not seen.

This Siluro-Devonian reworking has been described in this record as the Coen Orogeny, which can be viewed on a broad, regional scale. A number of observations that may support the model in general can be made in EBAGOOLA, where:

- close to the Palmerville Fault Zone, the metasediments have been demagnetised;

- away from this demagnetised zone (which is under cover), the degree of magnetisation decreases;

- the climax of M2 metamorphism decreases westwards, with sillimanite - sillimanite/andalusite - andalusite - biotite (with garnet) - biotite - muscovite - indurated sediments towards the west (where "-" means grades into);

- the degree of ductile shearing and transposition decreases westwards and hence bedding and stratigraphic contacts become more common westwards;

- macroscopic F2 folds become more common westwards;

- the amount of Siluro-Devonian granite decreases westwards to a point 90 km west of the Palmerville Fault Zone after which it is no longer observed;

- the zone of reworking is approximately 110 km wide, west of this no Devonian affects appear visible;

- a belt of Siluro-Devonian granites is around 70 km wide and extends from the Cape Weymouth 1:250 000 sheet area (northern Coen Inlier) 700 km to the southern Georgetown Inlier;

- the CYPB was intruded in a relatively short time span into upper amphibolite facies country rocks;

- the Siluro-Devonian intrusion of the CYPB occurred within the resolution (+ or - 2 to 3 Ma.) of the U/Pb zircon dates for the various plutons of the batholith (Black et al., 1992);

- there is no significant difference in the gravity anomalies across the Palmerville Fault Zone, so either it is an upper crustal feature, or the "mass" across the fault is roughly equivalent, or this fault is only a splay of Palmerville Fault (it may be further east than EBAGOOLA);

- S-type plutonism in the Georgetown Inlier occurred with a mid Proterozoic climax event at around 1550 Ma. (Withnall, 1984);

The steep dip imposed by upright F2 folding on the fabric of the inlier, together with the overall incompetent nature of the metasediments due to the large amount of schist, provided a strong anisotropy for subsequent oblique-slip ductile shearing. The degree to which the shearing (principally sinistral-oblique-slip) may have controlled the intrusion of the granites of the CYPB is unknown. Such models however, need to consider the enormous volumes of plutonism and associated orogenesis around 407 Ma, together with the basin forming processes which occurred throughout the Devonian and into the Carboniferous in the Hodgkinson Province to the east (Withnall et al., 1987).

The Mesozoic basins and the unroofing of the Coen Inlier

The geomorphological evolution of EBAGOOLA is covered in Pain & Wilford (1992), but some aspects are related to the tectonics of the sheet area.

The metamorphic rocks of the Coen Metamorphic Group and eastern part of the Holroyd Group comprise a wide zone of sillimanite-bearing schist and gneiss; their level is close to the top of the CYPB. No precise geothermometry or geobarometry exists for the emplacement of the CYPB, but such a wide regional upper amphibolite metamorphic aureole suggests emplacement depths for the CYPB could be as much as 10 km. In the southern half of the Coen Inlier, there is a 200 Ma. gap in time and perhaps 10 km in vertical space between the top of the CYPB (present erosion level for central east EBAGOOLA) and the base of the Mesozoic basins. The late Palaeozoic is missing so the Coen Inlier was probably an area of significant sediment bypass since Carboniferous times.

In the Carpentaria Basin the mid to late Jurassic Gilbert River Formation (Smart et al., 1980) and the Early Cretaceous Rolling Downs Group lie with a marked unconformity on the Coen Inlier. The unconformity is subhorizontal (depressions contain thicker deposits of sediment) above subvertically dipping rocks of the Holroyd Group and to a lesser extent the granites of CYPB. Pain & Wilford (1992) suggest that the basin may have extended further east onto the Coen Inlier, and that post-Mesozoic erosion has revealed the basement. For example the sharp swing in the Coleman River near Stew and Flyspeck Creeks may be the result of a now eroded barrier of Mesozoic sediments to westward flow. Other areas of the Kalkah 1:100 000 sheet show area evidence of superimposed drainage, for example – the Lukin River and Fish Creek – reflecting a drainage pattern inherited from the post-Palaeozoic cover (J. Wilford, BMR, pers. comm, 1992).

The Coen Inlier basement was at the land surface by early to middle Jurassic times. With the termination of folding events in the Carboniferous, uplift from these ductile regions to the surface occurred through the Permian, Triassic and perhaps earliest Jurassic, with the main structural development (flexure) of the basin occurring in Albian/Aptian (Cretaceous) times (Smart et al., 1980). The Laura Basin to the east is strongly asymmetric with greatest depths occurring adjacent to the Palmerville Fault, which had a strong influence over the formation of this basin during the Mesozoic (de Keyser, 1963).

Tertiary or younger faulting has been important in COEN where a reactivated extension of the Archer River Shear Zone (see Blewett & von Gnielinski, 1991b) places the mid to late Jurassic Gilbert River Formation sandstones and conglomerates adjacent to the Wigan and Kintore Adamellites (Whitaker & Gibson, 1977b). Faults such as these were important in exposing the gold-bearing base of the Mesozoics around Bairdsville and the Main Leader 5 km NE of Plutoville (Whitaker et al., 1973).

A number of N to NNW-trending faults cut the Rolling Downs Group and even some of the young deep weathering profiles developed on Tertiary/Quaternary alluvial systems (Pain & Wilford, 1992). These faults are easily seen as linear contrasts on the radiometrics and are just visible on the magnetics, for example the fault 7 km west of Strathburn Homestead, and the trace of the Palmerville Fault.

The Mesozoic basins and their faults in some areas reflect the structural framework of the basement. Many of the faults that cut up through these young levels are probably the reactivation of basement anisotropy.

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