

# Are there terranes within the Lamboo Complex of the Halls Creek Orogen?

by I. M. Tyler, T. J. Griffin, R. W. Page<sup>1</sup>, and R. D. Shaw<sup>1</sup>

## Abstract

The Early Proterozoic rocks of the Lamboo Complex of the Halls Creek Orogen can be divided into three zones that are interpreted as separate terranes. The trend of the zone boundaries is interpreted to have been originally to the northwest, and these zone boundaries are thought to have controlled the development of younger fault systems.

The western zone has much in common with the Hooper Complex of the King Leopold Orogen in that it is dominated by 1860–1850 Ma felsic volcanic rocks and associated granitoids that have been intruded into metasedimentary rocks and mafic sills that are between 1870 and 1860 Ma old. The central zone is dominated by the low- to high-grade mafic and metasedimentary rocks of the Tickalara Metamorphics. These were intruded by granitoid sheets at c. 1860 Ma, before being deformed and metamorphosed at c. 1855 Ma. This was followed closely by the intrusion of layered mafic–ultramafic bodies. Felsic volcanic rocks were erupted at c. 1840 Ma. The eastern zone is dominated by the mafic volcanic and metasedimentary rocks of the Halls Creek Group, the upper part of which was still being deposited at c. 1855 Ma. All three zones were intruded by c. 1820 Ma granitoids and gabbroic rocks.

The presence of tectonostratigraphic terranes and the different geophysical nature of the basement on either side of the Halls Creek Orogen are consistent with the operation of plate tectonics during the Early Proterozoic development of northern Australia.

**KEYWORDS:** Halls Creek Orogen, Lamboo Complex, Proterozoic, terrane analysis, plate tectonics.

The Halls Creek Orogen developed initially during the Early Proterozoic (Page, 1976, 1988) between a postulated Kimberley Craton, underlying the Kimberley Basin to the northwest, and a composite craton that included Archaean rocks within the Pine Creek Geosyncline and possibly within the Granites–Tanami Inlier. Most of this composite craton is now overlain by Middle Proterozoic, Late Proterozoic, and Palaeozoic basins (Fig. 1). The different nature of these

two cratons is evident in geophysical data used to produce a basement-elements map of Australia (Shaw et al., 1994). The rocks which were formed during the Early Proterozoic orogenic event are exposed in the Lamboo Complex (Griffin and Grey, 1990), and consist of deformed and metamorphosed plutonic and volcanic igneous rocks and sedimentary rocks.

Hancock and Rutland (1984) put forward a tectonic model for the evolution of Early Proterozoic rocks in the east and west Kimberley in

which they identified a style of orogeny that they regarded as distinct from that which typifies Phanerozoic orogenic belts. Rather than being the products of a complete plate-tectonic 'Wilson Cycle' involving the subduction of oceanic crust, the King Leopold and Halls Creek Orogens were regarded to be the result of initial extension where large areas of thinned Archaean crust were formed, followed by convergence. The Halls Creek Group, a sequence of metavolcanic and metasedimentary rocks, was thought to occur throughout both orogenic belts, and this was used as evidence that crustal separation did not take place. The thinned Archaean crust subsequently underwent limited A-subduction (Kröner, 1981, 1983) producing deformation, metamorphism, and igneous activity.

This model was modified by Etheridge et al. (1987) and extended throughout the Early Proterozoic of northern Australia. They envisaged a linked polygonal system of rifts, formed above a series of small-scale mantle-convection cells. Extension resulted from gravitational spreading of the hot, uplifted belts that had been thickened significantly by underplating. Subsequent thermal relaxation and flexural loading produced sag basins overlying the rift stage. Orogeny was driven by lithospheric delamination during cooling and sediment loading. This orogenic event was regarded as essentially synchronous throughout northern Australia between about 1880 and 1850 Ma (Page, 1988; Page and Williams, 1988; Wyborn, 1988), and was referred to as the Barramundi Orogeny.

<sup>1</sup> Australian Geological Survey Organisation

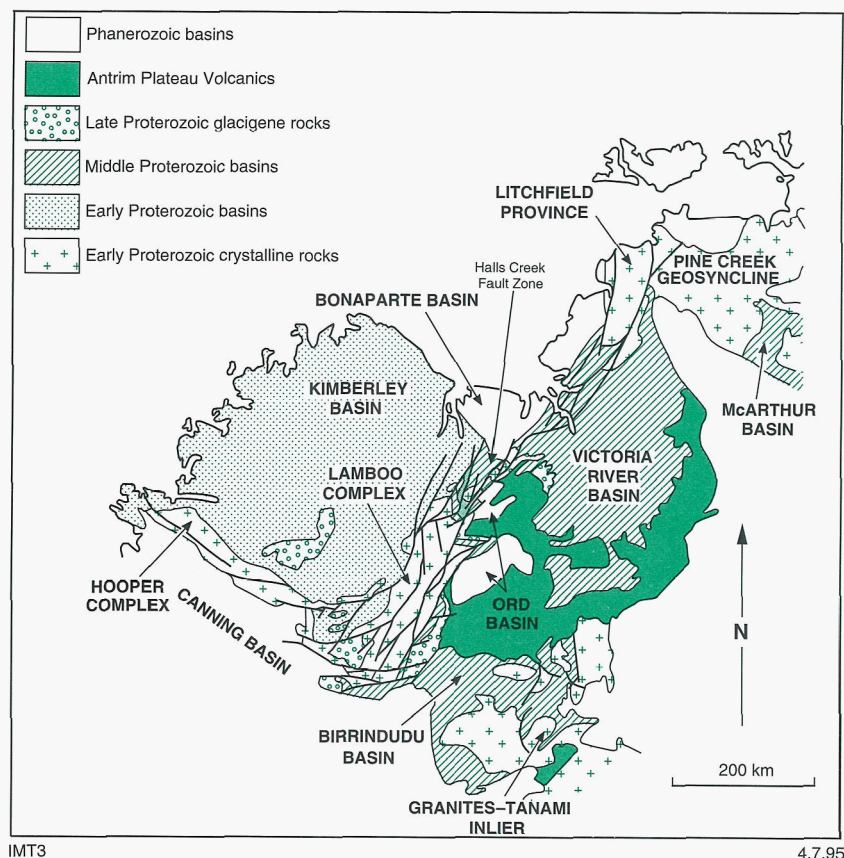


Figure 1. The main tectonic units of the Kimberley region

This intracratonic, essentially 'fixist', view of the Early Proterozoic evolution of Australia contrasts with the more dynamic views of workers on the Early Proterozoic of North America, Europe, and Africa. Recent models, such as those of Hoffman (1988, 1989, 1991) and Windley (1993), envisage the aggregation of Early to Middle Proterozoic continents by plate-tectonic processes similar to those operating in the present. Subsequent Middle and Late Proterozoic events involved the breakup of these continents, followed by the formation of a Late Proterozoic supercontinent (Hoffman, 1991; Dalziel, 1992). Myers (1993) has shown that the Precambrian history of southwest Australia can also be interpreted in a similar way.

Remapping of the King Leopold Orogen was commenced by the Geological Survey of Western Australia (GSWA) in 1986 (Griffin and Myers, 1988; Griffin, 1989; Tyler and Griffin, 1990, 1993; Griffin et al., 1993) and was subsequently

extended into the Halls Creek Orogen in 1990. The GSWA Halls Creek Orogen Project is being carried out in conjunction with the Australian Geological Survey Organisation (AGSO) as part of the National Geoscience Mapping Accord Kimberley–Arunta Project (Blake et al., 1991; Griffin and Tyler, 1992a; Blake and Hoatson, 1993; Hoatson, 1993; Hoatson and Tyler, 1993; Griffin and Tyler, 1994; Tyler and Griffin, 1994; Page et al., in prep.). This remapping, together with geochronological, geochemical, petrological, and remote-sensing studies, has allowed reassessment of the tectonic evolution of the King Leopold and Halls Creek Orogens.

### The terrane concept

A terrane is defined as 'a fault-bounded body of rock of regional extent, characterized by a geologic history different from that of contiguous terranes' (Bates and Jackson, 1987, p. 679). Discrete terranes have been recognized

within the North American Cordillera along the margin between the oceanic Pacific and Juan de Fuca Plates, and the continental North American Plate (Coney et al., 1980). This led to its interpretation as a vast mosaic or collage of discrete allochthonous fragments of oceanic or continental crust that had been added to an active continental margin by accretion during subduction of the oceanic plates beneath the North American continent. Tectonostratigraphic terranes have also been recognized in other Phanerozoic orogenic belts (Hutton, 1987; Coney et al., 1990; Sengor et al., 1993), within Proterozoic orogenic belts (Kröner, 1985; Rivers et al., 1989; Park, 1991), and within the Archaean cratons (Card, 1990; de Witt et al., 1992; Myers, 1993), and in each case plate-tectonic processes have been invoked (Windley, 1993).

Hancock and Rutland (1984) divided the Halls Creek Orogen into four distinct zones, each with particular geological characteristics. Griffin and Tyler (1992a) subsequently reduced the number of zones to three, amalgamating zones II and III of Hancock and Rutland (1984). In this paper we also recognize three zones (Fig. 2), although the boundaries differ from those of the previous workers to take account of new data. The geological histories of these zones (Fig. 3), based on geochronological data and field relationships identified during remapping, can be compared to see whether the conclusions of Hancock and Rutland (1984) are upheld (that geological units, and deformation, metamorphism, and igneous events can be correlated between zones), or whether one or more of the zones actually constitute distinct tectonostratigraphic terranes with independent histories.

### The eastern zone

The eastern zone is characterized by the low- to medium-grade meta-sedimentary and metavolcanic rocks of the Halls Creek Group. The oldest rocks within the zone, from which Sensitive High Resolution Ion Microprobe (SHRIMP) U–Pb ages of c. 1910 Ma have been obtained from zircons, are the bimodal volcanic rocks of the Ding Dong Downs Volcanics, and their associated high-



level granitoid intrusions (e.g. the Sophie Downs Granite). The Ding Dong Downs Volcanics were originally included within the Halls Creek Group (Dow and Gemuts, 1969), but the identification of an unconformity between the Sophie Downs Granite and the Saunders Creek Formation at the northern end of the Sophie Downs Dome (Griffin and Tyler, 1992a; Blake et al., in prep.) resulted in the redefinition of the Halls Creek Group by Griffin and Tyler (1992a) to exclude them.

The Halls Creek Group consists of three formations. The lowest unit is the Saunders Creek Formation, which is a thin fluvial sequence of cross-bedded sandstone and conglomerate. It overlies the Ding Dong Downs Volcanics and associated granitoids with minor angular discordance. The Biscay Formation consists of mafic volcanic rocks interbedded with minor felsic igneous rocks (with a SHRIMP U–Pb zircon age of c. 1880 Ma), and siliciclastic and calcareous meta-sedimentary rocks, and overlies the Saunders Creek Formation. The mafic volcanic rocks include massive and pillowed metabasaltic lava flows, together with fragmental, agglomeratic deposits, and fine-grained volcanoclastic deposits.

The Biscay Formation is overlain by the uppermost unit of the Halls Creek Group, the Olympio Formation, which consists of a monotonous sequence of turbiditic quartz wacke, greywacke, arkosic sandstone, and quartz sandstone, interbedded with siltstone and mudstone. Provenance and palaeo-current data obtained by Hancock (1991) indicate that at least part of the unit was derived from a predominantly granitic source to the northwest. A distinctive alkaline volcanic unit, the Butchers Gully Member (Griffin and Tyler, 1992a), occurs in the lower part of the Olympio Formation. This consists of trachyandesite lavas and intrusions, together with associated volcanoclastic deposits (Esselmont, 1990). SHRIMP U–Pb ages on zircons from a mineralized unit at the base of the member give a date of c. 1870 Ma (Taylor et al., in prep.). Remapping to the north of the Sophie Downs Dome (Blake et al., in prep.; Warren and Tyler, in prep.) indicates that the conventional zircon U–Pb age of



Figure 2. Map showing zones and zone boundaries within the Lamboo Complex of the Halls Creek Orogen

1856 ± 5 Ma obtained by Page and Hancock (1988), from what they thought to be the Biscay Formation, actually corresponds to a lava flow within rocks similar to those of the Butchers Gully Member. SHRIMP ages give a similar result. The two ages indicate that the lower Olympio Formation was deposited between 1870 and 1855 Ma.

The Halls Creek Group has been intruded by the Woodward Dolerite, which consists of a number of relatively thin, massive metadolerite sills that are conformable with bedding.

The earliest deformation ( $D_1$ ) in the eastern zone involved layer-parallel shearing, with the development of mylonitic rocks at the contact between the Saunders Creek Formation and underlying rocks. Warren (1994) described an area where parts of the upper Biscay Formation and lower Olympio Formation stratigraphy are missing,

suggesting that this event was produced by extension. Shear criteria within the mylonites indicate that this extension was to the south. Thin phyllonitic zones occur along bedding planes within the Olympio Formation.

The second deformation ( $D_2$ ) was pervasive, producing upright to moderately inclined folds at all scales, with horizontal to moderately plunging hinges. In the southern part of the zone, deformation was accompanied by medium-grade, low-pressure metamorphism.

To the southwest of Halls Creek the Mount Christine Monzogranite has been intruded into the Halls Creek Group. SHRIMP U–Pb ages from zircons indicate an intrusion age of c. 1810 Ma.

Deformed rocks of the Halls Creek Group are unconformably overlain by the Moola Bulla Formation, a

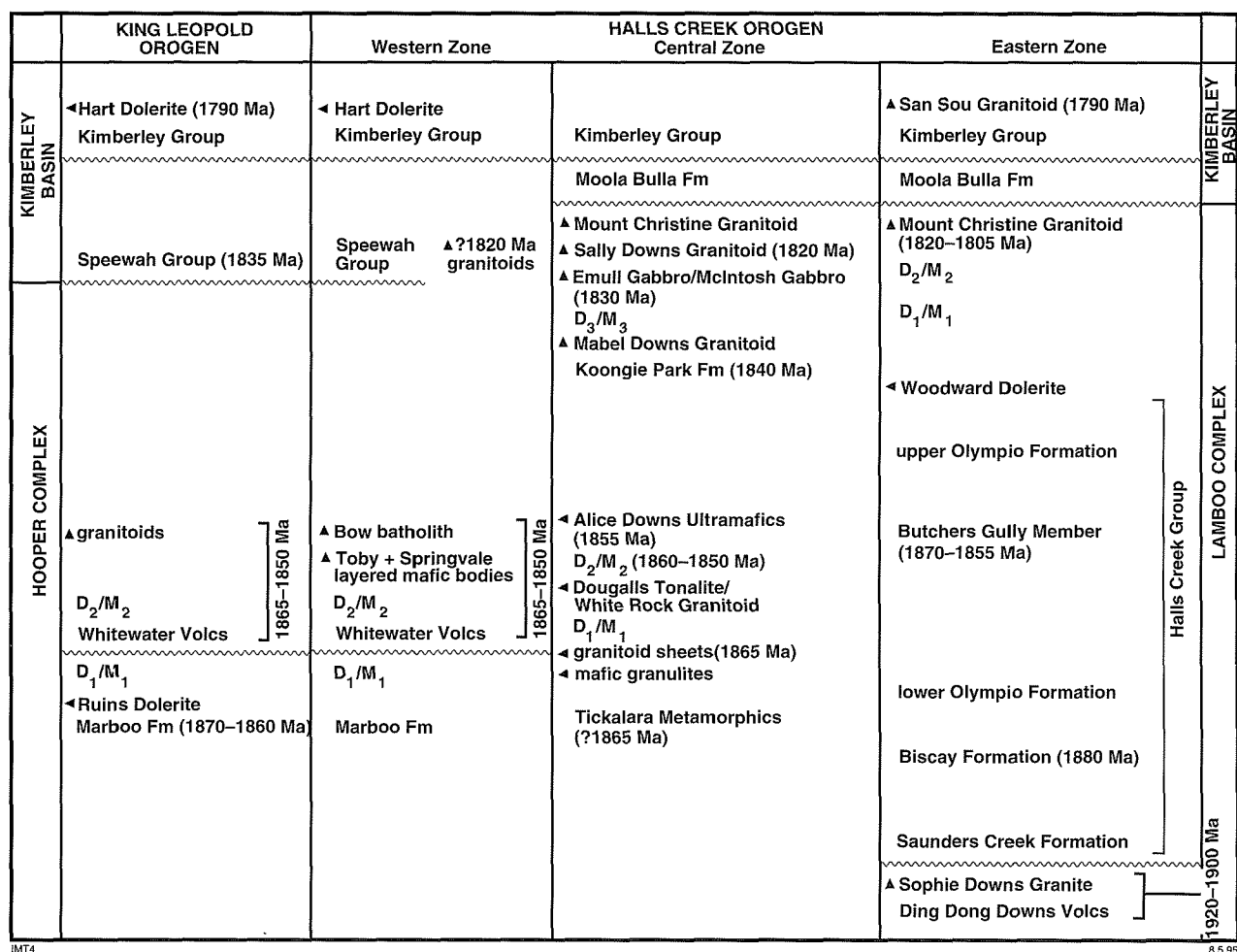


Figure 3. Comparative chart showing the geological histories of the Hooper Complex and zones within the Lamboo Complex

sequence of coarse clastic deposits of fluvial origin. The Moola Bulla Formation is itself overlain with minor angular discordance by the Kimberley Group, a sequence of fluvial and shallow-marine clastic deposits, and mafic volcanic rocks.

Towards the southern end of the eastern zone, the San Sou Monzogranite has been intruded into the Ding Dong Downs Volcanics and associated granitoids, as well as the Halls Creek Group. A SHRIMP U–Pb zircon age of c. 1790 Ma has been obtained from the San Sou Monzogranite.

### The central zone

The boundary between the eastern zone and the central zone is taken as a combination of the Angelo Fault, the Halls Creek

Fault, and the Osmond Fault (Fig. 2).

The oldest rocks in the central zone are the Tickalara Metamorphics, a deformed sequence of interbedded mafic volcanic rocks, and siliciclastic and calcareous sedimentary rocks, which have undergone low- to high-grade metamorphism. Metamorphic grade increases from southwest to northeast along the zone. In the lower grade areas the mafic volcanic rocks consist of massive, amygdaloidal, and pillowed basaltic lava flows, together with fragmental, agglomeratic deposits, and fine-grained volcanoclastic deposits. The sedimentary rocks consist of interbedded mudstones, siltstones, and sandstones, together with mappable carbonate and calc-silicate units.

The Tickalara Metamorphics have been intruded by a number of

phases of both felsic and mafic magmas. Amphibolites and mafic granulites derived from intrusive rocks occur in the higher grade areas. Also present are layer-parallel sheets of granitoid that contain zircons which yield SHRIMP U–Pb ages of c. 1860 Ma. These units are affected by a strong layer-parallel fabric, which was produced during D<sub>1</sub>. Although large-scale D<sub>1</sub> folds are not recognized, small-scale, layer-parallel D<sub>1</sub> isoclinal folds occur in the metasedimentary rocks. High-grade metamorphism (M<sub>2</sub>) occurred synchronously with the second deformation (D<sub>2</sub>), which produced tight to isoclinal, moderately inclined to recumbent folds on all scales. Extensive migmatization of the metasedimentary rocks and the early-formed granitoid sheets occurred during M<sub>2</sub>. SHRIMP U–Pb zircon results are consistent with a conventional zircon U–Pb date of

1854  $\pm$  6 Ma obtained by Page and Hancock (1988) from migmatitic rocks in the Tickalara Metamorphics, and this date is regarded as the age of peak metamorphism in the northeastern part of the central zone. Further granitoid sheets were intruded into the metamorphics during and after  $M_2$ .

A number of major layered mafic-ultramafic bodies (Groups 1 and 5 of Hoatson, 1993) were intruded into the deformed Tickalara Metamorphics. Contact aureoles around these intrusions post-date  $D_2$  and  $M_2$ . A SHRIMP U-Pb zircon age of c. 1855 Ma obtained from an anorthosite within a Group 1 intrusion in the central part of the zone suggests that peak  $M_2$  metamorphism may have been diachronous, occurring earlier in the southwest than the northeast.

The Koongie Park Formation (Griffin and Tyler, 1994), which is a sequence of felsic volcanic rocks and associated high-level intrusions, occurs in the southwestern part of the zone. A SHRIMP U-Pb zircon age of 1843  $\pm$  2 Ma has been obtained from these rocks (Page et al., in prep.). To the northeast, felsic veins probably correspond to this felsic event, and intrude medium-grade rocks of the Tickalara Metamorphics deformed during  $D_2$ . Further to the northeast, the Mabel Downs Granodiorite forms a large, linear pluton that also post-dates  $D_2$ .

The Group 1 mafic-ultramafic intrusions are folded by tight to isoclinal, upright, moderately to steeply plunging  $D_3$  folds. A well-developed foliation in the Mabel Downs Granodiorite is also attributed to  $D_3$ . These units have undergone medium-grade metamorphism, together with the felsic veins thought to correspond to the Koongie Park Formation. This metamorphic event ( $M_3$ ) has also resulted in retrogression of the high-grade mineral assemblages in the Tickalara Metamorphics.

Extensive intrusion of granitoid rocks into the Tickalara Metamorphics and the Koongie Park Formation occurred throughout the central zone after  $D_3$ . Preliminary SHRIMP U-Pb zircon ages for these intrusions (which include the Mount Christine Monzogranite, the Sally Downs Tonalite, and the McHale

Monzogranite) range from c. 1830 to 1805 Ma.

Large gabbroic and layered mafic-ultramafic bodies (Groups 2, 3a, and 4 of Hoatson, 1993) were also intruded at about this time. A SHRIMP U-Pb zircon age of c. 1830 Ma has been obtained from migmatitic rocks within a high-grade contact aureole developed at the margin of a Group 3a intrusion, and is interpreted as the age of the adjacent igneous body.

In the southwestern part of the zone, the Koongie Park Formation is unconformably overlain by the Moola Bulla Formation, whereas younger Kimberley Group rocks lie unconformably on rocks of the Koongie Park Formation and on granitoids. To the northeast of Halls Creek the Red Rock beds (Dow and Gemuts, 1969), the lower part of which are probably equivalent to the Moola Bulla Formation, unconformably overlie the Tickalara Metamorphics. The upper part of the Red Rock beds together with the Fish Hole Dolerite, are equivalent to the Kimberley Group (Griffin and Tyler, 1992a).

### *The western zone*

The boundary between the central zone and the western zone is taken to be a combination of the Ramsay Range Fault, the Springvale Fault, and the northern part of the Halls Creek Fault.

The western zone shows many similarities with the geological history of the Hooper Complex in the King Leopold Orogen (Tyler and Griffin, 1990, 1993; Griffin et al., 1993). The oldest rocks in the Hooper Complex are those of the Marboo Formation, which is a sequence of turbiditic quartz wacke, siltstone, and mudstone, and similar rocks occur in the western zone of the Lamboo Complex. Provenance and palaeocurrent data presented by Hancock (1991) indicate that this unit was derived from a continental source to the north-northeast. A maximum age for the Marboo Formation may be indicated by the presence of a suite of detrital zircons which give SHRIMP U-Pb ages of c. 1870 Ma.

In the Halls Creek Orogen, the earliest deformation to affect these

rocks in the western zone of the Lamboo Complex ( $D_1$ ) produced large-scale recumbent folds. In the Hooper Complex, high-grade metamorphism of the Marboo Formation post-dates  $D_1$  and occurred at c. 1860 Ma (based on SHRIMP U-Pb zircon ages from the Mount Joseph Migmatite), providing a minimum age for deposition.

The Marboo Formation is unconformably overlain by the felsic volcanic rocks and associated sedimentary rocks of the Whitewater Volcanics. Page and Hancock (1988) reported a conventional U-Pb zircon age of 1850  $\pm$  5 Ma for this unit. A SHRIMP U-Pb zircon age of c. 1855 Ma has been obtained from the Whitewater Volcanics in the Hooper Complex. Both the Whitewater Volcanics and the Marboo Formation have been folded into upright  $D_2$  folds with moderately plunging hinges, and have been intruded by extensive granitoid plutons. In the Hooper Complex, geochemical data indicate that the felsic volcanic rocks and the granitoids are co-magmatic (Griffin and Tyler, 1992b). SHRIMP U-Pb zircon ages from the granitoids cover a range from c. 1865 to 1850 Ma. In the western zone of the Lamboo Complex in the Halls Creek Orogen, preliminary SHRIMP U-Pb zircon ages are similar (c. 1860 to 1855 Ma).

Major layered mafic-ultramafic bodies (Group 3b of Hoatson, 1993) are associated with the c. 1860 Ma plutonic granitoids of the western zone of the Lamboo Complex and give similar SHRIMP U-Pb zircon ages. This is consistent with the broadly coeval intrusion of both felsic and mafic magma (Griffin and Tyler, 1992a; Blake and Hoatson, 1993).

As yet no c. 1820 Ma granitoids have been dated from the western zone, although they may be present (Figs 3 and 4).

The western zone of the Lamboo Complex is unconformably overlain by fluvial and shallow-marine deposits of the Speewah Group, which form the lower part of the Kimberley Basin sequence. A felsic volcanic unit from the Speewah Group has a SHRIMP U-Pb zircon age of 1834  $\pm$  3 Ma. The Kimberley Group unconformably overlies the



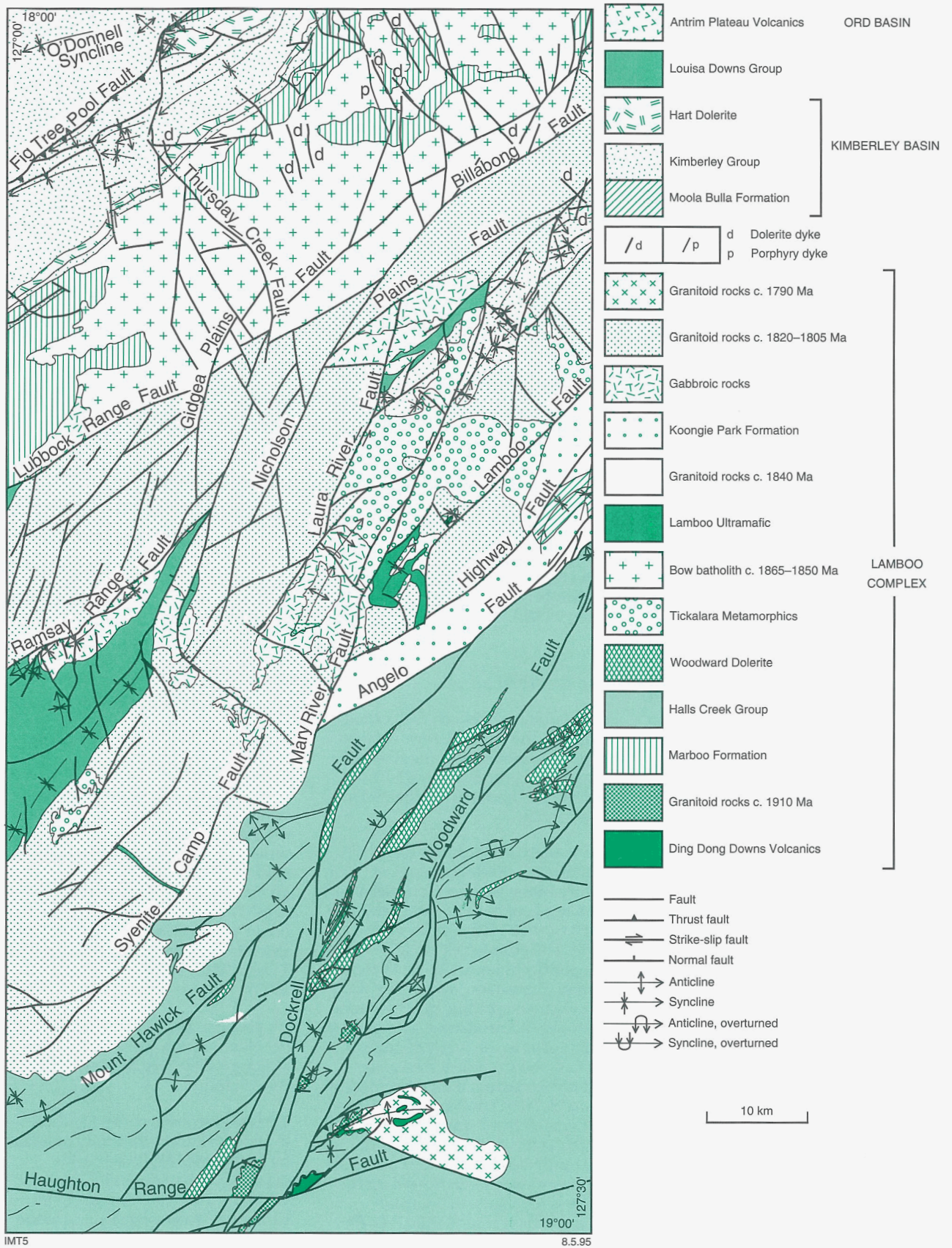


Figure 4. Tectonic sketch of ANGELO and DOCKRELL

Speewah Group with only minor angular discordance, and oversteps it onto the Lamboo Complex. The Kimberley Basin sequence is intruded by mafic sills, collectively called the Hart Dolerite, for which SHRIMP U–Pb–zircon ages of c. 1800 Ma have been obtained.

### *Reactivation of the zone boundaries*

A striking feature of the Halls Creek Orogen is the pattern of steeply dipping, north-northwesterly to north-northeasterly trending sinistral faults and easterly to east-northeasterly trending dextral faults (Figs 2 and 4) that cut rocks which are as young as Devonian in age. This pattern can be interpreted as that produced by synthetic and antithetic faults developed during overall sinistral strike-slip movement, controlled by deep-seated, northeasterly trending structures (Wilcox et al., 1973). The faults that define the zone boundaries have a northeasterly trend that has been offset by the later north-northwesterly to north-northeasterly trending sinistral faults. The Halls Creek Fault and associated structures offset the Angelo and Osmond Faults by 90 km. The zone boundaries are interpreted to reflect deeper structures that originated in the Early Proterozoic and which have controlled Middle Proterozoic, and younger, deformations.

Middle Proterozoic deformation (regionally  $D_{4/5}$ ) was initially ductile in nature, and took place under low- to medium-grade metamorphic conditions. This faulting affected rocks of the Kimberley Basin, and mylonites were developed in rocks in both the Halls Creek and Kimberley Groups along the Halls Creek Fault and its associated structures. Oblique, upright, tight folds with an axial-planar crenulation cleavage also developed. This cleavage affects pegmatite dykes that have preliminary SHRIMP U–Pb zircon ages of c. 1740 Ma. Close to the faults the folds become subparallel to them, suggesting a transpressive regime, possibly developed synchronously with the intracratonic, c. 1.3 to 1.0 Ga Yampi Orogeny in the King Leopold Orogen (Tyler and Griffin, 1990). Gold mineralization in the Halls Creek Orogen appears to be

controlled initially by this fault system.

Younger, brittle reactivations of the fault zones, again as sinistral strike-slip structures but at low- to very low-grades ( $D_6$  and  $D_7$ ), affected Late Proterozoic and Cambrian rocks. These reactivated structures are characterized by extensive, locally gold-bearing, quartz veins, and the development of kink-bands and an associated crenulation cleavage. Similar, young reactivations in fault zones in the King Leopold Orogen have K–Ar ages of c. 560 and 500 Ma (Shaw et al., 1992). Faulting and large-scale open folding of Devonian rocks may represent further reactivation due to the effects of the Late Devonian to Carboniferous (c. 300–370 Ma) Alice Springs Orogeny.

### *Discussion*

From the above description of the geological history of each zone (summarized in Fig. 3), it appears that each constituted a discrete terrane early in its history, although the similarities between the Hooper Complex and the western zone of the Lamboo Complex suggest that the two may have originally formed a continuous belt. In the eastern zone the oldest unit is the Ding Dong Downs Volcanics, which was formed at c. 1910 Ma. This does not appear to have an equivalent in either of the other two zones. In the western zone the Marboo Formation has previously been correlated with the Olympio Formation of the Halls Creek Group (Gellatly et al., 1974; Hancock and Rutland, 1984; Hancock, 1991); however, the depositional age of the Marboo Formation must be older than metamorphism at c. 1860 Ma, while the deposition of the Olympio Formation continued after eruption of the Butchers Gully Member at c. 1855 Ma. Hancock and Rutland (1984) speculated that the Biscay Formation of the Halls Creek Group may outcrop within the Hooper Complex on MOUNT RAMSAY\*; however, remapping (Tyler et al., in prep.) has shown the mafic rocks in question to be gabbroic intrusions.

There are many similarities between the lower part of the Halls Creek Group in the eastern zone and the

Tickalara Metamorphics in the central zone, and it has been assumed that the two are equivalent (Dow and Gemuts, 1969; Hancock and Rutland, 1984; Allen, 1986). The correlation is difficult to resolve, however, given the intrusion of granitoid sheets into the Tickalara Metamorphics at c. 1865 Ma, followed by two deformation events, the second being coincident with high-grade metamorphism at c. 1855 Ma, at a time when the lower part of the Olympio Formation was being deposited in the eastern zone. There is no evidence that deformation and metamorphism affected the Biscay Formation prior to the deposition of the Olympio Formation. In fact, the first deformation to affect the eastern zone must post-date c. 1855 Ma, and must therefore be younger than both  $D_1$  and  $D_2$  in the central zone. The differences in the ages of deformation and metamorphism also appear to rule out the possibility that the central zone is a deeper crustal equivalent of the eastern zone.

The suggestion by Allen (1986) that the Saunders Creek Formation can be recognized within the Tickalara Metamorphics has not been substantiated during recent remapping. The sandstones in question occur as low-strain pods strung out within mylonitic rocks along the Halls Creek Fault and its associated structures, and are most likely to correlate with the Red Rock beds.

In the western zone the earliest deformation pre-dated metamorphism of the Marboo Formation at c. 1860 Ma, and was followed by eruption of the Whitewater Volcanics, deformation, and the intrusion of granitoid plutons between c. 1860 and 1850 Ma. This style of felsic magmatism is not evident in either the central or eastern zones, but occurred at about the same time as the intrusion of granitoid sheets, deformation, high-grade metamorphism, and the intrusion of layered mafic–ultramafic intrusions, in the central zone, and the eruption of the alkaline volcanic rocks of the Butchers Gully Member in the eastern zone. The near synchronicity of these differing magmatic and thermal events within the orogen was recognized by Page and Hancock (1988) and was attributed

\* Capitalized names refer to standard map sheets.



to a rapid tectonic transition from sedimentation to orogenesis, and then to cratonization. An alternative view inherent in the terrane concept is that these different events did occur at about the same time, but in geographically separate terranes that were brought into their current juxtaposition by subsequent tectonism.

The zones continued to evolve separately after c. 1850 Ma, with the central zone experiencing the eruption of felsic volcanic rocks, and the intrusion of further granitoids, gabbros, and layered mafic-ultramafic bodies, as well as deformation and metamorphism. Both deformation events that affected the eastern zone occurred after eruption of the Butchers Gully Member at c. 1855 Ma, but before intrusion of the c. 1820 Ma granitoids.

The intrusion of the c. 1820 Ma granitoids appears to be the first event that can be correlated with certainty between the central zone and the eastern zone, with the Mount Christine Monzogranite intruding into the Halls Creek Group. The deposition of the Speewah Group onto the Lamboo Complex of the western zone began before c. 1835 Ma, while granitoids were still being intruded into the central and eastern zones. The deposition of the Kimberley Group appears to be the earliest event that can be correlated between all three zones.

### Tectonic implications

The intracratonic models of Hancock and Rutland (1984) and Etheridge et al. (1987) are inadequate to explain the tectonic evolution of the Halls Creek and King Leopold Orogens because they are based on correlations of units and events that are now regarded as invalid. Griffin and Tyler (1992b) have shown that the Early Proterozoic felsic igneous rocks in the Hooper Complex of the King Leopold Orogen have a calc-alkaline trend, and interpreted them to be subduction related, having formed as part of a magmatic arc. The overall evolution of the complex was consistent with a collisional orogeny, albeit involving thinner continental crust and higher heat flows than Phanerozoic collision orogenies.

Any model that seeks to explain the tectonic evolution of the Halls Creek Orogen must account for the differences between the three zones described here. Windley (1993), in a review of Precambrian orogenic belts, mainly from North America, Europe, and Africa, concluded that tectonophysical and geochemical processes that produced oceanic and continental rocks since the

early Archaean were not fundamentally different from those that operate in the present. The recognition of tectonostratigraphic terranes within the Halls Creek Orogen, and the different geophysical nature of the basement cratons on either side of it, are consistent with the operation of plate-tectonic processes in the Early Proterozoic.

### References

- ALLEN, R., 1986, Relationship of the thermal evolution to tectonic processes in a Proterozoic fold belt: Halls Creek mobile zone, East Kimberley, West Australia: University of Adelaide, PhD thesis (unpublished).
- BATES, R. L., and JACKSON, J. A., 1987, Glossary of geology (3rd edition): Alexandria, Virginia, American Geological Institute, 788p.
- BLAKE, D. H., GRIFFIN, T. J., and TYLER, I. M., 1991, Preliminary results of the Kimberley Arunta project 1. Halls Creek area, east Kimberley: Australia BMR, Research Newsletter, no. 14, p. 9–10.
- BLAKE, D. H., GRIFFIN, T. J., TYLER, I. M., and WARREN, R. G., in prep., The geology of the Halls Creek 1:100 000 geological sheet, Western Australia: Australian Geological Survey Organisation, Record.
- BLAKE, D. H., and HOATSON, D., 1993, Granite, gabbro, and migmatite field relationships in the Proterozoic Lamboo Complex of the East Kimberley region, Western Australia: Australian Geological Survey Organisation, Journal of Geology and Geophysics, v. 14, p. 319–330.
- CARD, K. D., 1990, A review of the Superior Province of the Canadian Shield: a product of Archaean accretion: Precambrian Research, v. 48, p. 99–156.
- CONEY, P. J., JONES, D. L., and MONGER, J. W. H., 1980, Cordilleran suspect terranes: Nature, v. 288, p. 329–333.
- CONEY, P. J., EDWARDS, A., HINE, R., MORRISON, F., and WINDRUM, D., 1990, The regional tectonics of the Tasman orogenic system, eastern Australia: Journal of Structural Geology, v. 12, p. 519–543.
- DALZIEL, I. W. D., 1992, Antarctica: a tale of two supercontinents?: Annual Reviews in Earth and Planetary Sciences, v. 20, p. 501–526.
- de WITT, M. J., ROERING, C., HART, R. J., ARMSTRONG, R. A., de RONDE, C. E. J., GREEN, R. W. E., TREDoux, M., PEBERDY, E., and HART, R. A., 1992, Formation of an Archaean continent: Nature, v. 357, p. 553–562.
- DOW, D. B., and GEMUTS, I., 1969, Geology of the Kimberley Region, Western Australia: The East Kimberley: Western Australia Geological Survey, Bulletin 120, 135p.
- ESSLEMONT, G., 1990, The geology and geochemistry of the Brockman alkaline volcanics and rare metal deposit: University of Western Australia, BSc Honours thesis (unpublished).
- ETHERIDGE, M. A., RUTLAND, R. W. R., and WYBORN, L. A. I., 1987, Orogenesis and tectonic process in the early to Mesoproterozoic of Northern Australia, in Proterozoic Lithospheric Evolution edited by A. KRONER: American Geophysical Union, Geodynamic Series, v. 17, p. 131–147.
- GELLATLY, D. C., SOFOULIS, J., DERRICK, G. M., and MORGAN, C. M., 1974, The older Precambrian geology of the Lennard River 1:250 000 sheet area, Western Australia: Australia BMR, Report 153, 126p.
- GRIFFIN, T. J., 1989, A major thrust between the Gibb River and Hooper Terranes in the King Leopold Orogen, West Kimberley region: Western Australia Geological Survey, Report 26, p. 69–81.
- GRIFFIN, T. J., and GREY, K., 1990, King Leopold and Halls Creek Orogens, in The geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 232–249.
- GRIFFIN, T. J., and MYERS, J. S., 1988, Geological Note: A Proterozoic terrane boundary in the King Leopold Orogen, Western Australia: Australian Journal of Earth Sciences, v. 35, p. 131–132.



- GRIFFIN, T. J., and TYLER, I. M., 1992a, Geology of the southern Halls Creek Orogen — A summary of field work in 1992: Western Australia Geological Survey, Record 1992/17, 28p.
- GRIFFIN, T. J., and TYLER, I. M., 1992b, Palaeoproterozoic calc-alkaline magmatism in the Hooper Complex, West Kimberley, Western Australia (abstract): Royal Society of Edinburgh, Transactions: Earth Sciences, v. 83, p. 490.
- GRIFFIN, T. J., and TYLER, I. M., 1994, Angelo, W. A.: Western Australia Geological Survey, 1:100 000 Geological Series.
- GRIFFIN, T. J., TYLER, I. M., and PLAYFORD, P. E., 1993, Lennard River, W.A., (3rd edition): Western Australia Geological Survey, 1:250 000 Geological Series, Explanatory Notes, 56p.
- HANCOCK, S. L., 1991, Tectonic development of the Lower Proterozoic basement in the Kimberley District of northwestern Western Australia: University of Adelaide, PhD thesis (unpublished).
- HANCOCK, S. L., and RUTLAND, R. W. R., 1984, Tectonics of a Palaeoproterozoic geosuture: the Halls Creek Orogenic Subprovince, northern Australia: *Journal of Geodynamics*, v. 1, p. 387–432.
- HOATSON, D., 1993, Correlation of structurally disrupted layered ultramafic–mafic intrusions in the East Kimberley: Is Big Ben part of the Panton intrusion?: Australian Geological Survey Organisation, Research Newsletter, no. 19, p. 9–10.
- HOATSON, D., and TYLER, I. M., 1993, Prospective layered mafic–ultramafic intrusions in the East Kimberley: Australian Geological Survey Organisation, Research Newsletter, no. 18, p. 8–9.
- HOFFMAN, P. F., 1988, United plates of America, the birth of a craton: *Annual Reviews in Earth and Planetary Sciences*, v. 16, p. 543–603.
- HOFFMAN, P. F., 1989, Speculations on Laurentia's first gigayear (2.0 to 1.0 Ga): *Geology*, v. 17, p. 135–138.
- HOFFMAN, P. F., 1991, Did the breakout of Laurentia turn Gondwanaland inside-out?: *Science*, v. 252, p. 1409–1412.
- HUTTON, D. W. H., 1987, Strike-slip terranes and a model for the evolution of the British and Irish Caledonides: *Geological Magazine*, v. 124, p. 405–425.
- KRÖNER, A., 1981, Precambrian plate tectonics, in *Precambrian plate tectonics edited by A. KRÖNER*: Amsterdam, Elsevier, p. 57–90.
- KRÖNER, A., 1983, Proterozoic mobile belts compatible with the plate tectonic concept: *Geological Society of America, Memoir 161*, p. 59–74.
- KRÖNER, A., 1985, Ophiolites and the evolution of tectonic boundaries in the Arabian–Nubian Shield of northeast Africa and Arabia: *Precambrian Research*, v. 27, p. 277–300.
- MYERS, J. S., 1993, Precambrian history of the West Australian Craton and adjacent orogens: *Annual Reviews in Earth and Planetary Sciences*, v. 21, p. 453–485.
- PAGE, R. W., 1976, Reinterpretation of isotopic ages from the Halls Creek Mobile Zone, northwestern Australia: Australia BMR, *Journal of Australian Geology and Geophysics*, v. 1, p. 79–81.
- PAGE, R. W., 1988, Geochronology of early to Mesoproterozoic fold belts in northern Australia: a review: *Precambrian Research*, v. 40/41, p. 1–19.
- PAGE, R. W., BLAKE, D. H., TYLER, I. M., GRIFFIN, T. J., and THORNE, A. M., in prep., New geological and geochronological constraints on VMS prospectivity near Halls Creek, W. A.: Australian Geological Survey Organisation, Research Newsletter.
- PAGE, R. W., and HANCOCK, S. L., 1988, Geochronology of a rapid 1.85–1.86 Ga tectonic transition: Halls Creek Orogen, northern Australia: *Precambrian Research*, v. 40/41, p. 447–467.
- PAGE, R. W., and WILLIAMS, I. S., 1988, Age of the Barramundi Orogeny in northern Australia by means of ion microprobe and conventional U–Pb zircon studies: *Precambrian Research*, v. 40/41, p. 21–36.
- PARK, A. F., 1991, Continental growth by accretion: a tectonostratigraphic terrane analysis of the evolution of the western and central Baltic Shield, 2.50 to 1.75 Ga: *Geological Society of America, Bulletin*, v. 103, p. 533–537.
- RIVERS, T., MARTIGNOLE, J., GOWER, C. F., and DAVIDSON, A., 1989, New tectonic divisions of the Grenville Province, southeast Canadian Shield: *Tectonics*, v. 8, p. 63–84.
- SENGOR, A. M. C., NATAL'IN, B. A., and BURTMAN, V. S., 1993, Evolution of the Altaid tectonic collage and Palaeozoic crustal growth in Eurasia: *Nature*, v. 364, p. 299–307.
- SHAW, R. D., TYLER, I. M., GRIFFIN, T. J., and WEBB, A., 1992, New K–Ar constraints on the onset of subsidence in the Canning Basin, Western Australia: Australia BMR, *Journal of Australian Geology and Geophysics*, v. 13, p. 31–35.

- SHAW, R. D., MORSE, M. P., and TARLOWSKI, C., 1994, The geological framework of northwestern Australia from geophysical mapping, in *Deformation processes in the Earth: from microcracks to mountain belts*: Special Group in Tectonics and Structural Geology Field Conference, Jindabyne, Geological Society of Australia, Abstracts, no. 36, p. 142–143.
- TAYLOR, W. R., PAGE, R. W., ESSELMONT, G., ROCK, N. M. S., and CHALMERS, D. I., in press, Geology of the volcanic-hosted Brockman rare-metals deposit, Halls Creek Mobile Zone, northwest Australia. I. Volcanic environment, geochronology and petrography of the Brockman volcanics: *Mineralogy and Petrology*.
- TYLER, I. M., and GRIFFIN, T. J., 1990, Structural development of the King Leopold Orogen, Kimberley Region, Western Australia: *Journal of Structural Geology*, v. 12, p. 703–714.
- TYLER, I. M., and GRIFFIN, T. J., 1993, Yampi, W. A., (2nd edition): Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 32p.
- TYLER, I. M., and GRIFFIN, T. J., 1994, Dockrell, W. A.: Western Australia Geological Survey, 1:100 000 Geological Series.
- TYLER, I. M., GRIFFIN, T. J., and PLAYFORD, P. E., in prep., Mount Ramsay, W. A. (2nd edition): Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes.
- WARREN, R. G., 1994, Role of early extensional faults in the Grants Patch district, East Kimberley, Western Australia: 12th Australian Geological Convention, Perth, Geological Society of Australia, Abstracts, no. 37, p. 453.
- WARREN, R. G., and TYLER, I. M., in prep., The geology of the Dixon 1:100 000 sheet: Australian Geological Survey Organisation, Record.
- WILCOX, R. E., HARDING, T. P., and SEELY, D. R., 1973, Basic wrench tectonics: *American Association of Petroleum Geologists, Bulletin*, v. 57, p. 74–96.
- WINDLEY, B. F., 1993, Uniformitarianism today: Plate tectonics is the key to the past: *Geological Society of London, Journal*, v. 150, p. 7–19.
- WYBORN, L. A., 1988, Petrology, geochemistry and origin of a major Australian 1880–1840 Ma felsic volcano–plutonic suite: a model for intracontinental felsic magma generation: *Precambrian Research*, v. 40/41, p. 37–60.