STRUCTURAL AND STRATIGRAPHIC RELATIONSHIPS IN THE ARCHAEAN GRANITE-GREENSTONE TERRAIN AROUND CUE WESTERN AUSTRALIA

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ABSTRACT

Recent mapping of Archaean granite-greenstone terrain in the Cue region of the Yilgarn Block has outlined two tectonic domains in the supracrustal (*i.e.* greenstone belt) rocks. One is characterized by isoclinal folding and intense deformation; the other by open to close folding, weak deformation, and preservation of primary lithological features. One of two alternative models could account for these domains: the domains represent supracrustal sequences of different ages separated by an unconformity, the intense deformation recorded in one domain predating deposition of rocks in the other; or the domains represent different tectonic levels (and regimes) within one stratigraphic sequence. In both models, the weakly deformed domain contains rocks which are younger than those in the other domain.

Large enclaves of banded gneiss occur in the granitoids; these are structurally more complex than the supracrustals and are probably remnants of a sialic basement to the granite-greenstone system. Two phases of granitoid intrude the gneisses and supracrustals: a volumetrically dominant early phase which is recrystallized and has foliated margins with the greenstone belts; and a later, post-tectonic phase which truncates all lithologic and tectonic trends and retains igneous mineral assemblages and textures.

INTRODUCTION

Cue is situated near the centre of a large tract of supracrustal rocks (greenstones), stretching from Meekatharra in the northeast to Perenjori in the southwest, which, together with the associated granitoids, forms the Murchison Province of the Archaean Yilgarn craton (Fig. 1). The geological framework of the Cue region is typical of the Murchison Province; isolated, irregularly shaped outcrops of greenstones occur in a much more voluminous granitoid terrain.

Recent mapping in this region has revealed the presence of distinct tectonic domains of differing styles and intensities of deformation in the greenstone belts. Large areas of banded granitoid gneisses which bear similarities to those in the Western Gneiss Terrain have been identified. In addition, two phases of intrusive granitoids have been recognized. Figure 2 is a simplified lithological interpretation map of the region; outcrop extent (particularly of the granitoids) is partly based on photo-interpretation, aeromagnetic data (Waller and Beattie, 1971), landsat scenes 120-079 CUE and 119-079 SANDSTONE (W), and previous geological mapping (de la Hunty, 1973). Structural information relating to this map is given in Figure 3.

In the following sections, the major structural relationships in the greenstones, gneisses, and granitoids are described, and models are proposed which may explain these. The stratigraphic implications of the models are discussed.

STRUCTURAL RELATIONSHIPS

Supracrustal rocks (greenstone belts)

Two distinct tectonic domains have been mapped in the greenstone belts (Fig. 3). The largest, domain A, is characterized by intense deformation and penetrative fabrics associated with isoclinal folding. In this domain, strain is often taken up in discrete shear zones (a few metres to a few hundred metres in width) in which primary lithologies become schistose; for example, komatiitic basalt becomes tremolite-chlorite-talc schist, and tholeiitic basalt becomes amphibolite (although other protoliths are possible for these rocks). Shear may also occur along anastomosing planes, between which primary textures are preserved (Fig. 4). Thick, competent units of gabbro and dolerite, and some tholeiitic piles, often have well-preserved interiors with relic igneous textures; however, the margins are generally sheared to amphibolite. Only one megascopic isocline, that at Tuckabianna (Fig. 3), has been mapped in domain A. This fold has an exposed (minimum) amplitude of 15 km; aeromagnetic data (Bureau of Mineral Resources Cue 1:250 000 aeromagnetic/radiometric sheet) indicate that the southeast limb extends a further 12 km southwest under Lake Austin. It is likely that other large isoclines exist in the area, but the exposure is such that these are obscured. Minor, tight to isoclinal folds are ubiquitous in the thin (1-5 m) units of banded iron-formation in this domain (Fig. 5); the foliation is axial planar to these folds. Minor folds are rare in other lithologies, which tend to be massive or schistose and to lack marker horizons.

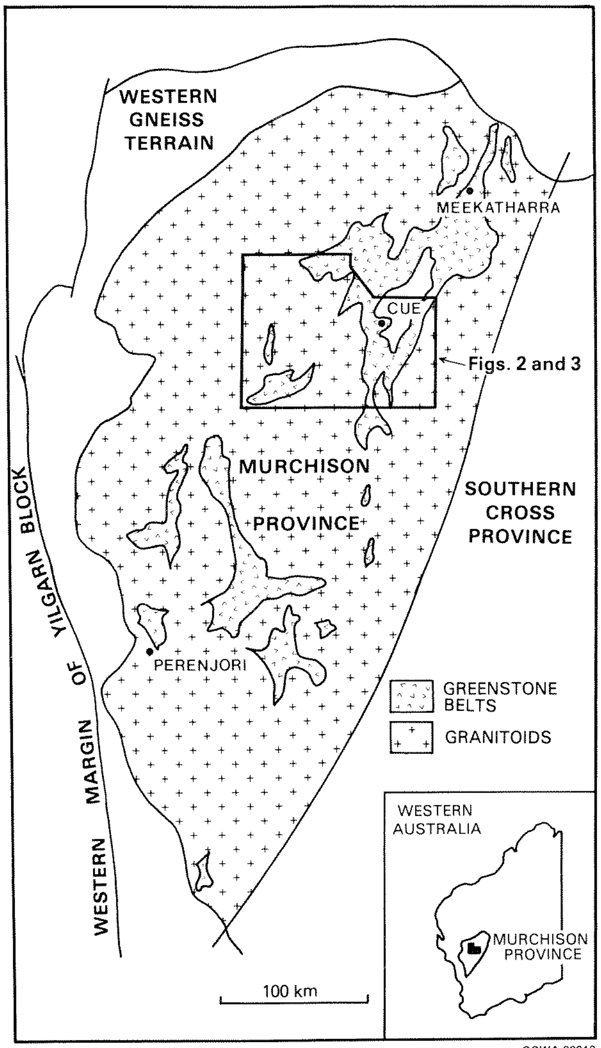

Figure 1. Distribution of granitoids and greenstone belts in the Murchison Province of the Yilgarn Block. Area of Figures 2 and 3 is indicated.

Domain B is characterized by megascopic open-to-close folding, *cf.* Ramsay (1967, p.349); minor folding is rare; axial-planar cleavages are developed only sporadically; and primary lithological features and textures are preserved. The outcrops at Ryansville and Dalgaranga (Figs 2 and 3) are assigned to this domain. At Ryansville, a sequence of komatiite, komatiitic basalt—terminology after Arndt and Nesbit (1982)—and tholeiite 3.5 km thick, is folded into an open syncline plunging about 70° southwest (Fig. 3). There is little internal deformation, and an axial-planar cleavage is not developed. An example of a well-preserved pillow lava from this sequence is shown in Figure 6. In the Dalgaranga region, a close syncline plunges about 65° towards the northeast (Fig. 3); this fold tightens towards the southwest. Structural elements (foliations etc.) in domain A swing around this fold (Fig. 3), *see* southwest portion of Cue 1:250 000 sheet (de la Hunty, 1973), and southeast portion of Murgoo 1:250 000 sheet (Baxter, 1974). Primary textures are preserved in dacitic tuffs and coarse-grained volcaniclastic sediments in the core of this fold (Fig. 7). Axial-planar cleavage is developed only towards the southwest, where the fold tightens; no minor folding has been found despite the abundance of planar marker horizons. A thick, multiple gabbro sill intruded and substantially thickened the sequence prior to folding. As a consequence of this intrusion, less competent pelitic sediments adjacent to the gabbro have been attenuated and statically metamorphosed to amphibolite facies—andalusite (-cordierite-garnet)-bearing assemblages.

A further two phases of folding and associated spaced cleavage affected the greenstone belts; but in order to preserve clarity, these are not marked on Figure 3. A phase of open folding with north- to north-northeast-trending axes occurs most noticeably between Tuckabianna and Ryansville, although a closure also occurs southeast of Moyagee. A cleavage associated with this folding cuts across the axial plane of the Ryansville syncline. A later phase of open folding with northwest-trending axes and an associated, spaced cleavage is seen in most of the greenstone belts. The axial plane of the Dalgaranga syncline, and the foliation in domain A, immediately to the south are folded by this phase. A phase of late, large-scale faulting, which trends north to northeast, dissects the Moyagee-Tuckabianna belt (Figs 2 and 3).

Banded gneiss

The gneisses are compositionally banded plagioclase-microcline-quartz-biotite rocks, which record a complex deformation history. They occur mainly along the western margin of the area as large, fairly coherent units and also as smaller "rafts" in the granitoids throughout the area (Fig. 2). The banding is folded, and a variety of fold styles are seen (Figs. 8, 9, and 10); an isoclinal phase is the most commonly observed. The main trend of the banding is parallel to tectonic trends in domain A of adjacent greenstone belts and in foliated granitoids.

The isoclinal fold phase commonly seen in the banded gneiss is thought to be the same as that seen in domain A. Axial planes of minor isoclinal folds in the Warda Warra greenstone belt (Figs 2 and 3) are approximately co-planar with those of isoclines in the banded gneiss to the west. The only evidence for a phase of deformation predating the isoclinal folding in the greenstones is an early lineation of unknown significance recorded at only one locality in the Tuckabianna fold. Extensive deformation must have occurred in the gneiss prior to isoclinal folding in order to develop the pronounced banding, *cf.* Myers (1978). Thus it is likely the banded gneiss predates the supracrustal rocks and forms an early sialic basement.

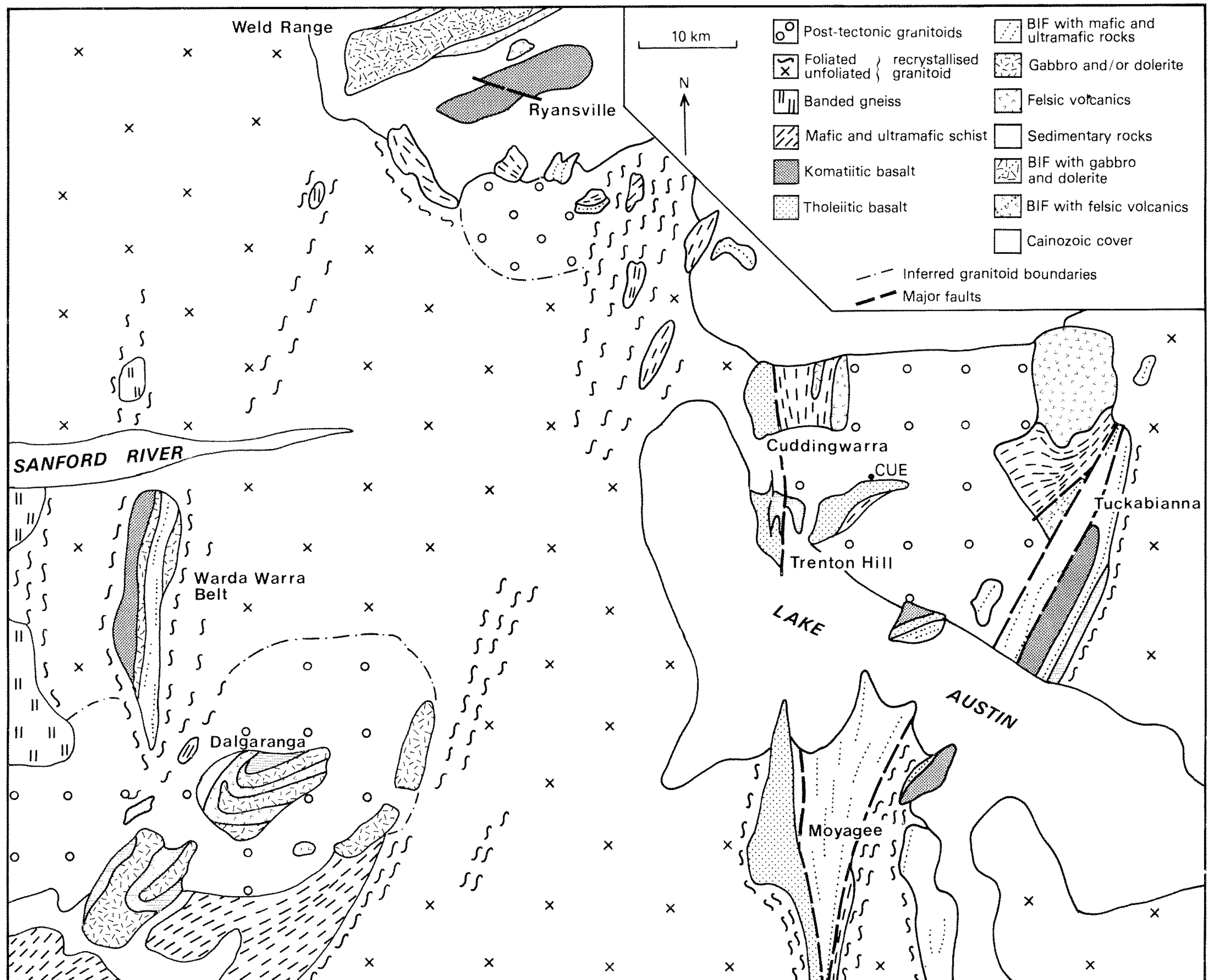

Figure 2. Simplified lithological interpretation map of the Cue region. Interpretation is impossible beneath some extensive areas of Cainozoic cover.

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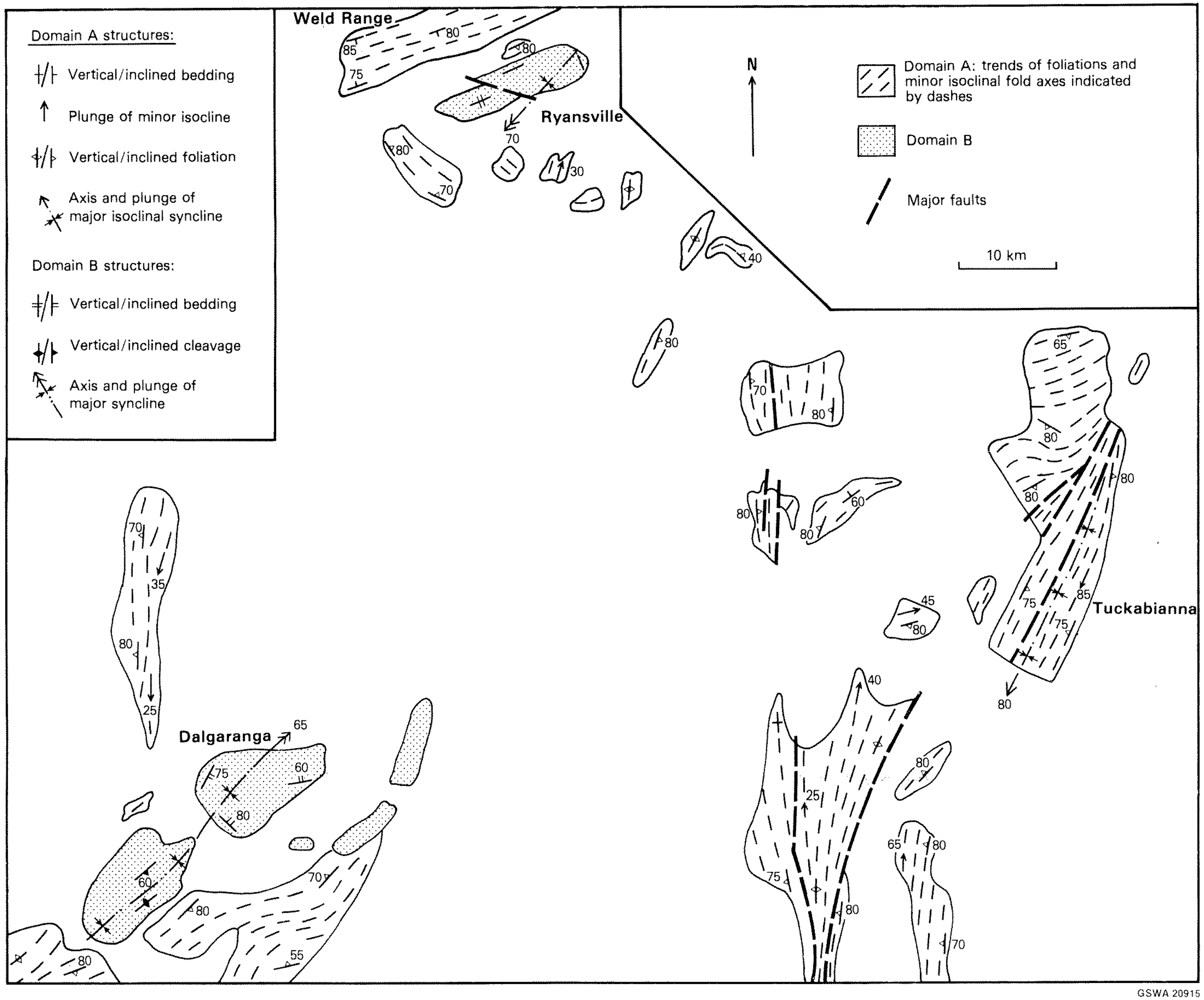

Figure 3. Structural map of the supracrustal rocks in the Cue region. Two, late, open phases of folding, with north and northwest axial trends, are omitted for clarity. Domain A is characterized by isoclinal folding and intense deformation. Domain B is characterized by open to close folding, weak deformation and preservation of primary lithological features.

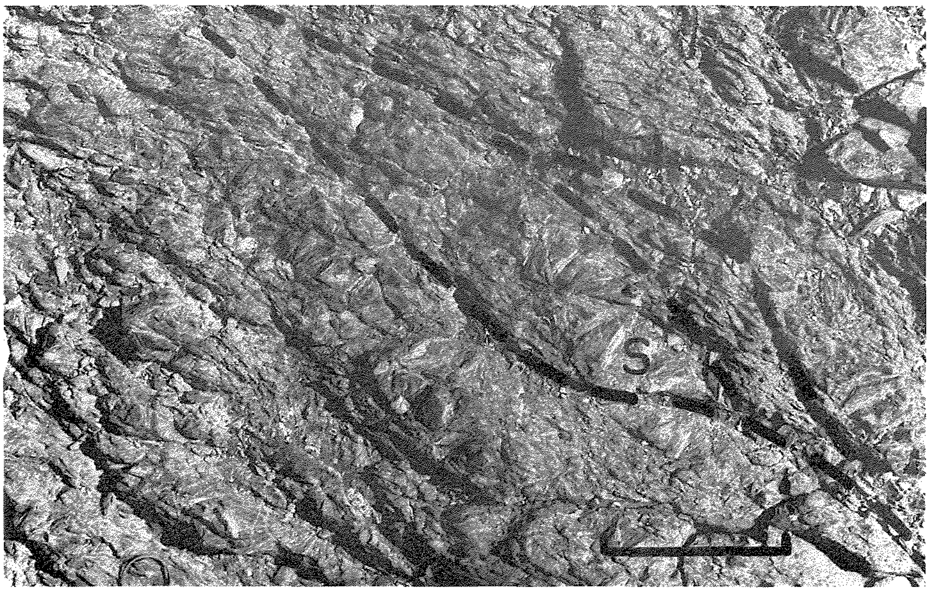

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Figure 4. Anastamosing shears composed of tremolite-chlorite-talc schist in a komatiitic basalt (examples are indicated by dashed lines); original spinifex texture is preserved in lenses between the shears (*e.g.* at S). The scale bar is 5 cm.

GSWA 20917

Figure 5. Minor, tight to isoclinal folding in a banded iron-formation in domain A. The hammer shaft is 30 cm long. GSWA

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Figure 6. Weakly deformed komatiitic pillow basalt at Ryansville, stratigraphic younging is towards the top of the photograph. A fracture cleavage (parallel to the short dimension of the photograph) cuts across the pillows and is axial planar to the late north-trending open phase of folding (see text).

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Figure 7. Undeformed coarse-grained (conglomeratic) volcaniclastic derived from underlying dacites at Dalgaranga. Bedding runs from bottom left to top right of the photograph. The lens cap is 5 cm in diameter.

GSWA 20920

Figure 8. Tight to isoclinal fold of banding in granitoid gneiss.

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Figure 10. Complex folding of banding in granitoid gneiss.

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Figure 9. Open to close folding of banding in granitoid gneiss.

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Figure 11. Strongly foliated and compositionally banded recrystallized granitoid, 300 m from a greenstone belt contact.

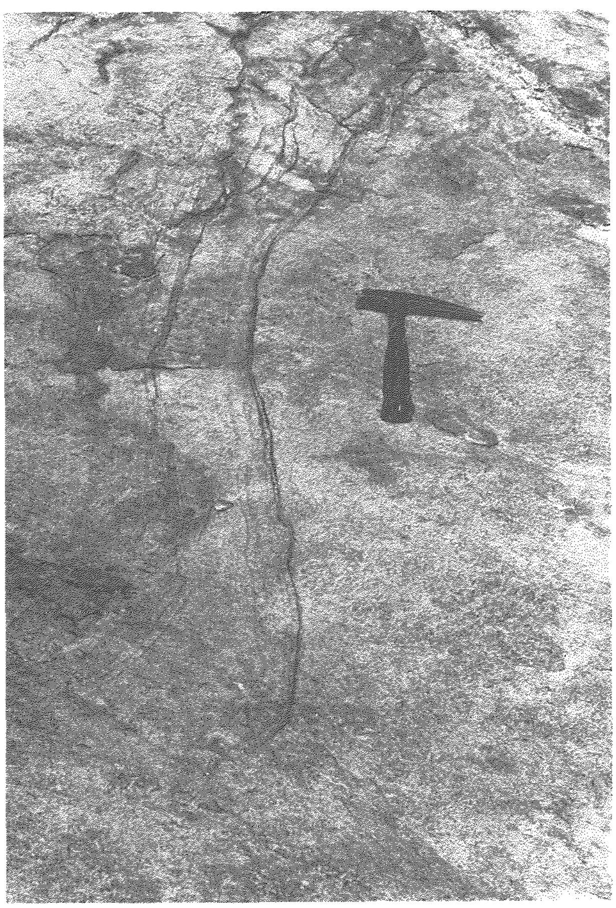

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Figure 12. "Ghost banding" in an unfoliated recrystallized granitoid; this is a recrystallized and partially absorbed xenolith of banded gneiss.

Intrusive granitoids

Two types of intrusive granitoid are recognized, a recrystallized and partly foliated phase and a post-tectonic phase. The recrystallized granitoids are the most voluminous (Fig. 2) and are adamellitic in composition. The margins of these granitoids adjacent to greenstone and gneiss belts are strongly foliated and often compositionally banded (Fig. 11). The foliation trends are generally parallel to the margins of the greenstone and gneiss belts, which themselves are often parallel to tectonic trends within these belts. The granitoid-greenstone contacts are generally zones of mixed and foliated granitoid and greenstone rocks ranging from a few tens of metres to a kilometre wide. The intensity of foliation and degree of compositional banding decrease rapidly away from the margins, and for the greater part of their outcrop, these granitoids are unfoliated. Both the foliated and unfoliated portions are thoroughly recrystallized and exhibit granoblastic metamorphic textures; original phenocrysts in unfoliated porphyritic varieties are pseudomorphed by microcline porphyroblasts. Metamorphic recrystallization outlasted deformation in foliated types. Several linear and apparently discontinuous zones of moderate to high strain trend north-northeast across these granitoids (Fig. 2); the significance of these is unknown. Throughout large areas of recrystallized granitoid adjacent to the gneiss outcrops, patches of "ghost banding", which are remnants of absorbed xenoliths of gneiss, are common (Fig. 12).

The post-tectonic granitoids occur as relatively small bodies which range in composition from adamellite to tonalite. They truncate tectonic and lithological trends in the country rocks (Figs. 2 and 3). Original igneous mineral assemblages and hypidiomorphic granular texture are preserved; the plagioclase characteristically exhibits complex oscillatory zoning.

TECTONO-STRATIGRAPHIC MODELS

Contacts between domains A and B in the supracrustal rocks are not exposed; therefore, relationships between these domains cannot be determined with certainty. However, it is possible to account for the sharply contrasting deformation styles in these domains by invoking one of two alternative models.

(i) The domains represent supracrustal sequences of different ages and are separated by an unconformity; the isoclinal fold phase recorded in domain A predates deposition of rocks in domain B (Fig. 13). In the Dalgaranga region, the lower (domain A) and upper (domain B) sequences may be broadly concordant. However, in the Weld Range — Ryansville area the situation is more complex. Trends in the lower sequence are not consistent to the south and southwest of Ryansville, where the rocks have been affected by the phase of late folding and are surrounded by granitoids (Fig. 2). A major unconformity of the type proposed here has been identified in the Warriedar greenstone belt in the southern Murchison Province (Baxter and others, 1980; Lipple and others, 1980; Seccombe and Frater, 1981, Fig. 1).

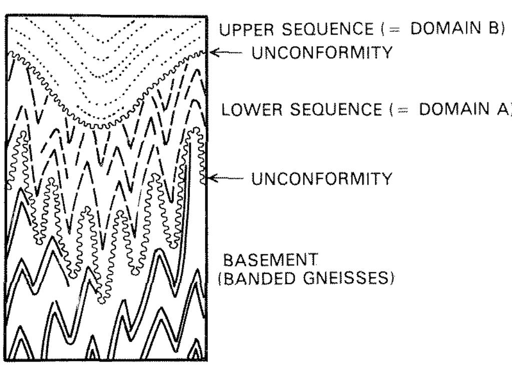

Figure 13. Schematic representation of tectono-stratigraphic model I.

(ii) The deformation in both domains is essentially contemporaneous, and they represent different tectonic levels within a single heterogeneously deformed supracrustal sequence (Fig. 14). They may be separated by a tectonic dislocation within this sequence, as indicated by the dashed line in Figure 14, or there may be a sharp gradation in deformation intensity between the two domains. Hickman (1975) and Hickman and Lipple (1975, Fig. 6) have described similar structures in the Pilbara Block, although no documented examples exist in the Yilgarn Block.

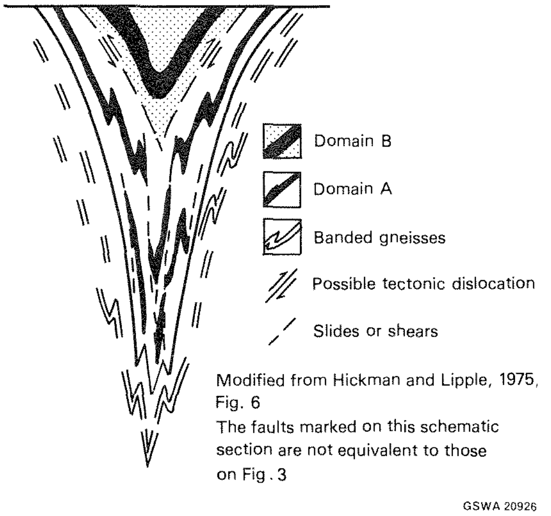

Figure 14. Tectono-stratigraphic model II.

In each of the models described above, it is possible to divide the supracrustal rocks into a lower (domain A) and an upper (domain B) sequence separated by the domain boundary. In the second model (II) this boundary has much less stratigraphic significance than in the first (I); however, it still separates rocks higher in the supracrustal sequence from those lower in it. In either case a sialic basement of branded gneiss is likely (Figs 13 and 14).

The relative age of the recrystallized granitoids is uncertain. Marginal foliations in these granitoids cut across fabrics associated with isoclinal folding in the greenstone belts in some parts of the area—*e.g.* at the western margin of the greenstone belt southeast of Moyagee (Figs 2 and 3). Thus, if the first model is correct, the foliations in the recrystallized granitoids probably formed during the open-close fold phase. If the second model is correct, these foliations probably formed during the phase of heterogeneous deformation of greenstone belts (isoclinal and open-close folding): however, a problem is posed here by the cross-cutting foliations mentioned above. The two later fold phases (north and northwest axial trends) are of insufficient intensity to impart a strong foliation to the recrystallized granitoids. The second model seems less likely in the light of these relationships. The intrusive granitoids are omitted from Figures 13 and 14 for simplicity.

SUPRACRUSTAL ROCK TYPES

In domain A (lower sequence) there appear to be three major mafic units (Fig. 2): a dominantly komatiitic unit; a dominantly tholeiitic unit; and a unit containing abundant banded iron-formation with intervening mafic and ultramafic rocks. Where deformation is particularly intense and protoliths are thus difficult to recognize, rocks are assigned to a unit of "mafic and ultramafic schist" on Figure 2. Facing evidence (differentiation in conformable layered gabbro sills) in the Moyagee and Tuckabianna areas indicates that the komatiitic unit overlies the unit with common banded iron-formation. The stratigraphic position of the tholeiitic unit is unknown. Felsic volcanics and sediments are much less common than mafic rocks in the lower sequence. The only major occurences are at Eelya Hill, Cuddingwarra, west of Moyagee, Trenton Hill, and the Weld Range. At Eelya Hill, an 8 km-thick (possibly tectonically thickened) sequence of strongly sheared rhyodacitic schists with minor metasediments is exposed. Sheared and disrupted mafic to ultramafic sills occur throughout the succession. In the Cuddingwarra area, a 1 km-thick unit of strongly sheared rhyodacitic schist occurs. Ten kilometres west of Moyagee, a 0.5 km-thick unit of sheared, poorly sorted, coarse sandstone occurs within an extensive mafic sequence. This unit is thought to extend northwards across Lake Austin to the Trenton Hill area, where sandstone units are exposed as pavements at the margin of the salt lake. These occurrences indicate that an exposed sialic terrain existed during development of the lower greenstone sequence. It is unlikely that this terrain was volcanic, as many of the sandstone units comprise about 70% large (up to 3 mm, average 1 mm) quartz grains with occasional quartz pebbles up to a few centimetres across; the matrix is a mixture of fine-grained quartz, sericite and kaolin (after feldspar). In the Weld Range, thick (up to 150 m) jaspilitic banded iron-formation, fine-grained felsic volcanics and volcaniclastics, and minor mafic volcanics are intruded by multiple dolerite sheets with little apparent disruption of bedding.

In domain B (upper sequence), the major mafic unit is a sequence of Komatiitic and tholeiitic volcanics, 3.5 km thick, which occurs at Ryansville. The unit is dominantly basaltic with pillowed flows and breccias (hyaloclastites): an ultramafic komatiite with bladed spinifex texture forms the base. The volcanics differ from komatiitic rocks in the lower sequence in that pillows and breccias are common. At Dalgaranga, three major depositional units occur. A 1.5 km-thick unit of pelitic and psammitic rocks, within which thin, banded iron-formation and mafic units are common, occurs at the base of the sequence. A unit of finely layered dacite tuff about 1 km thick overlies this. A coarse-grained, poorly sorted volcaniclastic unit, 300 to 400 m thick, derived directly from the underlying dacites, marks the top of the sequence. A thick, multiple gabbro sill intrudes the sequence (Fig. 2).

The fact that at least 50% of the basaltic rocks in the Cue region are komatiitic is significant, as it had previously been thought that this rock type was rare in the Murchison Province; this has been used as a major lithological criterion in distinguishing the province from the neighbouring Southern Cross Province, in which komatiitic rocks are common (Gee and others, 1981). Komatiitic rocks were not identified during the original GSWA mapping from 1966 to 1968 (de la Hunty, 1973) because these rocks were first documented in southern Africa in 1969 (Viljoen and Viljoen, 1969a, 1969b) and later in Western Australia (Nesbitt, 1971).

PREVIOUS STRATIGRAPHY

De la Hunty (1973) proposed a sequence of three litho-stratigraphic formations in the Cue region, the Moyagee, Cuddingwarra, and Ryansville Formations (Table 1). It seems unlikely, from recent mapping by the authors, that this scheme is tenable. For example, all the felsic volcanics and sedimentary rocks (with the exception of banded iron-formation and chert units) were grouped in one formation—the Cuddingwarra. Yet, from the preceding discussion it is evident that the occurrence of felsic and sedimentary lithologies span the chronological development of both lower (domain A) and upper (domain B) sequences. De la Hunty (1973) thought the Ryansville outcrop represented part of an upper mafic sequence; this is compatible with the models presented here; however, he also thought the rocks in the Tuckabianna fold were equivalent to these. No evidence is given by de la Hunty (1973) to support a major threefold division.

TABLE 1. De La HUNTY'S (1973) CUE STRATIGRAPHY

Name	*Description*
Ryansville Formation	Mafic extrusive and intrusive rocks; thickness=1524 m (5 000 ft)
Cuddingwarra Formation	Felsic volcanics and sediments minor mafic rocks, banded iron-formation; thickness=2 438 m (8 000 ft)
Moyagee Formation	Mafic and ultramafic extrusive and intrusive rocks, banded iron-formation, minor sediments; base of formation intruded by granite; thickness=4 267 m (14 000 ft)

CONCLUSIONS

(a) Two tectonic domains can be distinguished in the supracrustal rocks. It is likely that these have stratigraphic significance and represent older and younger sequences.

(b) Occurrences of complexly deformed, banded, granitoid gneiss probably represent remnants of a sialic basement to the granite-greenstone system.

(c) Two phases of granitoid intrusion are recognized: an early and volumetrically dominant phase, now recrystallized and partly foliated; and a later postectonic phase which retains original igneous features.

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