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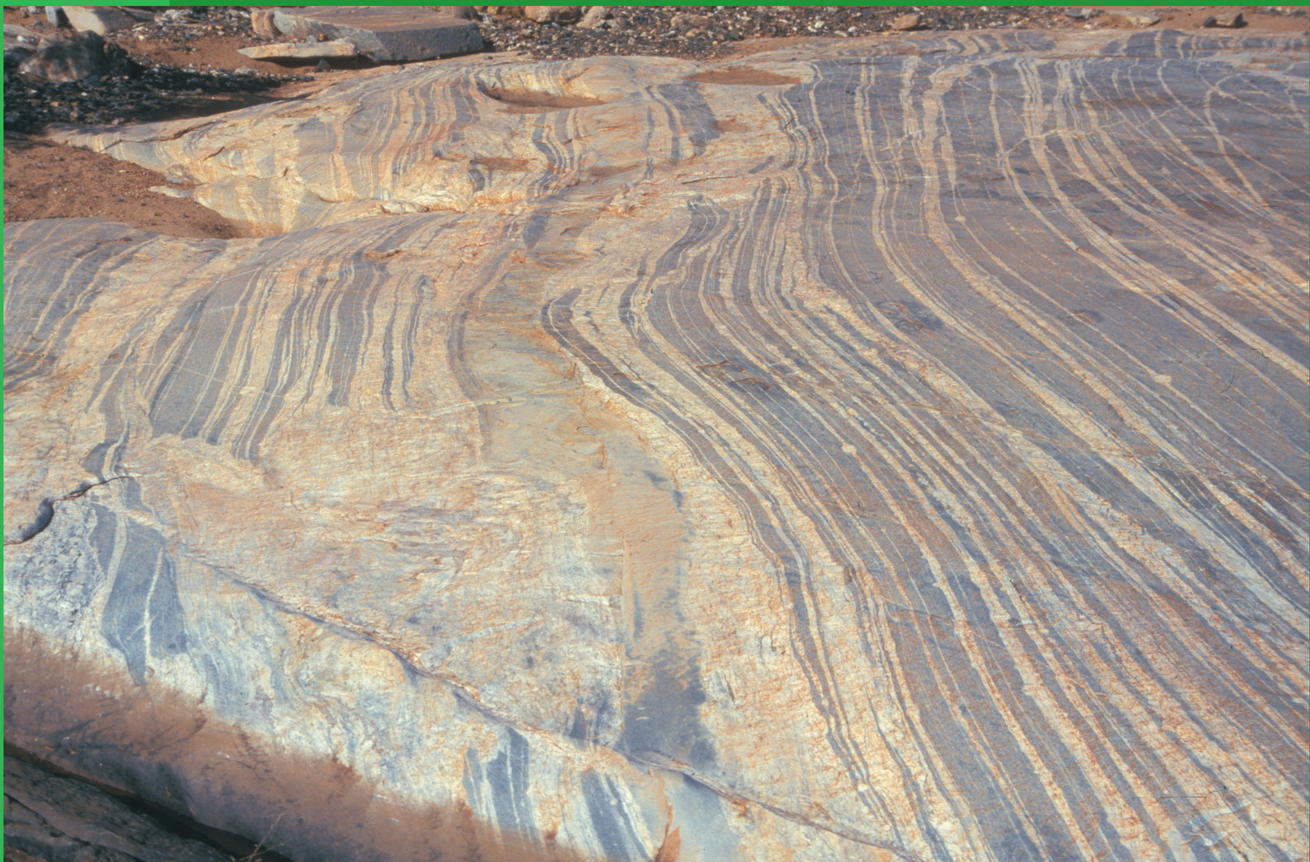
103

STRUCTURAL GEOLOGY OF THE CENTRAL PART OF THE LALLA ROOKH – WESTERN SHAW STRUCTURAL CORRIDOR, PILBARA CRATON, WESTERN AUSTRALIA

By MJ VAN KRANENDONK



Geological Survey of Western Australia

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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Cover photograph:
Amphibolite-facies, porphyroclastic straight gneiss mylonite from the western strand of the Mulgandinnah Shear Zone, at Tambourah Creek (7393406 7609900N). This 2 km wide zone forms part of the eastern margin of the Lalla Rookh – Western Shaw structural corridor. Kinematic indicators of sinistral transpressional deformation are abundant within the zone, which formed at c. 2930 Ma

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Structural geology of the central part of the Lalla Rookh – Western Shaw structural corridor, Pilbara Craton, Western Australia

by

MJ Van Kranendonk

Abstract

This report summarizes the geology of part of the Lalla Rookh – Western Shaw structural corridor, a roughly 150 km long, north to north-northeast striking zone of complex folding and shear deformation that formed at c. 2.93 Ga within the western part of the East Pilbara Terrane of the Pilbara Craton during the North Pilbara Orogeny. This deformation was superimposed on a pre-existing architecture developed during magmatic and structural events from 3.47 – 3.18 Ga. Kinematic analysis of shear zones and fold geometry shows that deformation within the 2–35 km wide corridor resulted from west-northwest directed compression and involved dominantly sinistral transpressional shearing on north to northeast-striking zones, although east-northeast striking dextral shear zones were also developed. A model of progressive rotation of structures is developed to account for northwest-striking segments of sinistral shear and for a compressional flower structure of folded and sheared granites and greenstones within a restraining bend of stepped sinistral shear splays along the northwestern margin of the Shaw Granitic Complex, which were previously interpreted as a tilted set of recumbent isoclinal folds resulting from c. 3.46 Ga Alpine-style orogeny. The structural model allows for the prediction of occurrences of gold mineralization within low pressure (extensional) domains that accords well with historical gold occurrences.

KEYWORDS: Structure, gold mineralization, Pilbara Craton

Introduction

This report describes the structural geology of the central, most structurally complex, part of the c. 2.93 Ga Lalla Rookh – Western Shaw structural corridor (LWSC), a north- to northeasterly trending zone of tightly folded, faulted, and sheared rocks that transects the East Pilbara Terrane of the Pilbara Craton (Fig. 1; Van Kranendonk and Collins, 1998; Van Kranendonk et al., 2002, 2006). This zone of dominantly sinistral transpressional shear deformation and related folding developed late in the structural history of the craton, and was superimposed on a pre-existing crustal architecture of ovoid granitic domes and intervening greenstone synclines, during a major period of compressional deformation that affected the whole of the Pilbara Craton; the North Pilbara Orogeny (Van Kranendonk et al., 2002, 2004, 2007). Deformation was synchronous with widespread emplacement of granitic rocks (Sisters Supersuite) and was accompanied by lode gold mineralization in several locations, as described further below.

A 1:50 000 interpreted bedrock geology map of the central part of the LWSC that accompanies this report includes more detail than the related parts of the previously published North Shaw and Tambourah 1:100 000 series maps (Van Kranendonk, 1999; Van Kranendonk and Pawley, 2002) and shows stratigraphic reinterpretations of the greenstone succession. The map area is characterized by very good and widespread exposure of bedrock, with only minor regolith cover (<10% by area) that has been omitted from the map to better show the interpreted distribution of bedrock units.

Previous tectonic models

Hickman (1975, 1983, 1984) ascribed deformation within the LWSC to the major deformational event that produced the dome-and-syncline geometry of the Pilbara Craton, and suggested that this event may have developed locally in some places and involved multiple phases of deformation elsewhere. More recent studies, however, have shown that doming occurred much earlier (c. 3.3 Ga) than the shear deformation in this area (Collins et al., 1998; Van Kranendonk, 2004). Oversby (1976) dated sheared rocks along the eastern margin of the LWSC (western margin of the Shaw Granitic Complex) and concluded that deformation and metamorphism occurred at c. 2950 Ma.

Bickle et al. (1980, 1985), and later Zegers et al. (1996, 2001), suggested that tightly folded granitic rocks and greenstones in the northwest Shaw area of the LWSC

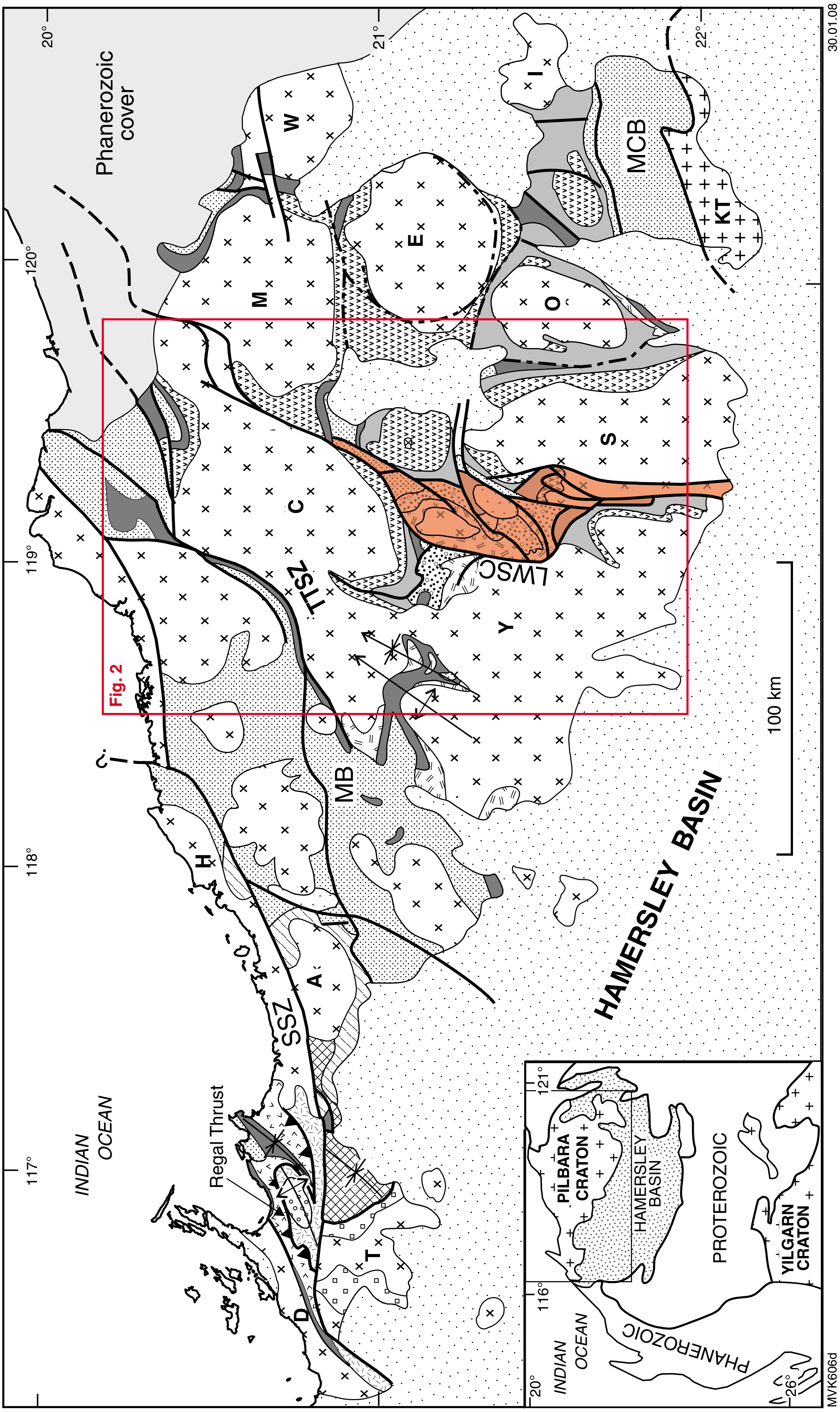


Figure 1. Simplified geological map of the Pilbara Craton, showing the location of the Lalla Rookh–Western Shaw structural corridor (LWSC shown as orange). Bold capital letters refer to granitic complexes: A = Caines Well; C = Carlindi; D = Dampier; E = Mount Edgar; H = Harding; I = Yilgalong; M = Muccan; O = Corunna Downs; S = Shaw; T = Cherratta; W = Warrawagine; Y = Yule. LRWS = Lalla Rookh – Western Shaw fault; MB = Mallina Basin; MCB = Mosquito Creek Basin; SSZ = Sholl Shear Zone; TTSZ = Tabba Tabba Shear Zone. Circled S = Strelley Monzogranite. Rectangle shows location of Figure 2. Modified from Van Kranendonk et al. (2007)

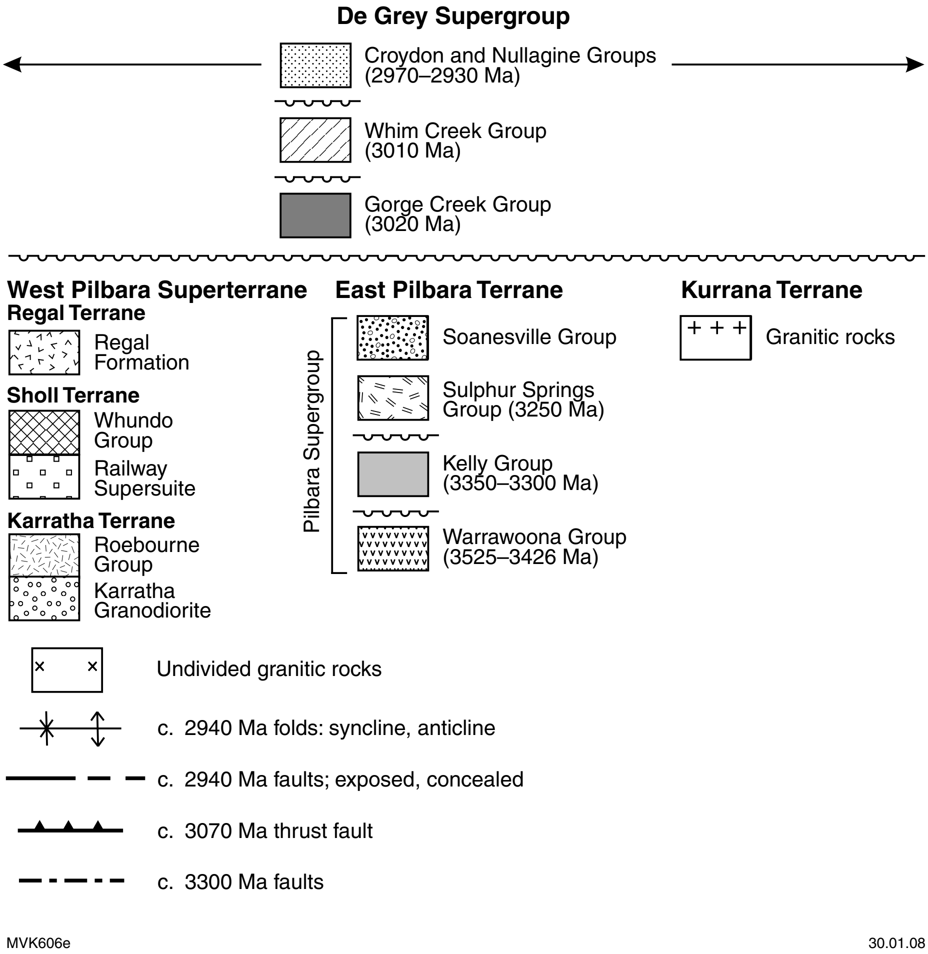


Figure 1 (continued)

developed as a result of Alpine-style thrusting and recumbent isoclinal folding that predated formation of the major dome-and-syncline geometry of the craton. These authors suggested that thrusting was the cause of local (relatively) high-pressure metamorphism in this area. Zegers et al. (2001) suggested that this episode of deformation occurred prior to 3470 Ma, when extensional detachments led to development of domes as metamorphic core complexes.

Krapez (1984), Krapez and Barley (1987), and Eriksson et al. (1994) interpreted the Lalla Rookh Basin in the middle northern part of the LWSC to represent an ensialic pull-apart basin that developed by the en echelon approach of left-stepping, sinistral strike-slip faults during local extension.

Horwitz and Krapez (1991) and Krapez (1993) applied sequence stratigraphy to the Pilbara Craton and divided it into five tectonostratigraphic domains, separated by northeast trending lineaments, following Krapez and Barley (1987). These lineaments were considered the dominant structural fabric of the Pilbara Block, and ascribed to a long history of development and reactivation. Barley (1997) suggested westward growth of the craton through accretion across these major lineaments, of which the LWSC was interpreted as one.

Van Kranendonk and Collins (1998) identified the LWSC as a corridor of linked fold structures and shear zones, developed in response to relatively late sinistral transpression. They provided evidence that the greenstone stratigraphy was continuous across the LWSC and that it therefore could not represent a terrane boundary. These authors also showed that the Lalla Rookh Basin was not a pull-apart basin, as previously suggested, but represented a fault-bounded structural remnant with symmetrical sinistral and dextral bounding faults. These authors interpreted the tight folds and high-pressure metamorphism of the northwest Shaw area to represent *post-doming* structures that developed in response to constriction within stepped shear splays of the late sinistral transpressional event (see also Van Kranendonk, 2003a,b; Van Kranendonk et al., 2004). Deformation across the LWSC was interpreted by these authors to have developed at c. 2930 Ma, based on previous isotopic dating, and this was independently verified by Zegers et al. (1998, 2001) by U–Pb zircon dating of a syn-kinematic pegmatite in the Mulgandinnah Shear Zone along the eastern margin of the LWSC.

Regional geology

The East Pilbara Terrane of the Pilbara Craton has a long and complex magmatic, sedimentary, and deformational history from 3515–2830 Ma (Van Kranendonk et al., 2006, 2007). Extensive mapping, geochronology, and geochemistry have shown that the East Pilbara Terrane was established as a protocontinental nucleus resulting from three plume-related magmatic events at 3515–3410 Ma, 3350–3290 Ma, and 3275–3235 Ma. These events resulted in the deposition of a thick, dominantly volcanic supracrustal succession, intrusion of widespread and voluminous granitic rocks, and periods of deformation at the end of each volcano-magmatic cycle arising from partial convective overturn of the upper and middle crust. These events produced the broad dome-and-keel architecture of the terrane, including bedding-(sub)parallel foliations and ring faults in older greenstones, shear zones along the margins of some of the domical granitic complexes, and chaotic internal structures within the granitic complexes (Collins et al., 1998; Van Kranendonk et al., 2004; Sandiford et al., 2004). The end product of these events was a thick crust and highly depleted subcontinental mantle lithosphere (Smithies et al., 2005b). Plume magmatism was followed by rifting of the margins of the protocontinent at between 3200–3165 Ma and the subsequent formation of juvenile, arc-related crust in the West Pilbara Superterrane at c. 3120 Ma (Smithies et al., 2005a; Van Kranendonk et al., 2007). Inferred collisional orogeny between the West Pilbara Superterrane and East Pilbara Terrane at c. 3060 Ma (Prinsep Orogeny) resulted in the development of thrusts and folds in the West Pilbara Superterrane (Hickman, 2004), but only mild deformation across the western margin of the East Pilbara Terrane. This was followed by a long period of crustal extension, when sedimentary and volcanic rocks of the c. 3020–2940 Ma De Grey Supergroup were deposited across the inferred suture zone (Van Kranendonk et al., 2007). The North Pilbara Orogeny affected the western half of the exposed craton at c. 2940–2930 Ma, followed by deformation across the southeastern margin of the exposed craton at c. 2905 Ma. Post-tectonic granitic rocks were emplaced across the southeastern part of the craton at between 2890–2830 Ma.

The LWSC varies in width from 2 km in the far south of the exposed craton, to a maximum of 35 km in the North Shaw – Tambourah area, and narrows back to a 1–2 km wide shear zone along the southeastern margin of the Carlindi Granitic Complex in the northeast (Fig. 2). The central part of the LWSC is marked by a series of kilometre-scale, close to isoclinal folds that are contained within, bounded by, and syn-kinematic with, bounding sinistral ductile shear zones and faults in, and adjacent to, granitic rocks. The lithotectonic elements of this area are shown in Figure 3 (modified from Van Kranendonk, 1998), along with the major named structural features of the map area.

The LWSC is subparallel to, and anastomoses in the same way as, the Tabba Tabba Shear Zone to the west, which developed at the same time in response to the same overall west-northwest compressional stress (Figs 1 and 2: Van Kranendonk and Collins, 1998). Contemporaneity of formation of the Tabba Tabba Shear Zone and LWSC is supported by geochronological data. A maximum age of deformation in the former zone is constrained by a deformed granite dated at 2940 ± 3 Ma (sample 160745 in GSWA 2006) and by folded and sheared rocks of the Mallina Formation that have a maximum depositional age of 2941 ± 9 Ma (sample 142188 in Smithies et al., 2002). The age of deformation in the LWSC is constrained by a 2934 ± 2 Ma age of a syn-kinematic pegmatite in the Mulgandinnah Shear Zone along the southeastern margin of the LWSC (Zegers et al., 2001), and by a 2936 ± 5 Ma age from the syn-kinematic Keep It Dark Monzogranite in the North Shaw greenstone belt (see Plate 1). Thus, the Tabba Tabba Shear Zone and LWSC define a broad, anastomosing zone of shear deformation that transects tectonic elements (e.g. the Lalla Rookh Basin, Carlindi Granitic Complex) and overprints the earlier, broad dome-and-keel geometry that is characteristic of the East Pilbara Terrane (Figs 1 and 2; Van Kranendonk et al., 2004, 2007). These zones represent an expression of the c. 2940 Ma North Pilbara Orogeny, that resulted from craton-wide compression (Van Kranendonk et al., 2006, 2007).

Lithostratigraphy of the map area

Bedrock units have been assigned to the lithostratigraphic scheme outlined in Van Kranendonk et al. (2006), based on lithological associations, structural considerations, geochemistry, and available geochronology, except for widespread areas underlain by highly strained ultramafic rocks that remain unassigned — as they may represent intrusive rocks of uncertain age and/or a mixture of intrusive and extrusive rocks of different ages/groups. In this scheme, greenstones and the sedimentary successions have been divided into the older Pilbara (3515–3165 Ma) and younger De Grey (3020–2940 Ma) Supergroups and their various component groups, formations and members, whereas granitic and mafic–ultramafic intrusive rocks have been divided into broad temporal supersuites, suites, and individual intrusions: two of the main granitic supersuites in the map area are described below. Readers are referred to the 1:50 000 scale map that accompanies this report for descriptions of rock units. Appendix 1 provides a table of rock code conversions between the published North Shaw and Tambourah 1:100 000 maps and the current map so that interested readers may look up more detailed descriptions of rock units in the published explanatory notes for those map areas (Van Kranendonk, 2000, 2003a).

Sisters Supersuite

The map area contains several intrusions that are ascribed to the 2955–2920 Ma Sisters Supersuite (Fig. 3; Van Kranendonk et al., 2006). These include: the 2927 ± 3 Ma Woodstock Monzogranite in the Yule Granitic Complex (Hickman, 1983; Van Kranendonk, 2003a); the 2936 ± 5 Ma Keep It Dark Monzogranite that intrudes greenstones across the boundary between the North Shaw greenstone belt and Emerald Mine Greenstone Complex; a small, triangular-shaped, 2933 ± 3 Ma monzogranitic intrusion in the saddle reef position of folded greenstones of the Western Shaw greenstone belt in the axial crest of the Tambourah Dome; numerous syn-kinematic pegmatite veins in the Shaw Granitic Complex, one of which is dated at 2934 ± 2 Ma (Zegers et al., 2001).

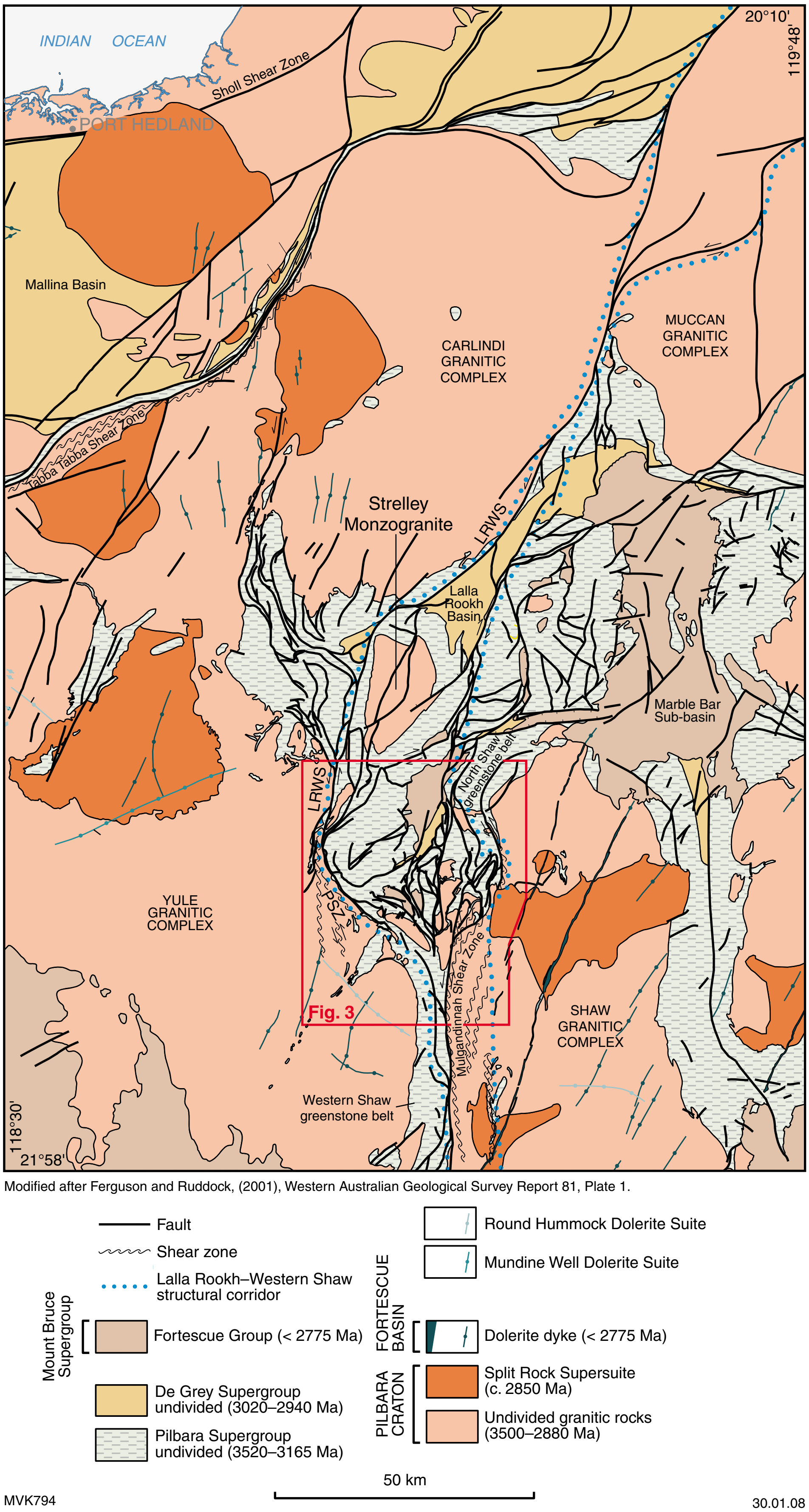


Figure 2. Simplified geological map of the western part of the East Pilbara Terrane, showing the extent of the LWSC and location of the map area

Split Rock Supersuite

The c. 2850 Ma Cooglegong Monzogranite of the Shaw Granitic Complex is the only member of the post-tectonic, 2890–2830 Ma Split Rock Supersuite (Van Kranendonk et al., 2006) in the map area. This large, multi-component, layered intrusion, which has a flat lower contact with older granitic rocks of the complex in the west (Van Kranendonk, 2003a), is undeformed except for minor faults filled with greisen veins and late quartz veins. Lithological descriptions of this unit are presented in Van Kranendonk (2003a) and Bagas et al. (2004).

Lithotectonic elements of the map area

The map area is located within the East Pilbara Terrane of the Pilbara Craton and includes outliers of the Lalla Rookh Basin (De Grey Superbasin: Croydon Group, De Grey Supergroup) and Marble Bar Sub-basin of the Fortescue Basin (Fortescue Group, Mount Bruce Supergroup; Fig. 3). The rocks can further be divided into four types of lithotectonic units, following Van Kranendonk (1998): greenstone belts, greenstone complexes, granitic complexes, and basins (Fig. 3). Map data suggest that greenstone lithostratigraphy can be traced continuously across greenstone belts and greenstone complexes, as described below.

Greenstone belts

Greenstone belts consist of tilted and/or folded supracrustal and intrusive igneous rocks belonging to the Pilbara Supergroup that are generally well preserved and generally at low metamorphic grade (prehnite–pumpellyite to upper greenschist facies, with local areas of amphibolite facies). Parts of the North Shaw, Pincunah, Soanesville, and Western Shaw greenstone belts are present in the map area (Fig. 3).

The North Shaw greenstone belt consists of a west-facing greenstone assemblage. The eastern margin is attached to the Shaw Granitic Complex across an intrusive contact with granitic rocks of the Callina Supersuite. The western margin of the belt is in depositional contact with unconformably overlying rocks of the Fortescue Group, and to the south, the belt is either in sheared contact with rocks of the Emerald Mine Greenstone Complex or intruded by the c. 2936 Ma Keep It Dark Monzogranite.

The fault-bounded Pincunah greenstone belt consists of a thin sliver of fault-dismembered and folded greenstones that represent the attenuated southern tip of a much broader succession of little-deformed greenstones to the north and west.

The Soanesville greenstone belt is fault-bounded along its southern contact with the Tambina Greenstone Complex (Cajaput Soak Fault) and western contact with the Yule Granitic Complex (Lalla Rookh–Western Shaw Fault; Fig. 3). The western contact of the belt is faulted against highly strained granitic rocks within the ductile Pulcunnah Shear Zone (see below). The eastern contact of the Soanesville greenstone belt is an unconformity with overlying rocks of the Fortescue Group.

The Western Shaw greenstone belt consists of an east-, north-, and northwest-facing panel of greenstones that wraps around the Tambourah dome. The belt has intrusive contacts with the Yule Granitic Complex in the west and northwest, and faulted contacts with the Emerald Mine Greenstone Complex and Shaw Granitic Complex in the north and east, respectively. Granitic rocks of the Shaw Granitic Complex exposed within the core of the Tambina Anticline have sheared intrusive contacts with greenstones of the Western Shaw greenstone belt.

Greenstone complexes

Greenstone complexes consist of Pilbara Supergroup rocks that have been affected by strong shear deformation, faulting, and tight folding. The Tambina Greenstone Complex includes areas of low- to highly strained greenstones (Warrawoona and Kelly Groups) and ultramafic rocks, and a large area of tightly folded rocks of the Soanesville Group. Rocks within this complex are highly structurally dismembered by a fanning array of faults that vary from northwest- to north-striking across the complex from west to east. Although some of the faults post-dated deposition of the Fortescue Group, most are the result of deformation during the North Pilbara Orogeny. The Emerald Mine Greenstone Complex shares a faulted western contact with the Tambina Greenstone Complex, along a fault that extends northward from the western edge of the Shaw Granitic Complex. The Emerald Mine Greenstone Complex is a faulted against strongly sheared intrusive rocks of the Shaw Granitic Complex deformed within the Mulgandinnah Shear Zone. The northern contact of this greenstone complex is a sheared or faulted contact with the North Shaw greenstone belt, and a faulted intrusive contact with the Keep It Dark Monzogranite.

Granitic complexes

Granitic complexes are composed predominantly of granitic rocks that have a variety of ages and compositions. Granitic components have been divided into a number of supersuites based on age, composition, and state of deformation (Van Kranendonk et al., 2006). Granitic Complexes may, however, include large rafts and xenoliths of supracrustal rocks, as is best seen in the Shaw Granitic Complex on TAMBOURAH (Van Kranendonk and Pawley, 2002).

The Shaw Granitic Complex is a large (60 × 30 km), structural and magmatic dome of a variety of age and composition of granitic rocks. It forms the core of the Shaw Dome that also includes the flanking North Shaw and Coongan greenstone belts (Fig. 3). Components of the Shaw Granitic Complex are also exposed within the core of the Tambina Anticline in the Western Shaw greenstone

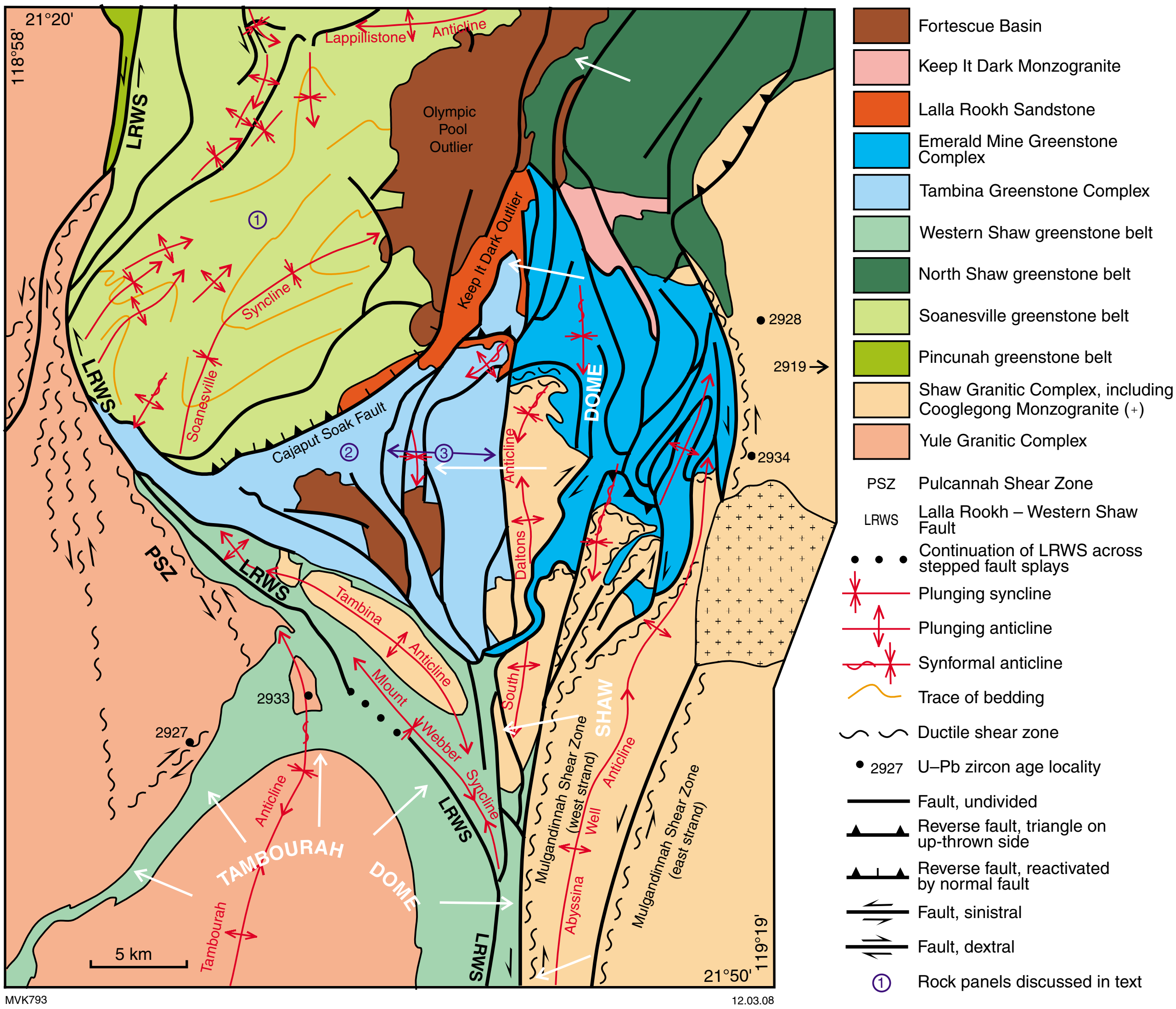


Figure 3. Simplified geological map of the central part of the LWSC, showing the major lithotectonic and structural elements and U–Pb zircon geochronology sites

belt. The complex developed through multiple stages of intrusion and partial melting that were accompanied by pulses of partial convective overturn from 3470–2850 Ma, with major phases of doming at c. 3.40 Ga and c. 2.93 Ga. Most of the doming was completed prior to emplacement of the Split Rock Supersuite (2890–2830 Ma), as these rocks show flat intrusive contacts against older granitic components (Van Kranendonk, 2003a). In the map area, the Shaw Granitic Complex contains remnants of older structural fabrics in the east, and a broad zone (1–4 km) of high strain along its western margin, known as the Mulgandinnah Shear Zone (described in more detail below).

The southeastern part of the 120 km-wide Yule Granitic Complex underlies the western part of the map area and may be divided into two components: a domal area of granitic rocks within the core of the Tambourah Anticline, with contacts subparallel to bedding in flanking greenstones and forming the core to the Tambourah Dome; and a larger area of granitic rocks to the north that has crosscutting intrusive or strongly sheared intrusive contacts with flanking greenstones.

Basins

Two phases of basin sedimentation are preserved in the map area. The first is in the Keep It Dark Outlier of the Lalla Rookh Basin in the north-central part of the map area, which contains coarse clastic rocks of the Lalla Rookh Sandstone (Croydon Group, De Grey Supergroup). Although commonly faulted, the basal unconformity of this succession on Pilbara Supergroup rocks is well preserved in a number of places (e.g. at MGA 723500E 7619000N, 730000E 7621000N, 730900E 7622600N).

The youngest phase of sedimentation is preserved in the synclinal Olympic Pool Outlier of the Marble Bar Sub-basin of the Fortescue Basin (Fortescue Group, Mount Bruce Supergroup) in the north-central part of the map area (Van Kranendonk, 2000), as well as two smaller synclinal outliers filled by basal clastic rocks of the group in the central part of the map area. The basal unconformity of the Fortescue Group is well preserved in many places for the Olympic Pool Outlier (e.g. MGA 725200E 7631000N), as well as for the two smaller structural outliers (e.g. MGA 720800E 7614200N). The unconformity that separates the two phases of basin fill is well preserved on NORTH SHAW (MGA 731400E 7629250N; Van Kranendonk, 2000). Chan (1998) and Van Kranendonk (2003a) provided evidence that the two smaller basins were developed partly as in situ grabens and partly as structural remnants of a larger basin.

Structural elements of the map area

Structural elements in the map area were formed during several deformational events, as outlined elsewhere (Van Kranendonk and Collins, 1998; Van Kranendonk, 2000, 2003a; Van Kranendonk et al., 2004). Most of the structural features, including the LWSC and all structures contained therein, are interpreted to be the product of deformation arising from the c. 2.94 Ga North Pilbara Orogeny (Van Kranendonk et al., 2006), although some older structures are preserved within the eastern part of the Shaw Granitic Complex and in the North Shaw greenstone belt, and some younger structures are the result of deformation synchronous with, or post-dating, deposition of the Fortescue Group (Van Kranendonk, 2003b). The major older structures include the Tambourah and Shaw Domes (Fig. 3), which developed from 3470–3165 Ma and were reactivated during subsequent events (Van Kranendonk et al., 2002, 2004, 2007).

The focus of this report is on structures developed during the North Pilbara Orogeny within, and immediately adjacent to, the LWSC. The following elaborates on previous structural interpretations of this area, as referenced above.

Lalla Rookh – Western Shaw structural corridor

The LWSC in the map area is a broad, north-trending zone of tightly folded and highly faulted greenstones and high strain ductile shear deformation within granitic rocks. The corridor varies from 7 km wide in the southern part of the map area, to 33 km wide in the central part, and narrows again to the north of the map area. The margins of the LWSC are locally sharply defined by discrete faults, but elsewhere the margins are ragged and splay into adjacent, less strongly deformed, rocks. The best example of this is the Lalla Rookh – Western Shaw Fault along the western boundary of the LWSC in the southern part of the map area. This fault is continuous both to the north and south of this area across the whole of the exposed northern part of the Pilbara Craton, a distance of ~150 km (see Figs 1 and 2). In other places, the margins of the LWSC are defined by ductile shear zones in granitic complexes, including two major shear zones developed within the Yule and Shaw Granitic Complexes, known as the Pulcunnah and Mulgandinnah Shear Zones, respectively (Figs 2 and 3). Both of these sinistral ductile shear zones have discrete strands and splays of high-strain ductile deformation.

Within the central part of the LWSC, greenstones have been tightly folded into a number of upright to overturned folds with moderate to steep, and even overturned, plunges. There are two broad clusters of folds in the map area: one is developed within the Emerald Mine and Tambina Greenstone Complexes and the northern part of the Western Shaw greenstone belt (Fig. 3). This fold cluster defines a fanning array of upright folds that vary in trend from north-northeast in the far eastern part of the Emerald Mine Greenstone Complex and western margin of the Shaw Granitic Complex (e.g. Abyssinia Well Anticline), through north-trending in the western part of this complex, eastern part of the Tambina Greenstone Complex and western margin of the Shaw Granitic Complex (e.g. South Daltons Anticline), to northwest-trending in the western part of the Tambina Greenstone Complex and northern part of the Western Shaw greenstone belt (Tambina Anticline and Mount Webber Syncline). The second cluster of folds is developed in the Soanesville greenstone belt, north of the Cajaput Soak Fault (Fig. 3). The folds in this cluster are predominantly northeast-trending and northeast-plunging, but include a radiating set of southwest-, south-, and southeast-plunging folds in the northern part of the map area.

A large number of linked, curviplanar faults, with dips that vary from vertical to moderate, transect rocks and bound folds within the central part of the LWSC, most prominently within the Emerald Mine and Tambina Greenstone Complexes and in the western part of the Shaw Granitic Complex. These faults display a variety of displacements, including sinistral, dextral, reverse, and normal, and locally grade laterally into ductile shear zones within granitic rocks, as described in detail below.

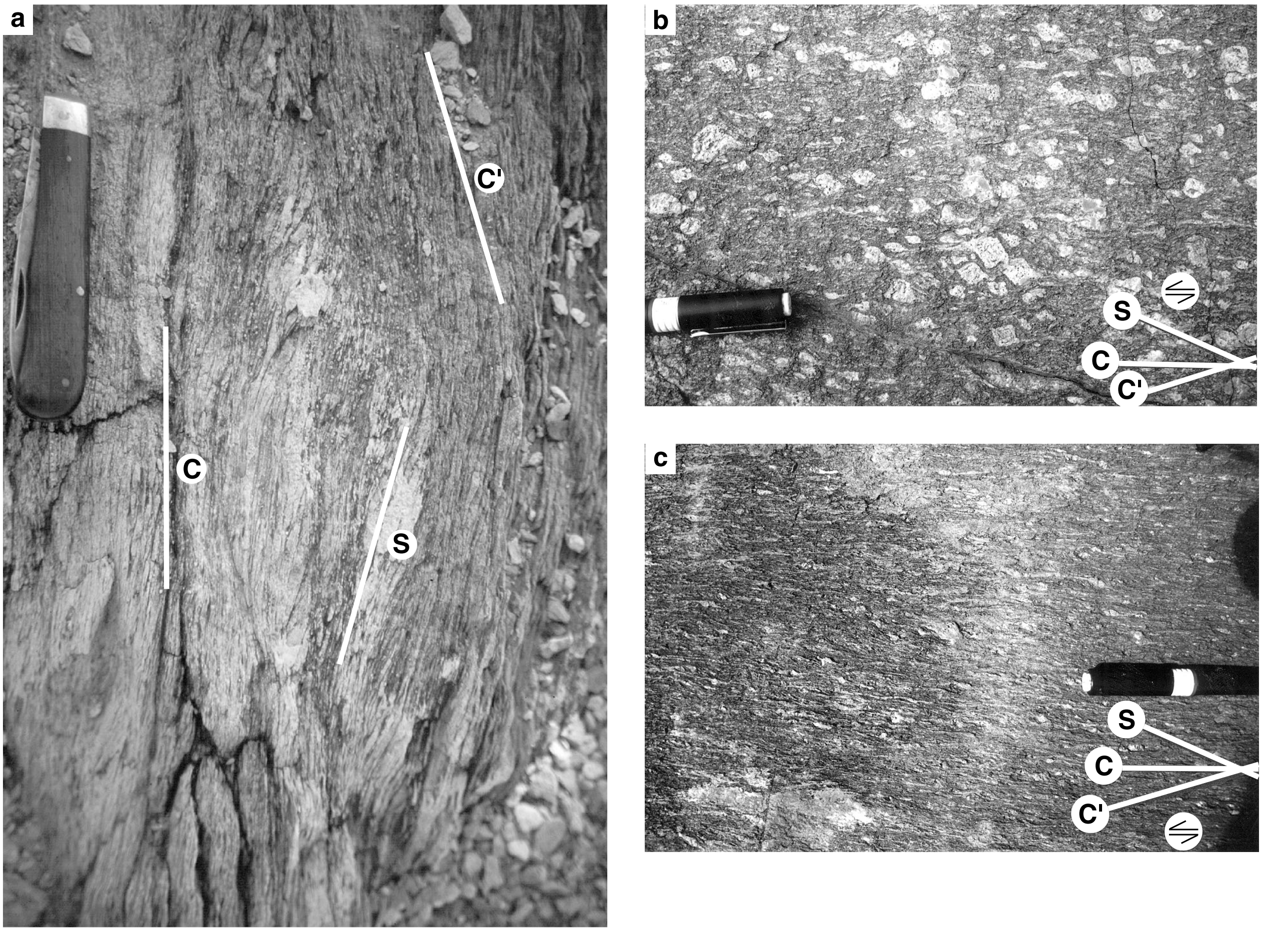
Lalla Rookh – Western Shaw Fault

The Lalla Rookh – Western Shaw (LRWS) fault is a (mostly) continuous, curviplanar, and steeply-dipping structure that marks the western margin of the LWSC (Fig. 2). The 'S'-shaped asymmetry of large-scale folds defined by rock units in the Soanesville greenstone belt adjacent to the fault indicate a sinistral sense of displacement across the fault, as does the offset of stratigraphy across the fault further north (cf. Van Kranendonk and Collins, 1998; Van Kranendonk, 1999, 2000).

In the northern part of the map area, the LRWS is subvertical and locally marked by thick (tens of metres) veins of massive white quartz. In the central part of the map area, where the fault swings from north–south to northwest–southeast striking, the fault dips steeply (~75°) to the northeast and is located along the boundary between the Yule Granitic Complex and greenstones of the Soanesville greenstone belt and Tambina Greenstone Complex. Splays of the fault extend to the northeast into the Soanesville greenstone belt. Along strike to the south, the fault continues within greenstones of the Western Shaw greenstone belt, where it is locally intruded by coarse-grained to pegmatitic, weakly foliated, syn-kinematic monzogranite (MGA 722200E 7607200N). In the central-southern part of the map area, the LRWS fault becomes discontinuous and transfers into a set of en echelon, north-northwest-striking fault strands that cut the axial trace of the Mount Webber Syncline (black dots on Fig. 3; see map and discussion below). To the south of this, the fault is re-established as a continuous structure, striking to the southeast and south within greenstones of the Western Shaw greenstone belt. Where developed in greenstones, the LRWS fault is a narrow zone (10 m wide) of chlorite schist, locally with well-developed S–C–C' fabrics indicating sinistral shear displacement (Fig. 4a).

Pulcunnah Shear Zone and related shear splays

The western-most structures of the LWSC are developed in the Yule Granitic Complex as splayed strands of sinistral ductile shear deformation. These include: a south-southwest striking western strand in, and west of, a large greenstone enclave that has moderately steep



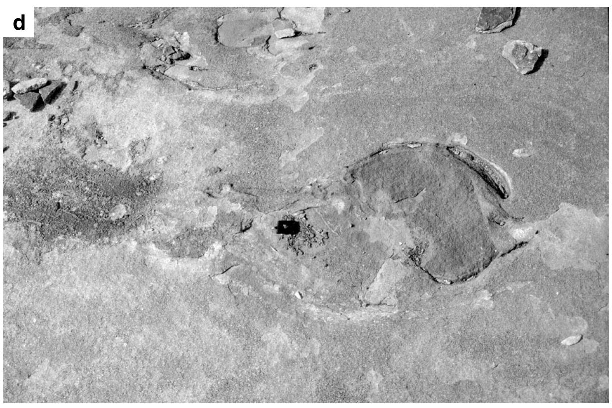


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Figure 4. Outcrop photographs of shear structures along the western margin of the LWSC: a) mylonitic chlorite schist from the southern part of the Lalla Rookh – Western Shaw Fault, showing C–S–C' fabrics indicative of sinistral shear (MGA 831240E 7591950N); b) coarsely porphyroclastic protomylonitic Woodstock Monzogranite from the sinistral Pulcunnah Shear Zone, showing well developed C–S–C' planes; c) porphyroclastic granite mylonite derived from the Woodstock Monzogranite from the sinistral Pulcunnah Shear Zone, showing strong development of C' extensional shear bands; d) a asymmetrically rotated xenolith in isotropic Woodstock Monzogranite, indicating dextral igneous flow (compass for scale)

northwest-dipping (60°) foliations and moderately north-plunging folds and mineral elongation lineations; a steeply west-dipping (85°), north–south oriented central strand that has subhorizontal to moderately north-plunging mineral elongation lineations (0–46°) in the north and south-plunging mineral elongation lineations in the south (4–20°); the moderate to steeply east-northeast dipping (47–83°), southeast-striking Pulcunnah Shear Zone along the northeastern margin of the complex that is characterized by moderately northwest-plunging mineral elongation lineations. All shear strands are characterized by closely spaced foliations and sinistral kinematic indicators, such as S–C–C' fabrics and rotated K-feldspar phenocrysts (see Fig. 4b,c). Strong ductile shear fabrics are developed over a maximum width across strike of 2 km where the shear strands merge in the northern part of the zone, but all shear strands die out along strike to the south (Fig. 3). Where the central shear strand dies out, the strain is partly accommodated by brittle quartz-filled faults that are slightly offset to the east.

A broad zone of 060º-trending dextral shear fabrics extends from the southern tip of the central shear strand of the Pulcunnah Shear Zone, manifest as a strong igneous flow alignment of K-feldspars in isotropic monzogranite and as rotational asymmetry of grey granitic xenoliths (Fig. 4d; Pawley and Collins, 2002; Van Kranendonk, 2003a). The igneous flow fabrics in this high strain zone indicate that shear deformation developed during emplacement of the host Woodstock Monzogranite, which is dated at 2927 ± 3 Ma (sample 142885 in GSWA, 2006). The eastern end of this zone dies out along the intrusive contact between the Woodstock Monzogranite and the Western Shaw greenstone belt.

Soanesville greenstone belt

Dominant structures within the Soanesville greenstone belt (labelled 1 on Fig. 3) include the upright, northeast-striking and -plunging Soanesville Syncline in the south, the west-plunging Lappillistone Anticline in the north, the LRWS Fault along the western margin of the belt, and the Cajaput Soak Fault along the southern margin. The Soanesville Syncline is subparallel to a series of northeast-plunging, 'S'-asymmetric folds adjacent to the western margin of the belt that root into the LRWS and Pulcunnah Shear Zone (see map). Subparallel, northeast- and southwest-plunging folds also affect rocks of the Sulphur Springs Group to the northwest of a prominent fault splay that forms the northwestern margin of the Soanesville Syncline. At the northern tip of this fault, fold axial planes show a radial orientation, from northwest-trending, to northeast-trending to south-trending to southeast trending, and west-trending (Lappillistone Anticline) in an anticlockwise fashion starting in the northwest (Fig. 5; Van Kranendonk, 2000). Although some folds in this area show overprinting relationships, most folds are *not* refolded and developed from a singularity at the northeastern tip of the Lapillistone Anticline, indicating their contemporaneous development in response to compression and pinching of rocks between competent blocks that are represented by: felsic volcanic rocks of the Sulphur Springs Group and Strelley Monzogranite in the north; Lappillistone Anticline in the east; and anticlinal remnants surrounded by Soanesville Group rocks in the southwest (Fig. 3).

The Cajaput Soak Fault (Fig. 3) is a complex structure with stratigraphic evidence for re-activation and periods of different displacement directions. In the southeast, the juxtaposition of rocks of the Euro Basalt to the north of the fault against rocks of the Soanesville Group to the south indicates that the main component of displacement across this fault was north-side-up displacement. Although the dip of the fault could not be directly observed in the field, the fact that it swings to the northwest on the western end of the fault, and that bedding of Euro Basalt dips to the north, suggests that the fault probably dips to the north and thus is a reverse fault. However, the presence of a small lens of coarse clastic rocks of the Croydon Group along the northern side of the northeastern extent of the fault (MGA 724000E 7619000N) suggests a period of north-side-down displacement during late reactivation of the fault. The presence of this small synclinal remnant of the Croydon Group is one piece of evidence for syn-deformational deposition of this group.

Emerald Mine and Tambina greenstone complexes and adjacent areas

A fanning array of upright folds and shallow to steeply dipping faults is developed across the widest part of the LWSC in the northern part of the Western Shaw greenstone belt, the Tambina and Emerald Mine Greenstone Complexes, and the northwestern part of the Shaw Granitic Complex. This set of structures is bounded to the southwest by the LRWS Fault, the Cajaput Soak Fault in the northwest, the Mulgandinnah Shear Zone in the east, and faults that separate the Emerald Mine greenstone complexes from the North Shaw greenstone belt (Fig. 3). The trend of fold axial planes and strike of major faults changes from northwest, to north, to north-northeast striking from west to east across this area. Faults are highly curved structures with a variety of dip directions and senses of displacement, whereas folds generally have approximately straight axial planes, and are locally developed within fault-bounded rock panels, but also locally affect faults, indicating their contemporaneous development as a linked set of structures that accommodated significant compressional deformation across the LWSC (see **Structural interpretation**, below).

The oldest structures in this area are the Tambina Anticline – Mount Webber Syncline fold pair in the Western Shaw greenstone belt, which trend parallel to the LRWS fault (Fig. 3). The Mount Webber Syncline to the southwest is developed in greenstones and has a hinge zone marked by the conspicuous development of strongly lineated (metamorphic mineral elongation and colinear pencil cleavage lineations) amphibolites (Fig. 6a). These folds represent an early component of compressional deformation under amphibolite-facies conditions, as indicated by the fact that they are locally cut by splays of the LRWS Fault (e.g. MGA 724000E 7605750N) and are locally overprinted by a second generation of northeast-

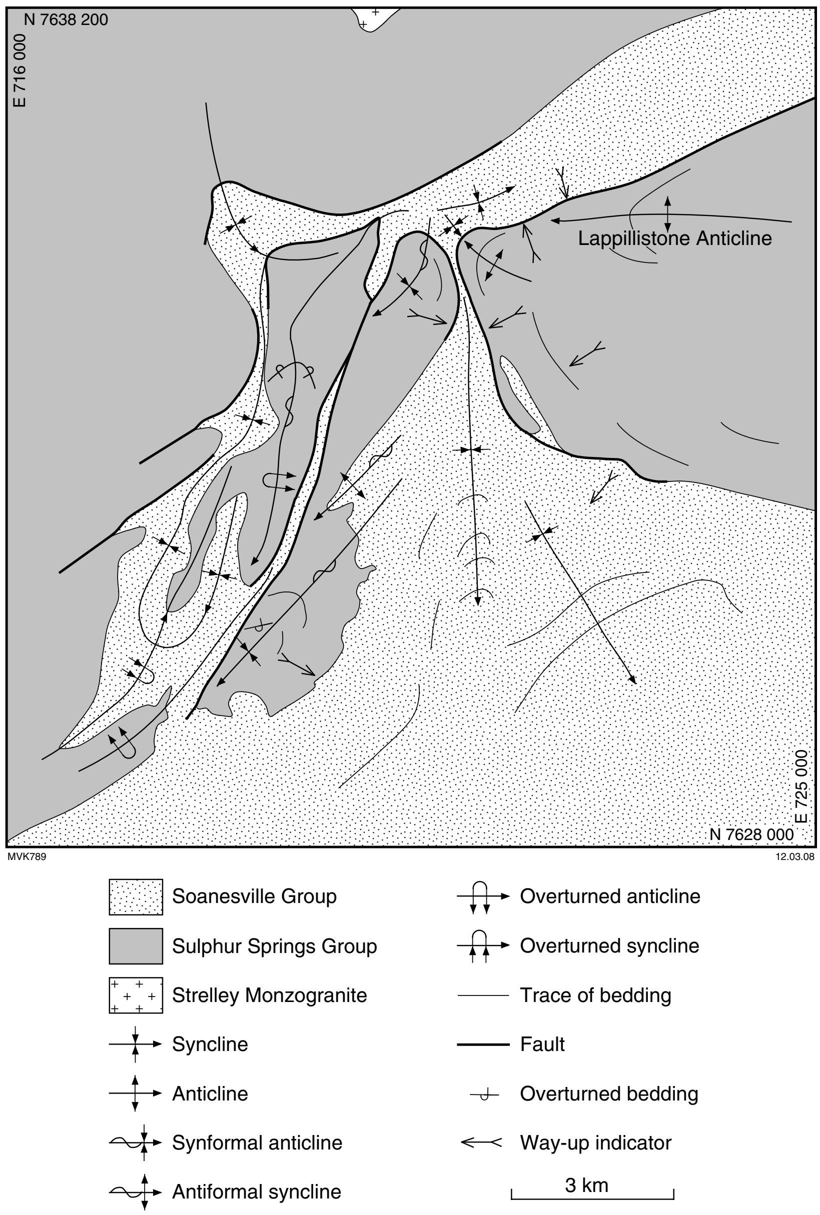


Figure 5. Summary sketch showing the radiating nature of fold axial traces out from the pinched area of rocks between the Lappillistone Anticline and Strelley Monzogranite

and southwest-plunging folds on steeply dipping, north-northwest striking axial planes in the southeastern hinge zone of the Tambina Anticline (Figs 6b, 7).

The western half of the Tambina Greenstone Complex, north and northeast of the Tambina Anticline (labelled 2 in Fig. 3), contains folds of pre-Fortescue Group rocks that trend north to north-northeast at a high angle to the Cajaput Soak Fault, which they do not transect. Faults in this area are curviplanar structures that vary in strike from west-northwest to north-northeast.

The panel of rocks to the east (labelled 3 on Fig. 3) is, in general, a complexly faulted syncline. Rocks in the southern part of this panel define a south-plunging syncline, but in the central-north part of this panel, only the eastern limb of the syncline is preserved between highly curved and folded faults (Fig. 8). Rocks in the northern part of this panel are deformed into a south-southwest-plunging synformal anticline, with a faulted out eastern limb. Based on lithological associations and the continuation of the unconformity between rocks of the Croydon Group and Soanesville Group, it is most likely that point 1 on the southern edge of the Keep It Dark Outlier of the Lalla Rookh Basin matches up with point 1' on the folded and fault-bounded slice in the middle of this panel, indicating that the fault that bounds this slice was sinistral (arrows near point 2 on Fig. 8). This suggests that the northwest-facing direction in Euro Basalt at point 2 likely represents a continuation of the greenstone panel at point 2'. What is also likely is that the felsic volcaniclastic rocks at point 3 match up with those

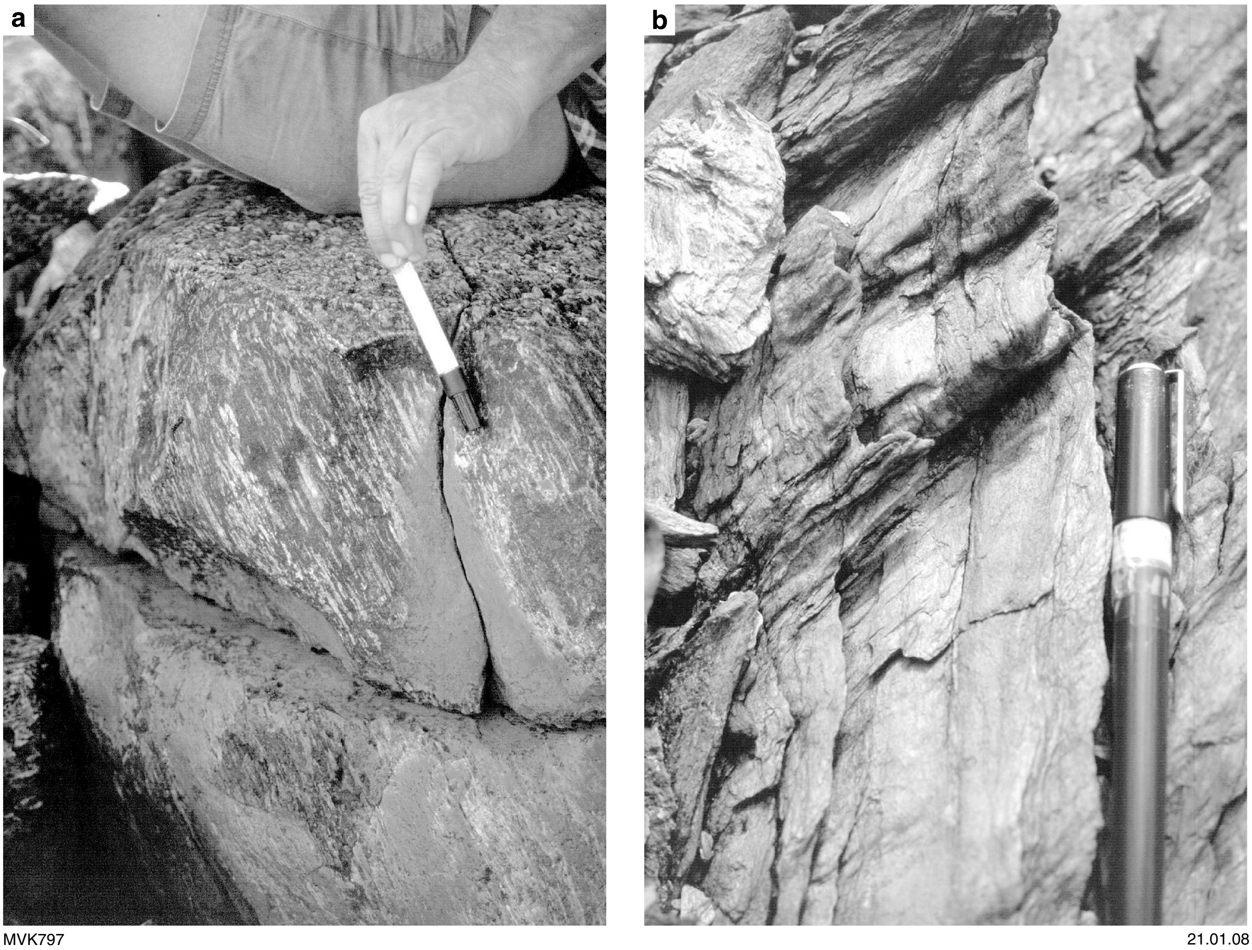


Figure 6. **Outcrop features of the structural fabric elements from the Western Shaw greenstone belt: a) outcrop view of the characteristic strongly lineated (metamorphic mineral elongation) amphibolite from the hinge zone of the Mount Webber Syncline (MGA 726040E 7603200N; marker pen is 14 cm long); b) crenulation F_2 folds of mylonitic schistosity (S_1) and lineations (L_1: parallel to pen) in chlorite schists from the southeastern hinge of the Tambina Anticline (MGA 728450E 7602910N)**

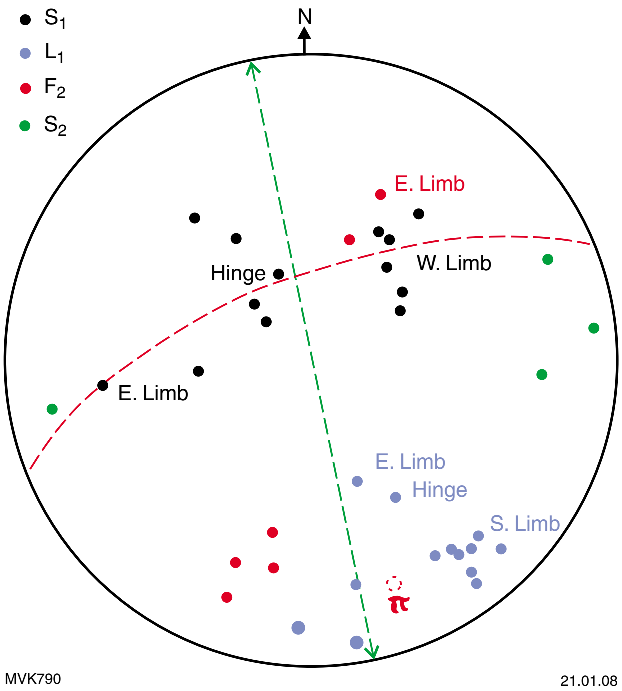


Figure 7. **Equal area stereoplot of overprinting structural fabric elements from the southeastern hinge zone of the Tambina Anticline, including L_1 lineations, poles to S_1 foliations, F_2 fold axes and poles to S_2 foliations. Areas of observation are indicated (western limb, hinge zone, or eastern limb of anticline). Dashed red line is girdle-to π–pole (22°→ 161°) of S_1 foliations. Dashed green line is girdle to S_2 foliations: note that F_2 folds lie off of this girdle, indicating progressive rotation of structures (see text for discussion)**

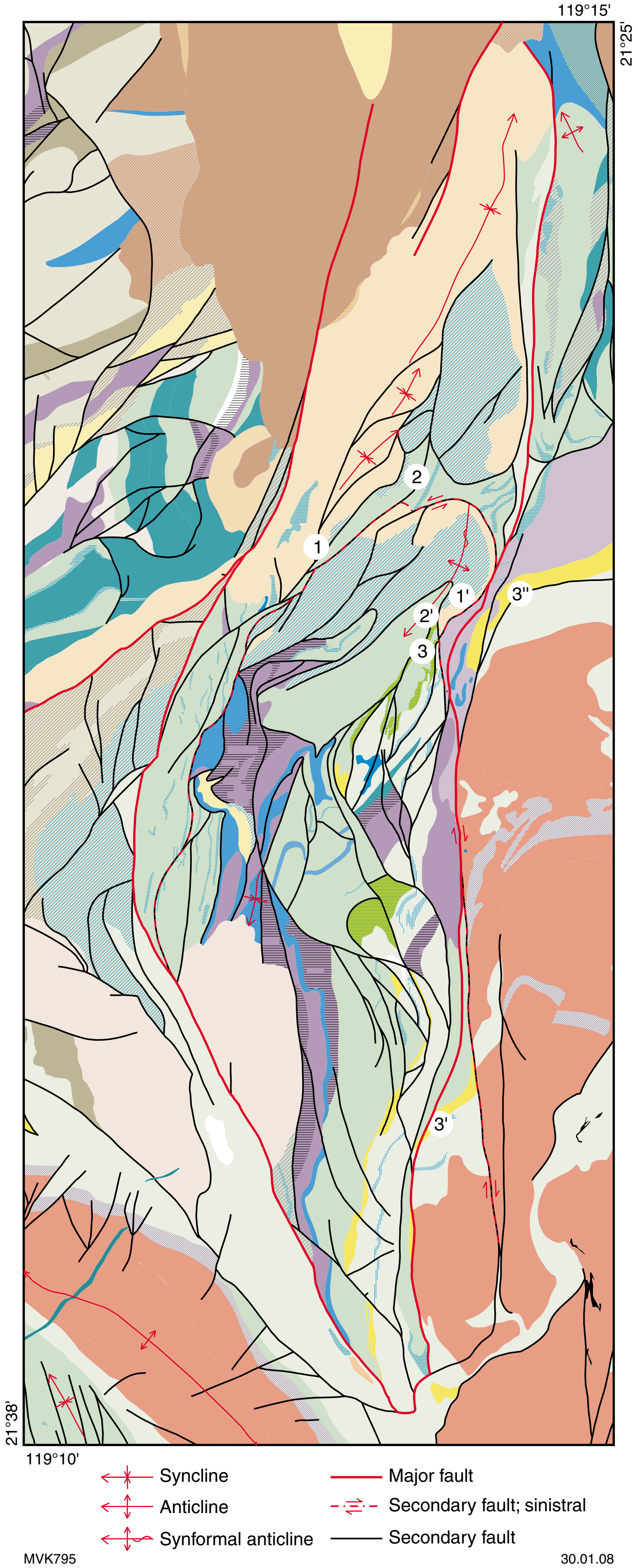


Figure 8. Annotated map of central panel 3 of the LWSC map (Fig. 3), showing major faults and synclines and points used for reconstruction of displacements discussed in the text

at 3', thereby implying significant translation (~9 km) of the whole of this panel to the north, relative to the Shaw Granitic Complex, across what must therefore be a dextral fault. However, since it is clear that the panel at point 3' matches up with point 3" (dash double dot fault on Fig. 8), parts of this fault represents a superimposed pair of faults that experienced both sinistral and dextral displacement over time.

Five fold lobes of granitic rocks and flanking greenstones are present in the northwestern part of the Shaw Granitic Complex and Emerald Mine Greenstone Complex (Fig. 9; see also Bickle et al., 1985). Two distinct granitic phases are deformed in the fold lobes. The largest (fold lobe 1) is a doubly plunging anticline cored by the homogeneous 3431 ± 6 Ma South Daltons Pluton of the Tambina Supersuite, which for the most part is medium-grained and weakly strained (McNaughton et al., 1993). The southern parts of lobe 1 and lobe 2, most of lobe 4, and parts of lobe 3 are composed of little-deformed, high level, weakly porphyritic granodiorite of the same supersuite. Weakly strained, magmatically-sheeted tonalite and mesocratic quartz diorite of the 3500–3450 Ma North Shaw Suite (Callina Supersuite) underlies lobes 3 and 5. Highly strained, gneissic equivalents of these rocks occupy part of lobes 4 and 5. The more homogeneous granitic rocks of the c. 3430 Ma Tambina Supersuite intruded the gneisses, thereby indicating that the gneissosity formed at between c. 3470–3430 Ma (e.g. Fig. 13a in Van Kranendonk, 2003a). However, both granitic components have been affected by the folding and faulting associated with formation of the LWSC, as have rocks of the Soanesville Group, such that these structures are all younger than c. 3200 Ma, which contradicts a previous interpretation by Zegers et al. (1996, 2001), as discussed below.

Felsic schist of the Duffer and/or Panorama Formations can be traced almost continuously around the folded granitic lobes as a series of tectonically thinned and locally dismembered slivers. These felsic schists strike southeast and dip to the southwest around the northern parts of lobes 1 and 3. Facing directions from underlying and overlying pillow basalt in these areas indicate that the succession faces away from the granitic rocks, but is overturned (cf. Bickle et al., 1980). The hinges of folds through the axes of these lobes plunge to the south-southwest, parallel to chlorite lineations, and thus the folds represent synformal anticlines (Fig. 9).

Lobe 1 is strongly foliated along its northern and southern contacts and lies in contact with amphibolite-facies pillow basalts that also occur as screens and inclusions within the lobe where they are extensively altered and metasomatized (see map). North of lobe 1 granitic rocks and their flanking amphibolites is a unit of chloritic schist and breccia which contains dismembered and folded units characterized by strongly developed, southwest-plunging lineations.

The sinistral mylonites of the western strand of the Mulgandinnah Shear Zone can be traced northward into the southern, mylonitic roots of lobes 2–4 (Fig. 9). The eastern margin of lobe 2 is a 500 m wide zone of sinistral porphyroclastic mylonite and straight gneiss (a ductile, recrystallized mylonite). Sinistral mylonite fabrics in the northern part of the zone are tightly folded and cut by discrete sinistral shears as a result of progressive deformation (Fig. 10a). To the west, mylonitic fabrics follow the outline of the lobe. Along the northern contact, foliation in black, weakly porphyroclastic, flinty ultramylonite derived from granitic protoliths (Fig. 10b) dips steeply to the north towards amphibolite-facies greenstones. Plunge directions of lineations within the mylonite and ultramylonite vary along strike from north-northwest in the northeast, to southwest along the western part of the contact where dextral kinematic indicators were observed (Fig. 9). North of lobe 2, lineated and foliated amphibolite-facies greenstones are disrupted and folded within a large-scale tectonic breccia (*API-muxt* on map), characterized by south-southwest plunging lineations.

Lobe 3 is composed entirely of granoblastic, annealed, tonalitic straight gneiss and mylonite. Mylonitic foliations outline the lobe margins and amphibolite-facies metavolcanics, and mineral elongation lineations plunge to the south and southwest. Kinematic indicators across the southern root of the lobe and along the western contact show sinistral displacement, whereas a 'Z'-asymmetric fold of a perturbation along the eastern contact, together with 'Z' folds and dextral shear bands in the adjacent greenstones, indicates a local component of dextral shear. Across the northern end of the lobe, kinematic indicators of reverse, south-side-up shear were observed.

Lobe 4 contains sinistral shear indicators along the southwestern contact and dextral indicators along the northwestern contact, with no evidence of overprinting relationships between the two. Along the northern contact, steeply plunging sheath folds were observed. In contrast, the southern part of the lobe is composed of weakly strained, homogeneous granodiorite–granite that contains folded S_1 foliations with a 'Z'-asymmetry. Amphibolite-facies mineral elongation lineations plunge to the southwest along the western contact, but folds and lineations in the east plunge to the north.

Lobes 3 and 4 are separated from a tight synform of amphibolites to the east by the Emerald Mine Shear Zone, a biotite-rich schist zone intruded by white-feldspar pegmatite, which dips steeply to the west and contains steeply plunging mineral elongation lineations. Amphibolites east of the shear zone are folded about northwest-plunging hinges that are co-linear with hornblende lineations.

Lobe 5 contains dextral porphyroclastic mylonite along the northeastern contact and within the lobe to the south (Figs 9 and 10c). The dextral mylonites are folded around the northern end of the lobe (Fig. 10d) and cut by strands of sinistral shear (Fig. 10e). Folds of the mylonitic foliations, like those of the amphibolites to the west, plunge to the northwest. The axial plane to the antiformal lobe 5 can be traced continuously south between the shear strands of the Mulgandinnah Shear Zone (Abyssinia Well Anticline; Fig. 3).

Greenstones to the north of lobes 3, 4, and 5 are deformed into a set of tight, upright north-northeast trending anticlinal and synclinal folds, in panels bounded by highly curved faults (see Plate 1). These folds die out along

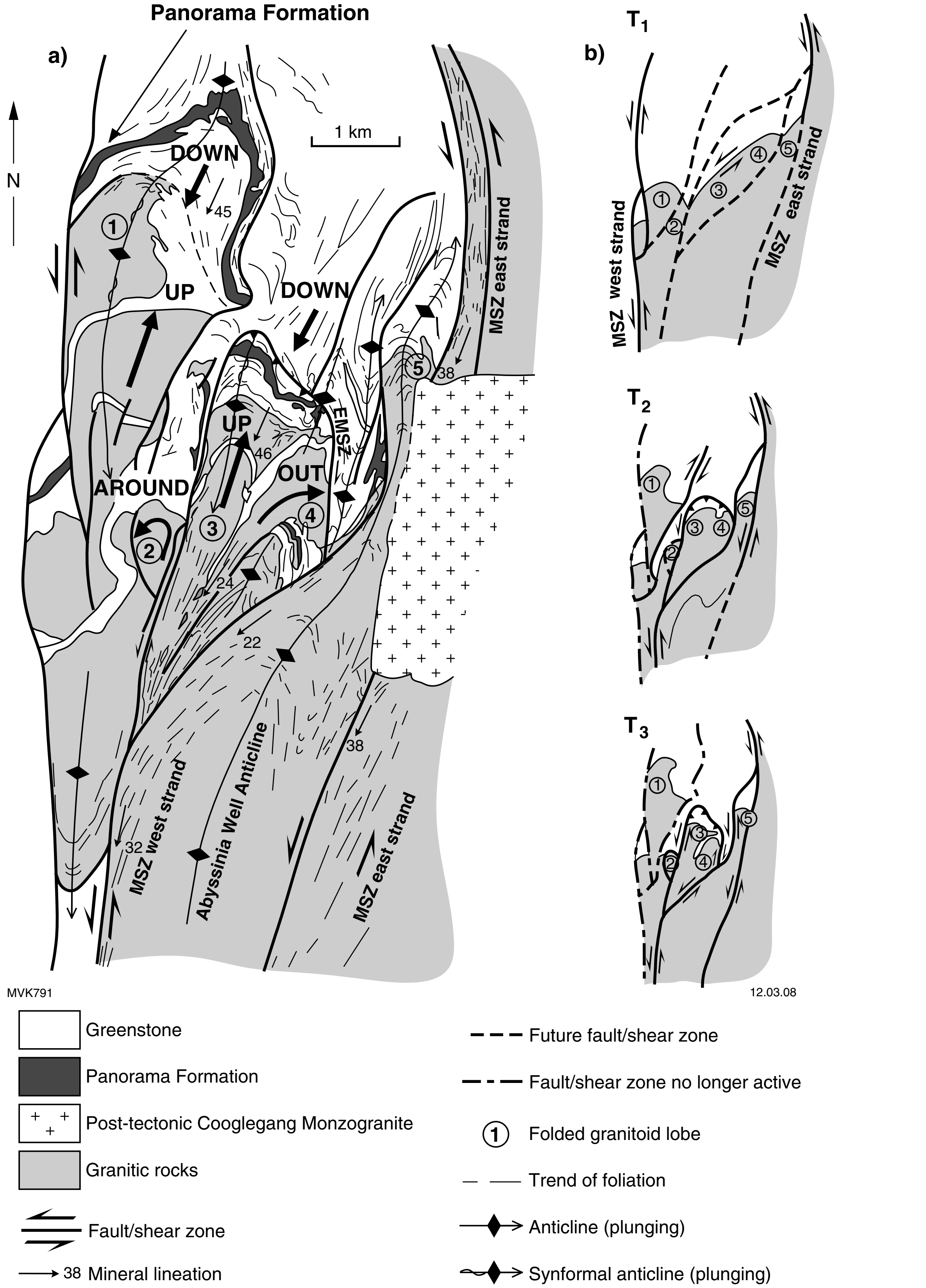
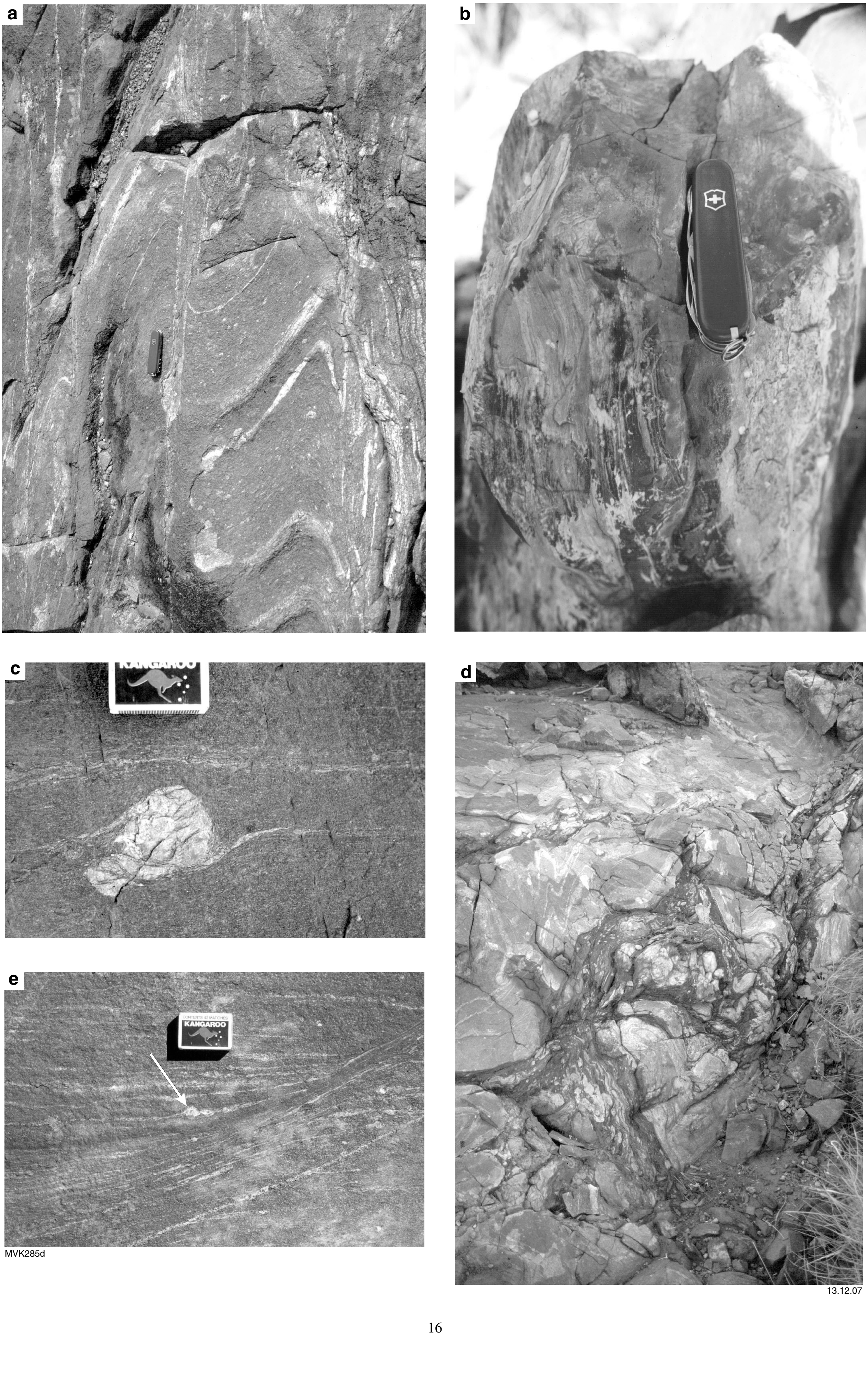


Figure 9. **a) schematic structural map of the folded granitic lobes (numbered 1–5) and greenstones in the northwest Shaw area and Emerald Mine Greenstone Complex, showing the kinematic geometry indicated by structural analysis of kinematic indicators in sheared granitic rocks. EMSZ = Emerald Mine shear zone; b) schematic evolution of the northwest Shaw area and Emerald Mine Greenstone Complex as a flower structure resulting from compression across stepped shear strands of the sinistral Mulgandinnah Shear Zone (MSZ); frames T_1–T_3 are representative of time slices during progressive deformation (modified from Van Kranendonk, 2003a)**



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the strike of the axial plane to the north, into a zone of schistose ultramafic rocks that bounds the southern edge of the little-deformed North Shaw greenstone belt.

Mulgandinnah Shear Zone

The 1–4 km-wide, sinistral Mulgandinnah Shear Zone along the western margin of the Shaw Granitic Complex marks the eastern margin of the LWSC in the map area (Figs 2 and 3; Van Kranendonk and Collins, 1998; Zegers et al., 1998). The shear zone consists of two parallel, kilometre-wide strands of strongly deformed granitic rocks that follow the stepped margin of the Shaw Granitic Complex across an area of tightly folded granitic lobes (see above). Both strands show evidence of a westward increase in strain, indicated by a change from weakly strained igneous precursors with a brittle network of intrusive pegmatite dykes (Fig. 11a), through amphibolite-facies straight gneiss (Fig. 11b), to porphyroclastic mylonite and greenschist-facies ultramylonite in the highest strain part of the zone (e.g. Fig. 10b). Both strands contain excellent and widely developed indicators of sinistral shear including S-asymmetrical folds (Fig. 11c), rotated feldspar porphyroclasts (Fig. 11d), both 'surf' and 'turf' styles of boudin trains, and C–S–C' fabrics (Hanmer and Passchier, 1991). The strands are characterized by steeply west-dipping foliations and by mineral elongation lineations (Fig. 11e), whose generally shallow plunge (0–35º) porpoises between north and south plunges along strike. A syn-kinematic granite pegmatite vein from within the northern part of the eastern strand of the shear zone is 2934 ± 2 Ma (Zegers et al., 2001).

The western strand of the Mulgandinnah Shear Zone follows the contact of the Shaw Granitic Complex from the southern part of the exposed complex into the southern part of the map area and then splays northward into the tight folds of granitic rocks and greenstones described above (Fig. 3). The roughly 1 km wide eastern strand is developed within the Shaw Granitic Complex, about 3 km east of the western strand, in the southern and north-central parts of the map area. In the southern part of the eastern strand, the western margin is marked by long thin peels of strongly foliated, amphibolite-facies greenstones (see Plate 1). South of the map area, the eastern strand steps to the west and dies out along strike (Fig. 2). In the central part of the map area, the eastern strand of the Mulgandinnah Shear Zone is cut by the post-tectonic Cooglegong Monzogranite, but the strand re-appears north of this intrusion along the western margin of the Shaw Granitic Complex (Fig. 3). The contact between mylonitic granitic rocks and greenstones in this area is marked by a brittle fault filled by massive white vein-quartz, 1–5 m wide (e.g. White Quartz Hill at MGA 741400E 7616600N).

The two strands of shear deformation are separated by moderately deformed granitic rocks and greenstones that are deformed into a tight, north-plunging anticline, herein referred to as the Abyssinia Well Anticline (Fig. 3). This fold is exemplified by a kilometer-scale, isoclinally folded greenstone raft in the southern part of the map area that forms the northern closure of a doubly plunging antiform (or sheath fold). In the area of the folded granitic lobes described above, the Abyssinia Well Anticline forms part of a large-scale Z-shaped asymmetrical fold with a short eastern limb (Fig. 9). This asymmetry is consistent with the inferred dextral shear torque experienced by the panel of rocks between the two shear strands of the Mulgandinnah Shear Zone (Fig. 9b, T2).

Figure 10. Outcrop features of the folded granitic lobes in the northwest Shaw area: a) folded sinistral porphyroclastic mylonite cut by discrete sinistral shears, from the northeastern margin of lobe 2; b) Porphyroclastic ultramylonite from the northern margin of lobe 2; c) K-feldspar porphyroclast in granitic mylonite showing dextral rotational asymmetry, from the northern contact of lobe 5; d) folded dextral mylonite and ultramylonite (black areas in fold hinge), from the northern margin of lobe 5; e) dextral porphyroclastic mylonite (see rotated porphyroclast below matchbox, arrowed) cut by sinistral shear zone, from the southern part of lobe 5

Marginal structures in the North Pole Dome

Northward movement of Shaw Granitic Complex is interpreted to be responsible for the development of the overprinting, steeply north-dipping foliations in the southern part of the North Pole Dome (Panorama greenstone belt) noted in Van Kranendonk (1999, 2000). These foliations are quite distinct on a regional scale because they dip at a high angle to bedding in the greenstones, which is unique throughout the East Pilbara Terrane. Deformation associated with formation of the LWSC was also probably responsible for the set of dextral faults that cut through the southwestern part of the North Pole Dome and offset the Panorama Formation in this area (MGA 740000E 7647000N), and also for the development of broad, upright, northeast-trending anticlines of the southwestern, northwestern, and northeastern parts of the dome that give the dome an elliptical shape.

Structural interpretation

The diverse types and orientations of folds and faults with variable kinematics described herein as part of the LWSC are interpreted as a contemporaneous set of linked structures arising from c. 2940 Ma northwest–southeast regional compression associated with the North Pilbara Orogeny (Van Kranendonk and Collins, 1998; Van Kranendonk et al., 2004). This is based primarily on the following observations:

1. the different structures and their kinematic displacement fit almost exactly with those predicted from strain analysis and field studies (Fig. 12; as described in session 12 of Ramsay and Huber, 1983), including north-northwest to northeast striking sinistral faults and shear zones, northwest striking normal

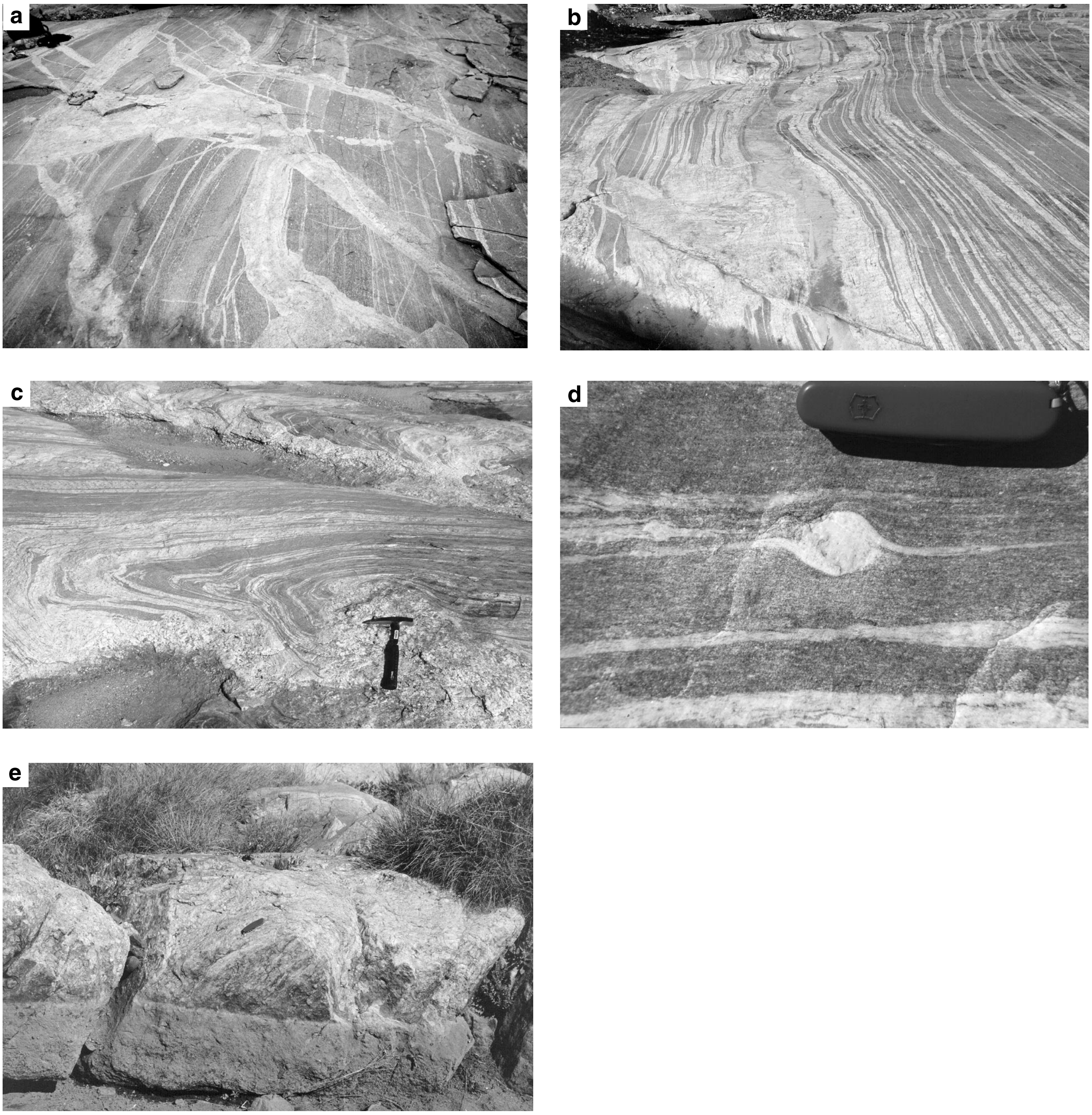

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Figure 11. Outcrop features of the western strand of the Mulgandinnah Shear Zone, at Tambourah Creek: a) low-strain enclave of grey-weathering tonalitic rocks, showing the multiple sheeted nature of the protolith (c. 3420 Ma Tambina Supersuite) and a random, fracture-fill pattern of younger (?c. 2930 Ma Sisters Supersuite) granitic dykes (MGA 739340E 7609900N); b) amphibolite-facies porphyroclastic straight gneiss mylonite, with highly transposed granitic pegmatite veins; c) one half of an 'S'-asymmetric fold in porphyroclastic straight gneiss that is cored by syn-kinematic granite pegmatite (under hammer); d) sinistral rotated feldspar porphyroclasts in porphyroclastic straight gneiss mylonite; e) view west of characteristic south-plunging mineral aggregate lineations on the margin of a foliated syn-kinematic granite pegmatite. Pocket knife is 9 cm long

faults, northeast striking reverse faults, east-northeast striking dextral faults, and northeast-trending fold axial traces;
2. faults with different kinematics have different orientations and do not cut across each other;
3. folds are characteristically developed within fault-bounded panels;
4. folds and faults do not cut one another and are thus linked as contemporaneous structures;
5. faults typically grade and splay out into ductile shear zones in granitic rocks.

An alternative interpretation is that at least some of the northeast-trending folds in the LWSC and adjacent areas formed during a later, overprinting event (Hickman, 1983).

The main structures indicating the connected nature of the shear-and-fold system within the LWSC are the north–south segment of the sinistral LRWS Fault, the north–south striking, sinistral Mulgandinnah Shear Zone, the northeast trend of the Soanesville Syncline and parallel folds throughout the LWSC, the east-northeast striking dextral faults in the northern part of the LWSC, and the northeast-striking reverse faults along the southern boundary of the Soanesville greenstone belt and in the northwestern part of the Shaw Granitic Complex (Fig. 12).

Features that superficially are not explained by this overall strain regime and deformational scheme are the northwest-trending Tambina Anticline and Mount Webber Syncline, as well as the northwest strike of the sinistral LRWS Fault and Pulcunnah Shear Zone along the southwestern margin of the Soanesville greenstone belt. However, these can be explained as rotated structures within the context of progressive deformation, as described below, although it must be considered that this is a model, and that other possible alternative scenarios (e.g. polyphase deformation) may apply.

The structures identified within the LWSC were developed in and adjacent to the flanking broad-scale domical granitic complexes that formed during prior deformational events related to episodes of partial convective overturn of the upper and middle crust. However, these earlier structures developed prior to deposition of the Soanesville Group at c. 3200 Ma and involved large-scale (2–60 km wavelength) folding of greenstones within synclines that developed between granitic domes (e.g. Van Kranendonk, 1997, 2004). Whereas many of the folds within the LWSC have not been dated, their geometrical association with dated shear zones helps constrain their age to the time of development of the LWSC at c. 2940 Ma. Deformation associated with the North Pilbara Orogeny within and across the LWSC caused re-activation of the Shaw and Yule Granitic Complexes and added a component of amplification to the domes themselves.

Soanesville greenstone belt

Van Kranendonk and Collins (1998) showed that the bulk of deformation in the LWSC arose from the north-northwestward (relative) movement of the Shaw Granitic Complex, which caused the Strelley Monzogranite laccolith and flanking greenstones within the Soanesville greenstone belt to pop out to the north, much as an orange seed will pop out from between squeezed fingertips. The simplified geometry of the structure around the Strelley Monzogranite in the north-central part of the LWSC is a large-scale omega (Ω) with a faulted western limb and clockwise rotation of the head of the omega (heavy line on Fig. 12). The offset across the western fault of this structure — the LRWS Fault — is on the order of 13 km. The reason that the Strelley Monzogranite is preserved in tilted cross-sectional view, facing east was interpreted to be the result of the laccolith traveling north along the curved, east-dipping eastern margin of the Yule Granitic Complex and in the process, tilting over onto its side, like a car that travels too fast up a ramp on two side wheels and flips over onto one side. Displacement of the laccolith continued northward until it collided with the Carlindi Granitic Complex and stopped, causing the rocks traveling behind to pile up like a train wreck, thus forming the Soanesville Syncline and the steep reverse fault (Cajaput Soak Fault) along the southern margin of the Soanesville greenstone belt. The fact that the main part of the Soanesville Syncline is parallel to the Cajaput Soak Fault, and that the southwestern end of the fold roots into the fault, is used to infer the contemporaneous development of these major structures.

Mulgandinnah Shear Zone and northwest Shaw area

The continuity of Mulgandinnah Shear Zone fabrics into the folded lobes of the northwestern Shaw Granitic Complex and Emerald Mine Greenstone Complex, in combination with the colinearity of fold hinges and greenschist-facies mineral elongation lineations between these lithostructural map elements, is used to suggest that structures in the northwest Shaw area resulted from sinistral transpressional deformation, which available age data indicate occurred at c. 2940 Ma, well after the formation of the broad-scale granitic-cored domes in this area (Fig. 9; Van Kranendonk and Collins, 1998; Van Kranendonk et al., 2004, 2006, 2007). This contradicts a previous interpretation that the folds formed as a result of Alpine-style crustal thickening at c. 3470 Ma, *prior to* doming (Bickle et al., 1985; Zegers et al., 1996).

In the current model, the folds of the northwest Shaw area are interpreted to represent a flower structure that formed within a restraining bend between the stepped, overlapping sinistral shear strands of the Mulgandinnah Shear Zone (Fig. 9; Van Kranendonk et al., 2004). The crust in between the stepped strands of the shear zone experienced intense shortening, resulting in crustal thickening and uplift that exposed the higher-grade rocks of this area (cf. Davis, 1984). Progressive displacement across the shear strands resulted in clockwise rotation of the granite–greenstone contact between the shear strands (Fig. 12) relative to the west-northwest direction of maximum compressive stress (σ_1), such that the sense of shear across this contact — which represents the short limb of a Z-fold, whose long limbs are the shear strands

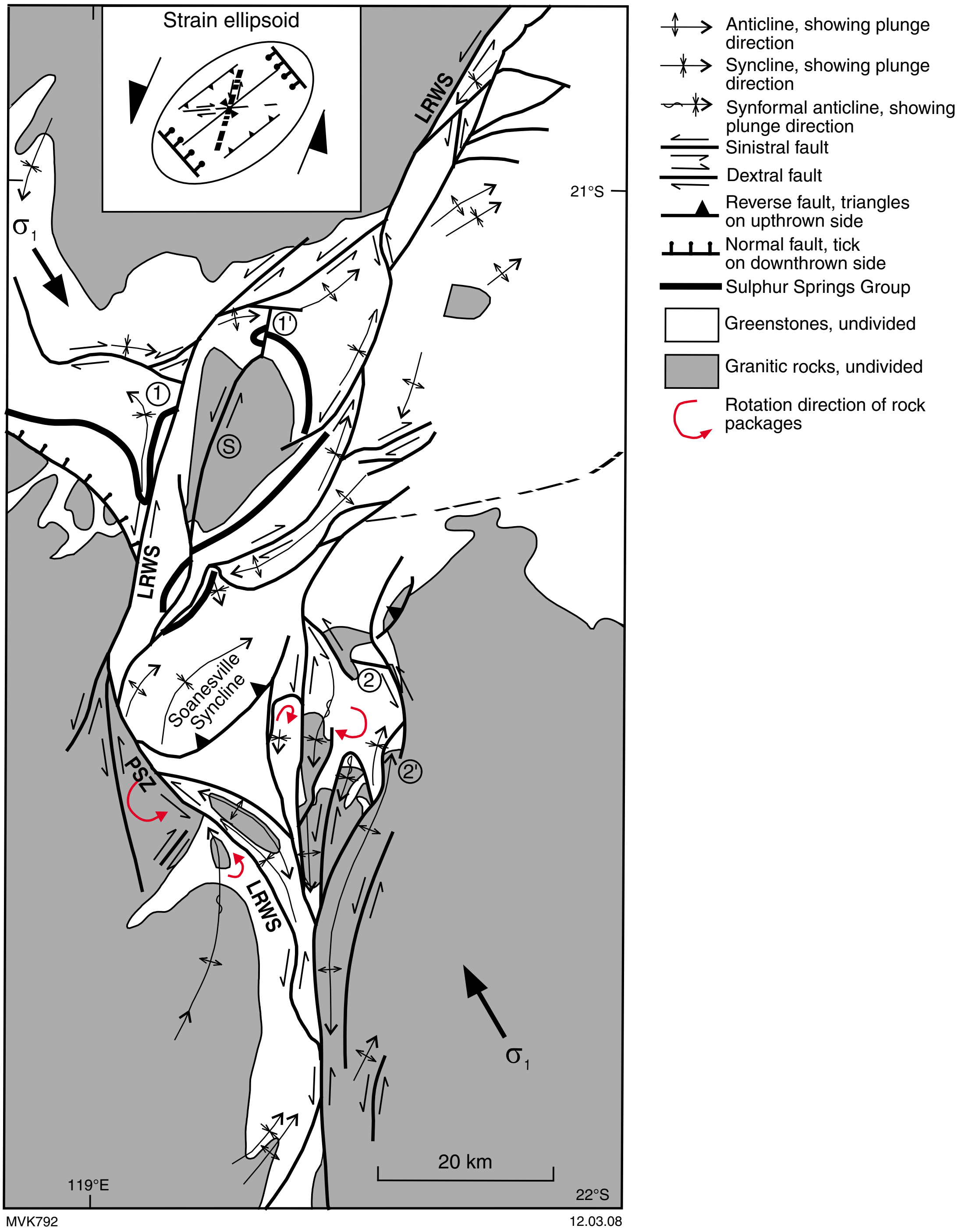

Figure 12. Schematic structural map of the LWSC, showing major faults and their displacement sense, major folds, and rotation movements of rock panels. The σ_1 direction is inferred from the orientation of the Soanesville Syncline and sinistral LRWS fault. 1–1' and 2–2' indicate points of measured offset across fault segments, as described in the text. Circled S = Strelley Monzogranite; PSZ = Pulcunah Shear Zone. Strain ellipsoid in inset is oriented according to the σ_1 direction in the map area and shows the major structures predicted from experimental studies

— changed from sinistral, through reverse, to dextral through time as it rotated (Fig. 9b, T1–T3). The clockwise rotation of this short limb is reflected by the kinked nature of the axial trace of synformal anticline through fold lobe 1 where it passes from granites to greenstones. During this event, fold lobes 3 and 4 were squeezed up and out to the north as a large sheath fold across a fault that changes in terms of displacement from a reverse fault to the north of the fold lobe, to strike-slip sinistral and dextral faults on the western and eastern sides of the fold lobe, respectively (Fig. 9). Sinistral drag along the western boundary of lobe 3 caused sinistral shear of the eastern margin of lobe 2 and counter-clockwise rotation of this lobe. North-plunging lineations in lobe 2 indicate that it was forced down to the north, under the flanking greenstones, whereas south-plunging lineations in lobes 3 and 4 indicate uplift of these rocks to the north. Lobe 4 was pushed out to the east and folded across the Emerald Mine Shear Zone, which formed the eastern lateral ramp of penetrative deformation in the sheath fold. The observation of sinistral shear overprinting dextral shear in lobe 5 may be explained by initial dextral shear during rotation (T1–T2 in Fig. 9b), followed by a sinistral shear overprint as the eastern strand propigated to the south (T2–T3 in Fig. 9b). Northerly directed extrusion and uplift of granitic lobes 1–4 caused overturning of the greenstones and exhumation of the deeper level metamorphic assemblages exposed in this area, as originally observed by Bickle et al. (1985).

Rocks to the north of the folded granitic lobes 3–5 are deformed into a series of upright, north-northeast-trending, tight folds bound by highly curved faults, indicating a strong degree of west-northwest–east-southeast compression. Note that in this area, faults are locally affected by the folding of bound panels of tightly folded supracrustal rocks.

The northern boundary to this area of complex folding and faulting in the Emerald Mine Greenstone Complex is in part a sinistral fault along the western boundary of the Keep It Dark Monzogranite, and in part an irregular boundary between coherent greenstones of the North Shaw greenstone belt to the north and ultramafic schists to the south. The undeformed Keep It Dark Monzogranite occupies a dilational gap between splays of sinistral shear, and is therefore interpreted as syn-kinematic with sinistral shear deformation (Van Kranendonk and Collins, 1998). This interpretation is confirmed by a U–Pb SHRIMP zircon age of ca. 2936 ± 5 Ma for the Keep It Dark Monzogranite, which is within error of a syn-kinematic pegmatite (Zegers et al., 2001) and Pb–Pb mineral isochron ages (2936 ± 9 Ma; Oversby, 1976) from the Mulgandinnah Shear Zone, and ^{40}Ar–^{39}Ar plateau ages from the Western Shaw greenstone belt (Wijbrans and McDougall, 1987). A sinistral sense of displacement for the fault along the western margin of the granite is supported by the S-asymmetry of the fold along the southwestern margin of this intrusion (see map). The youngest age of deformation in this area is given by a 2919 ± 3 Ma age of a syn-kinematic granitic vein in an 060°-striking dextral shear zone in the Shaw Granitic Complex (sample 142883 in GSWA, 2006).

Progressive deformation in the Yule Granitic Complex and Western Shaw greenstone belt

The Tambourah Dome is a broad structural dome cored by multiphase granitic rocks of the Yule Granitic Complex and flanked by greenstones of the Western Shaw greenstone belt (Fig. 3). This dome developed as a result of at least two periods of granitic intrusion, at c. 3240 Ma and at c. 2930 Ma (Wijbrans and McDougall, 1987; Van Kranendonk and Collins, 1998; Nelson, 1998; Van Kranendonk, 2003a). Doming occurred during regional deformation associated with the North Pilbara Orogeny, as supported by results from two U–Pb zircon age dates of c. 2933 Ma (GSWA samples 142884 and M95-31) from a small granite intrusion within the saddle reef position of folded greenstones around the crest of the dome (Fig. 13a; Van Kranendonk, 2003a). That at least part of the doming was accomplished prior to the final development of the LWSC is evidenced by the fact that the axial plane of the dome is deflected by 57° from a north-northeast trend (025°) throughout the core of the dome, to a northwest trend (328°) along strike in the Western Shaw greenstone belt (see Fig. 3). The northeast trend of the main part of the dome is parallel to other large-scale folds associated with the LWSC and consistent with the northwest-southeast direction of maximum compressive stress (σ_1) during this deformational event (Fig. 12). This anticlockwise sense of rotation is consistent with the sinistral sense of shear identified along the western margin of the LWSC (LRWS Fault). Van Kranendonk and Collins (1998) and Van Kranendonk (2003a) described the rotational aspect of this younger component of deformation, based on the geometry of pegmatitic intrusions and deflected greenstones within the Western Shaw greenstone belt (Fig. 13b).

In their present orientation, the Mount Webber Syncline and Tambina Anticline could not have formed in the northwest–southeast compressive stress regime of the North Pilbara Orogeny, as their fold axial traces are parallel to the maximum compressive stress direction (σ_1) associated with this event (Fig. 12). Therefore, either the folds are much earlier structures unrelated to North Pilbara orogenesis that have been overprinted by this younger deformational event — as locally indicated by overprinting structures in the southeastern part of the Tambina Anticline (Fig. 6b), or they are structures that formed during an early component of the North Pilbara orogenesis and rotated into their current position. The same can be said for the Pulcunnah Shear Zone, which is well off (45°) from the optimum orientation for sinistral shear within the maximum compressive stress direction identified for the North Pilbara Orogeny. An alternative interpretation is that the northwest elongated domes were rotated into their current position by post-2.94 Ga deformation (Hickman, 1983).

However, several conceptual arguments suggest that the structures mentioned above formed during an early component of North Pilbara orogenesis and rotated into position as a result of progressive deformation. First is the evidence for progressive deformation and rotation of the fold axial plane of the Tambourah Dome, which

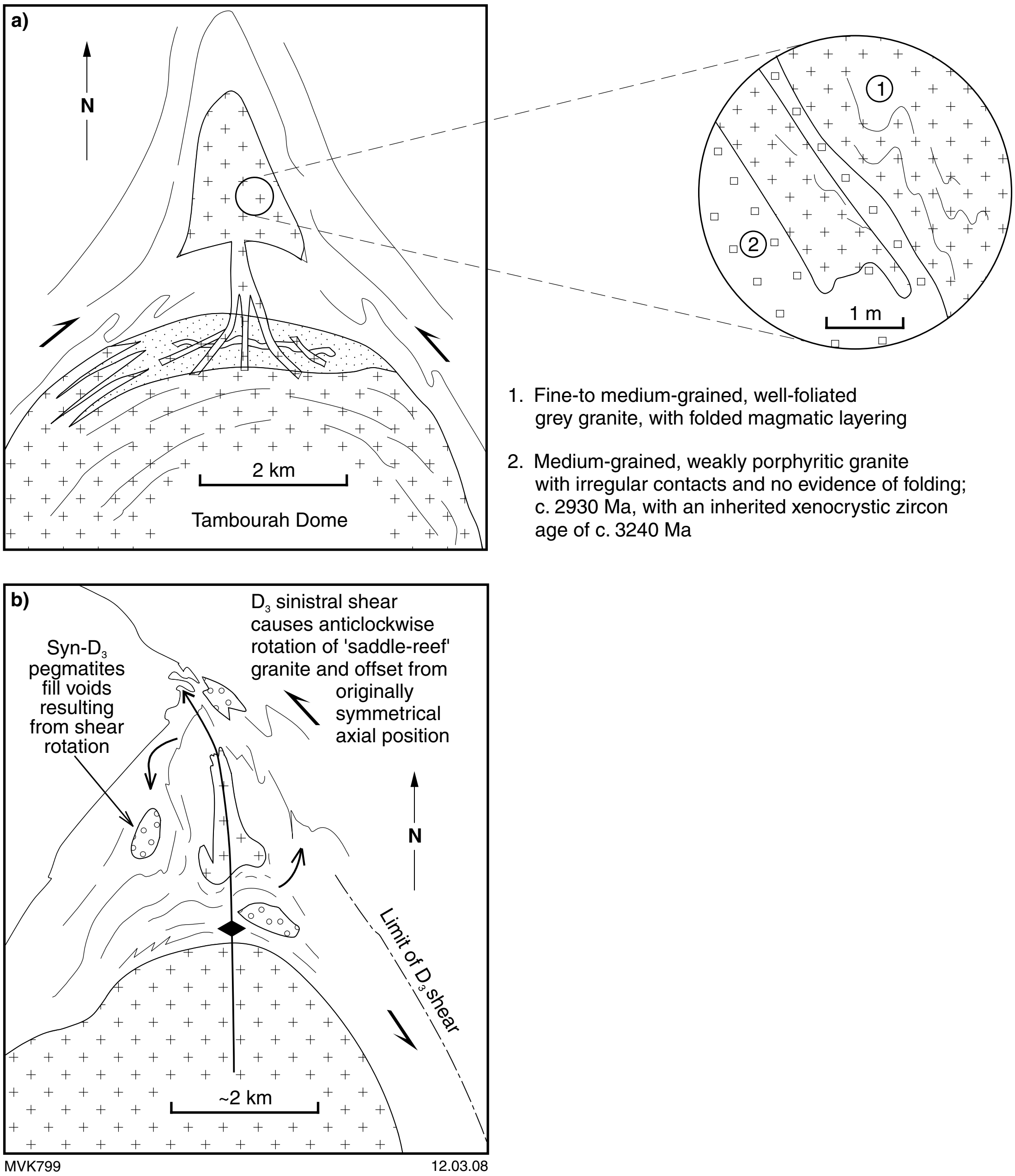

Figure 13. Major structures around the nose of the Tambourah Dome: a) folding of greenstones around the nose of the Tambourah Dome and syn-kinematic intrusion of the saddle reef granite that was fed by granite dykes along the axial plane of the dome. Enlarged sketch shows relationships between two phases of the saddle reef granite, both of which have been dated and return identical ages of c. 2933 Ma; b) schematic geological sketch showing the intrusion of small pegmatitic granitic bodies into dilational gaps formed by the rotation of the saddle reef granite due to sinistral shear across the Pulcunnah Shear Zone

shows that structures formed during early periods of North Pilbara orogenesis were rotated by significant amounts (57°) during continued deformation. Second is that the Tambina Anticline is similar to the folded granitic lobes of the northwest Shaw Granitic Complex, particularly the westernmost of these (lobe 1 on Fig. 9), which is a doubly plunging anticline that formed during deformation within the LWSC. Third is that the Mount Webber Syncline and Tambina Anticline form part of a large-scale fan of faults and folds across the Emerald Mine and Tambina Greenstone Complexes and northwestern Shaw Granitic Complex, suggestive of contemporaneous and related development.

Finally, the geometry of splayed ductile sinistral shears off the tip of the curve in the boundary of the Yule Granitic Complex at the northern end of the Pulcunnah Shear Zone, combined with the syn-kinematic nature of the Woodstock Monzogranite, suggests that the curved boundary between the Yule Granitic Complex and the Soanesville greenstone belt, and the Tambina Greenstone Complex and Western Shaw greenstone belt developed through anticlockwise rotation of about 45°. In this model, the splays of sinistral ductile shear in the Yule Granitic Complex are interpreted to have developed sequentially from east to west as the boundary rotated. Rotation of the boundary was accompanied by sheeted intrusion of the syn-kinematic, 2927 ± 3 Ma (sample 142885 in GSWA, 2006) Woodstock Monzogranite and by syn-kinematic dextral shear along a northeast-striking zone of magmatic sheeting (e.g. Fig. 4d: Pawley and Collins, 2002). The triad of shears in this area bound a triangular zone filled by the low-strain, syn-kinematic Woodstock Monzogranite, which in this area contains numerous enclaves of amphibolite-facies metabasalt that are locally folded into open structures on southeast-plunging hinges that are colinear with mineral elongation lineations. Structures in this area are interpreted to have developed during granite intrusion into a zone of extension within the overall northwest-southeast compressional deformation (Van Kranendonk and Collins, 1998). The concentration of mafic enclaves within the shear strands suggests that the strands represent stages of shearing during the easterly migration of the granite–greenstone contact.

Tambina Greenstone Complex

Significant northerly translation is evident in the panel of rocks within the eastern part of the Tambina Greenstone Complex (labelled 3 on Fig. 3), by the fact that the major fold of Soanesville and Croydon Group rocks in the middle part of this panel is a south-plunging, overturned anticline. The highly curved fault along the northern contact of this folded panel of greenstones indicates a clockwise component of rotation during the northerly translation of this crust (Fig. 12). This clockwise rotation fits with it having been deformed between parallel sinistral shear zones.

Summary

The evidence presented above for rotation of structures and sinistral shear deformation across numerous shear zones and faults suggests significant translation of crustal panels within the LWSC. A minimum of 13 km is indicated by the offset of marker units across the LRWS Fault (points 1–1' on Fig. 12), but units further to the south may have been translated a significantly greater distance, given the degree of ductile shear deformation within the Pulcunnah Shear Zone and associated shear splays. An offset of about 12 km can be measured across the eastern strand of the Mulgandinnah Shear Zone by the offset of the granite-greenstone contact (points 2–2' on Fig. 12), but again, this must be a minimum for the total displacement as this does not account for any offset across the western strand of the Mulgandinnah Shear Zone, which is up to 3 km wide to the south of the map area (Van Kranendonk and Pawley, 2002).

Geometrical and rotational data suggest that deformation and shear translation of the various crustal panels within the LWSC in the map area resulted from progressive easterly migration of deformation, commencing with shear movement across the Pulcunnah Shear Zone and LRWS Fault. Movement across these structures resulted in northerly translation of the Strelley Monzogranite and associated greenstones. As northward translation of the Strelley Monzogranite was terminated against the Carlindi Granitic Complex, rocks of the Soanesville Syncline (labelled 1 on Fig. 3) crumpled up behind like a highway multi-car pileup, followed by the structural emplacement of the western part of the Tambina Greenstone Complex. This was followed in turn by structural emplacement of the eastern part of the Tambina Greenstone Complex (labelled 3 on Fig. 3) and then by the structural emplacement of the fold lobes in the northwest Shaw area. Significant northerly translation of these rocks is indicated by the south-plunging synformal anticlines in these areas. Probably all of these events, but in particular the last two, were progressive and accompanied by shear deformation along the western strand of the Mulgandinnah Shear Zone that facilitated uplift of deeper crust around the northern part of the folded granitic lobes through a change from ductile shearing to brittle faulting conditions.

Following northward translation of panels within the LWSC, these panels fused together and moved across the western strand of the Mulgandinnah Shear Zone. Shearing across this zone produced anticlockwise rotation of internal components of the LWSC, and the Pulcunnah Shear Zone and Tambourah Dome across the shear strands that splay south and southwest off the Pulcunnah Shear Zone. As deformation continued, shear displacement migrated to the eastern strand of the Mulgandinnah Shear Zone, folding previously developed high strain fabrics in the western strand (e.g. Z-fold in Abyssinia Well Anticline south of lobe 5).

An interesting feature of the LWSC is the opposite sense of rotation of crustal panels across it. The ~57° counterclockwise rotation of the axial plane of the Tambourah Dome on the western side of the LWSC suggests significant northwesterly translation of the northern part of the Western Shaw greenstone belt, including the Tambina Anticline. Counterclockwise rotation was also documented for the curved, sheared margin of the Yule Granitic Complex (Pulcunnah Shear Zone) on the western side of the LWSC. On the eastern side of the LWSC, however, crustal panels show evidence of clockwise rotation (folded granitic lobes and panel 3 in the Tambina Greenstone Complex).

Several age dates constrain the main period of deformation in the LWSC (Fig. 3). These include the c. 2933 Ma saddle reef granite in the hinge of the Tambourah Dome (samples 142884 and M95-31), the 2927 ± 3 Ma syn-kinematic Woodstock Monzogranite (sample 142885; Nelson, 1998), the 2936 ± 5 Ma Keep It Dark Monzogranite, and the 2934 ± 2 Ma syn-kinematic pegmatite in the Mulgandinnah Shear Zone (Zegers et al., 2001). Deformation in the LWSC was accompanied by emplacement of the Mulgandinnah Monzogranite across the northern part of the Shaw Granitic Complex, at 2928 ± 2 Ma (sample 142882; Nelson, 1998). The youngest component of the deformation is dated by a 2919 ± 3 Ma, syn-kinematic porphyritic syenogranite dyke that lies within a 060° striking dextral shear zone in the Shaw Granitic Complex, just east of the map area (sample 142883; Nelson, 1998).

Significance for gold mineralization

The identification of the maximum compressive stress direction during deformation across the LWSC, together with the recognition of the major faults that were active within greenstones during this deformation event, has the potential to enhance exploration targeting for Au mineralization within this area. Given the northwest–southeast direction of the maximum compressive stress direction, predictive areas to explore for Au mineralization are:

1. in low strain domains within northeast and southwest parts of deformed rock packages,
2. in the hinge zone of northeast-plunging folds,
3. within and/or adjacent to the major shear/fault zones,
4. in dilational zones within rotated rock packages.

Examples of known Au mineralization that are consistent with examples 1 and 2 are the cluster of prospects in the southern hinge region of the Soanesville Syncline (e.g., Breen Brothers Reward, Old Timers, Miracle and Magnifique at around MGA 716000E 7617000N). The Soanesville prospect lies within a northeast-plunging fold hinge (MGA 717750E 7625200N). Many examples of known Au mineralization lie within, or adjacent to major shear/fault zones, including The Birthday (MGA 725500E 7613500N), those of the Dalton Mining Centre located to the northeast of the South Dalton Pluton (MGA 731725 7626000N), the Cavendish prospects in the far northwestern part of the map area (MGA 712000E 7636500N), and the many deposits along the southern part of the LRWS Fault in the map area (e.g. at MGA 728950E 7692600N). Deposits located within dilational zones of rotated rock packages include those of the Tambourah Mining Centre (MGA 726700E, 7691600N), which lie within a low pressure domain during rotation of the Tambourah Dome. Deposits of the Western Shaw Mining Centre (MGA 728500E 7667000N), roughly 6 km to the south of the map area, also lie within extensional sinistral shear zones that accommodated rotation of the Tambourah Dome.

According to this model, areas of good potential prospectivity for Au mineralization include:

- the dilational area underlain by ultramafic rocks between the Sub-basins of the basal Fortescue Group conglomerates, south of, and along from, The Birthday (at around MGA 726100E 7611700N);
- the northeast-striking dilational zone of ultramafic-hosted megabreccia that splits apart the South Daltons Pluton (at MGA 732600E 7611000E);
- the area of ultramafic rocks to the east of the Keep It Dark Monzogranite (MGA 739000E 7623000N), which occupy a dilational zone developed during clockwise rotation of the folded granitic lobes of the northwest Shaw area;
- bends in the north–south shear zone just northwest of the South Dalton Pluton (MGA 731200E 7620850N);
- the northeastern extension of the Cajaput Soak Fault, near the Soanesville North Au prospect (MGA 727200E 7621400N).

Given the structural model for the area, the evidence for the historical production of Au, and knowledge of Au-bearing systems in the more highly mineralized Eastern Goldfields Superterrane of the Yilgarn Craton, two areas are considered highly prospective for Au mineralization. One of these is the area around the southwestern hinge of the Soanesville Syncline, where a number of small Au prospects lie within folded and faulted, but weakly metamorphosed gabbro. This structural setting is similar to the Golden Mile at Kalgoorlie, where very large tonnages of economic Au occur within the Golden Mile Dolerite.

The second area of inferred high Au prospectivity is the Dalton Mining Centre located to the northeast of the South Dalton Pluton (MGA 731725 7626000N) in strongly sheared, greenschist-facies metabasalts. The series of prospects at this locality lie within a structurally favourable zone, in strongly sheared rocks near the hinge of a south-plunging synformal anticline within a restraining bend of a crustal-scale sinistral shear system. This setting is analogous in some ways to the large Sunrise Dam deposit of the Eastern Goldfields Superterrane, which lies within a restraining bend between obliquely offset granitic domes.

Little is known in detail about the age of the gold mineralization in the map area. Thorpe et al. (1992) identified several ages of gold mineralization within, or adjacent to, the Lalla Rookh–Western Shaw structural corridor, including c. 3150 Ma (Soanesville and Lalla Rookh deposits), c. 2988 Ma (Big Bertha Mine in the North Shaw greenstone belt), and c. 2742 Ma (Lynas Find), the latter clearly indicating a degree of re-activation of structures and mineralization by later events. The c. 2988 Ma mineralization at Big Bertha probably relates directly to the events discussed here, with the slightly older age due to small degrees of contamination by older crust. The c. 3150 Ma ages of mineralization may be used to indicate mineralization associated with an earlier rifting event (cf. Van Kranendonk et al., 2007), and/or remobilization of older lead by younger fluids.

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Appendix

Code conversion between current map and published 1:100 000 maps (NORTH SHAW and TAMBOURAH)

Code on current map	*Code on 1:100 000 map*
Supracrustal rocks	
AFOt-bbtt	AFkbt (N)
AFOt-fnv	AFks (N)
AFOk-bb	AFkb (N)
A-FOh-sp	AFhs (N)
AFOh-sh	AFhs (N)
A-FOr-b	AFr (N)
A-FOr-bbx	AFra (N)
A-FOb-sg	AF(st) (T)
A-FOb-sr	AF(sc) (T)
ACDl-sp	ADls (N), ADlc (T), AGct (N), AGcs (N)
ACDl-sg	ADlc (N, T)
API-map	Aup (N, T)
API-mats	Auc (N), Aup (T), Aus (T), Ab+B103s (T)
API-mutk	Auc (T)
API-muxt	Aucx (T)
API-xmus-mws	Aubs (T)
API-od	AWed (T)
ASOy-ci	AGyi (N)
ASOh-b	AGh (N)
ASOp-sh	AGph (N, T)
ASOp-shz	AGphc (N)
ASOp-ci	AGpi (T)
ASOc-sp	AGct (N)
ASOc-ss	AGph (N)
ASOc-stq	AGcq (T)
ASOc-sw	AGcw (T)
ASOa-sh	AGih (N, T), AGpi (T), AGii (T)
ASOa-shz	AGii (N), AGihc (N, T)
ASS-xmh-mtq	Ajx (N, T)
ASSc-fa	AScbi (N)
ASSc-fat	AScbt (N)
ASSc-fd	AScfd (N)
ASSc-fn	AScf (N), AGif (T)
ASSc-fntt	AGift (T)
ASSc-fnvz	AScc (N, T), AGifc (T)
ASSc-fnx	AScfa (N)
ASSc-fr	AScfr (N)
ASScp-ci	AGii (N, T)
ASSk-mbs	Ab (N, T), Aba (N), ASkb (N), Abs (T)
ASSk-mus	Aup (N)
ASSk-xmus-mbs	Aub (T), Aubs (N, T), Aup (N)
ASSk-xb-mbs	Ab (N), Abs (T)
ASSk-bk	Abm (N), ASkbm (T), ASkb (T)
ASSk-bnvt	ASkbt (T)
ASSk-uk	Auc (N), Aup(N), ASkuk (N, T), ASkbm (T)
ASSk-ccb	Ac (N), ASkcw (T)
ASSl-mtqm	Ajq (N), Asq (T)
ASSl-fnvz	ASlc (N, T), Ac (N)
ASSl-sw	ASls (N, T), AWesq (T)
AKEe-zso	go (T)
AKEe-zc	Ac (N), AWpch (T), Act (T)+B83
AKEe-mba	AWeb (N, T)
AKEe-xmwa-g	Abas (T)
AKEe-mbk	AWebc (N, T)
AKEe-mbms	Ab (N), Aup (N), Aur (N), AWebs (T), AWebm (T), Aus (T)
AKEe-xmus-mbs	Auc (N), Aubs (N), AWeubs (T)
AKEe-bb	AWeb (N, T)
AKEe-bk	AWebm (N, T), AWebk (T), ASmb (N), Ab (N), Abm (N)
AKEe-uk	Aus (T)

Appendix (continuedj)

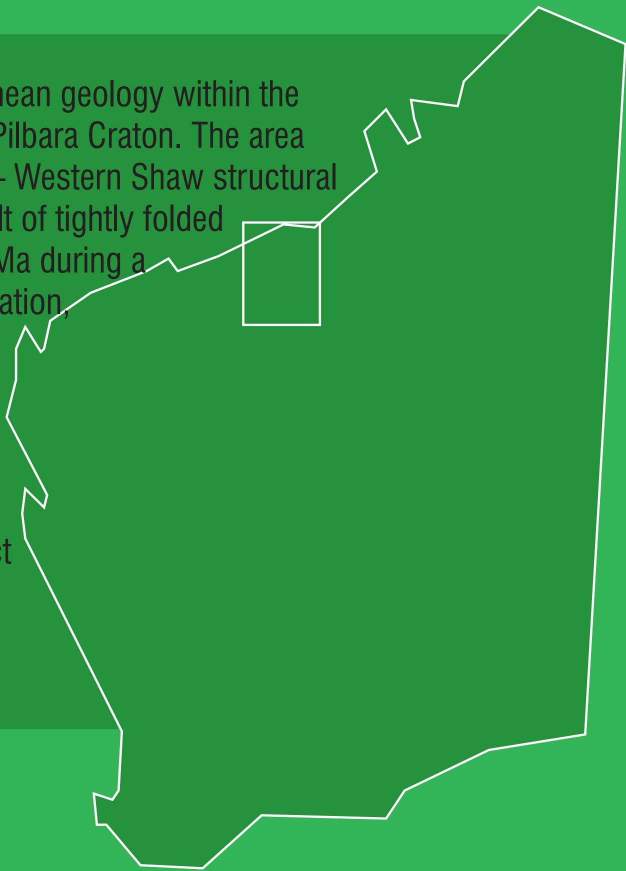
Code on current map	*Code on 1:100 000 map*
AKEe-ss	AWesh (N)
AKEe-stq	AWesq (T)
AKEe-ccb	Ac (N), AWec (N), ASmc (N)
AKEe-ci	AWeci (T)
AKEe-fnt	AW(f) (T)
AKEs-cc	AWs (N)
AKEs-stq	AWs (N), AWpsq (T)
AWAp-fnc	AWps (N, T)
AWAp-fntz	AWpsc (T)
AWAp-fr	AWpr (N, T)
AWAp-ci	AWpi (N)
AWAp-fnp	AWpp (T)
AWAa-mwa	Aba (T), AW(ba) (T)
AWAa-xmwa-g	Abag (T)
AWAa-mbb	AW(bh) (T)
AWAa-mbbs	Abas (T), AW(bvs) (T)
AWAa-mbbz	AW(bvz) (T)
AWAa-mbk	AWmb (N), AW(bvc) (T)
AWAa-mbms	AW(bms) (T)
AWAa-xmws-mus	AW(bus) (T), Aub (T)
AWAa-mut	AW(ut) (T)
AWAa-mc	AW(c) (T)
AWAa-mtq	As (N), Asq (T), B91AW(sq) (T)
AWAa-mfs	AW(f) (T)
AWAa-bk	AW(bm) (T)
AWAd-f	AWd (N)
AWAd-fnx	AWda (N)
AWAm-mwa	AWmb (N), AWmba (N), Aba (N)
AWAm-mbk	AWmbc (N)
AWAh-mwa	AWhba (N)
AWAh-mbk	AWhbc (N)
AWAh-mutc	AWhu (N)
AWAh-mc	AWhc (N)
AWAn-mba	Aba (N)
Intrusive rocks	
PRH-od	d (T)
PMW-od	dx (T)
APzqP	Aq (N)
APodP	d (T)
A-FO-od	AFd (N), AF(d) (T)
ASRcg-gmd	AgScgpe (T)
ASRcg-gmal	AgScgla (T)
ASRcg-gme	AgScge (T)
ASTmg-gm	AgSmu (N)
ASTmg-xgme-mgii	AgSnmu (T)
ASTmg-mgii	AgSmuxn (T)
AST-gnd	AgYpe (T)
ASTta-gmd	AgYta (T)
ASTwo-gmp	AgYwo (N, T)
ASTwo-gmpi	AgYwoi (T)
ASTwo-gmy	AgYwor (T)
ASTwo-xgmm-mwa	AgYwox (N, T)
ASTki-gme	Agki (N)
ADA-madt	AaDpd (N, T), Aup (T), AaDLpd (T)
ADA-mapt	Aup (N, T)
ADA-o	AaDo (N), Ao (N), AaDLo (T)
ADA-ocl	AaDlx (N), AaDLlx (T)
ADA-ax	Aux (N), AaDLx (T)
A-CEst-gmhb	Agste (N)
ACEst-gmy	Agsta (N)
ACE-gi	ASgd (N)
ACEka-mggb	AgYka (N, T)
ACE-od	ASd (N)
ATApe-mgtn	AgYpe (N), AgYpt (T)
ATApe-xmgtn-mggb	AgYpti (T)
ATA-mggl	AgSg (N, T), AgT (T)

Appendix (continuedj)

Code on current map	*Code on 1:100 000 map*
ATA-xmggl-gnl	AgTn (T), AgSgl (T)
ATA-xmgg-mwa	AgSgx (T)
ATA-mggu	AgTp (T)
ATA-mgma	AgSp (N)
ATA-mgml	AgSl (N, T)
ACLco-mgg	AgSco (N)
ACL-mgii	AgSn (N, T)
ACL-xmgii-g	AgSnl (T)
ACL-mgtn	AgSnl (T)

NOTES: (N) = North Shaw
(T) = Tambourah

This report describes an area of complex Archean geology within the central part of the East Pilbara Terrane of the Pilbara Craton. The area lies within the central part of the Lalla Rookh – Western Shaw structural corridor; a broad, generally north-trending, belt of tightly folded and sheared rocks that developed at c. 2940 Ma during a period of craton-wide orogenesis. The deformation, which was accompanied by emplacement of granitic rocks, was principally the result of west-northwest directed compression. The structures developed are linked in a coherent, time-integrated model that helps to explain the distribution of known gold deposits and predict areas where future gold exploration may be productive.



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VAN KRANENDONK

Structural geology of the central part of the Lalla Rookh – Western Shaw structural corridor, Pilbara Craton, Western Australia

REPORT 103

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COOYA POOYA 2355	MOUNT WOHLER 2455 PYRAMID	SATIRIST 2555	WODGINA 2655	NORTH SHAW 2755 MARBLE BAR	MARBLE BAR 2855
MILLSTREAM 2354	SF 50-7 MOUNT BILLROTH 2454	HOOLEY 2554	WHITE SPRINGS 2654	SF 50-8 TAMBOURAH 2754	SPLIT ROCK 2854
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ROCKLEA 2352	SF 50-11 MOUNT LIONEL 2452	MOUNT BRUCE 2552	MUNJINA 2652	SF 50-12 WEELI WOLLI 2752	ROY HILL 2852

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Published 1:100 000 geological mapping used in compilation

1:250 000 maps shown in brown

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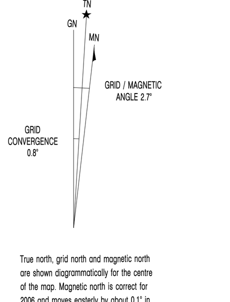
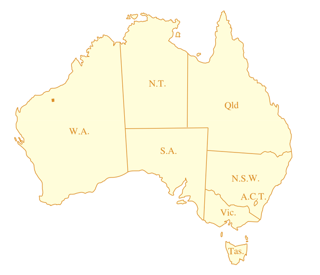


True north, grid north and magnetic north are shown diagrammatically for the centre of the map. Magnetic north is correct for 2006 and moves easterly by about 0.1° in 8 years.



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SCALE 1:50 000

1000 500 0 1 2 3 4 5
Metres Kilometres

UNIVERSAL TRANSVERSE MERCATOR PROJECTION
HORIZONTAL DATUM: GEOCENTRIC DATUM OF AUSTRALIA 1994
VERTICAL DATUM: AUSTRALIAN HEIGHT DATUM

Grid lines indicate 1000 metre interval of the Map Grid Australia Zone 50

The Map Grid Australia (MGA) is based on the Geocentric Datum of Australia 1994 (GDA94)
GDA94 positions are compatible within one metre of the datum WGS84 positions

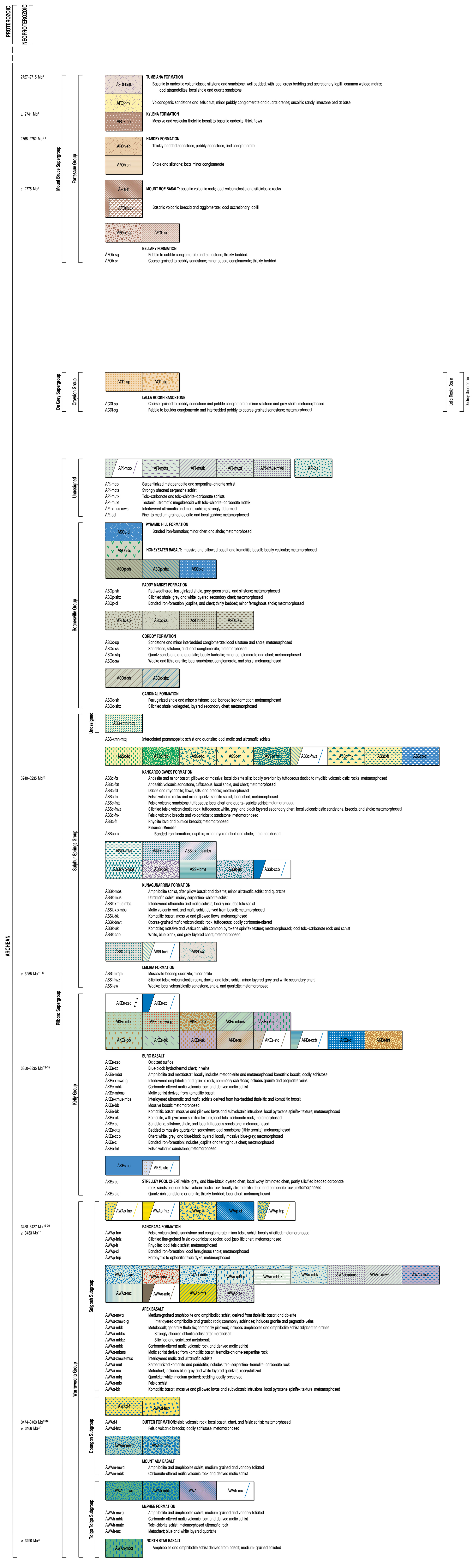
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

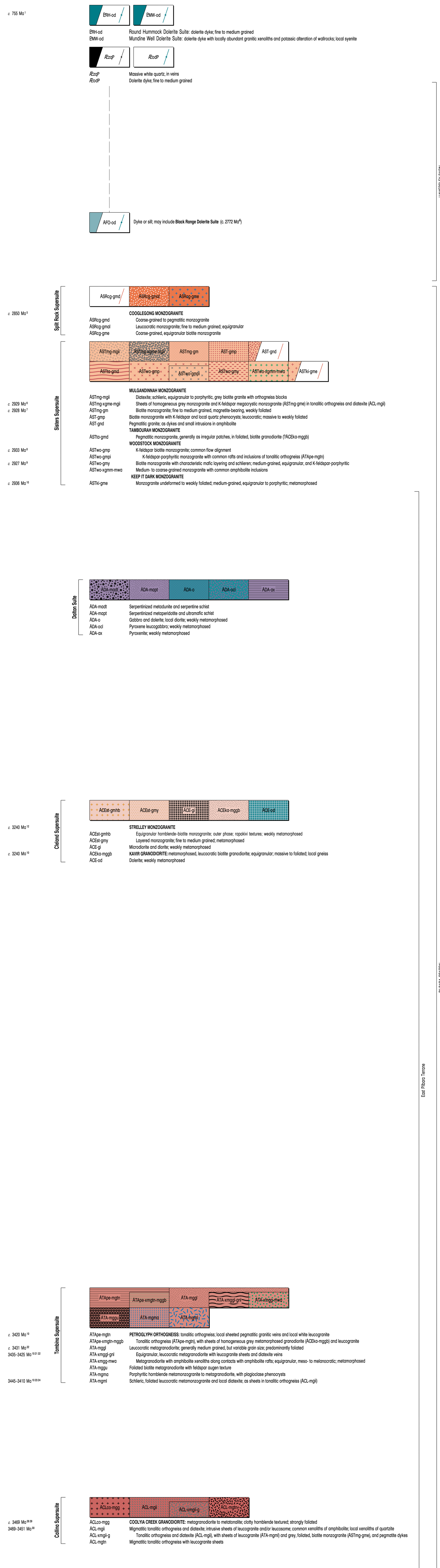
REPORT 103 PLATE 1

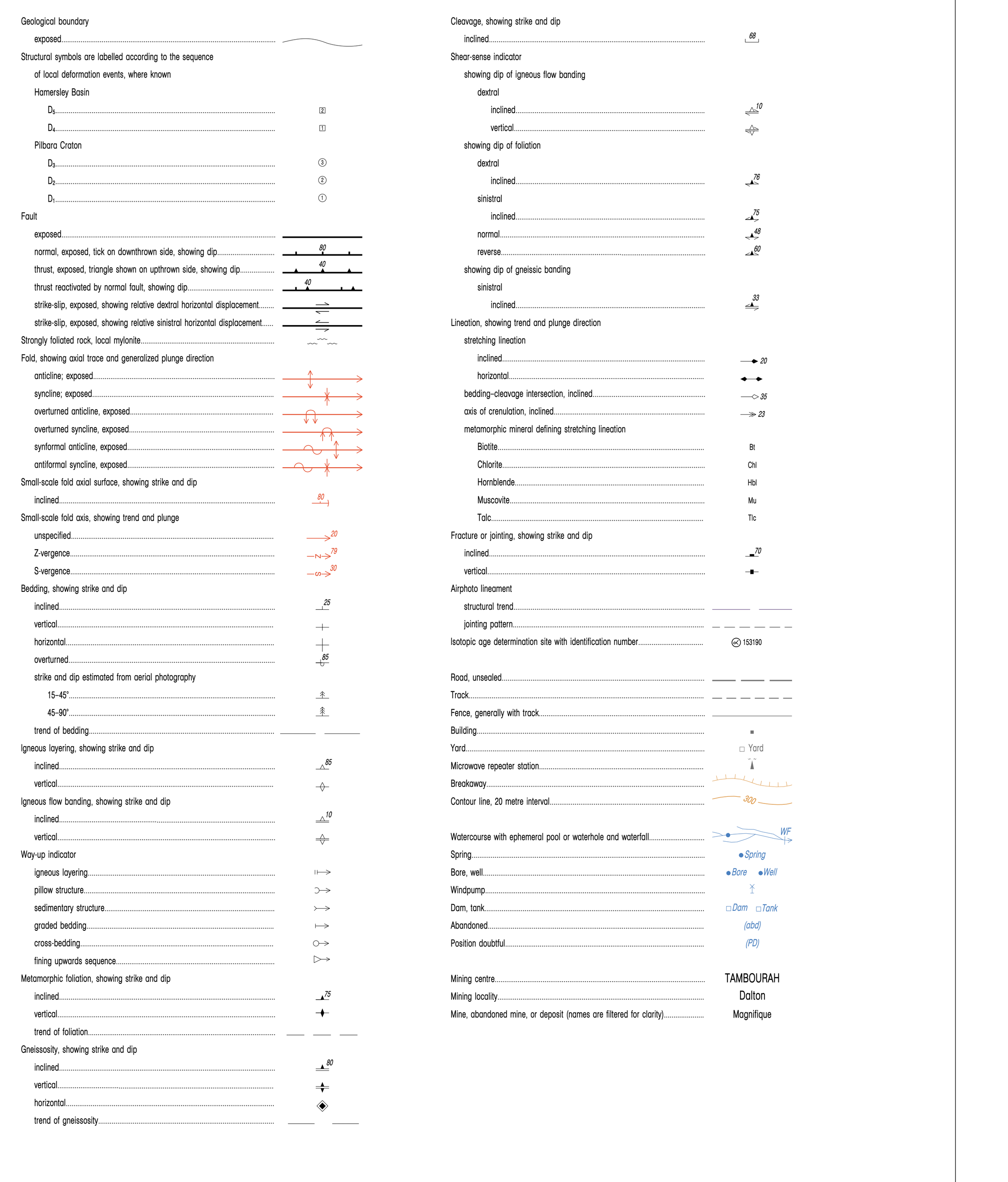
INTERPRETED BEDROCK GEOLOGY OF THE LALLA ROOKH — WESTERN SHAW STRUCTURAL CORRIDOR

PILBARA CRATON

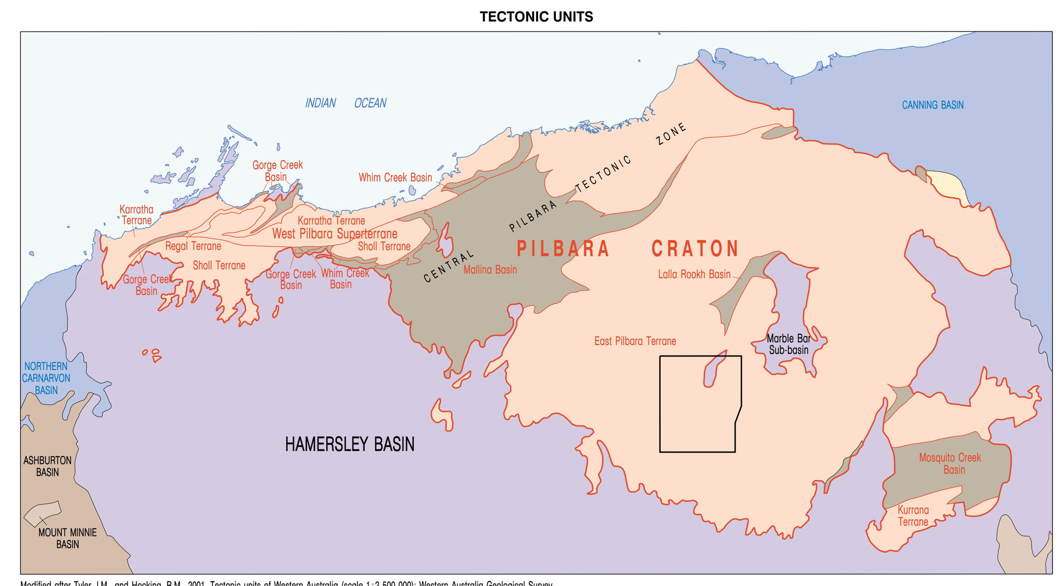
Version 1.0 – October 2006



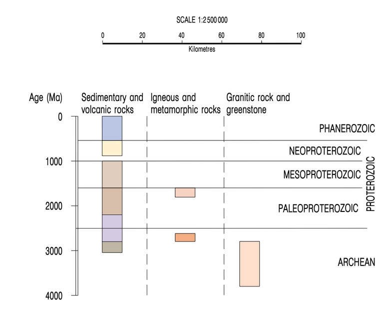




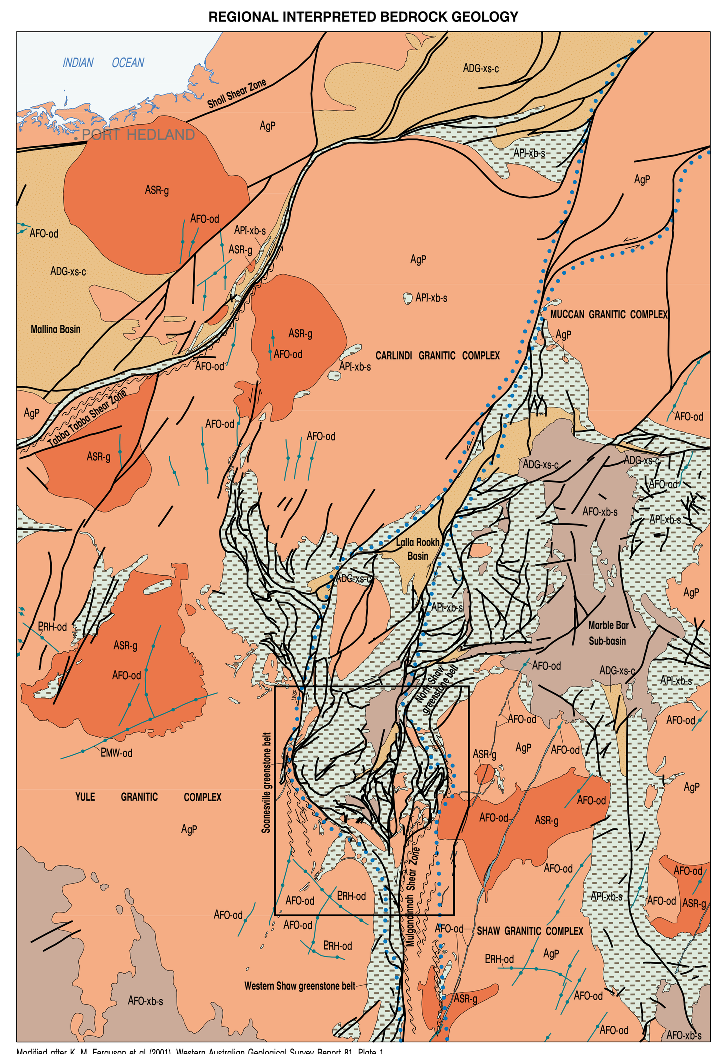
TECTONIC UNITS



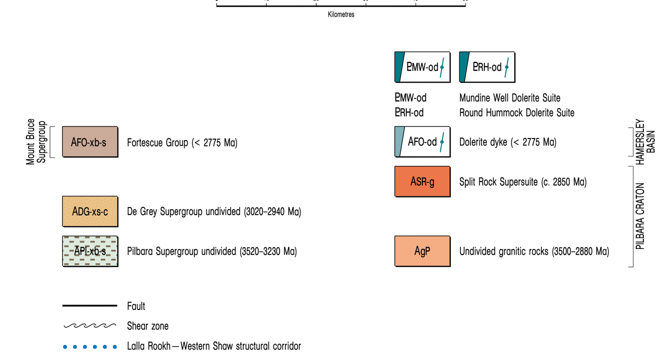
Modified after Tyler, I.M., and Hocking, R.M., 2001, Tectonic units of Western Australia (scale 1:2 500 000): Western Australia Geological Survey



REGIONAL INTERPRETED BEDROCK GEOLOGY



Modified after M. Van Kranendonk et al. (2001), Western Australian Geological Survey Report 91, Plate 1



REFERENCE LIST OF GEOCHRONOLOGICAL DATA FROM THE MAP AREA

Sample No. on map	Reference number in legend	Easting	Northing	Lithology/Mineral	Stratigraphic name	Locality name/unit	Dating method	Age (Ma)	Older zircon populations (Ma)	Interpretation of age data	Reference
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

MINERAL OCCURRENCES

MINERALIZATION STYLES*

- Vein and hydrothermal
- Regolith hosted
- Orthomagmatic mafic anf ultramafic
- Stratabound volcanic and sedimentary
- Porphyry, pegmatite, greisen, and skarn
- Stratabound sedimentary and/or sedimentary banded iron-formation

MINERAL AND ROCK COMMODITY GROUPS

- Precious mineral
- Precious metal
- Steel industry
- Speciality metal
- Base metal
- Iron
- Industrial mineral

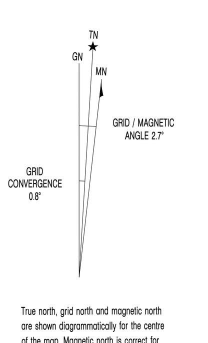
MINERAL AND ROCK COMMODITIES

Asbestos, serpentine C, chrysotile	Asbs
Beryl	Brl
Barite	Brt
Cobalt	Co
Chromium	Cr
Copper	Cu
Emerald	Brle
Gold	Au
Iron	Fe
Lead	Pb
Lithium	Li
Manganese	Mn
Nickel	Ni
Platinum Group Elements	PGE
Tantalum	Ta
Tin	Sn
Zinc	Zn

OPERATING STATUS AND SITE IDENTIFICATION NUMBER

Abandoned mine	e.g. *7103*
Mineral deposit	e.g. 3245
Mineral occurrence or prospect	e.g. *2943*

Mineral occurrences and numbers are from the GSWA WAMIN database.



DATA DIRECTORY

Theme	Data Source	Data Currency	Agency
Geology	GSWA	2005	Dept of Industry and Resources
Mineral occurrences (non-confidential)	WAMIN	JUN 2005	Dept of Industry and Resources
Cadastre	TENGRAPH*	2004	Dept of Industry and Resources
Horizontal control	GESMAR	2004	Dept of Land Information
Topographic nomenclature	GEONOMA	2004	Dept of Land Information
Topography	DLI and GSWA field survey	2004	Dept of Land Information

* GSWA and DOIR databases can be viewed online (www.doir.wa.gov.au/aboutus/geoview_launch.asp) or can be downloaded from GSWA Data and Software Centre (www.doir.wa.gov.au/GSWA/downloadcentre)

Compiled by M. J. Van Kranendonk 2002–2005

Geology by M. J. Van Kranendonk 1994–1999, M. Pawley 1997–1998

Geochronology by:

(1) M. T. D. Wingate and J. W. Giddings, 2000, Precambrian Research, v. 100, p. 335–357.
(2) T. S. Blake et al., 2004, Precambrian Research, v. 133, p. 143–173.
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(4) M. T. D. Wingate, 1999, Australian Journal of Earth Sciences, v. 346, p. 493–500.
(5) D. R. Nelson, 1998, GSWA geochronology dataset, GSWA 142879.
(6) D. R. Nelson, 2000, GSWA geochronology dataset, GSWA 142965, 142967.
(7) D. R. Nelson, 1998, GSWA geochronology dataset, GSWA 142882.
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(15) D. R. Nelson, 2003. GSWA geochronology dataset, GSWA 178042.
(16) D. R. Nelson, 2000, GSWA geochronology dataset, GSWA 142952, 148502.
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(24) D. R. Nelson, 1998, written communication.
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(26) D. R. Nelson, 2001, GSWA geochronology dataset, GSWA 168918, 168920, 168921.
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(28) D. R. Nelson, 2000, GSWA geochronology dataset, GSWA 142962.
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GSWA geochronology data are available online at www.doir.wa.gov.au/aboutus/geoview_launch.asp or on disk

Edited by C. Strong and G. Loan

Cartography by D. Bodeker, P. Backhouse, G. Wright, and B. Williams

Topography from the Department of Land Administration Sheets SF 50-8, 2754, 2755 with modifications from geological field survey

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The recommended reference for this map is:
VAN KRANENDONK, M. J., 2006, Interpreted bedrock geology of the Lalla Rookh–Western Shaw structural corridor, Pilbara Craton, *in* Geology of the Lalla Rookh–Western Shaw structural corridor, Pilbara Craton, WA. *by* M. J. VAN KRANENDONK: Western Australia Geological Survey, Report 103, Plate 1.

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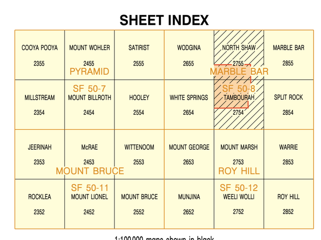

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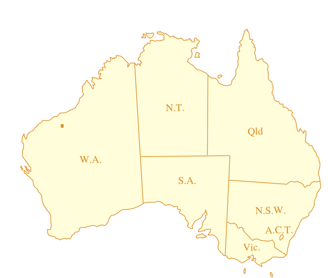

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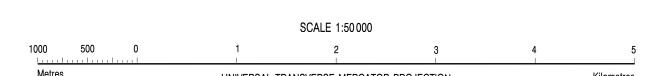

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

REPORT 103 PLATE 1A

INTERPRETED BEDROCK GEOLOGY OF THE LALLA ROOKH — WESTERN SHAW STRUCTURAL CORRIDOR

PILBARA CRATON

Version 1.0 – October 2006