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# New K-Ar constraints on the onset of subsidence in the Canning Basin, Western Australia

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Structural mapping and reconnaissance K–Ar studies have helped to delineate and date the latest deformational stages (D4 and D5) in the King Leopold Orogen, to the north of the Canning Basin. The dates have been determined for schists selected from both contractional shear zones and from rocks metamorphosed to the lower greenschist facies during the final phase of basement deformation. These dates imply that the basement-deforming event started in the latest Precambrian to earliest Cambrian (ca 560 Ma), and that tectonism recurred in the latest Cambrian to earliest Ordovician (ca 500 Ma). The final contractional deformation is slightly older than the oldest-known sedimentary rocks in the basin (latest Tremadoc), and helps to define the time that basin subsidence started.

## Introduction

The Fitzroy Trough (Fig. 1) is a deep, complex, composite set of sag basins and half-grabens formed during two or more extensional episodes in the Ordovician, in the Devonian, and possibly in the Permian (Drummond & others, 1991) in the northern part of the Canning Basin. Late deformation in the Jurassic produced open folds with east-northeasterly trending axes, many of which are truncated by steep faults established during earlier Palaeozoic rifting (Forman & Wales, 1981).

Results from BMR88.03 deep seismic profile in the Fitzroy Trough (located east of Blina well, see Fig. 1) suggest that the Phanerozoic sedimentary section might locally attain a thickness of 15–17 km. As the ages of sedimentary rocks in the deeper part of the trough are completely unknown, it has been speculated that Cambrian rocks, which occur in all the neighbouring Phanerozoic basins, might occur in the trough too. The oldest exposed rocks at the northeast margin of the Fitzroy Trough are the Early Ordovician (Arenig) Prices Creek Group and Carranya beds (McTavish & Legg, 1976). Outside the trough, sedimentary rocks as old as latest Tremadoc are known from Samphire Marsh 1 well in the southeast of the Canning Basin (McTavish & Legg, 1976). In order to both clarify the age of the last compressional event that affected the basement to the Fitzroy Trough, and provide maximum ages for the initiation of the Canning Basin, a program of age determination and structural mapping was instigated along the northern margin of the basin and within the adjacent orogen.

## Pertinent structural relationships and previous isotopic dating

The structural development of the King Leopold Orogen and adjacent Oscar and Pillara inliers within the Lennard Shelf (Fig. 1) has been re-examined by Tyler & Griffin (1990). Their results, combined with those of our study, are summarised in Table 1. They also observed that within the Precipice Fold Belt the D4 axial-plane cleavage cuts through the unconformity separating the Kimberley Basin succession from overlying Late Proterozoic glacigene rocks, indicating that the D4 cleavage postdates these rocks. The Proterozoic contractional events listed in Table 1 were probably accompanied by transcurrent movements in the Halls Creek Zone (along the eastern edge of the Kimberley Basin), as discussed — for example — by Plumb & others (1985) and White & Muir (1989).

Also formed at a late stage were high-strain zones in the southern part of the King Leopold Orogen (e.g., Stony Creek Shear, Fig. 1), at the southern margin of the Oscar inlier (e.g., Spielers Shear), and (as patchy shearing) along the southern margin of the Pillara inlier (e.g., precursor to Virgin Hills Fault). These zones have similar trends, and contain intensely foliated schists composed of similar lower greenschist facies assemblages (e.g., epidote, chlorite, sericite, biotite). They show ubiquitous quartz veining and post-shearing annealing. Asymmetrical fabrics and southerly dips to these zones, which contain a well developed down-dip stretching lineation, suggest northward-directed thrusting.

In the Oscar inlier the relationship between the final movements in the high-strain zones and the regional cleavage formation is clearer (Fig. 2). Here, only one phase of folding and regional cleavage formation is recognised. This phase postdates the unconformity between the Oscar Range Group (Griffin & others, in press), inferred to be of Middle to Late Proterozoic age, and conglomeratic units which are arguably glacigene (Derrick & Gellatly, 1971) and hence of possibly Late Proterozoic age.

At the southern margin of the Oscar inlier, the south-dipping mylonitic Spielers Shear (Figs. 1, 2), like the other late-stage high-strain zones, shows fabric features that suggest limited northward-directed thrusting, consistent with the fold vergence sense in the overfold zone developed in footwall rocks to the north. However, the thrusting direction indicated by the oblique mylonitic stretching lineation (in the northeastern part of the inlier, Fig. 2) suggests dextral transpression along the Spielers Shear, whereas the shortening direction indicated by the overfold zone implies sinistral transpression on the main fault system during folding (Fig. 2). These relationships indicate two movements separated in time. We suggest that the D4 dextral strike-slip movement on the main fault system in the north of the inlier was followed, somewhat later, by northward-directed thrusting in the Spielers Shear. We refer to this later event as the Spielers event (D5). The dominant shear fabric produced by movement on the Spielers Shear is older than the Late Devonian Pillara Limestone of the Canning Basin succession, which overlaps these sheared rocks.

West of Louisa Downs homestead (Fig. 1), eastward-directed thrusts are assigned to D4, as they formed during overfolding and regional cleavage formation and cut Late Proterozoic glacigene units. Northeasterly and easterly faults such as the Glidden and Pinnacles Faults, which are apparently linked to the same thrust-fault system, also cut the Antrim Plateau Volcanics, which is considered to be of probable Early Cambrian age as it underlies Early? to Middle Cambrian units (e.g., Negri Subgroup) with apparent conformity (Mory & Beere, 1985; cf. Muir, 1980). Thus, some post-Early Cambrian movement, presumed to be D5, has occurred on this fault system. Basement faulting and shearing along a splay of the Pinnacles Fault shows gossanous quartz veining, suggesting a similar style and, possibly, a similar age of movement to the Spielers Shear.

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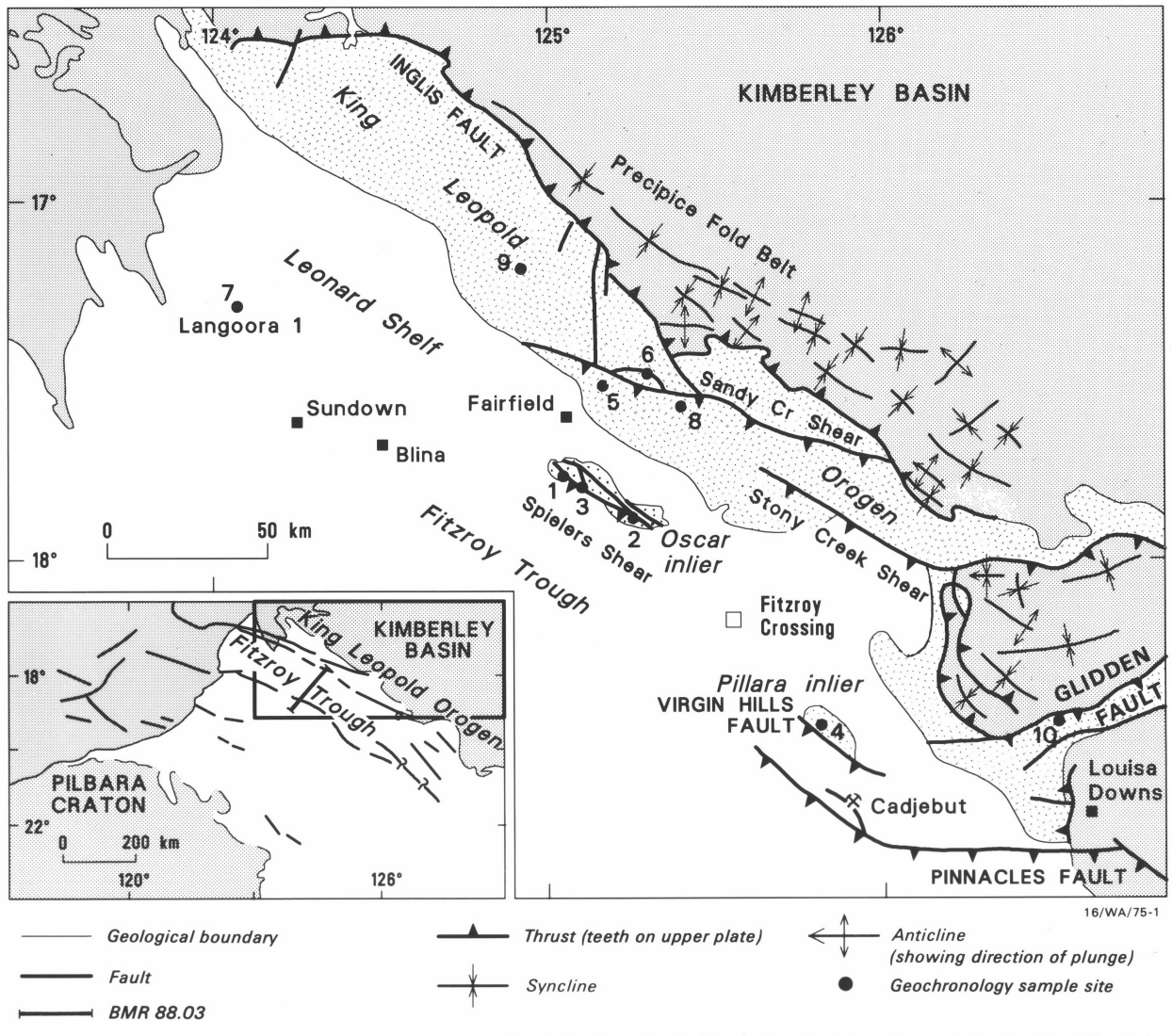


**Figure 1. Main structural features at the northern margin of the Canning Basin during the latest Precambrian to latest Cambrian interval.**

Before our work started, the consensus view was that the last major deformation to affect the King Leopold Orogen was about 600 Ma (Bennett & Gellatly, 1970). We consider that this date is too old for the King Leopold Orogen (D4), because of the poor precision of the isochrons and their high $Sr^{87}/Sr^{86}$ initial ratios, which imply a lack of isotopic equilibrium in the dated samples. The cleavage formed during D4 is younger than the glacigene successions. The depositional age of an undeformed shale that postdates the youngest tillite interval in an area not affected by D4 is considered to approximate its Rb–Sr age of 639 ± 48 Ma (whole-rock isochron from shale in the Elvira Formation, Plumb, 1981; recalculated after Bofinger, 1967). A shale overprinted by the D4 regional cleavage in the Louisa Downs area has yielded a younger Rb–Sr age of 576 ± 80 Ma (Plumb, 1981); the cleavage and high initial $Sr^{87}/Sr^{86}$ ratios of the shale suggest that this age reflects partial resetting during D4.

## Results of this study

We have determined K–Ar ages (Tables 2 and 3) from 10 different basement localities (Fig. 1) in the southern King Leopold Orogen and Lennard Shelf. The sample from site 10 is an undeformed tonalite selected to monitor the time of final plutonism in the basement within the King Leopold Orogen. It yielded an age of 1725 ± 17 Ma, which is considered to approximate the time of cooling following igneous crystallisation. Samples selected from sites 8 and 9 to estimate the age of

**Table 1. Summary of tectonic events**

| *Event,* ***orogeny*** | *Tectonic features* | *Estimated age (Ma)* |
|---|---|---|
| D5 Spielers | N- and E-directed shearing; sinistral transpression on faults[1,3] | 500–510[1] |
| D4 Precipice[1,2,3] | Regional phyllonitic cleavage; | 530–560[1] |
| **King Leopold** | SW-directed folding and limited thrusting[4,5]; local transpressional reactivation of D3 shears | |
| D3 Yampi[1,2,3] | Folding; N-directed shearing | ⩾1000[1] |
| | Pre-Kimberley Basin tilting | ?1830[1,2] |
| D2 **Hooper**[5] | Folding that is pre-granite and post-felsic intrusives[2] | ⩽1850[6] |
| D1 | Localised zones of high strain[2] | |

[1] This paper; [2]Tyler & Griffin (1990); [3]Tyler & others (1991); [4]Griffin & Myers (1988); [5]Griffin & others (in press: i.e., D2 postdates Whitewater Volcanics); [6]Page & Hancock (1988).

**Table 2. Sample details**

| *Site, field no. (prefix 8909–)* | | *Mineral analysed* | *Lithology* | *Mineral assemblage** | *Probable protolith* | *Location* | *Latitude (°S)* | *Longitude (°E)* |
|---|---|---|---|---|---|---|---|---|
| 1 | 1077A | Muscovite | Metasediment | ch–ms–qz–fd | ?Oscar Range Group | Oscar inlier | 17°46.04′ | 125°04.56′ |
| 2 | 1004 | Muscovite | Phyllonitic mylonite | bt–ms–qz–fd–ch | Whitewater Volcanics | Oscar inlier | 17°54.79′ | 125°17.04′ |
| 3 | 1056 | Muscovite | Deformed schist | ch–qz–fd–ms | Whitewater Volcanics sliver | Oscar inlier | 17°46.85′ | 125°05.72′ |
| 4 | 1012 | Biotite | Foliated adamellite | bt–qz–pl–kf ± ch ± ms | Lamboo Complex | Pillara inlier | 18°25.95′ | 125°48.87′ |
| 5 | 1039B | Muscovite | Schist | gt–bt–fd–qz–ch–ms | Marboo Formation | Kimberley Granite Quarry | 17°31.95′ | 125°09.29′ |
| 6 | 1043B | Biotite | Metasediment | ms–bt–qz–fd | Marboo Formation | NW Fairfield | 17°30.25′ | 125°18.59′ |
| 7 | 1091 | Hornblende | Schist | qz–bt–hb | Unknown | Langoora 1 well | 17°18.07′ | 125°06.48′ |
| 8 | 1049 | Biotite | Deformed tonalite | hb–bt–qz–kf–pl | McSherrys Granodiorite | N Kurrajong bore | 17°36.22′ | 125°24.02′ |
| 9 | 1026 | Biotite | Deformed granite | hb–bt–qz–pl–kf | Lennard Granite | Black Swan Quarry, Gibb River Rd | 17°13.69′ | 124°53.97′ |
| 10 | 1018 | Biotite | Tonalite | bt–cp–qz–kf–pl ± ch | Lamboo Complex | Margaret River crossing, N Louisa Downs | 18°28.52′ | 125°36.05′ |

*bt, biotite; ch, chlorite; cp, clinopyroxene; fd, feldspar; gt, garnet; hb, hornblende; kf, K-feldspar; ms, muscovite; pl, plagioclase; qz, quartz

metamorphism accompanying D3 Yampi deformation yielded ages of 1475 ± 12 Ma (site 8) and 999 ± 9 Ma (site 9). The 999-Ma age reflects intense deformational recrystallisation with the growth of new biotite, and provides a minimum age for the D3 Yampi event. The 1475-Ma age might reflect a composite age, as two size fractions of biotite are present in the sample; however, it places an outside maximum on the age of D3.

Biotite from a muscovite–biotite metasediment (site 6) showing evidence of only one low-grade metamorphism and deformation yielded an age of 700 ± 8 Ma. This rock is located within an offshoot of the Sandy Creek Shear, which cuts the Early Proterozoic Marboo Formation — a sequence of turbiditic rocks (previously designated as part of the Halls Creek Group) in the King Leopold Orogen (Tyler & Griffin, in press). Tyler & Griffin (1990) relate the main shearing recorded in the Sandy Creek Shear to the Middle Proterozoic Yampi event. The 700-Ma age might represent either a period of renewed movement and local isotopic resetting, or partial resetting of a Middle Proterozoic isotopic signature during either the D4 or D5 events.

White & Muir (1989, citing C.B. Smith, personal communication, 1988) record an unpublished K–Ar age of 727 ± 10 Ma for a dolerite dyke which they considered to be displaced and retrogressed by the same shear. This dyke continues to the north of the Sandy Creek Shear, and cuts folds and thrusts of the D4 event. Its K–Ar age is therefore anomalous, and the significance of it cannot be appraised until further information is published.

**Table 3. Potassium-argon analyses**

| *Site* | *Sample (prefix 8909–)* | *%K* | *$^{40}Ar^*$ ($\times 10^{-10}$ mole/g$^{-1}$)* | *$^{40}Ar^*/^{40}Ar_{Total}$* | *Age ± 1 (Ma)* |
|---|---|---|---|---|---|
| 1 | 1077A muscovite | 7.22<br>7.19 | 77.383 | 0.996 | 532 ± 3 |
| 2 | 1004 muscovite | 7.27<br>7.31 | 73.484 | 0.992 | 504 ± 4 |
| 3 | 1056 muscovite | 9.3 5<br>9.34 | 96.432 | 0.997 | 514 ± 4 |
| 4 | 1012 biotite | 7.21<br>7.25 | 81.899 | 0.993 | 557 ± 8 |
| 5 | 1039B muscovite | 3.43<br>3.43 | 34.739 | 0.994 | 506 ± 4 |
| 6 | 1043B biotite | 6.65<br>6.68 | 98.831 | 0.991 | 700 ± 8 |
| 7 | 1091 hornblende | 0.765<br>0.765 | 7.1804 | 0.982 | 473 ± 3 |
| 8 | 1049 biotite | 7.39<br>7.41 | 292.88 | 0.998 | 1475 ± 12 |
| 9 | 1026 biotite | 7.01<br>7.05 | 162.60 | 0.997 | 999 ± 9 |
| 10 | 1018 biotite | 4.63<br>4.64 | 2132.09 | 0.997 | 1725 ± 17 |

*Denotes radiogenic argon.
Constants: $\lambda_e + \lambda_{e'} = 0.581 \times 10^{-11}y^{-1}$; $\lambda_\beta = 4.962 \times 10^{-10}y^{-1}$; $^{40}K/K = 1.167 \times 10^{-4}$mol mol$^{-1}$.

In the southwest of the Oscar inlier, a schist showing the imprint of a regional greenschist foliation yielded a muscovite K–Ar age of 532 ± 3 Ma (site 1; Figs. 1, 2). In the Pillara inlier, biotite from a recrystallised adamellite showing an imposed regional deformational foliation yielded a similar age of

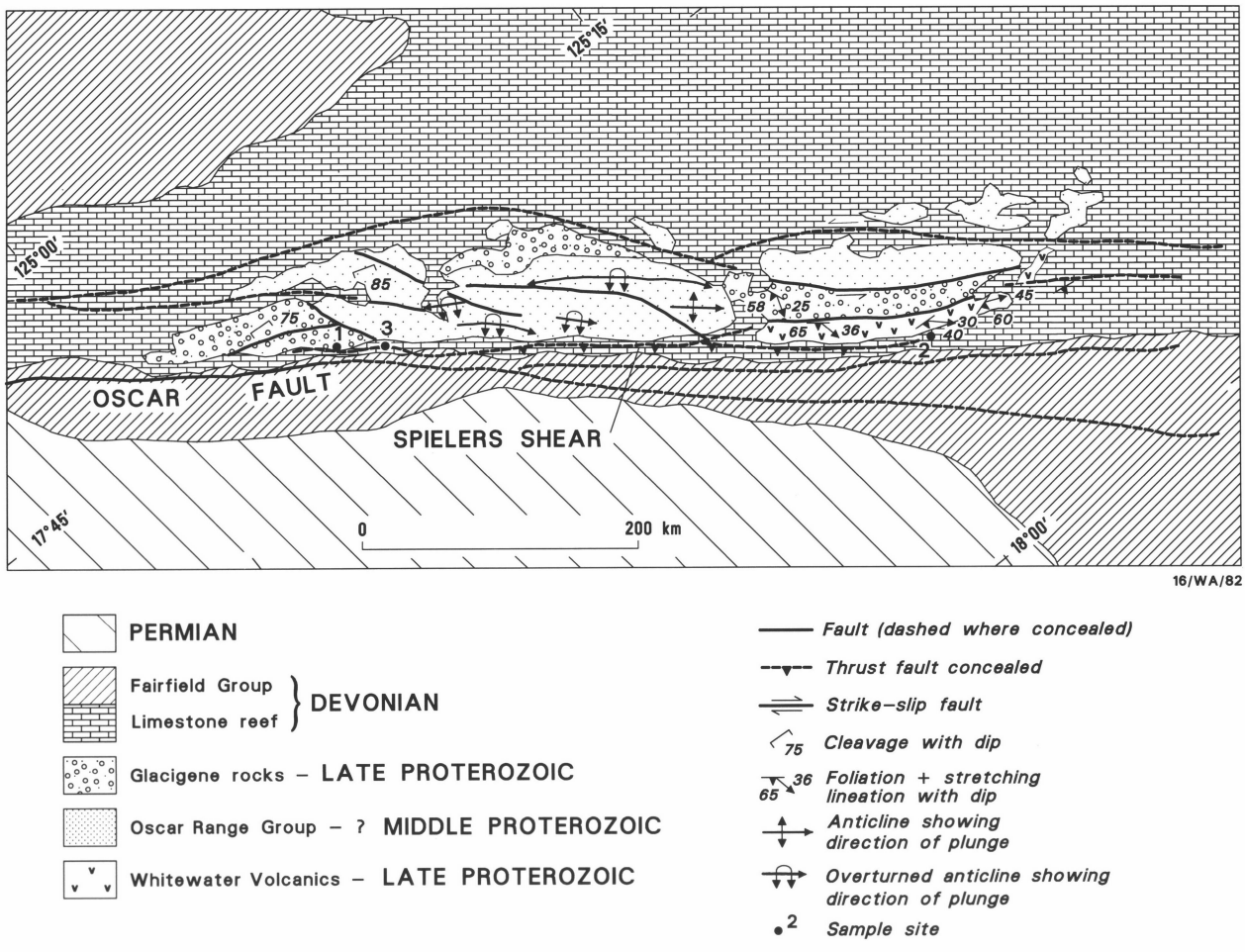


**Figure 2. Geological sketch map of the Oscar inlier.**

557 ± 8 Ma (site 4). These ages are considered to provide a guide to the time of regional phyllitic cleavage formation during D4.

In the Oscar inlier, the discontinuously exposed Spielers Shear has a weak fabric asymmetry, suggesting limited northward-directed thrusting. Muscovite in phyllonitic mylonite and deformed schist (sites 2 and 3; Figs. 1, 2) from two widely separated exposures of felsic volcanic rock cut by the shear zone yielded latest Cambrian K–Ar ages of 504 ± 4 and 514 ± 4 Ma respectively. These ages are considered to give a guide to the age of the northward-directed thrusting that we refer to D5.

Muscovite (site 5) from a schist in the southern part of the King Leopold Orogen provided a similar age — 506 ± 4 Ma. This schist, from the margin of a mid-Proterozoic dolerite dyke, is considered to be part of a cross-cutting retrograde zone which has a discordant, northerly trend and shows post-crystallisation microfolding. Similarly, deformed actinolite–biotite schist from basement core in Langoora 1 well, near the northwest margin of the Lennard Shelf (site 7), gave a slightly younger age of 473 ± 3 Ma, which is considered to represent somewhat more protracted cooling following low-grade regional metamorphism and subsequent uplift.

## Discussion

The foregoing data suggest that there might be two periods of Late Proterozoic to latest Cambrian contractional tectonism in the King Leopold Orogen — ca 530–560 Ma and 500–510 Ma (see Tyler & others, 1991). Even so, further structural and geochronological work is needed to clarify the interpreted events.

Although our results are of a reconnaissance nature, the consistency of the youngest K–Ar mineral ages from widely distributed deformed zones suggests a major period of contractional fault movement in the latest Cambrian to earliest Ordovician. The final contractional deformational event in the basement at the northern margin of the Canning Basin might have extended into the Fitzroy Trough, where it is perhaps recorded by movements along the faults evident in the seismic profile of Drummond & others (1991). This event might also have extended farther south. South of the Canning Basin, the 750–550-Ma ages of deformation in the Paterson Orogen, although poorly constrained (Myers, 1990), could have occurred at much the same time as the deformations that we have documented to the north of the basin. The D4 event south of the basin might be reflected by the cleavage affecting Late Proterozoic glacial rocks in the Paterson Orogen (Williams, 1990). The final phase of deformation in the King Leopold Orogen was apparently contemporaneous with the Delamerian Orogeny in the Adelaide Geosyncline, which is dated at 520–480 Ma (D1, 520–505 Ma; D2, 495–480 Ma; Parker, 1986; Preiss, 1987), and might represent a more widespread event. These speculations on the timing and extent of D5 require much more work before they can be accepted or refuted.

If this latest Cambrian deformation is represented under the basin, then the Canning Basin probably lacks a thick Cambrian succession similar to those in the Wiso, Amadeus, and Officer

Basins to the east (see Shaw & others, 1991), because much of the Canning region would have been elevated by crustal shortening at this time. Nevertheless, the possibility that restricted sedimentation took place between D4 and D5 — as seen, for example, in the Ord Basin (Mory & Beere, 1985) — cannot be excluded. Since the oldest-known trilobite faunas are of latest Tremadoc age (i.e., ca 485 to 490 Ma; Webby & Nicoll, 1989), subsidence and deposition in the Fitzroy Trough appear to have begun in the Early Ordovician, possibly between about 505 and 490 Ma.

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