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RECORD
2006/19

GEOLOGY OF THE KALBARRI AREA — A FIELD GUIDE

by R. M. Hocking and A. J. Mory

Reunite Gondwana · Realize the Potential
Perth, Australia
2006 AAPG International Conference and Exhibition
November 5-8, 2006
Host: Petroleum Exploration Society of Australia

Geological Survey of Western Australia

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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REFERENCE
The recommended reference for this publication is:
HOCKING, R. M., and MORY, A. J., 2006, Geology of the Kalbarri area — a field guide: Western Australia Geological Survey, Record 2006/19, 15p.

National Library of Australia Card Number and ISBN 978 1 74168 075 1

Grid references in this publication refer to the Geocentric Datum of Australia 1994 (GDA94). Locations mentioned in the text are referenced using Map Grid Australia (MGA) coordinates, Zone 50. All locations are quoted to at least the nearest 100 m.

Cover image modified from Landsat data, courtesy of ACRES.

Printed by The Digital Document Co (WA) Pty Ltd

Published 2006 by Geological Survey of Western Australia
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Contents

Figures

Geology of the Kalbarri area — a field guide

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This Record was prepared as a field guide for Field Trip 4 (Kalbarri – Shark Bay), part of the American Association of Petroleum Geologists 2006 International Conference and Exhibition, held in Perth, Western Australia, 5–8 November 2006. This guide covers the regional geology of the western margin of Western Australia and the portion of the field trip based at Kalbarri. There are separate notes for the Shark Bay component of the trip. Descriptions of regional geology and of the Kalbarri area in this guide are derived primarily from field guides by Hocking (2000) and Mory et al. (2005).

Regional geology

The greater Carnarvon Basin (Hocking et al., 1987; Hocking, 1990; Mory et al., 2003) extends onshore from Geraldton to Karratha along the western and northwestern coastline of Western Australia (Fig. 1), west and northwest of Archean and Proterozoic cratons and orogens. The basin covers about 115 000 km² onshore and 535 000 km² offshore to the continental–oceanic crust boundary. The basin is divisible into the Southern Carnarvon Basin, containing primarily Paleozoic sedimentary rocks with a Mesozoic and Cenozoic veneer, and the Northern Carnarvon Basin, which was the primary Mesozoic depocentre (Hocking, 1994; Tyler and Hocking, 2001). At about 27°S, the basin is transitional southwards into the Perth Basin, which in turn extends southwards to the southwest tip of Western Australia, west of the Archean Yilgarn Craton.

Sedimentary rocks in the greater Carnarvon Basin range in age from Ordovician to Holocene, and can be divided into twelve distinct packages of sedimentary rocks (Fig. 2), only some of which outcrop. These packages reflect major depositional episodes, are primarily unconformity-bounded, and each has unifying lithological characteristics. The packages are based on the successions seen in Phanerozoic basins throughout Western Australia (Trendall and Cockbain, 1990), rather than only in the Carnarvon Basin.

The three Paleozoic packages (Ordovician to mid-Devonian, Late Devonian and Early Carboniferous, and Late Carboniferous and Permian) formed in an intracratonic, northwards-opening basin, which initially developed because of rifting along the coast of Western Australia. They constitute most of the section in the Southern Carnarvon Basin, and have been intersected in marginal areas of the Northern Carnarvon Basin.

The Triassic, Jurassic and earliest Cretaceous, and Early and Late Cretaceous (siliciclastic) packages reflect the development of the Northern Carnarvon Basin as a rift system, related to the breakup of Australia and Greater India (Longley et al., 2002). They are pre-rift trough-infill (Triassic); rift valley (Jurassic); and post-breakup, trough-infill, and restricted circulation, trailing-margin successions (Cretaceous) respectively.

The Upper Cretaceous and Cenozoic packages (Upper Cretaceous, Paleocene and Early Eocene, Eocene, Oligocene and Middle Miocene, and Late Miocene to Holocene) are carbonate-dominated, trailing-margin successions that formed by progradation of the continental shelf in the Northern Carnarvon Basin.

A notable feature centred directly east of Hamelin Pool is the Woodleigh impact structure, a 120 km-diameter, multi-ring circular impact structure close to the Devonian–Carboniferous boundary in age (Uysal et al., 2001, 2005) that is buried below 60–200 m of Cretaceous marine strata and, near the impact epicentre, Lower Jurassic lacustrine deposits. There is virtually no surface expression of the structure apart from some drainage that implies Cenozoic movements along the outer ring faults, probably reactivated during Miocene compression (Iasky and Mory, 1999; Mory et al., 2000).

The Perth Basin (Playford et al., 1976; Cockbain, 1990; Mory and Iasky, 1996) is a north–south elongate rift or trough that covers about 100 000 km² along the western coast of Australia, and is underlain by the Pinjarra Orogen. This outcrops as fault-bounded, mid-basin ridges in the Leeuwin and Northampton Complexes. The northern Perth Basin contains mainly clastic rocks of mid-Carboniferous to Early Cretaceous age (Fig. 3), deposited in a rift system that culminated with the breakup of Gondwana in the Early Cretaceous. Two major tectonic phases are recognized: Permian extension in a southwesterly direction and Early Cretaceous transtension to the northwest during breakup. Sinistral and dextral movements, respectively, are inferred along the major north-striking faults during these phases, especially at breakup, which caused horizontal displacements, wrench-induced anticlines, and further faults (Harris, 1994; Mory and Iasky, 1996;

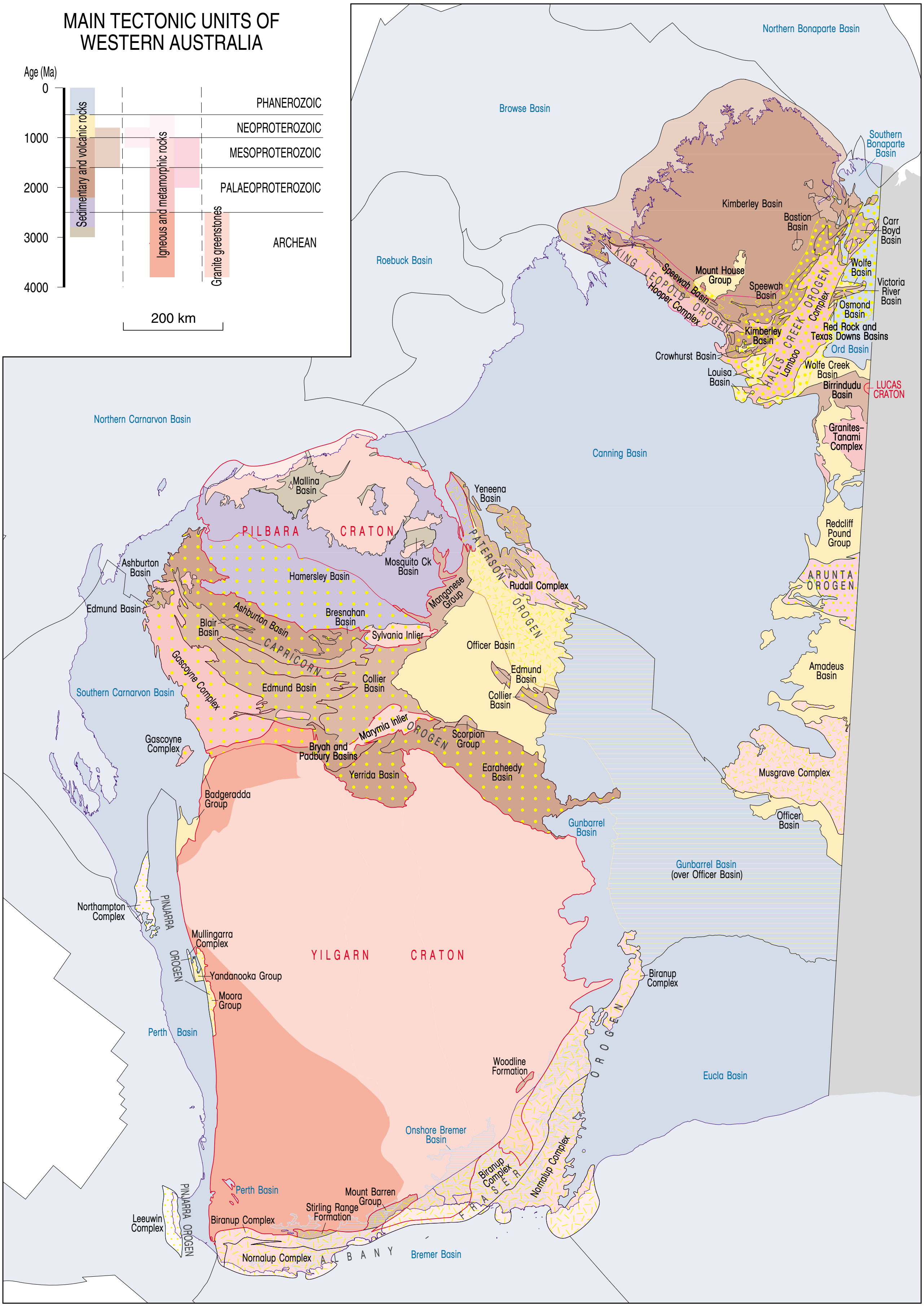

Figure 1. Tectonic units of Western Australia, after Tyler and Hocking (2001)

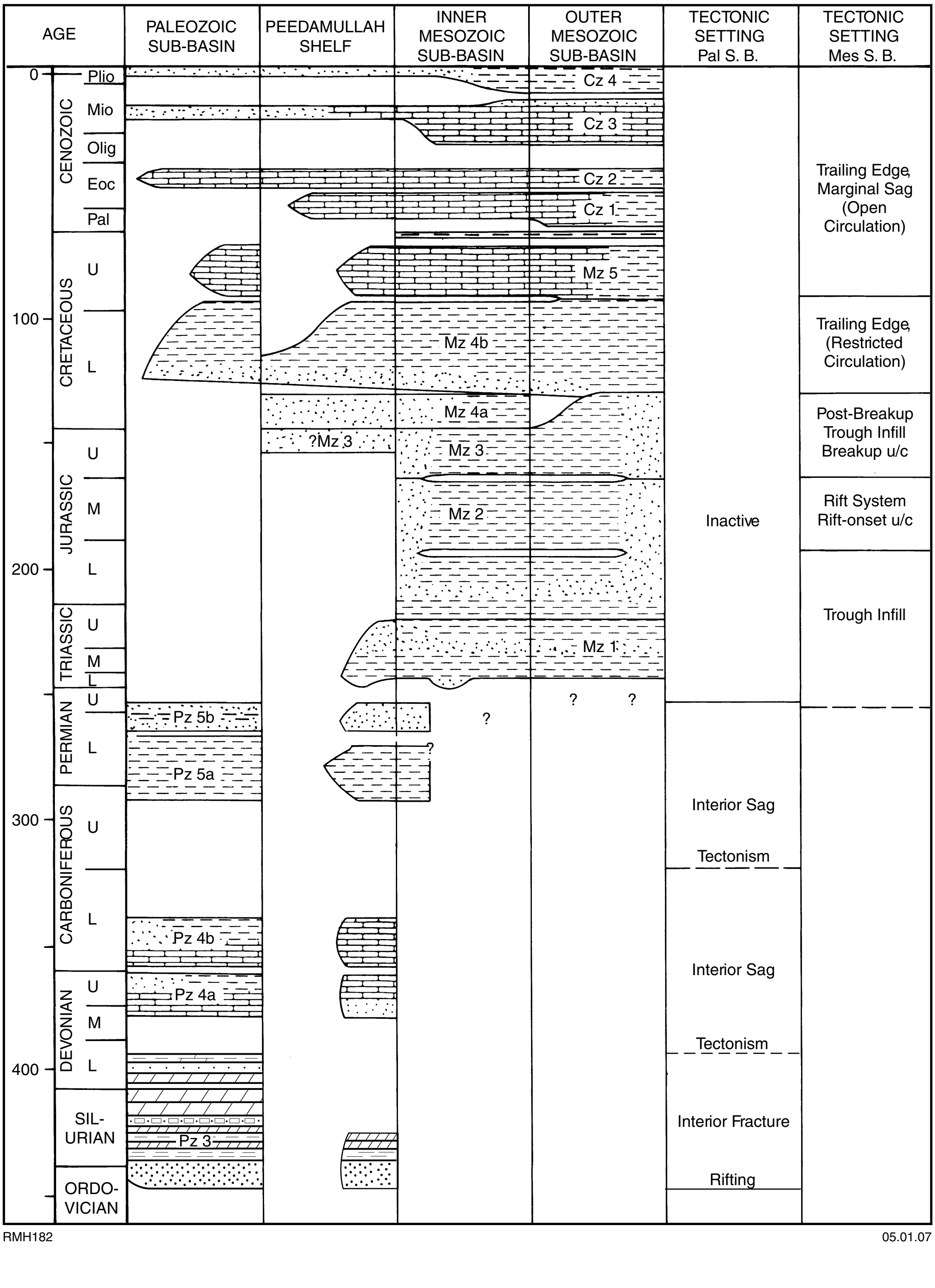

Figure 2. Depositional packages and tectonic development of greater Carnarvon Basin, after Hocking (2000). Alphanumeric codes refer to major depositional packages, and are placed where the packages are most significant

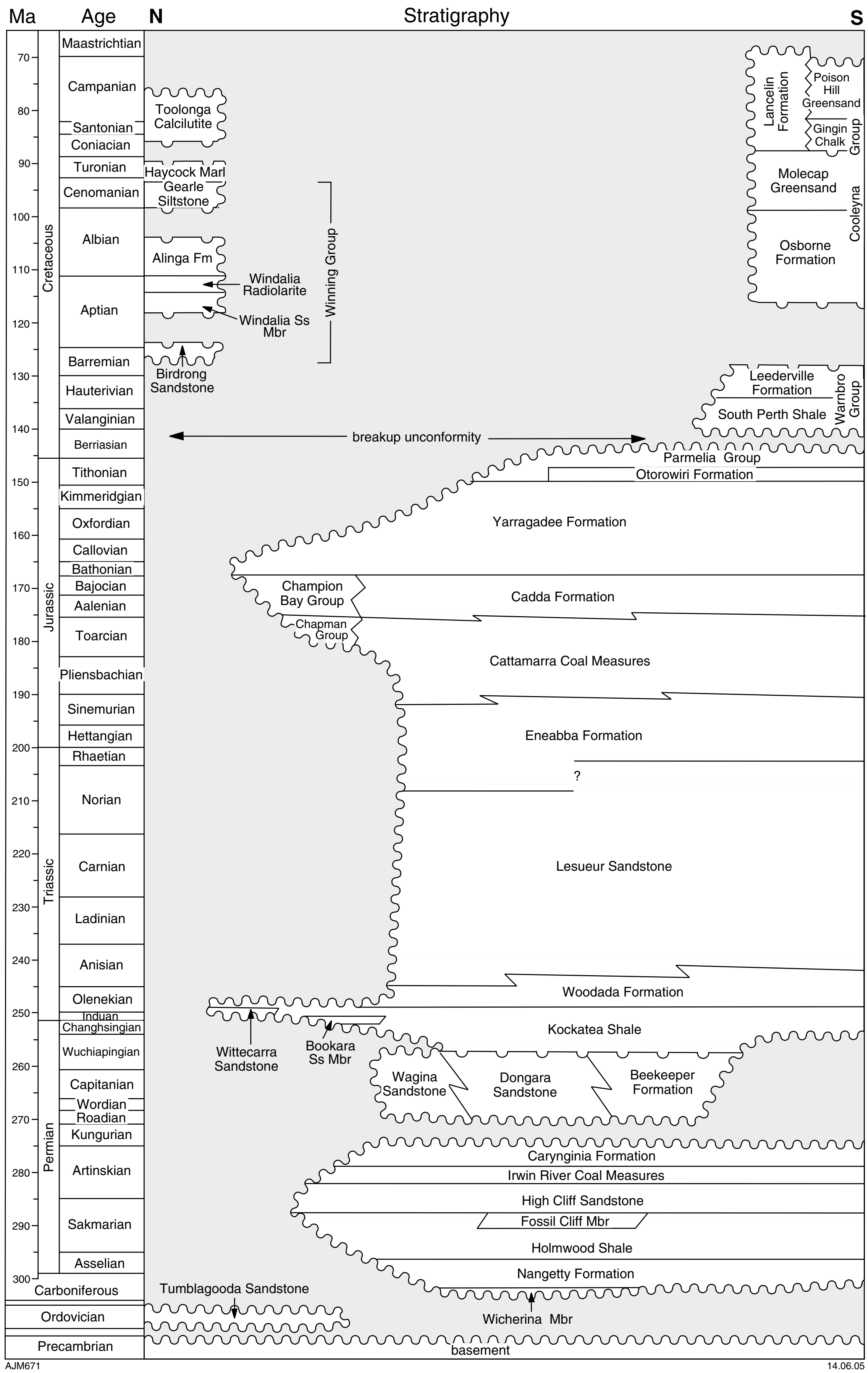

Figure 3. Pre-Cenozoic stratigraphy, northern Perth Basin, after Mory et al. (2005)

Song and Cawood, 2000). Transgressive marine deposits characterize the late Early Cretaceous and Cenozoic post-breakup phase of deposition. In the onshore Perth Basin these are virtually undeformed and, as in the central and western Southern Carnarvon Basin, Cenozoic sand and ferruginous duricrust cover most of the basin.

Kalbarri area

Kalbarri is located 600 km north of Perth, at the southern end of the Zuytdorp Cliffs. The town is a major tourist destination, largely because of the spectacular coastal and river gorges. The area around Kalbarri is transitional between the Perth and Southern Carnarvon Basins. Triassic rocks of the Perth Basin succession extend north almost to Kalbarri, and Ordovician and Cretaceous rocks characteristic of the Carnarvon Basin succession thin towards the south and terminate south of Kalbarri.

Ordovician and Silurian

The oldest known part of the Southern Carnarvon Basin succession is Upper Cambrian to Lower Ordovician, but is poorly known, restricted to the subsurface, and has a patchy distribution (Iasky et al., 1999, 2003). By comparison, Ordovician redbed deposition (Tumblagooda Sandstone) in braided fluvial, tidal sandflat, and nearshore to coastal, redbed settings (Hocking, 1991) covered the full extent of the Gascoyne Platform, from south of Kalbarri at least 700 km north to the Onslow area, and extends into the northern Perth Basin about 150 km southeast of Kalbarri. The Ordovician basin was a north-oriented, north opening, interior-fracture basin, which developed in equatorial to low tropical latitudes (Embleton, 1994). The western margin of the Ordovician basin is not preserved on the Australian plate.

In the Early Silurian, terrigenous influx to the basin lessened after a prolonged period of tectonic quiescence, and the calcareous to dolomitic deposits of the Dirk Hartog Group formed in nearshore-marine to marine-shelf settings, with a maximum preserved thickness of about 740 m beneath Dirk Hartog Island. Environments ranged from low to relatively high energy, and salinities from (probably) normal to hypersaline. A short hiatus at the end of the Silurian was followed by deposition of mixed siliciclastic rocks and dolomite in a shallow-marine environment (Faure Formation), then sand-dominated deposition in a similar setting to that of the Late Ordovician, but with minor dolomite (Kopke Sandstone). The return of a fully marine environment led to the deposition of a mixed siliciclastic–carbonate succession (Sweeney Mia Formation), at least over the central part of the Gascoyne Platform. These three units have a maximum combined thickness of approximately 900 m. The entire upper surface of the Sweeney Mia Formation is an eroded surface, and the magnitude of the hiatus separating it from later Devonian sedimentary rocks is unknown. The greater extent and different depositional style of the Devonian–Early Carboniferous succession suggest that the hiatus was substantial and was accompanied by considerable erosion.

The cyclical nature of Ordovician, Silurian, and Lower Devonian deposition is suggestive of a regular long-term control, perhaps mantle convection cycles (changes in spreading rates along global mid-ocean ridge systems inducing eustatic change) given the frequency of the cyclicity. Major orogenic pulses in central Australia, influencing the central Australian basins, may also have influenced the type of deposition.

Tumblagooda Sandstone

The best exposures of the Tumblagooda Sandstone are in Kalbarri National Park, along the Murchison River gorge (the type section) and adjoining coastal gorges, where about 1300 m of fluvial to tidal sandflat redbed facies are exposed in a lightly faulted section within which dips rarely exceed 5°. These exposures were studied in detail by Hocking (1991). North of the Murchison River the Tumblagooda Sandstone is overlain by Silurian shallow-marine dolomite, limestone, and evaporites in the subsurface (e.g. Kalbarri 1, Yaringa 1). These units are also characterized by low dips, and extend across all but the easternmost part of the basin (Hocking et al., 1987; Iasky et al., 2003).

There is no internal evidence of the age of the Tumblagooda Sandstone apart from trace fossils (Trewin and McNamara, 1995), which are not particularly age diagnostic; but a lower age limit is provided by paddle impressions associated with some arthropod trackways in the middle of the unit that are indicative of eurypterids, a group that first appeared in the Arenig (Early–Middle Ordovician; McNamara, *in* Mory et al., 2003). Previous suggestions for the age of the unit ranged from middle Cambrian to Cretaceous (Hocking et al., 1987; Hocking, 1991; Iasky and Mory, 1999, table 1), of which the most constrained was the Early Ordovician age based on paleomagnetism (Schmidt and Hamilton, 1990).

The dominantly sandy facies of the Tumblagooda Sandstone imply high sediment influx, probably a function of periodic faulting along the basin margin. Terrigenous influx to the basin lessened near the end of the Ordovician, and a prolonged period of tectonic quiescence commenced allowing dominantly dolomitic deposits to accumulate in nearshore-marine to marine-shelf settings (Dirk Hartog Group, present only in the subsurface to the north of Kalbarri). Environments ranged from low to relatively high energy, and salinities from (probably) normal to hypersaline.

The type section of the Tumblagooda Sandstone in the Murchison River gorge is about 1300 m thick, and was divided into four facies associations (FA1 to FA4) by Hocking (1991). These associations outcrop in stratigraphic sequence up the type section, and delineate two fining-upward megacycles of fluvially dominated facies overlain by tidal sandflat deposits or interdistributary bay deposits (FA1 to FA2, and FA3 to FA4). Fluvial paleocurrents flowed to the northwest, with remarkably little scatter. The section at the Z Bend in the Murchison River gorge is primarily in tidal sandflat deposits (FA2), with a laterally persistent fluvial sheet near the base, towards the top of the lower couplet. The coastal cliff sections extend from the top of the upper fluvial sandstone interval (FA3) up into interdistributary bay and coastal-channel deposits (FA4).

Facies Association 1 (FA1) consists of trough cross-bedded medium- to coarse-grained sandstone with unimodal, northwestwards paleocurrents. It was deposited as large, sheet-braided fluvial lobes, and grades upward into FA2. The base is not exposed.

Facies Association 2 (FA2) contains fine- to medium-grained, mostly thin-bedded sandstone, which was deposited in a very shallow marine, largely tidal, environment that became progressively more distal upsection and to the northwest. Laterally extensive, comparatively thin sheets of FA1 are interbedded in the lower part of FA2, and gradually diminish in abundance upward. The association can be explained as the product of lessening sediment influx, allowing relative transgression, or as a transgressive system gradational from FA1 and moving towards a maximum flooding surface high in FA2 prior to progradation during relative regression by FA3. Trewin (1993a,b) considered there was a strong eolian component in FA2, but this interpretation was not accepted by Hocking (2000). Adhesion surfaces and indicators of emergence are common, but eolian cross-bedding has not been recognized.

Facies Association 3 (FA3) sharply overlies FA2 and is similar to FA1, although it shows fining-upwards cyclicity on a scale of 10 to 15 m. Like FA1, it was deposited in a sheet-braided fluvial environment by lobes that prograded to the northwest, although depositional energy levels were higher overall than for FA1. It can be interpreted as a highstand to regressive prograding system, where abrupt progradation over FA2 took place in conditions of minimal accommodation.

Facies Association 4 (FA4) is a cyclic, interdistributary bay sequence that formed adjacent to and above the braided fluvial deposits of FA3. Most of the association consists of fining-upwards cycles, 0.5 to 2 m thick, from medium-grained sandstone to red, commonly bioturbated siltstone. There is a subaqueous channel complex near the top of the association, which is well exposed in the face of Red Bluff. The outcrops along the coast can be interpreted as the start of the succeeding transgressive system above the FA3 regressive system.

A fifth association (FA5), deposited as a conglomeratic alluvial fan or proximal braid-plain sequence, lies up paleoslope to the east of the Northampton Complex. Stratigraphic correlation between FA5 and the remainder of the Tumblagooda Sandstone is tentative only. Based on the abundance of *Skolithos* in both FA4 and the succession below FA5 just east of the Northampton Complex, FA5 may be the regressive system above and grading upwards out of FA4.

Triassic

In the Kalbarri region, Lower Triassic strata are exposed only in the coastal cliffs south of the town, as in the section at Shell House. They are part of the Perth Basin succession, and extend from the central part of the Perth Basin to about 200 km west-northwest of Kalbarri on the continental shelf (Iasky et al., 2003).

The Wittecarra Sandstone is disconformable on the Tumblagooda Sandstone, and consists of a basal conglomerate, overlain in turn by silty sandstone and siltstone, sandstone, conglomerate, and capped by sandstone with probable plant rootlets. The sandstone is a braided fluvial deposit with associated soil horizons presumably derived from the uppermost Tumblagooda Sandstone. Body fossils have not been found within the Wittecarra Sandstone, but its stratigraphic position beneath the Kockatea Shale implies an Early Triassic age. The unit possibly correlates with the Bookara Sandstone Member, or with a slightly higher level, near the base of the Kockatea Shale north of Dongara.

The Kockatea Shale consists of a uniform clayey siltstone that contains some ferruginous layers. These layers could be soil profiles, or they may originally have been calcareous. Rare conchostracans within the shale in the coastal cliffs south of Kalbarri (Cockbain, 1974) are the only fossils reported from the unit near Kalbarri, and imply it is here a brackish lagoonal deposit, whereas further south near Dongara open-marine facies predominate.

Cretaceous

Cretaceous sedimentary rocks are exposed north of the Murchison River on Murchison House Station, at Meanarra Hill, and at the top of the coastal cliffs. They are considered part of the Carnarvon Basin succession, and extend less than 50 km south of Kalbarri. The best exposures of the Winning Group (Birdrong Sandstone, Winning Sandstone Member of the Muderong Shale, Windalia Radiolarite, and Alinga Formation, in ascending order), and the Haycock Marl and Toolonga Calcilutite, are on Murchison House Station along the edge of the Pillawarra Plateau. Only the Birdrong Sandstone, the lowermost unit in the Winning Group, is present in the coastal cliffs. It is the reservoir for many petroleum accumulations in the Northern Carnarvon Basin, and the main artesian aquifer in the Southern Carnarvon Basin.

Cenozoic

About 27 km east of Kalbarri, float of Middle to Upper Eocene siliceous marine facies deposited in the shallow inner neritic zone contains abundant sponges, molluscs, bryozoans, foraminifera, and serpulid worms (Haig and Mory, 2003). The elevation of these marine facies (~220 m above sea level) implies a maximum age of Late Eocene for the major down-cutting of the Murchison Gorge, which Playford (2003) claimed is a response to Quaternary tectonism in the region.

The Pleistocene Tamala Limestone caps the coastal gorges, and is a calcareous eolian deposit that exceeds 300 m in thickness to the north of Kalbarri; the sea cliffs north of the Murchison River mouth are composed solely of Tamala Limestone except for rare exhumed hills of Cretaceous and Ordovician strata. At both Shell House and Red Bluff, it is less than 15 m thick, and original bedding has been largely obliterated by the development of calcrete.

Z Bend, Murchison River

Summary: Excellent exposures of tidal and fluvial redbed facies of the Ordovician Tumblagooda Sandstone; part of the type section.

Location: About 30 km east of Kalbarri, MGA 324900E 6938600N, KALBARRI 1:100 000 sheet. One of four public tourist lookouts and features within the river portion of Kalbarri National Park.

Access: Drive east of Kalbarri to the entrance of Kalbarri National Park and follow the signs to the Z Bend. There is a walk of about 500 m from the car park to the edge of the gorge and a climb of about 50 m down to the bed of the river. Before midday is preferable for the best light on these exposures. Note that samples cannot be taken without a permit, and an admission fee to the National Park will generally apply. Care should be taken on the steep slopes and rock faces, especially below overhangs. The park is registered with the National Estate (Place ID: 9686 and 19027) partly because of its geological value. Picnic seating and toilet facilities are provided next to the car park.

Geology: The gorge in this part of the Murchison River exposes an excellent section though part of the type section of the Tumblagooda Sandstone (Fig. 4). The access road through the National Park crosses a flat plain that lies close to the unconformity surface between the Ordovician Tumblagooda Sandstone and the overlying Cretaceous succession. The main tourist lookout at the Z Bend is immediately south of a prominent joint fissure, and consists of a projecting bluff of mostly thin-bedded, tidal sandflat deposits of the Tumblagooda Sandstone. Bioturbated and rippled tidal deposits are also exposed on the walk down from the car park. From the lookout, joint control of the Murchison River course is clearly visible (Fig. 5a). A thicker bedded sheet of trough cross-bedded fluvial sandstone cuts across the thin-bedded tidal deposits between 10 and 20 m above the base of the gorge (Fig. 6). This sheet of FA1 extends both up and down the gorge at least 2 km (Fig. 7).

Another major joint fissure and gully is present about 100 m south of the lookout and ladder. At the mouth of this gully near the base of the gorge, there are two large arcing sets of eurypterid tracks, superimposed on wave ripples (Fig. 5b). Several sets of wave ripples, some wind adhesion surfaces and setulfs, can be seen between the trackways and the corner of the gorge beneath the lookout, below the level of the fluvial sheet. The fine grain-size, thin bedding, and variety of bedding types are typical of the tidal deposits in the formation.

The sandstone in the lobate fluvial sheet is medium to coarse-grained, locally pebbly, poorly sorted, and

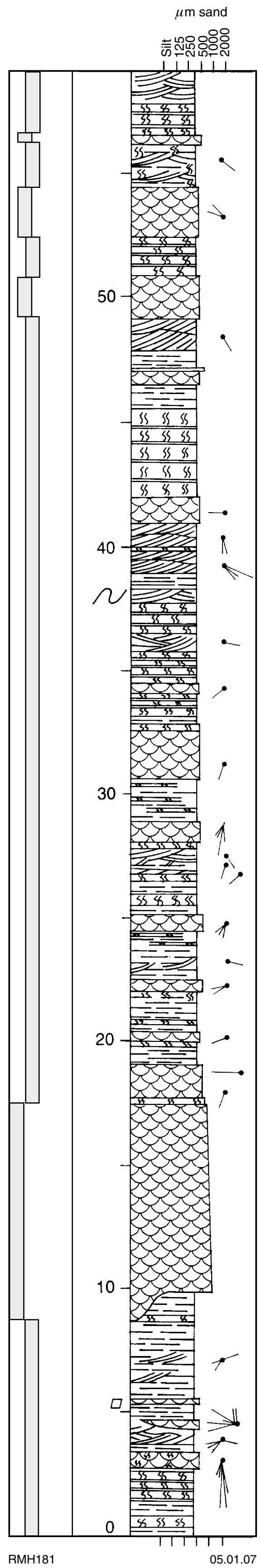

Figure 4. Measured section, the Z Bend, Kalbarri National Park, after Hocking (1991). Section line follows main fissure immediately north of lookout. Detailed sections of the fluvial interval near the base are in Figure 7

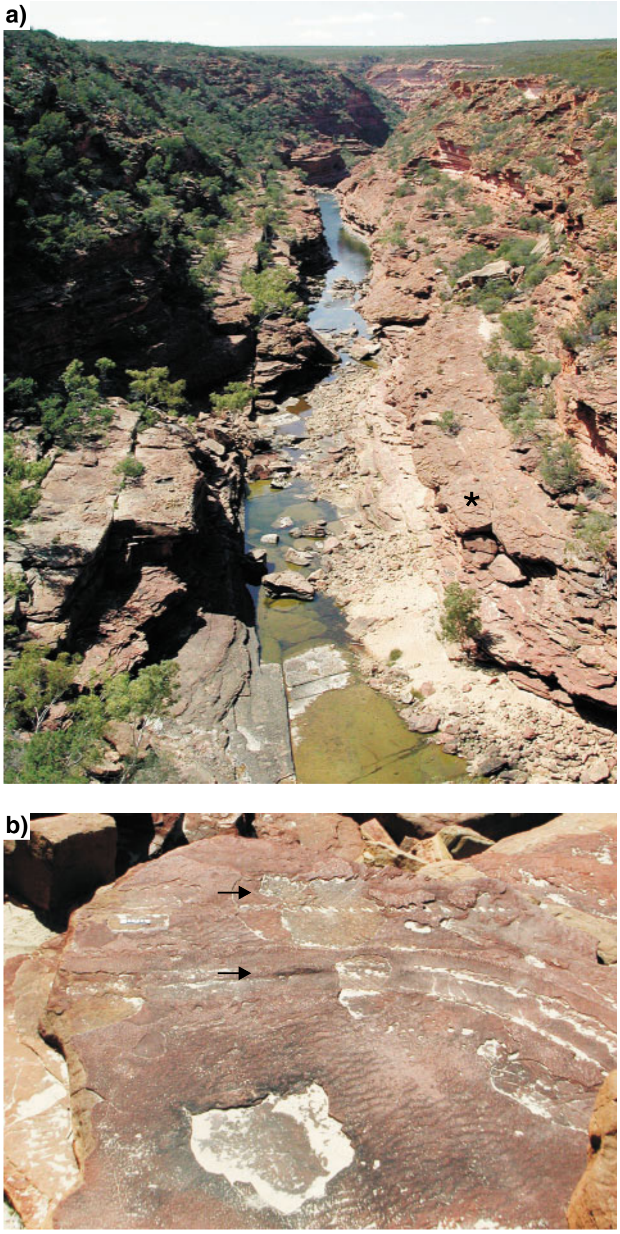

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Figure 5. Tumblagooda Sandstone, Z Bend, showing: a) joint control of the Murchison River. The asterisk marks the position of the channel shown in the section and Figure 7. Photograph taken from main lookout (MGA 249090E 6938590; b) arthropod trackways (arrowed) at the base of the Z Bend section (MGA 249075E 6938435N)

trough cross-bedded. Paleocurrents were to the northwest. Contorted bedding is present midway between the two prominent joint fissures on the west face of the Z Bend. At the top of the lobe, there is an interval in which the facies is similar to that below, but paleocurrent directions are reversed, implying reworking by marine currents.

Near the base of the gorge, about 100 m downstream from the lookout, there is a northwest-trending incised channel at the base of the fluvial lobe, cutting obliquely across the gorge (Fig. 6). This is one of the few channels in the gorges; elsewhere, and above this channel, bedforms are laterally continuous, which indicates sheet braiding. Undercutting and scouring of tidal sedimentary rocks is visible at the base of the channel on the southern side (Figs 4, 8).

Above the fluvial intercalation, there is a large, easterly facing overhang below the lookout that commonly has several seeps dripping from above it. There is a large, dewatered mound in the overhang. The main body of the mound, probably a megaripple, is white sandstone. This is capped by a red sandstone that has been disrupted and thrust-faulted on a small scale as water and sand escaped from the mound. The medium-grained sandstone also contains small ripples with granules concentrated on the crests, a feature characteristic of eolian deposition.

There is a small exposure of climbing ripples part way up the joint fissure to the lookout above the ladder, immediately left of the path. These formed in conditions of high sediment supply and are common in the tidal facies.

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Figure 6. Large channel within the Tumblagooda Sandstone, Z Bend, Murchison River (MGA 249290E 6938640N)

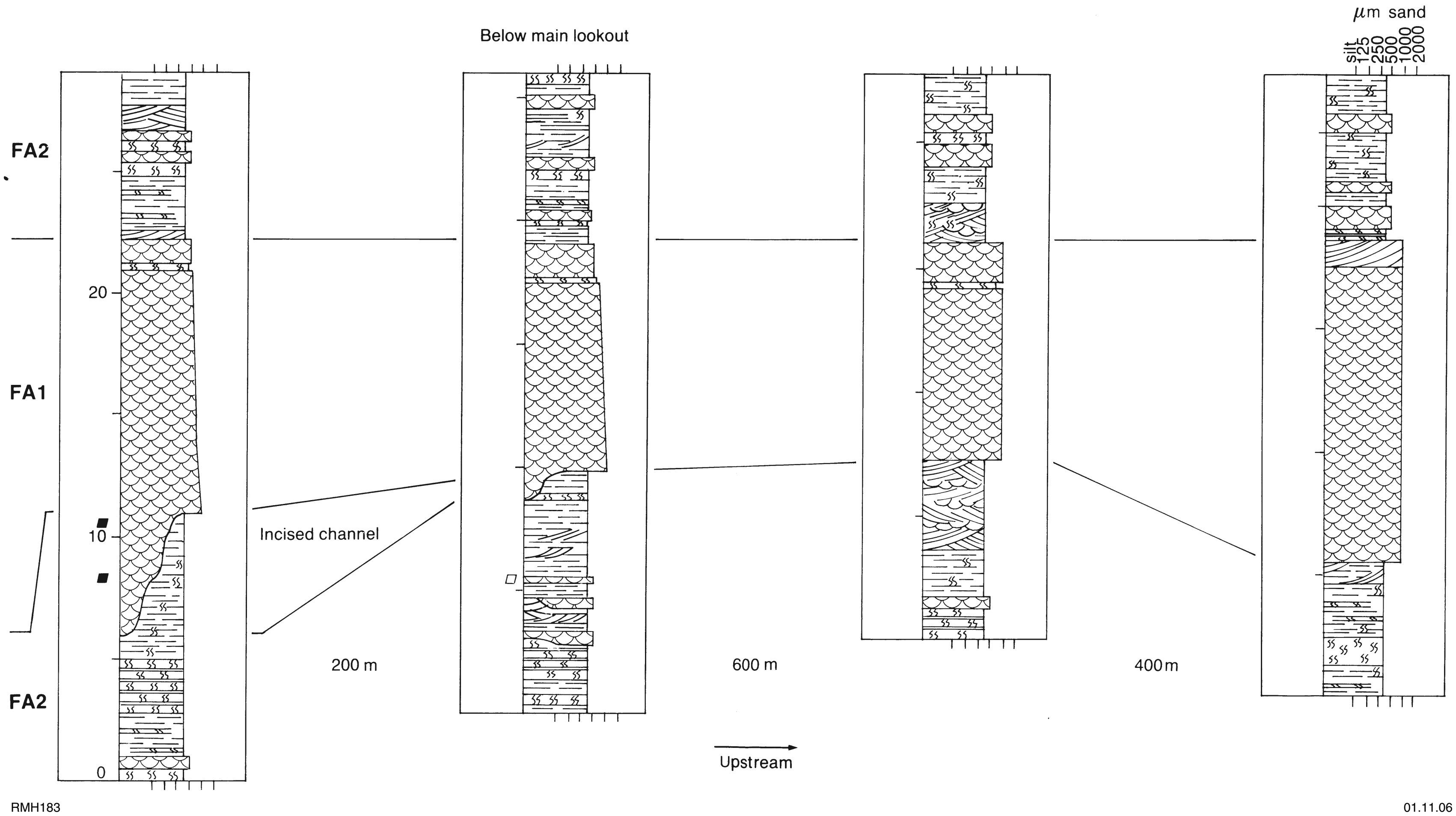

Figure 7. Detailed sections through fluvial sheet near base of Z Bend, after Hocking (1991)

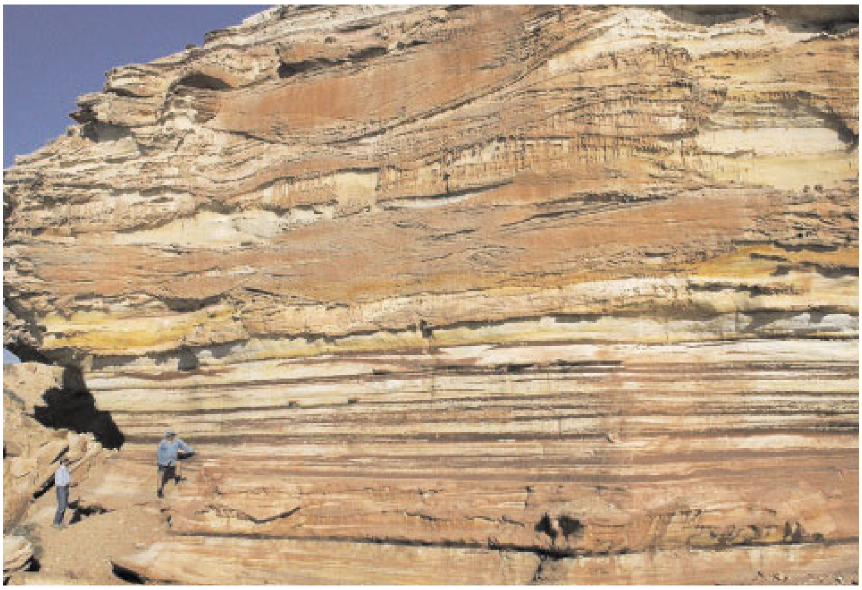

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Figure 8. Main face of Red Bluff, showing interdistributary deposits overlain by subaqueous coastal distributary. Cretaceous Birdrong Sandstone is at very top of photograph

Red Bluff

Summary: Excellent coastal exposures of a fluvial to coastal distributary and interdistributary transition in redbed facies of the Ordovician Tumblagooda Sandstone.

Location: Four kilometres south of Kalbarri, MGA 218100E 6927800N, KALBARRI 1:100 000 sheet.

Access: Drive about 4 km south of the river mouth, park in the lower car park at Red Bluff beach, and walk south around the base of the cliff. Note that a permit is required to collect samples as the site is within Kalbarri National Park. Be wary of material falling from the cliff, and waves on the lower slopes. The site is best visited in mid- to late afternoon for the best lighting on the main rock faces. The site is registered with the National Estate (Place ID: 9686 and 19029).

Geology: The car park at Red Bluff beach is on coarse-grained, poorly sorted, pebbly, trough cross-bedded sandstone that is stratigraphically much higher than the section at the Z Bend. The sandstone belongs to FA3, and was deposited in a coastal, high-energy sheet-braided setting. Paleocurrents were unimodal to the northwest, and very tightly clustered. Vertical burrows within the sandstone (?*Cylindricum*; Hocking, 1991), visible in some overhangs between the car park and the face of Red Bluff (Fig. 8), indicate that although fluvial processes dominated, deposition took place in a coastal setting. It is unlikely that the burrows are continental in origin, given the Tumblagooda Sandstone pre-dates all but the most primitive land plants. Sinuous trails (?*Aulichnites* or *Didymaulichus*; Hocking, 1991) are exposed in similar sandstone at Jakes Corner, about 1 km north of Red Bluff. The Gabba Gabba Member is present just below the uppermost terraces, and is well exposed directly in front of Red Bluff. This is a distinctive pebbly sandstone to pebble conglomerate bed about 1 m thick, which extends about 40 km along the river and coastal gorges within FA3, and can be used as a stratigraphic marker. The member generally marks the lowest appearance of vertical burrows such as *Cylindricum* or *Skolithos* in FA3 (Fig. 9).

Near the top of the terraces, the fluvial FA3 facies grades up into interdistributary deposits (FA4) with the amount of red siltstone gradually increasing at the tops of the fining-upwards cycles. Immediately above the upper, wide platform, trough cross-bedded sandstone is interbedded with laminated to rippled fine sandstone and siltstone. The laminated siltstones and sandstones are distal sheet-flood deposits that were deposited in an interdistributary bay setting. The coarser grained, cross-bedded sandstones were deposited in shallow, rapidly migrating and avulsing channels, within the interdistributary setting (Fig. 10). Where bioturbated, sediments were deposited below high-tide level, and where non-bioturbated, above high tide and exposed.

A subaqueous channel sequence of *Skolithos*-bearing, cross-bedded sandstone overlies and cuts into the interdistributary sequence (Fig. 8). It is best seen from the large fallen block immediately in front of Red Bluff. Further red siltstone at the very top of the exposure suggests the abandonment, avulsion, or lateral migration of the channel sequence. Additional good exposures of this section continue 600 m south to just west of the Mushroom Rock carpark (Fig. 10). Evans et al. (in press) made a reservoir-scale study of the area between Red Bluff and Mushroom Rock to the south, using detailed measured sections and outcrop gamma logging.

Cretaceous Birdrong Sandstone and Pleistocene Tamala Limestone are present at the top of the bluff, immediately below the upper lookout on the recessive slope.

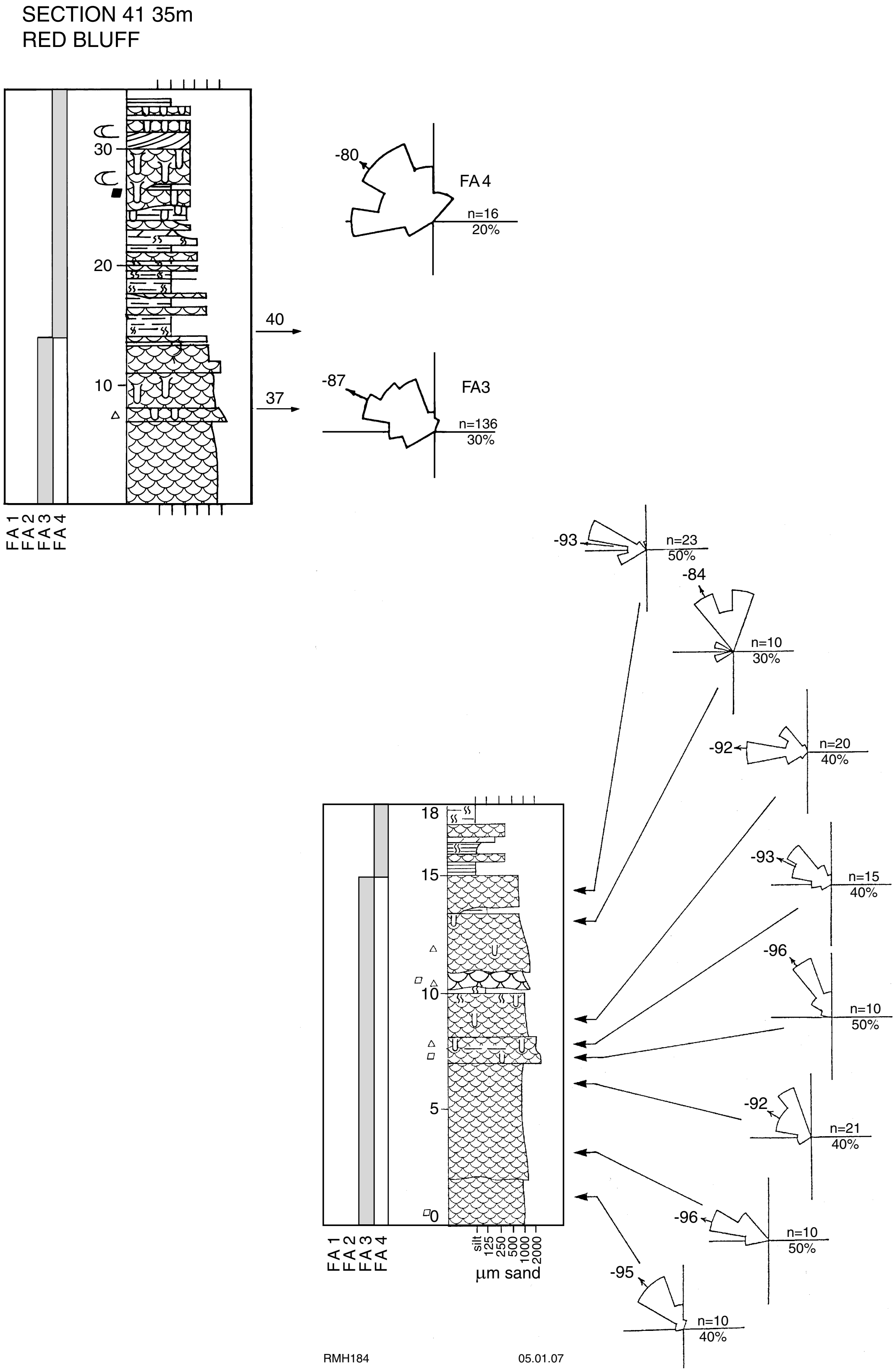

Figure 9. Measured sections of and in front of main face at Red Bluff, after Hocking (1991). The lower section is a more detailed version of the upper, showing development of bioturbation above Gabba Gabba Member (at 8 m), and paleocurrent variation

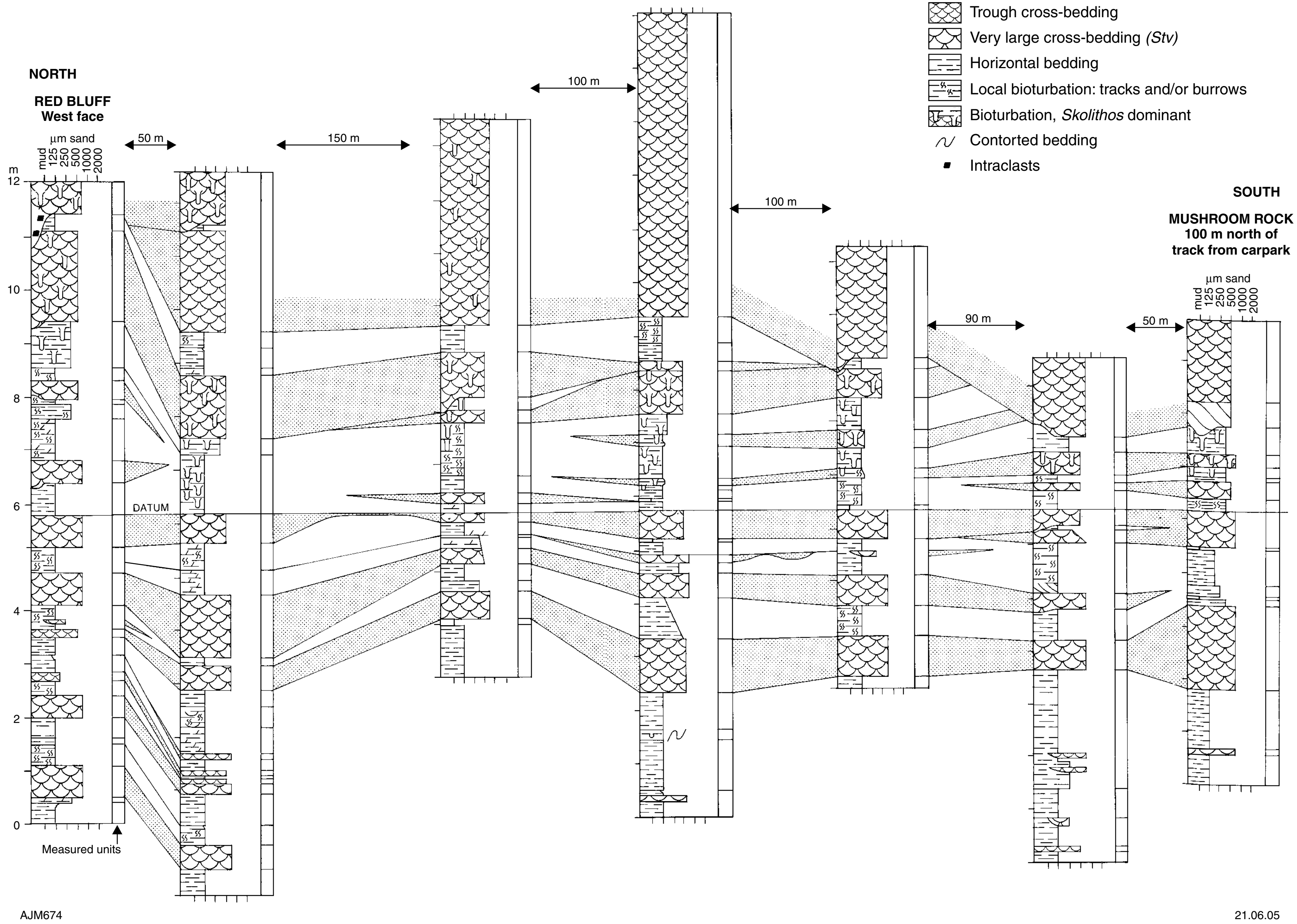

Figure 10. Measured sections through the Tumblagooda Sandstone, Red Bluff (MGA 218030E 6927700N) to Mushroom Rock (217950E 6927060N), after Hocking (1991)

Shell House

Summary: Excellent exposures of fluvial to tidal redbed facies of the Ordovician Tumblagooda Sandstone, disconformably overlain by fluvial Lower Triassic Wittecarra Sandstone (type section) and shallow-marine Kockatea Shale, are preserved in a small graben draped by the Lower Cretaceous Birdrong Sandstone and Pleistocene Tamala Limestone.

Location: About 11 km south of Kalbarri, MGA 215900E 6921500N, KALBARRI 1:100 000 sheet.

Access: Drive 10 km south of the river mouth, turn southwest into Natural Bridge Road and then northwest after 1.6 km to Shell House. Walk down the spur immediately north of the car park to near the top of the Tumblagooda Sandstone, and then a further 300 m to the northeast. Note that a permit is required to collect samples as the site is within Kalbarri National Park. Take care on the steep scree slopes and rock surfaces. The site is best visited in mid-afternoon for the best lighting on the main rock faces. The site is registered with the National Estate (Place ID: 9686 and 19029).

Geology: Shell House (Fig. 11) is one of the few localities where it is possible to climb down to sea level in the coastal cliffs south of Red Bluff. The Tumblagooda Sandstone at Shell House is a fluvial and interdistributary bay sequence, similar to that at Red Bluff. A small graben is present in the centre spur (Fig. 12). The southern and northern spurs are at approximately the same structural level, and the northern fault can be seen in the gully between the central and northern spurs (Figs 11a and 12). Uppermost *Skolithos*-bearing sandstone beds are the best indicators of the top of the Ordovician section (Fig. 11b). In the Tumblagooda Sandstone, the Gabba Gabba Member — a distinct pebbly sandstone — and the first appearance of *Skolithos* above a distinct red interval, allow reasonably precise determinations of the fault throws. Triassic strata are present only in the graben over the central spur. The Lower Cretaceous Birdrong Sandstone forms a blanket over the graben, which indicates that the structure formed between the Early Triassic and the Early Cretaceous. The Wittecarra Sandstone and Kockatea Shale are best exposed on the south side of the central spur (Figs 11a–c). Although the Wittecarra Sandstone is texturally similar to the underlying Tumblagooda Sandstone, from which it was undoubtedly derived, there is an erosional contact and a distinct change to a mottled character in the younger unit. The section is the northernmost known accessible outcrop of Perth Basin units on the coast.

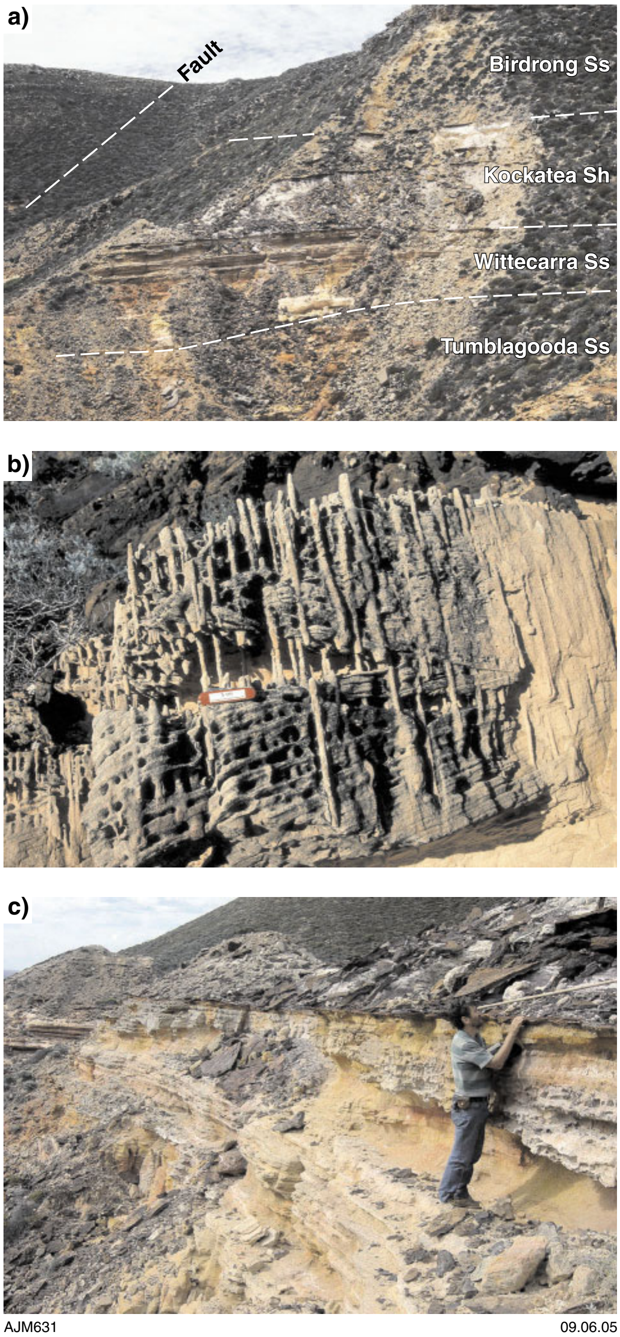

Figure 11. Shell House: a) Cretaceous and Triassic rocks overlying the Ordovician Tumblagooda Sandstone. Taken from MGA 216180E 6921500N; b) ***Skolithos*** **bed in Tumblagooda Sandstone (MGA 216120E 6921680N); c) top of the type section of the Wittecarra Sandstone (MGA 216150E 6921600N). Contact with Kockatea Shale is level with person's head. Photograph courtesy of Richard Evans, Curtin University**

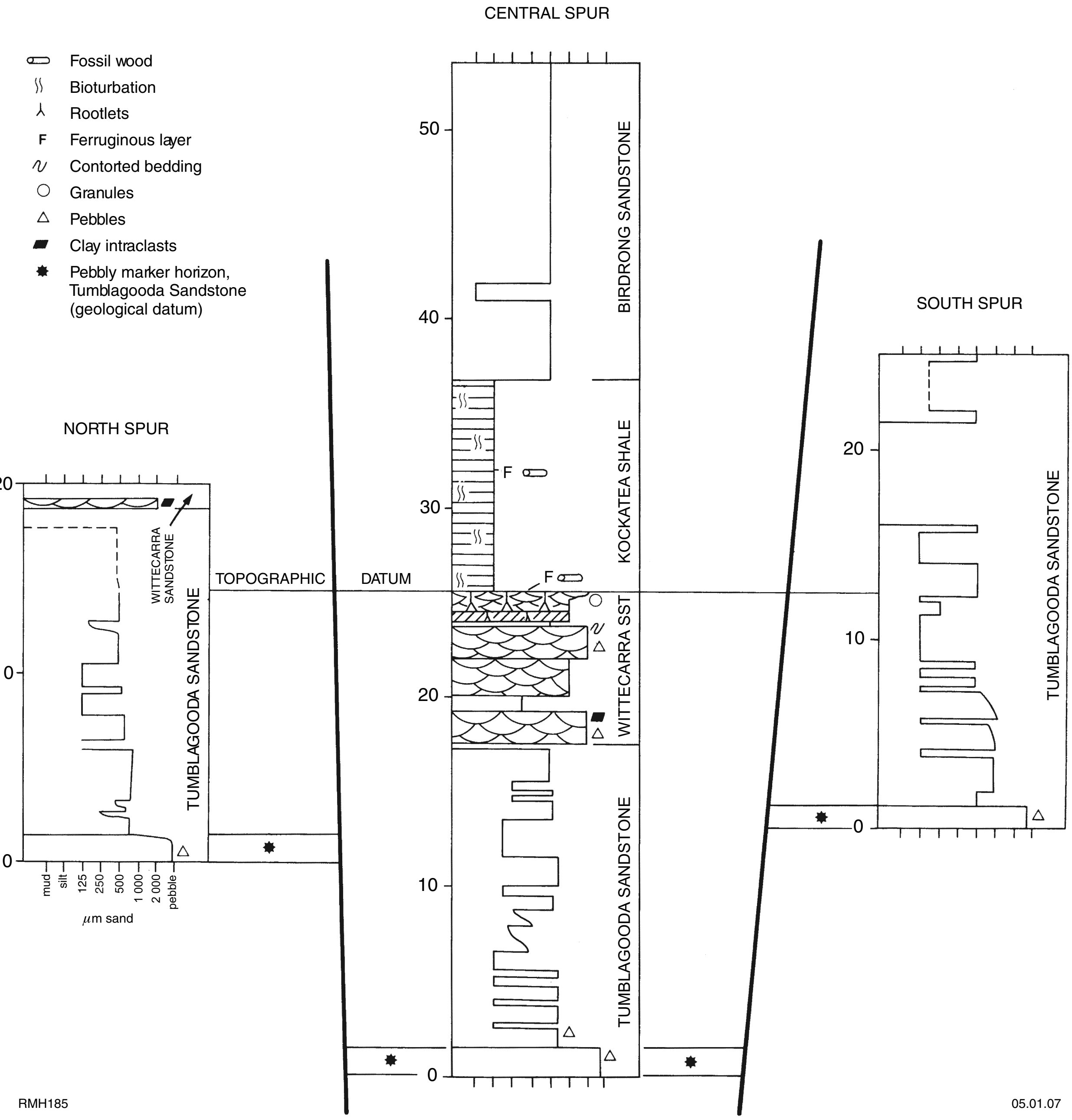

Figure 12. Measured sections showing the small graben at Shell House, after Hocking (1991); from MGA 216180E 6921500N to 216180E 6921750N)

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Geology of the Kalbarri area
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