CARBONIFEROUS OF WESTERN AUSTRALIA—A REVIEW

by A. E. Cockbain

ABSTRACT

Rocks of Carboniferous age (the base of which is taken at the base of Tournaisian Tnlb (Fig. 2) and the top at the base of microfloral assemblage Unit II) occur in the Carnarvon, Canning and Bonaparte Basins in Western Australia. Sedimentation was predominantly siliciclastic with a small amount of carbonate, particularly in the Bonaparte Basin. Early Carboniferous sediments were deposited under near-tropical conditions and cooling took place gradually, culminating in glacial conditions in Late Carboniferous (and continuing into Early Permain) times. There seems to have been a widespread period of non-deposition in the mid Carboniferous although sedimentation was continuous in the basinal parts of the Bonaparte Basin and probably in the deeper parts of the Fitzroy Trough.

INTRODUCTION

Carboniferous rocks make up only a small proportion of the Phanerozoic rocks of Western Australia. They crop out in three sedimentary basins—the Carnarvon, Canning and Bonaparte Basins*—and are known in the subsurface of all three basins from oil-exploration wells (Fig. 1). The Carboniferous rocks are mainly marine clastics and carbonates with some continental clastics. There are no coal deposits in the Carboniferous System in Western Australia.

The Carboniferous is taken to include the Tournaisian, Visean, Namurian, Westphalian and Stephanian Series and to extend from 280 to 345 million years ago. The Strunian Stage (Tnla) is here considered latest Devonian. Correlation of the rocks in Western Australia with the European series is based mainly on the brachiopod, conodont and foraminifer faunas and on the microfloras (Druce,1969; Kemp and others, 1977; Mamet and Belford, 1968; Nicoll and Druce, 1979; Playford,1971, 1976; Roberts, 1971; Thomas, 1971). No isotopic age determinations are available on Carboniferous rocks from Western Australia.

The boundary between the Carboniferous and Permian Systems has been traditionally taken as the unconformity at the base of the glacial sequence in Western Australia, that is at the base of the Lyons Formation, Grant Group and Keep Inlet Formation in the Carnarvon, Canning and Bonaparte Basins respectively. However, recent work indicates that the major break is not at the base of the Permian but is within the Upper Carboniferous.

*The Geological Survey of Western Australia has dropped the term "Gulf" from the name of this basin, thus bringing it in line with those other basins (e.g. Ord, Bremer) in which the geographic descriptor is omitted.

BIOSTRATIGRAPHY

The correlation of some of the biostratigraphic zones used in Western Australia is shown in Figure 2. Zonal schemes using conodonts have been erected in the Bonaparte Basin (Druce, 1969; modified by Nicoll and Jones, pers. comm., 1981) and Canning Basin (Nicoll and Druce, 1979) and ostracod zones have also been erected in the Bonaparte Basin by Nicoll and Jones (pers. comm., 1981). A number of brachiopod assemblages were established by Thomas (1971) in the Carnarvon, Canning and Bonaparte Basins and Roberts (1971) published a brachiopod zonation based on Bonaparte Basin material. Roberts' scheme is followed here with two modifications. The *Anthracospirifer milliganensis* zone and the *Echinoconchus gradatus* fauna are combined into one zone (*milliganesis—gradatus* zone); and the interzone between the *pauciplicatus* zone and this new zone is eliminated (see discussion under Burvill Formation). Two of the four species comprising the *gradatus* fauna occur in the *milliganesis* zone in the Burvill Formation and the other two species occur in the Waggon Creek Formation which is correlated with the Burvill Formation (Roberts, 1971). Consequently it seems that the *gradatus* fauna cannot be satisfactorily separated from the *milliganesis* zone.

The microfloral assemblages, described mainly from the Canning and Bonaparte Basins, have been synthesized by Kemp and others (1977). They provide additional evidence for amalgamating the *milliganensis* zone and the *gradatus* fauna. In Bonaparte 1, core 2, the *largus* microflora is associated with the *gradatus* fauna while in the lower cores 4, 5 and 6 it occurs with *milliganesis*-zone brachiopods However, in Kulshill 1 the brachiopods are associated with younger microfloras; the *gradatus* fauna in core 23 occurs with the *ybertii* microflora

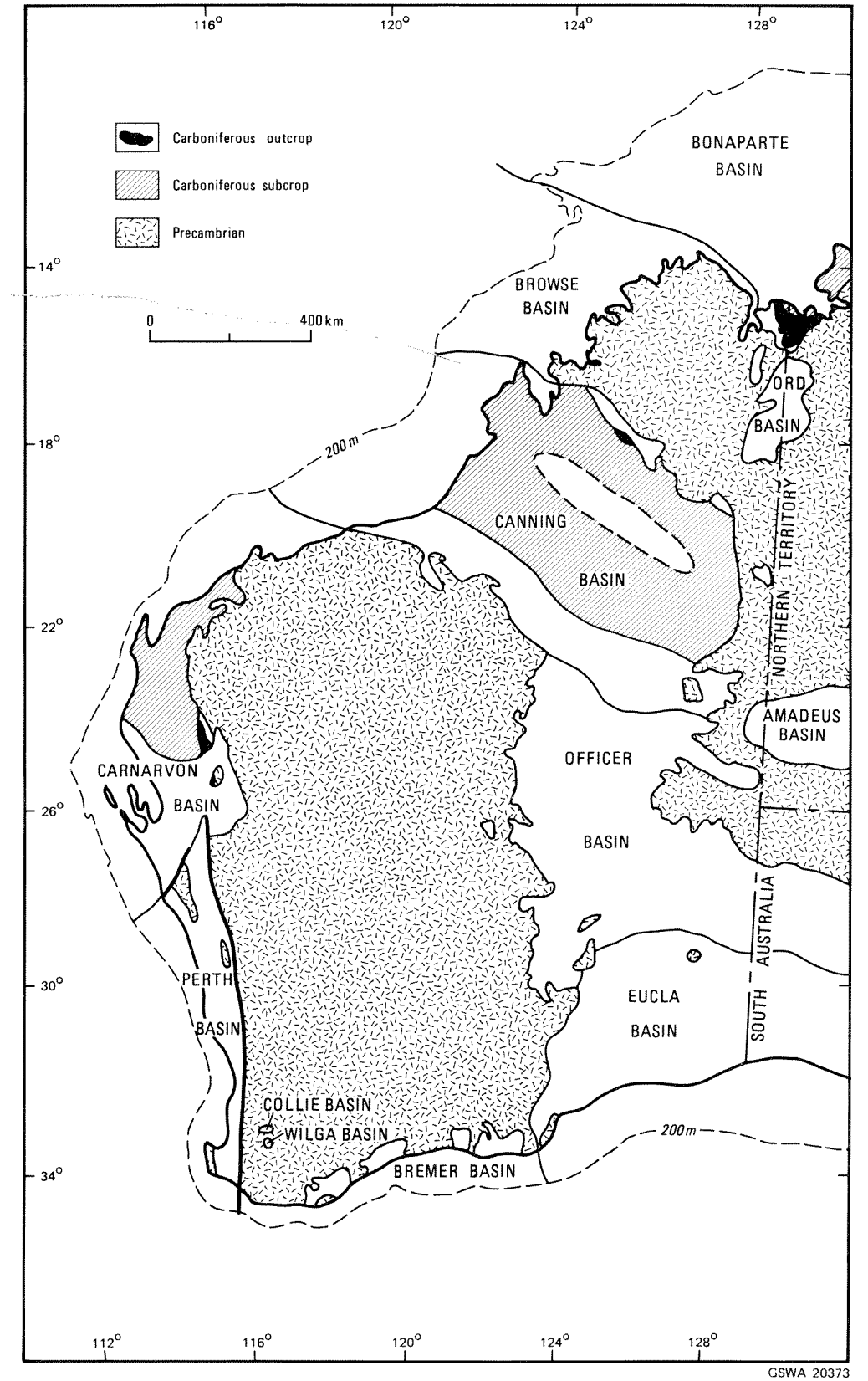

Figure 1. Phanerozoic sedimentary basins of Western Australia, showing outcrops and probably subsurface extent of Carboniferous (after Playford and others, 1975).

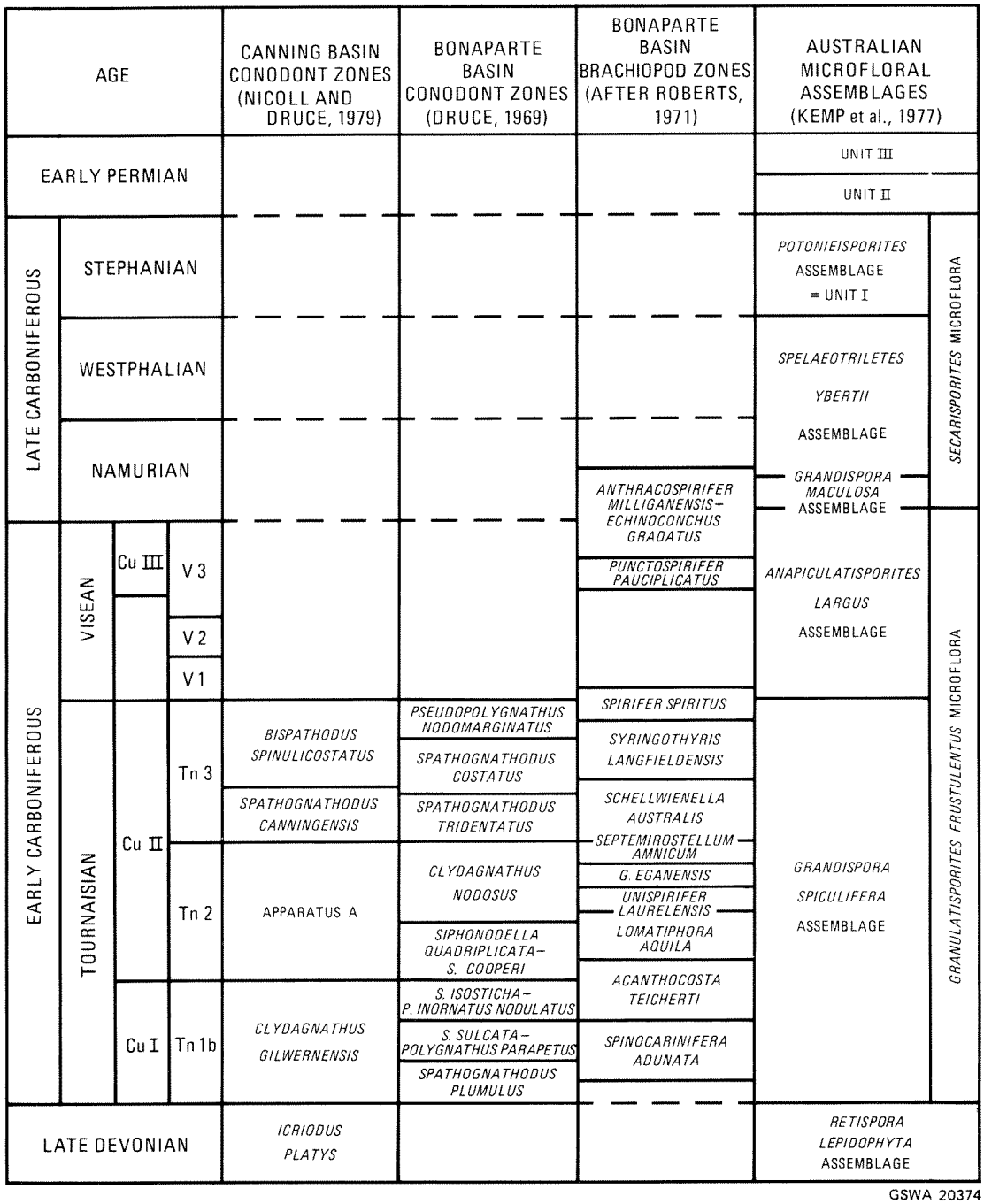

Figure 2. Correlation of conodont, brachiopod and mnicrofloral zonations in Western Australia.

and the deeper core 27 contains *milliganensis*-zone brachiopods and the *maculosa* microflora. Assuming that the zone boundaries are synchronous, the brachiopod and microfloral zones are correlated in Figure 2. This correlation supports Kemp and others' (1977) suggestion (attributed by them to Bischoff *in* Jones and others, 1973) that the upper limit of the *largus* microflora is early Namurian.

At various times the Carboniferous-Permian boundary has been drawn at the base of Unit I (Helby, 1969), the base of Unit II (Evans, 1969), or at the base Unit III (Balme, 1980). While this is not the place to review this problem (*see for example,* Kemp and others, 1977; Waterhouse, 1976; Archbold, 1982), the base of Unit II is here taken to coincide with the Carboniferous-Permian boundary; this has the additional advantage of retaining the bulk of the "Permian glacial sequence" in the Permian.

CARNARVON BASIN

Rocks of Carboniferous age crop out along the eastern margin of the Carnarvon Basin and have been encounted in a number of exploratory wells drilled in the northern part of the basin (Fig. 3). Four formations are recognised in the Williambury-Moogooree area

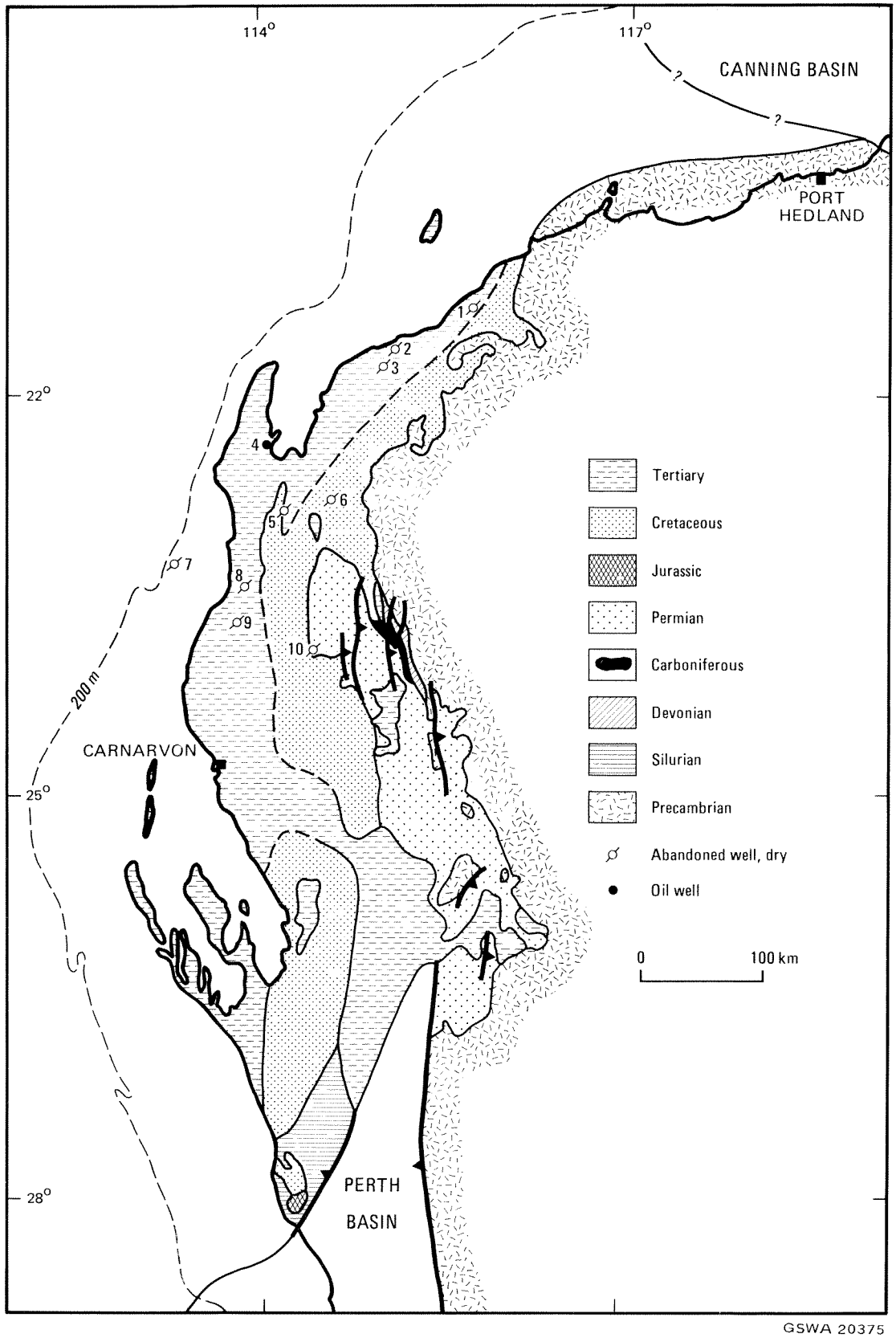

Figure 3. Carnarvon basin, showing solid geology and position of principal oil-exploration wells encountering Carboniferous rocks (after Playford and others, 1975). 1. Yarraloola 1; 2. Cane River 1; 3. Minderoo 1; 4. Rough Range 1; 5. Remarkable Hill 1; 6. East Marilla 1; 7. Pendock 1; 8. Warroora 1; 9. Gnaraloo 1; 10. Quail 1.

36540—3

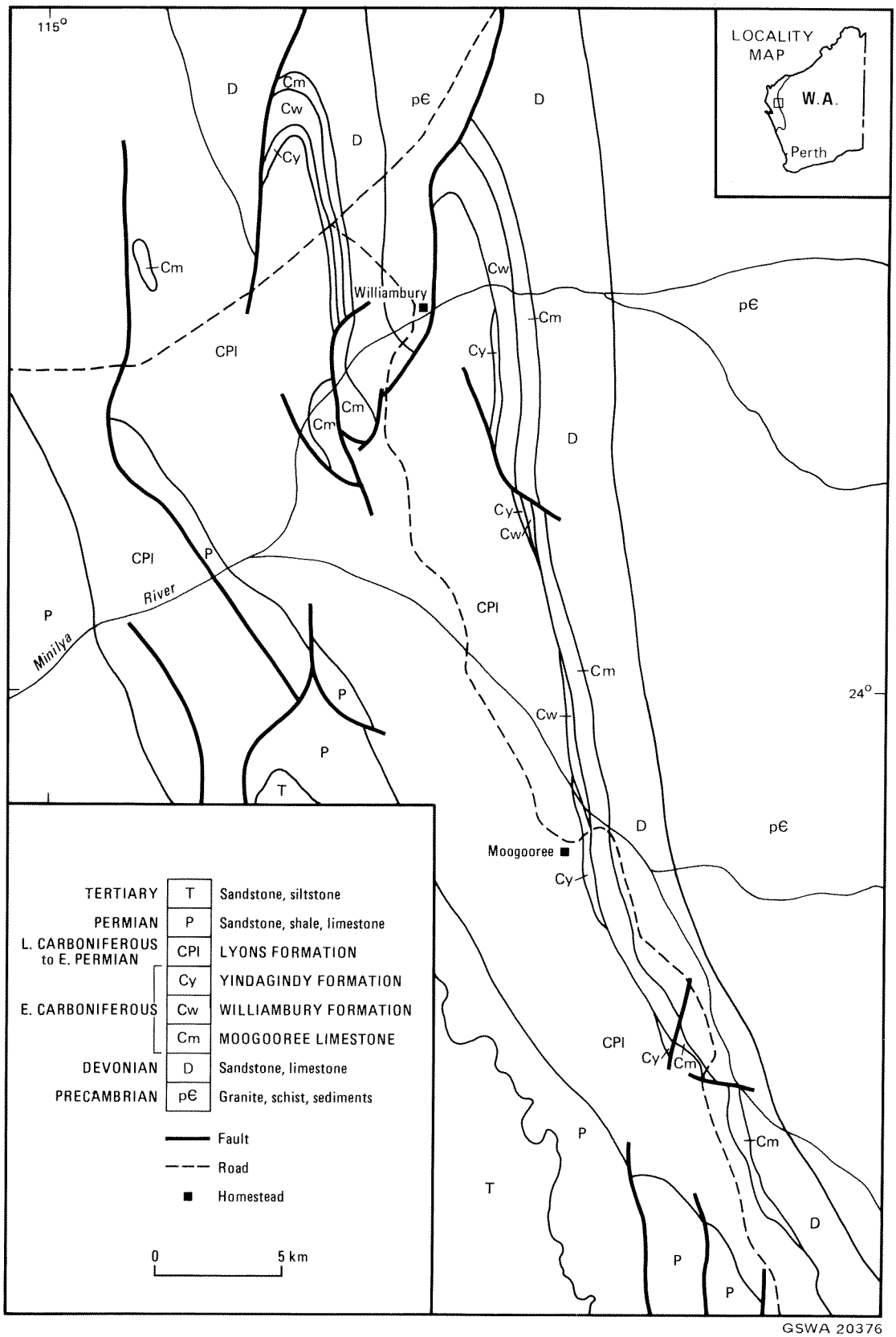

Figure 4. Carnarvon Basin, solid geology of the Williambury Moogooree area (after Hocking, Williams, Lavaring and Moore, 1983; and Hocking, Williams, Moore, Denman and Lavaring, 1983).

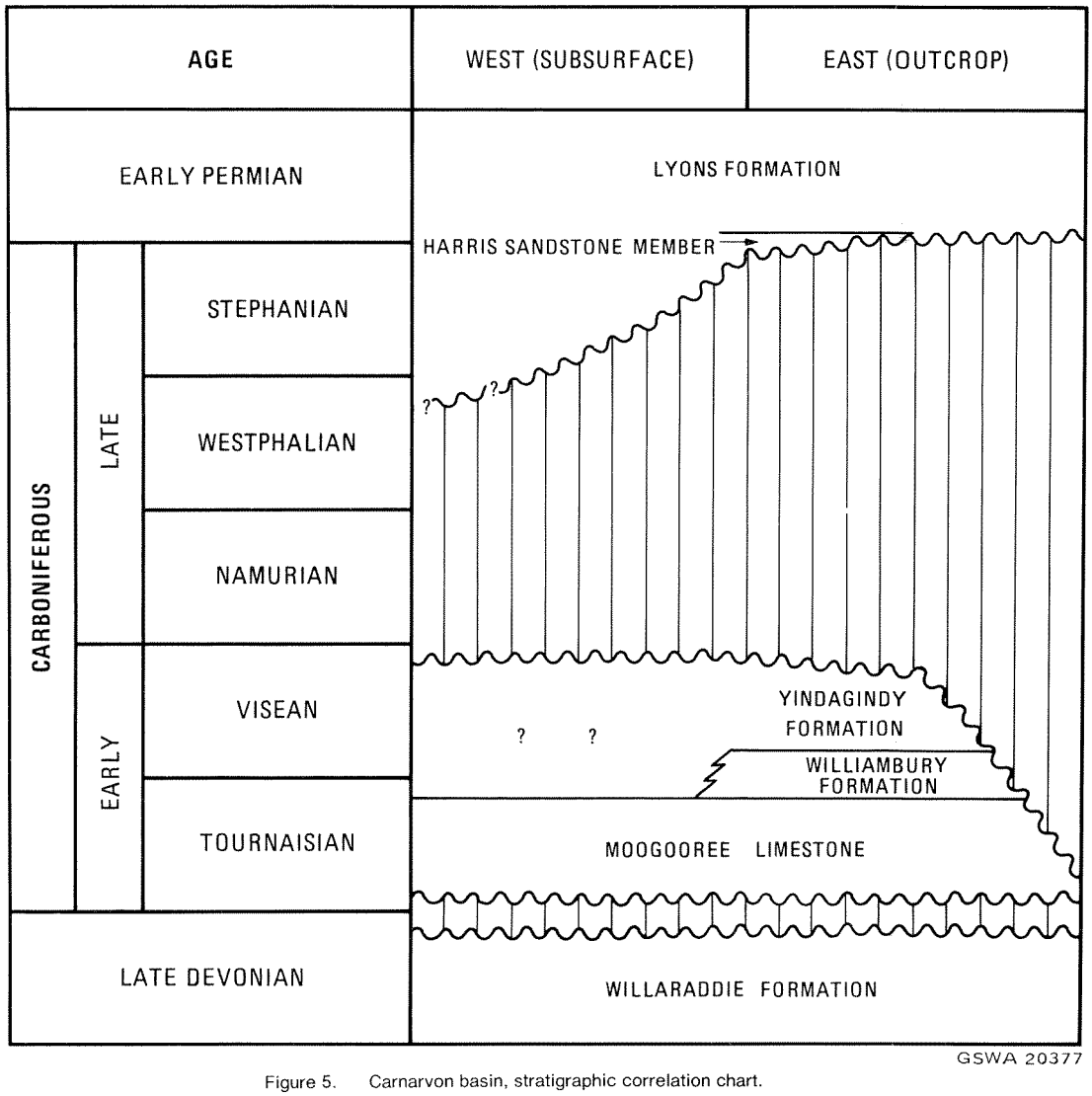

Figure 5. Carnarvon basin, stratigraphic correlation chart.

(Fig. 4), some 180 km northeast of Carnarvon. They are (in ascending order) the Moogooree Limestone, Williambury Formation, Yindagindy Formation and the Lyons Formation which continues into the Early Permian (Fig. 5). Only the Moogooree Limestone and the Lyons Formation can be confidently recognized in the subsurface. The maximum thickness of Carboniferous rocks exceeds 1 000m.

STRATIGRAPHY

Moogooree Limestone

The Moogooree Limestone (Teichert, 1949; Condon, 1954) is a sequence of calcarenite with some quartz sandstone and dolomite which overlies the Devonian Willaraddie Formation (possibly disconformably) and is overlain conformably by the Williambury Formation or unconformably by the Lyons Formation. The type section is 4 km northwest of Gneudna Well and is 326 m thick. The formation is exposed in a series of fault-controlled synclines around Williambury homestead and extends some distance south of Moogooree homestead. The unit is widespread in the subsurface of the northern Carnarvon Basin, and occurs in Pendock 1, Quail 1 and East Marrilla 1. The Moogooree Limestone was deposited in a near-shore shallow-marine environment (Lavaring, 1979) which at times may have been evaporitic (Radke an Nicoll, 1981).

The formation is richly fossiliferous. In the upper part of the unit the fossils are silicified and chert nodules are common. The most abundant fossils are brachiopods including *Prospira* aff. *laurelensis*, *Unispirifer fluctuosus*, *Syringothyris spissus* and *Rhipidomella michelini?* (Glenister, 1956; Thomas, 1962b, 1971; Veevers, 1959b; Lavering, 1979). Other fossils include the corals *Syringopora* and *Palaeacis*, ostracods, bivalves, gastropods, bryozoans, crinoid columnals and stromatolites. Thomas (1971) considered the fauna to belong to his *Unispirifer fluctuosus* assemblage and to be of Tournaisian age. This assemblage broadly correlates with *laurelensis*, *eqanensis* and *amnicum* zones of the Bonaparte Basin (Roberts, 1971) which on conodont evidence are of middle Tournaisian age (Druce, 1969).

Williambury Formation

The Williambury Formation ("Williambury Sandstone" of Teichert, 1949; emended Condon, 1954) is a sequence of sandstone, commonly conglomeratic, and siltstone which lies conformably between the Moogooree Limestone below and the Yindagindy Formation above. In some areas it is overlain unconformably by the Lyons Formation. The unit is poorly exposed between Williambury and Moogooree homesteads. The type section is in Gneudna paddock, 4 km southeast of Williambury homestead and is 235 m thick. Condon states that the maximum thickness is 338 m.

The Williambury Formation is of fluvial origin and formed as an alluvial fan centred on the Williambury area (Hocking, Williams, Lavaring and Moore, 1983). No fossils are known from the formation but it is probably Lower Carboniferous from its stratigraphic position.

Yindagindy Formation

The Yindagindy Formation ("Yindagindi Limestone" of Teichert, 1950; emended Condon, 1954) is a unit of coarse-to medium-grained sandstone with thin interbeds of oolitic and algal limestone which conformably overlies the Williambury Formation and is overlain disconformably by the Lyons Formation. The formation is named after Yindagindy Creek and the type section is 4 km west of Williambury homestead. This section is 76 m thick and the maximum thickness of the unit is about 115 m (Condon, 1965). The formation crops out between Williambury and Moogooree homesteads, generally with very poor exposure.

Some of the limestone beds are richly fossiliferous but the shells are difficult to extract. The fossils identified include brachiopods (e.g. *Camarotoechia* sp. and *Composita variabilis;* Thomas, 1962b, 1971), ostracods, bryozoans, gastopods, serpulid worms, crinoid columnals and stromatolites (Thomas, 1962b). Thomas (1971) considers that the brachiopods suggest a Visean age. However, in the Bonaparte and Canning Basins the highest unit beneath the major unconformity extends into the early Namurian and the Yindagindy Formation could be Visean to early Namurian in age. The unit was deposited in shallow-marine conditions with the sandy interbeds suggesting intermittent terrigenous sedimentation (Hocking, Williams, Lavaring and Moore, 1983).

Lyons Formation

The Lyons Formation ("Lyons Conglomerate" of Maitland, 1912; "Lyons Group" of Teichert, 1950; emended to Lyons Formation by van de Graaff and others, 1977) is a unit of feldspathic wacke with minor siltstone, conglomerate, limestone, calcareous sandstone, tillite and varved shale. The type section is on the north side of the Wyndham River, some 200 km east of Carnarvon and is about 1 125 m thick (Condon, 1967). The formation unconformably overlies the underlying Carboniferous and older rocks and is conformably overlain by the Callytharra or Carrandibby Formations. It crops out extensively in the eastern Carnarvon Basin and occurs in the subsurface of the northern part of the basin. The maximum known thickness is more than 2 300 m in Remarkable Hill 1. This figure includes the 850 m of "Permo-Carboniferous" clastic sediments originally excluded from the Lyons Formation by Berven (1969). At the base of the formation there is a discontinuous basal sandstone, the Harris Sandstone Member (here taken to include the Austin Member) which locally contains boulder beds, ice-drag striae and lepidodendroid plant remains.

The Lyons Formation was deposited in marine and fluvial environments under glacial conditions. It contains microfloras belonging to Unit I (in East Marilla 1; Dolby in Osborne, 1972) and Unit II (Kemp and others, 1977) and is of Late Carboniferous and Early Permian age. The macrofossils are all Sakmarian (Dickins and Thomas, 1959). Archbold (1982) considers the upper part of the formation to be early Sakmarian (Tastubian) in age, rather than late Asselian as suggested by Waterhouse (1976).

Subsurface Carboniferous rocks

Clastic rocks of Carboniferous or probable Carboniferous age have been encountered in Quail 1, Gnaraloo 1, Warroora 1, Rough Range 1, Minderoo 1, Cane River 1 and Yarraloola 1 drilled in the northern Carnarvon Basin. Palaeontological control is very poor.

The sequence in Quail 1 may be taken as typical (Pearson,1964). Here 67 m of siltstone rests on 285 m of sandstone. These rocks are underlain (probably conformably) by the Moogooree Limestone and are overlain (unconformably?) by the Lyons Formation and may correlate with clastic sediments in Rough Range 1, Warroora 1 and Minderoo 1. The microflora in Quail 1 is probably of Early Carboniferous age (B. E. Balme, pers. comm., 1981). In Minderoo 1 the section was originally dated as Late Carboniferous (Edgell *in* Johnstone and others, 1963) on the basis of a microflora that is now thought to be late Early Carboniferous in age (Balme *in* Hematite Petroleum Proprietary Ltd, 1972). The clastic unit in these four wells probably correlates with the Williambury and Yindagindy Formations.

STRUCTURE

The carboniferous rocks are exposed in three north-trending belts in the latitude of Williambury. The threefold repetition is interpreted as being due to faulting (Condon, 1954; Teichert, 1957; Thomas, 1962b).

GEOLOGICAL HISTORY

A shallow sea transgressed the northern Carnarvon Basin in the Early Carboniferous. Terrigenous input was small and carbonate rocks (Moogooree Limestone) were deposited. The sea was extremely shallow in the east, and near-shore (at times intertidal) sedimentation took place. Very little clastic sedimentation occurred at first but somewhat later an alluvial fan (Williambury Formation) formed in the Williambury area. Towards the close of the Early Carboniferous, mixed carbonate and clastic deposition was re-established (Yindagindy Formation) with intertidal and terrigenous sedimentation in the east and shallow-water clastics probably extending over most of the northern Carnarvon Basin. The sea withdrew, at least from the east part of the basin, for much of the Late Carboniferous. It returned in the late Late Carboniferous with glacial-marine sedimentation (Lyons Formation) which continued into the Permian.

CANNING BASIN

In the Canning Basin Carboniferous rocks crop out on the Lennard Shelf and occur in the subsurface in the Fitzroy Trough, Kidson Sub-basin and Lennard Shelf (Fig. 6). The Carboniferous sequence consists of the Fairfield Group, which extends into the Upper Devonian, the Anderson Formation, and the Grant Group, which passes up into the Lower Permian (Fig. 7). In parts of the Fitzroy Trough deposition was probably continuous but in most sections there is an unconformity at the base of the Grant Group. The exposed Carboniferous rocks are assigned to the Fairfield Group; the Anderson Formation and the Carboniferous part of the Grant Group do not crop out. The solid geology of the main areas of Carboniferous exposure is shown in Figure 8.

STRATIGRAPHY

Fairfield Group

The Fairfield Group ("Fairfield Formation" of Playford and Lowry, 1966; raised to group status by Druce and Radke, 1979), consisting of limestone, siltstone, shale and sandstone, overlies the Devonian reef complexes (apparently conformably) on the Lennard Shelf or the Luluigui Formation in the Fitzroy Trough and is overlain, probably conformably, by the Anderson Formation. Company seismic data from the Lennard Shelf indicate the possibility of an angular unconformity within or at the top or the Fairfield Group. The unit straddles the Devonian-Carboniferous boundary and comprises the Gumhole Formation at the base, the Yellow Drum Sandstone, and the Laurel Formation. The geology of the group has been summarized by Druce and Radke (1979) who also discuss the complex history of the term "Fairfield".

Gumhole Formation

The Gumhole Formation (Druce and Radke, 1979) consists of limestone, siltstone, shale and sandstone with minor dolomite. The type section is on the Great Northern Highway 19 km west-northwest of Fitzroy Crossing and 1.5 km southeast of Gumhole bore and is 70 m thick. The formation is over 200 m thick in the Fitzroy Trough. The Gumhole Formation conformably overlies the Nullara Limestone in the Horseshoe Range, at Red Bluffs, and in many wells on the Lennard Shelf; elsewhere it probably overlies the Luluigui Formation. The formation crops out in the Fairfield Valley, Oscar Range, Horseshoe Range, and Red Bluffs area, and occurs in the subsurface in the Lennard Shelf and Fitzroy Trough.

The Gumhole Formation contains a rich fauna of brachiopods (Veevers, 1959a), bryozoans (Ross, 1961), corals (Hill and Jell, 1971), condonts (Nicoll and Druce, 1979), ostracods (Jones, *in* Veevers and Wells, 1961) and spores (Balme and Hassell, 1962; Playford, 1976). The conodonts and spores suggest a late Famennian age (Druce and Radke, 1979), do V and do VI according to Nicoll and Druce (1979).

Yellow Drum Sandstone

The Yellow Drum Sandstone (Druce and Radke, 1979) is a unit of calcareous sandstone and silty dolomite with minor shale that lies stratigraphically between the Gumhole Formation and the Laurel Formation, probably conformably although the upper and lower contacts are nowhere exposed. The type section is 1 km northeast of Yellow Drum bore (25 km west-northwest of Fitzroy Crossing) where the formation is about 70 m thick (including 69 m penetrated in BMR Noonkanbah 4 drilled at the type section). The maximum thickness is 327 m in Napier 1 between 333 and 660 m. The Yellow Drum Sandstone outcrops mainly in the area of the type section but occurs extensively in the subsurface of the Lennard Shelf and Fitzroy Trough.

The biota consists predominantly of microfossils-ostracods, conodonts and spores. Conodont evidence suggests that the formation is latest Famennian (do VI, Tnla) to earliest Tournaisian (Tnlb) in age (Nicoll and Druce, 1979). The unit is diachronous, being almost entirely Famennian in Napier 1 and Tournaisian (Tnlb)in Meda 1, both on the Lennard Shelf and straddling the Famennian-Tournaisian boundary in the Fitzroy Trough (Druce and Radke, 1979).

Laurel Formation

The Laurel Formation ("Laurel Beds" of Thomas, 1957; Laurel Formation of Thomas, 1959) consists of interbedded limestone, shale, siltstone, sandstone and minor dolomite.The type area is near Twelve Mile

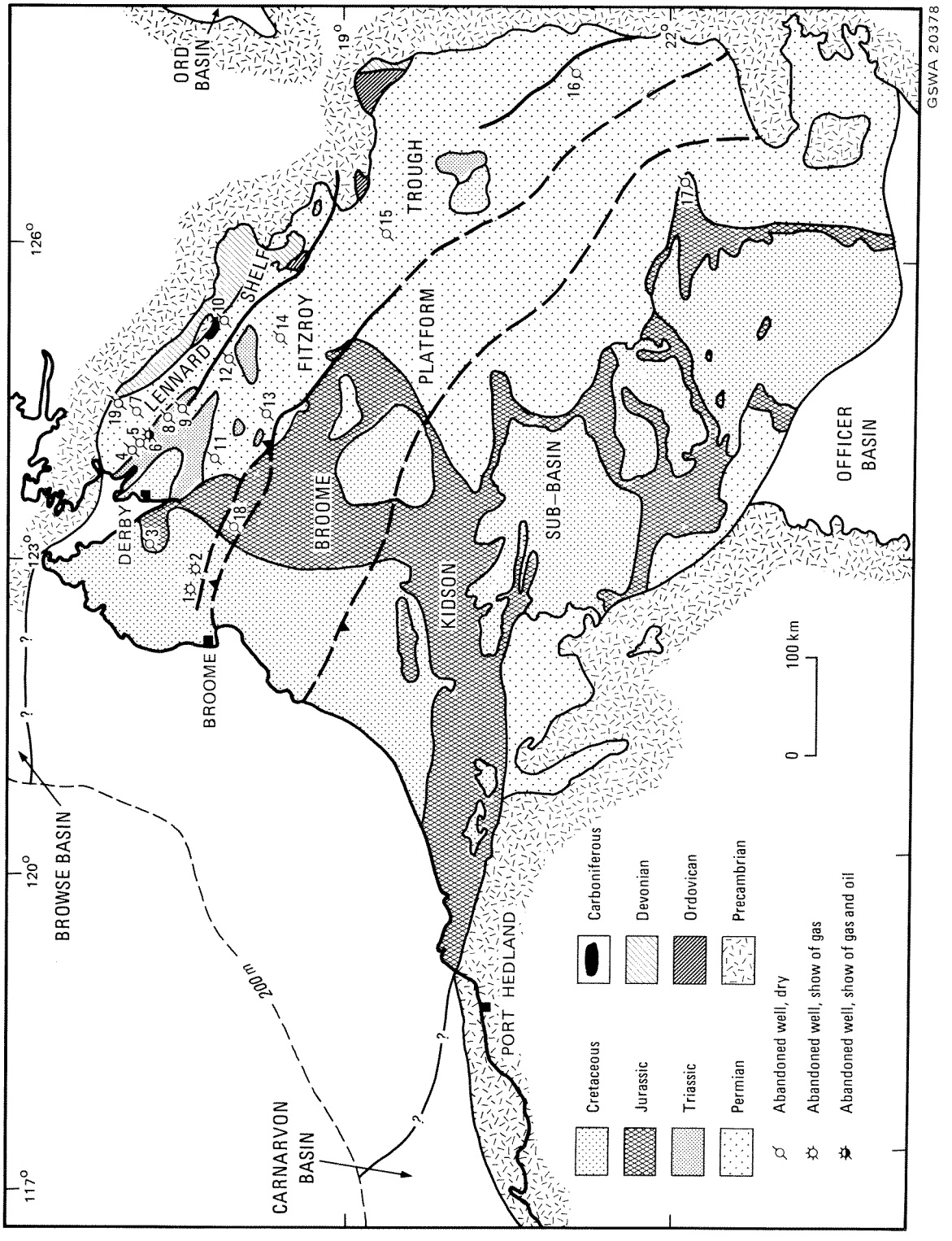

Figure 6. Canning Basin, showing solid geology and position of principal oil-exploration wells encountering Carboniferous rocks (after Playford and others, 1975). 1. Barlee 1; 2. Yulleroo 1; 3. Fraser River 1; 4. May River 1; 5. Langoora 1; 6. Meda 1 and 2; 7. Hawkstone Peak 1; 8. Blackstone 1; 9. Sisters 1; 10. BMR Noonkanbah 2 (formerly Laurel Downs 2); 11. Grant Range 1; 12. Mount Hardman 1; 13. Nerrima 1; 14. St George Range 1; 15. Lake Betty 1; 16. Point Moody 1; 17. Wilson Cliffs 1; 18. Logue 1; 19. Napier 1.

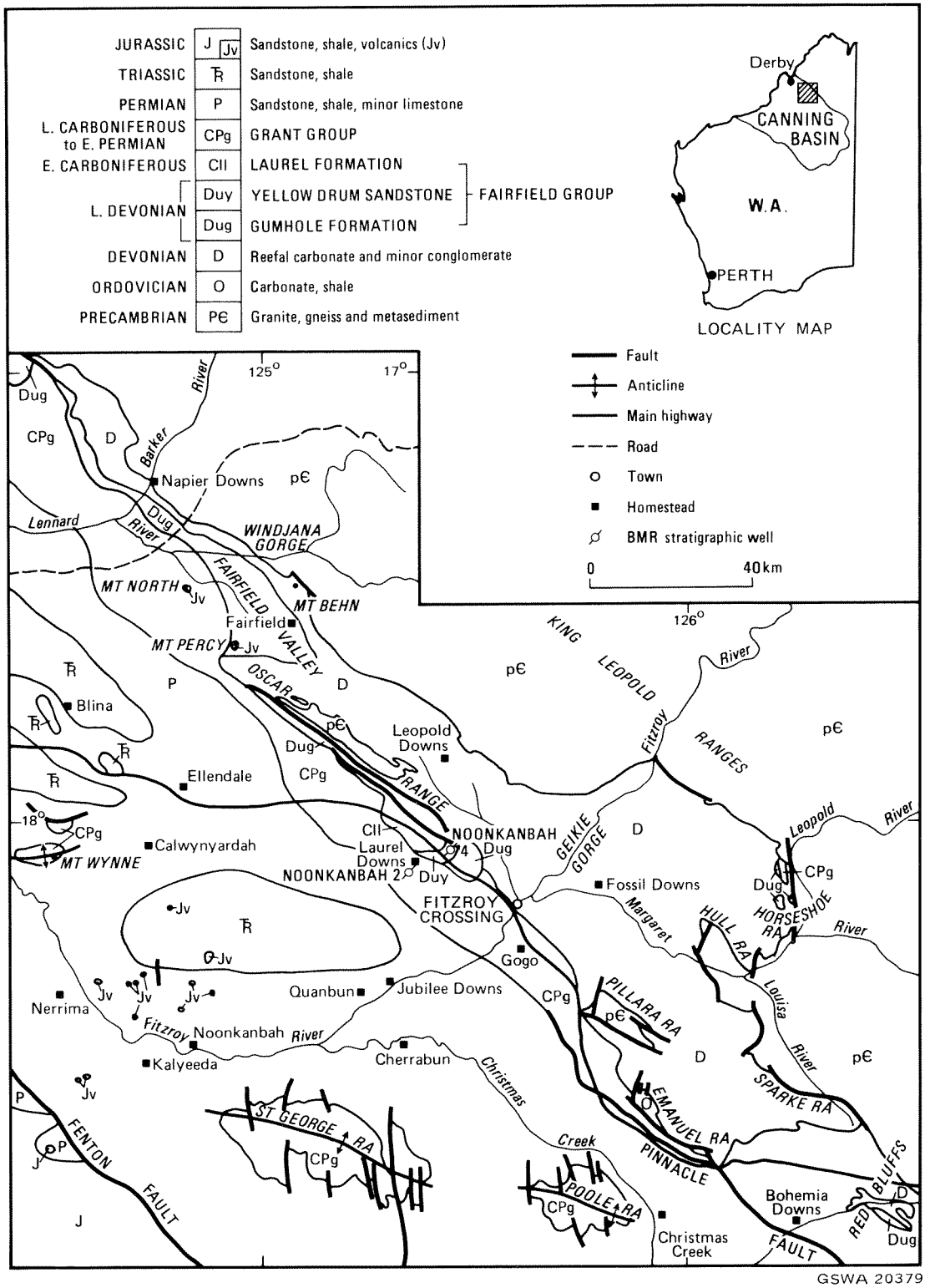

Figure 7. Canning Basin, solid geology of part of the northern Canning Basin (after Playford and Lowry, 1966; Druce and Radke, 1979).

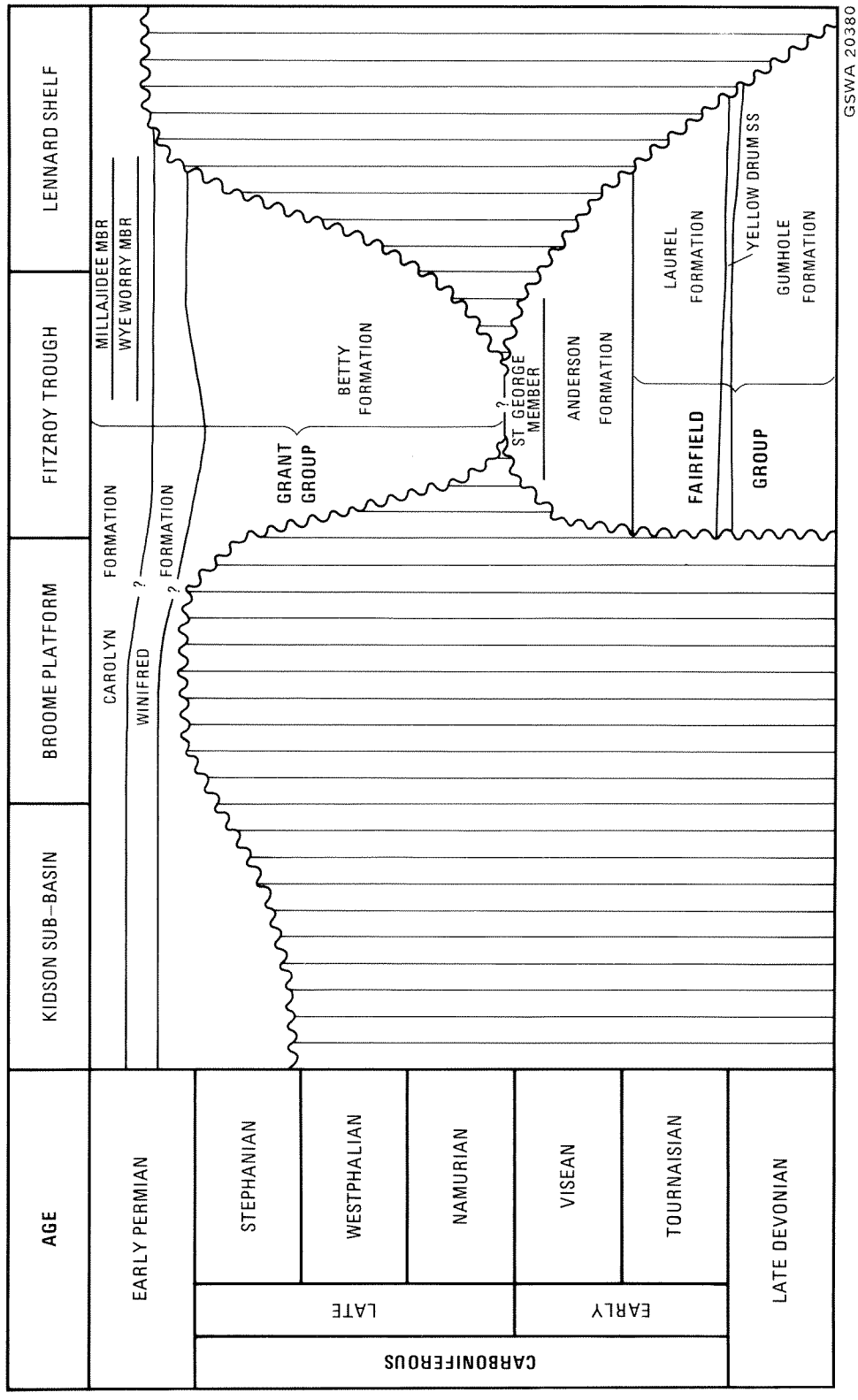

Figure 8. Canning Basin, stratigraphic correlation chart.

Bore, some 45 km northwest of Fitzroy Crossing, and the formation is named after the nearby Laurel Downs pastoral station. Thomas (1959) chose two type section near Twelve Mile Bore and estimated the total thickness to be 455 m. However, Druce and Radke (1979, p.24) measured 386 m but consider the 357 m penetrated in BMR Noonkanbah 2 as a "... more realistic figure than either of the thicknesses measured from surface outcrop". The formation conformably overlies the Yellow Drum Sandstone and is conformably overlain by the Anderson Formation in the subsurface.

The Laurel Formation is predominantly calcareous in the lower part and shaly in the upper part, and on this basis two unnamed members may be recognized.The lower limestone member has its maximum thickness (189 m) in BMR Noonkanbah 2 between 244 and 433 m, and the upper shale member reaches its greatest thickness (667 m) in Lake Betty 1 from 1 808 to 2 475 m. The formation outcrops mainly in front of the Oscar Range and is widespread in the subsurface of the Lennard Shelf and Fitzroy Trough.

Numerous fossils occur in the Laurel Formation including brachiopods (Veevers, 1959b; Thomas, 1971) which suggest a correlation with the *teicherti, aquila, laurelensis, eganensis* and *amnicum* zones of the Bonaparte Basin (Roberts, 1971), conodonts (Nicoll and Druce, 1979), spores of the *Grandispora spiculifera* Assemblage (Playford, 1976; Kemp and others, 1977); bryozoans, corals, bivalves, ostracods and fish also occur (Druce and Radke, 1979). The Laurel Formation conodonts are assigned to the upper part of the *Clydagnathus gilwernensis*, Apparatus A, *Spathognathodus canningensis* and *Bispathodus spinulicostatus* assemblage zones which are Tournaisian (Tnlb to Tn3) in age (Nicoll and Druce, 1979).

Anderson Formation

The Anderson Formation (McWhae and others, 1958) is a subsurface unit of interbedded sandstone, siltstone and shale, with minor limestone, dolomite and anhydrite, which overlies the Fairfield Group, probably conformably, and is overlain, usually unconformably, by the Grant Group. The type section is in Grant Range 1 from 2 408 to 3 936 m (total depth), a thickness of 1 528 m, and the formation is named after Mount Anderson. The formation occurs in the Fitzroy Trough and on the Lennard Shelf.

In Yulleroo 1, the Anderson Formation occurs from 1 060 to 3 409 m, which represents the maximum known thickness (2 349 m). Between 1 060 and 1 871 m Bischoff (1968) recognized a "Unit B". This is a continental unit of multicoloured red and green shale and kaolinitic sandstone with a minor amount of coal, which is present in several wells drilled in the Fitzroy Trough. It was encountered in St George Range 1 between 1 518 and 2 487 m where it was named the "St George Formation" by Shannon and Henderson (1966) and was considered to unconformably overlie the Anderson Formation. However, regionally the base of the unit appears to be conformable and it is best to regard the multicoloured beds as a member of the Anderson Formation confined to the Fitzroy Trough.

The Anderson Formation was deposited under paralic to continental conditions. The fossils include foraminifers, fish remains, bivalves, conchostracans, ostracods, conodonts and plant microfossils. Conodonts in Yulleroo 1 suggest a ?Tournaisian to Visean age for the formation. On palynological evidence, Dolby (*in* Broad and McDermott, 1974) dates samples from the Anderson Formation as ?late Tournaisian to Visean. The bulk of the formation is probably Visean. The lower part may extend into the Tournaisian and interfinger with the Laurel Formation. In Yulleroo 1 the formation is overlain by the Betty Formation ("Unit A" of Bischoff, 1968), the lowermost beds of which contain late Visean to early Namurian conodonts (Bischoff, 1968). Sedimentation may, therefore, have been continuous in the deeper parts of the Fitzroy Trough.

Grant Group

The Grant Group ("Grant Range Beds" of Talbot, *in* Blatchford, 1927 and Woolnough, 1933; "Grant Formation" of Guppy and others, 1958; raised to group status by Crowe and Towner, 1976b) is a unit of sandstone, conglomerate, siltstone, shale, tillite and minor varved shale which overlies the Anderson Formation, usually unconformably, and is overlain with minor disconformity by the Poole Sandstone. The group is Namurian to Sakmarian in age.

The Grant Group is widely distributed through the Canning Basin and has been encountered in most exploratory wells drilled to date. The base is one of the strongest and most widespread unconformities in the basin; and, in different areas, the group rests on Carboniferous, Devonian, Ordovician, or Precambrian rocks. Three units have been recognized in the subsurface in oil-exploration wells. These units were given formation status by Crowe and Towner (1976b) and in Table 1 their nomenclature is correlated with the informal units of other authors.

TABLE 1:
NOMENCLATURE OF UNITS
OF THE GRANT GROUP

Young and O'Shaugnessy, 1973	Crowe and Towner, 1976a	Crowe and Towner, 1976b
"Binda Member"	"Upper Sandstone Unit"	Carolyn Formation
"Dora Shale Member"	"Middle Shale Unit"	Winifred Formation
"Cuncudgerie Sandstone Member"	"Lower Sandstone Unit"	Betty Formation

The Carboniferous-Permian boundary corresponds approximately to the top of the Betty Formation.

Betty Formation

The Betty Formation (Crowe and Towner, 1976b) consists of medium- to coarse-grained sandstone with minor mudstone and conglomerate. It is rarely glauconitic or carbonaceous and frequently contains lithic fragments. The type section is in Lake Betty 1 between 1 058 and 1 657 m where it is conformably overlain by the Winifred Formation and disconformably overlies the Laurel Formation. It is thickest in the Fitzroy Trough where it reaches 1 713 m in Grant Range 1, and occurs throughout the Kidson Sub-basin. Towards the margin of the Canning Basin the Betty Formation is overlapped by higher units of the Grant Group and is not known to crop out. The sequence is probably glacial-marine in origin, at least in part.

Marine fossil fragments occur in Wilson Cliffs 1 (Creevey, 1969); and conodonts, ostracods, and foraminifers occur in Yulleroo 1 in "Carboniferous Unit A", which is here placed in the Betty Formation (Bischoff, 1968). Elsewhere, only palynomorphs are recorded from the formation. In the Fitzroy Trough, the base of the formation contains late Visean to early Namurian conodonts in Yulleroo 1 (Bischoff, 1968); and the Namurian *Grandispora maculosa* Assemblage is present in Fraser River 1 and Grant Range 1 (Playford and Powis, 1979). The oldest Betty Formation on the Lennard Shelf is in Blackstone 1 where the *Spelaeotriletes ybertii* Assemblage is recorded (Playford and Powis, 1979). On the Broome Platform (e.g. McLarty 1, Crosslands 2), Unit I is absent; and the oldest rocks are Unit II in age (Powis, 1979). The upper limit of the Betty Formation is diachronous. In Lake Betty 1 (Williams and Dolby, *in* Crank, 1972), Blackstone 1 (Balme, *in* Johnson, 1968) and Kidson 1 (Powis, 1979), the highest strata contain a Unit II microflora. In Logue 1, a sample just above the base of the overlying Winifred Formation is assigned to Unit I by Dolby (*in* Meath and Scott, 1972). Hence the top of the Betty Formation crosses the Carboniferous-Permain boundary.

Winifred Formation

The Winifred Formation (Crowe and Towner, 1976b) is a sequence of dark-grey mudstone with minor fine-grained sandstone and lenses of coal and limestone. The type section is at lat. 22°52′40″S, long.123°36′20″E near Lake Winifred and is 19 m thick. The base is not exposed and the unit is unconformably overlain by the (Cretaceous) Anketell Sandstone. At a nearby outcrop the formation lies conformably between the Paterson Formation below and the Carolyn Formation above. Crowe and Towner (1976b) nominated a subsurface reference section in Kidson 1 between 815 and 1 070 m. The formation is widespread through the basin and is usually readily recognizable in the subsurface.

Unidentified bryozoan, crinoid and echinoid fragments occur in the formation in Sahara 1 (Singleton, 1965) and trace fossils are found at the type section (Crowe and Towner, 1976b). Spores and pollen from oil-exploration wells indicate that the formation contains microfloral assemblages from Units I, II, and III. In the central part of the Fitzroy Trough (Logue 1), the formation correlates with Units I and II (Dolby *in* Meath and Scott, 1972). In other parts of the Trough, for example Lake Betty 1 (Williams and Dolby *in* Crank, 1972), and on the Lennard Shelf, for example Blackstone 1 (Balme *in* Johnson, 1968), only Unit II microfloras are recorded. However, in the Kidson Sub-basin (Kidson 1) and on the Broome Platform (McLarty 1, Crossland 2) the Winifred Formation contains Units II and III microfloral assemblages (Powis, 1979) and is younger than in the Fitzroy Trough and Lennard Shelf. It is not clear whether the Winifred Formation in the Fitzroy Trough and Lennard Shelf is the same mappable unit as that in the Kidson Sub-basin and Broome Platform or is a different, slightly older unit. For the present the formation is retained as a diachronous unit.

Carolyn Formation

The Carolyn Formation (Crowe and Towner, 1976b) is a unit of meduim-grained quartz arenite and quartz wacke with some shale and conglomerate. The type section is at the western end of the St George Range near Carolyn Valley and consists of two sections with an aggregate thickness of about 140 m. The formation is overlain uncomformably by the Poole Sandstone and rests conformably on the Winifred Formation, although the contact is nowhere exposed. The maximum thickness is 415 m in Logue 1.

The Carolyn Formation occurs throughout the Canning Basin except where removed by erosion. It is the only unit of the Grant Group that outcrops on the northern and eastern parts of the basin and all the rocks in this region formerly mapped as "Grant Formation" are now placed in the Carolyn Formation.

Crowe and Towner (1976a) have recognized two members at the top of the formation, the Wye Worry Member of tillitic conglomerate and siltstone and claystone, sometimes varved, and the overlying Millajiddee Member which is mainly sandstone.

Marine shells of Sakmarian age, together with trace fossils, occur in the Wye Worry Member (Crowe and Towner, 1976a; Dickins and others, 1977). Plant fragments including *Glossopteris* are known, and palynomorphs of Units II and III have been recovered from subsurface samples, for example in Blackstone 1 (Balme *in* Johnson, 1968). On the basis of these plant microfossils the formation is dated as Sakmarian.

Sandstone at Red Bluffs

A sandstone unit in the Red Bluffs area (referred to as the Bohemia Downs area by Playford and others, 1975) unconformably overlies the Gumhole Formation and the Nullara Limestone and was mapped as Permian "Grant Formation" by Playford and Lowry (1966). However, Veevers and others (1967) believe that it is of Early Carboniferous age, based on its stratigraphic position above Famennian rocks and on the occurrence of *Leptophloem australe*, which is supposed to be restricted to the Famennian and Tournaisian (Hill and Woods, 1964). B.E. Balme (pers. comm., 1981) points out that in South Africa the species is known from the Dwyka Tillite (*see* Plumstead, 1969 *for details*) which Truswell (1980) correlates with Stage 2 of the eastern Australian palynological zonation; this broadly equates with Unit II which is Early Permian. It is possible that the unit should be correlated with the Anderson Formation but in mapping, it has not been possible to separate the outcrops from those included in the Carolyn Formation. Provisionally, the Red Bluffs outcrops are considered to belong to the Grant Group.

STRUCTURE

The Canning Basin is not strongly faulted and the principal faults are those bounding the Fitzroy Trough. These are the Pinnacle Fault System on the northeast and the Fenton Fault on the southwest, both of which have a throw of up to 6 000 m. The Carboniferous rocks outside the Fitzroy Trough are comparatively undeformed. In the trough, they are folded into a series of en echelon anticlines trending at about 100°—Mt Wynne, St George Range and Poole Range Anticlines are examples of these folds. Most of the anticlines are cut by north-trending normal faults which are usually small, although some have displacements of as much as 300 m. The folds and their associated faults are believed to have resulted from regional right-lateral wrenching movements (Rattigan, 1967; Smith,1968) and the main period of folding may have been in the Jurassic.

GEOLOGICAL HISTORY

A considerable thickness of sediments was deposited in the Fitzroy Trough where there was contemporaneous movement along the bounding faults throughout the Carboniferous. Marine sedimentation, probably under tropical conditions, continued from the Late Devonian into the Early Carboniferous in both the Fitzroy Trough and Lennard Shelf (Fairfield Group) with a deepening of the trough in the early Tournaisian. Shallowing took place in the Visean with conditions gradually changing to paralic (lower part of Anderson Formation) and continental (St George Member). Deposition probably continued into the Namurian in the trough; and estuarine and intermittent marine conditions were re-established (lowest part of Betty Formation). On the Lennard Shelf and Broome Platform, erosion took place. The trough continued to subside, and sedimentation occurred on the edge of the Lennard Shelf and spread over the Kidson Sub-basin. Glacial conditions were established, both marine and continental (Betty Formation) in the Late Carboniferous, probably waned in the earliest Permian (Winifred Formation), and returned in the late Early Permian (Carolyn Formation).

BONAPARTE BASIN

Carboniferous rocks are exposed in the southeast and centre of the onshore part of the Bonaparte Basin in Western Australia (Figs 9, 10). The basin consists of a northern basinal area and a southern marginal shelf area which is divided into eastern and western parts by the Precambrian Pincombe Range Inlier. The basinal sequence consists (in ascending order) of the Bonaparte, Tanmurra and Keep Inlet Formations. On the western shelf the sequence includes the Milligans Formation, Utting Calcarenite, Waggon Creek Formation, Burvill Formation, Point Spring Sandstone and Keep Inlet Formation. The most complete Carboniferous section is on the eastern shelf and comprises (from the Base) the Burt Range Formation, Enga Sandstone, Septimus Limestone, Zimmerman Sandstone, Milligans Formation, Burvill Formation, Point Spring Sandstone and Keep Inlet Formation (Fig. 11). A solid geology sketch map is given in Figure 10. The total thickness of Carboniferous sediments in the basin exceeds 2 000 m.

STRATIGRAPHY

Burt Range Formation

The Burt Range Formation ("Burt Range Series" of Matheson and Teichert, 1948; "Burt Range Limestone" of Noakes and others, 1952, amended Veevers and Roberts, 1968) consists of olive-grey to olive-brown calcarenite grading to sandy calcarenite and sandstone in the upper part. It crops out on the shelf area east of the Pincombe Range inlier where it

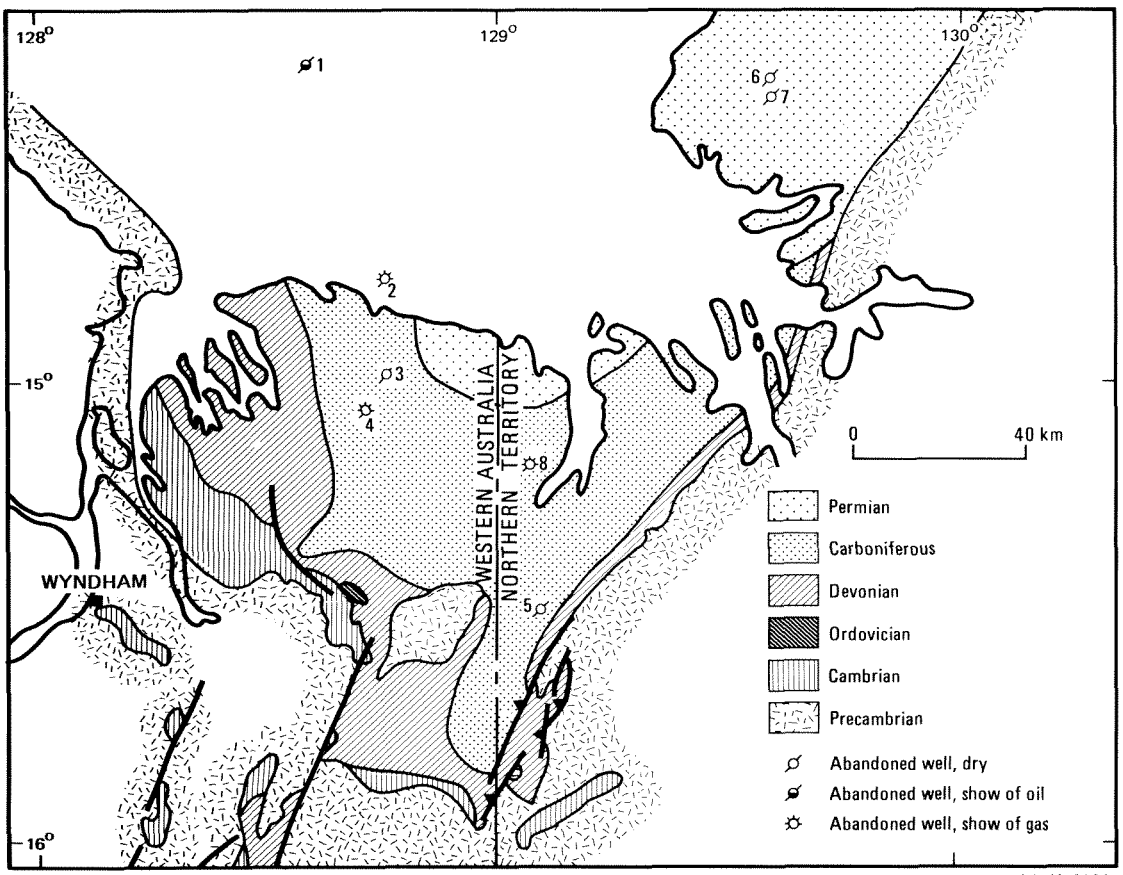

Figure 9. Bonaparte Basin, showing solid geology and position of principal oil-exploration wells encountering Carboniferous rocks (after Playford and others., 1975). 1. Lacrosse 1; 2. Pelican island 1; 3. Bonaparte 1; 4. Bonaparte 2; 5. Spirit Hill 1; 6. Kulshill 1; 7. Kulshill 2; 8. Keep River 1.

overlies the Buttons Formation disconformably and is overlain conformably by the Enga Sandstone or unconformably by the Keep Inlet Formation. The type section is situated 6 km west-southwest of Milligans Hills where the formation is 290 m thick with the top not exposed. The total thickness of the unit is believed to be about 460 m. The "Spirit Hill Limestone" of Traves (1955) was included in the Burt Range Formation by Veevers and Roberts (1968).

The formation is dated as early to middle Tournaisian, based on conodonts (Druce, 1969). Brachiopods (Roberts, 1971; Thomas, 1971) are abundant in the formation and Roberts (1971) recognized the *adunata, teicherti, aquila*, and *laurelensis* zones and part of the *eganensis* zone in the unit.

Enga Sandstone

The Enga Sandstone (Traves, 1955) is a unit of quartz sandstone with minor interbedded calcarenite, which lies conformably between the Burt Range Formation below and the Septimus Limestone above. The type section is near the middle of Enga Ridge and is 148 m thick. The top of the formation is not exposed in this section and its total thickness is estimated to be 158 m. The unit crops out at Burt Range and in the area immediately to the north.

The Enga Sandstone is dated as Tournaisian on the basis of the conodont fauna (Druce, 1969). Brachiopods (Roberts, 1971; Thomas, 1971), of the *eganensis* and *amnicum* zones, foraminifers (Mamet and Belford, 1968), gastropods and bivalves (Thomas, 1962a), bryozoans and trilobites also occur.

Septimus Limestone

The Septimus Limestone ("Mount Septimus Limestone" of Noakes and others, 1952, emended Traves, 1955) is a unit of olive-grey to brown calcarenite, sandy calcarenite and sandstone. The type section, 180 m thick, is on the northwestern flank of Mount Septimus. The formation, which crops out in the Mount Septimus—Spirit Hill area, overlies the Enga Sandstone with apparent conformity in the type area, although a slight disconformity may exist between them in some localities. The Septimus Limestone is overlain conformably by the Zimmermann Sandstone or unconformably by the Keep Inlet Formation.

The unit contains conodonts which indicate a Tournaisian age (Druce, 1969). Thomas (1962a, 1971) and Roberts (1971) have recognized a number of brachiopod assemblages in the formation. Thomas's (1962a) four faunal assemblages are now placed in the *australis* and *langfieldensis* zones and the lower part of the *spiritus* zone by Roberts (1971).

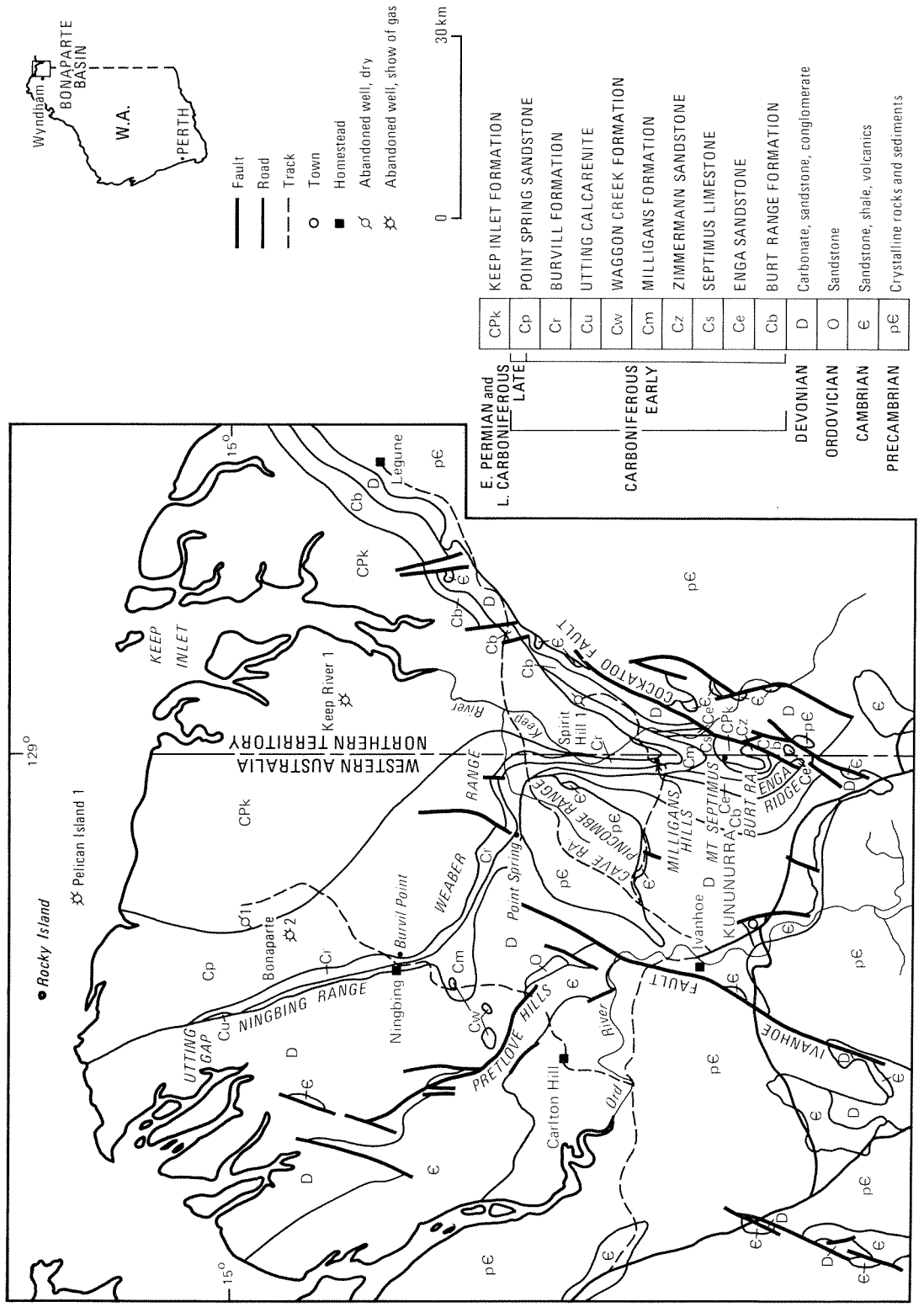

Figure 10. Bonaparte Basin, solid geology of the Carboniferous (after Veevers and Roberts, 1968; A. J. Mory and G. M. Beere pers. comm. 1982).

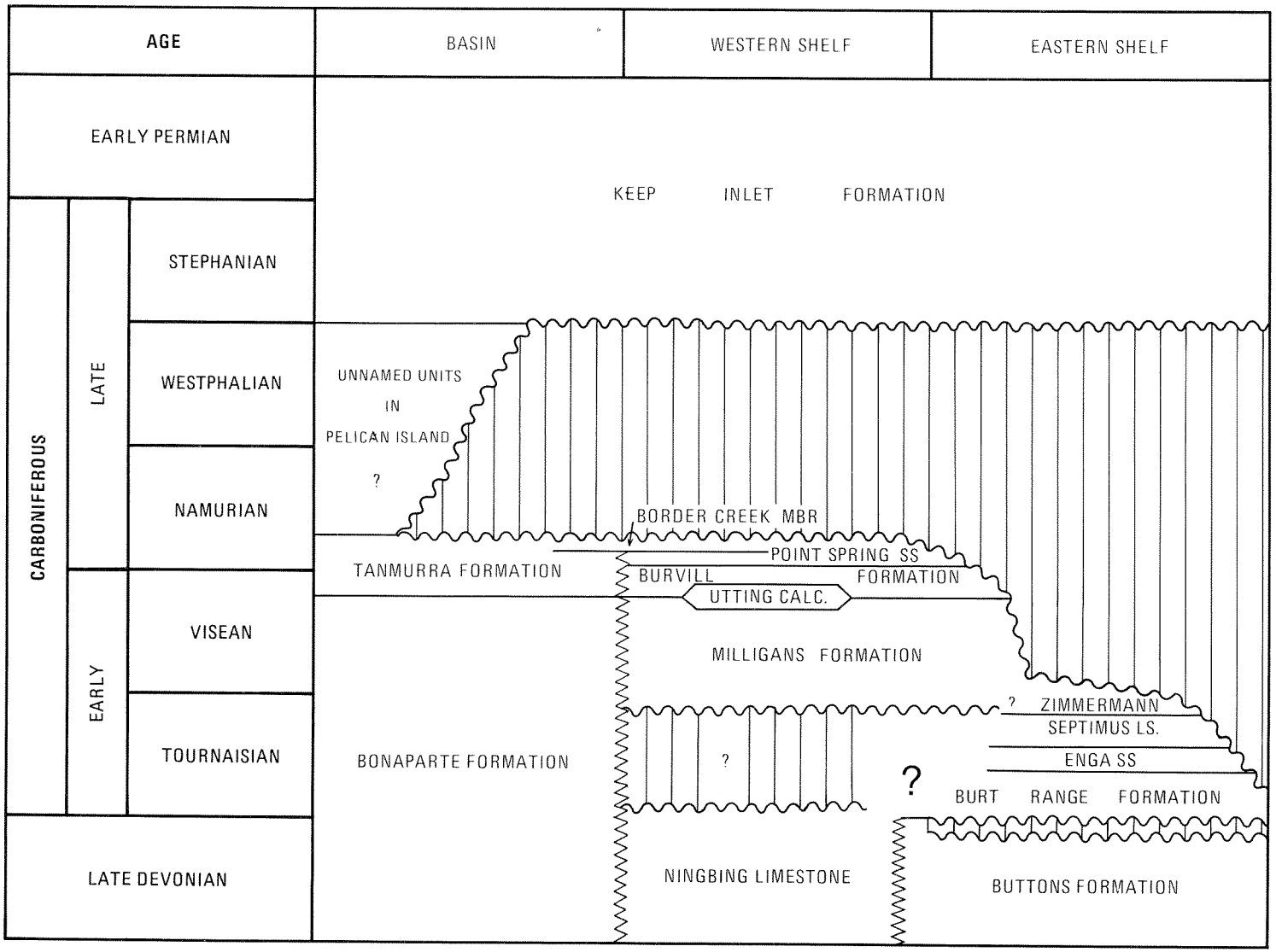

Figure 11. Bonaparte Basin, stratigraphic correlation chart.

Zimmermann Sandstone

The Zimmermann Sandstone (Veevers and Roberts, 1968) is a unit of brown to white quartz sandstone which overlies the Septimus Limestone and is overlain disconformably by the Keep Inlet Formation. The type section is at Mount Zimmermann and is 140 m thick. The formation is known only from the southern Burt Range area

The Zimmermann Sandstone is dated as late Tournaisian to early Visean by Veevers and Roberts (1968) on the basis of the brachiopod fauna, which is assigned to the *spiritus* zone (Roberts, 1971). The fauna also includes bivalves, bryozoans, and the trace fossil, *Rhizocorallium.*"

Milligans Formation

The Milligans Formation ("Milligans Beds" of Thomas, in Hare and Associates, 1961) is a unit of silty shale and siltstone which rests uncomfortably on the Burt Range Formation (in Spirit Hill 1) and is overlain probably conformably by the Burvill Formation or unconformably by the Keep Inlet Formation in the Spirit Hill area. The unit is poorly exposed around the basinward edge of the shelf area and occurs in the subsurface in the Spirit Hill and Milligans wells. The formation is a lateral equivalent of the upper part of the Bonaparte Formation. The type section is in Milligans 1 between 44 and 155 m (base not reached). In Spirit Hill 1, the unit is 252 m thick and the top is eroded. On the western shelf the formation is present (conformably?) below the Burvill Formation and (unconformably?) above the Ningbing Limestone.

Fossils in the Milligans Formation include ostracods, foraminifers, rare conodonts, echinoid fragments, bryozoans, fish scales and plant spores. The spores belong to the *Anapiculatisporites largus* assemblage (Playford, 1971: Kemp and others, 1977). The microfossils in the formation in Milligans 2 also occur in core 9 in Bonaparte 1 which is of Visean age (Veevers and Roberts, 1968); conodonts from the base of the unit are late Tournaisian in age (P. Jones and R. Nicoll, pers. comm., 1981).

Utting Calcarenite

The Utting Calcarenite (Veevers and Roberts, 1968 is a unit of grey and yellow-brown calcarenite and shale which is conformably overlain by the Burvill Formation. The nature of the contact with the adjacent Ningbing Limestone is indefinite but is probably faulted. The type section (61 m thick) and principal exposures are at Utting Gap and the total thickness of the formation is probably about 120 m. The unit is of very limited extent and is laterally equivalent to the upper part of the Milligans Formation and possibly to the lower part of the Burvill Formation.

The Utting Calcarenite contains a rich fauna of conodonts (Druce, 1969), foraminifers (Mamet and Belford, 1968), brachiopods of the *pauciplicatus* zone (Roberts, 1971), corals, echinoids, trilobites, ostracods and sharks. The foraminifers suggest an early Late Visean age for the unit (Mamet and Belford, 1968).

Burvill Formation

The Burvill Formation ("Burvill Beds" of Veevers and Roberts, 1968) is a sequence of sandstone, shale and interbedded sandy limestone that lies conformably between the Utting Calcarenite or Milligans Formation below and the Point Spring Sandstone above. The formation is exposed along the Weaber Range and at Milligans Hills. The type section is at Burvill Point 1, ½ km east of Ningbing homestead, and is 40 m thick. The thickest measured section is 85 m thick.

The formation contains a rich fossil fauna of brachiopods, gastropods, foraminifers and conodonts. The brachiopods belong to the *milliganensis-gradatus* zone which is of late Visean to early Namurian age. The conodont fauna suggests the same age (Druce, 1969) but Mamet and Belford (1968) regard the foraminifer fauna as probably latest Visean. Jones and Nicoll (pers. comm., 1981) state that the conodont faunas from the type Utting Calcarenite and from the Burvill Formation near Point Spring are time-equivalent. This could suggest that the Burvill Formation is slightly older near Point Spring than at Utting Gap. Certainly from their stratigraphic position the two formations are very close in age and there seems to be no good reason for the interzone which Roberts (1971) shows between the *pauciplicatus* and the *milliganensis-gradatus* zones.

Waggon Creek formation

The Waggon Creek Formation (Veevers and Roberts, 1968; emended Beere, 1984) consists of a lower unit of conglomerate (containing dolomite blocks), pebbly sandstone, and sandstone, overlain by a unit of sandstone and shale. The formation rests with angular unconformity on the Devonian Cockatoo Sandstone. Veevers and Roberts (1968) mapped the upper unit as Point Spring Sandstone but Beere (1984) considers it to be part of the Waggon Creek Formation. The unit is known only from the Waggon Creek area on the north side of the Pretlove Hills and is 120 m thick. It contains brachiopods of the *milliganensis-gradatus* zone and correlates with the Burvill Formation and Point Spring Sandstone.

In the same area, Veevers and Roberts (1968) recognize an unnamed breccia having the same lithology and stratigraphic position as the Waggon Creek Formation. Roberts (1971) records an

amnicum zone brachiopod fauna from these beds and Druce (1969) found abraded conodonts referred to *Clydagnathus cavusformis*, both of which suggest a mid-Tournaisian age. The relationship of this breccia to the Waggon Creek Formation is not clear. They may be different units as stated by Veevers and Roberts (1968) or they may be the same unit of late Visean to early Namurian age with reworked Tournaisian fossils as proposed by Beere (1984).

Point Spring Sandstone

The Point Spring Sandstone (Noakes and others, 1952; emended Veevers and Roberts, 1968; emended herein) is a unit of quartz sandstone, pebbly quartz sandstone, conglomerate and siltstone which conformably overlies the Burvill Formation and is overlain disconformably by the Keep Inlet Formation. The type section is 6.4 km northeast of Point Spring in the Weaber Range and is 236 m thick. The maximum known thickness is 383 m.

As emended, the formation includes the "Border Creek Formation" of Veevers and Roberts (1968) which is here considered a member of the Point Spring Sandstone and Tanmurra Formation. These authors considered that the base of the Border Creek Member was a major disconformity. However, recent mapping (Beere and Mory, pers. comm., 1981) suggests that the Border Creek Member is the conglomeratic upper part of the Point Spring Sandstone with local channelling at its base which is diachronous. Veevers and Roberts (1968) have already pointed out the similarity between the quartz sandstone of the two units and the rapid lateral lithological change in the Point Spring Sandstone. The formation occurs only in the Weaber Range area and is known in the subsurface in Bonaparte 2. Outcrops mapped as Border Creek Formation by Veevers and Roberts (1968) in the Burt Range and Spirit Hill areas are now considered to be Keep Inlet Formation (Beere, pers. comm., 1981).

Fossils in the Point Spring Sandstone include brachiopods, bivalves, trace fossils, plant remains and spores and pollen. The brachiopods belong to the *milliganensis-gradatus* zone and the fauna extends up to the base of the Border Creek Member which contains only *Phyllotheca*-like plants (Veevers and Roberts, 1968). The Border Creek Member in Bonaparte 2 contains an *Anapiculatisporites largus* Assemblage microflora (Kemp and others, 1977). The fossil evidence suggests that the formation is late Visean to early Namurian in age.

The Point Spring Sandstone and Burvill Formation correlate with the Tanmurra Formation which is the more open-marine basinal equivalent of these two shelf units. The Border Creek Member is probably a fluvial deposit and does not extend very far into the basin.

Bonaparte Formation

The Bonaparte Formation ("Bonaparte Beds" of Veevers and Roberts, 1968) is a subsurface unit of dark shale, siltstone and sandstone of Late Devonian and Early Carboniferous age which underlies the Tanmurra Formation in wells drilled in the northern part of the onshore part of the Bonaparte Basin. The type section is in Bonaparte 1 between 497 and 3 209 m (total depth), a thickness of 2 712 m, although the base of the formation had not been reached at the total depth of the well.

The Bonaparte Formation is the basinal equivalent of the Devonian and Early Carboniferous carbonates and sandstones deposited on the marginal shelf of the basin. In Bonaparte 1 the highest Devonian sample is core 28 at 2 533 m which contains the bivalve *Buchiola*. The overlying Early Carboniferous section is dated as Tournaisian and Visean on the basis of foraminifers (Mamet and Belford, 1968). Ostracods, brachiopods of the *milliganensis-gradatus* zone, corals and bryozoans also occur (Belford, Jones and Roberts, *in* Le Blanc, 1964). Playford (1971) has described spores, mainly from the upper part of the formation. They belong to the *Anapiculatisporites largus* Assemblage (Kemp and others, 1977).

Tanmurra Formation

The Tanmurra Formation (Le Blanc, 1964; Veevers and Roberts, 1968) is a subsurface unit of limestone, dolomite and sandstone which conformably overlies the Bonaparte Formation and is overlain conformably by an unnamed unit in Pelican Island 1 or disconformably by the Keep Inlet Formation in Bonaparte 1. The type section is from 194 to 497 m in Bonaparte 1.

The Tanmurra Formation is dated as late Visean to early Namurian in age on foraminifers, the boundary between the Lower and Upper Carboniferous occurring between 204 and 207 m in the type section (Mamet and Belford, 1968). The type section has yielded brachiopods of the *milliganensis-gradatus* zone (Roberts, 1971). Spores of the *Anapiculatisporites largus* Assemblage occur in the formation (Kemp and others, 1977).

Keep Inlet Formation

The Keep Inlet Formation ("Keep Inlet Beds" of Glover and others, 1955; Veevers and Roberts, 1968) is a sequence of calcareous sandstone, lithic quartz sandstone, siltstone and conglomerate. The type locality is 4 km northeast of Cleanskin bore, which is west of Keep Inlet. Exposures are poor in this area, and the stratigraphic relationships have been determined from borehole information. The maximum known thickness is 176 m in Bonaparte 1, where the

formation rests disconformably on the Tanmurra Formation. On the shelf in the Burt Range area the formation (formerly mapped as "Border Creek Formation") oversteps all units down to the Septimus Limestone. The conglomerate in the type section contains pebbles and boulders of various rock types (Veevers and Roberts, 1968) and the unit is considered to be glacial-marine in origin.

The only macrofossil from the Keep Inlet Formation is one specimen of *Strophalosia* sp. (Veevers and Roberts, 1968). A Unit I microfloral assemblage occurs in the formation in Bonaparte 1 and Pelican Island 1 (where the unit was named "Border Creek Formation") and the age is Late Carboniferous (Kemp and others, 1977).

The Keep Inlet Formation occurs in Keep River 1 and Kulshill 1, where it was called the Kulshill Formation. In Kulshill 1, it extends into the Early Permian and is conformably overlain by the Sugarloaf Formation (Kemp and others, 1977). According to Laws and Brown (1976) the Kulshill Formation is overlain by the Fossil Head Formation. All three formations (Kulshill, Sugarloaf and Fossil Head) are placed in the Port Keats Group and clearly there is a need to clarify the stratigraphic nomenclature of these units.

CARBONIFEROUS STRATA IN THE OFFSHORE BONAPARTE BASIN.

Kemp and others, (1977) correlate, a number of stratigraphic units belonging to the *Spelaeotriletes ybertii* and *Grandispora maculosa* Assemblages in the offshore Bonaparte Basin. In Pelican Island 1 the strata are unnamed interbedded sandstone and shale with minor limestone lying, probably conformably, between the overlying Keep Inlet Formation and the underlying Tanmurra Formation. In Lacrosse 1 they are unnamed sandstone and siltstone, and the "Medusa Beds" of limestone and calcareous sandstone. In Kulshill 1 the strata were named "Tanmurra Formation" and "Bonaparte Formation" but these assignments are questionable as both these formations are older.

While the relationship of these units is not clear and their nomenclature has not been formalized, they represent (at least in Pelican Island 1) a sequence deposited during the time when erosion took place further south. The unconformity between the Keep Inlet Formation and the Tanmurra Formation (seen in Bonaparte 1) disappears to the north where deposition in the basin was continuous throughout the Late Carboniferous and into the Early Permian.

STRUCTURE

The Carboniferous rocks in the Bonaparte Basin crop out as basinward-dipping strata except on the eastern shelf in the Burt Range and Spirit Hill areas wher they are gently folded along north- to northeast-trending axes. Faulting is common in the southeast part of the basin where the Cockatoo Fault system occurs.

GEOLOGICAL HISTORY

Deposition of fine-grained sediments (Bonaparte Formation) continued uninterruptedly from Late Devonian into Early Carboniferous in the basinal part of the Bonaparte Basin. Reef development (Ningbing Limestone) possibly continued into the Tournaisian on the western shelf; on the eastern shelf there may have been a short break in sedimentation at the end of the Devonian (Buttons Formation—Burt Range Formation boundary). A shallow sea covered the eastern shelf in the Tournaisian and Visean, and carbonate (Burt Range Formation, Septimus Limestone) and clastic (Enga and Zimmermann Sandstones) deposition took place. The sea may have withdrawn from the western shelf in the mid-Tournaisian and returned depositing shales (Milligans Formation) which spread on to the eastern shelf. Gradual shallowing of the shelf area (both east and west) occurred with the deposition of shallow near-shore sand (Burvill Formation, Point Spring Sandstone) culminating in fluvial sand and pebbles (Border Creek Member). Local areas of carbonate (Utting Calcarenite) and breccia (Waggon Creek Formation) occurred on the western shelf. Uplift and erosion took place on the shelf in early Namurian time. Further offshore, in the basinal area, sedimentation was continuous throughout the Carboniferous (Bonaparte and Tanmurra Formations, unnamed units in Pelican Island 1). In the Late Carboniferous glacial-marine sedimentation (Keep Inlet Formation) extended over the whole basin as the sea spread on to the shelf area once more.

ACKNOWLEDGEMENTS

This review is based on a manuscript prepared in 1972 as a contribution to the International Stratigraphic Lexicon and so far unpublished. In revising it I have been helped by P. J. Jones and R. S. Nicoll (Bureau of Mineral Resources), B. E. Balme (University of Western Australia), and M. H. Johnstone (Esso Australia Ltd), to whom I express my thanks.

REFERENCES

Archbold, N. W., 1982, Correlation of the Early Permian faunas of Gondwana: its implications for the Gondwana Carboniferous-Permian Boundary: Jour. Geol. Soc. Australia, v.29, p.267-276.

Balme, B. E., 1980, Palynology and Carboniferous-Permian boundary in Australia and other Gondwana continents: Palynology, v.4, p.43-55.

Balme, B. E., and Hassell, C. W., 1962, Upper Devonian spores from the Canning Basin, Western Australia: Micropaleontology, v.8, p.1-28.

36540—4

Beere, G. M., 1984, The Waggon Creek Formation—an Early Carboniferous submarine fan deposit in the Bonaparte Gulf Basin: West. Australia Geol. Survey, Report 12, p.7-14.

Berven, R. J., 1969, Remarkable Hill 1 well completion report: Marathon Petroleum Australia Ltd (unpublished).

Bischoff, G., 1968, Yulleroo 1 well completion report: Gewerkschaft Elwerath (unpublished).

Blatchford, T., 1927, The geology of portions of the Kimberley Division, with special reference to the Fitzroy Basin and the possibility of the occurrence of mineral oil: West. Australia Geol. Survey, Bull. 93.

Broad, D. S. and McDermott, R. J., 1974, Jones Range 1 well completion report:11 West Australian Petroleum Pty Ltd (unpublished).

Condon, M. A., 1954, Progress report on the stratigraphy and structure of the Carnarvon Basin, Western Australia: Australia Bur. Mineral Resources, Rept 15.

Condon, M. A., 1965, The geology of the Carnarvon Basin, Western Australia Part 1: Pre-Permian Stratigraphy: Australia Bur. Mineral Resources, Bull. 77(1).

Condon, M.A., 1967, The geology of the Carnarvon Basin, Western Australia Part 2: Permian stratigraphy: Australia Bur. Mineral Resources, Bull. 77(2).

Crank, K. A., 1972, Lake Betty 1 Well completion report: West Australian Petroleum Pty Ltd (unpublished).

Creevey, K. J., 1969, Wilson Cliffs 1 well completion report: Australian Aquitaine Petroleum Pty Ltd (unpublished).

Crowe, R. W. A. and Towner, R. R., 1976a, Permian stratigraphic nomenclature, Noonkanbah 1:250 000 sheet: West. Australia Geol. Survey, Ann. Rept 1975, p.56-58.

Crowe, R. W. A. and Towner, R. R., 1976b, Definitions of some new and revised rock units in the Canning Basin: West Australia Geol. Survey, Rec. 1976/24 (unpublished).

Dickins, J. M., and Thomas, G. A., 1959, The marine fauna of the Lyons Group and the Carandibby Formation of the Carnarvon Basin, Western Australia: Australia Bur. Mineral Resources, Rept 38, p.65-96.

Dickins, J. M., Towner, R. R., and Crowe, R. W. A., 1977, A Permian cold water marine fauna in the Grant Formation of the Canning Basin, Western Australia: Jour. Palaeont. Soc. India, v.20, p.275-278.

Druce, E. C,. 1969, Devonian and Carboniferous conodonts from the Bonaparte Gulf Basin, northern Australia: Australia Bur. Mineral Resources, Bull. 98.

Druce, E. C., and Radke, B. M., 1979, The geology of the Fairfield Group, Canning Basin, Western Australia: Australia Bur. Mineral Resources, Bull. 200.

Evans, P. R., 1969, Upper Carboniferous and Permian palynological stages and their distribution in eastern Australia: Internat. Gondwana Symposium, 1st, Argentina, Proc., p.41-45.

Glenister, B. F., 1956, Devonian and Carboniferous spiriferids from the North-West Basin, Western Australia: Royal Soc. West. Australia Jour., v.39, p.46-71.

Glenister, B. F., 1960, Carboniferous conodonts and ammonoids from northwestern Australia: Cong. av. etudes stratigraphie geologie Carbonifere, 4th, Heerlen 1958, Compte Rendu, v.1, p.213-217.

Glenister, B. F., and Klapper, G. J., 1966, Upper Devonian conodonts from the Canning Basin, Western Australia: Jour. Paleontology, v.40, p.777-842.

Glover, J. E., Richardson, L. A., and McGilvray, E., 1955, Geological and geophysical report on the Keep River area, Bonaparte Gulf Basin: Associated Australia Oilfields (unpublished).

Guppy, D. J., Lindner, A. W., Rattigan, J. H., and Casey, J. N., 1958, The geology of the Fitzroy Basin, Western Australia: Australia Bur. Mineral Resources, Bull. 36.

Hare, R., and Associates (revised by G. A. Thomas), 1961, Spirit Hill 1 well completion report: Oil Development N. L. and Westralian Oil Limited (unpublished).

Helby, R. J., 1969, The Carboniferous—Permian boundary in eastern Australia: an interpretation on the basis of palynological information: Geol. Soc. Australia, Spec. Pub. 2, p.69-72.

Hematite Petroleum Proprietary Ltd, 1972, Cane River 1 well completion report: Hematite Petroleum Pty Ltd (unpublished).

Hill, D., and Jell, J. S., 1970 [1971]. Devonian corals from the Canning Basin, Western Australia: West. Australia Geol. Survey, Bull. 121.

Hill, D., and Woods, J. T., 1964, Carboniferous fossils of Queensland: Queensland Palaeontographical Soc.

Hocking, R. M., Williams, S. J., Lavaring, I. H., and Moore, P. S., 1983, Explanatory notes on the Winning Pool-Minilya 1:250 000 geological sheet, Western Australia: West. Australia Geol. Survey, Record 1982/9, 61p.

Hocking, R. M., Williams, S. J., Moore, P. S., Denman, P. D. and Lavaring, I. H., 1983, Explanatory notes on the Kennedy Range 1:250 000 geological sheet, Western Australia: West. Australia Geol. Survey, Record 1983/5, 55p.

Johnson, N. E. A., 1968, Blackstone 1 well completion report: West Australian Petroleum Pty Ltd (unpublished).

Johnstone, M. H., Burdett, J. W., Smith, D. N., and Pearson, G. R., 1963, Marilla 1 and Minderoo 1 stratigraphic bores: West Australian Petroleum Pty Ltd, (unpublished).

Jones, P. J., Campbell, K. S. W., and Roberts, J., 1973, Correlation chart for the Carboniferous System of Australia: Australia Bur. Mineral Resources, Bull. 156A.

Kemp, E. M., Balme, B. E., Helby, R. J., Kyle, R. A., Playford, G. and Price, P. L., 1977, Carboniferous and Permian palynostratigraphy in Australia and Antartica: a review: BMR Jour. Australian Geology Geophysics, v.2, p.177-208.

Lavaring, I. H., 1979, Palaeoecological and palaeogeographic implications of *Rhipidomella michelini?* (Leveille) in the Carboniferous of the Carnarvon Basin: West. Australia Geol. Survey, Ann. Rept 1978, p.89-92.

Laws, R. W., and Brown, R. S., 1976, Bonaparte Gulf Basin—south eastern part, *in* Leslie, R. B., Evans, H. J., and Knight, C. L. (eds), Economic geology of Australia and Papua New Guinea, 3, Australasian Inst. Mining Metall., Petroleum: p.200-208.

Le Blanc, M. C., 1964, Bonaparte 1 well completion report: Alliance Oil Development N. L., (unpublished).

Maitland, A. G., 1912, Relics of Permo-Carboniferous ice-age in Western Australia: Nat. History Sci. Soc. West. Australia, Jour. v.4, p.12-29.

Mamet, B. L., and Belford, D. J., 1968, Carboniferous foraminifera, Bonaparte Gulf Basin, northwestern Australia: Micropaleontology, v.14, p.339-347.

Matheson, R. S., and Teichert, C., 1948, Geological reconnaissance in the eastern portion of the Kimberley Division, Western Australia: West. Australia Geol. Survey, Ann. Rept 1945, p.73-87.

McWhae, J. R. H., Playford, P. E. Lindner, A. W., Glenister, B. F. and Balme, B. E., 1958, The stratigraphy of Western Australia: Geol. Soc. Australia Jour. v.4, pt.2

Meath, J. R., and Scott, R. J., 1972, Logue 1 well completion report: West Australian Petroleum Pty Ltd (unpublished).

Nicoll, R. S., and Druce, E. C., 1979, Conodonts from the Fairfield Group, Canning Basin, Western Australia: Australia Bur. Mineral Resources, Bull. 190.

Noakes, L. C., Opik, A. A., and Crespin, I., 1952, Bonaparte Gulf Basin, northwestern Australia: a stratigraphical summary with special reference to the Gondwana System: Internat. Geol. Cong., 19th, Algiers 1952, Symposium sur les series de Gondwana, p.91-106.

Osborne, D. G., 1972, East Marilla 1 well completion report: West Australian Petroleum Pty Ltd, (unpublished).

Pearson, G. R., 1964, Quail 1 well completion report: West Australian Petroleum Pty Ltd, (unpublished).

Playford, G., 1971, Lower Carboniferous spores from the Bonaparte Gulf Basin, Western Australia and Northern Territory: Australia Bur. Mineral Resources, Bull.115.

Playford, G., 1976, Plant microfossils from the Upper Devonian and Lower Carboniferous of the Canning Basin, Western Australia: Palaeontographica B, v.158, p.1-71.

Playford, G. and Powis, G. D., 1979, Taxonomy and distribution of some trilete spores in Carboniferous strata of the Canning Basin, Western Australia: Pollen et Spores, v.21, p.371-394.

Playford, P. E. Cope, R. N. Cockbain, A. E., Lowry, D. C. and Low, G. H., 1975, Phanerozoic, *in* The geology of Western Australia. West. Australia Geol. Survey, Memoir 2, p.223-433.

Playford, P. E. and Lowry, D. C., 1966, Devonian reef complexes of the Canning Basin, Western Australia: West. Australia Geol. Survey, Bull. 118.

Plumstead, E. P., 1969, Three thousand million years of plant life in Africa: Geol. Soc. South Africa, Annexure to v. 72.

Powis, G. D., 1979, Palynology of the late Palaeozoic glacial sequence, Canning Basin, Western Australia: Univ. West. Australia, Science Ph. D. thesis (unpublished).

Radke, B. M., and Nicoll, R. S., 1981, Evidence for former evaporites in the Carboniferous Moogooree Limestone, Carnarvon Basin, Western Australia: BMR Jour. Australian Geology Geophysics, v. 6, p. 106-108.

Rattigan, J. H., 1967, Fold and fracture patterns resulting from basement wrenching in the Fitzroy Depression, Western Australia: Australasian Inst. Mining Metall., Proc. 223, p.17-22.

Roberts, J., 1971, Devonian and Carboniferous brachiopods from the Bonaparte Gulf Basin, northwestern Australia: Australia Bur. Mineral Resources, Bull. 122.

Ross, J. P., 1961, Ordovician, Silurian and Devonian Bryozoa of Australia: Australia Bur. Mineral Resources, Bull. 50.

Shannon, P. H., and Henderson, S. W., 1966, St George Range 1 well completion report: Continental Oil Co. Australia, Rept (unpublished).

Singleton, A. E., 1965, Sahara 1 well completion report: West Australian Petroleum Pty Ltd rept (unpublished).

Smith, J. G., 1968, Tectonics of the Fitzroy wrench trough, Western Australia: Am. Jour. Sci., v.266, p.766-776.

Teichert, C., 1949, Discovery of Devonian and Carboniferous rocks in the North-West Basin, Western Australia: Australian Jour. Sci., v.12, p.62-65.

Teichert, C., 1950, Some recent additions to the stratigraphy of Western Australia. Am. Assoc. Petroleum Geologists Bull., v.34, p.1787-1794.

Teichert, C., 1957, Notes on the geology of the Carnarvon (Northwest) Basin, Western Australia: Royal Soc. West. Australia Jour., v.40, p.65-72.

Thomas, G. A., 1957, Lower Carboniferous deposits in the Fitzroy Basin: Western Australia: Australian Jour. Sci., v.19, p.160-161.

Thomas, G. A., 1959, The Carboniferous Laurel Formation of the Fitzroy Basin: Australia Bur. Mineral Resources, Rept 38.

Thomas, G. A., 1962a, The Carboniferous stratigraphy of the Bonaparte Gulf Basin: Cong. av. etudes stratigraphie geologie Carbonifere, 4th, Heerlen 1958, Compte Rendu, v.3, p.727-732.

Thomas, G. A., 1962b, The Carboniferous stratigraphy of Western Australia: Cong. av. etudes stratigraphie geologie Carbonifere, 4th, Heerlen 1958, Compte Rendu, v.3, p.733-740.

Thomas, G. A., 1971, Carboniferous and Early Permian brachiopods from Western and northern Australia: Australia Bur. Mineral Resources, Bull. 56.

Traves, D. M., 1955, The geology of the Ord-Victoria region, northern Australia: Australia Bur. Mineral Resources, Bull. 27.

Truswell, E. M., 1980, Permo-Carboniferous palynology of Gondwanaland: progress and problems in the decade to 1980: BMR Jour. Australian Geology Geophysics, v.5, p.95-111.

Van de Graaff, W. J. E., Hocking, R. M., and Denman, P. D., 1977, Revised stratigraphic nomenclature and interpretations in the east-central Carnarvon Basin, W.A.: West. Australia Geol. Survey, Ann. Rept, 1976, p.37-39.

Veevers, J. J., 1959a, Devonian brachiopods from the Fitzroy Basin, Western Australia: Australia Bur. Mineral Resources, Bull. 45.

Veevers, J. J., 1959b, Devonian and Carboniferous brachiopods from northwestern Australia: Australia Bur. Mineral Resources, Bull. 55.

Veevers, J. J., 1970, Upper Devonian and Lower Carboniferous calcareous algae and stromatolites from the Bonaparte Gulf Basin, northwestern Australia: Australia Bur. Mineral Resources, Bull. 116, p.173-188.

Veevers, J. J., and Roberts, J., 1968, Upper Palaeozoic rocks, Bonaparte Gulf Basin of northwestern Australia: Australia Bur. Mineral Resources, Bull. 97.

Veevers, J. J., Roberts, J., White, M. E. and Gemuts, I., 1967, Sandstone of probable Lower Carboniferous age in the north-eastern Canning Basin, W.A.: Australian Jour. Sci., v.19, p.330-331.

Veevers, J. J., and Wells, A. T., 1961, The geology of the Canning Basin, Western Australia: Australia Bur. Mineral Resources, Bull. 60.

Waterhouse, J. B., 1976, World correlations for Permian marine faunas: Univ. Queensland Papers Dept Geology, v.7, no.2.

Woolnough, W. G., 1933, Report on aerial survey operations in Australia during 1932: Australia Commonwealth Parliamentary Paper 2164.

Young, R. J. B., and O'Shaughnessy, P. R., 1973, Mt Hardman 1 well completion report: West Australian Petroleum Pty Ltd, rept (unpublished).