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## A census of the larger fungi of Western Australia

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### Abstract

299 taxa of larger fungi are listed for Western Australia. All taxa are listed of which the type locality is within the State; these number 72, excluding 20 synonyms. The remaining 227 are records for which one or more voucher specimens can be cited from herbaria of the Index Herbariorum.

### Introduction

The census which follows includes some 300 species and varieties of larger fungi of Western Australia chosen on the authority of having been first described as new from local material, or on the basis of citable herbarium specimens. The foundation of the list has been laid by special attention to the pioneer collections of Drummond, Preiss and von Mueller. Very little else has been collected in the State until recent years, and the records for Western Australia given by M. C. Cooke (1892) and McAlpine (1895) are almost entirely those of Drummond and Preiss. All taxa based on Western Australian material are included; they number 72, of which 20 appear to be synonyms.

The first, and only other, census is that of McAlpine (1895) in which 242 species are listed for Western Australia, including Lower Fungi and Fungi Imperfecti. The list does not cite vouchers and is arranged in the now out-dated classification of Masee's British Fungus Flora, published in 1892-5.

As the present census is of Larger Fungi, all Myxomycetes, Lower Fungi and Fungi Imperfecti are deliberately excluded. Microscopic Ascomycetes and microscopic Basidiomycetes are also excluded. A preliminary census of plant parasitic fungi was published in this journal by Carne (1925) and subsequently expanded by the Department of Agriculture (Commonwealth Mycological Institute 1975).

The census does not purport to be a check list, which is a work in which the records are accepted on the authority of the compilers and in which a complete synonymy is presented.

### *Drummond collection*

Drummond was collecting plants and fungi in Western Australia from 1828 to 1863. His main fungal collection is known to have been from Hawthornden Farm in the Toodyay district (Drummond 1843). Of 300 cryptogams collected, 200 were fungi and 130 of these survived as reasonable specimens to be sent to Sir William Jackson Hooker at Kew and passed by him to the Rev. M. J. Berkeley (1803-89) for naming. Where Berkeley describes new species they are in both Latin and English in the original publications and most are repeated in 'Decades of Fungi' (Berkeley 1845), now available in reprint. Hilton (1982) updates the assembly in 'Decades of Fungi', giving additional comments from Drum-

mond's letters, subsequent records of distribution outside Western Australia, and revised synonymy.

### *Preiss collection*

Preiss was active over a much shorter time than Drummond: he arrived in December 1838 and left on 8 January 1842. The Director of the Hamburg Botanic Garden, J. G. C. Lehmann, who handled the collection, passed the fungi to Elias Fries (1794-1878) for naming. It appears that Fries was unaware of Berkeley's publication in the London Journal of Botany for 1844, pre-dating *Plantae Preissianae* (1845-47). The Keeper at Uppsala has reported (Santesson pers. comm. 1972) that only one of the type specimens for Fries' list is extant there. The remainder were believed to be at Hamburg but enquiry there yielded the information (Friederichsen pers. comm. 1972) that the Preiss cryptogams had been lodged at the Berlin herbarium and were lost when that building was burnt down during the war. In the systematic list which follows it can be surmised that of Preiss's collection some of the fungi described are the same as species described by Berkeley. Fries' species are described only in Latin in the original publication, but an English translation appears in Cooke (1892).

### *von Mueller collection*

Preiss's sojourn in Western Australia indirectly stimulated a third collection of larger fungi from the State. Preiss recommended the young botanist, Ferdinand von Mueller, to move to Australia as a cure for his asthma and as an opportunity for botanical work; this he did in 1847. von Mueller, on his second visit to the West in 1877, noted the predilection of the ladies there for water colouring and persuaded some, notably Lady Forrest, to paint wild flowers and fungi. A shipment of dried fungi and accompanying water colours was sent to the Austrian agaricologist, Rev. C. Kalchbrenner (1807-86) and the results published in the Proceedings of the Linnean Society of New South Wales for 1882. In the case of Kalchbrenner's species, there is a Latin description in the original publication, but an entry in neither Saccardo (*Sylloge Fungorum*) nor in Cooke (1892). They are, however, included in McAlpine's arrangement (1895). von Mueller also sent specimens to M. J. Berkeley and, later, to M. C. Cooke. Amongst his correspondents was Thomas Muir, a number of whose collections are extant at Kew and Melbourne.

*Other collections*

References to specimens from Western Australia occur in the works on Australian fungi by Cleland (1934) and Cunningham (1944, 1963, 1965), but rest largely on collections made by others, including the historic collections.

In 1935-36 a survey of wood-attacking fungi was made by Tamblin and the results incorporated in his M.Sc. thesis (1936). This survey was expanded to include forest fungi in general by T. E. H. Aplin, whose specimens, together with those of Mrs E. R. L. Johnson and her students, provided the foundation of the mycology herbarium at the University of Western Australia.

*Arrangement*

The classification used is that given in Ainsworth, Sparrow, and Sussman (1973) (Geoglossaceae to Phal-laceae). Within that classification orders and families are arranged alphabetically. Where abbreviations of publication titles and of author citations are used they follow Hawksworth (1974).

Collections which involve the type specimen are indicated by an asterisk (\*).

The concept followed is that of Doidge (1950) for South African Fungi and Lichens, and G. G. Smith (1966) for Western Australian Pteridophytes. Subsequent species records will be presented in a similar manner, when their number has built up to a total to warrant publication.

Class Ascomycetes

Order Heliotales

Family Geoglossaceae

**Geoglossum nigratum** (Fr.) Cooke in Mycographia 1:205 (1879). Porongorups, (UWA 842); Nedlands (UWA 864); Cottesloe (UWA 872).

Order Pezizales

Family Ascobolaceae

**Ascobolus furfuraceus** Pers. ex Hook. in Fl. scot. 2:33 (1821). Swan River s. dat. Drummond (K) On cow dung. Rifai (1968) p. 266 Cannington (UWA 2239).

Family Helvellaceae

**Cyathipodia corium** (Weberbauer) Boud. in Hist. Class. Discom. d'Europe 39 (1907). Lake Clifton (UWA 2263).

Family Morchellaceae

*Morchella angusticeps* see **Morchella elata**

*Morchella conica* see **Morchella elata**

**Morchella elata** Fr. aggr. Augusta, as *Morchella angusticeps* Peck, (UWA 764, 773); Canning Dam, as *Morchella conica* Pers., (UWA 787); Nedlands (UWA 1937). Associated with extensive fires in the karri forests. See Johnson, E. R. L., W.A. Naturalist 8:79 (1962).

Family Pezizaceae

*Peziza ammophila* see **Peziza austrogeaster**

**Peziza applanata** Fr. in Syst. mycol. 2:64 (1821). Swan River, Drummond No. 186 (K but not found).

**Peziza austrogeaster** (Rodway) Rifai in Australasian Pezizales p. 227 (1968). South Perth (K); Lake Clifton (UWA 2234) (K). Rifai (1968) p. 228 explains how this species has been confused with the European species *Peziza*, later *Sarcosphaeria*, *ammophila* Duricu & Mont.

**Peziza badia** Pers. ex Mérat in Nouv. Fl. env. Paris 2e Ed. 1:24 (1821). S.W. Australia, T. Muir 1881 (K). Muir was collecting near Pemberton that year. Rifai (1968) p. 246 states that the record is based on immature specimens. Collie (UWA 2403).

**Peziza cochleata**, form. Swan River, Drummond No. 210 (K but not found).

**Peziza drummondii** Berk. in Lond. J. Bot. 4:71 (1845). Swan River, Drummond No. 183 (K\*). Rifai (1968) p. 277 describes, but recommends placing in a new genus in the Sarcoscyphaceae.

*Peziza melaloma* see **Anthracobia melaloma**, Pyronemataceae.

*Peziza melanodon* see **Humaria melanodon**, Pyronemataceae.

*Peziza ollaris* see **Humaria ollaris**, Pyronemataceae.

**Peziza psammobia** Rifai in Australasian Pezizales p. 243 (1968). Narrogin (K).

*Peziza rutilans* see **Leucoscypha rutilans**, Pyronemataceae.

*Peziza scutellata* see **Scutellinia scutellata**, Pyronemataceae.

**Peziza vesiculosa** Bull. ex St. Am. in Fl. agén. 534 (1821). Nedlands (UWA 1542).

*Sarcosphaeria ammophila* see **Peziza austrogeaster**

Family Pyronemataceae

**Aleuria rhenana** Fuckel in Jb. nassau. Ver. Naturk, 23-24:325 (1870). Lake Muir, (K); Porongorups, as *Sarcoscypha rhenana* (Fuckel) Sacc. (UWA 147) (K); Balingup (UWA No. 913). Rifai (1968) p. 157 discusses the Lake Muir specimen.

**Anthracobia melaloma** (Alb. & Schw. ex Fr.) Boud. in Bull. Soc. Mycol. Fr. 1:106 (1885). Swan River, as *Peziza melaloma*, Drummond No. 189 (K). Rifai (1968) p. 142 comments that the identity of Drummond No. 189 cannot be confirmed because of the absence of colour annotation.

**Geopyxis carbonaria** (Alb. & Schw. ex Pers.) Sacc. in Syll. Fung. 8:71 (1889). Augusta (UWA 148) (K).

**Humaria melanodon** (Fr.) Sacc. in Syll. Fung. 8:130 (1889). Canning River, as *Peziza melanodon* Preiss, no number\* based only on Preiss's drawing and description, and omitted from subsequent descriptive works.

**Humaria ollaris** (Fr.) Sacc. in Syll. Fung. 8:131 (1889). Lake "Daujamlur" (Joondalup?) as *Peziza ollaris* (Herb. Preiss. No. 2691).

*Lachnea scutellata* see **Scutellinia scutellata**

**Leucoscypha rutilans** (Fr.) Dennis & Rifai in Australasian Pezizales p. 164 (1968). Swan River, as *Peziza rutilans*, Drummond No. 190 (K).

**Octospora carbonigena** (Berk.) Dennis in British Cup Fungi p. 33 (1960). Mundaring Weir (UWA 2245) (K).

**Pulvinula archeri** (Berk.) Rifai in Australasian Pezizales p. 213 (1968). Mandurah (UWA 2240); Gleneagle (UWA 2452).

**Scutellinia scutellata** (L. ex St.-Am.) Lamb. in Fl. mycol. Belg. Suppl. 1:299 (1887). Swan River, as *Peziza scutellata*, (K); Porongorups (UWA 1190); Boxer Is, as *Lachnea scutellata* (L. ex St. Am.) Gill. (MEL). Rifai (1968) p. 116 describes and identifies the Swan River specimen but comments "collector unknown".

*Sepultaria austrogeaster* see **Peziza austrogeaster**, Pezizaceae.



Family Sarcoscyphaceae

*Sarcoscypha rhenana* see *Aleuria rhenana*.

Order Tuberales

Family Tuberaceae

*Elderia arenivaga* (Cooke & Masee) McLennan in Proc. R. Soc. Victoria 74:112 (1961). Lake Hazlett (MEL\*). Formerly placed in the genus *Stephensia*.  
*Stephensia arenivaga* see *Elderia arenivaga*.

Class Hymenomycetes

Sub-class Phragmobasidiomycetidae

Order Auriculariales

Family Auriculariaceae

*Auricularia mesenterica* Pers. in Mycol. eur. 1:97 (1822). Prince Regent River (UWA 1957, 1969, 1972). The West Australian specimens are remarkable for the beautiful grey blue of the hymenial surface.

*Auricularia minuta* Berk. in Lond. J. Bot. 4:59 (1845). Swan River, Drummond No. 163 (K\*). The specimen is only doubtfully an *Auricularia* (Hilton 1982).

Order Septobasidiales

Family Septobasidiaceae

*Septobasidium* sp.

Nornalup Inlet (UWA 124; IMI 146956); Pemberton, on *Chorilaena quercifolia* Endl. (UWA 1909); Pemberton on *Trymalium spatulatum* (Labill.) Ostf. (UWA 1931) Specific identification awaits fertile specimens. Samples have been taken at different times of the year but all have proved to be sterile. Coccids are invariably found associated with the fungus.

Order Tremellales

Family Tremellaceae

*Eichleriella macrospora* (Ell. & Everh.) G. W. Martin in Univ. Ia Stud. nat. Hist. 18:48 (1944). Yanchep (UWA 711, 729, 760).

*Exidia glandulosa* Fr. in Syst. mycol. 2:224 (1822). Swan River, Drummond No. 194 in part, Drummond No. 123 in part; Gngara (UWA 2128).

*Sirobasidium sanguineum* Lagerh. & Pat. in J. Bot., Paris 6:467 (1892). Swan River, as *Dacrymyces rubro-fuscus* Berk. n.sp. in Lond. J. Bot. 4:61 (1845), Drummond No. 212 (K\*), Drummond No. 225 in part (K).

*Tremella foliacea* Fr. in Syst. mycol. 2:212 (1822). Swan River, Drummond No. 93; Wanneroo (UWA 2260).

*Tremella mesenterica* Fr. in Syst. mycol. 2:214 (1822). Swan River, Drummond No. 193 (K); Porongorups (UWA 443); Dwellingup (UWA 444); Busselton (UWA 659); Northcliffe (UWA 660); Crystal Brook (UWA 1521).

*Tremelloscypha australiensis* Reid in Beihefte zur Sydowia 8:332 (1979). Yanchep (ADW); Porongorups (ADW).

Sub-class Holobasidiomycetidae

Order Agaricales

Family Agaricaceae

*Agaricus arvensis* Schaeff. ex Secretan in Mycographie 1:99 (1833). Belmont (UWA 261).

*Agaricus campestris* L. ex Fr. in Syst. mycol. 1:291 (1821) Midland (UWA 2210). Drummond (1843), quoted by Berkeley (1845), states that the cultivated

mushroom was introduced into the Colony, and soon became naturalised about Perth.

*Agaricus campestris* var. *maximus* Drummond in Berkeley (1845) p. 47. Swan River, Drummond No. 104 (K\*). Drummond (1843), quoted by Berkeley (1845), states that it is found in poor clay land in the white gum (*Eucalyptus wandoo*) forests, with middle size specimens 0.3 m in diam. and the short stem 5 cm thick.

*Agaricus campestris* var. *varius* Drummond in Berkeley (1845) p. 47. Swan River, Drummond No. 105 (K\*). Drummond (1843) quoted by Berkeley (1845), states that it is found under the York Gum (*Eucalyptus loxophleba* Benth.), and is much smaller than var. *maximus* as well as having gills variable in colour.

*Agaricus (Psalliota) semiglobatus* see *Stropharia semiglobata*, Strophariaceae.

*Psalliota* see *Agaricus*.

Family Amanitaceae

*Amanita austro-pulchella* see *Amanita xanthocephala*.

*Amanita dumosorum* Reid in Victorian Naturalist 95:47 (1978). Two Peoples Bay (K\*).

*Amanita forrestiae* Kalchbr. in Proc. Linn. Soc. N.S.W. 7:638 (1883). Western Australia\* as *Agaricus forrestiae*.

*Amanita griselloides* Reid in Victorian Naturalist 95:47 (1978). Walpole (K\*); Two Peoples Bay (K).

*Amanita hiltonii* Reid in Victorian Naturalist 95:48 (1978). Dale Forest (K\*); Walpole (K).

*Amanita ochroterrea* Gentilli ex Bas. in Persoonia 5:505 (1969). King's Park, as *Amanita preissii* f. *ochroterrea*, (L\*); King's Park (UWA 1832); Southern Cross (UWA 1862); Glencagle (UWA 2001).

*Amanita peltigera* Reid in Victorian Naturalist 95:49 (1978). Stirling West (K\*).

*Amanita preissii* (Fr.) Sacc. in Syll. Fung. 5:9 (1887). W. Aust., as *Agaricus (Amanita) preissii*, in sandy places in forests (Herb. Preiss No. 2665\*); King's Park, as *Amanita preissii* f. *levis* Gentilli (K); Mundaring (UWA 1656), (UWA 2248); Kalamunda (UWA 2065).

*Amanita preissii* f. *levis* see *Amanita preissii*.

*Amanita preissii* f. *ochroterrea* see *Amanita ochroterrea*.

*Amanita pulchella* see *Amanita xanthocephala*.

*Amanitopsis pulchella* see *Amanita xanthocephala*.

*Amanita umbrinella* Gilbert & Cleland in Iconographia Mycologica 27: 273 (1941). Margaret River (UWA 1300); King's Park (UWA 1855); Mundaring Weir (UWA 1545); Glen Forrest (UWA 2249).

*Amanita virgineoides* Bas in Persoonia 5:435 (1969). Two Peoples Bay (UWA 2014); Lancelin (UWA 2264).

*Amanita xanthocephala* (Berk.) Reid & Hilton in Aust. J. Bot. Suppl. Ser. No. 8 p. 65 (1969). Swan River, as *Agaricus (Volvaria) xanthocephalus* Drummond No. 107 (K\*); Margaret River, as *Amanita pulchella* (Cooke & Masee) Gilbert, (UWA 227); Porongorups (UWA 289); Churchman Brook (UWA 1633). Reid (Victorian Naturalist, 1968) pointed out that the name *pulchella* had been given to an *Amanitopsis* and became pre-occupied for *Amanita*; he proposed the epithet *austropulchella*. Later the identity with Berkeley's *Ag. xanthocephalus* was realised (Reid 1979), (Hilton 1982).

## Family Bolbitiaceae

*Agrocybe pediades* see *Agrocybe semiorbicularis*.

*Agrocybe semiorbicularis* (Fr. ex Bull.) Fayod in Ann. Sci. Nat., Bot., Ser. 7, 9:181 (1889). Wanneroo, as *Agrocybe pediades* (Pers. ex Fr.) Fayod, (UWA 2257, 2268).

*Bolbitius boltonii* see *Bolbitius vitellinus*.

*Bolbitius fragilis* Fr. see *Bolbitius vitellinus*.

*Bolbitius vitellinus* (Pers. ex Fr.) Fr. in Epicr. Syst. mycol. p. 254 (1838). Swan River, as *Bolbitius fragilis* Fr., Drummond No. 118 (K); Crawley (UWA 1273); Bassendean, as *Bolbitius boltonii* (Pers. ex Fr.) Fr., (UWA 1698).

*Conocybe rickenii* (J. Schaeff.) Kühner in Galera p. 115 (1935). Wanneroo, as *Galera siliginea* (Fr. ex Fr.) Quél., (UWA 2215).

## Family Boletaceae

*Boletellus ananas* (Curtis) Murrill in Mycologia 1:10 (1909). Glencagle (UWA 1889); Bunbury (UWA 2124). The species described by Cooke & Masee as *Strobilomyces pallescens*, placed in *Boletellus* by Gilbert.

*Boletellus obscure-coccineus* (Hoehn.) Singer in Farlowia 2:127 (1945). Mt. Helena (UWA 1726); Pickering Brook (UWA 1728); Snake Gully (UWA 2115); Manjimup (UWA 1708).

*Boletellus pallescens* see *Boletellus ananas*.

*Boletus alliciens* Berk. in Lond. J. Bot. 4:50 (1845). Swan River, Drummond No. 156 (K\* but not found).

*Boletus arenarius* Fr. in Lehmann Pl. Preiss. 2:134 (1846). Swan River (Herb. Preiss No. 2680\*).

*Boletus caesarcus* Fr. in Lehmann Pl. Preiss. 2:134 (1846). Perth Town (Herb. Preiss No. 2678\*, 2679).

*Boletus cyanescens* see *Gyroporus cyanescens*

*Boletus granulatus* see *Suillus granulatus*.

*Boletus infractus* Fr. in Lehmann Pl. Preiss. 2:134 (1846). W. Australia (Herb. Preiss No. 2677\*).

*Boletus luteus* see *Suillus luteus*.

*Boletus marginatus* see *Phaeogyroporus portentosus*.

*Boletus polyporoides* see *Phaeogyroporus portentosus*.

*Boletus portentosus* see *Phaeogyroporus portentosus*.

*Boletus sinape-cruentus* Cleland in Trans. R. Soc. S. Aust. 58: 213 (1934). Kalamunda (UWA 2266).

*Boletus subsimilis* Preiss in Lehmann Pl. Preiss. 2:134 (1846). Description\* only; neither specimen nor drawing.

*Boletus sphacroccephalus* Barla in Champ. Nice p. 72 (1859). Kalamunda (UWA 1856); Pemberton (UWA 2067).

*Gyroporus cyanescens* (Fr.) Quél. in Ench. fung. p. 161 (1886). Tammin, as *Boletus cyanescens*, (UWA 2308).

*Phaeogyroporus portentosus* (Berk. & Broome) McNabb in N.Z. J. Bot., 6:142 (1968). Swan River, as *Boletus marginatus* Berk., Drummond No. 155 (K\*). Merredin, as *Boletus polyporoides* Gentilli\* n. sp. West. Aust. Nat. 1:142 (1947) non rite publicatum; Dryandra Reserve, as *Boletus portentosus*, (UWA 1988); Ongerup (UWA 1870).

*Phylloporus hyperion* (Cooke & Masee) Singer in Sydowia 9:420 (1955). Star Swamp (UWA 2272); King's Park (UWA 1930). Singer (1955) uses the epithet *hypericon*, which can be rejected as an orthographic error.

*Porphyrellus pseudoscaber* (Secretan) Singer in Farlowia 2:115 (1945). Star Swamp (UWA 2271); King's Park (UWA 2405).

*Strobilomyces pallescens* see *Boletellus ananas*.

*Suillus granulatus* (L. ex Fr.) Kuntze in Revis. Gen. Pl. 3(2):535 (1898). Dwellingup, as *Boletus granulatus*, (UWA 1850).

*Suillus luteus* (L. ex Fr.) Gray in Nat. Arr. Br. Pl. 1:646 (1821). Gleneagle, as *Boletus luteus*, (UWA 1833).

## Family Cantharellaceae

*Cantharellus cibarius* see *Cantharellus viscosus*.

*Cantharellus lilacinus* Cleland & Cheel in Trans. R. Soc. S. Aust. 43:271 (1919). Pemberton (UWA 1696); Mt. Barker (UWA 1739); Denmark (UWA 2367).

*Cantharellus viscosus* Berk. in Lond. J. Bot. 4:49 (1845). Swan River, Drummond No. 114 (K\*). The species is described by Pegler (1965) p. 348 and Corner (1966) p. 59, both concluding that it is close to the widespread species *Cantharellus cibarius* Fr.

*Craterellus multiplex* see *Podoserpula pusio*, Coniophoraceae, Aphyllophorales.

*Craterellus pusio* see *Podoserpula pusio*, Coniophoraceae, Aphyllophorales.

## Family Coprinaceae

*Coprinus atramentarius* (Bull. ex Fr.) Fr. in Epicr. Syst. mycol. p. 243 (1838). Esperance (UWA 1336).

*Coprinus comatus* (Muller ex Fr.) Gray in Nat. Arr. Br. Pl. 1:633 (1821). Floreat Park (UWA 820); Crawley (UWA 1217); Esperance (UWA 1588).

*Coprinus disseminatus* (Pers. ex Fr.) Gray in Nat. Arr. Br. Pl. 1:634 (1821). Porongorups, as *Psathyrella disseminata*, (UWA 359); King's Park (UWA 1427).

*Coprinus micaceus* (Bull. ex Fr.) Fr. in Epicr. Syst. mycol. p. 247 (1838). Peppermint Grove (UWA 1425); Crawley Campus (UWA 899).

*Coprinus patouillardii* Quél. apud Pat. in Tab. anal. Fung. 107 (1884). Belmont (UWA 1685).

*Coprinus phlyctidosporus* Romagnesi in Rev. mycol. 10:73 (1945). Lesmurdie, from base rot of passion vine (K).

*Coprinus plicatilis* (Fr.) Fr. in Epicr. Syst. mycol. p. 252 (1838). Mondrain Is. (MEL); Lake Joondalup (UWA 2212).

*Lacrymaria asperospora* (Cleland) Watling in Notes Roy. Bot. Gdn. Edinburgh 37:370 (1979). Warren Forest Park (UWA 1871).

*Panaeolina foenicisii* (Pers. ex Fr.) Maire in Treballs del Museu De Ciencies Nat. Barcelona 15:109 (1933). Pemberton (UWA 2218); Wanneroo (UWA 2127).

*Panaeolus campanulatus* (Fr.) Quél. in Champ. Jura 1:151 (1872). Cannington as *Panaeolus sphinctrinus* (Fr.) Quél. (UWA 2300).

*Panaeolus ovatus* (Cooke & Masee) Sacc. in Syll. Fung. 9:147 (1889). Dampier (UWA 2281).

*Panaeolus retirugis* Fr. in Epicr. Syst. mycol. p. 235 (1838). Belmont (UWA 406); Bibra Lake (UWA 2118).

*Panaeolus sphinctrinus* (Fr.) Quél. in Champ. Jura 1:151 (1872). Wanneroo (UWA 2270).

*Panaeolus sphinctrinus* see *Panaeolus campanulatus*.

*Psathyrella candolleana* (Fr.) Maire in Mem. Soc. Sci. Nat. Maroc 45:112 (1937). Pemberton (UWA 2189).

*Psathyrella disseminata* see *Coprinus disseminatus*.

## Family Cortinariaceae

**Cortinarius basirubescens** Cleland & Harris in Rec. S. Aust. Museum 45 (1948). Denmark (UWA 2321).

**Cortinarius erythracus** Berk. in Lond. J. Bot. 4:48 (1845). Swan River, Drummond No. 112 (K\*); Perth (UWA 1921) (K). Moser & Horak (1975) p. 574 equate *C. ruber* Cleland with this species.

**Cortinarius radicans** Cleland in Trans. Roy. Soc. S. Aust. 57:191 (1933). Mundaring Weir (UWA 1895); Perup River (UWA 2025); Kalamunda (UWA 2031); Dale Forest (UWA 2088); Wanneroo (UWA 2119) (UWA 2123).

*Cortinarius ruber* see **Cortinarius erythracus**.

**Crepidotus lepton** (Berk.) Sacc. in Syll. Fung. 5:885 (1887). Swan River, as *Agaricus lepton*, Drummond No. 299 (K\*). Discussed by Pilát, Trans. Br. mycol. Soc. 33:226 (1950) and Pegler (1965) p. 338.

*Crepidotus mollis* see **Crepidotus uber**.

**Crepidotus subhaustellaris** Cleland in Trans. Roy. Soc. S. Aust. 48:242 (1924), Mondrain Is. (MEL).

**Crepidotus uber** (Berk. & Curtis) Sacc. in Syll. Fung. 5:878 (1887). Swan River, as *Agaricus mollis* Fr. Drummond No. 129 (K), No. 272 (K), No. 296 in part (K).

*Flammula carbonaria* see **Pholiota highlandensis**, Strophariaceae.

*Flammula eucalyptorum* see **Gymnopilus penetrans**.

*Galera siligena* see **Conocybe rickenii**, Bolbitiaceae.

**Galcrina autumnalis** (Peck) Smith & Singer in Galerina p. 236 (1964). Denmark (UWA 2370).

*Galerina marginata* see **Galerina unicolor**.

**Galerina unicolor** (Vahl ex Sommerf.) Singer in Acta Inst. Bot. Komarov. 6:468 (1950). South Perth as *Galerina marginata* (Batsch ex Secr.) Kühner (UWA 1176); Gnaranga (UWA 1700); Bentley (UWA 1699).

**Gymnopilus allantopus** (Berk.) Pegler in Aust. J. Bot. 13:324 (1965). Swan River, as *Agaricus (Pholiota) allantopus*, Drummond No. 100 (K\*).

**Gymnopilus pampeanus** (Speg.) Singer in Lilloa 22:561 (1951). Darkan, as *Pholiota spectabilis* Fr. (UWA 1989).

**Gymnopilus penetrans** (Fr. ex Fr.) Murrill in Mycologia 4:254 (1912). Kings Park (UWA 1253, UWA 1255); South Perth (UWA 1257). The fungus provisionally identified as this species, the most common stipitate lignicolous agaric in W. Australia, is more robust than the European *G. penetrans*. It fits *Flammula eucalyptorum* Cleland.

**Gymnopilus purpuratus** (Cooke & Masee) Singer in Sydowia 9:411 (1955). Riverton (UWA 1148) (K); Brunswick (UWA 2434).

**Hebeloma crustuliniforme** (Bull. ex St. Amans) Qué. in Champ. Jura 1:128 (1872). Crawley, associated with *Pinus radiata* (UWA 1688).

**Inocybe dulcamara** (Alb. & Schw. ex Pers.) Kummer in Führ. Pilzk. p. 79 (1871). Wanneroo (UWA 2259).

**Inocybe lanuginosa** (Fr.) Sacc. in Syll. Fung. 5:765 (1887). Swan River, as *Agaricus lanuginosus* Fr. non Bull. Drummond No. 229 (K).

**Naucoria centunculus** (Fr.) Kummer in Führ. Pilzk. p. 78 (1871). Wanneroo (UWA 2258).

*Naucoria drummondii* see **Pholiota drummondii**, Strophariaceae.

*Naucoria semiorbicularis* see **Agrocybe semiorbicularis**, Bolbitiaceae.

**Rozites australiensis** Cleland & Cheel in Trans. R. Soc. S. Aust. 42:90 (1918). Greenmount (UWA 2086). A good *Cortinarius*, see Moser & Horak (1975) pp. 34, 573 & 607.

## Family Entolomataceae (= Rhodophyllaceae)

**Clitopilus pleurotelloides** (Kühner) Josseland in Bull. Soc. Linn. Lyon. 1:90 (1941). Wanneroo (UWA 2262).

**Entoloma scricellum** (Fr. ex Fr.) Kummer agg. Walpole (UWA 2380).

## Family Hygrophoraceae

**Hygrocybe coccinea** (Fr.) Kummer in Führ. Pilzk. p. 112 (1871). Two Peoples Bay (UWA 2072).

**Hygrocybe conica** (Fr.) Kummer in Führ. Pilzk. p. 111 (1871). Dalkeith (UWA 1663, 1683).

## Family Lepiotaceae

**Chlorophyllum molybdites** (Meyer ex Fr.) Masee in Kew Bull. p. 136 (1898). Carnarvon (UWA 1405).

*Lepiota aurea* see **Lepiota lutea**.

**Lepiota australiana** (Fr.) Sacc. in Syll. Fung. 5:72 (1887). Mt. Eliza, as *Agaricus australis* Fr., Preiss No. 2663\*.

**Lepiota bubalina** (Berk.) Sacc. in Syll. Fung. 5:69 (1887). Oolingyarrak, or similar name, as *Agaricus (Lepiota) bubalinus* (K\*). Aberdeen (1962) comments that the type is but one poor, immature, specimen doubtfully a *Lepiota*, *Cystoderma* or *Limacella*. No name similar to Oolingyarrak is listed in the Australia 1:250 000 Map Series Gazetteer (1975). Reject as a Western Australian species.

**Lepiota excoriata** (Fr.) Sacc. in Syll. Fung. 5:31 (1887). Swan River, as *Agaricus (Lepiota) excoriatus*, (K). Drummond No. 108.

*Lepiota leucothites* see **Leucoagaricus naucinus**.

**Lepiota lutea** (Bolt. ex Secr.) Godfrin in Bull. Soc. Mycol. Fr. 13:33 (1897). Nedlands, as *Lepiota aurea* Masee, (UWA 2006).

*Lepiota naucina* see **Leucoagaricus naucinus**.

**Lepiota procera** (Scop. ex Fr.) S. F. Gray in Nat. Arr. Br. Pl. 1:601 (1821). Upper Swan (K). Aberdeen (1962) comments that the spores were quite characteristic of the species but the specimens small.

**Lepiota rhacodes** (Vitt.) Qué. in Champ. Jura 1:32 (1872). Nedlands (UWA 979); Applecross (UWA 1152).

**Lepiota rhizobola** (Berk.) Sacc. in Syll. Fung. 5:41 (1887). Swan River, as *Agaricus (Lepiota) rhizobolus*, Drummond No. 106 (K\* but not found). It can be assumed to be based on an *Amanita*, (Hilton 1982).

**Lepiota rhytipelta** (Mueller ex Kalchbr.) Sacc. in Syll. Fung. 9:7 (1892). Lake Muir, as *Agaricus (Lepiota) rhytipelta*, coll. Thomas Muir 1879 (MEL\*).

**Leucogarius macrorrhizus** (Locquin) Singer in Lilloa 22:418 (1951). Nedlands (UWA 2233).

**Leucoagaricus naucinus** (Fr.) Singer in Lilloa 22:418 (1951). Esperance, as *Lepiota naucina* (UWA 1100); Pemberton, as *Lepiota leucothites* (Vitt., P. D. Orton) (UWA 1481) (K); Mundaring Weir (UWA 1474) (K).

*Macrolepiota* see **Lepiota**.

**Melanophyllum echinatum** (Roth ex Fr.) Singer in Lilloa 22:236 (1951). Denmark (UWA 2343). See Pegler, Kew Bull. 21:504 (1968) for description.



## Family Paxillaceae

**Paxillus eucalyptorum** Berk. in Lond. J. Bot. 4:49 (1845). Swan River, under York Gum (*Eucalyptus loxophleba* Benth.), Drummond No. 111 (K\* but not found) probably a *Lentius*, not *Paxillus* (Hilton 1982).

*Paxillus infundibuliformis* see **Paxillus muelleri**.

**Paxillus involutus** (Batsch ex Fr.) Fr. in Hymen. Eur. p. 403 (1874). Crawley Campus (UWA 1297).

**Paxillus panuoides** (Fr. ex Fr.) Fr. in Hymen. Eur. p. 404 (1874). Beking Pine Plantation (UWA 1677); Pemberton (UWA 1742); Kalamunda (UWA 2062).

**Paxillus muelleri** (Berk.) Sacc. in Syll. Fung. 5:986 (1887). Pingelly, as *Paxillus infundibuliformis* Cleland (UWA 998); Mt. Dale (UWA 2089); Quininup (UWA 2116); King's Park (UWA 2159). Singer (Farlowia 2:284, 1945) placed the species in *Phylloporus*, as did Reid (Kew Bull. 10:645) but Horak (Sydowia 32:156) retains as **Paxillus**.

## Family Pluteaceae (= Volvariaceae)

*Locellina cynopotamia* see **Volvariella cynopotamia**.

**Pluteus atromarginatus** (Konrad) Kühner in Bull. Soc. Linn. Lyon. 4:51 (1935). Mundaring Weir (UWA 1204).

**Pluteus cervinus** (Schaeff. ex Fr.) Kummer in Führ. Pilzk. p. 99 (1871). Bentley (UWA 981); Bassendean (UWA 1003); Boddington (UWA 1073).

*Volvaria xanthocephala* see **Amanita xanthocephala**, Amanitaceae.

**Volvariella bombycina** (Schaeff. ex Fr.) Singer in Lilloa 22:401 (1951). Crawley (UWA 1219).

**Volvariella cynopotamia** (Berk.) Singer in Sydowia 15:67 (1962). Swan River, as *Agaricus (Acetabularia) cynopotamia*, Herb. Berkeley (K\*). Saccardo (Syll. Fung. 5:762) classifies as a *Locellina*. Pegler (1965) p. 329 confirmed this as a species of *Volvariella*.

**Volvariella speciosa** (Fr. ex Fr.) Singer in Lilloa 22:401 (1951). Esperance (UWA 1566); Condingup (UWA 1065); King's Park (UWA 819). Specimens so far collected intergrade with var. *gloiocephala* (DC ex Fr.).

## Family Russulaceae

**Russula lepida** Fr. in Epicr. Syst. mycol. p. 355 (1838). Mondrain Is. (MEL).

**Russula delicata** Fr. in Epicr. Syst. mycol. p. 350 (1838). Wanneroo (UWA 2093).

**Russula persanguinea** Cleland in Trans. R. Soc. S. Aust. 57:193 (1933). Forrestdale (UWA 876).

**Russula flocktonae** Cleland & Cheel in Trans. R. Soc. S. Aust. 43:274 (1919). Mundaring (UWA 1226).

**Russula erumpens** Cleland & Cheel in Trans. R. Soc. S. Aust. 43:279 (1919). King's Park (UWA 1158).

## Family Strophariaceae

*Hypholoma* see **Naematoloma**.

**Naematoloma ericaeum** (Fr.) Kühner in Bull. trimest. Soc. mycol. Fr. 52:23 (1936). W. Aust., as *Agaricus (Psilocybe) ericaeum* (Herb. Preiss. 2668). Cannington as *Hypholoma ericaeum* (UWA 2101) (E). Cleland's *Psilocybe subnuda* is referable to this complex, according to Guzman & Watling, Notes Roy. Bot. Gard. Edinb. 36:201 (1978).

**Naematoloma fasciculare** (Huds. ex Fr.) Kummer in Führ. Pilzk. p. 72 (1871). Manjimup (UWA 1658); Mundaring Weir (UWA 1943).

*Pholiota allantopoda* see **Gymnopilus allantopus**, Cortinariaceae.

**Pholiota bicincta** (Kalchbr.) McAlpine in Systematic Arrangement of Australian Fungi p. 32 (1895). Swan River, as *Agaricus bicinctus* sent by von Mueller. Kalchbrenner in Proc. Linn. Soc. N.S.W. 7:639 (1882) comments that it is close to the European species *Pholiota heteroclita* (Fr.) Quéf.

*Pholiota carbonaria* see **Pholiota highlandensis**.

**Pholiota drummondii** (Berk.) Pegler in Aust. J. Bot. 13:330 (1965). Swan River, as *Agaricus (Naucoria) drummondii*, Drummond No. 116 (K\*).

**Pholiota eriogena** (Fr.) Sacc. in Syll. Fung. 5:758 (1887). W. Aust., as *Agaricus (Pholiota) eriogenus*, (Herb. Preiss. No. 2664\*).

*Pholiota fulvizonata* see **Pholiota highlandensis**.

**Pholiota highlandensis** (Peck) A. H. Smith & Hesler in North American Species of *Pholiota* p. 287 (1968). Mt. Dale (UWA 1941); King's Park (UWA 1863, 2152); Mundaring (UWA 2069); Mundaring Weir (UWA 2099, 2302) (K); Denmark (UWA 2374) (K). Early records are as *Flammula*. This common fungus of burnt forest is in the Carbonicolae section of Smith & Hesler (ibid. p. 278) but variants have affinity with *P. carbonaria* (Fr.) Sing. and *P. fulvizonata* A. H. Smith also of this section.

**Pholiota praecox** (Fr.) Sacc. in Syll. Fung. 5:738 (1887). W. Aust., *Agaricus (Pholiota) praecox* (Herb. Preiss. No. 2703).

*Pholiota spectabilis* see **Gymnopilus pampeanus**, Cortinariaceae.

**Pholiota squarrosa** (Pers. ex Fr.) Kummer in Führ. Pilzk. p. 84 (1871). Denmark (UWA 2371).

**Psilocybe atrorufa** (Schaeff. ex Fr.) Quéf. in Ench. fung. p. 114 (1886). W. Aust., as *Agaricus (Deconica) atrorufus* Preiss, drawing only. See Guzman & Watling, Notes Roy. Bot. Gard. Edinb. 36:200 (1978).

**Psilocybe coprophila** (Bull. ex Fr.) Kummer in Führ. Pilzk. p. 71 (1871). Wanneroo (UWA 2261); Cannington (UWA 2299).

*Psilocybe ericaea* see **Naematoloma ericaeum**.

*Psilocybe subnuda* see **Naematoloma ericaeum**.

**Stropharia scmiglobata** (Fr.) Sacc. in Syll. Fung. 5:1022 (1887). W. Aust., as *Agaricus (Psalliota) semiglobatus* (Herb. Preiss No. 2667); Mundaring Weir (UWA 1673); Gleneagle Forest (UWA 1691).

## Family Tricholomataceae

*Acanthocystis hepatotrichus* see **Lentinellus hepatotrichus**, Auriscalpiaceae, Aphyllophorales.

**Anthracophyllum archeri** (Berk.) Pegler in Aust. J. Bot. 13:324 (1965). Swan River, as *Xerotus drummondii* Berk. (K\*); Long, Mondaine, & Middle Is., as *Xerotus archeri* (MEL); Pemberton (UWA 1671); Dwellingup (UWA 1689); Esperance (UWA 1761). Pegler (1965) p. 330 describes, and equates the type material of *X. drummondii* with *A. archeri*.

**Clitocybe dealbata** (Sow. ex Fr.) Kummer in Führ. Pilzk. p. 121 (1871). Gngara (UWA 2100); Glen Forrest (UWA 2290).

**Clitocybe gilva** Fr. in Hymen. Eur. p. 95 (1874). Swan River, as *Agaricus gilvus*, Drummond No. 115 (K). Berkeley named No. 115, which represents fragments of a smaller fungus than typical *C. gilva*, as a variety.

**Clitocybe semioculta** Cleland in Trans. R. Soc. S. Aust. 51:300 (1927). King's Park (UWA 1259).

- Collybia fusipes* (Bull. ex Fr.) Quél. in Champ. Jura 1:57 (1872). Wanneroo (UWA 2078).
- Collybia lepidopoda* (Fr.) Sacc. in Syll. Fung. 5:225 (1887). W. Aust.\*, as *Agaricus (Collybia) lepidopus*, from drawing by Preiss, no locality given or specimen cited.
- Collybia radicata* see *Oudemansiella radicata*.
- Geopetalum applicatum* see *Resupinatus applicatus*.
- Hohenbuehelia atrocaerulea* (Fr.) Singer in Agaricales (1949) p. 255. Swan River, as *Agaricus atro-caeruleus*, Drummond No. 131 (K); Barton's Mill, as *Pleurotus* (UWA 2267) (K).
- Laccaria laccata* (Scop. ex Fr.) Berk. & Broome in Ann. & Mag. Nat. Hist. 12:370 (1883). Nedlands (UWA 997); Condingup (UWA 1140).
- Lentinellus* see Auriscalpiaceae, Aphyllophorales.
- Lentinus dactyloides* Cleland in Trans. R. Soc. S. Aust. 59:220 (1935). Pemberton (UWA 2076). Cleland (1934) states that it was described in South Australia from karri railway sleepers imported from Western Australia.
- Lentinus dealbatus* Fr. in Lehmann Pl. Preiss. 2:133 (1846). Kelmscott, as "Kelmsedth" (Herb. Preiss. No. 2669\*).
- Lentinus fasciatus* see *Panus fasciatus*.
- Lentinus hepatotrichus* see *Lentinellus hepatotrichus*, Auriscalpiaceae, Aphyllophorales.
- Lentinus lepideus* (Fr. ex Fr.) Fr. in Hymen. Europ. p. 526 (1874). Dalyup (UWA 1579) (K); Esperance (UWA 1592) (K); Esperance (UWA 1854); Karra-gullen, on dead macrozamia, (UWA 2084); North-cliffe, on macrozamia stump (UWA 2087).
- Lentinus terrestris* see *Panus fasciatus*.
- Lepista nuda* (Bull. ex Fr.) Cooke in Hand. Br. Fung. 1:192 (1871). Swan River, as *Agaricus personatus*, Fr. ex Fr. Drummond No. 128 (K).
- Melanoleuca melaleuca* (Pers. ex Fr.) Murrill in Mycologia 3:167 (1911). Melville (UWA 1227); Cannington (UWA 1415); Crawley (UWA 1459); Applecross (UWA 1470).
- Mycena crinalis* (Berk.) Sacc. in Syll. Fung. 5:289 (1887). Swan River, *Agaricus (Mycena) crinalis*, Drummond No. 221 (K\*).
- Mycena leptoccephala* (Pers. ex Fr.) Gill. in Hymen. p. 267 (1874). Mondrain Is. (MEL).
- Mycena pura* (Pers. ex Fr.) Kummer in Führ. Pilzk. p. 107 (1871). Mundaring Weir (UWA 1430).
- Mycena subgalericulata* Cleland in Trans. R. Soc. S. Aust. 55:156 (1931). Boxer Is. (MEL); Dwellingup (UWA 418).
- Oudemansiella radicata* (Relhan ex Fr.) Singer in Ann. mycol. Berl. 34:333 (1936). Porongorups, as *Collybia radicata*, (UWA 426); Tuttaning Reserve (UWA 1004); Garden Is. (UWA 1351); Esperance (UWA 1381); Mundaring Weir (UWA 2278).
- Oudemansiella radicata* var. *superbiens* (Berk.) Sacc. in Syll. Fung. 5:201 (1887). Swan River, as *Collybia radicata*, Drummond No. 119 (K\*). Reported on by Pegler (1965) p. 345.
- Panus cinnabarinus* Fr. in Lehmann Pl. Preiss. 2:133 (1846). Darling Range near to Kelmscott\*, as "Kelmstedt" (Herb. Preiss No. 2671).
- Panus fasciatus* (Berk.) Pegler in Aust. J. Bot. 13:331 (1965). Swan River, as *Lentinus fasciatus*, Berkeley Herbarium (K); Yeeda Station, nr. Derby (K), as *Lentinus fasciatus*, see Reid, Kew Bull. 10:643 (1955); Tutanning (UWA 1250) (K); Karnet (UWA 1260). Broughton and Hilton, J. Roy. Soc. W.A. 55:31 (1972), describe the structure in detail and show that this fungus is not synonymous with *Lentinus terrestris* Lloyd, as suggested by Cleland (1934) p. 171.
- Pleurotellus chioneus* (Pers.) Kühner in Botaniste 17:114 (1926). Swan River on dry dung, as *Agaricus chioneus*, Drummond, s.n. (K).
- Pleurotus atrocaeruleus* see *Hohenbuehelia atrocaerulea*.
- Pleurotus chioneus* see *Pleurotellus chioneus*.
- Pleurotus eucalyptorum* (Fr.) Sacc. in Syll. Fung. 5:364 (1887). W. Aust., as *Agaricus (Pleurotus) eucalyptorum*, on bark of eucalyptus no locality cited (Preiss No. 2666\*).
- Pleurotus hepatotrichus* see *Lentinellus hepatotrichus*, Auriscalpiaceae, Aphyllophorales.
- Pleurotus lampas* see *Pleurotus nidiformis*.
- Pleurotus nidiformis* (Berk.) Sacc. in Syll. Fung. 5:357 (1887). Swan River, as *Agaricus nidiformis* (K\* but not found); as *Pleurotus lampas* Berk., Drummond No. 109 (K\*); Mondrain Is. (MEL); Peppermint Grove (UWA 1186); Perth (UWA 1261). Bibliography: Willis, J. H. (1967) *Muelleria* 1:213. The W. Australian species is known to induce nausea on eating.
- Pleurotus ostreatus* (Jacq. ex Fr.) Kummer in Führ. Pilzk. p. 105 (1871). W. Australia (K). Recorded by Reid, Kew Bull. (1955) p. 643.
- Pleurotus perpusillus* (Fr.) Sacc. in Syll. Fung. 5:383 (1887). Swan River, as *Agaricus perpusillus*, Drummond No. 132 (K).
- Resupinatus applicatus* (Batsch ex Fr.) S. F. Gray in Nat. Arr. Br. Pl. 1:617 (1821). Swan River, as *Agaricus applicatus*, Drummond No. 224 (K), No. 286 (K). Classified as a *Geopetalum* by Kühner and Romagnesi.
- Tricholoma carneo-flavidum* (Kalchbr.) McAlpine in Systematic Arrangement of Australian Fungi p. 30 (1895). Swan River, sent by F. von Mueller (not located\*).
- Tricholoma coarctatum* see *Tricholoma eucalypticum*.
- Tricholoma eucalypticum* Pearson in Trans. Br. mycol. Soc. 33:293 (1950). Mundaring Weir (UWA 1370); Pemberton (UWA 2189). This is *T. coarctatum* Cleland non Cooke & Masee.
- Tricholoma muculentum* (Berk.) Sacc. in Syll. Fung. 5:91 (1887). Swan River, *Agaricus muculentus*, Drummond No. 113 (K\*).
- Tricholoma nudum* see *Lepista nuda*.
- Tricholoma plagiotum* (Kalchbr.) McAlpine in Systematic Arrangement of Australian Fungi. p. 30 (1895). Swan River, sent by F. von Mueller (not located\*).
- Tricholoma rutilans* see *Tricholomopsis rutilans*.
- Tricholoma turbinipes* (Kalchbr.) McAlpine in Systematic Arrangement of Australian Fungi. p. 30 (1895). Swan River, sent by F. von Mueller (not located\*).
- Tricholomopsis rutilans* (Fr.) Singer in Schweiz. Zeitschr. Pilzk. 17:13 (1939). Serpentine, as *Tricholoma rutilans*, (UWA 1649); Perth (UWA 2251).
- Xerotus drummondii* see *Anthrachophyllum archeri*.

Order Aphyllophorales

Family Auriscalpiaceae

*Auriscalpium barbatum* Maas G. in Persoonia 9:491 (1978). Bremer Bay (UWA 2149\*) (L\*).

- Lentinellus cochleatus** (Fr.) Karsten in Bidr. Kann. Finl. Nat. Folk 32:246 (1879). New Holland, as *Lentius cochleatus*, (Herb. Preiss, No. 2670); King's Park (UWA 1254) (K).
- Lentinellus hepatotrichus** (Berk.) Reid in Kew Bulletin, 10:642 (1956). Chittering Lakes, on living *Eucalyptus rudis*, (K); Ludlow Forest, on living Tuart, (K); Yanchee (UWA 1262); Denmark (UWA 2377); Wembley Downs (UWA 1424). The South Australian fungus described by Cleland as this fungus, and recombined by him as *Pleurotus* (subsequently recombined by Singer as an *Acanthocystis*) is (*vide* Reid *loc. cit.*) a *Hohenbuehelia*, and an unrelated species. The Chittering Lakes specimen is thus the first record for the Australian mainland.

## Family Clavariaceae

- Clavaria botrytes** see **Ramaria botrytoides**.
- Clavaria botrytis** spelling variant on *botrytes* q.v.
- Clavaria flaccida** see **Ramaria flaccida**
- Clavaria helvola** see **Clavulinopsis helvola**.
- Clavaria juncea** see **Clavariadelphus juncea**.
- Clavaria (Ramaria) phlebeja** see **Clavaria plebeia**.
- Clavaria plebeia** Fr. in Lehmann Pl. Preiss. 2:137 (1846). Western Australia, as *Clavaria (Ramaria) phlebeja*, (Herb. Preiss. No. 2690\*). Corner (1950) p. 714 lists only, under the correct spelling *plebeia*.
- Clavaria setulosa** see **Lachnoeladium setulosum**.
- Clavariadelphus juncea** (Fr.) Corner in Ann. Bot. Memoirs 1:275 (1950). Denmark, as *Clavaria juncea* (UWA 2352).
- Clavulinopsis helvola** (Fr.) Corner in Ann. Bot. Memoirs 1:372 (1950). Denmark, as *Clavaria helvola* (UWA 2351).
- Lachnoeladium setulosum** (Berk.) Lév. in Ann. Sc. Nat. Ser. 3:5 (1846). Swan River, as *Clavaria setulosa*, Drummond No. 199 (K\*).
- Ramaria botrytoides** (Peck) Corner in Ann. Bot. Memoirs 1:562 (1950). Swan River, as *Clavaria botrytes*, Drummond No. 197, 198 (K). Corner (1950) p. 563 comments that this is common in all southern parts of Australia.
- Ramaria flaccida** (Fr.) Ricken in Vademecum p. 254 (1918). Kalamunda, as *Clavaria flaccida*, (UWA 2231) (K).

## Family Coniophoraceae

- Craterellus multiplex** see **Podoserpula pusio**.
- Podoserpula pusio** (Berk.) Reid in Kew Bull. 16:439 (1963). Forrestdale, as *Craterellus multiplex* Cooke & Masee (UWA 874); Two Peoples Bay (UWA 2022); Dwellingup (UWA 2113).
- Serpula lacrymans** Gray in Nat. Arr. Br. Pl. 1:637 (1821). Swan River, as *Merulius lacrymans*, Drummond No. 269 (K). There is no authenticated specimen of Dry Rot from W. Australian buildings, and collections from the forest have proved to be *S. himantioides*.
- Serpula himantioides** (Fr.) G. Cunn. in Polyp. N.Z. p. 328 (1964). Dwellingup, as *Merulius himantioides*, (UWA 68); Karragullen (UWA 93).

## Family Corticiaceae

- Corticium comedens** see **Vuilleminia comedens**.
- Corticium incarnatum** see **Peniophora incarnata**.
- Corticium radicale** see **Steccherinum ochraceum**, Hydnaceae.

**Corticium vinosum** see **Lopharia crassa**, Stereaceae.

**Hypodontia arguta** (Fr.) J. Eriksson in Symb. bot. Ups. 16:104 (1958) Hydnaceae, (MEL). Mondrain Is., as *Odontia arguta*.

**Merulius corium** Fr. in Elench. fung. 1:58 (1828). Swan River, Drummond No. 249 (K), 253 (K); Pemberton (UWA 747).

**Merulius lacrymans** see **Serpula lacrymans**, Coniophoraceae.

**Peniophora incarnata** (Fr.) Karsten in Hedwigia 28:27 (1889). Swan River, as *Corticium incarnatum*, Drummond No. 165 (K).

**Seytinostroma portentosum** (Berk. & Curtis) Donk in Fungus 26:20 (1956). Boxer Is., Sandy Hook Is., as *Vararia portentosa*, (MEL).

**Vararia portentosa** see **Seytinostroma portentosum**.

**Vuilleminia comedens** (Fr.) Maire in Bull. Soc. Mycol. Fr. 18 supp. p. 81 (1902). Recorded Berkeley (1845) as *Corticium comedens*. Swan River, as *Thclephora comedens*, Drummond s.n. (K).

## Family Fistulinaceae

**Fistulina hepatica** Fr. in Syst. mycol. 1:396 (1821). Crawley (UWA 329); Dwellingup (UWA 1496); Gleneagle (UWA 1905); Mt. Dale (UWA 1933) (K); Pickering Brook (UWA 2032). Tamblyn (M.Sc. 1936) comments that this is the most common fungus on living jarrah trunks, and that it is associated with 'pencilled wood' but not with obvious decay. Meagher (1974) cites a red 'boletus' eaten by aborigines that can be only this species.

## Family Ganodermataceae

- Ganoderma applanatum** (Gray) Pat. in Hymen. Eur. p. 143 (1887). Pemberton (UWA 1349); Churchmans Brook (UWA 1020).
- Ganoderma lucidum** (Fr.) Karsten in Rev. Mycol. 3:17 (1881). Drysdale River National Park, at base of *Terminalia grandiflora* Benth., (UWA 2137).

## Family Hydnaceae

- Hydnellum scrobiculatum** (Fr. ex Secr.) P. Karst. in Fl. Fenn. 5:41 (1880). Mundaring Forest, as *Hydnum scrobiculatum* (UWA 1232) (K).
- Hydnum dispersum** Berk. in Lond. J. Bot. 4:58 (1845). Swan River, Drummond No. 207 (K\*).
- Hydnum investiens** Berk. in Lond. J. Bot. 4:57 (1845). Swan River, Drummond No. 138 (K\*).
- Hydnum isidioides** see **Sarcodontia isidioides**.
- Hydnum repandum** L. ex Fr. in Syst. mycol. 1:400 (1821). Two Peoples Bay (UWA 2195).

**Odontia arguta** see **Hypodontia arguta**, Corticiaceae.

**Sarcodontia isidioides** (Berk.) Reid in Kew Bull. 10:641 (1956). Swan River, as *Hydnum isidioides*, Drummond No. 149 (K\*) on hymenium of *Polyporus gryphaeiformis* Berk. n. sp.

**Steccherinum ochraceum** (Pers.) Gray in Nat. Arr. Br. Pl. 1:651 (1821). Swan River, as *Corticium radicale* Berk. Drummond No. 162 (K\*). Masee recombined as *Stereum radicale* (Berk.) Masee. Cunningham (1963) p. 339 recognised the type specimen as being identical with a fungus already named *S. ochraceum*.

## Family Hymenochaetaceae

**Coltriciella dependens** (Berk. & Curt.) Murrill in Bull. Torrey bot. Cl. 3:348 (1904). Julimar, as *Coltricia dependens*, (UWA 1665); King's Park (UWA 1849).



- Coltricia cinnamomea** (Pers.) Murrill in Bull. Torrey bot. Cl. 31:343 (1904). Swan River, as *Polyporus oblectans*, Berk. Drummond No. 157 (K\*); Swan River as *Polyporus cladonia* Berk. Drummond No. 220 (K\*); as *Polyporus bulbipes* Fr. (Preiss No. 2682) (UPS\*). Saccardo placed as *Polystictus*, and Cunningham as *Coltricia* under the one species *C. oblectans*.
- Coltricia dependens* see *Coltriciella dependens*.
- Hymenochaete rubiginosa** (Fr.) Lév. in Ann. Sc. Nat. Bot. Ser. 3, 5:151 (1846). Swan River, as *Stereum rubiginosum*, Drummond No. 161 (K).
- Hymenochaete vinosa* see *Lopharia crassa*, Stereaceae.
- Phellinus ferruginosus** (Fr.) Pat. in Essai taxon. p. 97 (1900). Swan River, as *Polyporus ferruginosus*, Drummond s.n. (K). Described by Saccardo as *Poria ferruginosa* in Syll. Fing. 6:327 (1888), and Cunningham (1965) p. 215 under *Fuscoporia punctata* (Fr.) G. Cunn. see Ryvardeen (1978) p. 337.
- Phellinus gilvus** (Schwein.) Pat. in Essai Hymén p. 97 (1900). Swan River, as *Polyporus gilvus* Drummond No. 247 (K, not found), Drummond No. 278 (K, not found); Leederville, as *Fomes gilvus*, (K). It has a variety of forms according to Ryvardeen (1978) p. 364.
- Phellinus hamatus* see *Phellinus setulosus*.
- Phellinus igniarius** (Fr.) Qué. in Ench. fung. p. 172 (1886). Swan River, *Polyporus igniarius*, Drummond No. 143, No. 146 (K, but not found). Cunningham (1965) p. 273 points out that all specimens at Kew on which Cooke (1892 p. 131) based his Australian records were of other species, and Ryvardeen (1978) gives the distribution as entirely North Temperate.
- Phellinus lukinsii** Walters in Trans. Brit. Mycol. Soc. 52:499 (1969). Collie (K\*) (MEL\*).
- Phellinus rimosus** (Berk.) Pilát in Ann. Myc. 38:80 (1940). Swan River, as *Polyporus rimosus*, Drummond No. 144 (K\* but not found); W. Aust., *Polyporus fulvus* Scop. ex. Fr. (Herb. Preiss. No. 2683\*) = *Fomes pomaceus* (Pers.) Lloyd; King George's Sound, as *Fomes fulvus* (Scop. ex. Fr.) Gill. (K); North Twin Peaks Is., as *Fomes rimosus*, (MEL); Mt. Arid (K). Common on wandoo, in which it causes a distinctive pocket rot.
- Phellinus robustus** (Karst.) Bourd. & Galz. in Hymén. Fr. p. 616 (1928). Ludlow State Forest (K). More records may prove to be this species, as it has a variety of forms according to Ryvardeen (1978) p. 364.
- Phellinus scruposus** (Fr.) G. Cunn. in Polyp. N. Z. p. 230 (1965). King Georges Sound, as *Fomes fomentarius* (L. ex Fr.) Fr. (K); Remark Is., Mondrain Is., as *Fomes scruposus*, (MEL); Byford (K).
- Phellinus setulosus** (Lloyd) Imazeki in Bull. Tokyo Sci. Museum 6:104 (1943). W. Aust., as *Fomes hamatus* (Corner) Imazeki, on jarrah, (K); Long Is., Mondrain Is., Middle Is., as *Fomes setulosus* (MEL); Prince Regent River (UWA 1950).
- Family Polyporaceae
- Bjerkandera fumosa** (Fr.) Karsten in Medd. Soc. Fauna Fl. Fenn. 5:38 (1879). Swan River, as *Polyporus demissus* Berk. Drummond No. 150 (K\*). Under *Gloeoporus theleporoides* (Hooker) G. Cunn. in Cunningham 1965 p. 111.
- Chaetoporus euporus** (Karsten) Bondarzew & Singer in Ann. Myc. 39: 51 (1941). Porongorups (UWA 455).
- Coriolus azureus* see *Coriolus versicolor*.
- Coriolus velutinus* see *Coriolus versicolor*.
- Coriolus (Polystictus) versicolor** complex of the genera *Polystictus*, *Coriolus*, *Trametes*, and the species *velutinus*, *azureus*, *versicolor*. Karragullen (UWA 14); Dwellingup (UWA 45, 81); Canning Dam (UWA 977); Roleystone (UWA 1125).
- Coriolus zonata* see *Coriolus versicolor*.
- Favolus discolor* see *Hexagonia discolor*.
- Fomes fulvus* see *Phellinus rimosus*, Hymenochaetaceae.
- Fomes gilvus* see *Phellinus gilvus*, Hymenochaetaceae.
- Fomes igniarius* see *Phellinus igniarius*, Hymenochaetaceae.
- Fomes rimosus* see *Phellinus rimosus*, Hymenochaetaceae.
- Fomes fomentarius* see *Phellinus scruposus*, Hymenochaetaceae.
- Fomes griphaeformis* see *Polyporus gryphaeformis*.
- Fomes hamatus* see *Phellinus setulosus*, Hymenochaetaceae.
- Fomes pomaceus*, see *Phellinus rimosus*, Hymenochaetaceae.
- Fomes scruposus* see *Phellinus scruposus*, Hymenochaetaceae.
- Fomitopsis ochroleuca* see *Truncospora ochroleuca*.
- Fuscoporia ferruginosa* see *Phellinus ferruginosus*, Hymenochaetaceae.
- Fuscoporia punctata* see *Phellinus ferruginosus*, Hymenochaetaceae.
- Gloeophyllum concentricum** G. Cunn. in Polyp. N.Z. p. 251 (1965). Prince Regent River (UWA 1948, 1949).
- Gloeoporus dichrous** (Fr.) Bres. in Hedwigia 53:74 (1914). Mondrain Is., as *Polyporus dichrous* (MEL).
- Gloeoporus theleporoides* see *Bjerkandera fumosa*.
- Grifola campyla* see *Polyporus campylus*.
- Heterobasidion ochroleucum* see *Truncospora ochroleuca*.
- Hexagonia decipiens* see *Phaeotrametes decipiens*.
- Hexagonia discolor** Fr. in Lehmann Pl. Preiss. 2:136 (1846). Western Australia, as *Favolus discolor*, (Herb. Preiss. No. 2701 & 2702\*).
- Hexagonia gunnii* see *Hexagonia vesparius*.
- Hexagonia tenuis** Fr. in Epicr. Syst. mycol. p. 498 (1838). Prince Regent River, as *Pseudofavolus tenuis* (Hooker) G. Cunn (UWA 1962); Drysdale River (UWA 2141).
- Hexagonia vesparius** (Berk.) Ryvardeen in Kew Bull. 31:83 (1976). Swan River, Drummond No. 153 as *Hexagonia gunnii* Berk. (K); Perth (K); Mandurah (UWA 333, 868); Yanchepp (UWA 668); Ballidu (UWA 1447). Placed as *Osmoporus* by Cunningham (1965) p. 241.
- Osmoporus brunneo-leucus* see *Polystictus brunneo-leucus*.
- Osmoporus decipiens* see *Phaeotrametes decipiens*.
- Osmoporus gunnii* see *Hexagonia vesparius*.
- Perenniporia ochroleuca* see *Truncospora ochroleuca*.
- Phaeotrametes decipiens** (Berk.) Lloyd apud Wright in Mycologia 58:532 (1966). Swan River, as *Hexagonia decipiens*, Drummond No. 151, 152 (K\*); Leederville (BPI); W. Aust. (UWA 7, UWA 23); Junana Rock (K); Murchison River (K). Cunningham (1950) renamed the species *Trametes drummondii* because *Trametes decipiens* was preoccupied. Cunningham (1965) reverted to the original specific epithet when he transferred it to the genus *Osmoporus*, and the same applies to *Phaeotrametes*.

- Piptoporus australiensis** (Wakef.) G. Cunn. in Polyp. N.Z. p. 107 (1965). Geopraphe Bay as *Polyporus stipticus* Fr. (K); Porongorups as *Polyporus australiensis* (UWA 338); Yanchep (UWA 1420) (K), (UWA 1391). The cause of a brown cubical rot in wandoo, karri, yellow tingle, and tuart. Not found growing on jarrah.
- Piptoporus portentosus** (Berk.) G. Cunn. in Polyp. N.Z. p. 106 (1965). Swan River, as *Polyporus portentosus*, Drummond No. 125 (K\*), Drummond No. 142 (K); as *Polyporus eucalyptorum* Fr. (Preiss No. 2681\*); Wembley Downs (UWA 1513); Porongorups (UWA 317); King's Park (UWA 2135). A cause of brown rot in living jarrah, blackbutt, tuart, marri, and flooded gum.
- Polyporus anthracophilus* see **Polyporus campylus**.
- Polyporus applanatus* see **Ganoderma applanatum**, Ganodermataceae.
- Polyporus australiensis* see **Piptoporus australiensis**.
- Polyporus bulbipes* see **Coltricia cinnamomea**, Hymenochaetaceae.
- Polyporus campylus** Berk. in Fl. Tasm. 2:252 (1860). S.W. Aust., Thos. Muir, as *Polyporus anthracophilus* Cooke (K). Described by Cunningham (1965) p. 92, as *Grifola campyla*.
- Polyporus cervino-gilvus** Junghuhn in Prae. fl. crypt. Javae ins. p. 45 (1838). Prince Regent River (UWA 1967). Cunningham (1965) p. 96 places it in *Trichaptum*.
- Polyporus cinnabarinus* see **Pycnoporus coccineus**.
- Polyporus cladonia* sec **Coltricia cinnamomea**, Hymenochaetaceae.
- Polyporus compressus* see **Truncospora ochroleuca**.
- Polyporus demissus* see **Bjerkandera fumosa**.
- Polyporus dichrous* see **Gloeoporus dichrous**.
- Polyporus eucalyptorum* see **Piptoporus portentosus**.
- Polyporus feei* see **Trametes lilacino-gilva**.
- Polyporus ferruginosus* see **Phellinus rubiginosus**, Hymenochaetaceae.
- Polyporus fulvus* see **Phellinus rimosus**, Hymenochaetaceae.
- Polyporus gilvus* see **Phellinus gilvus**, Hymenochaetaceae.
- Polyporus gryphaeformis** Berk. in Lond. J. Bot. 4:54 (1845). Swan River, Drummond No. 149 (K\*). Saccardo, Syll. Fung. 6:183 gives it as *Fomes griphaeformis*.
- Polyporus igniarius* Fr. see **Phellinus igniarius**, Hymenochaetaceae.
- Polyporus lilacino-gilvus* see **Trametes lilacino-gilva**.
- Polyporus lucidus* see **Ganoderma lucidum**, Ganodermataceae.
- Polyporus mylittae** Cooke & Masee in Grevillea 21:37 (1892). Pemberton (UWA 1979, 1980). Bibliography: Willis, J. H., (1967) Muelleria 1:203. Macfarlane *et al.*, Trans. Br. mycol. Soc. 71:359, describe the ultrastructure of the sclerotium *Mylitta australis* Berk.
- Polyporus oblectans* see **Coltricia cinnamomea**, Hymenochaetaceae.
- Polyporus ochroleucus* see **Truncospora ochroleuca**.
- Polyporus oviformis** (G. Cunn.) G. Cunn. in Bull. N.Z. Dep. Sci. industr. Res. Pl. Dis. Div. 74:34 (1948). King's Park (UWA 1741). Transferred to *Tyromyces* in Cunningham (1965) p. 139.
- Polyporus parilis* see **Poria parilis**.
- Polyporus pelles* see **Polyporus pelliculosus**.
- Polyporus pelliculosus** Berk. in Lond. J. Bot. 7:575 (1848). Teesdale, as *Polyporus pelles* Lloyd, (UWA 53, 60); Dwellingup (UWA 80); Bibra Lake (UWA 1510). Transferred to *Tyromyces* in Cunningham (1965) p. 124.
- Polyporus pocula** (Schw.) Berk. & Curtis in Proc. Am. Acad. Arts & Sci. 4:122 (1858). Shannon River (UWA 342); Augusta (UWA 709) (ADW). Transferred to *Tyromyces* in Cunningham (1965) p. 119 and confused with other species (see Reid, Trans. Br. mycol. Soc. 50:161 1967).
- Polyporus portentosus* sec **Piptoporus portentosus**.
- Polyporus rimosus* see **Phellinus rimosus**, Hymenochaetaceae.
- Polyporus sanguineus* see **Pycnoporus coccineus**.
- Polyporus scruposus* see **Phellinus scruposus**, Hymenochaetaceae.
- Polyporus stipticus* see **Piptoporus australiensis**.
- Polyporus tardus* see **Poria tarda**.
- Polyporus tumulosus** Cooke & Masee in Grevillea 17:55 (1889). Mundaring State Forest (UWA 1421, 1981); Walpole (UWA 2232) (K). Reid *et al.* W.A. Naturalist 14:120 (1979) described the form of a large sclerotium of this species.
- Polyporus vaporarius* see **Poria versipora** and **Poria medullaris**.
- Polyporus varius** Fr. in Syst. mycol. 1:352 (1821). Swan River, Drummond No. 154 (K, but not found).
- Polyporus venustus* see **Trametes versatilis**.
- Polystictus azureus* see **Coriolus versicolor**.
- Polystictus brunneo-leucus** (Fr.) Cooke in Grevillea 14:83 (1886). Pemberton, as *Poria westraliensis* Rodway & Cleland (HO\*). Transferred to *Osmoporus* in Cunningham (1965) p. 243.
- Polystictus bulbipes* see **Coltricia cinnamomea**, Hymenochaetaceae.
- Polystictus cinnabarinus* see **Pycnoporus coccineus**.
- Polystictus feei* see **Trametes lilacino-gilva**.
- Polystictus lilacino-gilvus* see **Trametes lilacino-gilva**.
- Polystictus oblectans* see **Coltricia cinnamomea**, Hymenochaetaceae.
- Polystictus persoonii* see **Trametes scabrosa**.
- Polystictus sanguineus* see **Pycnoporus coccineus**.
- Polystictus versicolor* see **Coriolus versicolor**.
- Poria ferruginosa* see **Phellinus ferruginosus**, Hymenochaetaceae.
- Poria healeyi* see **Poria mutans**.
- Poria medullaris** Gray in Nat. Arr. Br. Pl. 1:639 (1821). Swan River, as *Polyporus vaporarius* Fr., Drummond No. 141 (K).
- Poria mutans** (Peck) Peck in N.Y. State Museum Ann. Report 43:39 (1890). W. Australia. Described as *Poria healeyi* N.E.M. Walters in Trans. Br. mycol. Soc. 41:95 (1958) (K\*). The cause of yellow straw rot in jarrah. Identified as *Poria mutans* by J. J. Lowe using interfertility tests.
- Poria parilis** (Fr.) Sacc. in Syll. Fung. 6:299 (1888). W. Aust., as *Polyporus parilis*, (Herb. Preiss No. 2685\*).

- Poria tarda** (Berk.) Cooke in Grevillea 14:109 (1886). Swan River, Drummond No. 130 as *Polyporus tardus* (K\*). The identity is discussed by Ryvarden, Norw. J. Bot. 24:226 (1977).
- Poria vaporaria* see **Poria versipora** and **Poria medullaris**.
- Poria versipora** (Pers.) Romell in Svensk Bot. Tids. 20:15 (1962). Swan River, as *Polyporus vaporarius* Fr., Drummond No. 136, (K).
- Poria westraliensis* see **Polystictus brunneo-leucus**.
- Pseudofavohus tenuis* see **Hexagonia tenuis**.
- Pycnoporus cinnabarinus* see **Pycnoporus coccineus**.
- Pycnoporus coccineus** (Fr.) Bond. & Singer in Ann. Mycol. 39:59 (1941). W. Aust., as *Polyporus sanguineus* Fr. (Herb. Preiss. No. 2684); Swan River, as *Polyporus cinnabarinus* (Jacq. ex Fr.) Fr. Drummond No. 148 (K); King Georges Sound (K); Dwellingup (UWA 22); Mt. Barker (UWA 1725); Esperance (UWA 1748); Early records are under the North Temperate species *Polyporus*, *Polystictus*, *Pycnoporus* or *Trametes cinnabarina*. Cunningham (1965) p. 169 under *Trametes cinnabarina*, drew no distinction between this species and *Polyporus*, *Polystictus* or *Coriolus sanguineus*, but the differences had been worked out by Nobles & Frew (Canad. J. Bot. 40:987, 1962).
- Pycnoporus sanguineus** (Fr.) Murrill in Bull. Torrey bot. Cl. 31:421 (1904). W. Aust., Tropical & Subtropical collections. Drysdale River (UWA 2144). See comments under *Pycnoporus coccineus*.
- Trametes azurea* see **Coriolus versicolor**.
- Trametes corrugata* see **Trametes scabrosa**.
- Trametes drummondii* see **Phaeotrametes decipiens**.
- Trametes feei* see **Trametes lilacino-gilva** complex.
- Trametes lilacino-gilva** complex. Swan River, as *Polyporus feei*/*Polyporus lilacino-gilvus*, Drummond No. 147 (K); Dwellingup (UWA 87); Porongorups (UWA 341); Rottneest Is. (UWA 1740). Both species *feei* and *lilacino-gilvus* have been put in the three genera *Trametes*/*Polyporus*/*Polystictus* together with a third species named *Trametes stowardii*.
- Trametes muelleri** Berk. in J. Linn. Soc. 10:320 (1868). Napier Downs (UWA 2285); Prince Regent River (UWA 1954, 1966).
- Trametes persoonii* see **Trametes scabrosa**.
- Trametes pini** Fr. in Epicr. Syst. mycol. p. 489 (1838). Swan River, Drummond No. 145 (K, but not found).
- Trametes scabrosa** (Pers.) G. Cunn. in Polyp. N.Z. p. 162 (1965). Prince Regent River, as *Trametes corrugata* (Pers.) Bres. (UWA 1970) (K). A well-known tropical species commonly cited as *Trametes* or *Polystictus persoonii*.
- Trametes stowardii* see **Trametes lilacino-gilva** complex.
- Trametes versatilis** Berk. in Lond. J. Bot. 1:150 (1842). Swan River, as *Polyporus venustus* Berk., Drummond No. 135 (K\*) placed as a *Trichaptum* in Cunningham (1965) p. 99.
- Trametes versicolor* see **Coriolus versicolor** complex.
- Trichaptum venustum* see **Trametes versatilis**.
- Truncospora ochroleuca** (Berk.) Pilát in Atlas. Champ. Eur. 3:365 (1941). Swan River, as *Polyporus ochroleucus*, Drummond No. 248 (K\*), 285 (K); Swan River, as *Polyporus compressus* Berk., Drummond No. 141 (K)\*. Cunningham (1965) p. 145 placed as *Heterobasidium* and Ryvarden (Norw. J. Bot. 24:223, 1977) as *Perenniporia*.
- Tyromyces oviformis* see **Polyporus oviformis**.
- Tyromyces pelliculosus* see **Polyporus pelliculosus**.
- Family Punctulariaceae
- Punctularia strigosa-zonata** (Schw.) Talbot in Bothalia 7:143 (1958). Dwellingup, as *Stereum strigoso-zonatum*, (UWA 32); Mondrain Is., as *Stereum hispidulum* (Berk.) G. Cunn., (MEL).
- Family Schizophyllaceae
- Schizophyllum commune** Fr. ex Fr. in Syst. mycol. 1:330 (1821). Perth (Herb. Preiss No. 2676); Swan River, Drummond Nos. 133, 280, (K); Cannington (UWA 19); Mundaring Weir (UWA 1172); Esperance (UWA 1333, 1398); Prince Regent River (UWA 1960).
- Family Stereaceae
- Chondrostereum purpureum** (Pers. ex Fr.) Pouzar in Ceska Mykol. 13:18 (1959). Swan River, Drummond No. 281, as *Stereum purpureum*, (K, but not found). This is the only record for the State.
- Lopharia crassa** (Lév.) Boidin in Bull. trimest. Soc. mycol. Fr. 74:479 (1958). Swan River, as *Corticium vinosum* Berk., Drummond No. 160 (K\*) filed under *Hymenochaete vinosa* (Berk.) Cooke; Yancheep, as *Lopharia vinosa* (Berk.) G. Cunn. (UWA 716); Augusta (UWA 779); York (UWA 790); Margaret River (UWA 1641).
- Lopharia vinosa* see **Lopharia crassa**.
- Stereum complicatum** Fr. in Epicr. Syst. mycol. p. 548 (1838). S.W. Australia (K).
- Stereum hirsutum** (Willd.) Pers. ex Gray in Nat. Arr. Br. Pl. 1:652 (1821). Swan River, Drummond No. 159 (K); Mondrain Is., as *S. hirsutum* (Fr.) Fr. (MEL). Tamblyn (M.Sc. thesis 1936) records on marri, banksia, wandoo but not jarrah. Associated with dieback in apple by Doepel, J. Agric. W. Aust. 3 No. 9 (1962).
- Stereum hispidulum* see **Punctularia strigoso-zonata**, Punctulariaceae.
- Stereum illudens* see **Xylobolus illudens**.
- Stereum purpureum* see **Chondrostereum purpureum**.
- Stereum radicale* see **Steccherinum ochraceum**, Hydnaceae.
- Stereum rubiginosum* see **Hymenochaete rubiginosa**, Hymenochaetaceae.
- Stereum strigoso-zonatum* see **Punctularia strigoso-zonata**, Punctulariaceae.
- Stereum umbrinum** Fr. in Lehmann. Pl. Preiss. 2:137 (1846). Swan River (Herb. Preiss. No. 2686\*).
- Stereum vittaeforme* see **Stereum vittiforme**.
- Stereum vittiforme** Fr. in Lehmann Pl. Preiss. 2:137 (1846). Swan River, as *Stereum vittaeforme*, (Herb. Preiss. No. 2687\*).
- Xylobolus illudens** (Berk.) Boidin in Revue Mycol. 23:341 (1958). Swan River, as *Stereum illudens*, Drummond No. 158 (K\*) Drummond No. 298 (K); Watheroo (UWA 452); Julimar (UWA 1672).
- Family Thelephoraceae
- Hydnellum* see Hydnaceae.
- Thelephora caryophyllea* see **Thelephora terrestris**.
- Thelephora comedens* see **Vuilleminia comedens**, Corticiaceae.
- Thelephora concrescens** Fr. in Lehmann Pl. Preiss. 2:136 (1846). On old wood on the bank of the Canning River (Herb. Preiss. No. 2688\*).



**Thelephora myriomera** Fr. in Lehmann Pl. Preiss. 2:137 (1846). Canning River (Herb. Preiss. No. 2689\*). Cunningham (1963) p. 337 states that the type no longer exists, and that the description is too fragmentary to be useful.

**Thelephora terrestris** Ehrh. ex Fr. in Syst. mycol. 1:431 (1821). Swan River, as *T. carophyllea* Fr, Drummond No. 200 (K); S. Perth (UWA 88); Ludlow (UWA 108); Bridgetown (UWA 751); Denmark (UWA 752). *T. carophyllea* is a name given to the infundibuliform habit, see Cunningham (1963) p. 229.

Order Dacrymycetales  
Family Dacrymycetaceae

**Calocera guepinoides** Berk. in Lond. J. Bot. 4:61 (1845). Swan River, Drummond No. 204 (K\*); Mundaring Weir (UWA 1308).

*Dacrymyces militinus* see **Heterotextus peziziformis**.

*Dacrymyces rubro-fuscus* see **Sirobasidium sanguineum**, Tremellaceae.

*Guepinia pezizaeformis* see **Heterotextus peziziformis**.

**Heterotextus peziziformis** (Berk.) Lloyd in Mycol. Notes 67:1151 (1922). Swan River, as *Guepinia pezizaeformis*, Drummond No. 205 (K\*). Cleland (1935) p. 335 describes under *Dacrymyces militinus* Berk.

Class Gasteromycetes  
Order Gautieriales  
Family Gautieriaceae

**Gautieria drummondii** Berk., in herb., ex Cooke in Grevillea 11:63 (1882). Swan River, Herb. Berk. No. 4446 (K\*). Cunningham (1942) p. 211 rejects this as a valid species and there is insufficient material at Kew to confirm even the genus.

Order Hymenogastrales  
Family Hymenogastraceae

**Rhizopogon rubescens** Tulasne in Giornal Botanica Italiana 2:58 (1844). Mundaring Weir (PERTH).

Family Secotiaceae

**Endoptychum agaricoides** Czerniaiev in Bull. Soc. Imp. Nat. Moscou 18:148 (1845). W. Australia, as *Secotium acuminatum* Mont. (Lloyd herbarium); Swan River as *Secotium drummondii* ined., thence *Chainoderma drummondii* Masee (K\*); Margaret River as *Secotium agaricoides* (Czerniaiev) Hollos (UWA 497); Yanchee (UWA 514); Murdoch Campus (UWA 2038). For synonymy of *Chainoderma drummondii* with this species instead of with *Podaxis pistillaris* (as in Cunningham 1944 p. 197) see Hilton (1982).

**Endoptychum melanosporum** (Berk.) Singer & Smith in Brittonia 10:220 (1958). Swan River, as *Secotium melanosporum*, Drummond No. 180 (K\*).

*Secotium acuminatum* see **Endoptychum agaricoides**.

*Secotium agaricoides* see **Endoptychum agaricoides**.

**Secotium coerctatum** Berk. in Lond. J. Bot. 4:63 (1845). Swan River, Drummond No. 181 (K\*).

*Secotium drummondii* see **Endoptychum agaricoides**.

*Secotium melanosporum* see **Endoptychum melanosporum**.

Order Lycoperdales  
Family Geastraceae

*Geaster* see **Geastrum**.

**Geastrum drummondii** Berk. in Lond. J. Bot. 4:63

(1845). Swan River, Drummond unnumbered (K\*); Tammin (ADW).

**Geastrum minimum** Schw. in Schrift. Natur, Ges. Leipzig 1:166 (1822). Swan River, Drummond No. 175 (K); Mondrain Is., Round Is., (MEL).

**Geastrum minus** (Pers.) Fischer in Nat. Pflanzenfamilien 7a p. 73 (1933). Tammin (ADW).

**Geastrum pectinatum** Pers. in Synop. method. Fung. p. 132 (1801). Swan River, as *Geaster striatus* DC, Drummond No. 173 (K).

**Geastrum pusillum** Fr. in Lehmann Pl. Preiss. 2:139 (1846). Canning River (Herb. Preiss. No. 2695\*). Cunningham (1942 p. 212) suggested deleting this record but he appears not to have been aware of Preiss' collection.

*Geastrum rufescens* see **Geastrum simulans**.

**Geastrum simulans** Lloyd in The Lycoperdaceae of Australia p. 17 (1905). W. Australia, Drummond No. 174 as *G. rufescens* Pers. (K\*); North Twin Peaks Is. (MEL).

*Geastrum striatum* see **Geastrum pectinatum**.

Family Lycoperdaceae

*Bovista lilacina* see **Calvatia lilacina**.

*Calvatia cyathiformis* see **Calvatia lilacina**.

**Calvatia lilacina** (Mont. & Berk.) P. Henn. in Hedwigia 43:205 (1904). Swan River, as *Bovista lilacina*, Drummond No. 167 (K\*). Perth (UWA 2319). Dring (1964) p. 38 describes as subspecies *fragilis* of *C. cyathiformis*.

**Lycoperdon asperum** (Lév.) de Toni in Sacc. Syll. Fung. 7:119 (1888). Middle, Goose, and Christmas Is. (MEL).

*Lycoperdon gemmatum* see **Lycoperdon pusillum**.

**Lycoperdon polymorphum** Vitt. in Mon. Lycoperd. p. 39 (1842). Middle Is. (MEL).

**Lycoperdon pusillum** Pers. in J. Botanique 2:17 (1809). W. Aust. (Herb. Preiss. No. 2692); Tammin (ADW); Swan River, as *L. gemmatum* Batsch, Drummond No. 172 (K), 250 (K).

**Lycoperdon stellatum** Cooke & Masee in Grevillea 15:97 (1887). Israelite Bay (K\*); Stirling Range (UWA 1164); Esperance (UWA 1569).

**Mycenastrum corium** (Guersent) Desv. in Annal. des Sci. Nat. 11: 17:147 (1842). Swan River, as *Mycenastrum phaeotrichum* Berk., Drummond No. 166 (K\*), Kalgoorlie (ADW); Christmas Is. (MEL).

*Mycenastrum phaeotrichum* see **Mycenastrum corium**.

Family Mesophelliaceae

**Castoreum cretaceum** (Lloyd) G. Cunn. in Proc. Linn. Soc. NSW 57:320 (1932). Denmark (UWA 2365). Described by Lloyd as a *Diploderma*.

*Diploderma cretaceum* see **Castoreum cretaceum**.

*Diploderma glaucum* see **Mesophellia glauca**.

**Mesophellia glauca** (Cooke & Masee) Reid in Kew Bull. 17:306 (1963). Gardner River, as *Potoromyces loculatus* Muell. ex Hollos., collected by Th. Muir 1881, (K). Mueller named his genus after the Potoroo, known to feed on the fruit bodies. (Hilton, R. N. The Western Australian Naturalist 14:235 (1980)).

**Mesophellia arenaria** Berk. in Trans. Linn. Soc. 22:131 (1857). Gingin (UWA 1207); Applecross (PERTH).

*Potoromyces loculatus* see **Mesophellia glauca**.

## Order Nidulariales

## Family Nidulariaceae

*Arachnion drummondii* Berk. in J. Linn. Soc. 18:389 (1881). W. Aust. Attached to *Volvariella cynapnotamia* (Berk.) Singer (K\*). Cunningham (1942) p. 209 comments that the type is too fragmentary for determination, but more recent examination by others suggests that it represents a good species (Hilton, 1982).

*Crucibulum laeve* (Huds. ex Relh.) Kambly, Kambly & Lee in Uni. Iowa Stud. Nat. Hist. 17(4):167 (1936). W. Aust. Near to Kelmscott (as "Kelmsedth") by the Canning River, as *Nidularia crucibulum* (Pers.) Fr. (Herb. Preiss. No. 2693); as *Crucibulum vulgare* Tulasne, Dwellingup, (UWA 10); Augusta (UWA 632); Gleneagle (UWA 2440).

*Crucibulum vulgare* see *Crucibulum laeve*.

*Cyathus olla* Pers. in Syn. meth. Fung. 237 (1801). Swan River, as *Cyathus vernicosus* DC, Drummond No. 228 (K); Yanchep (UWA 892).

*Cyathus vernicosus* see *Cyathus olla*.

*Nidularia crucibulum* see *Crucibulum laeve*.

*Nidula cmodensis* (Berk.) Lloyd in The Nidulariaceae p. 12 (1906). Forrestdale (UWA 571); Nannup (UWA 572).

## Family Sphaerobolaceae

*Sphaerobolus stellatus* Tode ex Pers. in Synop. method. Fung. p. 115 (1801). Applecross (UWA 1450); Mundaring Weir (UWA 1461). See Aplin, W.A. Naturalist 8:27 (1961) for the first record and description from W. Australia.

## Order Phallales

## Family Clathraceae

*Clathrus gracilis* see *Heodictyon gracile*.

*Coleus read* *Colus*.

*Colus hirudinosus* see *Clathrus pusillus*.

*Clathrus pusillus* Berk. in Lond. J. Bot. 4:67 (1845). Swan River, Drummond No. 176 (K\*); Perth, as *Calus hirudinosus* Cavalier & Sechier, (Herb. Preiss. No. 2694\*); Mandurah (UWA 530, 906); Yanchep (UWA 532); Cannington (UWA 907); Welshpool (UWA 1915).

*Heodictyon gracile* Berk. in Lond. J. Bot. 4:69 (1845). Swan River, Drummond No. 177 (K\*); Mundaring (UWA 594); Mt. Helena, as *Clathrus gracilis* (Berk.) Schlecht. (UWA 1826) (K).

## Family Phallaceae

*Lysurus australiensis* see *Lysurus gardneri*.

*Lysurus gardneri* Berk. in Lond. J. Bot. 5:355 (1846). Cannington, as *Lysurus australiensis* Cooke & Massee *apud* Cooke, (UWA 520); Como (UWA 596); Crawley (UWA 1194). The first record and description from Western Australia is given by Herbert in J. & Proc. Roy. Soc. W.A. 6:107 (1920).

*Mutinus curtus* (Berk.) E. Fisch. in Sacc. Syll. Fung. 7:13 (1888). Swan River, as *Phallus curtus*, Drummond No. 178 (K\*).

*Phallus costatus* (Pers.) Lloyd in Synopsis of the Known Phalloids p. 10 (1909). King's Park Botanic Garden (UWA 2134).

*Phallus curtus* see *Mutinus curtus*.

## Order Podaxales

## Family Podaxaceae

*Chainaderma drummondii* see *Endoptychum agaricoides*, Secotiaceae.

*Podaxis pistillaris* (L. ex Pers.) Morse in Mycologia 25:27 (1933). Roebourne (ADW); Kurrawang (ADW); Kalgoorlie (UWA 1403); Kookynie (UWA 1906); Mingenew (UWA 676); Mt. Magnet (UWA 1371); Wongan Hills (UWA 1413).

## Order Sclerodermatales

## Family Sclerodermataceae

*Pisolithus tinctorius* (Mich. ex Pers.) Coker & Couch in Gasteromycetes p. 170 (1928). Swan River around Perth, as *Polysaccum degenerans* (Fr.) Cooke (Herb. Preiss. No. 2704, not Drummond as assumed by Cunningham (1944) p. 215); Swan River, as *Polysaccum pisocarpium* Fr., Drummond No. 170 (K); as *Polysaccum crassipes* DC & Despr. var. & *Polysaccum turgidum* Fr., Drummond No. 171 (K); *Polysaccum crassipes* var. & *Polysaccum turgidum*, Drummond No. 171 (K); Narrogin (ADW); South Perth (SYD); Crawley Campus (UWA 70); Mandurah (UWA 508, 516); Medina (UWA 517); Yanchep (UWA 569); King's Park (UWA 592); Esperance (UWA 1750).

*Polysaccum crassipes* see *Pisolithus tinctorius*.

*Polysaccum? degenerans* see *Pisolithus tinctorius*.

*Polysaccum pisocarpium* see *Pisolithus tinctorius*.

*Polysaccum turgidum* see *Pisolithus tinctorius*.

*Scleroderma aurantium* see *Scleroderma flavidum* forma *macrosporum*.

*Scleroderma flavidum* Ellis & Everh. in J. Mycol. 1:88 (1885). Lake Muir, as *S. vulgare* Fr. (K); Mondrain Is., Middle Is. (MEL); Donnybrook (ADW); Dwarda (PERTH).

*Scleroderma flavidum* Ellis & Everh. forma *macrosporum* G. Cunn. p. 128 (1944). Pemberton (ADW); Mundaring Weir (PERTH). Described by Cunningham (1944) p. 120, with the comment that this is the form on which most of Cooke's records of *S. aurantium* Pers. *S. geaster* Fr. and *S. vulgare* Fr. are based.

*Scleroderma geaster* Fr. in Syst. mycol. 3:46 (1829). Narrogin (ADW). Preiss collected near Swan River, but took no voucher. Cunningham (1944 p. 118) describes and comments that the Narrogin specimen is the only authentic Australian record. Others that he examined at Kew proved to be *S. flavidum* Ellis & Everh.

*Scleroderma phaeotrichum* see *Mycenastrum corium*, Lycoperdaceae.

*Scleroderma radicans* Lloyd in Mycol. Notes p. 246 (1906). Bindoon (PERTH).

*Scleroderma verrucosum* Pers. in Synop. method. Fung. p. 154 (1801). Swan River, as *Scleroderma vulgare* Fr., Drummond No. 169 (K). Esperance (UWA 1752); Perup (UWA 1985) (K). Dring describes this species in Mycol. Paper 98 p. 20.

*Scleroderma vulgare* see *Scleroderma verrucosum* and *Scleroderma flavidum*.

## Order Tulostomatales

## Family Calostomataceae

*Calostoma fuscum* (Berk.) Massee in Ann. Bot. 2:43 (1888). Lake Muir, as *Mitremyces fuscus*, (K); Lake King (UWA 1188).

*Calostoma luridum* (Berk.) Masee in Ann. Bot. 2:43 (1888). Swan River, Drummond No. 182, as *Mitremyces luridus* (K\*); Beverley (UWA 922).

*Mitremyces fuscus* see *Calostoma fuscum*.

*Mitremyces luridus* see *Calostoma luridum*.

Family Tulostomataceae

*Battaraea phalloides* see *Battaraea stevenii*.

*Battaraea stevenii* Fr. Syst. mycol. 3:7 (1829). Israelite Bay (K) Kurrawong, as *Battaraea phalloides* (Dicks.) Pers. (ADW); East Mt. Barren (UWA 816); Como (UWA 817); Zanthus (UWA 1187); Esperance (UWA 1266); Gingin (UWA 1471).

*Chlamydopus meyenianus* (Klotzsch) Lloyd in Mycol. Notes p. 134 (1903). Gascoyne River, coll. Mrs Gribbie via Von Mueller 1886, as *Tulostoma maximum* Cooke & Masee (K\*); Kalgoorlie (ADW); Kurrawong (ADW); Kitchener (UWA 1877).

*Phellorina herculeana* (Pallas ex Pers.) Kreisal in Ces. Mykol. 15:196 (1961). Wongan Hills, as *Phellorinia inquinans* Berk. (K).

*Phellorina inquinans* see *Phellorina herculeana*.

*Phellorinia* see *Phellorina*.

*Tulostoma albicans* White ex G. Cunn. in Proc. Linn. Soc. NSW 50:250 (1925). Tammin (ADW); North Lake (UWA 889); Claremont (UWA 890).

*Tulostoma album* Masee in Grevillea 19:95 (1891). Israelite Bay, coll. Miss Brooke (K\*); Crawley (UWA 115).

*Tulostoma australianum* Lloyd ex G. Cunn. in Proc. Linn. Soc. NSW 50:256 (1925). Swan River, as *Tulostoma fimbriatum* Fr., Drummond No. 179 (K); Boxer Is. (MEL).

*Tulostoma fimbriatum* see *Tulostoma australianum*.

*Tulostoma maximum* see *Chlamydopus meyenianus*.

*Tulostoma obesum* Cooke & Ellis ex G. Cunn. in Proc. Linn. Soc. NSW 57: 37 (1932). Tammin (ADW); Carnarvon (UWA 1418).

*Tylostoma* see *Tulostoma*.

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Index

("a" and "b" refer to page columns)

<i>acuminatum</i> , <i>Secotium</i> 12a	<i>applicatus</i> , <i>Resupinatus</i> 7b	<i>atromarginatus</i> , <i>Pluteus</i> 6a	<i>astropulehella</i> , <i>Amanita</i> 3b
<i>agaricoides</i> , <i>Endoptychum</i> 12a	<i>archeri</i> , <i>Anthracoephyllum</i> 6b	<i>atrorufa</i> , <i>Psilocybe</i> 6b	<i>autumnalis</i> , <i>Galerina</i> 5a
<i>albicans</i> , <i>Tulostoma</i> 14a	<i>archeri</i> , <i>Pulvinula</i> 2b	<i>aurantium</i> , <i>Scleroderma</i> 13b	<i>azureus</i> , <i>Coriolus</i> 9a
<i>album</i> , <i>Tulostoma</i> 14a	<i>arenaria</i> , <i>Mesophellia</i> 12b	<i>aurea</i> , <i>Lepiota</i> 5b	<i>badia</i> , <i>Peziza</i> 2b
<i>allantopus</i> , <i>Gymnopilus</i> 5a	<i>arenarius</i> , <i>Boletus</i> 4a	<i>australiana</i> , <i>Lepiota</i> 5b	<i>barbatum</i> , <i>Auriscalpium</i> 7b
<i>alliciens</i> , <i>Boletus</i> 4a	<i>arenivaga</i> , <i>Elderia</i> 3a	<i>australianum</i> , <i>Tulostoma</i> 14a	<i>basirubescens</i> , <i>Cortinarius</i> 5a
<i>ammophila</i> , <i>Sarcosphaeria</i> 2b	<i>arguta</i> , <i>Hypodontia</i> 8b	<i>australiensis</i> , <i>Lysurus</i> 13a	<i>bicincta</i> , <i>Pholiota</i> 6b
<i>ananas</i> , <i>Boletellus</i> 4a	<i>arvensis</i> , <i>Agaricus</i> 3a	<i>australiensis</i> , <i>Piptoporus</i> 10a	<i>boltonii</i> , <i>Bolbitius</i> 4a
<i>angusticeps</i> , <i>Morchella</i> 2a	<i>asperospora</i> , <i>Lacrymaria</i> 4b	<i>australiensis</i> , <i>Rozites</i> 5b	<i>bombycina</i> , <i>Volvariella</i> 6a
<i>anthracophyllus</i> , <i>Polyporus</i> 10a	<i>asperum</i> , <i>Lycoperdon</i> 12b	<i>australiensis</i> , <i>Tremelloscypha</i> 3a	<i>botryoides</i> , <i>Ramaria</i> 8a
<i>applanata</i> , <i>Peziza</i> 2a	<i>atramentarius</i> , <i>Coprinus</i> 4b	<i>australis</i> , <i>Mylitta</i> 10a	<i>botrytes</i> , <i>Clavaria</i> 8a
<i>applanatum</i> , <i>Ganoderma</i> 8b	<i>atrocaerulea</i> , <i>Hohenbuchelia</i> 7a	<i>austrogeaster</i> , <i>Peziza</i> 2a	



- botrytis*, *Clavaria* 8a  
*brunneo-leucus*, *Polydicticus* 10b  
*bubalina*, *Lepiota* 5b  
*bulbipes*, *Polyporus* 10a
- caesareus*, *Boletus* 4a  
*campanulatus*, *Panaeolus* 4b  
*campestris*, *Agaricus* 3a  
*campylus*, *Polyporus* 10a  
*candolleana*, *Psathyrella* 4b  
*carbonaria*, *Geopyxis* 2b  
*carbonaria*, *Pholiota* 6b  
*carbonigena*, *Octospora* 2b  
*carneo-flavidum*, *Tricholoma* 7b  
*caryophyllea*, *Thelephora* 11b  
*centunculus*, *Naucoria* 5a  
*cervino-gilvus*, *Polyporus* 10a  
*cervinus*, *Pluteus* 6a  
*cinnabarinus*, *Panus* 7a  
*cinnabarinus*, *Pycnoporus* 11a  
*cinnamomea*, *Coltricia* 9a  
*chioneus*, *Pleurotellus* 7b  
*cibarius*, *Cantharellus* 4b  
*cladonia*, *Polyporus* 10a  
*coarctatum*, *Secotium* 12a  
*coarctatum*, *Tricholoma* 7b  
*coccinea*, *Hygrocybe* 5b  
*coccinea*, *Pycnoporus* 11a  
*cochleata*, *Peziza* f. 2b  
*cochleatus*, *Lentinellus* 8a  
*comatus*, *Coprinus* 4b  
*comedens*, *Vuilleminia* 8b  
*commune*, *Schizophyllum* 11b  
*complicatum*, *Stereum* 11b  
*compressus*, *Polyporus* 10a  
*concentricum*, *Gloeophyllum* 9b  
*conrescens*, *Thelephora* 11b  
*conica*, *Hygrocybe* 5b  
*conica*, *Morchella* 2a  
*coprophila*, *Psilocybe* 6b  
*corium*, *Cyathipodia* 2a  
*corium*, *Merulius* 8b  
*corium*, *Mycenastrum* 12b  
*corrugata*, *Trametes* 11a  
*costatus*, *Phallus* 13a  
*crassa*, *Lopharia* 11b  
*crassipes*, *Polysaccum* 13b  
*cretaceum*, *Castoreum* 12b  
*crinalis*, *Mycena* 7a  
*crucibulum*, *Nidularia* 13a  
*crustuliniforme*, *Hebeloma* 5a  
*curtus*, *Mutinus* 13a  
*cyanescens*, *Gyroporus* 4a  
*cyathiformis*, *Calvatia* 12b  
*cynopotamia*, *Volvariella* 6a
- dactyloides*, *Lentinus* 7a  
*dealbata*, *Clitocybe* 6b  
*dealbatus*, *Lentinus* 7a  
*decipiens*, *Phaeotrametes* 9b  
*degenerans*, *Polysaccum*? 13b  
*delica*, *Russula* 6a  
*demissus*, *Polyporus* 10a  
*dependens*, *Coltriciella* 8b  
*dichrous*, *Gloeoporus* 9b  
*discolor*, *Hexagonia* 9b  
*dispersum*, *Hydnum* 8b  
*disseminatus*, *Coprinus* 4b  
*drummondii*, *Arachnion* 13a  
*drummondii*, *Chainoderma* 13b  
*drummondii*, *Gautieria* 12a  
*drummondii*, *Geastrum* 12a  
*drummondii*, *Peziza* 2b  
*drummondii*, *Pholiota* 6b  
*drummondii*, *Trametes* 11a  
*drummondii*, *Xerotus* 7b  
*dulcamara*, *Inocybe* 5a  
*dumosorum*, *Amanita* 3b
- echinatum*, *Melanophyllum* 5b  
*elata*, *Morchella* 2a  
*emodensis*, *Nidula* 13a  
*ericaceum*, *Naematoloma* 6a  
*eriogena*, *Pholiota* 6b  
*erumpens*, *Russula* 6a  
*erythraeus*, *Cortinarius* 5a  
*eucalypticum*, *Tricholoma* 7b  
*eucalyptorum*, *Paxillus* 6a  
*eucalyptorum*, *Pleurotus* 7b  
*eucalyptorum*, *Polyporus* 10a  
*euporus*, *Chaetoporus* 9a  
*excoriata*, *Lepiota* 5b
- fasciatus*, *Panus* 7a  
*fasciculare*, *Naematoloma* 6a  
*feei*, *Polyporus* 10b  
*ferruginosus*, *Phellinus* 9a  
*finbriatum*, *Tilostoma* 14a  
*flaccida*, *Ramaria* 8a  
*flavidum*, *Scleroderma* 13b  
*flocktonae*, *Russula* 6a  
*foenicicii*, *Panaeolina* 4b  
*foliacea*, *Tremella* 3a  
*fomentarius*, *Fomes* 9b  
*forrestiae*, *Amanita* 3b  
*fragilis*, *Bolbitis* 4a  
*fragilis*, *Calvatia* s.sp. 12b  
*fulvizonata*, *Pholiota* 6b  
*fulvus*, *Fomes* 9b  
*fumosa*, *Bjerkandera* 9a  
*furfuraceus*, *Ascobolus* 2a  
*fuscum*, *Calostoma* 13b  
*fusipes*, *Collybia* 7a
- gardneri*, *Lysurus* 13a  
*geaster*, *Scleroderma* 13b  
*gemmatum*, *Lycoperdon* 12b  
*gilva*, *Clitocybe* 6b  
*gilvus*, *Phellinus* 9a  
*glandulosa*, *Fxidia* 3a  
*glauca*, *Mesophellia* 12b  
*gloiocephala*, *Volvariella* var. 6a  
*gracile*, *Ileodictyon* 13a  
*granulatus*, *Suillus* 4b  
*griphaeformis*, *Fomes* 9b  
*griselloides*, *Amanita* 3b  
*gryphaeformis*, *Polyporus* 10a  
*guepinoides*, *Calocera* 12a  
*gunnii*, *Hexagonia* 9b
- humatus*, *Phellinus* 9a  
*healeyi*, *Poria* 10b  
*helvola*, *Clavulinopsis* 8a  
*hepatica*, *Fistulina* 8b  
*hepatotrichus*, *Lentinellus* 8a  
*herculana*, *Phellorina* 14a  
*heteroclita*, *Pholiota* 6b  
*highlandensis*, *Pholiota* 6b  
*hiltonii*, *Amanita* 3b  
*himantioides*, *Serpula* 8a  
*hirsutum*, *Stereum* 11b  
*hirudinosus*, *Colus* 13a  
*hispidulum*, *Stereum* 11b  
*hypericon*, *Phylloporus* 4a  
*hyperion*, *Phylloporus* 4a
- igniarius*, *Phellinus* 9a  
*illudens*, *Xylobolus* 11b  
*incarnata*, *Peniophora* 8b  
*infractus*, *Boletus* 4a  
*insidubuliformis*, *Paxillus* 6a  
*inquinans*, *Phellorina* 14a  
*investiens*, *Hydnum* 8b  
*involutus*, *Paxillus* 6a  
*isidioides*, *Sarcodontia* 8b
- juncea*, *Clavariadelphus* 8a
- laccata*, *Laccaria* 7a  
*lacymans*, *Serpula* 8a  
*laeve*, *Crucibulum* 13a  
*lampas*, *Pleurotus* 7b  
*lanuginosa*, *Inocybe* 5a  
*lepida*, *Russula* 6a  
*lepideus*, *Lentinus* 7a  
*lepidopoda*, *Collybia* 7a  
*leptocephala*, *Mycena* 7a  
*lepton*, *Crepidotus* 5a  
*leucolithes*, *Lepiota* 5b  
*levis*, *Amanita* f. 3b  
*lilacina*, *Calvatia* 12b  
*lilacino-gilva*, *Trametes* 11a  
*lilacinus*, *Cantharellus* 4b  
*loculatus*, *Potoromyces* 12b  
*lucidum*, *Ganoderma* 8b  
*lukinsii*, *Phellinus* 9a  
*luridum*, *Calostoma* 14a  
*lutea*, *Lepiota* 5b  
*luteus*, *Suillus* 4b
- macrorhizus*, *Leucoagaricus* 5b  
*macrospora*, *Eichlericella* 3a  
*macrosporum*, *Scleroderma* f. 13b  
*marginata*, *Galerina* 5a  
*marginatus*, *Boletus* 4a  
*maximum*, *Tilostoma* 14a
- maximus*, *Agaricus* var. 3b  
*medullaris*, *Poria* 10b  
*melaleuca*, *Melanoleuca* 7a  
*melaloma*, *Anthracoia* 2b  
*melanodon*, *Humaria* 2b  
*melanosporum*, *Endoptychum* 12a  
*mesenterica*, *Auricularia* 3a  
*mesenterica*, *Tremella* 3a  
*meyenianus*, *Chlamydotus* 14a  
*micaceus*, *Coprinus* 4b  
*millinus*, *Dacrymyces* 12a  
*minimum*, *Geastrum* 12b  
*minum*, *Geastrum* 12b  
*minuta*, *Auricularia* 3a  
*mollis*, *Crepidotus* 5a  
*molybdites*, *Chlorophyllum* 5b  
*mulcentum*, *Tricholoma* 7b  
*muelleri*, *Paxillus* 6a  
*muelleri*, *Trametes* 11a  
*multiplex*, *Craterellus* 8a  
*mutans*, *Poria* 10b  
*mylittae*, *Polyporus* 10a  
*myriomera*, *Thelephora* 12a
- naucinus*, *Leucoagaricus* 5b  
*nidiformis*, *Pleurotus* 7b  
*nigritum*, *Geoglossum* 2a  
*nuda*, *Lepista* 7a
- ohesum*, *Tilostoma* 14a  
*oblectans*, *Polyporus* 10b  
*obscure-coccineus*, *Boletellus* 4a  
*ochraceum*, *Steccherinum* 8b  
*ochroleuca*, *Truncospora* 11a  
*ochroterrea*, *Amanita* 3b  
*olla*, *Cyathus* 13a  
*ollaris*, *Humaria* 2b  
*ostreatus*, *Pleurotus* 7b  
*ovatus*, *Panaeolus* 4b  
*oviformus*, *Polyporus* 10a
- pallescens*, *Strobilomyces* 4b  
*pampeanus*, *Gymnopilus* 5a  
*panuoides*, *Paxillus* 6a  
*parilis*, *Polyporus* 10b  
*patouillardii*, *Coprinus* 4b  
*pccinatum*, *Geastrum* 12b  
*pediades*, *Agrocybe* 4a  
*pelles*, *Polyporus* 10b  
*pelliculosus*, *Polyporus* 10b  
*peltigera*, *Amanita* 3b  
*penetrans*, *Gymnopilus* 5a  
*perpusillus*, *Pleurotus* 7b  
*persanguinea*, *Russula* 6a  
*personati*, *Agaricus* 7a  
*personii*, *Trametes* 11a  
*pezizaeformis*, *Guepinia* 12a  
*peziziformis*, *Heterotextus* 12a  
*phaeotrichum*, *Mycenastrum* 12b  
*phalloides*, *Battaraea* 14a  
*plebia*, *Clavaria* 8a  
*phlyctidosporus*, *Coprinus* 4b  
*pini*, *Trametes* 11a  
*pisocarpium*, *Polysaccum* 13b  
*pistillaris*, *Podaxis* 13b  
*plagiotum*, *Tricholoma* 7b  
*plebia*, *Clavaria* 8a  
*pleuroteloides*, *Clitopilus* 5b  
*plicatilis*, *Coprinus* 4b  
*pocula*, *Polyporus* 10b  
*polymorphum*, *Lycoperdon* 12b  
*polyporooides*, *Boletus* 4a  
*poniacus*, *Fomes* 9b  
*portentosum*, *Scytinostroma* 8b  
*portentosus*, *Phacogyroporus* 4a  
*portentosus*, *Piptoporus* 10a  
*praecox*, *Pholiota* 6b  
*preissii*, *Amanita* 3b  
*procera*, *Lepiota* 5b  
*psammobia*, *Peziza* 2b  
*pseudoscaber*, *Porphyrellus* 4b  
*pulchella*, *Amanita* 3b  
*punctata*, *Fuscoporia* 9b  
*pura*, *Mycena* 7a  
*purpuratus*, *Gymnopilus* 5a  
*purpurcum*, *Chondrostereum* 11b  
*pusillum*, *Geastrum* 12b  
*pusillum*, *Clathrus* 13a  
*pusillum*, *Lycoperdon* 12b  
*pusio*, *Podoserpula* 8a
- radicale*, *Corticium* 8a  
*radicans*, *Scleroderma* 13b
- radicata*, *Oudemansiella* 7a  
*radicatus*, *Cortinarius* 5a  
*repandum*, *Hydnum* 8b  
*retirugos*, *Panaeolus* 4b  
*rhacodes*, *Lepiota* 5b  
*rhenana*, *Aleuria* 2b  
*rbizobola*, *Lepiota* 5b  
*rhytipelta*, *Lepiota* 5b  
*rickenii*, *Conocybe* 4a  
*rimosus*, *Phellinus* 9a  
*robustus*, *Phellinus* 9a  
*ruber*, *Cortinarius* 5a  
*rubescens*, *Rhizopogon* 12a  
*rubiginosa*, *Hymenochaete* 9a  
*rubro-fuscus*, *Dacrymyces* 12a  
*rufescens*, *Geastrum* 12b  
*rutilans*, *Leucoscypha* 2b  
*rutilans*, *Tricholomopsis* 7b
- sanguineum*, *Sirobasidium* 3a  
*sanguineus*, *Pycnoporus* 11a  
*scabrosa*, *Trametes* 11a  
*scrobiculatum*, *Hydnum* 8b  
*scruposus*, *Phellinus* 9a  
*scutellata*, *Scutellaria* 2b  
*semiglohata*, *Stropharia* 6b  
*semiocculta*, *Clitocybe* 6b  
*semiorbicularis*, *Agrocybe* 4a  
*sericellum*, *Entoloma* 5b  
*setulosum*, *Lachnocladium* 8a  
*setulosus*, *Phellinus* 9a  
*silligena*, *Galeria* 5a  
*simulans*, *Geastrum* 12b  
*synape-crucentus*, *Boletus* 4a  
*species*, *Septobasidium* 3a  
*speciosa*, *Volvariella* 6a  
*spectabilis*, *Pholiota* 6b  
*sphaerocephalus*, *Boletus* 4a  
*sphinctrinus*, *Panaeolus* 4b  
*squarrosa*, *Pholiota* 6b  
*stellatum*, *Lycoperdon* 12b  
*stellatus*, *Sphaerobolus* 13a  
*stevanii*, *Battaraea* 14a  
*stipticus*, *Polyporus* 10b  
*stowardii*, *Trametes* 11a  
*striatum*, *Geastrum* 12b  
*strigoso-zonata*, *Punctularia* 11b  
*subgalericulata*, *Mycena* 7a  
*subhastellaris*, *Crepidotus* 5a  
*subsimilis*, *Boletus* 4a  
*superbicus*, *Oudemansiella* var. 7a
- tarda*, *Poria* 11a  
*tenuis*, *Hexagonia* 9b  
*terrestris*, *Lentinus* 7a  
*terrestris*, *Thelephora* 12a  
*thelephoroides*, *Gloeoporus* 9b  
*tinctorius*, *Pisolithus* 13b  
*tumulosus*, *Polyporus* 10b  
*turbipipes*, *Tricholoma* 7b  
*turgidum*, *Polysaccum* 13b
- uber*, *Crepidotus* 5a  
*umbrinella*, *Amanita* 3b  
*umbrinum*, *Stereum* 11b  
*unicolor*, *Galeria* 5a
- vaporarius*, *Polyporus* 10b  
*varius*, *Polyporus* 10b  
*varius*, *Agaricus* var. 3b  
*velutinus*, *Coriolus* 9b  
*venustum*, *Trichaptum* 11a  
*vernicosus*, *Cyathus* 13a  
*verrucosum*, *Scleroderma* 13b  
*versatilis*, *Trametes* 11a  
*versicolor*, *Coriolus* 9b  
*versipora*, *Poria* 11a  
*vesiculosa*, *Peziza* 2b  
*vesiculosus*, *Hexagonia* 9b  
*vinosum*, *Corticium* 8b  
*virginoides*, *Amanita* 3b  
*viscosus*, *Cantharellus* 4b  
*vitellinus*, *Bolbitis* 4a  
*vittaeforme*, *Stereum* 11b  
*vittiforme*, *Stereum* 11b  
*vulgare*, *Crucibulum* 13a  
*vulgare*, *Scleroderma* 13b
- westraliensis*, *Poria* 11a  
*xanthocephala*, *Amanita* 3b  
*zonata*, *Coriolus* 9b



## Some aberrant australite forms from Western Australia

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### Abstract

Australites which cannot be classified according to the shapes inherited from primary bodies and the recognised modifications resulting from aerodynamic and terrestrial processes are regarded as aberrant. Some aberrant australites appear to be solitary examples of their kind; others are represented by many specimens and can be classified into general types. Aberrant australites of interior Western Australia are closely similar in their specific gravities to other australites from the same area. The dimensional proportions of some types are characteristic. A knowledge of the abundance and distribution of aberrant australites in eastern Australia could be advantageous when considering the manner of their development.

### Introduction

Most australites which are in reasonably well-preserved condition may be classified morphologically according to the first or both of the following factors:

(a) The shape seen when looking along the line of flight. Round, oval, boat, dumb-bell and tear-drop shapes which are most commonly recognised are directly related to the forms of the australite primary bodies.

(b) The modifications of the original primary shapes caused by aerodynamic processes during oriented flight in the atmosphere and terrestrial processes of weathering and erosion since arrival on the earth's surface e.g. flanged forms, lens forms, indicators and cores.

After classifying a collection along the above general lines, there are usually a few specimens which do not conform to those simple concepts of classification by being, for example, "flat-topped" or "oblique-ended". Such shape features were not inherited from known primary forms; nor are there obvious ways in which they might have been developed by later processes. Moreover, the flight orientations of these specimens are not always determinable with confidence and have sometimes been inconstant. These australites are generally referred to as aberrant forms or simply as "aberrants".

Few figures are available on the abundance of aberrant forms. In some recent studies of localized collections from interior Western Australia, the numbers of morphologically classifiable specimens and percentages of aberrant forms amongst them were as follows:—

Earaheedy station	876	3.3%
Hampton Hill station	2524	1.9%
Edjudina station	1000	3.5%
Mount Remarkable station	100	3.0%
Total:	4500	Mean: 2.6%

Baker (1969) found 6 aberrant out of 261 named specimens or 2.3% of australites from Mulka, South Australia, but only 10 aberrant out of 733 named specimens or 1.4% of combined collections from various localities in south-west Victoria (Baker 1956). Collectively, the aberrant forms are sufficiently abundant not to be regarded as rarities, though the word would certainly apply to some of their less common varieties.

About 200 aberrant specimens were considered during the present investigation but more than 100 of them were rejected as being too broken or worn to be informative. The collections represented are as follows: the South Australian Museum (SAM), the Western Australian Museum (WAM), the Geology Department University of Melbourne F. B. Allen collection (UM), Geology Department, W.A. School of Mines collection (SM), the private collections of Mr and Mrs R. G. Tillotson and Mr L. D. Tillotson (TC), Mr J. L. C. Jones (JLCJ), Mr J. B. Mitchell (JBM), Ms N. Moylan (NM), Mr P. J. Simmonds (PJS), and the E. S. Simpson collection held at the Western Australian Museum (ESS).

The literature on aberrant australites is almost non-existent, comprising generally the briefest mentions and an occasional illustration. Baker's (1969) illustration of aberrant forms from Mulka, South Australia and proffered explanation of their development is exceptional.

### Classification of aberrant australites

The aberrant australites are here divided into two broad and very unequal groups.

*Group 1.*—These are forms known to the writer by only a single specimen and are therefore, perhaps, the product of some rare and accidental happening such as a collision in flight or a fragmentation followed by the adoption of a steady flight orientation and the development of a fragment as an individual. The word "aberrant" is usually defined as "straying from the right path" or "deviating from the normal"

and it is to seemingly unique individuals that the word appears most appropriate because they approach most closely a "freak of nature". The examination of almost any large collection is likely to reveal a shape not previously encountered. The number of these specimens is relatively small and may be reduced by further observations or reports. Thus the "tailed" or "beaked" core was unique in my experience when reported (Cleverly 1974) but two further examples have since been examined and the type may now be relegated to the second or repetitive group of aberrant forms reported below, or even removed from the aberrant group altogether. The three specimens had a common flight orientation and with the advantage of that observation an alternative, and hopefully a more acceptable, explanation for the development of the form by processes normally contributing to australite development has become possible. The view is taken that if development of the form can be explained in an acceptable way by such processes, then use of the word "aberrant" is no longer necessary.

**Group 2.**—This more populous group contains those aberrant forms known by at least a few and sometimes by many specimens. The propriety of applying "aberrant" to these specimens is doubted. Here, it is not so much a case of nature straying from the normal as of our simple concepts of morphogenesis and classification being inadequate. When a shape feature is found to occur time and again, it should be the aim to explain its development and incorporate it in the general theory. The commonest aberrant forms occasionally constitute a per cent or so of classifiable specimens e.g. the "nut-like" form, 5 out of 261 named specimens or 1.9% at Mulka (Baker 1969) and 7 out of 876 or 0.8% at Earraheedy station (unpublished study). If Baker's explanation for development of the form is acceptable, then it is merely necessary to note that minor instabilities in flight may include rocking on the longer axis normal to the line of flight. This will account for a distinctive pattern of flow ridges instead of the more usual concentric (ring wave) or helical patterns; the helical pattern itself on some specimens is probably to be explained as resulting from a different minor instability—an axial wobble (Chapman *et al.* 1962).

## Descriptive notes

### Group 1.

Brief statements of examples from this group are given in Table 1. The specimen numbers used in the additional notes below are those of the Table.

1. (Figs. 1A1 and 1A2).—The flight orientation is unknown. The convex side is the more likely to have faced forward. The shape suggests a piece of stress shell or fragment of a hollow form (*e.g.* Figs. 1B1 and 1B2) aerodynamically modified, but by the time that flight conditions led to cooling and detachment of stress shell they would no longer favour ablation stripping and development of the form.

2. (Figs. 1C1 and 1C2).—"Discoidal" is used in the description to mean like a disc but much thicker and lacking flange (Baker 1959 p.33) as with a highly oblate spheroid. The flight orientation is unknown, the two major surfaces being much alike and lacking features such as flow ridges or flow swirls, which are indicators of anterior or posterior surface and thence of flight orientation. The specimen is too large and heavy and too rounded in the elevational profile to be a lens yet it shows no signs of having lost a stress shell and is proportionately too shallow to be a core. Discoidal, highly oblate spheroids are not generally recognised as being represented amongst australites though they are common forms of some other tektites (Baker 1959, Table 1).

3. (For illustrations, see Cleverly 1973 Fig. 2-43 and P1.1-43).—The coarse pattern of flow ridges is probably on the anterior surface. The parental form was evidently discoidal.

4. (Fig. 1D).—The well-shaped core portion of the specimen contrasts with the other half which looks almost as if plastically deformed, a possibility which is not only completely at variance with accepted concepts of very shallow aerodynamic heating but is scarcely possible for only one half of the specimen.

5. (Fig. 1E).—The flight orientation is unknown. Elongated indicators which have retained a piece of stress shell wrapping partly around one end are sometimes abraded until they have a smooth bulbous end, but this specimen shows no sign of having possessed a stress shell and appears to be of completely different development.

Table 1

*Aberrant australites from Western Australia, Group 1*

No.	Form	Collection	Locality	Dimensions (mm)	Mass (g)	S.G.
1	Centrally thickened, dished form with two unequal, non-opposed scallops in edge	JLCJ	Edjudina station	(26.2-23.2) x 9.2 Glass thickness 5.5 mm in middle of form, c. 3 mm near edge	4.462	2.453
2	Discoidal	TC	Kambalda	(24.9-24.0) x 9.6	7.083	....
3	Flow-ridged, plano-convex form, initially discoidal	SM 10610	Wonganoo station	(21.6-20.5) x 9.4	4.564	....
4	Elongated core tapering off obliquely and somewhat asymmetrically	SM 11714	Mount Remarkable station	42.4 x 18.0 x 15.1	15.147	2.463
5	Clublike	JLCJ	Hampton Hill station	....	....	....
6	Clublike (air bomb?)	PJS No. 150	Kurnalpi	....	12.341	2.415
7	Lens with nearly diametral flow ridge across anterior surface	SM 12004	Menangina station	(13.4-12.9) x 9.4	1.649	2.449
8	Canoe?	UM	Eastern Goldfields	19.2 x 11.4 x 9.3	2.318	2.453



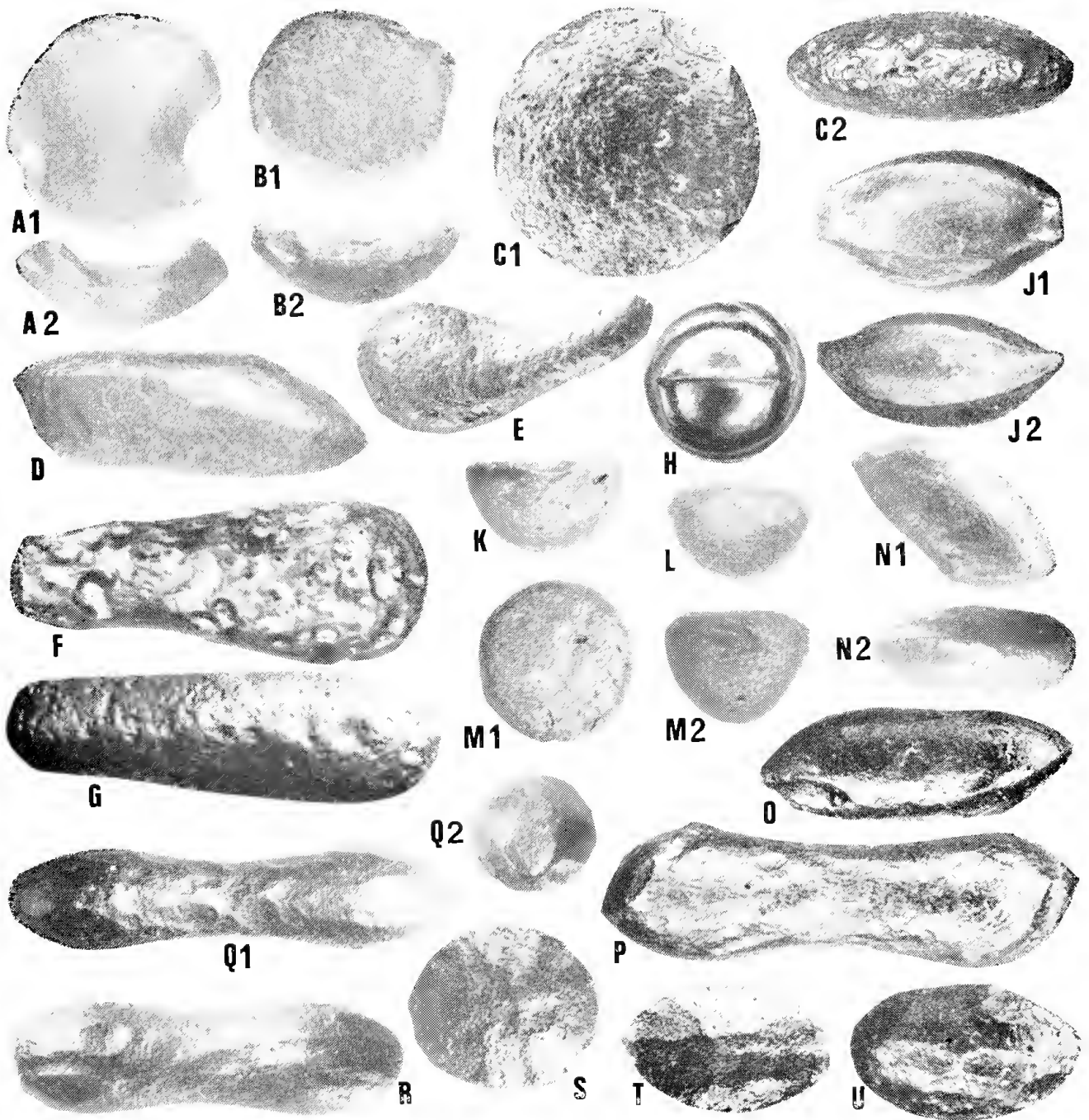


Figure 1.—Aberrant australites from Western Australia. For dimensions and key to specimens Nos. 1-8 see Table 1; for No. 9 onwards see Table 2. A1.—No. 1, concave side. A2.—No. 1, edge view. B1.—Fragment of hollow form, concave side, length 17.3 mm, Edjudina station, JLCJ. B2.—Fragment of hollow form, edge view. C1.—No. 2, one of the major (unidentified) surfaces. C2.—No. 2, edge view. D.—No. 4. E.—No. 5. F.—No. 6. G.—Very weathered, elongated core, side view, obliquely illuminated to show shallow remnants of flake scars, length 64 mm, Earabeedy station, SM 10943. H.—No. 7, anterior surface. J1.—No. 8, posterior surface. J2.—No. 8, side view. K.—No. 9. L.—No. 10. M1.—No. 11, the flat "top" with bevelled edge. M2.—No. 11, side view. N1.—No. 13, side view in supposed orientation for flight towards bottom of page. N2.—No. 13, "plan" view assuming N1 is correctly oriented, showing worn flow ridges on oblique end. O.—No. 15. P.—No. 16. Q1.—No. 17. Q2.—No. 17, flatly concave end. R.—No. 19. S.—No. 20, posterior surface. T.—No. 21, posterior surface. U.—No. 22, posterior surface.

6. (Fig. 1F).—Some specimens of this general shape have been called "air bombs" and are said to orient in flight with the larger end forward. However, it is improbable that such a body with an approximately hemispherical forward end could satisfy the stability requirements enunciated by Chapman *et al.* (1962 p. 14 *et seq.*). Some so-called "air bombs" have faint

traces of a rim or a row of flake scars running lengthwise around them, showing that they were asymmetrical boat or dumb-bell bodies which were oriented with the long axis approximately normal to the line of flight (Fig. 1G). The specimen under discussion cannot be dismissed with that explanation.

7. (Fig. 1H).—The distinctive and very well-preserved feature (flow ridge?) across the anterior surface of this lens is not complemented by a similar one on the posterior surface which is severely etched and thus in contrast to the anterior surface.

8. *Canoe?* (Figs. 1J1 and 1J2).—This form is more stoutly constructed than normal canoes. It is less elongated (length/width 1.68) and proportionally wider (width/thickness 1.23) than the canoe-like form of Group 2 below, but it has the seed-type pattern of flow ridges on the anterior surface as does that form.

#### Group 2

The specimen numbers refer to Table 2.

*Flat-topped form* (Nos. 9-12, Fig. 1K to M).—A round form with a flat top over a rounded, bullet-like nose. The flight orientation is unknown and

hence the "top" is not necessarily a posterior surface. The top may be faintly concave (e.g. No. 10 has overall thickness 5.4 mm, glass thickness at the axis 5.1 mm). A bevelled edge may be prominent (Figs. 1M1 and 1M2). The flat tops are not the result of fracturing and severe erosion would tend to round rather than flatten a surface. Round conical cores can approximate to the shape of this form, but even if severely abraded, the convexity of their posterior surfaces is generally evident and the conical surfaces usually show traces of the edges between facets where pieces of stress shell have been detached.

*Oblique-ended form* (Nos. 13-16, Figs. 1N to P).—Baker (1962 P1.4, Fig. 6) figured an oblique-ended aberrant specimen from Port Campbell, Victoria having a complete covering of flow ridges. He remarked: "This is one of the few well-preserved australites for which no surface can be specifically determined as

Table 2

*Aberrant australites from Western Australia, Group 2*

No.	Form	Collection	Locality	Dimensions (mm)	Mass (g)	S.G.
9	Flat topped	SM 10152	Mount Remarkable station	(15.1-14.7) x 9.1	2.427	2.455
10	Flat topped	SAM T411	Eastern Goldfields of W.A.	(7.2-6.8) x 5.4	0.325	2.432
11	Flat topped	JLCJ	Hampton Hill station	(8.7-8.0) x 5.8	0.505	
12	Flat topped	SM 9585	c. 90 km NNE of Haig	(18.8-18.4) x 9.2	4.051	2.457
13	Oblique ended	SM 11563	Earaheedy station	19.1 x 10.2 x 7.8	2.252	2.460
14	Oblique ended	ESS 42(ii)	Beru Pool, Yelma station	20.7 x 10.1 x 8.2	2.131	2.457
15	Oblique ended	TC	Taurus near Bulong	29.0 x 9.5 x 9.6		
16	Oblique ended	UM	Eastern Goldfields of W.A.	44.2 x 12.2(12.0) x 13.2 (11.9)	3.887	2.456
17	Complex dumb-bell	JBM	Eastern Goldfields of W.A.	40.5 x 9.8(9.4) x 9.4 (8.4)	4.326	2.446
18	Complex dumb-bell	JLCJ	Edjudina station	34.2 x 10.1(9.6) x 9.8 (9.6)	4.481	2.453
19	Complex dumb-bell	SM 12004	Menangina station	36.0 x 11.0(10.8) x 10.7 (10.5)	5.600	2.456
Tortoise-shell ovals:						
20	Broad oval lens	JLCJ	Edjudina station	L 17.1		
21	Narrow oval canoe	SM 11775	Mount Remarkable station	19.4 x 12.4 x 8.0	1.784	2.445
22	Narrow oval lens	WAM 13116	c. 100 km N. of Haig	19.4 x 11.9 x 7.5	1.883	2.451
23	Square ended	SM 10901	Earaheedy station	20.8 x 13.5 x 11.4	4.434	2.453
24	Square ended	SM 10670	Broad Arrow	21.4 x 13.8 x 9.7	3.664	2.453
25	Square ended	JLCJ	Edjudina station	19.9 x 12.3 x 7.8	2.640	2.466
26	Square ended	SM 11704	Yerilla Station	21.4 x 13.1 x 9.8	3.830	2.455
27	Square ended	WAM 11948	Hannans Lake	25.1 x 14.7 x 11.4	5.637	2.444
28	Square ended	SM 11771	Mount Remarkable station	18.5 x 10.1 x 7.5	2.138	2.433
29	Square ended	SM 10873	Eastern Goldfields of W.A.	27.6 x 14.2 x 12.2	6.646	2.456
30	Square ended	WAM 12477	Edjudina station	23.0 x 11.7 x 9.8	3.727	2.459
31	Square ended	JLCJ	Hampton Hill station	21.1 x 10.2 x 9.2	2.807	
32	Square ended	NM	Mount Remarkable station	29.1 x 14.0 x 11.8	6.740	
33	Square ended	SM 10901	Earaheedy station	25.0 x 11.9 x 10.1	4.336	2.458
34	Square ended	WAM 13434	Edjudina station	22.3 x 10.2 x 8.8	2.653	2.459
35	Square ended	SM 12034	Edjudina station	21.0 x 13.5 x 9.0	3.210	2.447
36	Square ended	WAM 13434	Edjudina station	29.4 x 11.9 x 9.5	4.889	2.451
37	Canoe like	SM 9833	Edjudina station	24.2 x 11.9 x 10.6	3.398	2.458
38	Canoe like	JLCJ	Hampton Hill station	(>21.7) x 10.4 x 8.7	2.182	2.455
39	Canoe like	SM	Western Australia	(>22.4) x 9.4 x 8.0	2.049	2.448
40	Canoe like	PJS 134	Kurnalpi	(>23.2) x 9.7 x 8.6	2.333	2.443
41	Canoe like	WAM 12481	Edjudina station	26.3 x 10.0 x 9.3	3.439	2.461
42	Canoe like	UM	Eastern Goldfields of W.A.	(>25.1) x 9.5 x 8.9	2.548	2.451
43	Canoe like	SM 11755	Wangine Soak	(>24.2) x 8.8 x 7.4	1.978	2.449
44	Canoe like	SM 9502	Buningonia Soak	(>26.8) x 9.2 x 8.2	2.781	2.454
45	Canoe like	TC	15 km N. of Bulong	L 23.9		
46	Seed type	JLCJ	Edjudina station	15.1 x 11.3 x 11.1	2.200	
47	Seed type (fragment)	SM 10901	Earaheedy station	(>14.2) x 12.8 x 11.4	2.372	2.450
48	Seed type	WAM 11 944	Kalgoorlie	15.4 x 12.3 x 10.4	2.222	2.448
49	Seed type	SM 10873	Eastern Goldfields of W.A.	14.2 x 10.8 x 8.7	1.436	2.461
50	Seed type	WAM 12227	Earaheedy station	14.4 x 12.1 x 9.4	1.825	2.451
51	Seed type	JLCJ	Hampton Hill station	10.2 x 9.6 x 6.7	0.850	
52	Seed type	SM 10901	Earaheedy station	13.7 x 10.2 x 7.0	0.984	2.457
53	Seed type	JLCJ	Edjudina station	13.6 x 10.9 x 7.4	1.391	
54	Seed type	WAM 12147	Yellow Lake, Israelite Bay	11.9 x 9.4 x 6.2	0.838	2.445
55	Seed type	SAM T97	Israelite Bay	Fragment L 14.2		
56	Unnamed form	TC	Kunanalling	14.4 x 9.7 x 8.9		
57	Seed form with crinkly top	SM 10609	Menangina station	19.2 x 13.2 x 8.9	1.771	2.449
58	Pine-seed form	TC	Seven-mile Hill, Kalgoorlie	L 18.3		
59	Pod like	JLCJ	Edjudina station	25.8 x 14.2 x 11.9	0.668	2.457



the posterior or anterior surface". Although the Western Australian specimens have flow ridges on the ends only or even on a single end, they are believed to be of the same aberrant type. When on the ground, the long axis would lie parallel to the surface of the ground leading to abrasion of flow ridges from the flanks but with the possibility that some remnant of them might survive on the ends not in contact with the ground.

Specimen No. 14 is deeply etched. Fingers (Barnes 1961) stand out in relief on the major surfaces but not on the ends. Fingers may extend a few millimetres into an australite and are believed to have been primary features because they are usually observed on posterior surfaces only. The distribution of fingers on specimen No. 14 suggests that only a thin layer of glass can have been lost from the flanks but at least some millimetres from the ends. It was speculated that if an elongated primary body contained a bubble cavity centred somewhat off the mid-point of the length, it might orient as in Figure 1N1 (heavier end forward and moving towards bottom of page). When a sufficient frontal thickness had been removed, retreat of the centre of gravity could cause instability and a turning over through 180° to a complementary position; this process could be repeated. However, the specific gravities of the specimens do not suggest the presence of cavities of significant size; nor could cavities be detected using strong illumination. The sequence of the specimens in Table 2 is of increasing elongation culminating in a dumb-bell. At the same time, width/thickness declines, but this might be fortuitous as only 4 Western Australian specimens were available.

*Complex dumb-bell form* (Nos. 17-19, Figs. 1Q, R).—Specimens have flow ridges over the entire surfaces with strong tendency to longitudinal pattern. The width/thickness is close to unity (Table 2) i.e. they approach the "peanut" form (Fenner 1934) which is nearly circular in section and therefore has much the same appearance in posterior as in side view. Less constant features are slightly concave ends (Fig. 1Q2) and a distribution of flow ridges suggestive of changes in flight orientation.

*Tortoise-shell ovals* (Nos. 20-22, Figs. 1S to U).—Oval lenses and the flanged forms from which they were derived sometimes have a coarse pattern of ridges, evidently flow ridges, upon their posterior surfaces. There may be a strong tendency to longitudinal pattern. Nothing quite comparable has been observed on round forms or on those more elongated than narrow oval.

*Square-ended form* (Nos. 23-36, Figs. 2A to G).—With the possible exception of the seed type, this is the commonest of all the aberrant forms noted in Western Australia. About 30 specimens were examined but most were severely etched or abraded and lacked all surface detail. The better-preserved specimens show complex flow ridges or roughly longitudinal ridges approximating to seed type (see below) on the anterior surface and flanks (Figs. 2A2, D1, G2), but the most characteristic feature is the way in which the supposed posterior surface rolls down to meet ends which are at right angles to the length (Fig. 2D2). The survival of the characteristic shape even after all surface detail has gone (Figs. 2B, C, E, F) has increased the abundance of this

form relative to those such as the crinkly top from which the removal of glass a few tenths of a millimetre thick effectively destroys them as aberrant forms.

*Canoe-like form* (Nos. 37-45, Figs. 2H to M).—This form is of moderate abundance amongst aberrant types (15 inspected, most of them too worn to be informative). One specimen of this form was figured by Fenner (1934, Pl.8, A5e 1 and 2) but his other figured specimen (A5e 3 and 4) looks more like a normal form derived from the saddle region of a symmetrical dumb-bell rather than a canoe-like form. Fenner placed these specimens under the general heading of canoes in a sub-class termed "aberrant elongates". Characteristics of the canoe-like form are the high elongation in combination with roughly equidimensional cross-section; flow ridges tending to longitudinal on the supposed posterior surface and often on the anterior surface also if not abraded (Fenner 1934 noted "flow lines on both surfaces"); and the pinched and slightly turned ends (presumably backwardly turned), one or both of which are likely to be found in broken condition.

*Seed type* (Nos. 46-55, Figs. 2N to R).—Fenner (1940 Pl. 19, No. 14) figured an australite as the "seed type", the essential feature being the arrangement of the flow ridges and troughs on the anterior surface. The pattern resembles that of meridians of longitude radiating from the two blunt ends of the length as poles (Fig. 2N). The most typical specimens have low elongation and the resemblance of the pattern to meridians is then emphasized. Baker (1969) figured and described as the "nut-like" form specimens in which the flow ridges encroached on to what would normally be the posterior surface, tending towards an almost complete surface coverage by flow ridges and troughs. He postulated that rocking on the long axis had exposed parts of the posterior surface. If both seed and nut-like names are to be retained, then the nut-like form could perhaps be confined to this less common variety with flow ridges distributed around more than 180° of the cross-section; only two of the specimens examined showed this feature (Fig. 2Q). There is variation in width/thickness from about 1.7 (shallow forms) to about 1.0 (globular, especially the nut-like forms—see proportions of those illustrated by Baker 1969, Fig. 3). Three other specimens showed what appeared to be very small remnants of the butt of a flange but this could not be confirmed. Two specimens showed not only the seed-type flow ridges but concentric ridges on the other major surface, apparently as the result of overturning and re-establishing at least some degree of stability (Figs. 2O, P). The sequence of development of these two anterior surfaces is not evident. Seed-type flow ridges are present also on No. 8 of Group 1 and on a rare broad oval form with pointed ends (No. 56, Fig. 2R). Specimens with a crinkly top (Fenner 1934) may occasionally have a seed-type anterior surface. Thus the seed-type pattern is present on a considerable variety of forms having various kinds and degrees of instability ranging from a rocking to complete overturning. There is doubt that it should be regarded as an aberrant form but perhaps rather as one of the less common but by no means rare patterns of flow ridges.

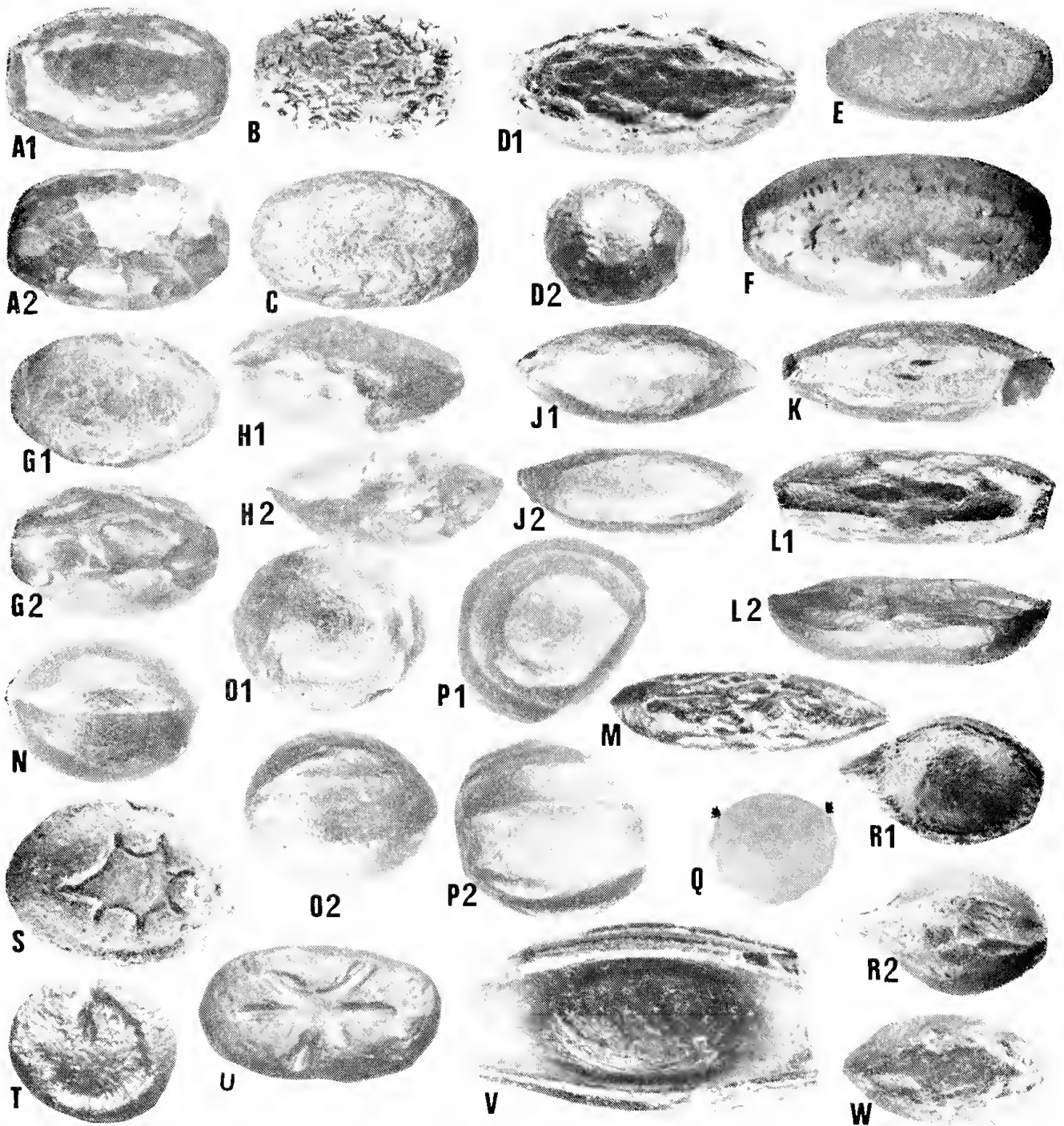


Figure 2.—Aberrant australines from Western Australia. For dimensions and key to specimen numbers see Table 2. In side or end (elevational) views direction of flight is towards bottom of page. If the view is not specified flight orientation is uncertain or unknown. A1.—No. 24, posterior surface. A2.—No. 24, anterior surface. B.—No. 23. C.—No. 26. D1.—No. 29, anterior surface. D2.—No. 29, end view. E.—No. 31. F.—No. 32. G1.—No. 35, posterior surface. G2.—No. 35, anterior surface. H1.—No. 37, posterior surface, broken at upper right. H2.—No. 37, side view. J1.—No. 40, posterior surface. J2.—No. 40, side view. K.—No. 42. L1.—No. 44, posterior surface. L2.—No. 44, side view. M.—No. 45. N.—No. 49, anterior surface. O1.—No. 50, surface with concentric ridges. O2.—No. 50, surface with seed-type flow ridges. P1.—No. 55, surface with concentric flow ridges. P2.—No. 55, surface with seed-type flow ridges. Q.—No. 47, broken end ground flat. Flow ridges are present from the arrow-head at about 2 o'clock clockwise to the arrow-head at about 10 o'clock. R1.—No. 56, posterior surface. R2.—No. 56, anterior surface. S.—No. 57, posterior surface. T.—Broad oval lens, posterior surface, length 16 mm, from about 95 km NNE of Haig, SM 11028. U.—Narrow oval lens, posterior surface, length 24.4 mm, Earabeedy station, SM 10943. V.—No. 58, posterior surface. W.—No. 59.



*Other forms*

The following were omitted from detailed listing because of the small numbers available, poor state of preservation, or doubts about identification as aberrant forms.

*Crinkly top* (No. 57, Fig. 2S).—The distinctive feature was defined by Fenner (1934). The crinkly top has usually been regarded as comprising thin tongues of secondary melt which have overflowed on to the posterior surface from various points around its edge, but I have been unable to detect any junction line between the supposed flows and posterior surface. It is suggested that the crinkly top might develop by removal of material from the central part of the posterior surface rather than by addition of material to the peripheral part. Shallow depressions may be developed by weathering of posterior surfaces (Fig. 2T). Radial systems of grooves, especially V-grooves centred upon posterior poles are common and might provide the starting point. An oval specimen (Fig. 2U) on which the grooves have widened into shallow U-grooves and the “front” has retreated may be an intermediate stage in formation of a crinkly top. If crinkly tops developed in that way, they need not be regarded as aberrant.

*Pine-seed form* (No. 58, Fig. 2V).—The form was defined by Skeats (1915). It has a relatively flat posterior surface with broad and extensive flange at the ends merging into narrow, backwardly-curved flange along the sides; these are essentially exaggerated canoe features. The process which forms a canoe could also form the pine seed, the flat top possibly resulting from the considerable loss of material from the body to provide the end-flange.

The frail end-flanges of pine-seed forms have usually been either folded backward to be partially or wholly fused to posterior surface (Cleverly 1973, Fig. 2-24 and Pl. 1-24 and -35) or broken off during weathering (Fig. 2V).

*Pod-like form* (Baker 1969).—The specimen available (No. 59, Fig. 2W) is in only fair condition, and other possible examples are worse.

**Discussion**

Most of the aberrant australites examined are relatively small; only two of them weigh more than 10 g. The mode of the masses is in the 2 g - 3 g interval (Fig. 3A), but the distribution is skewed to masses greater than 3 g when compared with a general sample from the area. This shows up in the distinctly higher mean mass of 3.54 g compared with 2.89 g for 3562 complete or essentially complete australites from Earraheedy, Hampton Hill, Edjudina and Mount Remarkable stations.

The specific gravities of occasional aberrant specimens were determined initially because it was speculated that a large bubble cavity, appropriately located, might cause some instability or peculiarity flight and hence the development of an aberrant form. No unusually low result was obtained and when a relative frequency diagram was prepared, its degree of agreement with that for other australites of the area was remarkable (Fig. 3B). Note that this is not the usual random sample comprising australites of all morphological types and sizes from a localized area; on the contrary, this sample is highly biased to the 2% or so of aberrant types

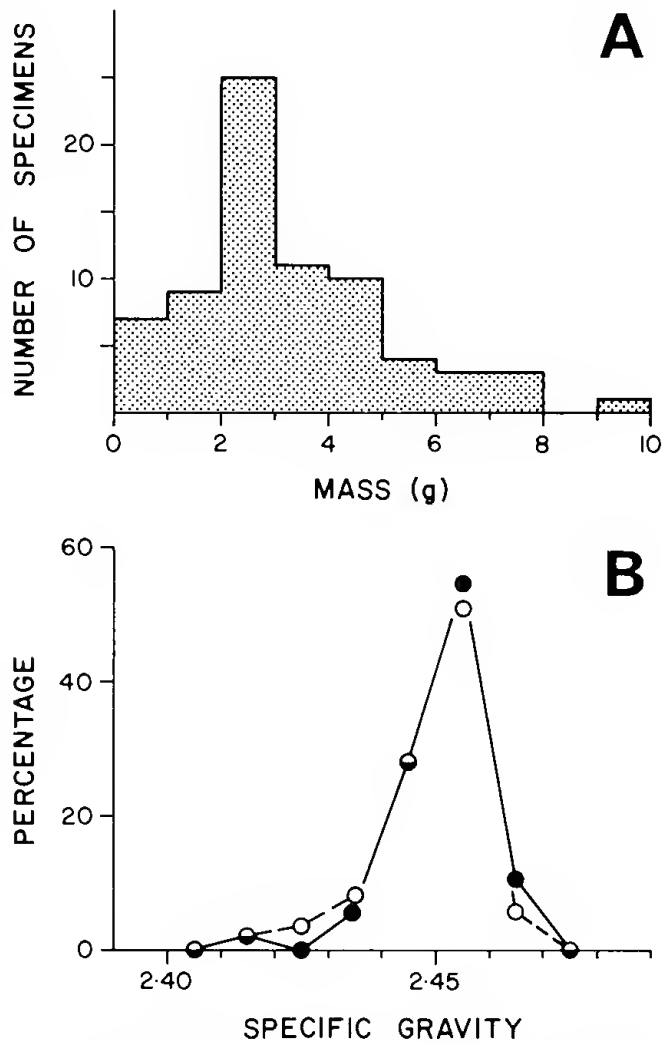


Figure 3.—A.—Masses of 73 aberrant australites with mode in the 2-3 g interval. Single specimens of 12.3 g and 15.1 g have been omitted. B.—Relative frequency polygons of specific gravity. Polygon for 56 aberrant australites shown by solid circles and firm lines. Polygon for 420 australites from the Kalgoorlie area from Chapman *et al.* (1964) shown by open circles and broken lines.

occurring throughout a considerable region. It appears that the aberrant australites of the region are thoroughly typical as regards specific gravity, being representative of the whole range and in the same proportions as “normal” forms. Reasons for the peculiarities of aberrant australites needs to be sought in other properties.

The dimensional proportions of a form are concerned in determining such things as its flight orientation, the amount of cross-sectional area relative to mass and the depth below the frontal surface of the centre of gravity. In combination with the frontal curvature, these affect the stability of a body in ablation flight and the course of its development. Various plots were made of the dimensions and their ratios such as length/width (elongation) and width/thickness. Because the number of specimens of any type is generally small, these plots showed little that cannot be seen in the tabulated dimensions and they have not been included. However, the fields on those diagrams might eventually be useful for defining some of the forms, especially after additional

specimens from elsewhere have been studied. Thus the oblique-ended form combines increasing elongation (1.87-3.62) with decreasing width/thickness (1.31-0.92); the canoe-like form is of high elongation (2.03-2.91) with small width/thickness (1.08-1.24) in conformity with the observation that some specimens of that type are almost cylindrical in the mid-section. The complex dumb-bell form has very high elongation (3.27-4.13) in combination with width/thickness about 1.04 ("peanut type"). However, it would appear pointless to apply this consideration of dimensions to the seed type because the structure can occur on a wide variety of forms; it might not apply to the crinkly top either as that structure evidently occurs on specimens ranging from round to boat shaped (Fenner 1934, Pl. 9F). It might be advantageous to recognise two kinds of aberrant types in Group 2. On the one hand there are the surface features such as the seed-type flow-ridge pattern and the crinkly top which are of secondary or even later origin and which are shallow enough to be removed during erosion; on the other hand there are the shapes such as the square ended which have a high capacity for survival after all surface detail has gone, and for the origins of which it might be necessary to go back to the consideration of primary forms.

It is conceivable that some kinds of aberrant australites occur in certain regions because their development was related to factors such as distance from source. Information on eastern Australian aberrant australites is, however, exceedingly meagre. From personal observation, excellent examples of tortoise-shell ovals, square-ended and canoe-like forms as well as a number of seemingly unique specimens (Group 1) have been found in parts of South Australia (Australian and South Australian Museum collections).

Some of the specimens of the Shaw collection placed by Fenner (1930) in sub-classes A7e and A5e appear to be aberrant and the Shaw collection is generally thought of as being from the Nullarbor Plain spanning parts of Western and South Australia. However, it is quite clearly stated (Fenner 1930, p.65) that the majority were found in the vicinity of Israelite Bay which is in Western Australia and about 270 km outside the south-western margin of the Nullarbor Plain. Figures from the Shaw collection are not therefore pertinent to a consideration of australites from eastern Australia.

For the Kennett collection from the general vicinity of Charlotte Waters, Fenner (1940, p.315) has given a list from which some items may be eliminated to leave, at most, 37 aberrant australites out of about 5400 identifiable specimens, or about 0.7%. This low percentage is in accord with the writer's experience of australites from that general

area. The detail of those specimens apart from two (three?) illustrated ones is not given.

Baker (1969) recorded pod-like and nut-like forms from Mulka, South Australia, but it is peculiar that in the voluminous and detailed literature which Dr Baker produced on Victorian australites he should say so little of aberrant ones. The impression is gained that aberrant forms are more abundant on the western than on the eastern side of Australia but information is so meagre that this is little more than speculation. Some account of the aberrant australites of South Australia and the eastern states is needed, and particularly so because the better-preserved specimens of Victoria and parts of South Australia should provide better opportunities for determining the mechanisms of development.

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## Notes on the revised taxonomic position of the Black Wishbone spider *Dekana diversicolor* Hogg (Mygalomorphae: Dipluridae)

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### Abstract

The common diplurine species *Dekana diversicolor* Hogg of which the holotype is lost, has long been identified on a combination of male characters and the distinctive Y-or wishbone-shaped burrow. The stated type locality, Deka station, cannot be traced, thus association of this biologically distinct species with a topotypic population cannot be made. In the interests of maintaining nomenclatural stability a neotype for *Dekana diversicolor* Hogg is designated and a new type locality 26 km north-west of Elliston, South Australia, chosen. On morphological criteria *Dekana* cannot be separated from *Aname* Koch, therefore *D. diversicolor* is transferred to *Aname* and *Dekana* becomes a synonym of *Aname*. *Chenistonia* (*Dekana*) *atra* Strand, the type species of *Sugenia* Rainbow and Pulleine, is synonymised with *Aname diversicolor* (Hogg) and *Sugenia* is also placed in synonymy with *Aname*.

### Introduction

The common diplurine spider, the Black Wishbone spider, for long identified as *Dekana diversicolor*, is widespread, although rarely occurring abundantly, in southern Australia, especially west of the Flinders Ranges. Wandering male spiders are frequently encountered during humid weather in early and mid-summer in Perth suburbs and other localities in Western Australia south of Shark Bay. The species also occurs on offshore islands. Because of their large size, black colouring and aggressive behaviour, they are often mistakenly reported as Funnel-web spiders which belong to the unrelated venomous genus *Atrax*.

During my initial studies on mygalomorph spiders I coined the group name of wishbone spiders to denote a group of diplurine species (of which some are still unnamed) that were behaviourally distinct from morphologically similar groups of species. The wishbone species all make forked or Y-shaped burrows of which one arm has a blind end just below the surface of the ground and can be broken open as an escape hatch by the spider. In various species the distance between the two arms of the fork varies considerably. The burrow of the Black Wishbone spider has a heavy silk lining and the arms are generally closer than in other species (Fig. 1); in some instances the two arms of the silken tube are suspended within a single burrow lumen.

There has always been taxonomic confusion between the genera *Aname*, *Ixamatus*, *Chenistonia* and *Dekana*. Main (1972) in an account of the genus *Stanwellia*, briefly diagnosed the above genera on a combination of characters including the curvature of the fovea, armature of the first tibia in males and the type of burrow constructed. *Chenistonia* has a straight fovea whereas it is usually procurved in the other three genera. In addition, *Chenistonia*

frequently has a sheen on the body and legs and especially on the carapace due to a thin clothing of fuscous hair. The males of both *Chenistonia* and *Dekana* have on the first tibia a large median spur which bears one large spine. Occasionally a second, more slender, spine occurs underneath the base of the spur especially in *Chenistonia*. The spur is lacking in *Ixamatus* which has an array of spines on the first tibia. This sexual character difference of males is consistent with the condition found in the type species of *Chenistonia*, *Dekana* and *Ixamatus*. However the holotype of the type species of *Aname*, *A. pallida* Koch, is a penultimate instar male, allegedly from the same locality (Bowen, Queensland) as the type species of *Ixamatus*, *I. varius* (Koch), and there was the possibility that the specimen was an immature *Ixamatus*. Main (1972) distinguished *Aname* as comprising those species with a procurved fovea and in which the male has a tibial spur and which build a simple (i.e. unforked) burrow. Subsequently Raven (1980) after examination of the syntypes of *I. varius* (Koch) has shown that both males and females of the species can be readily distinguished from other diplurine genera by the presence of a tarsal rod. Likewise I have noted the presence of a tarsal rod on the holotype of *I. broomi* Hogg from Hillgrove, New South Wales. This reasserts the distinction of *Aname*, as suggested by Main (1972), but still does not readily distinguish it from *Dekana* except on behavioural criteria e.g. the burrow structure.

*Dekana* and *Aname* are, on present morphological analysis, similar and can justifiably be synonymised. A supporting observation is that in southern Western Australia there occurs a species which does not build a wishbone burrow but in which the female spiders closely resemble those of the Black Wishbone spider. To date no males have been collected from such



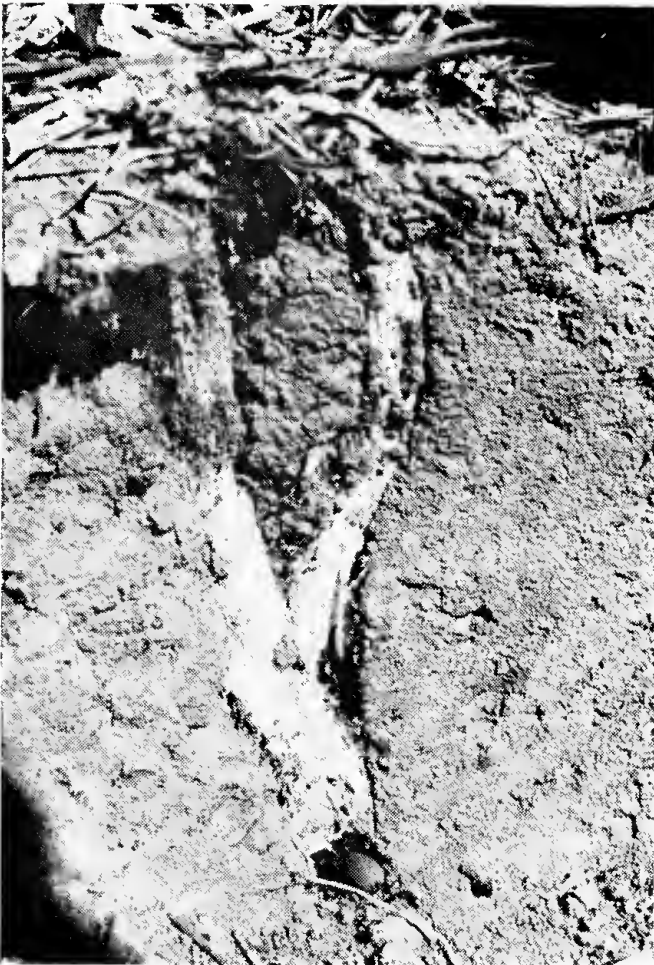


Figure 1.—Exposed burrow and silk lining of a Black Wishbone spider, *Aname diversicolor* (Hogg) (9.5 km west of Zanthus, Western Australia, 29 January 1956, BYM 1956/65) W.A. Museum 80/1775. Note spider protruding from bottom of tube; burrow 26 cms deep.

burrows. Furthermore there are several other "species pairs" in which one species builds a wishbone-like burrow and the other constructs a normal oblique or vertical nest. It appears that at least some wishbone burrowing species have been independently derived from species with simple burrows. The wishbone burrow, as a character, is therefore not *shared* but *convergent*. Although each of the wishbone burrowers represents a particular behavioural level and together comprise a related group of species they are not a monophyletic group and thus do not constitute a separate genus. The biology and evolutionary radiation of these species will be discussed elsewhere. In conclusion *Dekana* is synonymised with *Aname* Koch and the type species of *Dekana*, *D. diversicolor* Hogg, is placed in *Aname*.

Some species previously transferred from *Aname* to *Dekana* by Main (1972) should be reinstated in *Aname* e.g. *aurea*, *grandis* and *armigera* (Rainbow and Pulleine); *Dekana wonganensis* Main is transferred to a new genus (Main, in prep.).

#### Type locality of *Dekana diversicolor* Hogg

Hogg (1902) gave the type locality of *Dekana diversicolor* as "Deka station, near Blackhall". Neither localities can be traced.

Although most of the other species described by Hogg at the same time came from South Australian localities, I assumed that "Blackhall" could readily have been a misnomer for Blackall in western Queensland. Knowing that the species which I tentatively identified from Hogg's description as *Dekana diversicolor* is widespread in South Australia (at least from the Flinders Ranges westward) and across the southern part of Western Australia, I rationalised that the species could be continuous into south-western Queensland. Hence Blackall would be a possibility as the type locality. However, correspondence with the Queensland Department of Public Lands revealed that no such place as "Deka station" existed (pers. comm. 1957). Correspondence with the appropriate Government departments in New South Wales, Victoria and South Australia indicated that there was no such locality as Deka station in these states either. However in 1965, I learned from the Government Botanist in Queensland that there was a Delta station near Blackall in western Queensland. Thus it is possible that Hogg misread the locality label of his specimen which could have referred to Delta Station, Blackall. On the other hand, Robert Raven (pers. comm.) suggests that "Blackhall" could have been a misreading of "Blackhill", a locality near Adelaide in South Australia. A further possibility, and the most likely one, is that the original locality was "Colona station, Blackhill" which is in South Australia.

#### Location of the type specimen

The type (holotype, ♂) of *Dekana diversicolor* Hogg has never been located. Although many of Hogg's types are in the British Museum (Natural History) including types of other species described at the same time, the type of *Dekana diversicolor* has not been found in the collections (G. Owen Evans pers. comm. 1957). Subsequent searching by myself (1958 and 1979) and by F. Wanless has not revealed its presence. Nevertheless Hogg's description appears to be adequate for identification at least of male specimens. By association, females have subsequently been attributed to the species.

#### Taxonomy of *Dekana* Hogg 1902

Strand (1913) regarded *Dekana* as a subgenus of *Chenistonia* and described the species *Chenistonia (Dekana) atra* from central Australia. This species I regard as a synonym of *Aname diversicolor* (Hogg). The type (holotype, ♂) of *C. (D.) atra*, is in the Senckenberg Museum, Frankfurt (sighted in 1958). Prior to my sighting the specimen, Dr O. Kraus kindly figured the palp for me in order to compare it with specimens collected in Western Australia and South Australia. The salient characters of the spined spur on the first tibia and the characteristic palpal structure, consisting of a simple bulb and long tapering embolus (Fig. 2A) and the faint down of silvery hairs on the carapace identify it as conspecific with *A. diversicolor*. In the British Museum (Natural History) there is also a male specimen from central Australia (collected from Hermansburg by H. J. Hillier, no date) which closely agrees with Strand's type of *atra*. Additional specimens have been sent to me from localities near Alice Springs. It should be noted however, that the type of *atra* differs in several points from Hogg's figures (Hogg 1902, text fig. 27) and description of



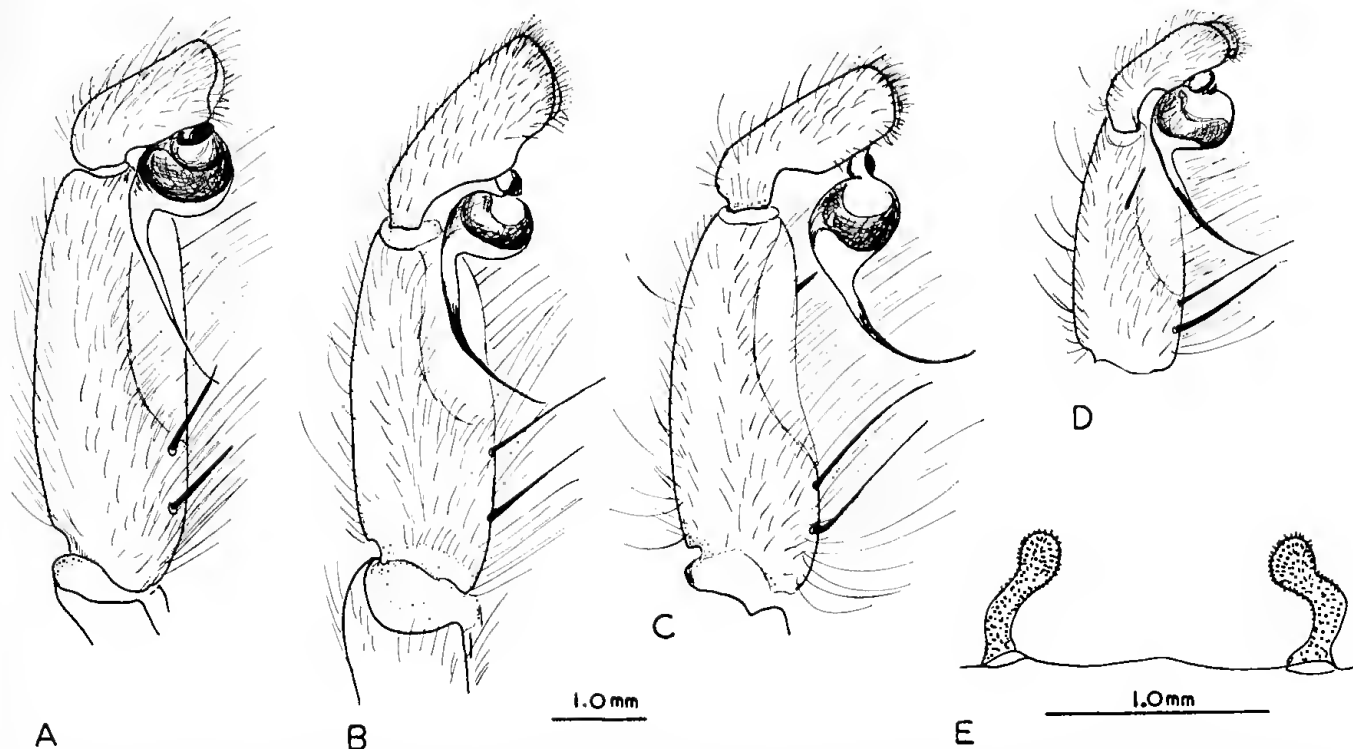


Figure 2.—A, B, C, D, Retrolateral views of right palps of males. A.—Holotype of *Chenistonina (Dekana) atra* Strand. B, C, D.—*Aname diversicolor* (Hogg). B.—Neotype, SAM N1980196. C.—BYM 1953-522 (Magooinya, Balladonia station, Western Australia, 10 December 1953, B. Y. Main) W.A. Museum 80/1776. D.—BYM 1957/1 (Rottneest Island, Western Australia, 17 January 1957, M. J. Littlejohn) W.A. Museum 80/1777. E.—Internal genitalia of female *Aname diversicolor* (Hogg); BYM 1952/637 (26 km northwest Elliston, South Australia, 28 December 1952, B. Y. Main) W.A. Museum 80/1778.

*D. diversicolor* as follows: *atra* clearly has two proximal retrolateral spines on the palp tibia whereas these are lacking in Hogg's figure of *diversicolor* (which appears to be a retrolateral view); the stigma or embolus of *atra* is relatively longer, tapering and only very slightly curved whereas it is shown to be pronouncedly bent in Hogg's figure of *diversicolor*. If the specimen was dry (as indeed several of the early Australian mygalomorph types were) it is possible that the stigma had become bent as a result of desiccation and that the basal spines may have become detached. Furthermore, it has been noticed that in freshly collected specimens of the Black Wishbone spider retrolateral spines may be present or absent, or reduced to bristles and the curvature and length of the stigma varies (see Figs. 2 B,C,D.)

Rainbow and Pulleine (1918) erected a new genus *Sungenia* for Strand's species *C. (Dekana) atra*. The distinguishing features of *Sungenia* were stated to be a procurved fovea (as distinct from straight in *Chenistonina*) and marginal sternal sigilla (as distinct from removed from the margin in *Dekana*). *Sungenia* was stated to resemble *Chenistonina* and *Dekana* in the presence of a tibial spur on the first leg of the male.

During 1954 and again in 1965 while visiting The Australian Museum I examined the available mygalomorph types of Rainbow and Pulleine but was unable to see their specimen of *Sungenia atra* (Strand) from Balingup until May 1979. It has a procurved fovea but the posterior sternal sigilla are not marginal. I regard it as conspecific with Hogg's species *Dekana diversicolor* and Strand's

species *Chenistonina (Dekana) atra*. Although labelled as "TYPE", Rainbow and Pulleine's specimen is not a type, since the type of Strand's species *Chenistonina (Dekana) atra* properly becomes the type of the genus *Sungenia*. It is doubtful whether Rainbow and Pulleine even regarded their specimen (Australian Museum K41258) as a type, as the original label is lost and has been replaced by an ink label marked as follows "*Sungenia? (Chenistonina)? atra*". This specimen agrees generally with Hogg's description of *Dekana diversicolor* and the type of *Chenistonina (Dekana) atra* Strand. Previously Main (1972) had tentatively synonymised *Sungenia* with *Chenistonina*.

#### Tribe Anamini Simon 1889

##### *Aname* Koch 1873

*Aname* Koch, 1873. Die Arachniden Australiens, p. 465. Type species by monotypy *A. pallida* Koch, 1873, Die Arachniden Australiens p. 465-7. Pl. XXXV, Type locality: Bowen, Queensland.

*Dekana* Hogg, 1902. Proc. Zool. Soc. London, 1902 (Vol. 2): 138. Type species *D. diversicolor* Hogg by original designation. NEW SYNONYMY.

*Sungenia* Rainbow and Pulleine, 1918. Rec. Austr. Mus. 12: 162. Type species by monotypy *Chenistonina (Dekana) atra* Strand. NEW SYNONYMY.

*Diagnosis* (modified from Main 1972): Carapace usually with procurved fovea, broad with rounded sides; pronounced eye tubercle; labium broad and anteriorly indented, usually without cusps; cheliceral furrow with teeth on promargin only, apart from basal group of small granular teeth; occasionally with pseudo-rastellum of stout "teeth" on inner, apical edge of paturon; maxillae with numerous

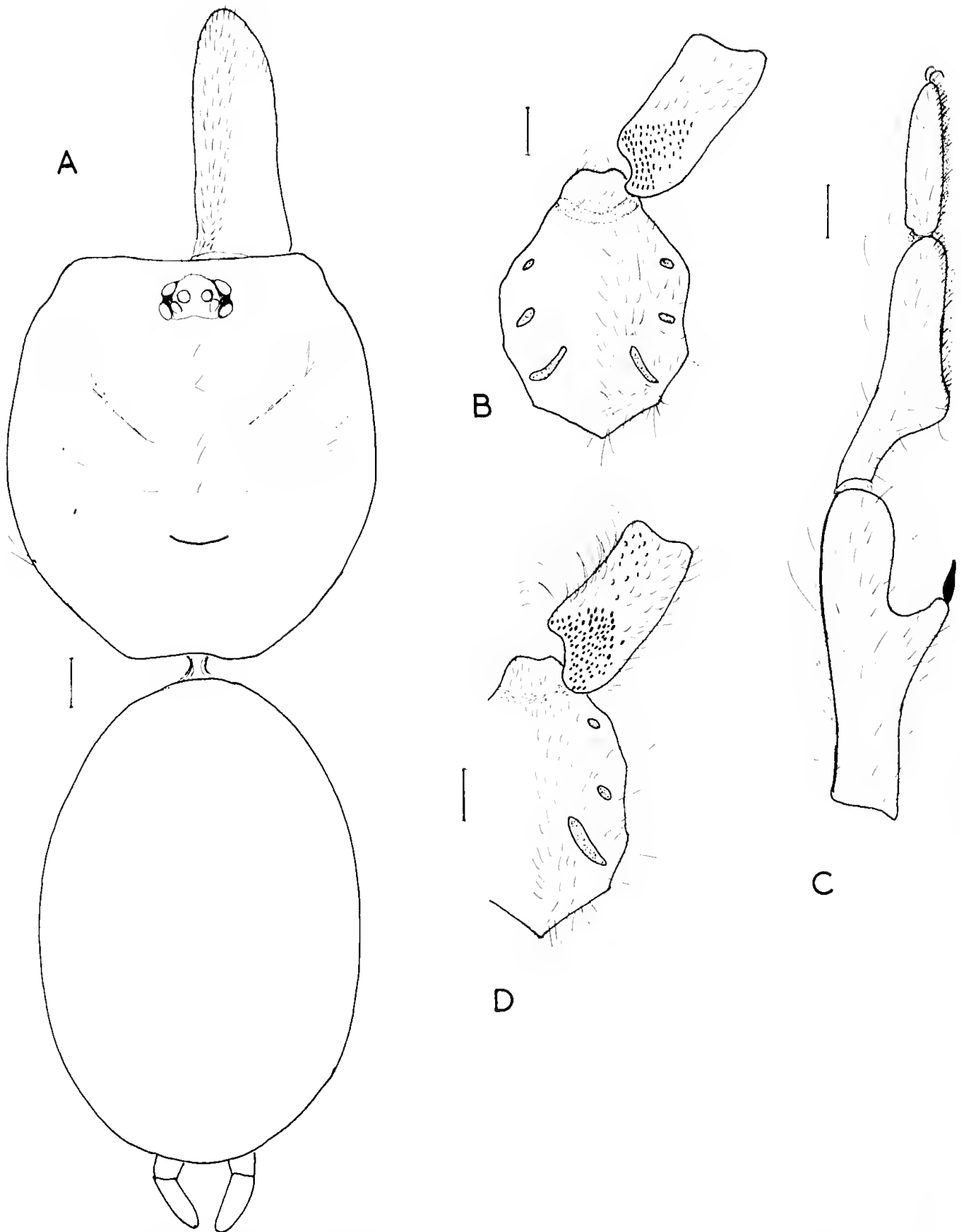


Figure 3.—*Aname diversicolor*. A, B, C. Neotype, SAM N1980196. A.—Outline of carapace and abdomen, dorsal view. B.—Sternum, labium and maxilla. C.—Right leg I, tarsus, metatarsus, tibia, retrolateral view. D.—Female (BYM 1952/631), SAM N1980195 sternum, labium and maxilla. All scales = 1.0 mm.

cuspsules over whole proximal area; posterior sternal sigilla large, broad oval or acutely elliptical and sometimes non-marginal; bipectinate superior tarsal claws; a proximal pair of spines on palp tarsus of female; leg tarsi without spines; scopula on tarsi of palp and at least tarsi I and II; tarsi without a "tarsal rod" (as defined by Raven 1980); two pairs spinnerets, posterior lateral pair relatively long with tapering terminal segment. Male with a spine-bearing spur in mid-region of tibia I; palpal tibia with few spines; embolus thin and tapering to a point. Burrow simple or forked i.e. "wishbone" shaped. Males generally wander during summer.

The genus is widespread throughout Australia and also occurs in Tasmania.

#### *Aname diversicolor* (Hogg), new combination

*Dekana diversicolor* Hogg, 1902. Proc. Zool. Soc. London 1902: 138, fig. 27. Male holotype from Deka Station, Blackhall, lost. Main, 1964, 1967. Spiders of Australia: 48, 49 (Jacaranda). Main, 1976. Spiders: 71, 257 (Collins).

*Chenistonia* (*Dekana atra* Strand, 1913. Zoologisches Jahrb. 1913: 601. Male holotype from Central Australia in Senckenberg Museum, Frankfurt, examined, NEW SYNONYMY.

*Chenistonia atra* Strand, Main 1972. J. Roy. Soc. W. Austr. 55: 101.

*Sungenia atra* (Strand). Rainbow and Pulleine, 1918. Rec. Austr. Mus. 12: 162. Male holotype of *Chenistonia* (*Dekana atra* Strand. Rainbow and Pulleine described a male specimen from Balingup, Western Australia, in Australian Museum, examined.

? *Aname comosa* Rainbow and Pulleine, 1918. Rec. Austr. Mus. 12: 143, Pl. 23, Fig. 91. Female holotype from Pichi Richi, South Australia in Australian Museum, examined. Main, 1972, J. Roy. Soc. W. Austr. 55: 100, synonymised *A. comosa* with *Dekana diversicolor*.

? *Aname hirsuta* Rainbow and Pulleine, 1918. Rec. Austr. Mus. 12: 142, Pl. 23, 89, 90. Female holotype from Mallala, South Australia, in Australian Museum, examined. Main, 1972, J. Roy. Soc. W. Austr. 55: 100, synonymised *A. hirsuta* with *Dekana diversicolor*.

**Designation of neotype:** In the interests of maintaining nomenclatural stability for a common and widespread species which frequently attracts human attention and to which references have already been made in medical literature, a neotype is designated and a new type locality nominated, for *Dekana diversicolor* Hogg [= *Aname diversicolor* (Hogg)].

Neotype: ♂, 26 km north-west of Elliston, South Australia, 20 December 1952, B. Y. Main (BYM 52/636), taken from wishbone shaped burrow. South Australian Museum (SAM) N1980196.

Female: data as for neotype, (BYM 52/631). SAM N1980195.

**Description:** Large spiders, (with carapace length of 6.5 mm to over 10.00 mm), long-legged, black in life and with sometimes a bluish bloom on abdomen; the carapace broad, with rounded lateral margins (Fig. 3A), it may have a pelt of silvery hairs (especially in males); the fovea is generally procurved but sometimes distorted in males; eye tubercle pronounced; single row of large teeth on inner margin of cheliceral furrow and a group of small basal teeth; posterior sternal sigilla are large, longer than wide, oval or irregular in outline (Figs. 3B,D) and of variable distance from the margin; rastellum teeth sometimes present on inner apical face of chelicerae; numerous cuspsules over proximal third of maxilla (Figs. 3B,D); a few cuspsules occasionally

present on first and second coxae as well as on palpal coxae; stout, spinule-like bristles on prolateral faces of coxae; labium broad and anteriorly indented; legs sparsely spinose, ventral spines on all metatarsi and tibia (lacking on first leg of male), proximal spines present on palpal tarsi of female (usually two) but absent from leg tarsi in both female and male; scopula present on all tarsi and at least partial scopula on metatarsi, divided by a band of bristles on tarsi III and IV.

Male with large median spur bearing a heavy spine on tibia I (Fig. 3C); metatarsus I distally inflated and proximally depressed. Stigma (embolus) of palpal bulb long and tapering (see Figs. 2A,B,C,D). Internal genitalia of female; vesicles unbranched (see Fig. 2E).

**Measurements:** Male (neotype): Carapace length, 9.7; width, 8.4. Leg formula 4/3.01, 1/2.83, 2/2.54, 3/2.22. Tibial index I, 13.04; tibial index IV, 13.72. Female (BYM 52/631): Carapace length, 8.5 mm; width, 7.5 mm. Leg formula 4/2.8, 1/2.55, 2/2.28, 3/2.03. Tibial index I, 14.77; tibial index IV, 14.94.

The most important diagnostic character is the configuration of the burrow which is a wishbone or Y-shape with the two arms close together and with a strong silk-lining (Fig. 1); occasionally the silk tube alone forms the Y and is suspended in an unbranched burrow. Males mature and wander during early and mid-summer at the onset of humid weather which is frequently associated with spasmodic thunderstorms.

**Deposition of specimens:** All specimens figured apart from the neotype and female (BYM 52/(631)) are deposited in the Western Australian Museum.

A full account of the morphological variability and geographic distribution is to be presented elsewhere in a comparative account of the wishbone-building and related species of *Aname* in south-west Western Australian and South Australia.

**Acknowledgements.**—Thanks are due to the following who made available relevant type specimens: M. R. B. Gray and the late A. Musgrave of The Australian Museum, Dr G. O. Evans formerly of the British Museum (Natural History), F. Wanless BM(NH), and Dr O. Kraus of the Senckenberg Museum. Dr L. Koch of the Western Australian Museum made available specimens for comparison with freshly collected material. Robert Raven read an early draft of the manuscript.

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- Note added in proof.**—While the above was in press Raven (1981) in a review of the diplurine genera synonymised *Dekana* Hogg and *Sungenia* Rainbow and Pulleine with *Aname* Koch but retained *Aname atra* (Strand) as a separate species. See Raven, R. J. (1981). A review of the Australian genera of the mygalomorph spider subfamily Diplurinae (Dipluridae: Chelicerata). *Aust. J. Zool.*, 29: 321-63.





## Obituary

### Francis Gloster Forman 1904-1980

Francis Gloster Forman, known to everyone as Frank Forman, passed away on 5 September 1980. He was a true Western Australian having been born at Claremont on 28 December 1904. He was educated at Scotch College and went on to the University of Western Australia (then housed in tin sheds in Irwin Street) majoring in geology. He was active in student affairs being a very good rower, swimmer and good shot in the University Rifle Club. In the citizen forces he gained commissioned rank.

After graduation he started work in Papua and then visited the United States of America touring the oilfields. In 1929 he returned to Western Australia to join the Geological Survey and to spend the rest of his working career based in Perth.

This was a period of the Geological Survey's history when there were only 2 to 4 geologists on the staff and each was required to handle any type of investigation. Initially Frank examined the oil prospects of the Fitzroy Trough but his later responsibilities included gold, underground water, coal, tin, copper and feldspar. His numerous reports are recorded in the Geological Survey's publications and in the Journal of Royal Society Volume 23 where his Presidential Address dealt with the "Precambrian succession in Western Australia".

In the early thirties during a field trip in the Carnarvon Basin, Frank was dislodged from a camel. This left him with partial paralysis in one side and, in particular, one leg. It was not discovered until years later that he had actually a fracture in the neck. Despite numerous operations, his leg did not recover and this hampered movement for the rest of his life and in latter years confined him to a wheel chair. He was never heard to complain of his disability and retained his smiling jovial personality. He did not want sympathy and insisted on handling his collapsible wheel chair as he slid himself in and out of his car. In one of his investigations in later years he insisted on going underground down a narrow low adit and arranged for a stretcher to be made to carry him down.

In June 1934 he was appointed Government Geologist and with new staff initiated the regional and detailed examination of the Yilgarn and Mt Margaret Goldfields, with particular reference to gold. He was a member of the committee supervising the Aerial,

Geological and Geophysical Survey of Northern Australia, which operated in the Pilbara and Kimberley. In 1938 he was granted leave for 16 months to accept a Commonwealth Fund Service Fellowship tenable at the Geology Department, Harvard University.

During the war years he was associated mainly with the search for strategic minerals until he resigned in August 1945 to join Australian Mines Management and Secretariat Ltd, Perth. It was said at the time that Frank Forman "takes with him to the mining industry a wide knowledge of the mineral deposits of this State". He later joined Berwick Moreing & Co., and in the early fifties became a private consultant.

During his remaining years he consulted for numerous companies and was responsible, in association with a syndicate, for identifying the value of the mineral sand deposits near Capel and pegging the claims which later formed Western Titanium NL. He used a geiger counter to trace the deposits which contain monazite.

He served as a member of many organisations at various times such as Australian National Research Council, Chamber of Mines and others. Perhaps his best record of service was with the Royal Society of Western Australia. He was elected a member in 1927 and an Honorary Member in 1973. His offices include: Councillor (1934-35, 1939-43), Joint Honorary Secretary (1930-34), Vice President (1935-36), President (1936-37), Past President (1937-38) and Treasurer (1944-45).

Frank was a geologist who covered all facets of his profession but in particular economic minerals. He was a true field geologist being dedicated to his profession, and was a very observant person with a keen eye and love of native plants, flowers and birds. The eucalypt *E. formani* C. A. Gardner, and the tantalum mineral formanite, were both named in his honour. Frank endeared himself to everyone with his friendly, kind and likeable manner and was respected by all. Even in his later years, when confined to a wheel chair he still loved to attend "Sundowners" to talk and exchange ideas with other geologists both young and old.

Frank is survived by a widow, two sons, and a daughter, to whom we extend our condolences.

J.H.L.



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Contents

	Page
A census of the larger fungi of Western Australia. By R. N. Hilton ....	1
Some aberrant australite forms from Western Australia. By W. H. Cleverly ....	17
Notes on the revised taxonomic position of the Black Wishbone spider <i>Dekana diversicolor</i> Hogg (Mygalomorphae: Dipluridae). By Barbara York Main ....	25
Obituary. Francis Gloster Forman ....	31

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## The association between the mealybug, *Pseudococcus macrozamia*, ants and the cycad *Macrozamia reidley* in a fire-prone environment

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### Abstract

The mealybug, *Pseudococcus macrozamia*, was found on the cycad, *Macrozamia reidley*, near Jandakot, Western Australia. In 1979, *M. reidley* plants which had not been burnt for at least 10 years had fewer leaves, fewer distortions to leaflets and less mealybugs when compared with plants that had regenerated from burns in 1977 and 1978. Where present, the mealybugs were found at the base of leaves or where leaflets were forced together or were distorted by fire. Ants were found with all colonies of mealybugs. The exclusion of ants did not affect the abundance of mealybugs, nor were ants necessary for the establishment of mealybug colonies. We suggest that ants are incidental in this mealybug/plant association and both the mealybug and the plant respond favourably to increased fire frequency.

### Introduction

Fire is an important feature of Australian ecosystems. Many plants show adaptations to survive fire, some even require fire for reproduction, seed release, germination and new growth (Gill 1975). These fire-induced changes in plants are likely to affect obligatory plant feeders such as homopterans. After a fire insects may respond either by initial population decrease that slowly returns to the pre-fire level, as do certain stick insects (Campbell 1961), or by an immediate response to the presence of new growth on the plant, resulting in a large population after the fire. This then decreases to the pre-fire level as with the mealybugs in this study. Few other examples of the latter response are known (Gillon 1971) and there are no documented cases involving homopterans, although such a response by this taxon has been suggested by Tippins (1972).

Some homopterans extrude excess sugars as honeydew while feeding on plants. Ants are attracted to the honeydew, and incidentally provide benefit for the homopterans. Such mutualistic associations are well documented for agricultural ecosystems (Nixon 1951, Way 1963) but not for natural systems (Miller and Kosztarab 1979). Studies in agricultural situations show these associations to vary from obligatory to incidental. The homopterans may benefit in the following ways: the removal of honeydew and therefore reduction of sooty-mould infestations; the removal of dead individuals; protection from predators and parasites; transport to overwintering sites, and the colonization of new areas (Nixon 1951, Way 1963). In exchange, the ants are provided with a reliable source of live and dead individuals, as well as a supply of honeydew. The predation by ants is usually at a low level, not threatening the survival of the homopteran population (Way 1963).

An association between ants and the mealybug, *Pseudococcus macrozamia* (Fuller) (Homoptera: Pseudococcidae), occurs on the cycad, *Macrozamia reidley* (Gaud.) C. A. Gardn., in an area of natural bushland near Perth, Western Australia. Some parts of this area are subject to frequent fires. We initiated a study, directed towards three specific questions associated with the interaction between mealybugs, plants and ants. Firstly, what role does fire play in the occurrence of mealybugs on *M. reidley*? Secondly, does the abundance of mealybugs differ in the presence or absence of ants? Thirdly, are ants necessary for establishing new mealybug colonies?

### Species biology

*Macrozamia reidley* is found in the south-western part of Western Australia. It is a small shrub with a mainly subterranean bulb with leaves standing up to 2 m. It forms a conspicuous part of the understorey of the *Banksia* woodland in the area studied at the Marsupial Breeding Station near Jandakot (32°10'S; 115°50'E). Vigorous growth of new leaves occurs after a fire and 1-2 years later there is an increase in the production of reproductive structures (Baird 1977).

The mealybug, *Pseudococcus macrozamia*, was specific to *M. reidley* at the study site. It favoured protected sites on the plants, the most abundant being at the bases of the leaves where there was protection by the cotton-like growth on the bulb, and on new growth where the leaflets were held together to form a partially closed environment. Enclosed habitats located distally on leaves may be formed by immature leaves which have been damaged by fire. Damaged leaflets remain on the leaves after the latter emerge from the bulb, and in this paper are



referred to as 'crinkled' habitats. Other habitats of closely associated leaflets occurred most commonly on new leaves and where damaged leaflets were held together by resin-like substances from wounds on the leaf. These, as well as leaflets held together by stems of climbing plants, are referred to as 'straight' habitats.

Fire removed exposed leaves from the cycad, leaving the bulb and bases of the leaves. Insects on these exposed leaves were burnt, whereas those within the cotton like substance at the base of the leaves could survive. This is shown by the presence of adult mealybugs soon after a fire.

The mealybugs appeared to reproduce throughout the year because young were present at all times. We found no alates and presumed that reproduction was entirely parthenogenetic. There were four instars and an imago (J. Dolva, unpublished observation).

Two species of ant, *Iridomyrmex chasei* Forel and *Camponotus* sp., were found with the colonies. The mealybugs feeding between the leaflets were not always accessible to these ants, however, mealybugs may move to the edge of leaflets where they are tended.

A number of other insects was found with the mealybug colonies including: Blattodea species nymphs; one Chrysopidae larva which was covered in wax resembling that of the mealybugs; *Cryptolaemus montrouzieri* (Coccinellidae) adults and larvae; Araneida and Pseudoscorpionidae, some of which may be predators on the mealybugs. The beetle, *C. montrouzieri*, is known to eat scale insects at the study site and Chrysopidae larvae are known to eat homopterans. The araneida probably eat ants (B. Main, pers. comm.). None of these arthropods were present in large numbers. *C. montrouzieri*, which was the most abundant predator, was found on 22.6% of mealybug colonies in a survey of 31 colonies on 65 plants.

## Methods

### Effect of fire

We surveyed plants during March 1979 in areas burnt in March 1977, November 1978 and a third area not burnt for at least 10 years. We counted the number of leaves in all areas and measured the length of leaves in the 1978 burn area and the pre-1969 area. We noted the presence of crinkled leaflets and mealybugs in each area.

### Ant exclusion experiment

In the 1977 burn area, we selected 12 plants with mealybug present in 'crinkled' habitats on the distal parts of leaves. Below the colonies we placed 'tanglefoot' (Tanglefoot Company, Grand Rapids, Michigan) to prevent invasion by ants and to stop migration of mealybugs to base of the leaves. All leaflets and other material which may have provided a bridge for the ants to the isolated colony and any ants remaining on the colony were removed by hand. Ten similar sized colonies were selected as controls. These were marked for later identification but were otherwise unchanged. After 115 days the leaves of the mealybug habitats were prised apart and the insects counted. The duration of the experiment allowed for at least 2 generations of mealybugs to develop. We counted the mealybugs in 3 size classes (first and second instar, 2 mm;

third and fourth instar, 2-4 mm; imago, 4 mm). Insects were not counted at the start of experiments because this method destroys the habitat.

Because the initial number of insects was not known, differences in population sizes were analysed by controlling for the size of the colony. Analysis of covariance (Li 1964) was used with the number of sides of leaflets occupied by the mealybugs ( $\log(x + 1)$  transformed) as the independent variable. The dependent variables were counts of the 3 size classes and total number of mealybugs ( $\log(y + 1)$  transformed) and the regression lines were compared between samples with and without ants.

### Importance of ants for colonization

To test whether the presence of ants was necessary for the successful establishment of new colonies, we made 19 artificial colonies in the recently burnt areas. These were made by binding together 4 leaflets with waterproof adhesive tape. This produced habitats similar to a number of naturally occurring straight habitats, where leaflets had been forced together. Artificial habitats were arranged, 3 per leaf, on the top, middle and bottom. Four adult mealybugs were introduced into each habitat. Ants were excluded from some of the leaves ( $N = 7$ ) by the use of 'tanglefoot'. After 115 days we collected the colonies and counted the mealybugs.

## Results

### Effect of fire

Plants from the area which had not been burnt recently had over a third fewer leaves than plants in recently burnt areas (Table 1). The length of leaves was similar between areas. The presence of crinkling of leaflets was associated with burnt areas (Table 2). Crinkling did not occur at all in our sample from the area which had not been burnt

Table 1

Mean  $\pm$  standard error of length and number of leaves of *M. reidley* for areas with different fire histories. ANOVA on number of leaves, significant at  $p < 0.001$ . T-test on length of leaves, not significant.

Year burnt	No. of leaves per plant (N = No. of plants)	Length of leaves (cm) (N = No. of leaves)
pre 1969	8.0 $\pm$ 1.45 N = 21	125.1 $\pm$ 3.74 N = 153
1977	13.5 $\pm$ 0.77 N = 54	No data
1978	13.0 $\pm$ 1.01 N = 48	130.7 $\pm$ 0.04 N = 479

Table 2

Occurrence of crinkled habitats in areas of different fire histories. Fisher exact probability test, significant at 0.001 level

	Crinkled leaflets on plants	
	Present	Absent
Burnt before 1969	0	21
Burnt in 1977 or 1978	15	97

recently whereas in the burnt areas about 15% of plants exhibited this type of damage. All crinkled habitats investigated were occupied by mealybugs in the 1977 burnt area. Mealybugs were starting to occupy crinkled habitats in the 1978 burnt area during our study. There were from one to 57 gaps between leaflets on each leaf for the mealybug to occupy (mean  $\pm$  S.E.,  $14.3 \pm 0.12$ , N = 128 crinkled habitats).

Mealybugs were more common on plants in the areas that had been recently burnt (Table 3). Less than 10% of plants in the area burnt before 1969 had mealybugs, compared with about 20% for the 1977 burnt area. The 2 colonies of mealybug were at the bases of 2 plants in the area burnt before 1969. In the 1977 burnt area all plants with mealybugs had basal colonies; 60% had distal straight colonies and 40% had distal crinkled colonies.

*Ant exclusion experiment*

Ants were always found with colonies of mealybug. Larger mealybug colonies, as measured by the number of gaps that were occupied, had more ants

**Table 3**

*Occurrence of mealybugs on plants with different fire histories. Fisher exact probability test significant at 0.005 level*

	Number of plants	
	Mealybugs present on plants	Mealybugs absent on plants
Burnt before 1969	2	19
Burnt in 1977	33	79

**Table 4**

*Comparison of the habitat choice of individual ants tending colonies of mealybugs.  $\chi^2 = 8.89$ , 1 d.f.,  $p < 0.001$*

Location of ants on tended colony	Number of ants	
	<i>I. chasei</i>	<i>Camponotus</i> sp.
At base or on new fronds	55	140
Distal on fronds	31	33

present ( $r = 0.943$ , log/log transformation, 24 d.f.  $p > 0.001$ ). Different species of ant were associated with different types of mealybug colonies (Table 4). More (36%) of *I. chasei* individuals occurred distal on leaves than *Camponotus* sp. (19%).

Except for the control treatment for the large instars and the imagines, a relationship was found between the abundance of the mealybugs and the number of sides of leaflets showing signs of mealybug occupation (Table 5). The low coefficients of determination for both these controls were partially due to one large colony which was found to have few large instars and no imagines. However, even with these values included, there was an overall significant regression equation for the analysis of covariance (Table 5). The slopes of the lines and the mean number of mealybugs calculated from the overall mean size of colony did not differ between the controls which had ants in attendance and the experimental colonies where the ants had been removed (F tests). Similarly, in both the experimental and control groups, the ratio of young per adult d.d not differ (t-test,  $t = 1.34$ , 16 d.f. N.S.).

*Importance of ants for colonization*

Colonies of mealybug became established in all artificial habitats. After 115 days there were over twice as many individuals of all instars and imagines at the habitats on the bottom on the leaves (Table 6).

When ants were excluded from artificial colonies, the total number of insects did not differ from artificial colonies with ants (Table 7). Apart from the result for the number of imagines, it seemed that colonization did not require ants. It was likely that the difference in the number of imagines was due to mortality or migration as the abundance of instars was similar between treatments.

**Discussion**

Fire, which was necessary for healthy growth and reproduction of *Macrozamia reidleyi* (Baird 1977) also benefited *Pseudococcus macrozamiaae*. We found that with long absence of fire plants produced few leaves. In unburnt areas there were fewer plants with mealybugs. Possible reasons for this are decreased health of plants, absence of suitable habitats and increased predation. Following a fire mealybugs which had survived at the base of leaves colonized new growth and in due course distal habitats.

**Table 5**

*Regression of the numbers of small instars, large instars and imago and total mealybugs (log (y + 1) transformed) (Y's) with the numbers of sides of leaflets showing signs of occupation (log (x + 1) transformed) (X's) with and without ants*

Dependent variable	Treatment (ants)	N	Regression equation	r <sup>2</sup>	Probability $\beta = 0.0$	Adjusted number of mealybugs*
Small instars	present	10	$Y = -2.74 + 1.94X$	0.71	<0.05	47.4
	excluded	12	$Y = -1.63 + 1.45X$	0.79	<0.01	26.7
Large instars	present	10	$Y = 0.86 + 0.41X$	0.39	0.2 < p > 0.1	8.7
	excluded	12	$Y = -0.20 + 0.75X$	0.72	<0.01	9.8
Imago	present	10	$Y = 0.49 + 0.34X$	0.26	0.5 < p > 0.4	4.2
	excluded	12	$Y = -0.45 + 0.67X$	0.73	<0.01	5.2
Total mealybugs	present	10	$Y = -0.97 + 1.52X$	0.66	<0.05	68.4
	excluded	12	$Y = -0.98 + 1.42X$	0.85	<0.001	47.9

\*Adjusted to X = 3.42 (i.e. 29.6 sides of leaflets) which represents the average sized colony.

Table 6

Mean  $\pm$  standard error of numbers of mealybugs in artificial colonies with ants on three sites along the leaves on 12 *M. reidleyi* plants. Kruskal—Wallis one-way ANOVA was significant at 0.05 level for imago and large instars and significant at 0.01 level for the small instars and total mealybugs

	Position on frond		
	Top	Middle	Bottom
Small instars ....	22.4 $\pm$ 10.98	50.4 $\pm$ 20.75	133.3 $\pm$ 25.89
Large instars ....	6.3 $\pm$ 1.74	5.9 $\pm$ 1.96	12.8 $\pm$ 3.35
Imago ....	1.5 $\pm$ 0.47	3.4 $\pm$ 1.20	8.3 $\pm$ 3.11
Total mealybugs	29.3 $\pm$ 10.83	59.8 $\pm$ 22.66	155.7 $\pm$ 28.43

Although ants were always found with mealybug colonies, the association was not obligatory for mealybugs. Survival, reproduction and the establishment of new colonies of mealybugs was not dependent on the presence of ants. The mealybug is mobile, lives in protected habitats, is host specific and tended by more than one species of ant. Other species of *Pseudococcus* with similar biology have analogous relationships with ants (Strickland 1950, Way 1963) but contrasting obligatory relationships have been described for many Homoptera (Das 1969, Way 1954). These latter Homoptera are sedentary, often exposed, host generalists and they are frequently tended by only one species of ant.

The mealybugs were more abundant lower on leaves and most abundant at the bases. We saw exposed adults moving on leaves and we suggest this is the means by which colonization occurs within plants. We do not know how the mealybugs arrive at new host plants. Strickland (1950) and Way (1963) give examples of *Pseudococcus* being carried to new habitats by ants. This possibly does not occur with *P. macrozamia* as ants were never seen carrying the mealybugs. Some bushes were touching and it is likely that such closely adjacent bushes are directly colonised by moving adults or instars. Colonization by wind is another possibility since exposed individuals can be dislodged (McClure 1979).

It is still not clear what combined role ants, predators and fire play in the maintenance of the mealybug population. It is apparent that fire, which stimulates new plant growth and provides new mealybug habitats, is important to this homopteran-host plant relationship, and ants are of minor importance to the survival, reproduction and colonization of this mealybug.

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Table 7

Mean  $\pm$  standard error of numbers of small instars, large instars, and imago mealybugs from artificial colonies with and without ants on plants burnt in 1977. Mann—Whitney U Test was significant at 0.01 level for imago but was not significant for instars and total mealybugs

	Sample size (colonies)	Small instars	Large instars	Imago	Total mealybugs
Ants present ....	12	54.7 $\pm$ 26.31	6.8 $\pm$ 2.07	3.2 $\pm$ 1.06	64.7 $\pm$ 23.74
Ants absent ....	7	46.1 $\pm$ 16.66	10.0 $\pm$ 2.97	12.6 $\pm$ 4.82	62.3 $\pm$ 28.34

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## Seasonal activity of hexapods in woodland and forest leaf litter in the south-west of Western Australia

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### Abstract

Invertebrates were collected in pitfall traps monthly between March 1976 and February 1977 at 3 localities in the south-west of Western Australia, namely Perth (Reabold Hill), Dwellingup and Manjimup. The Collembola and Insecta are treated here.

Herbivore diversity was high in spring, summer and early autumn at Perth, and in summer and early autumn at Manjimup; although diversity fluctuated less with season at Dwellingup it was lower in the winter. Predator and parasite diversity was highest in late autumn and early spring at Perth and Manjimup, but seasonal trends again were less obvious at Dwellingup. The numbers of individuals and species of ant were low in winter, increased in spring and summer, and decreased again towards the end of autumn at Perth and Dwellingup. At Manjimup, the seasonal activity of ants was less marked although more species were active in summer. Most Collembola species were trapped in Perth in winter, and in autumn, winter and spring at Dwellingup; but the Manjimup data are insufficient for interpreting.

The data from this paper are combined with those of Koch and Majer (1980) on non-hexapod groups collected at the same time. The 3 sites had different phenological patterns and this was particularly marked at Manjimup where temperatures are lower and relative humidities higher.

### Introduction

In a previous paper, we (Koch and Majer 1980) reported on the phenology (seasonal-succession) of non-hexapod invertebrates collected in pitfall traps operated at monthly intervals for 1 year (between March 1976 and February 1977) at 3 sites in the south-west of Western Australia. These sites and the numbers of years from the last fire to the start of the study were: Perth (Reabold Hill) 5 years, Dwellingup 8 years, Manjimup 3 years. Site data are summarised in Koch and Majer (1980). The present paper continues recording the investigations by dealing with the hexapod component of the catches.

In both papers, the extent of a feeding activity, such as predation, is judged by the number of species trapped per month. As in our previous paper, we recognise the limitations of pitfall trapping for sampling. The numbers of a species caught depend upon its abundance and activity.

In treating the non-hexapod component of the epigeic fauna, we (Koch and Majer 1980) compared the decomposers with the predators and concluded that the species richness of both these categories was reduced for at least 3 years after fire. We also found that the activity/abundance of decomposers, and presumably the amount of decomposition, was higher at Perth and Dwellingup during the wetter months but was more closely associated with the warmer months at Manjimup. Predators, active throughout the year, showed a decrease in activity

during the cool moist months at Dwellingup and Manjimup.

The aims of this study are to record the species in the study areas, to examine the relationship between species richness and climate and to describe seasonality of the different taxa and types of feeding taking place on the forest or woodland floor. Finally, the data from the paper are combined with those on non-hexapods to attempt to summarise seasonality of epigeic invertebrate activity.

### Methods

The sites have been described and climatic data figured in Koch and Majer (1980). Temperature and rainfall records are directly comparable between sites. Relative humidity records, however, are for 0900 hours at Perth and Dwellingup and 0800 hours at Manjimup. The consistently higher relative humidity values at Manjimup partly result from the lower temperatures at the time of recording although some records available for 0900 hours at Manjimup suggest that humidity is generally higher there.

The samples were collected in pitfall traps spaced 3 m apart in a 6 by 6 trap grid. Each trap was a tube (15 cm long and 1.8 cm internal diameter) containing a 3 mL mixture of alcohol/glycerol (70/30 v/v) and sunk vertically at ground level (Majer 1978). Traps were operated for a 7-day period every 4 weeks between March 1976 and February 1977. The specimens were sorted into species,

some sent to specialists, and representatives lodged in the Western Australian Museum.

The various species encountered in the present paper have been tentatively regarded as belonging to 6 feeding categories: decomposers, herbivores, omnivores, scavengers, predators and parasites. The numbers of individuals in these feeding categories are, where possible, analysed in relation to climatic conditions.

**Results**

The numbers of specimens of each species collected during each trapping week over the study period are shown in Table 1. The collembolans (springtails) and the ants are dominant in terms of numbers of individuals and species and are treated separately. Because sampling was performed at 4-weekly intervals, the sampling dates did not necessarily coincide with the calendar months. Therefore for clarity, the data have been centralised under each calendar month in Table 1. In the few instances where 2 samples were obtained in a month the mean number is given. In Table 1, the 6 feeding categories are given; however most of the species are herbivores, predators or parasites.

The Collembola species collected at each site are shown in Table 2. It is not possible to give monthly counts because these minute, delicate creatures rapidly decompose when the liquid in their traps becomes

diluted by rain. Owing to such decomposition it would be more likely for a particular species to pass unrecognised in a monthly rather than in a seasonal sample count. Therefore seasonal totals of the species at Perth and Dwellingup are given (Table 3). The census of Collembola species at Manjimup is a gross underestimate, perhaps due to deterioration of material in the traps and laboratory. The Manjimup Collembola data are therefore not examined for seasonality.

The monthly totals and overall counts of individuals and species of ants trapped at each site are shown in Table 4. The determinations and individual species counts will be presented in a separate paper on the ants.

The decomposer, omnivore, or scavenger components of the fauna in Table 1 are insufficient for species richness between sites or seasonal trends to be compared. The total numbers of species and individuals of the more frequently trapped categories (the herbivores, and predators and parasites) are shown for each site in Table 5. The data on predators and parasites are pooled since both are consumers of living animal material. Table 5 also shows the total numbers of species of herbivores and of predators/parasites trapped each month. The collembolans are treated as a group associated with decomposition of organic material although their feeding habits are diverse. Ants are treated as a

**Table 1**

The number of individuals of each species of hexapods collected per month in pitfall traps at three sites in the south-west of Western Australia from March 1976 to February 1977

	1976					1977						
	M	A	M	J	J	A	S	O	N	D	J	F
<b>COLLEMBOLA</b>												
(See Tables 3 and 4)												
<b>BLATTODEA</b>												
Blaberidae												
<i>Calolampra</i> (herb., omniv.)†	P*	0	0	0	1	0	0	0	1	0	0	0
	D	0	0	1	0	1	0	0	0	0	0	0
	M	3	7	12	19	1	0	3	0	0	0	2
<i>Laxta</i> (herb., omniv.)	M	0	0	0	0	0	0	0	1	0	0	0
Blattidae												
Polyzosteriinae (herb., omniv.)	P	0	1	0	0	0	0	0	0	1	1	0
Blattidae (b) (herb., omniv.)	D	0	0	0	0	0	0	1	0	0	1	0
Blattidae (c) (herb., omniv.)	P	0	0	0	0	1	0	0	1	0	0	0
	D	0	0	8	3	0	0	3	0	0	0	0
<b>MANTODEA</b>												
Amorphoscelidae												
Paraoxyphilinae (a) (pred.)	P	2	0	0	0	0	0	0	0	0	0	0
Paraoxyphilinae (b) (pred.)	D	0	0	0	0	0	0	0	1	0	1	0
<b>DERMAPTERA</b>												
2 or 3 spp. (pred.)	P	171	86	46	30	44	17	78	77	289	247	714
	D	68	67	60	63	7	0	3	57	59	37	103
	M	12	8	11	5	2	3	3	16	17	21	84
<b>ORTHOPTERA</b>												
Stenopelmatidae												
<i>Onosandrus</i> (omniv.)	P	0	0	0	3	2	1	0	0	0	5	3
	D	0	0	12	0	5	3	5	5	4	4	0
Gryllidae (a) (herb.)	P	1	3	1	0	5	3	0	0	0	0	13
	D	0	0	3	0	0	1	0	0	4	0	0
	M	0	2	3	2	0	0	0	0	0	2	0
Gryllidae (b) (herb.)	D	3	0	0	0	0	0	0	0	0	0	1
Gryllotalpidae (herb.)	P	0	0	0	1	0	0	0	0	0	0	0
Acrididae												
<i>Phaulacridium vittatum</i> (herb.)	P	0	1	0	0	0	0	0	0	0	0	0
	D	0	0	0	0	0	0	0	0	1	0	0
	M	0	0	0	0	0	0	0	0	0	0	2

Table 1 continued

			1976							1977				
			M	A	M	J	J	A	S	O	N	D	J	F
<b>HEMIPTERA</b>														
Fulgoroidea (herb.)	....	P	0	0	0	0	1	0	0	0	0	0	0	0
		D	0	0	0	0	0	0	0	1	0	1	0	0
Cicadellidae														
Ledrinae (herb.)	....	P	0	1	0	0	0	0	0	0	0	0	0	0
		D	0	1	0	0	0	0	0	0	0	0	0	0
		M	0	0	0	0	0	0	0	0	0	0	0	1
Alydidae														
<i>Leptocoris</i> (herb.)	....	P	5	1	0	0	0	0	0	0	0	0	0	1
		M	0	0	0	0	0	1	0	0	0	0	0	4
Reduviidae (pred.)	....	P	0	1	4	0	0	0	1	2	4	1	1	0
		M	0	0	1	0	0	0	0	0	0	0	0	0
Lygaeidae (herb.)	....	D	0	1	0	0	1	0	0	0	0	0	0	0
Cydnidae														
<i>Cydus</i> (herb.)	....	P	4	1	2	0	0	0	1	4	14	14	4	4
		D	0	0	0	0	0	0	0	0	0	1	0	0
		M	0	0	0	0	0	0	0	0	0	1	1	4
Gelastocoridae														
<i>Nerthra stali</i> (pred.)	....	D	0	0	0	0	0	0	0	2	0	0	0	0
		M	0	0	0	0	0	0	0	0	0	0	0	4
Hemiptera Nymph (herb.)		D	0	0	0	0	1	0	0	0	0	0	0	0
<b>THYSANOPTERA (dec.)</b>														
		P	0	0	0	0	1	1	0	0	0	0	0	0
		D	0	0	0	0	0	0	0	0	0	0	1	0
<b>COLEOPTERA</b>														
Carabidae														
Broschinae														
<i>Gnathoxys crassipes</i> (pred.)	P	5	1	1	0	0	0	0	51	1	6	5	4	
<i>Promecoderus</i> (pred.)	....	P	2	0	56	71	45	24	15	5	54	6	0	
		D	13	5	12	0	1	3	0	0	7	14	8	
		M	11	3	5	6	0	0	2	2	8	19	9	
Scaritinae														
<i>Scaraphites lucidus</i> (pred.)	P	0	0	0	1	0	0	3	5	1	3	0	0	
Psydrinae														
<i>Neonomius</i> (pred.)	....	D	0	0	0	0	1	0	0	0	1	0	0	
Pterostichinae														
<i>Simodontus</i> (pred.)	....	P	16	61	10	16	7	4	2	0	15	0	1	
		D	0	1	1	0	1	0	0	0	1	0	0	
		M	4	2	11	6	5	2	5	2	0	0	3	
Carabidae Larva (pred.)	....	P	0	0	0	10	23	8	2	0	1	0	0	
		D	0	0	0	4	2	3	0	0	0	0	0	
		M	0	0	1	0	0	0	0	2	0	0	0	
Staphylinidae														
Staphylininae														
<i>Quedius</i> (pred.)	....	D	0	0	3	1	0	0	1	1	0	0	0	
		M	0	0	26	2	2	0	2	0	0	2	0	
Staphylinidae (b) (pred.)	....	D	0	0	0	0	0	0	1	0	0	0	0	
Oxytelinae														
<i>Anotylus</i> (pred.)	....	P	0	0	0	1	0	1	2	0	0	0	1	
		D	0	0	0	52	4	7	51	94	3	0	0	
		M	0	0	1	0	0	0	0	13	3	0	0	
Aleocharinae (pred.)	....	P	0	0	1	1	0	0	3	0	0	0	0	
		D	102	24	11	20	0	0	27	4	6	2	29	
		M	0	0	0	0	0	0	3	5	0	0	0	
Staphylinidae Larva (pred.)		P	0	0	0	0	0	1	0	0	1	0	0	
		D	0	0	7	0	0	0	0	0	0	0	0	
Pselaphidae (pred.)	....	P	1	1	0	30	11	1	5	2	0	0	0	
		D	2	22	2	3	1	0	2	5	2	12	2	
		M	0	0	4	0	0	0	3	0	0	0	0	
Trogidae (scav.)	....	M	0	0	0	0	0	0	0	0	1	0	0	
Scarabaeidae (a) (herb.)	....	P	0	0	0	0	0	0	0	0	0	0	1	
Scarabaeidae (b) (herb.)	....	P	0	0	0	0	0	0	0	0	0	0	0	
Scarabaeidae (c) (herb.)	....	D	0	0	0	1	0	0	0	0	0	0	0	
Dynastinae														
<i>Semanopterus leai</i> (herb.)	M	0	0	0	0	0	0	0	0	0	0	0	1	
Melolonthinae														
<i>Biphylocera kirbyana</i> (herb.)	M	0	0	0	0	0	0	0	0	0	0	1	1	
<i>Byrrhomorpha ponderosa</i> (herb.)	....	D	0	0	0	1	0	0	1	0	2	0	2	
		M	0	0	0	0	0	0	0	0	0	0	1	
<i>Neophylloctocus</i> (herb.)	....	P	0	0	0	0	0	0	1	0	11	0	2	
		D	1	0	0	0	0	0	0	0	0	0	0	
		M	1	0	0	0	0	0	0	0	0	0	8	
Elateridae														
<i>Conoderus</i> (herb.)	....	M	0	0	0	0	0	0	0	0	0	0	2	
Dermestridae Larva (scav.)		P	4	0	0	0	0	0	0	0	0	0	0	
		D	0	0	0	0	1	0	0	0	0	0	0	
Tenebrionidae														
Hylaeinae														
<i>Sympetes</i> (herb.)	....	P	4	0	0	0	0	3	9	4	35	59	21	
		D	0	0	0	0	0	0	0	0	0	0	1	
<i>Hylaeus perforatus</i> (herb.)	M	0	0	0	0	0	0	0	0	0	0	1	1	
Ulominae														
<i>Tribolium</i> (herb.)	....	P	1	0	0	0	0	0	0	0	0	0	0	
		D	0	0	0	0	0	0	0	0	0	2	0	



Table 1 continued

		1976										1977	
		M	A	M	J	J	A	S	O	N	D	J	F
<b>Tenebrioninae</b>													
<i>Tenebrio molitor</i> Larva (herb.)	P	0	0	0	0	0	1	0	1	0	0	0	0
Tenebrionidae (e) (herb.)	P	0	0	0	0	0	0	0	0	1	0	0	0
Cerambycidae (herb.)	D	0	0	0	0	0	0	0	0	1	0	0	0
<b>Apionidae</b>													
<i>Apion</i> (herb.)	M	0	0	0	0	0	0	0	0	1	0	0	0
<b>Curculionidae</b>													
Cryptorrhynchinae (herb.)	P	0	0	0	0	1	0	0	0	0	1	0	0
<b>Amycterinae</b>													
<i>Acantholopus lateralis</i> (herb.)	M	0	0	0	0	0	0	0	0	0	1	0	1
<i>Aedriodes innuus</i> (herb.)	M	0	0	0	1	0	0	0	0	0	0	0	0
<i>Amorphorhinus polyacanthus</i> (herb.)	D	1	0	0	0	0	0	0	0	0	0	0	0
<i>Dialeptops collaris</i> (herb.)	M	0	0	0	0	0	1	0	0	0	0	0	0
<i>Talaurinus</i> (herb.)	D	1	0	0	0	0	0	0	0	0	0	0	0
<b>Amalactinae</b>													
<i>Tranes roei</i> (herb.)	M	2	0	0	0	0	0	0	0	0	0	0	0
<b>Leptopiinae</b>													
<i>Cherrus mastersii</i> (herb.)	M	0	0	0	0	0	0	0	0	0	0	0	1
<i>Essolithna</i> (herb.)	D	0	0	0	0	2	0	0	0	0	0	0	0
Curculionidae (j) (herb.)	D	1	0	0	0	0	0	0	0	0	0	0	0
Curculionidae (k) (herb.)	M	1	0	0	0	0	0	0	0	0	0	0	0
Curculionidae (l) (herb.)	D	0	0	0	3	0	0	0	1	1	1	1	0
Curculionidae Larva (herb.)	D	2	0	0	0	0	0	0	0	0	0	0	0
<b>Scolytinae</b>													
<i>Xyloborus saxeseni</i> (herb.)	D	0	0	0	0	0	0	18	4	0	0	0	0
Coleoptera Larva (un.)	D	0	0	0	0	0	0	0	0	0	1	0	0
Coleoptera Misc. spp. (un.)	P	0	0	0	0	1	2	4	1	0	0	2	0
	D	2	5	17	6	2	6	11	4	8	7	17	1
	M	0	1	0	0	0	1	6	0	1	0	0	0
<b>MECOPTERA</b>													
<b>Bittacidae</b>													
<i>Harpobittacus</i> Larva (scav.)	P	0	0	0	0	4	1	0	0	0	0	0	0
<b>TRICHOPTERA</b>													
Larva (herb.)	D	1	0	0	0	0	0	0	0	0	0	0	0
<b>LEPIDOPTERA</b>													
Pyrilidae (?) Larva (herb.)	D	0	0	1	0	1	0	2	0	1	1	0	0
Arctiidae Larva (herb.)	D	0	0	0	0	0	0	0	1	0	0	0	0
Noctuidae Larva (herb.)	P	0	0	0	2	0	0	0	0	0	0	0	0
Lepidoptera Larva (d) (herb.)	P	1	0	0	0	0	0	0	0	0	0	0	0
Lepidoptera Larva (e) (herb.)	D	0	0	0	0	1	0	0	0	0	0	0	0
Lepidoptera Larva (f) (herb.)	M	0	0	0	0	0	0	0	0	0	1	0	0
<b>HYMENOPTERA</b>													
<b>Ichneumonidae</b>													
Campopleginae (par.)	D	0	0	0	0	0	1	0	0	1	0	0	0
Ceraphronidae (par.)	D	1	0	0	0	0	0	0	0	1	0	0	0
<b>Scelionidae</b>													
Bacinae (par.)	D	3	1	0	0	0	0	1	0	0	0	0	0
Scelioninae (par.)	P	0	0	0	0	0	0	0	0	0	0	0	1
	D	1	1	0	0	1	0	0	0	0	0	0	0
<i>Oxytelus</i> (par.)	M	1	0	0	0	0	0	0	0	0	1	0	0
<b>Diapriidae</b>													
<b>Diapriinae</b>													
<i>Basalys</i> (par.)	D	0	0	0	0	0	0	0	0	2	0	1	1
	M	1	0	0	0	0	0	0	0	0	0	0	0
<b>Belytinae</b>													
<i>Stylactista</i> (par.)	P	0	0	0	0	0	0	2	0	0	0	0	0
Diapriidae (c) (par.)	D	0	0	0	0	0	0	0	0	0	0	0	1
<b>Mymaridae</b>													
<i>Alaptus</i> (par.)	D	1	0	0	0	0	0	0	0	0	0	0	0
<b>Pteromalidae</b>													
<b>Pteromalinae</b>													
<i>Grahamsia</i> (par.)	D	0	1	0	0	0	0	0	0	0	0	0	0
<b>Encyrtidae</b>													
Genus near <i>Anisotylus</i> (par.)	P	0	0	0	0	0	0	0	0	1	0	0	0
Chalcidoidea (par.)	M	0	0	0	0	0	0	0	0	0	0	0	1
<b>Bethylidae</b>													
<i>Parasierola</i> (par.)	D	0	0	0	0	0	0	0	0	0	0	2	0
Pompilidae (a) (pred.)	P	0	0	0	0	0	0	0	0	0	0	0	1
Pompilidae (b) (pred.)	M	0	0	0	0	0	0	0	0	0	0	0	1
<b>Tiphidae</b>													
<i>Tachynomys</i> ? <i>aurifrons</i> (par.)	P	1	0	0	0	0	1	0	0	0	2	1	0
Tiphidae (b) (par.)	D	1	0	0	0	0	0	0	0	0	0	0	0
	M	0	0	0	0	0	0	0	0	0	0	0	1
<b>Formicidae (see Table 5)</b>													

\* P—Perth; D—Dwellingup; M—Manjimup.

† (dec.)—decomposer; (herb.)—herbivore; (omniv.)—omnivore; (scav.)—scavenger; (par.)—parasite; (pred.)—predator; (un.)—unknown.

separate category because many species feed on seeds, on saps produced by homopteran bugs or plants, or they are predacious.

In numbers of individuals, the predator/parasite category together with the ant category exceeds the herbivore category at all 3 sites (Tables 4 and 5). The low number of herbivores is regarded as being due to their lower vagilities, and hence probability of being trapped, rather than to their lower densities.

Species richness of herbivores, predators and parasites, collembolans, and ants (Tables 3, 4 and 5) are all greatest at Dwellingup. Manjimup has the lowest number of species in all categories with the exception of herbivores which are least diverse at Perth. The extremely low number of collembolan species trapped at Manjimup (Table 2) is, as mentioned, an artifact. Comparison of the total numbers of individuals of collembolans at each site is not made because of the variations in trapping efficiency (Southwood 1966).

For each category, the number of species trapped each month may be regarded as the index of activity. The numbers of species of herbivores, predators/parasites, and ants, and also the numbers of individuals of ants trapped each month are compared (using Spearman's rank correlation) with the climatic data for the corresponding month and the previous month; the correlation coefficients and significance values are shown in Table 6. The seasonality observed for each category and the correlations significant at the 0.05, 0.01 and 0.005 probability levels are discussed below.

**Herbivores**

At Perth, the herbivores show high levels of activity in spring, summer and early autumn. Numbers of species are positively correlated with the temperature of the current and the previous months, and negatively correlated with relative humidity and rainfall (Table 6). The causal agent here is uncertain because temperature is negatively correlated with relative humidity and rainfall.

At Dwellingup, the levels of herbivore activity are less obviously dependent upon the season although a decrease in activity is observed in August-September at a time of high rainfall. The only significant correlation with environmental factors is a negative correlation with the rainfall of the corresponding month (Table 6).

At Manjimup, the herbivores show highest activity levels in early autumn and summer; however, the seasonal trend is less marked than in Perth. The numbers are negatively correlated with the relative humidity and rainfall of the previous month, but the results are not significant at the 0.5 probability level (Table 6).

**Table 2**

List of Collembola species collected in pitfall traps at Perth (P), Dwellingup (D) and Manjimup (M)

	P	D	M
Dicyrtomidae	+	O	O
Entomobryidae			
<i>Entomobrya lamingtonensis</i>	+	+	O
<i>Lepidocrytoides</i> sp. A	+	+	+
<i>Lepidocrytoides</i> sp. B	+	+	+
<i>Lepidosira terraereginae</i>	O	+	O
<i>Lepidosira</i> sp. B	+	O	O
<i>Lepidosira</i> sp. C	O	+	O
<i>Lepidosira</i> sp. D	O	O	+
Unidentified	+	O	O
Hypogastruridae			
<i>Hypogastrura</i> sp.	O	+	O
<i>Triacanthella</i> sp.	O	+	O
Isotomidae			
<i>Acanthocyrthus plumbeus</i>	O	+	+
<i>Cryptopygus antarcticus</i>	O	+	O
<i>Cryptopygus thermophyla</i>	+	O	O
<i>Isotoma</i> sp. near <i>tridentifera</i>	O	+	O
<i>Isotomurus</i> sp. A	+	O	O
<i>Isotomurus</i> sp. B	+	O	O
<i>Proisotoma</i> sp.	O	+	O
Unidentified, immature	O	+	O
Neauridae			
<i>Brachystomellini</i> sp. A	+	O	O
<i>Brachystomellini</i> sp. B	+	O	O
<i>Brachystomellini</i> sp. C	O	+	+
<i>Brachystomiella</i> sp. near <i>paravula</i>	O	+	O
? <i>Subclavontella</i> sp. A	O	+	O
? <i>Subclavontella</i> sp. B	O	+	O
<i>Ceratrimeria</i> sp.	O	+	O
<i>Neanura</i> sp.	O	+	O
<i>Arlesia</i> sp.	+	O	O
Odontellini	O	+	O
<i>Triodontella</i> sp.	O	+	O
<i>Zealandella</i> sp.	O	+	O
Poduromorpha unidentified and immature	+	+	O
Sminthuridae			
<i>Sphaeridia</i> sp.	+	O	O
<i>Sminthurinus</i> sp.	+	+	O
Genus near <i>Katianna</i>	+	O	O
<i>Katianna</i> sp.	+	O	O
Genus nov. near <i>Sminthurinus</i>	+	+	O
<i>Pseudokatianna</i> sp.	O	+	O
<i>Aneuempodialis cinereus</i>	+	O	O
<i>Corynephorina</i> sp. A	+	O	O
<i>Corynephorina</i> sp. B	O	+	O
<i>Rastriopes dromedarius</i>	+	O	O
<i>Rastriopes</i> sp. B	O	+	O
<i>Temeritas</i> sp.	O	+	O
Unidentified and immature	+	+	O

+ = present      O = absent

Total Collembola species trapped at each site = Perth 22, Dwellingup 29, Manjimup 5.

**Table 3**

Total numbers of Collembola species collected in pitfall traps each season at Perth and Dwellingup

	Autumn	Winter	Spring	Summer	Total species trapped at site
Perth	21	10	5	6	22
Dwellingup	15	20+	20+	5	29

**Table 4**

The numbers of individuals and of species of ants (Formicidae) trapped per month and the total ant species and individuals trapped at each of the three sites

Site	1976					1977					Total species trapped at site	Total individuals trapped at site		
	M	A	M	J	J	A	S	O	N	D			J	F
	Ant individuals													
Perth ....	261	55	37	27	21	56	103	65	129	112	208	181	....	1255
Dwellingup	46	54	65	30	29	36	104	94	84	148	98	84	....	872
Manjimup ....	48	54	53	25	27	40	25	86	99	103	102	25	....	687
	Ant species													
Perth ....	17	11	12	10	6	8	14	14	17	17	19	16	39	....
Dwellingup	11	12	10	8	7	8	19	17	15	20	18	19	43	....
Manjimup ....	9	9	8	8	7	8	5	8	9	12	13	10	32	....

**Table 5**

The numbers of hexapod herbivores, and predators and parasites trapped at each of the three sites: the numbers per month and the total species and the total individuals

Site	1976					1977					Total species trapped at site	Total individuals trapped at site		
	M	A	M	J	J	A	S	O	N	D			J	F
	Herbivores													
Perth ....	7	6	2	3	4	4	3	4	5	5	7	5	21	314
Dwellingup	8	2	4	4	6	1	2	6	3	7	4	3	28	98
Manjimup ....	4	2	2	3	1	2	1	0	2	3	5	1	22	99
	Predators and parasites													
Perth ....	6	5	6	8	5	6	10	6	8	5	5	4	17	2852
Dwellingup	8	8	6	6	8	4	7	5	11	4	7	4	23	1250
Manjimup ....	5	3	8	4	3	2	5	5	3	4	3	4	14	364

**Table 6**

Spearman's rank correlation coefficients and significance values for trapped species (herbivores, predators and parasites, ants), and trapped individuals (ants) against climate of corresponding month and previous month at three sites (n = 12)

Site	Average Temperature§		Relative Humidity		Rainfall	
	Corresponding month	Previous month	Corresponding month	Previous month	Corresponding month	Previous month
	Herbivore species					
Perth ....	0.75‡	0.67†	-0.75‡	-0.62*	-0.71‡	-0.75‡
Dwellingup....	0.27	0.13	-0.10	-0.29	-0.59*	0.08
Manjimup ....	0.27	0.48	-0.31	-0.41	-0.36	-0.41
	Predator and parasite species					
Perth ....	-0.60*	-0.44	0.44	0.47	0.41	0.61*
Dwellingup....	-0.04	0.12	0.05	0.09	-0.04	-0.17
Manjimup ....	0.02	0.18	0.17	-0.54*	-0.54*	0.41
	Ant individuals					
Perth ....	0.76†	0.55*	-0.83‡	-0.66†	-0.84‡	-0.47
Dwellingup....	0.52*	0.09	-0.68†	-0.46	-0.32	-0.11
Manjimup ....	0.45	0.14	-0.45	-0.31	-0.19	-0.12
	Ant species					
Perth ....	0.78‡	0.53*	-0.86‡	-0.70†	-0.86‡	-0.52*
Dwellingup....	0.66†	0.25	-0.78‡	-0.61*	-0.45	-0.30
Manjimup ....	0.86‡	0.69†	-0.71‡	-0.59*	-0.58*	-0.65†

\* P < 0.05

† P < 0.01

‡ P < 0.005

§ The average of the monthly maximum and minimum temperatures was used.

*Predators and parasites*

At Perth, activity of predators and parasites is highest in late autumn and early spring although low in summer. Numbers of species are negatively correlated with the temperature of the corresponding month and positively correlated with the rainfall of the previous month.

At Dwellingup, there is no evidence of any seasonal trend, all the coefficients being extremely low (Table 6).

At Manjimup, as at Perth, most activity is in late autumn and early spring. However, because rainfall is here distributed throughout autumn and spring, as well as in winter, numbers of this feeding group are negatively correlated with the relative humidity of the previous month and the rainfall of the corresponding month (Table 6).

*Ants*

In terms of the numbers of individuals and species, the Perth and Dwellingup ant faunas show similar patterns with low activity in winter, which increases in spring and summer, and decreases in autumn. Numbers of species and individuals are positively correlated with the temperature and negatively with the relative humidity of the corresponding month at both these sites and negatively correlated with the rainfall of the corresponding month at Perth (Table 6).

Although more ant individuals and species were active in the summer than in the other seasons at Manjimup, there is generally less seasonal variation in the numbers of individuals and species caught than at the other two sites. Both measures were low in September. The species richness of ants at Manjimup is positively correlated with the temperature, and negatively correlated with the relative humidity and with the rainfall of the corresponding and the previous months. Numbers of ant individuals at Manjimup are not significantly correlated with climatic factors (Table 6).

*Collembola*

Species richness of Collembola is highest in winter at Perth, and high in autumn, winter and spring at Dwellingup (Table 3).

**Discussion**

As stated in our previous paper (Koch and Majer 1980) the value of undertaking seasonal studies of forest fauna is: (1) to enable a more satisfactory understanding of seasonal influences than solely by using meteorological variables, (2) to reveal the relative importance of various faunal groups in biological processes such as litter decomposition, and (3) to provide a framework of ecological information on which to base forest management decisions.

We are treating the phenology of a single component of the forest and woodland ecosystem, viz. activity/abundance of the invertebrate fauna of the floor layer. Because seasonal events in other strata may differ, the general findings should not be extrapolated to other components of the ecosystem. For instance, in the northern jarrah forest, flowering in the upper strata (e.g. of the relatively deep rooting marri) occurs from February to March (Beard 1970), whereas flowering in most understorey plants occurs in October (Majer 1981).

For each study area, Figure 1 shows the activity of the main groups of forest floor invertebrates described in the present and the previous paper (Koch and Majer 1980). Data on herbivores and ants are from the present paper, predator-parasite data are from both papers, and data on fauna associated with the decomposition process are from a combination of the data in the previous paper and the Collembola data in the present paper. Figure 1 is tentative and generalised since it shows the seasonal relationships rather than the actual values for the index of activity (total species collected each month). We hope these findings will stimulate further phenological work in forests and woodlands.

The three study sites had characteristically different invertebrate phenological patterns. As stated (Koch and Majer 1980), the three sites have different

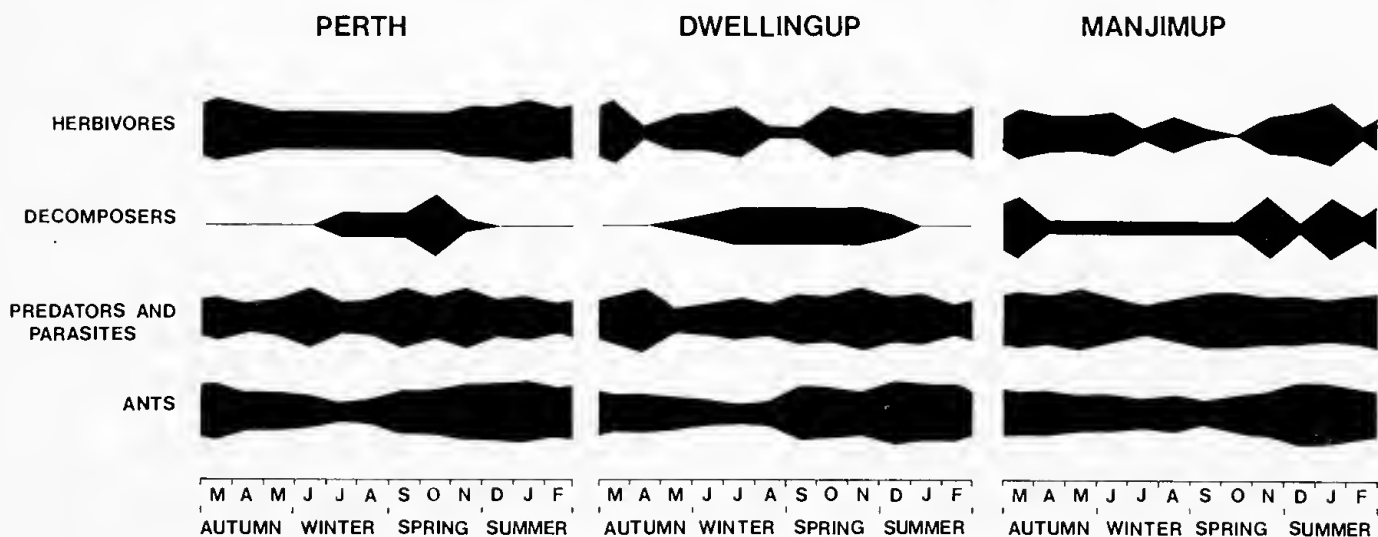


Figure 1.—Schematic diagram of the seasonal activity of herbivores, decomposers, predators and parasites, and ants at Perth, Dwellingup and Manjimup. The width of the bar indicates the level of activity as measured by the numbers of species in each category collected in the pitfall traps.



climatic patterns and soil types; these factors are responsible for concomitant differences in the forest floor micro-environment (Monteith 1973). Basically, the more southern the study site the lower the temperatures and the higher the relative humidities (Koch and Majer 1980). The length of the growing season—a measure of the excess of effective rainfall over evaporation (assuming that temperature is not limiting)—also increases to the south: e.g. it has been calculated as 6.3 months at Perth, 7.6 months at Dwellingup, and 8.0 months at Manjimup (Director of Meteorology 1965, 1966). These estimates are for introduced commercial crops, not native perennials, but the growing periods of these may be expected to increase in the same proportion.

The herbivore activity is negatively correlated with rainfall at these 3 sites, and it increases during spring (Fig. 1). Recently, increases in the activity of grasshoppers during spring in woodlands near Perth have also been recorded (Whelan and Main 1979). Spring is the period when many understorey shrubs exhibit growth flushes (Baird 1977, and D. Backshall, pers. comm. 1980) owing to the increase in available moisture and the warmer temperatures. The decrease in herbivore activity during the cooler months at all 3 sites might be connected with the contemporaneously slower growth rate of certain plant species (Baird 1977), the direct influence of climatic factors on the life cycles of the herbivores or it might be a combination of both factors. Thus the decreases in activity of the herbivores at Dwellingup (during August-September) and at Manjimup (during June-October) (Fig. 1) may be due to the low temperatures during these months.

The length of decomposer activity increases progressively from north to south (Fig. 1). It is largely restricted to the wetter months at Perth and Dwellingup and continues throughout the year at Manjimup. This is probably because humid conditions are apparently present for longer at Manjimup. It would be worthwhile to compare rates and seasonality of litter decomposition at the sites, but no data are available.

Compared to the decomposers, the activity of the predator/parasite category appears less dependent on season. This is probably because a wide range of organisms, with different feeding preferences and whose activities are not in phase, are preyed on or parasitised. The only trends detectable are slight increases in the activity of predators and parasites in the spring and autumn at Perth and Dwellingup (Fig. 1), probably due to the increases in herbivore numbers during those seasons.

It has been demonstrated that the natural feeding rate of ants (Kajak *et al.* 1972), and hence their activity, was correlated with availability of food. Ant numbers may therefore be a good general indicator of seasonal trends in overall biological activity although the influence of temperature should also be considered. The times of maximum ant activity (Fig. 1), which is in spring and summer at Perth and Dwellingup and summer at Manjimup, may be connected with high temperatures and with food availability. In spring and summer there are abundant food sources such as herbivorous invertebrates (Fig. 1), plant saps (Majer 1981), and seeds. At Perth and Dwellingup decomposers are most abundant during the cooler months. At all 3 sites, however,

the herbivores, and predators and parasites have lowered activity during the cooler months—the resulting reduced availability of such food sources may be one reason for the observed low activity of the ants during the winter.

In the northern hemisphere, seasonal activity of ant communities has also been related to climatic factors, with greatest summer activity occurring around June-August. In Quebec, foraging of the red wood ant, *Formica lugubris* Zett., was largely influenced by temperature, although excessive rain reduced foraging during cool periods (McNeil *et al.* 1978). In a Polish meadow, ants exhibited greatest activity in June-July, and significantly high numbers of one species were positively correlated with temperature (Woyciechowski and Miszta 1976). In a Chihuahuan desert, increases in temperature, rainfall, and food served as thresholds, but not regulators, of the seasonal foraging activities of ant communities (Whitford 1978).

In the 3 present study areas ant activity, as measured by the numbers of species collected, is positively correlated with the temperature and negatively with the rainfall (Table 6). The high correlation coefficients suggest that the activity has a direct link with these climatic factors rather than an indirect link via the availability of food. The extended period of decreased activity between mid-autumn and late-spring at Manjimup is in keeping with this suggestion because the period of high moisture availability and low temperature persists longer at Manjimup than at the more northern sites, Dwellingup and Perth.

Biological processes in forests and woodlands are related to the periods of activity of living organisms: e.g. pollination and seed dispersal may only occur when particular animals are present; the extent of damage to plants is related to the abundance of herbivores which in turn is affected by the presence of appropriate predators and parasites; and litter decomposition depends upon the action of certain fauna and microflora. This study has suggested that these processes occur at particular periods (phenophases) of the year, which differ at the 3 study sites.

To assist decision-making, managers of forests and woodlands should have information about relevant seasonal events. For instance, the ecological results of the prescribed burn of a forest, of artificial seeding of a disturbed area, or of logging would differ depending upon the times of implementation.

The findings of the present paper indicate that, at least with regard to the ground-living (epigeic) fauna, marked phenological differences occur between the southern site (Manjimup) and the two northern sites. We recommend that for a better understanding of the ecology of forests and woodlands in the south-west of Western Australia, processes such as litter decomposition, grazing by insects, and seed carrying by animals should be studied simultaneously at northern and southern localities.

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## Geomorphology and Holocene history of the tidal flats, King Sound, north-western Australia

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### Abstract

King Sound in north-western Australia, with a tropical semi-arid climate, is situated in a tide-dominated regime. The shores of King Sound are bordered by wide tidal flats that exhibit a considerable variation in geomorphology and stratigraphy. The stratigraphic sequence has developed as a result of tidal flat accretion during 3 Quaternary (2 Pleistocene, 1 Holocene) transgressions; this has built a shore-fringing sediment platform or wedge upon which modern geomorphic processes act. Erosion is the dominant and net geomorphic process forming the tidal flats today. Three types of erosion—sheet, cliff and tidal creek—are important. The local geomorphology of tidal flats is an expression of which erosion type is dominant and the regional geomorphology is largely an expression of the extent that erosion has removed Holocene, Pleistocene and bedrock stratigraphic units. Determination of erosion rates over the past few decades, extrapolation of these rates into the past, together with stratigraphic and diagenetic data point to a long-term erosional history for King Sound. However, sedimentation occurred earlier in the Holocene, when a more humid climate provided a large river runoff and sediment input, and tidal flat sediments built up an extensive coastal plain. Since about 5000 years BP conditions have become more arid and the Holocene deposits have been trimmed back or totally removed. This has continued up to the present, with erosion today the dominant shore-forming process.

### Introduction

This paper reports the results of an investigation on the tidal flats of King Sound (Fig. 1) which are undergoing widespread regional erosion. The area is situated in the tropical north-west of Australia along a coastline with a large tidal range. The shores of King Sound are bordered by tidal flats that exhibit a considerable variation in geomorphology and stratigraphy. Previous studies have shown that sediments which comprise this tidal flat wedge (or platform) have accumulated during 3 Quaternary marine transgressions (2 Pleistocene and 1 Holocene; Semeniuk 1980). However, studies of modern processes, rates of erosion, geomorphology and stratigraphy of the tidal flats show that the modern King Sound morphology has formed largely by erosion. The range of shoreline types is merely the expression of age and extent of erosion as well as type of underlying stratigraphy. The Holocene history of King Sound is preserved in lithofacies of Holocene formations, in gravel lags across King Sound and in diagenetic overprints on the Quaternary formations. Within these features is recorded a history of Holocene deposition, climatic change, erosion, evolution of groundwater chemistry and progressive change in geomorphology.

### Methods

The King Sound tidal flats were studied during 1973-1977. Tidal flats were surveyed along transects (Fig. 2) and related to tide levels and

Australian Height Datum (AHD). Eighty two field stations were set up along the transects and at numerous other localities, to document geomorphology, stratigraphy and biotic communities, and to collect samples of sediment, groundwater and biota.

Stratigraphy was investigated by hand augering (to 5 m depth), vibrocoreing to extract intact core (to 7 m depth) and augering with Gemco rig (to 16 m depth). Stratigraphic relationships are well exposed for direct observation and measurement on deeply incised tidal creek walls, clifflines and across vast erosion surfaces from which the modern sedimentary veneer has been stripped (Semeniuk, 1980).

The relative importance of erosion over sedimentation was assessed (a) by using vertical aerial photographs taken in 1949, 1967, 1974 and 1977, (b) by oblique aerial photographs taken annually of key areas during 1972-6 and (c) by observation and experiments in the field. On the ground, processes of erosion and sedimentation were observed and were documented as they took place. The products of erosion and sedimentation were also documented locally at field stations and regionally by mapping along the coastline and creeks. Rates of erosion and sedimentation were calculated from (a) measurements taken directly against fixed datum points such as stable markers (10 in total) or iron pegs (16 in total), (b) measurements taken from aerial photographs and (c) measurement of an



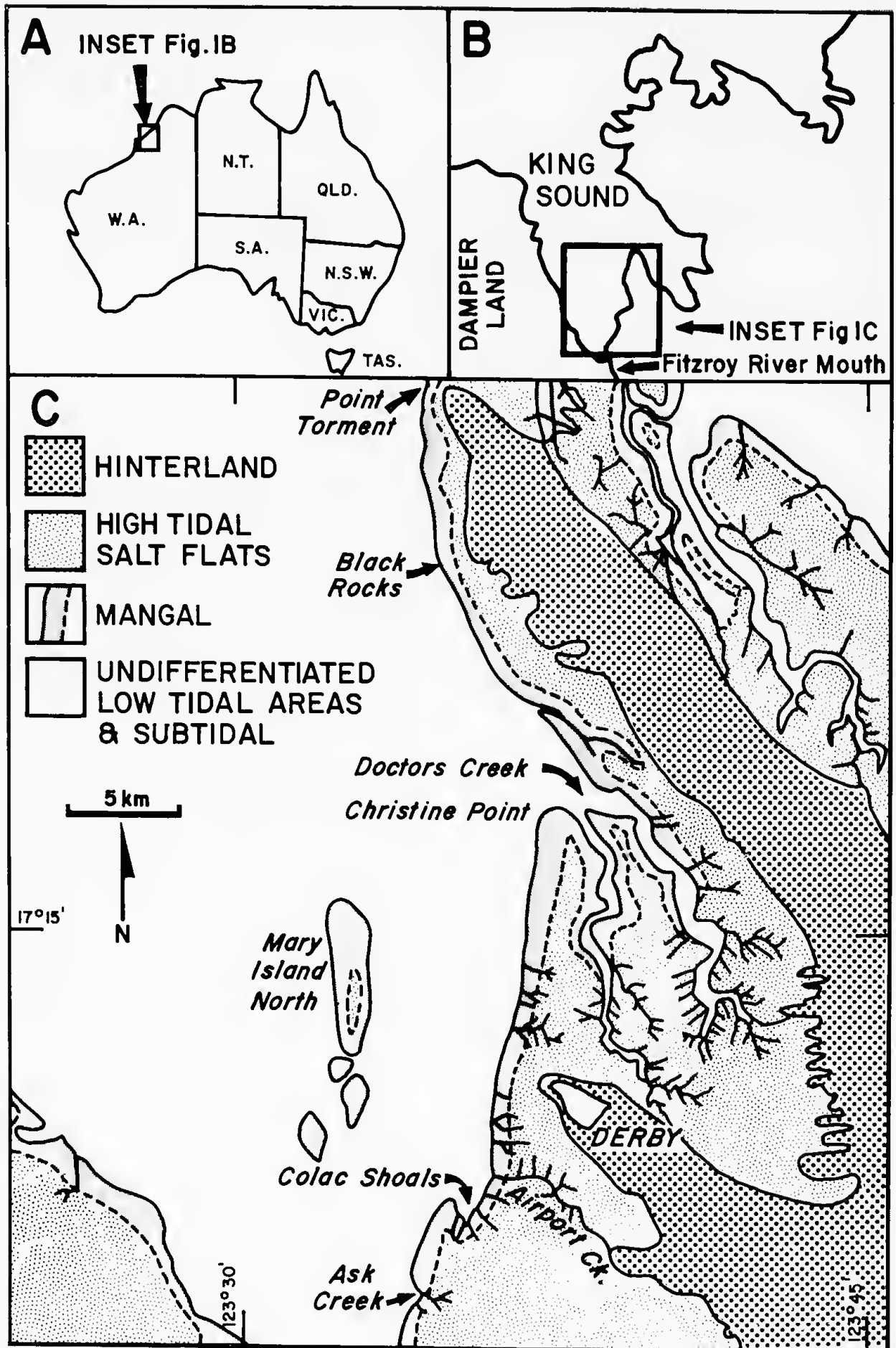


Figure 1.—Map showing location of study area within King Sound along the north-western coast of Australia. Figure 1C shows broad geomorphic units of the tidal flats and key geomorphic localities mentioned in text.

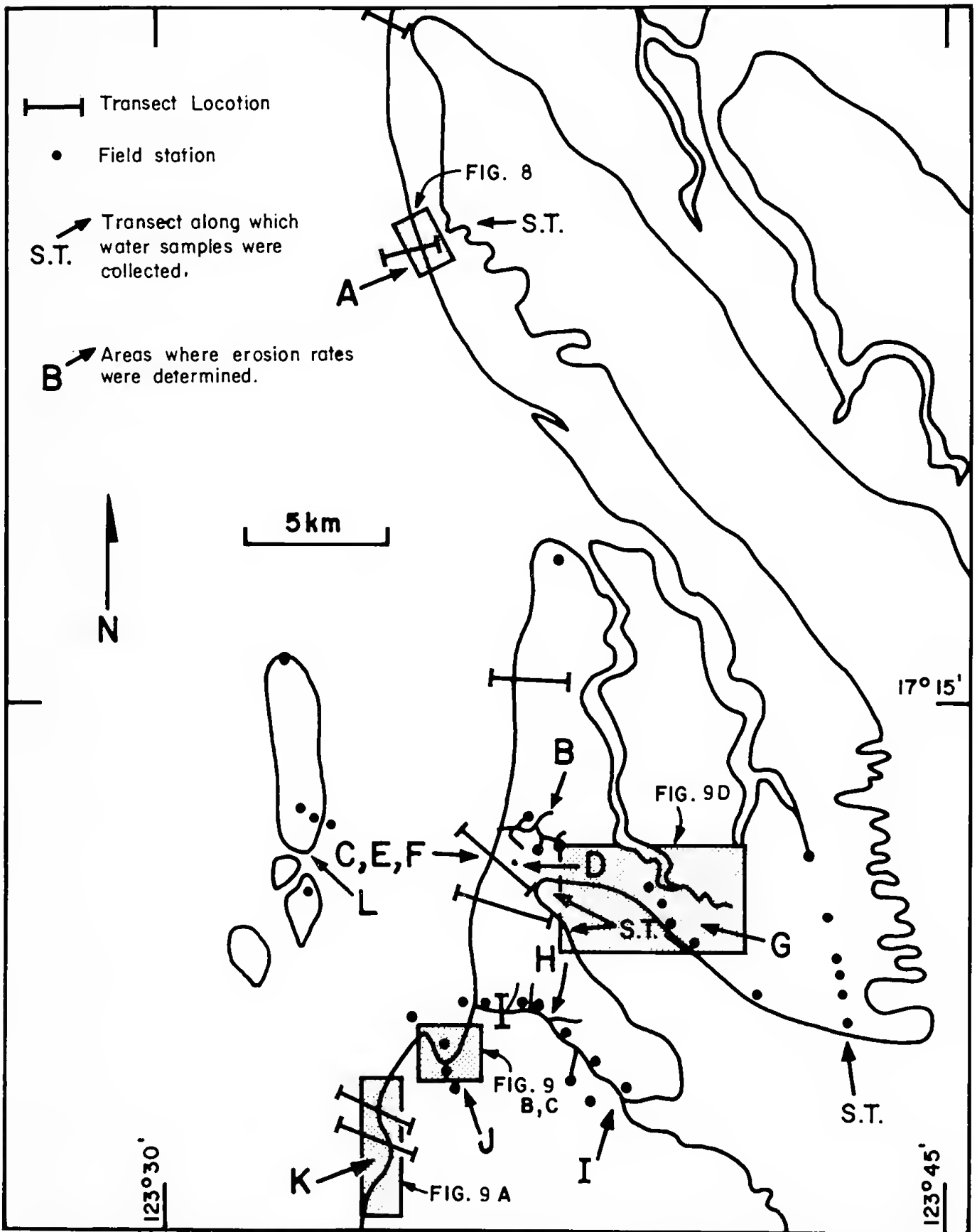


Figure 2.—Map showing location of various transects, field stations and erosion study areas. Insets are illustrated in more detail in Figures 8 and 9.

erosional scour against a feature of known age (c.g. mangrove roots). Field measurements were made during 1974-1977 on a 6-12 monthly basis. The areas used for determination of rates of erosion by aerial photos and by ground measurement are indicated on Figure 2.

The physical oceanography of King Sound in terms of circulation, tidal currents, waves and wind set is largely unknown in detail. It was necessary therefore to make observations and measurements particularly on tidal currents and waves at selected localities and at various times to assess their range of values. While these results are not exhaustive they give some idea of the magnitude of oceanographic features in the embayment. Tidal currents were measured in several localities to check routinely the magnitude of flow. Floating markers were released and their travel timed to determine surface current velocity both in open waters (7 markers) and in tidal creeks (25 markers). Heights of waves generated by sea breezes were estimated by rise and fall of water level against a calibrated tide pole.

### Regional setting

#### *Physiography and geology*

King Sound, a large shallow (6-18 m deep), marine embayment of approximately 5000 km<sup>2</sup> is located in the Kimberley region of north Western Australia. During the wet season King Sound is the estuary of the Fitzroy River (Fig. 1); during the dry season King Sound essentially is a marine embayment. Geologically, King Sound is a Quaternary depositional embayment within the Canning Basin. To the north King Sound is flanked by a hinterland of pre-Quaternary (Proterozoic to Tertiary) rocks and vegetated Quaternary red sand dunes; there are rocky coastlines and narrow tidal flats (Casey 1958; Gellatly and Sofoulis 1973).

To the south the shore is composed of Quaternary sedimentary materials, such as vegetated red sand dunes, grassy alluvial plains and broad tidal flats (Fig. 1); these Quaternary sediments overlie, at shallow depths, Mesozoic rock and Tertiary ironstone (Casey 1958). The main King Sound embayment, as delineated by mangroves that occur at about mean sea level, is funnel-shaped narrowing to the south toward the Fitzroy River. However, its shape at the high spring tide mark tends to be more irregular to sub-rectangular.

The main area of study was the southern portion of the east shore of King Sound where tidal flats are broad and mangroves well-developed. In these locations the tidal flats can be zoned into several units based on geomorphology and distinct vegetation communities.

#### *Climate*

Commonwealth Bureau of Meteorology (1975) data show that Derby has a semi-arid, tropical climate of monsoonal character (Bshw type of Köppen 1936). Approximately 620 mm of rain falls in a short wet period in summer between December and March. During winter there is negligible precipitation. The annual evaporation is approximately 3600 mm (class A pan or 2400 mm, sunken pan). Air temperatures are relatively high for both the wet and dry season (maximum commonly 33-39°C and 30-34°C respectively).

Wind data for 0900 hrs and 1500 hrs over 4 years analysed by Jennings (1975) show there are 2 wind seasons corresponding to the wet and dry seasons. Winds in general are light, with speeds mostly < 4.5 m/s. Only 13% of wind in the dry season have speed > 4.5 m/s and 17% of winds are > 4.5 m/s in the wet season (Jennings 1975).

In the dry season Trade winds from east and south-east are dominant in strength and frequency; an afternoon seabreeze is developed from north-west and west. During the wet season wind from north-west and west are dominant in frequency and seabreezes are subordinate. The wet season is also the period of tropical cyclones. Analysis of cyclone tracks over a 60 year period shows that a cyclone passes within 100 km of Derby approximately every 2 years, while one passes within 50 km of Derby every 5 or 6 years (Coleman 1971).

The importance of wind for the study area is the generation of waves. Seabreezes (during the dry season) and north-westerly to northerly winds (during the wet season) are responsible for generating small waves (generally < 0.5 m in height).

#### *Physical oceanography*

The coastline of King Sound has large semidiurnal tides (Easton 1970). Equinoctial spring tide range recorded at Derby is up to 11.5 m; the mean spring tide range is about 9.4 m; the mean neap range is 4.5 m (Australian National Tide Table 1979). Abbreviations for tidal levels used throughout this paper are:

EHWS = equinoctial high water spring  
MHWS = mean high water spring  
MHWN = mean high water neap  
MSL = mean sealevel  
MLWN = mean low water neap  
MLWS = mean low water spring  
ELWS = equinoctial low water spring.

Tidal currents reach velocities of 1.5-2 m/s in open waters, and 3 m/s (and greater) in narrow tidal creeks during periods of ebbing spring tide. During spring tides flood tidal waters traverse high tidal (salt) flats with velocity of up to 0.1 m/s. Ebbing tidal water draining along shallow creeks on high tidal flats may reach a velocity of 0.5 m/s.

Wave action overall is negligible. The embayment is protected from oceanic swell by islands of the Buccaneer Archipelago. However small waves are generated for a short period by afternoon seabreezes and by periodic summer storms. The waves are responsible for local coastline erosion and some shoreward transport of sand and debris. In the main, however, the embayment may be viewed as tide dominated.

During the wet season a combination of high (astronomical) tides, wind set (from north-westerly and northerly winds) and outflow of water from the flooding Fitzroy River creates a higher than normal regional water level. These are locally termed "king tides".

#### *Surface and groundwater*

The surface salinity of open water is 32-35‰. During spring tides tidal creeks that drain salt flats may have salinities above normal, up to 40-50‰.

The depth and chemistry of ground-water changes to landward with distance from the mangal. The water table is within 30 cm of the surface in the mangal; it may lie 2-3 m below the salt flat surface 4-10 km from the mangal (Fig. 3). Ground-water salinity at the seaward edge of the mangal is essentially that of seawater but it increases to landward gradually up to a maximum recorded value of 240‰. (Fig. 3D, E, F). Selected groundwater chemistry is shown in Table 1. These data show that groundwater is at concentrations where it is carbonate-precipitating and gypsum-precipitating (Clark 1924; Posnjak 1940). Under the more saline high tidal flats there are halite crystals (within 10 cm of the surface) as well as gypsum crystals and

weakly indurated carbonate nodules in the shallow subsurface (0.1-3 m).

The waters of King Sound and creeks that drain high tidal flats are turbid throughout the year. Turbidity is especially marked during spring tides. Water samples from selected transects across tidal creeks and the main embayment of King Sound have up to 1-2% (by weight) of mud in suspension. Since the Fitzroy River ceases flow after the wet season the turbidity cannot be attributed to river input. Rather it reflects the continual tidal flat erosion. Aerial observation show that these turbid waters extend out of King Sound as a plume. The suspended muds most likely are deposited far offshore out of King Sound in deep water.

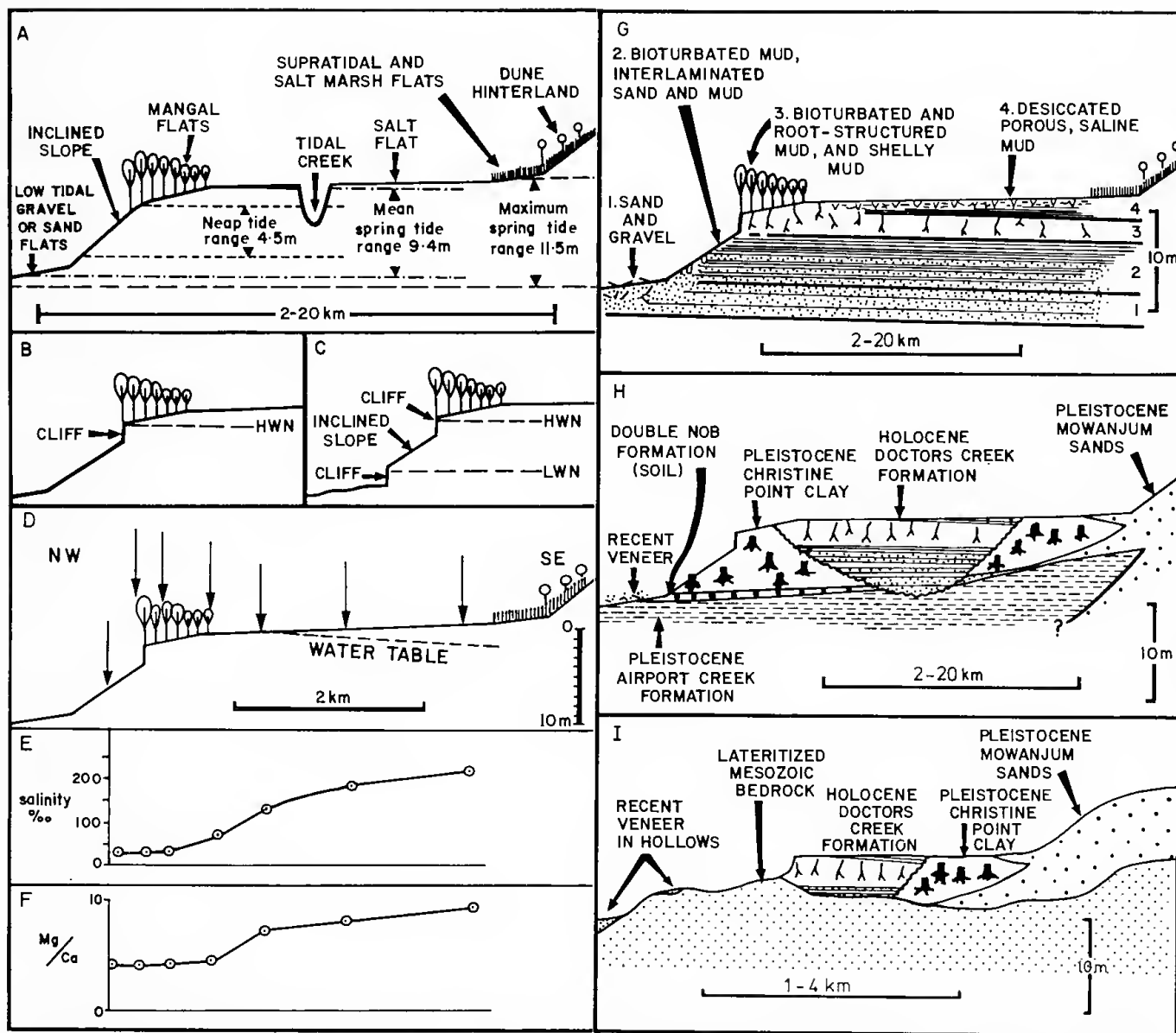


Figure 3.—A.—The full sequence of geomorphic/vegetation units; this profile is based on a transect from Derby (Fig. 1) but it is representative of profiles throughout the area. B and C.—Variation on the basic profile with seacliffs developed at levels of HWN and LWN. D.—Profile across tidal flat in a traverse from Derby (see Fig. 1) showing geomorphic profile and position of water table. Location of stations (auger holes for water samples) are arrowed. Data collected 15 September 1974 and are representative of other traverses made on the flats. E.—Salinity of water samples collected from the field stations shown above. F.—Variation in Mg/Ca in water samples from field stations shown above. G.—Characteristics and distribution of the 4 surface sediment types on the modern tidal flat. The section under the tidal flat illustrates the ideal stratigraphy which develops with an accreting coastline. H.—Profile illustrating the actual stratigraphy that underlies the tidal flats in southern areas. Summary of lithology of each stratigraphic unit is given in Table 2. I.—Profile illustrating the actual stratigraphy underlying tidal flats in northern parts of the study area. Erosion has stripped away tidal flat and dune sediments, exposing underlying rock, and has cut out some geomorphic and stratigraphic units. Spits and cheniers are present where erosion has cut into dunes.



Table 1

Chemistry and Mg/Ca ratio of groundwater samples from selected localities

Sample No.	Sample location	Ions (mg/L)				Mg/Ca
		Cl	SO <sub>4</sub>	Ca	Mg	%
13	Middle salt flat transect 3	103 000	14 150	1 020	8 500	13.74
16	Seaward edge salt flat transect 3	19 100	2 650	470	1 310	4.59
30	Landward edge salt flat transect 4	120 000	10 950	1 220	6 750	9.13
32	Middle salt flat transect 4	107 250	10 450	.....	.....	.....
23	Seaward edge salt flat transect 4	81 900	7 800	1 140	5 320	7.70
20	Landward edge of mangal transect 4	23 050	3 150	600	1 550	4.26
33	Seawater transect 4	19 850	2 600	470	1 270	4.46
011E	Middle salt flat, transect 5	132 400	11 300	1 065	3 825	5.93
011D	Seaward edge salt flat transect 6	67 350	7 250	1 200	1 960	2.69

### Stratigraphy

Much of the surface of the tidal flat is cut into Pleistocene units, and less commonly into Tertiary laterite and Mesozoic rock. Accordingly the tidal flat surfaces in essence are unconformity surfaces. Six Quaternary formations are recognised underlying the tidal flats and onshore hinterland of the King Sound area (Semeniuk 1980). They are: (6) Point Torment Sand, (5) Doctors Creek Formation, (4) Christine Point Clay, (3) Double Nob Formation, (2) Airport Creek Formation and (1) Mowanjum Sand. The stratigraphic relationship between these formations is illustrated in Figure 3G, H and I, and their lithology is summarised in Table 2.

The Mowanjum Sand is the oldest Quaternary unit in the area; it rests unconformably on lateritized Mesozoic rocks, underlies the Airport Creek Formation and extends as tongues across the unconformity interfaces that separate the other Quaternary units. The Airport Creek Formation, the oldest Pleistocene marine unit in the area, is composed of semilithified to indurated laminites and beds of sand and mud. It is overlain by a thin palaeosol termed the Double Nob Formation which is overlain by the Christine Point Clay (4-6 m thick), a Pleistocene mangrove sediment unit. The Doctors Creek Formation (10-12 m thick), which is a Holocene shoaling tidal-flat sequence of sand, sand/mud laminite and bioturbated mud, unconformably

overlies the Christine Point Clay and occurs in large-scale scours cut into the underlying formation. The youngest formation, the Point Torment Sand, is a Holocene sequence of shoreline sandy spits. It overlies and interfingers with the Doctors Creek Formation and the modern veneers.

An ephemeral thin blanket of sediment covers much of the unconformity surfaces of the modern tidal flats is termed the Modern Veneer. The veneer on low to mid tidal areas is stripped frequently on a monthly or seasonal basis by spring tides or storms. Shallow excavations or augering distinguishes Modern Veneer from the lithologically similar Doctors Creek Formation.

### Geomorphic units

The tidal flats and adjoining physiographic entities of King Sound are readily divisible into 12 geomorphic units (Fig. 3A, B C). These units are: (1) Vegetated dunes, (2) Supratidal and saltmarsh flats, (3) Salt flats, (4) Mangal flats, (5) Inclined slope, (6) Shoals, (7) Sand flats, (8) Gravel pavements, (9) Spits and cheniers, (10) Rocky outcrop, (11) Tidal creeks and (12) Sea cliffs. Many of these units are restricted to specific tidal levels but some (shoals, gravel pavements and rocky shores) occur across several tidal levels. Subtidal features are not subdivided nor considered further here.

Table 2

Summary of lithology of stratigraphic units \*

Stratigraphic unit	Age	Lithology	Remarks
Point Torment Sand	(Youngest) Holocene	Cross-laminated, cross-bedded and locally bioturbated quartz skeletal sand; locally shelly and lithoclastic	Shoreline sand spits and cheniers derived by erosion of Mowanjum Sand
Doctors Creek Formation	(Older) Holocene	Top—laminated mud, bioturbated mud mud/sand laminate Base—sand and shelly sand	Shoaling sequence of tidal-flat sediments
Christine Point Clay	Pleistocene	Bioturbated and root-structured slate grey mud with in situ large mangrove stumps	Tidal-flat unit deposited with sea level 1.5 m below present
Double Nob Formation	Pleistocene	Homogeneous, grey muddy sand with granule-sized pedogenic nodules	Nodular soil similar to those forming today under inland black soil savannah plains
Airport Creek Formation	Pleistocene	Interlayered, laminated and cross-laminated sand, silt and clay; semi-indurated by calcite cement	Tidal-flat unit irregularly cemented into nodules
Mowanjum Sand	Pleistocene	Red to orange quartz sand; homogenous, root-structured to mottled	Oldest Quaternary unit, aeolian in origin

\* Data from Semeniuk 1980.

*Vegetated dunes.*—All types of tidal flat are bordered by a hinterland of red sand dunes (Fig. 1). These longitudinal dunes, with up to 5 m relief above highest astronomical tide, are fixed by *Eucalyptus* and *Acacia* "pindan" shrub (Stewart *et al.* 1960). They impinge onto and extend as fingers beneath the tidal flat sediments (Jennings 1975; Semeniuk 1980).

*Supratidal and saltmarsh flats.*—These are gently sloping surfaces (up to 200 m wide, gradients 1:100) underlain by mud or muddy sand that border the hinterland. The higher parts of the flats, vegetated by terrestrial grasses and other low-growing angiosperms, are above EHWS; the lower parts, vegetated by samphires, are inundated by EHWS tides.

*Salt flat.*—The salt flat is vegetation-free, sub-horizontal with gradient of  $\leq 1:2000$  and up to 50 km<sup>2</sup> in area. It is flooded by tides higher than MHWS. The surface mostly is firm, desiccated saline mud with burrowing crabs, worms and insects at its more seaward portions. Groundwater hypersalinity precludes biota over most of the flat.

*Mangal flat.*—This is a vegetated flat tens of metres to over 1.5 km wide with gradients of 1:600 to 1:25 that occurs from about MSL to MHWS. It is vegetated mainly by mangroves (mangrove community = mangal: terminology of McNae 1968); samphires occur toward landward portions. The surface is underlain by mud, shelly mud and sandy mud bioturbated by plants and animals.

*Inclined slope.*—This surface is a vegetation-free slope, 100–200 m wide, with gradients of 1:20 to 1:40, between LWN to MSL (or HWN). It is underlain by thixotropic muds or interlayered mud and sand or Pleistocene units (Fig 8B of Semeniuk 1980) and is inundated by all tides.

*Shoals.*—Shoals are developed within the main King Sound embayment. They are large-scale hummocky units with an area of several square kilometres; channels and washaways are common. Shoals range in relative height from subtidal to generally above MSL. Some shoals are capped by mangroves and have built up to above HWN.

*Sand flats.*—Sand flats are typically low tidal sub-horizontal surfaces and are up to 1 km<sup>2</sup> in area. They are rippled, megarippled and plane-bed sand sheets (Fig. 4C) that have local shell and rock gravel veneers on the surface.

*Gravel pavements.*—These are subhorizontal to gently inclined surfaces up to several square kilometres in area that are subtidal or only exposed by LWS tides. The surface is littered by platy gravel derived from shallow subcropping Airport Creek Formation. Locally small knolls of outcrop < 1 m high protrude through the gravel veneer. In some localities the gravel pavements are reworked into megaripples (Fig. 4A, B).

*Spits and cheniers.*—These are narrow shoreline sand accumulations. They form single spits, or may be stacked, or may form a chenier plain. Individual spits are up to 1.5 km long; width varies from a few metres to over 20 m. Splays may span a total width of 200 m. Subaerially and tidally degraded spits are < 1 m high.

The spits and cheniers occur from HWS up to, and above, EHWS. Within tidal ranges the units are

vegetation free, but above EHWS they are vegetated by *Spinifex hirsutus* and *Acacia*.

*Rocky outcrop.*—Lateritized sandstone and other pre-Quaternary rock locally crop out either as a headland or a knoll. These may extend from supratidal to subtidal, but outcrop may be restricted to a narrow range of the tidal zone.

*Tidal creeks.*—Tidal creeks range from small ruts and gullies, < 1 m deep and wide, to > 10 m deep and 1 km wide. Creeks in plan are meandering, ramifying and bifurcating, but are not laterally migrating because they are entrenched. Small tidal creeks and gullies are commonly V-shaped in cross section; larger systems are characteristically a broad U-shape. Tidal creeks incise all but highest tidal and supratidal units.

*Sea cliffs.*—Sea cliffs occur continuously along most of the tidal zone of King Sound and are developed at many tidal levels (Fig. 5) although more usually they are developed at 2 levels: the more common is immediately in front of the mangal flat (Fig. 5C); the other is at LWN level (Fig. 5D). Cliffs are 1–2 m high; rarely they are up to 6 m high. The retreating toe of a sea cliff often is marked by debris reworked from the eroded formation. The debris includes: (a) mangrove wood fragments, (b) mud-ball conglomerates, (c) blocks of mud, (d) lithoclast pebble conglomerate (carbonate nodules reworked from Airport Creek Formation) and (e) wedges and sheets of granule deposits (carbonate nodules reworked from Double Nob Formation).

#### *Types of tidal flats*

The tidal flats of King Sound are varied in morphology and stratigraphy. Six main types of tidal flat occur and each type consists of a different combination of geomorphic units. The tidal flat types are: (1) Depositional flats, (2) Unconformity flats, (3) Shoal flats, (4) Spit and chenier flats, (5) Rocky shores and (6) Channelled flats. These types of flats with their component geomorphic units are diagrammatically illustrated in Figure 6.

*Depositional flats* (Fig 6).—This type of tidal flat occurs in restricted areas where deposition of sediment is taking place or where there is a state of equilibrium between sedimentation and erosion. The geomorphic units on this type of tidal flat include: a broad salt flat followed to seaward by a wide mangal flat, then an inclined slope and low tidal sand flats; there is a gradual unbroken slope from high tide through to low tide; the inclined slope is underlain by interlayered mud and sand to some depth and ultimately low-tidal sand underlies most of the flat. A characteristic feature is the general absence of cliffs and lack of subcropping or shallowly buried Pleistocene formation.

*Unconformity flats* (Fig. 6 and 7B).—This type of tidal flat is most common south of Doctors Creek (Fig. 1). It is essentially similar in morphology to the depositional tidal flats except for the following features: (a) Seacliffs are developed at levels of HWN and LWN and (b) Pleistocene sediments form the tidal flat surface on the inclined slope (i.e. Christine Point Clay with protruding fossil mangrove stumps) and low tidal flats (i.e. outcrops of Airport Creek Formations or gravel pavements). Doctors Creek Formation locally may form the foundation material,



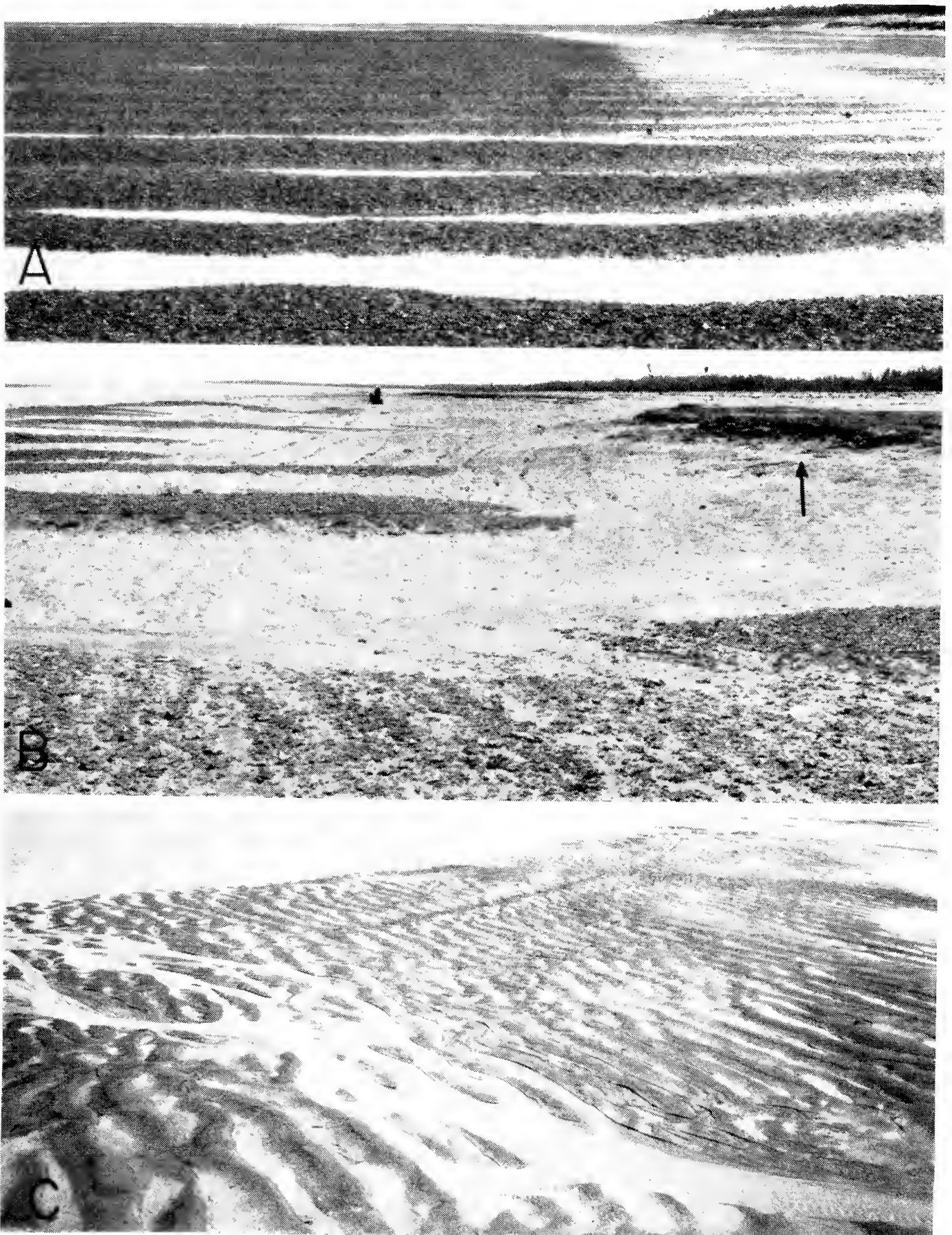


Figure 4.—Low tidal flats. A.—Gravel pavement exposed by low spring tide. Gravel here has been formed into megaripples oriented normal to the coast. B.—Patchy distribution of gravel veneer on exposed Pleistocene Airport Creek Formation. Arrow points to outcrops of Pleistocene nodular soil (Double Nob Formation). C.—Megarippled sand flat exposed by low spring tide.





Figure 5.—Seacliffs cut at various tidal levels. A.—Cliff cut into hinterland dune terrain. Mangroves are on right. The steeply inclined sandy surface encompasses the interval between MHWS and EHWS. Erosion has incised into the grassy plain to the left and here has exposed roots of the Boab tree. During the 1940s the cliff was some 6 m further to seaward from this tree (H. Bromby, pers. comm.). B.—Cliff cut into salt flat. Evident here are hanging valleys of a truncated high tidal creek system. C.—Cliff (1 m high) cut at level of HWN into the seaward edge of the mangal flat. Mangrove roots are exposed and mangrove trees are in various stages of collapse. Note gravel developing at toe of cliff. D.—Cliff cut at level of LWN into the inclined slope. Note gravel developing at toe of cliff.



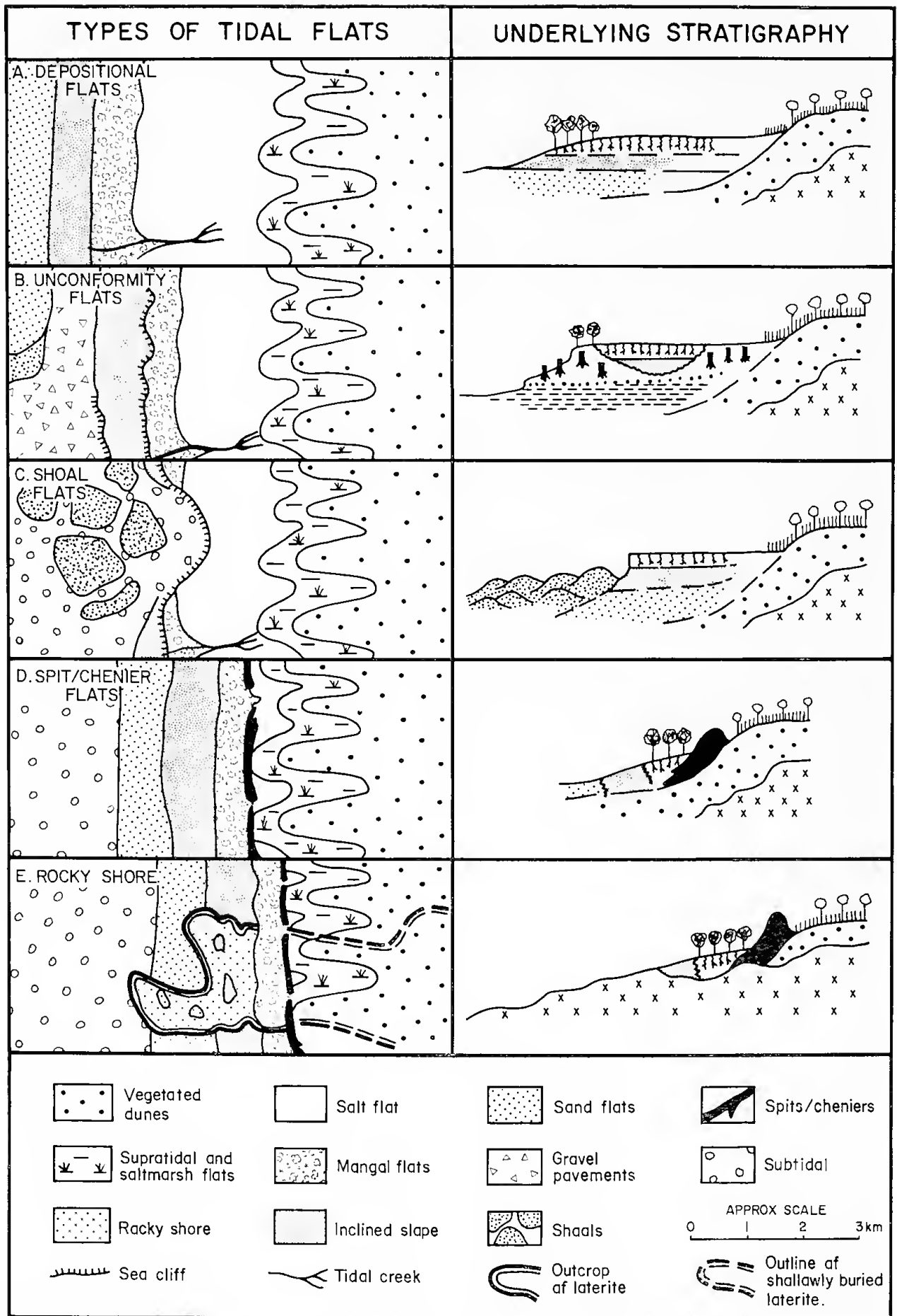


Figure 6.—Diagram illustrating various types of tidal flats, their component geomorphic elements and the typical underlying stratigraphy. Key to stratigraphic units is shown in Figure 3G, H, and I.



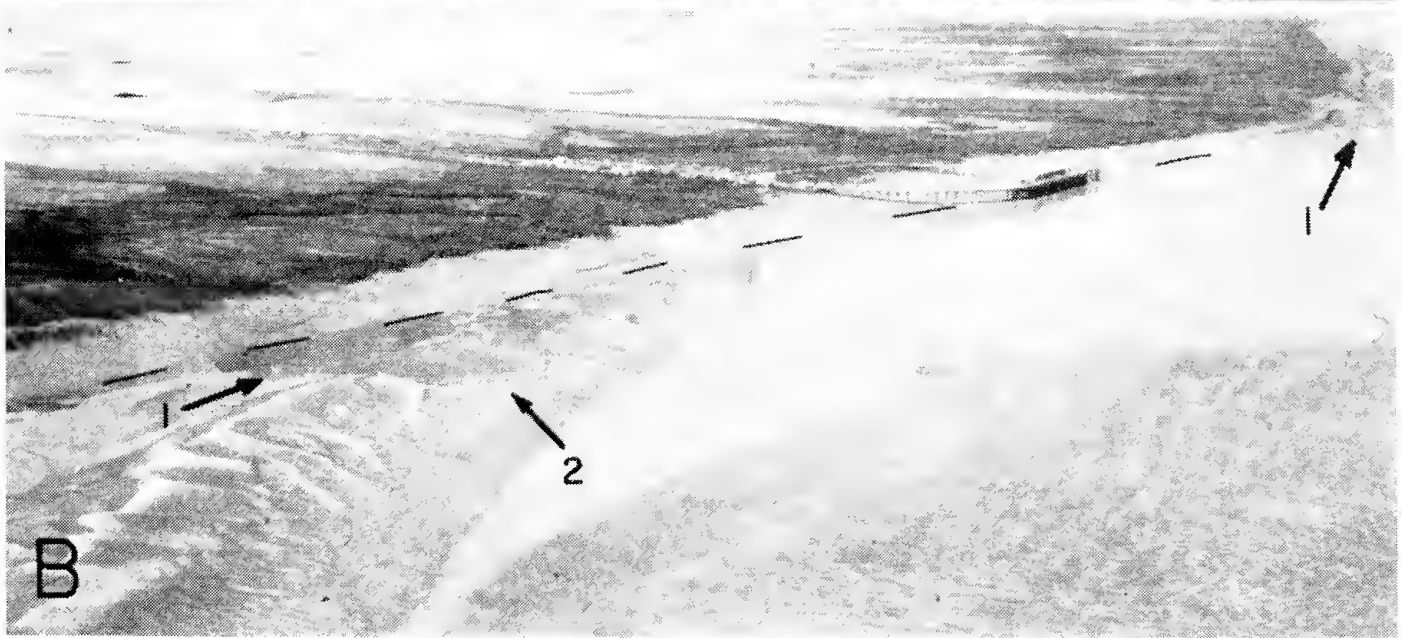


Figure 7.—Aerial view of various types of tidal flats. A.—Spit/chenier flats and locally rocky shore (arrowed). The eroding line marked by spits cut into the tips of dunes is evident here. B.—Unconformity flats. Note the wide salt flat, the narrow mangal flats which are flanked to seaward by an inclined slope. The seaward margin of the inclined slope is marked by the broken line. Arrows labelled 1 point to gravel pavements; arrow 2 points to sand flats that overlie gravel. C.—Shoal flats. Portion of this shoal system is capped by mangroves.



*Shoal flats* (Figs. 6 and 7C).—These flats are characterised by shoals in subtidal to mid-tidal areas. Shoals are abundant in the southern parts of the King Sound embayment where they effectively choke the estuary of the Fitzroy River. Shoal tidal flats also occur against rapidly eroding shorelines cut into Doctors Creek Formation (Fig. 6). In both cases they occur offshore from the main tidal flat that flanks the hinterland.

*Spit and chenier flats* (Figs 6 and 7A).—These flats are so named because they contain spits and

cheniers as important components; otherwise they are similar in mid-tidal to subtidal portions to unconformity and depositional tidal flats. The mid to low tidal parts are gravel pavements, sand flats, inclined slope (underlain by contemporary sediments or shallowly buried Pleistocene Christine Point Clay) and mangal flats. Mangal flats however, abut either supratidal flats, or vegetated red sand dunes, or spits and cheniers (Fig. 8). In many areas mangal flats are invaded by spits and cheniers. Salt flats, if present, are narrow or occur in corridors between longi-

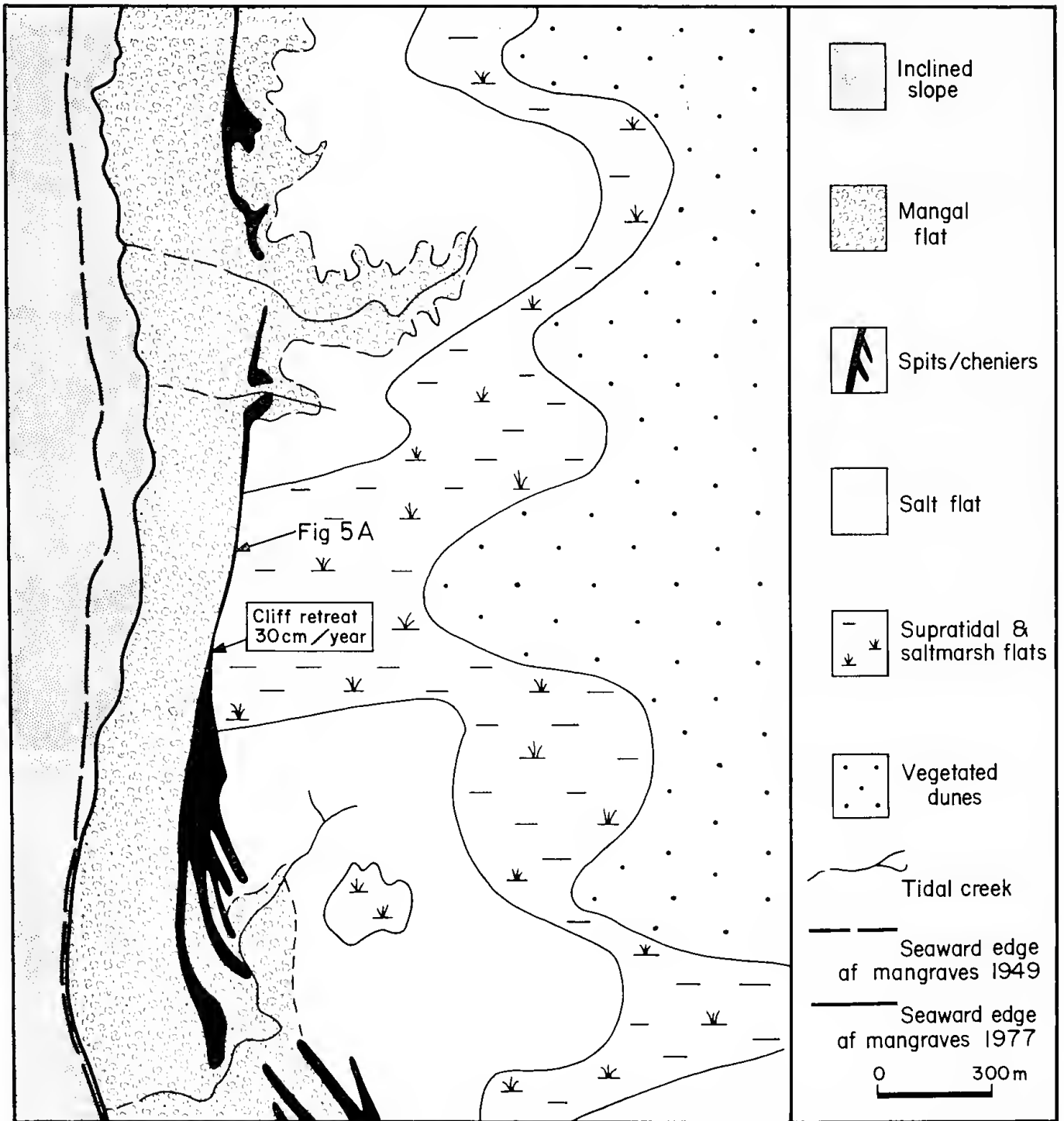


Figure 8.—Map showing distribution of geomorphic elements in a spit/chenier flat. Note the relationship of spit/cheniers to the eroding tip of a longitudinal dune. Erosion is evidenced by the retreat of the mangrove, the measured retreat of the high tidal cliff and the exposed roots of the boab tree (see Figure 5A).

tudinal dune fingers (Fig. 8). Spit and chenier flats are abundant north of Doctors Creek (Fig. 1).

*Rocky shores* (Figs. 6 and 7A).—This type of tidal zone is developed where there is rocky outcrop. Outcrops may extend across the full tidal range. More usually outcrops form distinct knolls that protrude above surrounding Quaternary sediments and so form "reefs" or headlands of limited extent. Local pockets of sediments occur in depressions in the rocky shores and the sediment type is typical of the tidal level at which it occurs e.g. low tidal depressions are filled with sand, mid-low tidal depressions are filled with sand/mud laminites. Rocky shores are more common in the far northern parts of King Sound, north of the study area depicted in Figure 1B.

*Channelled flats*.—All tidal flats and all types of stratigraphic profiles are incised by tidal creeks to varying extent but, where tidal flats are abundantly incised, the tidal zone becomes merely a complex of channels. Here, the integrity of the various tidal flats described above, becomes subordinate to channels. Channelled flats are distributed in discreet areas along the coast (Fig. 1C). The stage to which a flat is incised to be termed channelled flat is arbitrary, since every gradation from one extreme to the other occurs. For purposes of this paper, creek systems as large as, and larger than Airport Creek are termed channelled flats. Since creeks deepen, widen and lengthen in time the relative age of a creek can be inferred. The sequence Ask Creek, Airport Creek, Doctors Creek probably represent an age sequence from youngest to oldest (Fig. 1C). Within the larger channel systems sediment remobilisation and redistribution has resulted in development of large mid-channel shoals, point bar deposits and creek mouth fans.

### Surface processes

Erosion and local sedimentation are taking place concurrently along some parts of the King Sound coastline and are alternating along other parts. However, erosion today is the obvious and dominant process and from a review of aerial photographs spanning 28 years it is also obvious that it is the net process (Jennings 1975; Semeniuk 1980).

A study of stratigraphy also leads to this conclusion. Modern tidal flat sediment can be categorized into 4 suites correlated to geomorphic units (Fig. 3G). Low tide areas are underlain by sand shaped into megaripples and ripples. Inclined slopes are underlain by interlaminated sand and mud passing upslope into laminated mud. Sediment under mangroves is root-structured mud, sandy mud or shelly mud, thoroughly mixed by animals and plants. Salt flat sediments are vesicular and laminated mud; during periods of long exposure on high-tide parts of flats, there is growth of evaporite minerals such as halite and gypsum. With coastal accretion, these 4 suites would migrate to seaward, to build a shoaling stratigraphy (Fig. 3G).

On the tidal flats however the 4 sediment types usually form a thin sheet (modern veneer) that blankets a contrasting underlying stratigraphy (Semeniuk 1980). Where the veneer is stripped by spring-tide currents or storms, the underlying sediments exposed may bear no relationship to the modern sediment normally found in that environment (Figs. 3H, I; 4A, B; and Fig. 8B of Semeniuk 1980). For

most of the tidal flats therefore, there is a major discrepancy between surface sediments and the underlying stratigraphy, indicating that the coastline did not accrete by shoaling or progradation of recent sediments, but rather that the coast is undergoing net erosion.

Deposition of sediment does take place locally and during specific times, but it is overall negligible. The predicted shoaling stratigraphy (Fig. 3G) is present in two types of settings: (a) in large-scale hollows or scours which at present are not depositional and appear to be former embayments (Semeniuk 1980) and (b) in small embayments where deposition is taking place locally.

### Types of erosion

Erosion is the principal process shaping the modern geomorphic surface in southern King Sound. It is occurring at all tidal levels and is reflected in numerous small-and large-scale geomorphic features depending on location, type of substrate, substrate cohesion, intensity of current flow, slope of surface, and many other factors. Three types of erosion appear to bear directly on the development of geomorphology; these are sheet, cliff and tidal-creek erosion. They occur to some extent at all localities but the geomorphology is determined by those which are dominant.

*Sheet erosion*.—Sheet erosion strips away extensive sheets of sediment at all tidal levels. It is an important erosive process, because it involves large expanses of the tidal flat which are progressively lowered a few millimetres at a time. Sheet erosion occurs most readily on salt flats that have dried out during neap tides. During this period the mud becomes vesicular as gas bubbles coming from shallow depths are trapped by a cohesive drying surface layer. Worms, insects and crustaceans burrow into the mud, producing innumerable small tunnel systems and desiccation results in shrinkage cracks aligned both parallel to and perpendicular to the surface. During prolonged exposure, soil moisture evaporates and salt crystals grow into mud-disrupting aggregates. A spring tide returning after 2-4 weeks rapidly traverses this indurated mud pavement virtually picking up no sediment. With inundation water fills cavities in the mud and the salt dissolves ceasing to support the surrounding mud which collapses. Thus, the mud quickly becomes a thick suspension and the substrate which did not easily yield to tidal scour on the flooding tide, now readily erodes. The topmost layer is removed and theebb tide carries abundant mud particles in suspension out to sea.

Sheet erosion is evident on mangal flats where mangrove roots are progressively exposed. It occurs on the inclined slope in front of mangroves as evidenced by both erosional scours and the seasonal stripping of a thin oxidised surface that forms on the underlying fossil stratigraphic units. Bioturbation aids this erosion by loosening the stiff Pleistocene sediments and producing a thixotropic surface layer up to 5 cm thick. Periodic storms, waves or spring tides rework this loosened surface.

*Cliff erosion*.—Cliff erosion involves the retreat of coastline cliffs 1-2 m high and locally up to 6 m high. In plan the coast is typically scalloped. The seaward edge of mangal flats is the most common location for cliff erosion. The baffling effect of mangroves on tidal currents and the binding effect of



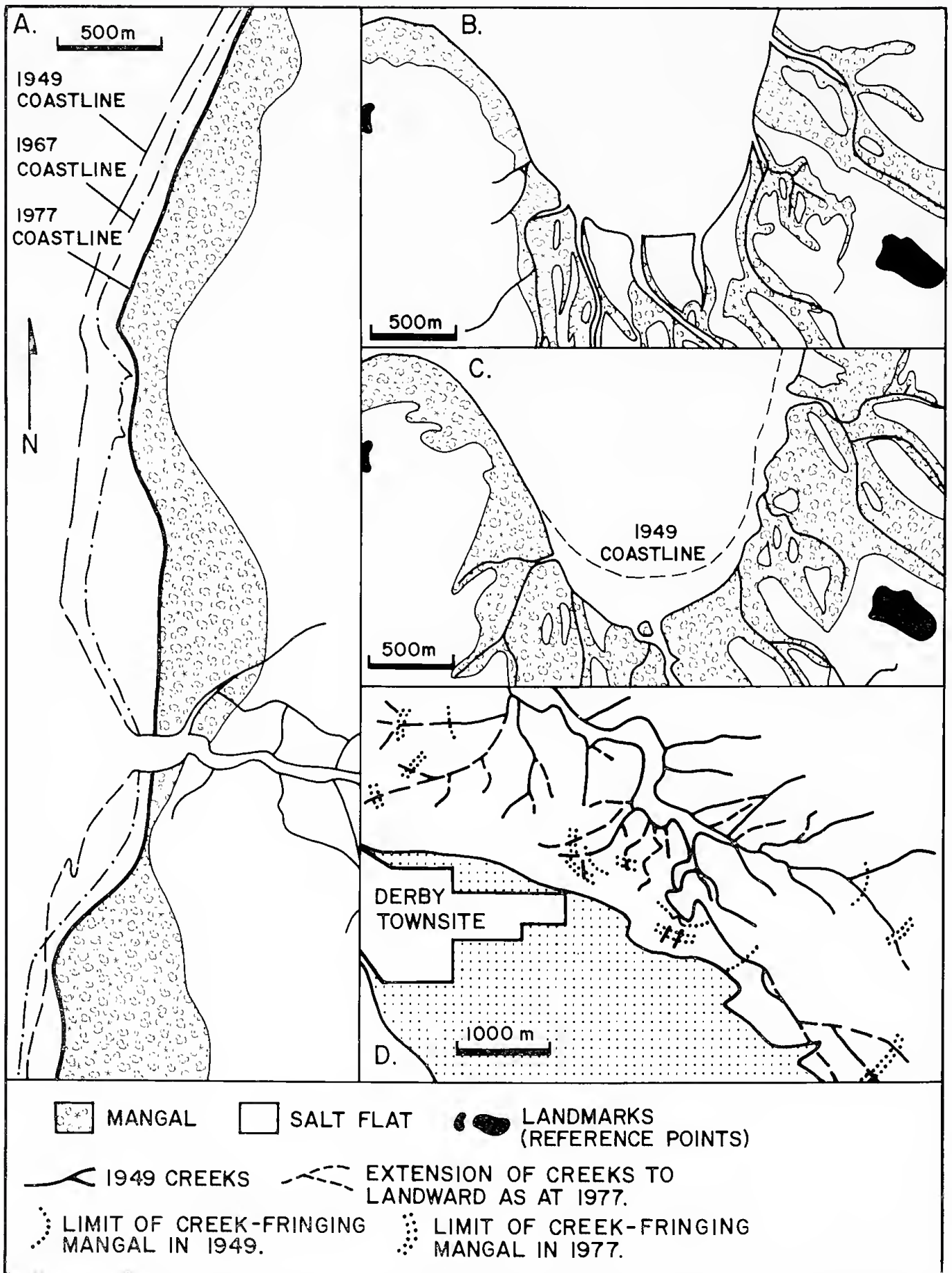


Figure 9.—Maps showing changes in coastline. A.—Southernmost portion of study area showing changes of coastline and erosion of mangal from 1949 to 1977. B and C.—Colac Shoals area showing retreat of coastline over the interval 1949 to 1977. Creeks have extended landward and mangal has encroached to landward along creeks and across salt flats. D.—Map centred on Derby peninsula showing headwater regions of Doctors Creek where the creek has extended headwaters to landward and creek-fringing mangals have followed.

their roots tends to make a marked distinction between the inclined-slope environment and the mangal flat and a sea cliff is formed most readily at their junction (Fig. 5C). Cliff erosion is caused by tidal scour, mass slumping and undercutting of mangrove root systems. Wave action during neap tides is also important because erosion can be localized at a standing water level during the high and low tide period. The rate of cliff retreat is dependent upon the stratigraphy of the coastline; cliffs cut into Doctors Creek Formation retreat faster than those cut into Pleistocene units.

*Tidal-creek erosion.*—Erosion by channels is termed tidal-creek erosion. Measurements in tidal creeks, intensely over 8 weeks, more generally over 4 years, and over 28 years from aerial photographs, show that they progressively deepen, widen and extend their headwaters to landward. Thus the gradation in creek size from small rut to large channel reflects stages of creek development. The small ruts a few centimetres deep at the headwaters of a tidal creek are initiated by mud cracks in the salt flat surface. The array of cracks between mud-crack polygons coupled with the slope of the tidal flat probably generates the meandering channel which, once it is formed, becomes entrenched. This meandering pattern remains with the creeks through all stages of their growth.

Within 10-20 years the small tidal ruts develop into small channels; these channels are only flooded during spring tides and are subject to sheet erosion typical of salt flats except that channelled ebbing tide waters are more erosive. Creeks continue to deepen and widen until the floor reaches a level below that of high water neap tide where sediment remains moist and waterlogged. A new process then operates; waterlogged banks frequently and repeatedly slump, resulting in a more rapid widening and deepening of the channels. The creek cross-section changes from a shallow V-shaped to a deeper U-shape.

*Rates of erosion*

Rates of erosion were variable from place to place, and at the same field station rates varied in time. The data presented below and in Table 3 give maximum rates of erosion. Erosion rates currently operating and those rates deduced from aerial photography (Fig. 11) indicate that qualitatively there are 3 rates related to foundation materials. The fastest rate occurs where there is erosion of Doctors Creek Formation. Moderate rates occur where there is erosion into Pleistocene formations. Slowest rates occur where there is erosion of hinterland dunes and bedrock.

*Rates of sheet erosion.*—Rates of degradation by sheet erosion were determined in areas A, D and I (Fig. 2). Erosion in area A indicates a loss of 30 cm of sediment within 10-15 years i.e. within the lifetime of mangroves whose roots are exposed. This gives a conservative estimate of erosion rate as 2-3 cm/year. Rate of erosion in area D was determined over 3 years and gave a value of 1-2 cm/year. A rate of approximately 1 cm/year has been determined in area I by levelling areas of salt flat which 28 years ago were supratidal grassy flats and now lie 30 cm below modern supratidal flats.

*Rates of cliff erosion.*—Rates of cliff erosion were determined by aerial photographic comparisons over a 28 year period and by direct measurement (Table 3). In southern parts of King Sound a fast retreat of 30-50 m/year has been estimated (areas K and L). Even faster rates of about 90 m/year occurred between 1949 and 1967 in the Alligator Creek area near the mouth of the Fitzroy River (Fig. 1). However, erosional rates of up to 2 m/year, which were directly measured (areas E and F), were more typical of most cliffs in the study area. Slow rates of 30 cm/year were determined from areas A and E.

This unequal rate of cliff erosion along a stretch of coastline typically results in a scalloped coast.

**Table 3**

*Rates of erosion<sup>1</sup>*

Area <sup>2</sup>	Type of erosion				
	Sheet	Cliff	Extension of creek headwaters	Channel widening	Channel deepening
A	2-3 cm/yr <sup>3</sup>	0.3/yr <sup>4</sup>	.....	.....	.....
B	.....	.....	30-60 m/yr <sup>4</sup>	3 m/yr <sup>4</sup>	.....
C	.....	.....	.....	3-4 m/yr <sup>4</sup>	.....
D	1 cm/yr <sup>4</sup>	.....	.....	0.3 m/yr <sup>4</sup>	0.3-0.6 m/yr <sup>4</sup>
E	.....	0.3-2 m/yr <sup>4</sup>	.....	.....	.....
F	.....	0.3-2 m/yr <sup>4</sup>	.....	2-4 m/yr <sup>4</sup>	.....
G	.....	.....	3 m/yr <sup>4</sup>	.....	0.6 m/yr <sup>6</sup>
H	.....	.....	5-60 m/yr <sup>5</sup>	.....	.....
I	1 cm/yr <sup>5</sup>	.....	0-3 m/yr <sup>4</sup>	0.3-3 m/yr <sup>4</sup>	.....
J	.....	.....	10 m/yr <sup>4</sup>	.....	.....
K	.....	10 m/yr <sup>4</sup>	30-100 m/yr <sup>5</sup>	.....	.....
L	.....	40-50 m/yr <sup>5</sup>	15-17 m/yr <sup>5</sup>	.....	.....
Alligator Creek	.....	30 m/yr <sup>5</sup>	.....	.....	.....
	.....	90 m/yr <sup>5</sup>	.....	.....	.....

<sup>1</sup> Maximum rates of erosion are rounded off to approximate values.

<sup>2</sup> Area location shown on Figure 2.

<sup>3</sup> Estimated from inferred age of mangroves whose roots are exposed.

<sup>4</sup> Direct measurement.

<sup>5</sup> Determined from aerial photography over 28 years.

<sup>6</sup> Measurement of depth against known age.



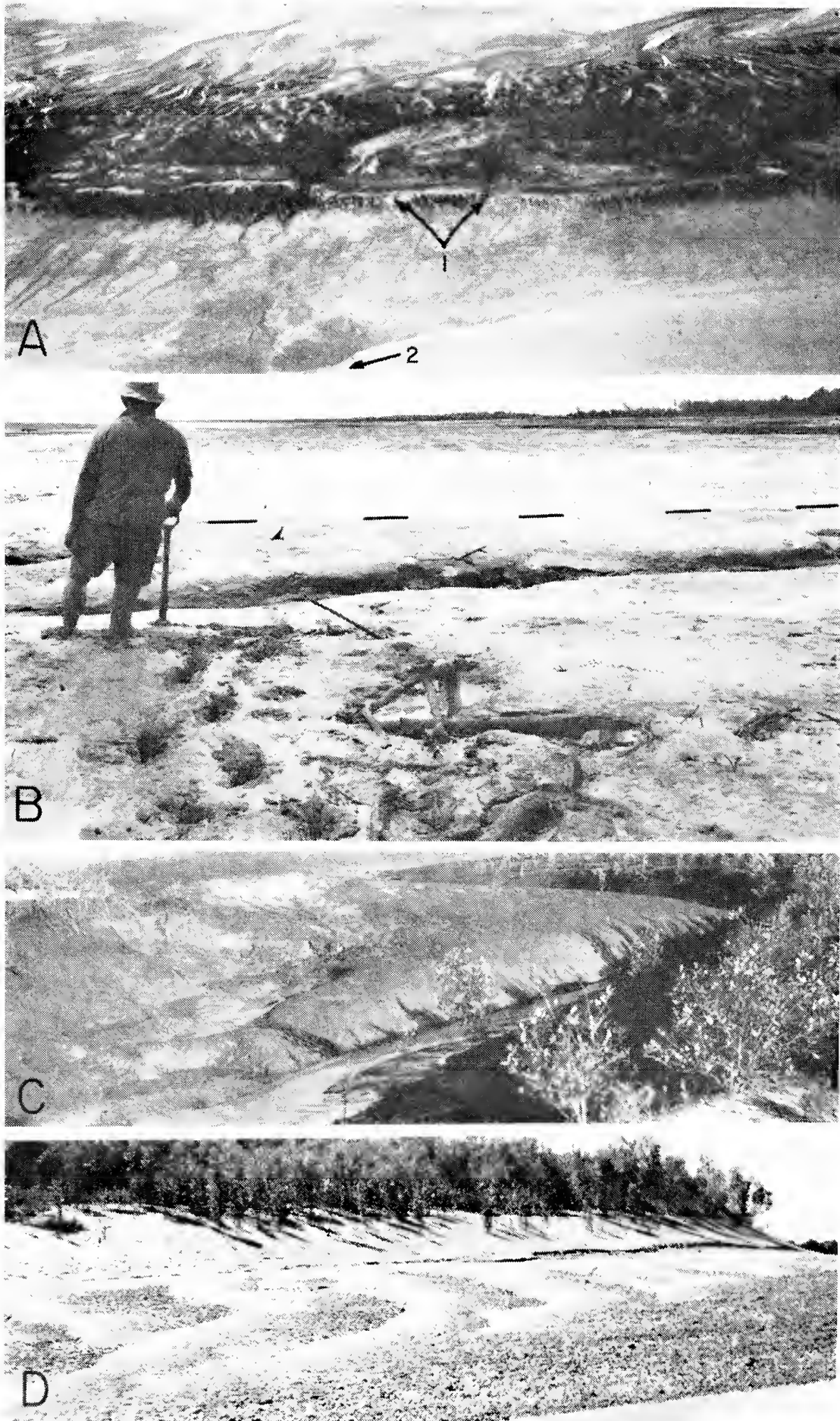


Figure 10. — Sites of sedimentation. A. — Aerial view showing a belt of mangrove (arrow 1) recolonizing a surface in front of a high tidal cliff. These mangroves have influenced deposition of mud. Once buried this cliff would appear as a scar within the mangal flat. Arrow 2 indicates sediment deposited at the mouth of a tidal creek. B. — Close-up of a creek-mouth deposit. Dashed line indicates the contact of the deposit (vener) on Pleistocene sediments. The creek deposit is composed of mud-pebble conglomerate, homogenous mud and mangrove debris. C. — Point bar of small creek showing (ephemeral) deposit of mud-pebble conglomerate. D. — Point bar deposit of large creek which has incised Pleistocene formations. The point bar consists of lithoclasts gravel with patchy veneer of megarippled sand.





Figure 11.— Carbonate nodules. A. Platy nodules parallel layering in upper Doctors Creek Formation under a salt flat; exposed by a tidal creek. B.— Platy nodules parallel to sedimentary layering exposed on wall of seacliff in front of mangroves. In foreground are nodules that have been reworked. Ruler for scale is 15 cm.

*Rates of creek erosion.*—The rate of creek headwater erosion, with ruts a few centimetres deep, directly measured was 3 m/year (area G). However, aerial photograph comparisons of deeper channels indicate that rates of 30-100 m/year for headwater erosion locally occur (areas G and I); more moderate rates determined by aerial photography were 5-10 m/year (area G). The rate of channel deepening has been estimated tentatively by measuring channel depths of creeks that have formed since 1949. A conservative estimate is that, on the salt marsh, centimetre-sized ruts develop into metre-sized creeks over a period of about 10-20 years. Direct data about the rate of channel deepening for established creek systems are lacking. However, the numerous exposures of young mangrove root systems as erosion removes the enclosing soil indicate that it can occur rapidly. For instance, some creeks 3-4 m deep have incised the flats after the establishment of a mangrove community that is at the most 10 years old. The mangrove roots hang exposed

across the creeks. Measured rates of channel widening range from 2-4 m/year and have been determined in areas B, C, D, F and H (Table 3).

#### *Types of sedimentation*

Sedimentation on tidal flats of King Sound in a regional context must be viewed as minor and the stratigraphic products transitory. The main sites of sedimentation are: (1) shoals, (2) sheltered embayments, (3) spits and cheniers, (4) mangal flats and (5) creek mouths and point bars.

The sediments range from coarse lithoclast and shell gravel through to sand, muddy sand and mud. Sediment types and their environmental location are summarised in Table 4. The various sources of sedimentary particles are summarised in Table 5.

*Shoals.*—Shoals are the most important of the depositional features within King Sound. Internally they are composed of the ideal shoaling stratigraphic sequence (Fig. 3G). Aerial photography and on-site



**Table 4**

*Modern sediment types*

Sediment	Structure	Fabric	Texture	Composition <sup>1</sup>	Locality
Sand and shelly sand; locally lithoclastic sand	laminated to cross laminated	grainstone ....	medium and coarse sand; locally gravelly	quartz and skeletons; locally lithoclastic	low tidal sand flat, spits and cheniers, mid-channel shoals and point bars of large creeks
Lithoclast gravel; locally shelly	structureless to crudely laminated	grainstone ..	granules and pebbles some with sand interstitial to gravel frame	carbonate rock; locally shelly and with wood debris	low tidal gravel pavement; also at toe of sea cliffs cut into Pleistocene formations; point bars of large creeks
Mud-pebble conglomerate	structureless ....	packstone ....	pebbles and boulders with interstitial mud	mud clasts; locally with wood debris	toe of sea cliffs cut into Pleistocene and Holocene formations; point bars of small creeks; creek mouth deposits
Mud/sand laminite ....	bedded and laminated; cross-cutting burrows are common	grainstone to packstone in sand layers; mudstone in mud layers	medium to fine sand; silt and clay	quartz, skeletons, clay minerals, plant detritus	lower inclined slope
Mud laminite ....	laminated; commonly with burrows	mudstone ....	silt and clay in distinct laminae	quartz, skeletons, clay minerals, plant detritus	upper inclined slope
Bioturbated mud (locally shelly)	homogenous bioturbated locally laminated; in situ mangrove stumps	mudstone to packstone	silt and clay; locally with sand and gravel	clay minerals, quartz silt, skeletal silt, sand and gravel, wood, plant detritus lithoclasts	mangal flat
Laminated and vesicular mud	bedded to laminated; vesicular beds; rare to common burrows	mudstone ....	silt and clay; locally mud clasts	clay minerals, quartz silt, skeletal silt	salt flat

<sup>1</sup> See Table 5 for types of sediment particles.

**Table 5**

*Types and sources of sediment particles*

Sedimentary particle	Composition	Source				
		Fitzroy River input	Generated in basin	Eroded from older Holocene marine formations	Eroded from Pleistocene marine formations	Eroded from hinterland dunes and rock
Mud ....	Skeletal silt <sup>1</sup> ....	....	X	X	X	....
	Quartz silt ....	X	....	X	X	....
	Clay minerals ....	X	....	X	X	....
	Plant detritus ....	....	X	....	X	....
Sand ....	Skeletons <sup>2</sup> ....	....	X	....	X	....
	Quartz ....	X	....	X	X	X
	Carbonate lithoclasts ....	....	....	X	X	....
	Other lithoclasts ....	....	....	....	....	X
	Plant detritus ....	....	X	X	X	....
Gravel ....	Shell <sup>3</sup> ....	....	X	X	X	....
	Platy carbonate lithoclasts ....	....	....	X	X	....
	Granule-sized pedogenic nodules ....	....	....	....	X	....
	Plant debris ....	....	X	X	X	....

<sup>1</sup> foraminifer tests, spicules, mollusc fragments.

<sup>2</sup> fragments of molluscs, echinoids, crustaceans, foraminifer tests, spicules.

<sup>3</sup> bivalves, gastropods, crustaceans.

observations show that large shoals develop proximal to rapidly retreating coasts where sediment input exceeds the rate of erosion at the site. Shoals themselves are subject to erosion and redistribution and in the long term they are transitory features. A series of shoals in the vicinity of Mary Island South for instance was completely eroded from above HWN to below MSL between 1949 and 1977.

*Sheltered embayments.*—Deposition takes place in sheltered embayments or backwaters where local eddies are developed in the main tidal flow. In these localities local progradation results in a complete or an incomplete ideal stratigraphic sequence as shown in Figure 3G. Again, in the context of net erosion along these coasts such deposits are transitory.

*Spits and cheniers.*—Spits and cheniers are accumulating along the northern half of the study area (Jennings and Coventry 1973). They have formed where the tips of longitudinal dunes are exposed to tidal erosion (Fig. 8) or (if shallowly veneered by Holocene deposits) periodically exposed to erosion (Semeniuk 1980). The sand is dispersed by long-shore tidal current both north and south from the eroded tip of a dune and is transported upslope by periodic storms. The sand progrades onto salt flats that occur in interdune depressions and also invades mangrove habitats.

*Mangal flats.*—Deposition locally occurs in front of sea cliffs where mangroves have recolonised a previously rapidly eroding coastline (Fig. 10A). Sediments probably accumulate due to mangrove effect of baffling, trapping and binding. Deposits built up during a mangrove colonising phase are severely cut back during the next erosional phase. Portions of the coast show scars of buried cliffs indicating they have undergone alternating erosion and deposition under such mangrove cover.

*Creek deposits.*—Sediments associated with creek deposits are thin (< 2 m) and generally ephemeral. Point-bar deposits, mid-channel shoals and creek-mouth fan deposits are the main accumulations (Fig. 10B, C and D).

## Geomorphological development

### *Local geomorphology*

Erosion is the dominant process on the tidal flats and therefore much of the geomorphology is directly related to it. However sedimentation also plays a minor part locally.

Sheet, cliff and creek erosion all occur to some extent everywhere on the tidal flats, but local geomorphology such as gradients, seacliffs and creeks, is largely dependent on which dominates. Broad, gently inclined surfaces are developed where sheet erosion is dominant, and scalloped coastlines with abrupt cliff lines occur where cliff erosion is dominant. Narrow, more steeply inclined surfaces are produced where sheet and cliff erosion alternate or where sheet erosion keeps pace with cliff erosion. Where sheet erosion occurs on flats adjoining creeks, then creek banks gently slope towards the channel. Cliff erosion that is parallel to the coast and concurrent with creek erosion results in abruptly terminating channels and hanging valleys. Cliff erosion parallel to creek margins is viewed as a type of rapid creek erosion and results in vertical banks.

The types of sedimentation that have influence on development of local geomorphology are (a) deposition of sediments in creeks (mouth fans, channel shoals, point bars) and (b) mangal flat deposits that bury seacliffs.

### *Geomorphic units*

The various geomorphic units are formed mainly by erosional processes but they also reflect the availability of varying sedimentary particles. The vegetated dunes of the hinterland existed prior to the Holocene transgression (Jennings 1975; Semeniuk 1980) and so this geomorphic unit has not developed by tidal processes. Supratidal and saltmarsh flats develop by sheet wash of sediment off hinterland dunes onto tidal flats (producing aprons of muddy sand). Some supratidal and saltmarsh flats are erosional residuals of stranded high level Quaternary sediments that border the hinterland; these sediments are now undergoing erosion to levels of high water spring.

Most salt flats have formed by sheet erosion of high tidal and supratidal flats. Once a surface has been degraded to levels where there is periodic tidal inundation then physical, chemical and biological processes (desiccation, salt crystallization, gas bubbling, burrowing, periodic wetting) operate to develop the distinctive salt flat surface. Some salt flats associated with depositional tidal flats have formed by vertical accretion of tidal muds.

Mangal flats have formed where tidal flats have been degraded to levels at which mangroves can colonise (Semeniuk 1980) and inclined slopes develop where erosion has proceeded to the stage where the surface has been degraded to below mangrove level. In shoaling and prograding areas mangal flats and inclined slopes develop by sediment accretion.

Low tidal areas are composed of gravel pavements where erosion has exposed Pleistocene formations and a lag of carbonate nodules form at the surface. Sand flats form in low tidal areas where sand is available and is distributed as a sheet across tidal flats.

The other geomorphic units such as tidal creeks, seacliffs, spits and cheniers and rocky outcrops are the products of various types and/or stages of erosion and their origin is self evident.

### *Regional geomorphology*

The regional geomorphology is dependent mainly on the extent to which erosion has incised coastal sedimentary sequences and on the type of foundation stratigraphy (Fig. 6). Depositional flats develop where sedimentation is dominant or where erosion/sedimentation is in equilibrium.

Unconformity flats with sea cliffs develop where erosion becomes accelerated and exposes Pleistocene units. Spit and chenier flats develop where erosion proceeds to the extent that salt flats are totally removed and the sea cliffs incise hinterland dunes. Further erosion ultimately exhumes bedrock and rocky shores are developed. Rapid erosion into Holocene deposits of the Doctors Creek Formation results in large amounts of reworked sediment that pile up into shoals, developing shoal flats. Finally where tidal creeks become abundant channelled flats are formed.

Sedimentation in localized sites within a net erosional framework has influence on development of regional geomorphology in the development of (a) shoals (shoal flats), (b) sheltered embayment deposits (depositional flats) and (c) spits and cheniers (spits and chenier flats).

#### Additional features

There are several additional features in the area that emphasise or reinforce the conclusions about erosion and sedimentation. When coupled with erosion rates (Table 3) these enable an extrapolation of erosion into the past. These features are: (a) nodules under the tidal flats, (b) dieback of grasses and pindan and (c) the imprint of (supratidal) vegetation roots on the stratigraphic sequence.

**Carbonate nodules.**—Nodules composed of Mg calcite, aragonite, dolomite, calcite or mixtures of these minerals occur imbedded in the Doctors Creek, Christine Point, Double Nob and Airport Creek Formations (Fig. 11). Generally there is a distinct association of nodule shape, nodule internal structure and chemical composition linked to host formation (Table 6).

The nodules occur at several stratigraphic levels and have formed in response to chemical alteration associated with unconformities or hypersaline groundwater fields (Table 6). All these types of nodules are being exposed and reworked by coastal erosion but those important to reconstruction of Holocene history are ones formed in hypersaline environments within Holocene formations under salt flats where groundwaters are carbonate-precipitating. An indication of how far erosion has incised the sedimentary formations is given by those nodules that are exhumed along the seacliffs in front of the mangrove belt (Fig. 11B); the nodules originally would

have formed under a salt flat at least several kilometres inland from the mangrove belt.

**Dieback of grasses and pindan scrub.**—Aerial photography shows that in past decades there were more extensive supratidal grassy plains and associated samphire flats. These have largely died back in response to sheet erosion that has lowered supratidal surfaces to levels of high water spring tide. On-ground inspection around residual grassy or samphire hummocks show that this dieback is continuing up to the present. Similar observations have been made on the seaward edge of the *Eucalyptus-Acacia* pindan scrub. At the junctions of the tidal flats where sheet erosion is proceeding at fast rates this terrestrial scrub is dying back and being replaced progressively by samphires and salt flat.

**Imprint of vegetation roots on stratigraphic sequences.**—Extensive areas of salt flats in the shallow subsurface (1-3 m) exhibit sediments that are riddled with fine rootlet structures. These root structures are unlike the coarse root structures forming under landward-fringe mangrove cover. The modern analogue for the fine rootlets is under supratidal grassy plains. Here sediment is desiccated mud, covered by a variety of annual and perennial grasses and samphires. Thus although hypersalinity has caused the supratidal grasses to die back and retreat, the former presence of the vegetation is indicated by their root structure.

#### Holocene tidal flat history

The synthesis of Holocene history of King Sound presented below revolves around 5 main points. These are: (a) alteration (diagenetic) overprints displaced from their environment, (b) erosion rates extrapolated into the past, (c) tidal flats in relation to large scale erosion, (d) origin of the Holocene Doctors Creek Formation and (e) ultimate sink for eroded materials.

Table 6

Features of carbonate nodules

Stratigraphic location	Shape	Size	Internal structure	Fabric relationship to host	Composition†	Inferred environment of precipitation	Comments
Upper parts of Doctors Creek Formation	platy to irregular	2-10 cm	structureless to internally laminated (inherent from host), unless replacing wood	replaces muddy sediment, mangrove wood, fossil crustaceans and sediment fill in <i>Teredo</i> borings	Mg calcite (aragonite and dolomite)	hypersaline groundwater	related to hypersaline diagenesis under salt flats*
Upper parts of Christine Point Clay	irregular	2-10 cm	structureless, unless replacing wood	replaces muddy sediment, mangrove wood, fossil crustaceans and sediment fill in <i>Teredo</i> borings	Mg calcite (aragonite and dolomite)	hypersaline groundwater	related to hypersaline diagenesis under salt flats*
Throughout Double Nob Formation	equant to spherical	1-10 mm	structureless	incorporates particles of the host	calcite	fresh water pedogenic	related to fresh water diagenesis associated with unconformity
Throughout Airport Creek Formation	platy concordant to layering in host	1-45 cm	internally laminated, inherent from host	cements the particles of the host	calcite	fresh water during sub-aerial exposure of host	

\* See Table 1.

† brackets indicate that the mineral species is uncommon.



*Alteration overprints displaced from their environment.*—A study of the modern processes and biota on the tidal flat surface and subsurface shows that there is marked zonation of chemical and biological alteration features that correspond to specific tidal levels (supratidal, salt flat and mangal flat environments). It follows that an alteration feature if now found out of its environment will be a valuable tool in reconstructing Holocene geomorphic history. The main 2 imprints used in this study are nodules (indicative of hypersaline salt flat) and grass roots (indicative of supratidal flats). In King Sound these overprints in many localities are now out of their environment and indicate that (as coastal erosion proceeded) the geomorphic surface passed from supratidal with fresh groundwater, to salt flat with hypersaline groundwater, to the seacliff with oceanic groundwater. It also indicates that erosion has been a net event in the more recent Holocene.

Similarly as coastal retreat takes place mangroves encroach landward and alteration associated with mangrove environment overprints sediments that have passed through salt flat and supratidal flat alteration. The displaced alteration features indicate that at least several kilometres of coast have been lost in the Holocene. The maximum value is unknown but may be inferred by extrapolating rates of erosion into the past.

*Extrapolation of erosion rates into the past.*—The geomorphic, stratigraphic and diagenetic data suggest that erosion (and not coastal accretion) has also been a long-term event. The question then arises: for how long has erosion been operating? Mangrove wood has been dated by radiocarbon from various localities in southern King Sound (Jennings and Coventry 1973; Jennings 1975). Mangrove stumps under spits and cheniers dated at ca. 1000 yrs BP and younger showing that the Point Torment spits and cheniers were the last stratigraphic unit to be emplaced, confirming the stratigraphic evidence (Fig. 7 of Semeniuk 1980). However the Point Torment Sand is a unit developed by erosion of hinterland dunes and in essence represents the products of late phase erosion. Dates from the Doctors Creek Formation centre around 5000-6000 yrs BP showing that the bulk of that formation was rapidly deposited about middle Holocene. The formation is not accumulating today and stratigraphic and geomorphic data suggest it ceased deposition several thousand years ago. It is worthwhile then to explore the possibility that King Sound tidal flats have been eroding since 5000 yrs BP, the date about which the tidal flats ceased prograding. If the King Sound area earlier in the Holocene was a coastal plain then with erosion of both shores and leaving about 1 km for the Fitzroy Channel, there is: (a) only 2.5 km of shoreline erosion on each side of King Sound necessary to scour out the area alongside Alligator Creek, (b) 5-6 km of shoreline erosion necessary to scour out the embayment opposite Airport Creek, (c) 12 km of shoreline erosion is necessary opposite Christine Point and (d) 15 km of erosion is necessary opposite Point Torment.

The faster rates of cliff retreat (30-50 m/year up to 90 m/year) if they were consistent and if extrapolated back 5000 years give extraordinary widths (150-250 km) of coastline inferred to have been lost through erosion. This is far too excessive. More conservative rates of 30 cm/yr varying up to

2 m/y yield, over 5000 years of erosion, coastal loss of 1.5 km varying up to 10 km. It is obvious from these rates that the entire King Sound embayment potentially may have formed by large scale erosion and that this erosion is continuing to the present. The extrapolation of slow and moderate rates of sheet and tidal creek erosion leads to the same conclusion. Sheet erosion rates of 1 cm/year over 5000 years leads to a lowering of tidal flats by 50 m. This figure again seems excessive and very conservative rates of tidal flat degradation appear to be well capable of eroding large tracts of tidal flat. Tidal creek channel widening is a more important rate to extrapolate than deepening and lengthening of creeks. Tidal creek widening at a rate of 2-4 m/yr means that a creek 1 km wide (such as Doctors Creek) may form in 250-500 years. If the larger channel between Mary Island and the mainland (Fig. 1) represents a widened creek than it could have formed in 1500-3500 years.

The results are clear that, given present rates of erosion, it is conceivable that King Sound has formed by erosion of more extensive tidal flats.

*Tidal flats in relation to the inferred large-scale erosion.*—The 6 tidal-flat types (Fig. 6) are interpreted to represent stages in the large-scale erosion of tidal flats and hinterland. Depositional flats represent equilibrium or depositional conditions. Unconformity flats represent net erosion situations where Pleistocene formations are exposed. Spit and chenier flats and rocky shores represent situations where erosion has trimmed back the extensive tidal flats until it is incising the hinterland of dunes and bedrock. Channelled flats represent situations where tidal flats are thoroughly incised by tidal creeks.

If this thesis is correct then herein lies an explanation for the variation south to north along King Sound shores. Large-scale erosion would have commenced in northern parts and progressed south such that it largely completed removal of tidal flat material in northern areas (spit and chenier flats) and is in process of removing them in south areas (the extensive flats south of Derby).

*Origin of the Doctors Creek Formation.*—If erosion is the net process today and has continued for the last several thousand years, how did the Doctors Creek Formation originate? The lithology and stratigraphic sequence within the formation show that it formed by a combination of lateral progradation and vertical shoaling (Semeniuk 1981). The similarity of sediment types, sedimentary structures, biogenic structures, fauna and flora in the formation with modern equivalents is direct. However, apart from local sheltered embayment accumulations and shoal areas the bulk of the Doctors Creek Formation is largely eroding.

This anomaly may be explained by viewing the modern tidal flat in a regional context of sedimentary budget. The Fitzroy River, the ultimate source of sediments for King Sound flows for only 3-4 months of the year (Public Works Department 1976). During this time flow rates are not sufficient to mobilise sediments for the full 3 months. River flow is intermittent although instantaneous flow may reach 5000 m<sup>3</sup>/sec. Therefore it appears that the estuarine and tidal environment of King Sound receives sediment for less than 3 months from the river but



undergoes semidiurnal tidal erosion for the remainder of the year. Clearly, today the sediment input is insufficient to counter erosion.

For the Doctors Creek Formation to accumulate there needs to be a sufficient sediment supply. A larger and more continuous river input would provide this so that sedimentation can overwhelm erosion. However this suggests a more humid climate with a longer and more intense wet season. The implication of this conclusion is clear. The stratigraphy/erosion/sedimentation history points to a climatic change from humid to semi-arid during the Holocene. As the climate became more arid, less rainfall resulted in less river (and sediment) input and the balance between sedimentation/erosion was tipped toward erosion which is the dominant process today. Erosion since then has been stripping and redistributing sediments deposited earlier in the Holocene and sediments of pre-existing Pleistocene formations.

*Ultimate sink for eroded materials.*—The bulk of the tidal-flat sections consists of mud (upper Doctors Creek Formation, the entire Christine Point Clay and major portions of the Airport Creek Formation). Erosion of mud results in the turbid waters of King Sound. These turbid waters extend out of King Sound and deposition of mud probably takes place in deep water offshore. Thus there would be a net removal of mud from the King Sound embayment. This would account for the loss of most of the sedimentary section.

Sand however is not so easily mobilised. Much of it forms the lower stratigraphic unit of the Doctors Creek Formation and as erosion proceeds it is left as a residual sheet that is being dispersed continually across King Sound. Erosion of King Sound shores taken to completion thus would result in spit and chenier flats and rocky shores bordering the hinterland and the interior of King Sound would be underlain by a vast residual sheet of sand and lithoclast gravel.

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## A layered ultramafic intrusion in Archaean granulites near Lake Kondinin, Western Australia

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### Abstract

An ultramafic body is enclosed in felsic and mafic granulites and is composed of lherzolite and harzburgite units. The lherzolite is considered in detail; it consists of 11 cycles, each ranging from olivine-rich to olivine-poor rocks. In one cycle, the olivine-pyroxene rocks are followed successively by hornblende-plagioclase and clinopyroxene-plagioclase rocks. There is considerable Fe-enrichment in the hornblende-rich zone. The lherzolite is a layered body formed by repetitive intrusion, crystal settling, and expulsion of tholeiitic magma under conditions of high-grade metamorphism. The crystallization of Fe-rich hornblende suggests that the body could have been a source of calc-alkaline magma.

### Introduction

The effects of high-grade metamorphism on ultramafic rocks have been a matter of some controversy (O'Hara 1961, 1965; Bowes *et al.* 1964). More recently, workers such as Davies (1974) and Windley (1977), in studies of Archaean ultramafics from high-grade metamorphic terrains, have detected relict igneous stratigraphy, layering, and chemistry through a possible metamorphic overprint. Although these complexes appear to have crystallized from hydrous tholeiitic magmas (Windley 1977), precipitation of amphibole and magnetite was largely responsible for the overall calc-alkaline character of many of these intrusions. The present investigation discusses a lherzolite unit in an ultramafic body in the light of these several views.

### General geology

The ultramafic complex, of which the lherzolite is a part, is located 3 km north of the Corrigin-Kondinin road, near Lake Kondinin, 217 km east-south-east of Perth, Western Australia (Fig. 1). It occurs in the Archaean Yilgarn Block, which consists of granitoids, high-grade gneisses and schists, and greenstone belts. Work by Prider (1945), Wilson (1971), Wilson and Green (1971), Davidson (1968, 1971), and Davidson and Mathison (1973, 1974) shows that lenticular, often structurally deformed, mafic and ultramafic bodies occur within hypersthene gneisses in the Dangin-Quairading area, 80 km north-north-west of Lake Kondinin, and the ultramafic complex described here seems to form part of this granulite-facies terrain.

Between Corrigin and Kondinin, the sparsely outcropping felsic gneisses have contorted foliation trending north to north-west with steep easterly and north-easterly dips. The gneisses, which are fine-grained and foliated, contain microcline-perthite,

plagioclase, biotite and, in places, hypersthene and cordierite. Mafic gneisses are known only from rubble in wheat paddocks. They contain intermediate plagioclase, two pyroxenes and, commonly, hornblende.

Surface geology of the ultramafic complex is mostly obscured by a salt lake; a few poor outcrops of silicified and ferruginized serpentinite, along with some amphibole-rich peridotite, can be found on the western side of the lake. A simplified map of part of an aeromagnetic survey carried out by the Electrolytic Zinc Co. of Australasia is presented in Figure 1. The reticulate pattern of positive anomalies represents Proterozoic dolerite dykes. The crescent-shaped anomaly is the ultramafic complex, and indicates that it covers an area of 2.5 km by 1 km. The anomaly was drilled by Electrolytic Zinc at the four locations indicated on Figure 1 and details of drill hole depth and orientation are given in Table 1. This paper results from a detailed petrographic examination of the cores with analyses of selected rocks and their minerals from DDH C3, C4, and C5.

Because of the location of the complex beneath the western side of the lake the holes were drilled down the dip of the regional structure. An attempt

Table 1

Diamond drill hole data

Hole No.	Azimuth (magnetic)	Plunge	Depth (metres)
C2	90°	60°	243.84
C3	82°	45°	265.18
C4	90°	45°	231.65
C5	47°	65°	249.02

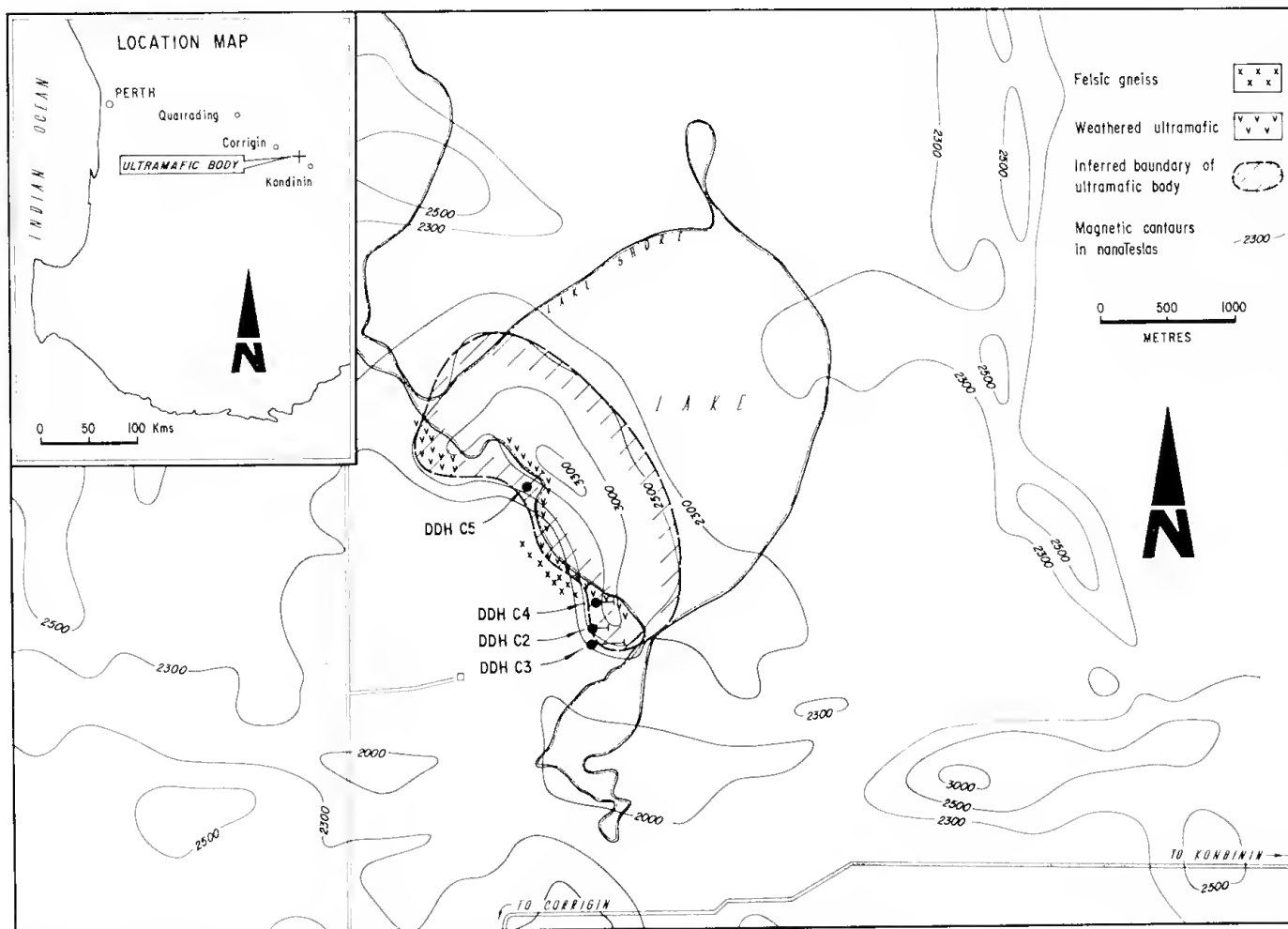


Figure 1—Simplified aeromagnetic anomaly map of the ultramafic near Lake Kondinin. Reproduced by permission of the Electrolytic Zinc Co. of Australasia. Inset: Location map, south Western Australia.

was made to find the angular and azimuthal relation between vague planar structures occasionally seen in the cores and the plunge of the drill holes by the Phillips (1971) method; however, this failed, hence the true thicknesses of the units to be described are not known.

Contact relations between the ultramafic body and the surrounding felsic gneiss—at 63 m in DDH C4 and 36 m in DDH C2—are inconclusive. In C4, weathered gneiss abuts dark ferruginous clay that shows serpentinite-like structures. In C2, the gneiss is in contact with silicified and ferruginized serpentinite. In neither case are there any structures or textures that would suggest a faulted contact, or hornfelsing of the gneiss by the ultramafic.

#### Harzburgite unit

Investigation of the harzburgite unit is still proceeding; the results will be described in a second paper (Morgan in prep.). Work so far shows it to consist of olivine and orthopyroxene, together with chromiferous magnetite and phlogopite. It is strongly serpentinitized, particularly in DDH C3. Texturally, it contains orthopyroxene megacrysts up to 10 cm long enclosed in a matrix of olivine and orthopyroxene with an average grain size of about 2 mm. In DDH C3, the southernmost hole, the megacrysts are euhedral and unstrained. In DDH

C4, and particularly the northernmost hole, DDH C5, the megacrysts are increasingly strained, showing mosaic substructure and marginal to complete polygonization. The matrix minerals in all holes are sub-rounded to polygonal and unstrained. Chemical analysis of rocks and minerals suggest that the harzburgite is unlike “depleted” ophiolite and mantle peridotite. The contact of the harzburgite and lherzolite is obscured by a later thin granitic intrusion in DDH C4, and unrecovered core in DDH C5.

#### Amphibole lherzolite unit

##### Petrography

*Mineral variations.*—Variations in the proportions of minerals in the lherzolite suggest a relict igneous layering, the layers ranging between 0.3 and 8 m along the core. The lherzolite unit consists, for the most part, of olivine, orthopyroxene, and tremolite, with subordinate colourless clinopyroxene, magnetite and, rarely, phlogopite. Olivine and sometimes orthopyroxene are slightly to moderately serpentized. In DDH C4 rocks containing hornblende, pale green clinopyroxene and plagioclase are present between 217.48 m and 219.46 m depth.

Modal variations with depth in the lherzolite unit in DDH C4 are shown in Figure 2. The diagram shows a series of repeated layers. In each of the layers there is a gradation from olivine-rich to



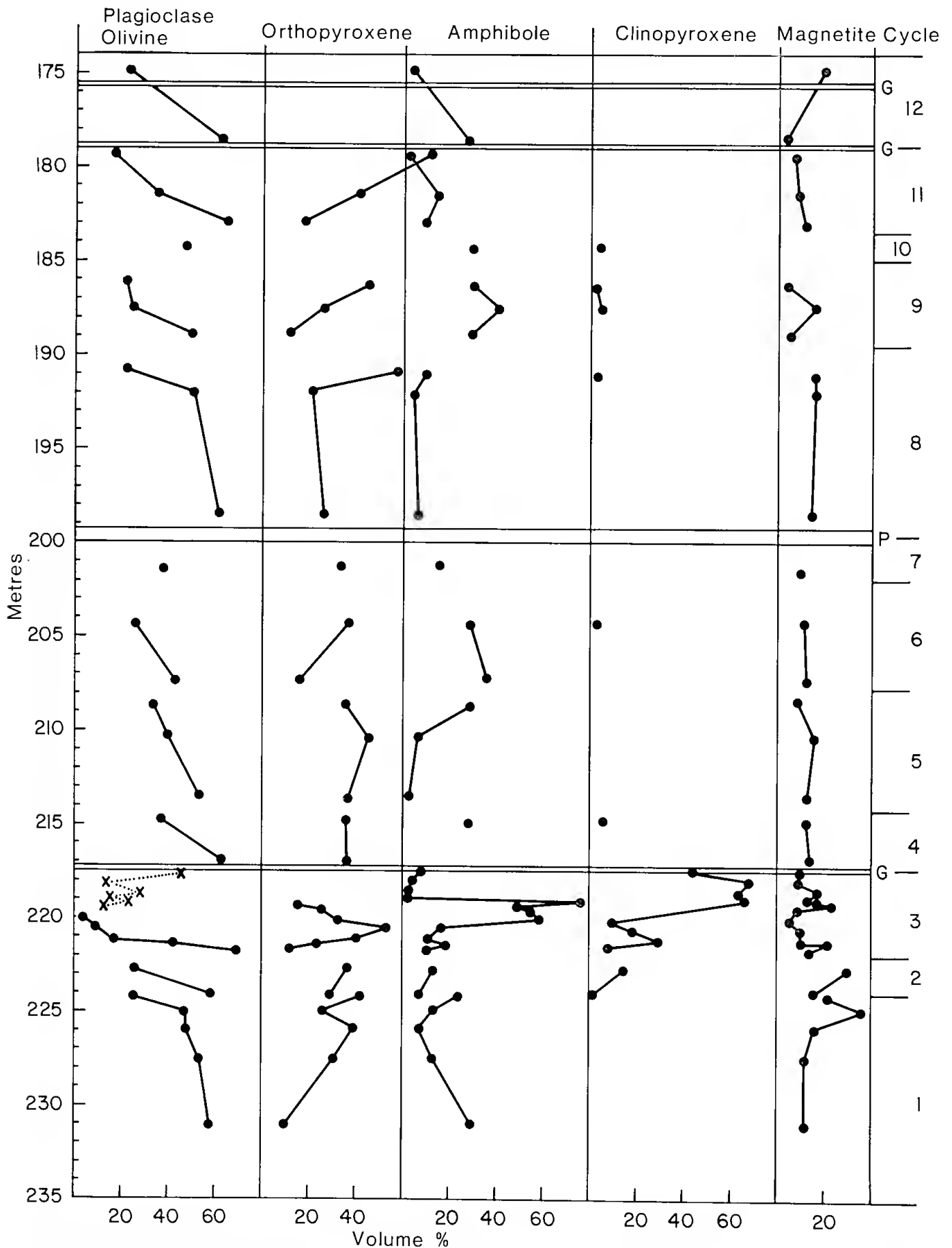


Figure 2.—Modal variations with depth in the lherzolite unit, DDH C4. • = ferromagnesian minerals, X = plagioclase, P = pegmatite, G = acid intrusive.

olivine-poor ultramafic rock. The cycles are not identical; some lead to impoverishment and others to enrichment in lime-bearing minerals. Cycle 3, between 221.74 m and 217.4 m, proceeds from tremolite lherzolite at 221.74 m to tremolite orthopyroxene at 220.68 m. Next, amphibole increases and changes in composition from tremolite to hornblende until at 219.47-219.30 m the rocks are orthopyroxene hornblende; at this level, subordinate amounts of plagioclase are present, and there is a moderate increase in magnetite content. At 219.25 m orthopyroxene is absent. Just above this level, at 219.15 m, hornblende is absent, the amount of magnetite is reduced and rocks with pale green clinopyroxene and plagioclase extend up to 217.48. Immediately above this point is a thin, later, biotite adamellite intrusion, followed by olivine-rich rocks of cycle 4.

That the cycles in the drill core are not the result of repetition by folding or faulting is shown by the fact that the decrease in olivine content trends "up" the core in every cycle and because of the significant differences in mineralogy between the cycles (as shown in Fig. 2). Mineralogical variations suggest that this is relict igneous layering.

**Textures.**—Olivine, orthopyroxene and, where present, clinopyroxene, form polygonal grains ranging from 0.3 to 3 mm diameter. None of the minerals shows straining or kinking. Grain margins are curved or straight. In some rocks olivine has a coarsely amoeboid form. No relict igneous cumulate textures can be seen. Tremolite, in many samples, forms large poikilitic-like plates ranging up to 5 mm across enclosing embayed olivine and orthopyroxene. At first sight this relationship appears to be igneous. However, in other rocks, tremolite is euhedral against olivine and orthopyroxene; some tremolite, indeed, forms fibrous crystals growing into olivine. Commonly, where tremolite encloses clinopyroxene, there is a ragged margin between the two suggesting a reaction relationship with clinopyroxene the primary mineral. The textures as a whole, therefore, are metamorphic. In the hornblende-plagioclase and clinopyroxene-plagioclase rocks of cycle 3 the constituent minerals form polygonal grains with near-straight margins and triple junctions.

**Chemistry.**—Samples were analysed from cycles 1, 2, 3 and 9 in order to examine the mineralogical trends noted from the modal analyses. The chemical analyses and norms are shown in Table 2. Except for some calcic melanocratic gabbro in cycle 3 all rocks are normatively ultramafic.

In the lherzolite Fe/Mg ratios are higher than in alpine-type ultramafics, demonstrating that the body is not a slice of ophiolite but chemically more similar to cumulate rocks in layered intrusions. All the lherzolites are low in  $Al_2O_3$ . For the most part,  $CaO/Al_2O_3$  ratios are greater than 1, hence they do not seem to be komatiitic rocks (e.g. Nesbitt and Sun 1976; Morgan 1977) as is shown in Figure 3. The lherzolites, the hornblende and the plagioclase-clinopyroxene rocks show little correspondence with the Archaean tholeiitic, komatiitic or calc-alkaline series (Fig. 3).

Variation of elements with depth is shown in Figure 4. The ultramafic rocks in each cycle are similar, except for slight differences in the behaviour of Ca, Si and Fe. Rocks above the lherzolite zone of cycle 3 show curious features, particularly in the

interval between 220.17 m and 219.25 m where plagioclase and amphibole are present. Here, Si, Mg, Cr and Ni decrease, and  $Fe^{+2}/(Fe^{+2} + Mg)$ ,  $Fe^{+3}$ , Al and Ti increase. Above 219.25 m, in the clinopyroxene-plagioclase rocks, Si and particularly Ca increase,  $Fe^{+2}/(Fe^{+2} + Mg)$  and  $Fe^{+3}$  decrease, and other elements remain more or less constant.

Although cycle 3 gives the impression of a series of rocks in a cumulative differentiation sequence, the  $Fe^{+2}/(Fe^{+2} + Mg)$  ratios, the enrichment in Ca and Al, and the decrease in Si are unusual. One could conclude that the hornblende-rich zone between 220.07 m and 219.25 m resulted from reaction between the ultramafic rock below and the clinopyroxene-plagioclase rock above during the metamorphism. A similar situation was described by O'Hara (1961) from the Scottish Lewisian, where elemental variation across the contact from dunite peridotite to garnetiferous basic gneiss is similar to that described in this report. At Kondinin, several factors argue against this interpretation. Firstly, a hornblende zone is not seen above the clinopyroxene-plagioclase rock, at the top of which is a one-metre wide adamellite intrusion; above the adamellite is the olivine-rich base of cycle 4 with no sign of a hornblende-rich zone. Secondly, is the general cyclic nature of the lherzolite—all cycles trend "up" the core. Thirdly (following from the second point) is the clinopyroxene-plagioclase rock, with over 20% CaO (Table 2); it is far too calcic to be a metagabbro and must, itself, have been a cumulative rock of clinopyroxene and, perhaps, plagioclase thus continuing the cumulative sequence of cycle 3.

The iron-enriched, silica-poor hornblende zone between 220.07 m and 219.25 m probably represents a cumulative horizon possibly where hornblende crystallized as a cumulative phase. This point will be discussed further.

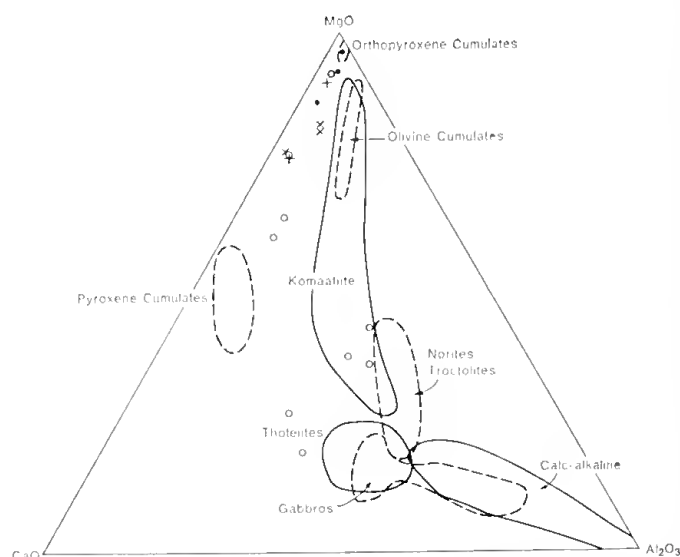


Figure 3.—Plot of MgO-CaO- $Al_2O_3$  in Archaean tholeiite, komatiite, and calc-alkali suites in relation to the Kondinin rocks: modified from Morgan (1977). Data from Anhaeusser (1971), Donaldson (1974), Hallberg (1972), Hallberg *et al.* (1976 a and b), Hallberg & Williams (1972), Jaques (1976), McCall & Leishman (1971), Melver (1975), Naldrett & Mason (1968), Nesbitt (1971), Purvis, *et al.* (1972), Pyke, *et al.* (1973), Viljoen & Viljoen (1971), White, *et al.* (1971), Williams & Hallberg (1973), Wilson, *et al.* (1969).

**Table 2**  
Analyses and norms of the *lherzolites* and associated rocks from *DDH C4*

Depth in metres	Cycle 1										Cycle 2										Cycle 3										Cycle 9							
	225-86	224-94	224-33	224-18	222-81	221-74	221-29	220-68	220-09	220-07	219-46	219-30	219-25	219-51	218-08	217-48	188-67	187-45	186-08	225-86	224-94	224-33	224-18	222-81	221-74	221-29	220-68	220-09	220-07	219-46	219-30	219-25	219-51	218-08	217-48	188-67	187-45	186-08
SiO <sub>2</sub>	41-95	36-39	43-29	40-91	44-31	40-25	49-94	50-84	51-88	51-70	40-77	40-44	40-34	44-39	48-49	44-32	44-22	46-78	48-04	41-95	36-39	43-29	40-91	44-31	40-25	49-94	50-84	51-88	51-70	40-77	40-44	40-34	44-39	48-49	44-32	44-22	46-78	48-04
TiO <sub>2</sub>	0-14	0-18	0-14	0-11	0-17	0-13	0-13	0-14	0-19	0-36	0-83	0-82	0-92	0-77	0-39	0-87	0-17	0-20	0-25	0-14	0-18	0-14	0-11	0-17	0-13	0-13	0-14	0-19	0-36	0-83	0-82	0-92	0-77	0-39	0-17	0-20	0-25	
Al <sub>2</sub> O <sub>3</sub>	8-84	0-92	0-99	0-93	1-31	0-96	0-84	1-24	2-71	2-97	11-89	13-39	12-00	12-17	8-50	14-74	2-06	0-68	1-69	8-84	0-92	0-99	0-93	1-31	0-96	0-84	1-24	2-71	2-97	11-89	13-39	12-00	12-17	8-50	14-74	2-06	0-68	1-69
Fe <sub>2</sub> O <sub>3</sub>	7-82	14-51	9-08	7-77	10-28	8-51	7-28	4-90	2-97	1-30	10-37	10-25	10-81	5-12	2-69	5-21	6-68	6-79	5-88	7-82	14-51	9-08	7-77	10-28	8-51	7-28	4-90	2-97	1-30	10-37	10-25	10-81	5-12	2-69	5-21	6-68	6-79	5-88
Cr <sub>2</sub> O <sub>3</sub>	0-65	0-64	0-55	0-58	0-51	0-61	N.D.	0-56	0-65	0-02	0-02	0-02	0-02	0-02	N.D.	0-01	0-46	0-56	0-45	0-65	0-64	0-55	0-58	0-51	0-61	N.D.	0-56	0-65	0-02	0-02	0-02	0-02	N.D.	0-01	0-46	0-56	0-45	
FeO	9-48	12-67	10-10	10-51	10-05	10-02	7-36	8-62	7-14	7-37	9-79	8-97	7-88	6-77	4-89	4-84	7-02	6-16	7-59	9-48	12-67	10-10	10-51	10-05	10-02	7-36	8-62	7-14	7-37	9-79	8-97	7-88	6-77	4-89	4-84	7-02	6-16	7-59
MnO	0-32	0-29	0-32	0-33	0-29	0-34	0-24	0-26	0-25	0-31	0-44	0-39	0-36	0-33	0-36	0-31	0-26	0-31	0-29	0-32	0-29	0-32	0-33	0-29	0-34	0-24	0-26	0-25	0-31	0-44	0-39	0-36	0-33	0-36	0-31	0-26	0-31	0-29
MgO	33-19	29-73	28-47	32-13	24-56	32-62	25-28	24-97	21-88	22-10	15-02	12-97	13-92	9-12	12-28	8-39	29-71	28-46	28-11	33-19	29-73	28-47	32-13	24-56	32-62	25-28	24-97	21-88	22-10	15-02	12-97	13-92	9-12	12-28	8-39	29-71	28-46	28-11
NiO	0-17	0-19	0-16	0-18	0-15	0-22	N.D.	0-15	0-14	0-06	0-02	0-02	0-01	0-02	N.D.	0-01	0-19	0-16	0-13	0-17	0-19	0-16	0-18	0-15	0-22	N.D.	0-15	0-14	0-06	0-02	0-02	N.D.	0-01	0-19	0-16	0-13		
CaO	0-52	1-55	3-47	2-48	6-54	1-80	7-31	6-65	9-36	11-28	8-10	9-78	11-11	20-36	20-69	20-26	4-87	7-71	4-33	0-52	1-55	3-47	2-48	6-54	1-80	7-31	6-65	9-36	11-28	8-10	9-78	11-11	20-36	20-69	20-26	4-87	7-71	4-33
Na <sub>2</sub> O	0-04	0-05	0-05	0-06	0-12	0-18	0-06	0-12	0-29	0-23	0-67	0-74	0-78	0-19	0-20	0-18	0-26	0-17	0-18	0-04	0-05	0-05	0-06	0-12	0-18	0-06	0-12	0-29	0-23	0-67	0-74	0-78	0-19	0-20	0-26	0-17	0-18	
K <sub>2</sub> O	0-03	0-02	0-03	0-03	0-08	0-21	0-03	0-05	0-10	0-11	0-18	0-23	0-27	0-05	0-14	0-06	0-55	0-04	0-39	0-03	0-02	0-03	0-03	0-08	0-21	0-03	0-05	0-10	0-11	0-18	0-23	0-27	0-05	0-14	0-06	0-55	0-04	0-39
P <sub>2</sub> O <sub>5</sub>	0-003	0-002	0-002	0-003	0-002	0-005	N.D.	0-007	0-003	0-017	0-009	0-088	0-04	0-04	N.D.	0-06	0-01	0-01	0-01	0-003	0-002	0-002	0-003	0-002	0-005	N.D.	0-007	0-003	0-017	0-009	0-088	0-04	0-04	N.D.	0-06	0-01	0-01	0-01
Loss	4-93	2-39	3-03	4-09	1-79	4-39	1-09	1-37	1-90	1-60	1-60	1-71	1-38	0-85	1-18	0-41	3-29	1-42	2-13	4-93	2-39	3-03	4-09	1-79	4-39	1-09	1-37	1-90	1-60	1-60	1-71	1-38	0-85	1-18	0-41	3-29	1-42	2-13
Total	100-08	99-53	99-68	100-11	100-16	100-24	99-56	99-88	99-47	99-43	99-87	99-82	99-84	100-20	99-81	99-81	99-74	99-46	99-47	100-08	99-53	99-68	100-11	100-16	100-24	99-56	99-88	99-47	99-43	99-87	99-82	99-84	100-20	99-81	99-81	99-74	99-46	99-47
Ba	N.D.	N.D.	N.D.	N.D.	N.D.	100	N.D.	100	100	240	220	100	100	100	N.D.	100	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	100	N.D.	100	100	100	100	100	N.D.	100	N.D.	N.D.	N.D.	N.D.	
Co	276	352	241	280	222	280	N.D.	166	106	98	212	157	231	48	N.D.	108	218	130	196	276	352	241	280	222	280	N.D.	166	106	98	212	157	231	48	N.D.	108	218	130	196
Cr	4-460	4-386	3-742	3-962	3-492	4-156	N.D.	3-850	4-445	1-38	1-36	1-43	1-00	1-66	N.D.	60	3-135	3-800	3-084	4-460	4-386	3-742	3-962	3-492	4-156	N.D.	3-850	4-445	1-38	1-36	1-43	1-00	1-66	N.D.	60	3-135	3-800	3-084
Ni	1-330	1-500	1-280	1-400	1-180	1-700	N.D.	1-180	1-130	4-58	1-38	1-80	80	1-20	N.D.	80	1-460	1-255	1-000	1-330	1-500	1-280	1-400	1-180	1-700	N.D.	1-180	1-130	4-58	1-38	1-80	80	1-20	N.D.	80	1-460	1-255	1-000
V	41	106	67	49	102	47	N.D.	57	71	94	261	246	N.D.	234	N.D.	80	49	N.D.	58	41	106	67	49	102	47	N.D.	57	71	94	261	246	N.D.	234	N.D.	80	49	N.D.	58
Zn	45	80	80	135	105	80	N.D.	135	95	70	110	85	84	40	N.D.	30	110	85	70	45	80	80	135	105	80	N.D.	135	95	70	110	85	84	40	N.D.	30	110	85	70
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Total	100-06	99-53	99-69	100-12	100-17	100-24	99-54	99-91	99-45	99-41	99-78	99-80	99-86	100-11	99-81	99-97	99-72	99-46	99-45	100-06	99-53	99-69	100-12	100-17	100-24	99-54	99-91	99-45	99-41	99-78	99-80	99-86	100-11	99-81	99-97	99-72	99-46	99-45

All except FeO determined by XRF.  
FeO determined by titration, with subsequent adjustment of Fe<sub>2</sub>O<sub>3</sub>.  
Analysts: Major elements, Cr, V, Ni: General Superintendent, Perth, W.A.  
Ba, Co, Zn: W. R. Morgan, Department of Geology, King's College, London.



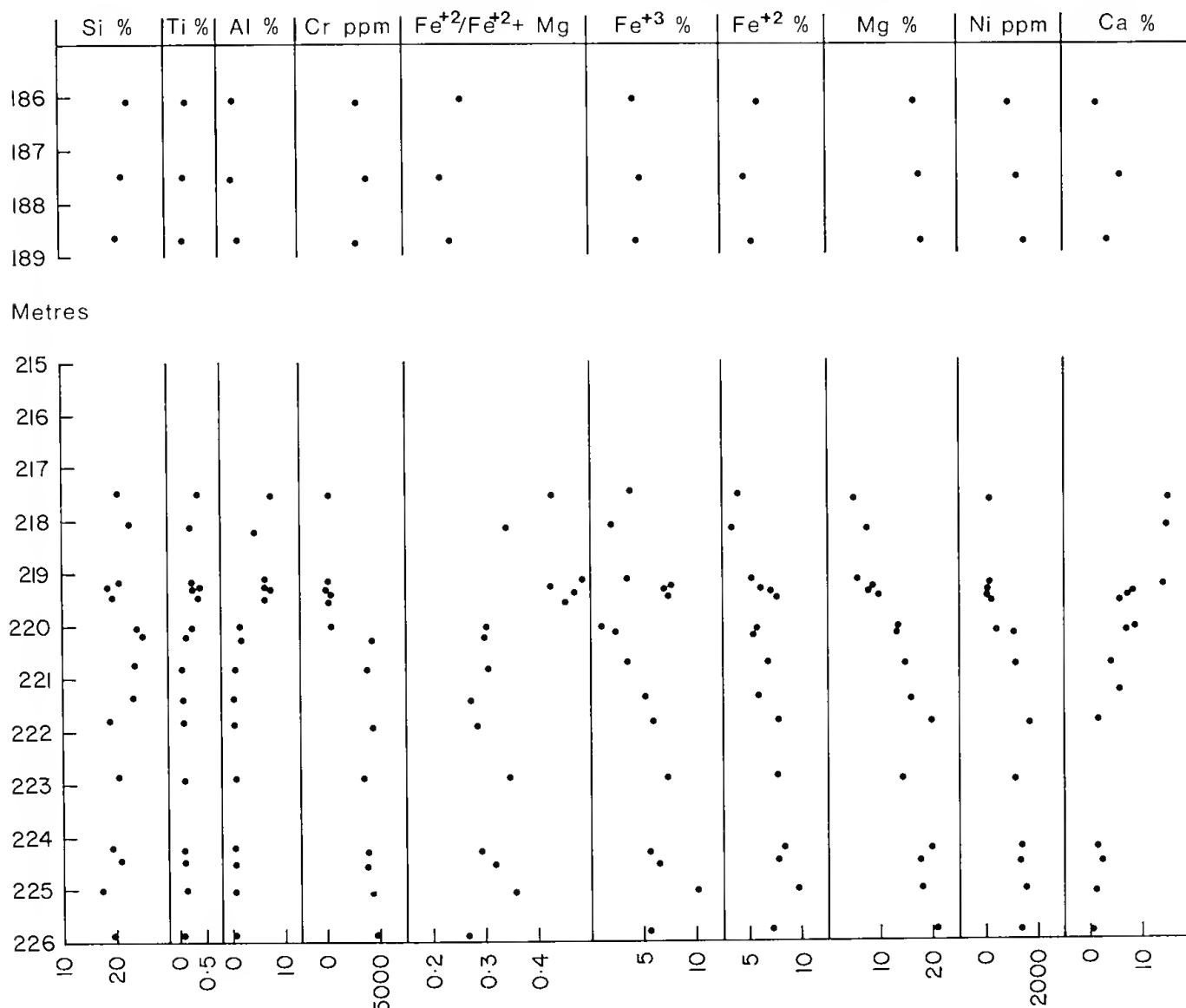


Figure 4.—Variation of elements with depth, DDH C4.

The recast analyses are plotted on the ACF diagram (Fig. 5). They seem to best fit amphibolite granulite-to-transitional facies. The presence in the ultramafic rock of tremolite in preference to clinopyroxene (which tends to occur as relics) and of the assemblage hornblende-plagioclase (though with minor orthopyroxene) supports this view. The presence, in the ultramafic rocks, of hypersthene rather than anthophyllite supports a transition to the granulite facies. However, outcropping on the lake shore are xenolithic inclusions enclosed in ultramafic rock composed of plagioclase, hedenbergite and andradite. The presence of andradite would suggest that the xenoliths, and therefore the ultramafic rock, equilibrated under amphibolite facies conditions (Winkler 1967).

**Mineral Chemistry.**—Electron microprobe analyses of olivine, orthopyroxene, clinopyroxene, amphibole, magnetite and plagioclase are presented in Tables 3 to 8. All analyses were carried out by the author on the Western Australian Institute of Technology Siemens Etec Microprobe Analyser, using an

accelerating voltage of 20 kV, specimen current of  $0.25 \times 10^{-7}$  amps and a 1-2  $\mu\text{m}$  beam diameter. X-ray intensities were converted to oxide percentages using the Magic IV programme.

The Mg/(Mg + Fe) ratios of *olivine* (Table 3) range between 0.845 and 0.889; these values are lower than those of olivine from "depleted" alpine peridotite and peridotite nodules and close to those of cumulate rock in layered intrusion (Green 1964; Frost 1975; Boyd *et al.* 1976). The Fe/Mg ratios vary from cycle to cycle, being lowest in cycle 1 (0.125 - 0.143) and highest in cycle 2 (0.169 - 0.183). Fe-enrichment increases "up" the core in cycles 1 and 2, in agreement with the direction of modal olivine depletion.

The distribution of Mg and Fe between olivine and co-existing orthopyroxene is somewhat variable (Table 9). In cycle 1, the olivine is more Mg-rich than orthopyroxene, with values of  $K_D$ ,  $[=(\text{Fe}/\text{Mg}_{\text{opx}})/(\text{Fe}/\text{Mg}_{\text{ol}})]$  of 1.1 to 1.2. In other cycles, these values are lower, ranging from between 0.9 and 1.0. However, the  $K_D$  values are close to those of Frost

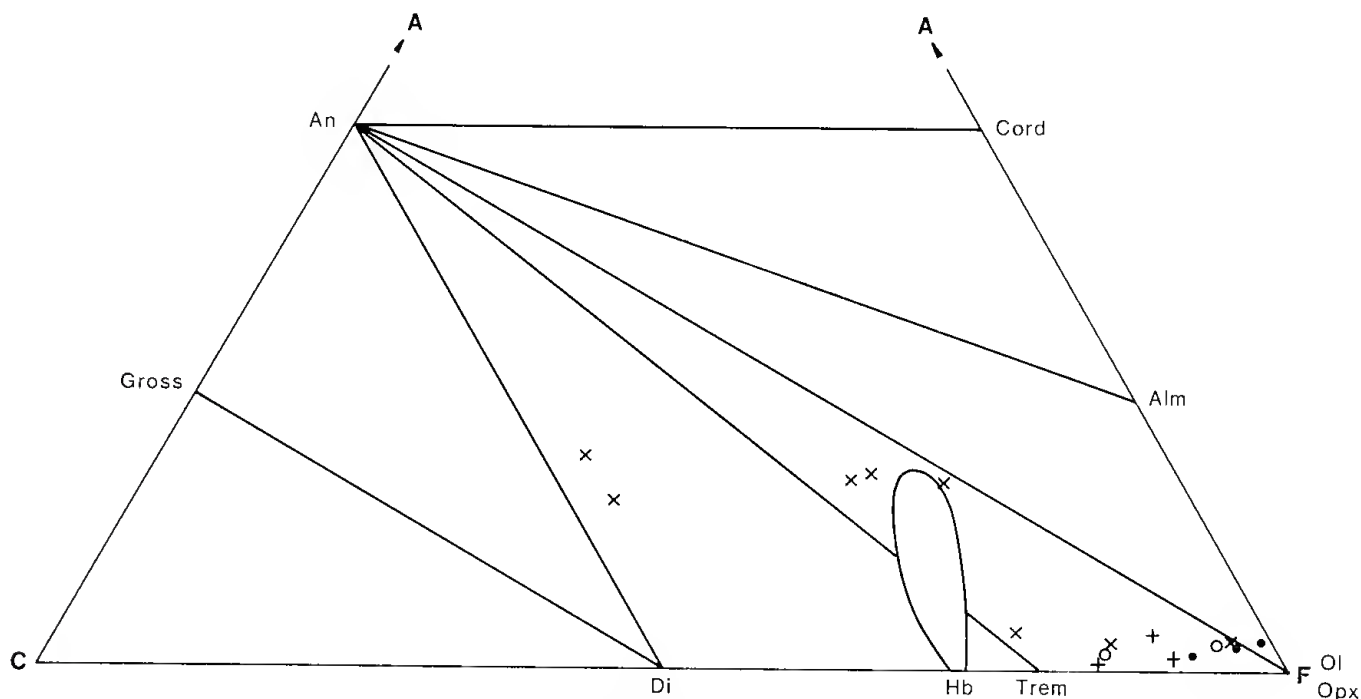


Figure 5.—Plot of Kondinin rocks on A-C-F diagram. Symbols: • cycle 1, o cycle 2, x cycle 3, + cycle 9.

Table 3

Electron microprobe analyses and unit cell contents of olivine in samples selected from DDH C4

Depth in metres	Cycle 1			Cycle 2		Cycle 3	Cycle 9		
	226.86	224.94	224.33	224.18	228.81	221.74	188.67	187.45	186.08
SiO <sub>2</sub> ....	40.22	40.28	40.32	39.35	39.80	40.50	41.51	39.68	40.32
TiO <sub>2</sub> ....	0.01	N.D.	0.01	0.03	0.01	N.D.	0.03	0.01	0.02
Al <sub>2</sub> O <sub>3</sub> ....	0.60	0.05	0.58	0.26	0.12	0.04	0.11	N.D.	0.05
Cr <sub>2</sub> O <sub>3</sub> ....	0.02	N.D.	0.03	0.04	0.04	0.04	0.01	0.01	0.02
*FeO ....	10.78	11.44	11.90	13.71	14.71	13.35	12.02	12.14	11.76
MnO ....	0.45	0.44	0.42	0.49	0.53	0.47	0.41	0.45	0.43
NiO ....	0.28	0.30	0.31	0.31	0.33	0.27	0.42	0.44	0.41
MgO ....	48.38	48.44	46.88	45.70	45.12	45.22	45.67	46.54	47.37
CaO ....	0.03	0.02	0.01	0.03	0.02	0.11	0.01	N.D.	0.02
Na <sub>2</sub> O ....	0.15	N.D.	N.D.	N.D.	0.05	N.D.	N.D.	N.D.	N.D.
K <sub>2</sub> O ....	N.D.	0.01	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Total ....	100.92	100.98	100.46	99.92	100.73	100.00	100.19	99.27	100.40

Number of ions on the basis of 4 oxygens

Si ....	.984	.989	.955	.987	.994	1.100	1.025	.994	.996
Al ....	.017	.002	.017	.008	.004	...	.003	...	.002
Ti ....	Tr.	...	Tr.	.001	Tr.	.001	.001	Tr.	.002
Fe ....	.221	.235	.246	.288	.307	.277	.248	.255	.243
Cr ....	Tr.	...	.001	.001	.001	.001	Tr.	Tr.	Tr.
Mn ....	.009	.009	.009	.010	.011	.010	.009	.010	.009
Ni ....	.006	.006	.006	.006	.007	.005	.008	.009	.008
Mg ....	1.765	1.771	1.724	1.708	1.679	1.681	1.680	1.738	1.744
Ca ....	.001	.001	Tr.	.001	.001	.003	Tr.	...	.001
Na ....	.007	...	...	...	.002	...	...	...	...
K ....	...	Tr.	...	...	...	...	...	...	...
Mg ....	88.9	88.3	87.5	85.6	84.6	85.9	87.1	87.2	87.8
Fe ....	11.1	11.7	12.5	14.4	15.5	14.1	12.9	12.8	12.2
Mg/(Mg + Fe)	.889	.883	.875	.856	.845	.858	.871	.872	.878
Fe/(Fe + Mg)	.111	.117	.125	.144	.155	.141	.129	.128	.122
Fe/Mg ....	.125	.133	.143	.169	.183	.165	.148	.147	.139

\*All iron as FeO.

Analyst: W. R. Morgan, W.A.I.T.

(1975), Challis (1965), Green (1964), and other workers. Of the minor elements, Ni is, as expected, concentrated in olivine. Ti, Al, Cr and alkalis are very low.

Analyses of *orthopyroxene* and *clinopyroxene* are shown in Tables 4 and 5, respectively. Both pyroxenes contain only minor quantities of Cr, Ti, Ni and alkalis. Ti rises to around 0.5% in the more iron-rich clinopyroxene of Cycle 3. Ni reaches 0.22% in the orthopyroxene at 220.68 m. This is presumably because the rock contains as much as 1180 ppm of Ni (Table 2) but no olivine present to accommodate it. Ni is more evenly distributed between the pyroxenes of the olivine-free rock at 220.09 m.

The lherzolite, and the pyroxenes it contains, are all poor in Al<sub>2</sub>O<sub>3</sub>. However, Al<sub>2</sub>O<sub>3</sub> increases in the higher rocks of cycle 3 reaching 4.33% in the orthopyroxene at 219.3 m, and 3.77% in the clinopyroxene at 217.48 m.

The clinopyroxene of cycle 3, and the orthopyroxene of cycles 1, 2 and 3 show increasing Fe/Mg ratios "up" the core. However, Fe/Mg in orthopyroxene does not vary significantly from cycle to cycle, as in the olivines.

The pyroxenes, particularly the four pairs of co-existing pyroxenes, are rich in Mg with molecular values ranging between 0.911 - 1.042 (clinopyroxene) and 1.623 - 1.730 (orthopyroxene). Hence a direct comparison of these pairs with those of Quairading, Western Australia (Davidson 1968) and Broken Hill, New South Wales (Binns 1962) cannot be made as can be seen from Figure 6. On this diagram, the "higher grade" and "lower grade" granulite facies curves of the Broken Hill and Quairading pyroxenes show clearly their converging increase in  $K_D$  [ $=(\text{Fe}/\text{Mg opx})/(\text{Fe}/\text{Mg cpx})$ ] with decreasing total iron content (the  $K_D$  values were recalculated from Binns' and Davidson's work using total iron, to facilitate comparison with the Kondinin pyroxenes). The Kondinin pyroxenes plot just on the "higher grade" side of the curves close to their origin. If there is any significance in this, bearing in mind the closeness of the curves and the limits of analytical accuracy, it may represent the imprint of an original (igneous) high temperature equilibrium state retained in spite of later metamorphism. Pyroxene, amphibole and olivine, are plotted on the pyroxene quadrilateral of Figure 7. Clinopyroxene is irregularly distributed, plotting over the range of the "higher" and "lower" grade pyroxenes of Broken

Table 4

Electron microprobe analyses and unit cell contents of orthopyroxene in samples selected from DDH C4

Depth in metres	Cycle 1			Cycle 2		Cycle 3					Cycle 9		
	225.86	224.94	224.33	224.18	222.81	221.74	220.68	220.09	219.46	21.930	188.67	187.45	186.08
SiO <sub>2</sub> ....	57.09	57.23	58.32	57.03	57.32	57.10	56.49	55.40	54.00	53.39	57.22	57.35	57.39
TiO <sub>2</sub> ....	0.01	0.05	0.04	0.05	0.05	0.08	0.02	0.06	0.11	0.11	0.07	0.04	0.07
Al <sub>2</sub> O <sub>3</sub> ....	0.51	0.97	0.28	0.69	0.69	0.53	0.68	1.23	3.28	4.32	0.48	0.58	0.19
Cr <sub>2</sub> O <sub>3</sub> ....	0.08	0.05	0.04	0.03	0.03	0.11	0.10	0.17	0.13	0.03	0.11	0.12	0.04
*FeO ....	8.52	8.85	9.20	9.26	9.62	8.96	11.11	11.51	13.59	13.52	8.32	8.02	8.47
MnO ....	0.42	0.44	0.53	0.50	0.52	0.50	0.38	0.50	0.85	0.97	0.51	0.60	0.46
NiO ....	0.07	0.12	0.06	0.07	0.06	0.08	0.22	0.11	0.04	0.05	0.11	0.11	0.14
MgO ....	34.01	32.18	30.45	32.53	31.94	32.33	31.09	31.04	28.41	28.28	32.43	33.36	33.55
CaO ....	0.20	0.71	0.56	0.66	0.64	0.68	0.73	0.61	0.44	0.19	0.61	0.63	0.49
Na <sub>2</sub> O ....	N.D.	N.D.	0.07	0.04	N.D.	N.D.	0.11	N.D.	0.04	0.09	0.06	0.05	N.D.
K <sub>2</sub> O ....	N.D.	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	N.D.	0.01	N.D.	N.D.	0.03	0.02
Total ....	100.91	100.60	99.55	100.86	100.88	100.27	100.93	100.63	100.90	100.95	99.92	100.89	100.82

Number of ions on the basis of 6 oxygens

Si ....	1.973	1.986	2.041	1.980	1.990	1.989	1.978	1.952	1.916	1.893	1.996	1.981	1.986
Al <sup>iv</sup> ....	.021	.014	...	.020	.010	.011	.022	.048	.084	.107	.004	.019	.008
Al <sup>vi</sup> ....	...	.026	.012	.008	.018	.011	.006	.003	.053	.074	.016	.005	...
Ti ....	.0003	.001	.001	.001	.001	.002	.001	.002	.003	.003	.002	.001	.002
Fe ....	.246	.257	.269	.269	.279	.261	.325	.339	.403	.401	.243	.232	.245
Cr ....	.002	.001	.001	.001	.001	.003	.003	.005	.004	.001	.003	.003	.001
Mn ....	.012	.013	.016	.015	.015	.015	.011	.015	.026	.029	.015	.018	.014
Ni ....	.002	.003	.002	.002	.002	.002	.006	.003	.001	.001	.003	.003	.004
Mg ....	1.752	1.664	1.587	1.683	1.653	1.678	1.623	1.630	1.502	1.494	1.686	1.717	1.730
Ca ....	.008	.027	.021	.025	.024	.025	.027	.023	.017	.007	.023	.023	.018
Na ....	...	...	.005	.003	...	...	.008	...	.003	.006	.004	.003	...
K ....	...	...	...	...	Tr.	...	...	...	Tr.	...	...	.001	.001
Mg ....	87.3	85.4	84.6	85.1	84.5	85.4	82.2	81.8	78.2	78.6	86.4	87.1	86.8
Fe ....	12.3	13.2	14.3	13.6	14.3	13.3	16.5	17.0	21.0	21.1	12.5	11.8	12.3
Ca ....	0.4	1.4	1.1	1.3	1.2	1.3	1.4	1.2	0.9	0.3	1.1	1.1	0.9
Mg/(Mg + Fe)	.887	.866	.855	.862	.856	.865	.833	.841	.788	.788	.874	.881	.876
Fe/(Fe + Mg)	.123	.134	.145	.138	.144	.135	.167	.172	.211	.212	.126	.119	.124
Fe/Mg	.140	.155	.170	.160	.169	.156	.200	.208	.268	.268	.144	.135	.142

\*All iron as FeO. Analyst: W. R. Morgan, W.A.I.T.



**Table 5**

*Electron microprobe analyses and unit cell contents of clinopyroxene in samples selected from DDH C4*

Depth in metres	Cycle 2		Cycle 3			Cycle 9
	222.81	220.68	220.09	218.08	217.48	186.08
SiO <sub>2</sub> ....	53.41	53.64	53.08	50.82	50.00	53.26
TiO <sub>2</sub> ....	0.08	0.11	0.49	0.51	0.31	0.15
Al <sub>2</sub> O <sub>3</sub> ....	1.02	1.17	1.04	3.52	3.77	0.97
Cr <sub>2</sub> O <sub>3</sub> ....	0.07	0.17	0.16	0.02	0.04	0.19
FeO* ....	3.22	3.94	4.28	7.10	7.18	3.08
MnO ....	0.16	0.19	0.29	0.53	0.62	0.20
NiO ....	0.12	0.11	0.16	N.D.	0.04	0.10
MgO ....	17.45	17.07	16.52	13.39	14.05	19.27
CaO ....	23.52	24.20	23.07	23.58	23.27	23.33
Na <sub>2</sub> O ....	0.10	0.26	N.D.	0.44	0.33	N.D.
K <sub>2</sub> O ....	N.D.	0.01	N.D.	N.D.	N.D.	N.D.
Total ....	99.15	100.87	99.09	99.91	99.61	100.55

Number of ions on the basis of 6 oxygens						
Si	1.965	1.952	1.963	1.898	1.876	1.933
Al <sup>iv</sup>	.035	.048	.037	.102	.124	.041
Al <sup>vi</sup>	.009	.002	.008	.053	.043	....
Ti	.002	.003	.014	.014	.009	.006
Fe	.099	.120	.133	.222	.225	.094
Cr	.002	.005	.005	.001	.001	.006
Mn	.005	.006	.009	.017	.020	.006
Ni	.003	.003	.005	....	.001	.003
Mg	.957	.926	.911	.745	.786	1.042
Ca	.927	.943	.914	.944	.935	.907
Na	.007	.018	....	.032	.024	....
K	....	.0004	....	....	....	....
Mg	48.3	46.4	46.5	38.6	40.0	51.0
Fe	5.0	6.6	6.8	12.4	12.5	4.6
Ca	46.7	47.4	46.7	49.0	47.6	44.4
Mg/(Mg+Fe)	.906	.902	.873	.770	.777	.916
Fe/(Fe+Mg)	.094	.114	.127	.229	.223	.083
Fe/Mg	.103	.130	.146	.298	.286	.090

\* All iron as FeO. Analyst: W. R. Morgan, W.A.I.T.

Hill and Quairading. Again, perhaps this indicates partial re-equilibration from a higher to a lower temperature environment.

*Amphibole* analyses are presented in Table 6. In cycle 3, Fe/Mg ratios increase from the lherzolite to the plagioclase-bearing rocks. In other cycles the ratios are less regular unlike those of the olivine and orthopyroxene. Similarly  $K_D$  [ $=(\text{Fe}/\text{Mg opx})/(\text{Fe}/\text{Mg amph})$ ] and  $K_D$  [ $=(\text{Fe}/\text{Mg ol})/(\text{Fe}/\text{Mg amph})$ ] are less regular than those for olivine and pyroxenes (Table 9), and this may be due to the late crystallization/recrystallization of amphibole in lherzolite. Textural relationships suggest that it partly replaces clinopyroxene and olivine. Hence the irregular Fe/Mg ratio and  $K_D$  values probably indicate disequilibrium.

In cycle 3 however, as hornblende succeeds tremolite the amphibole Fe/Mg ratios rise considerably, more than in the co-existing orthopyroxene and clinopyroxene (Fig. 8; see also Fig. 7). At 219.46 m and 219.3 m the rocks consist largely of hornblende and the rocks themselves have high Fe/Mg ratios.

The amounts of the minor constituents Ti, Cr and Mn, though low, differ from cycle to cycle

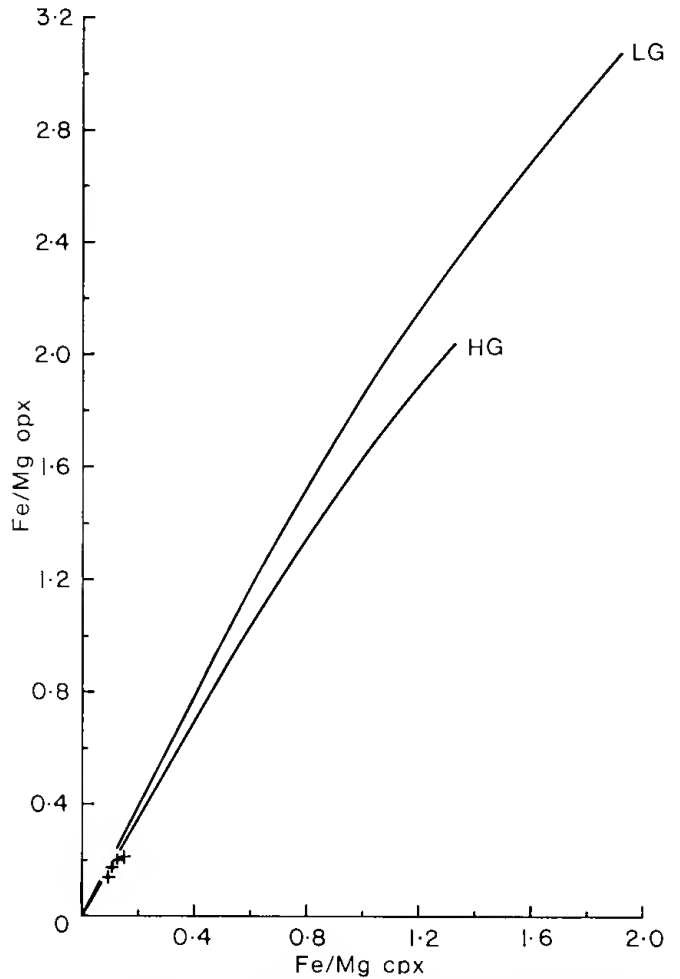


Figure 6.—Graphical solution of  $K_D$  [ $=(\text{Fe}/\text{Mg opx})/(\text{Fe}/\text{Mg cpx})$ ]. Full lines indicate “higher” and “lower” grade pyroxenes of Quairading and Broken Hill. Crosses are the Kondinin rocks.

confirming that the cycles are real and not structurally repeated. The alkali content is higher than in the other femic mineral; K and Na show preference for hornblende over plagioclase (see 219.46 m, 219.3 m, 219.25 m and 217.48 m, Tables 6 and 7).

*Plagioclase* (Table 7) with An percentages ranging from 94 to 99, is extremely calcic with practically no K<sub>2</sub>O. The rocks at 219.15 m, 218.08 m and 217.48 m contain up to 50% plagioclase and the rocks themselves are extremely rich in CaO.

Analyses of *magnetite* are given in Table 8. Total iron was analyzed as Fe<sub>2</sub>O<sub>3</sub>; Fe<sup>+2</sup> and Fe<sup>+3</sup> were calculated assuming ideal stoichiometry. Compositions range from chromiferous magnetite in the lherzolite to nearly pure magnetite in the clinopyroxene-plagioclase rocks. Chrome is concentrated in the magnetite, very little being present in the silicate phases.

In Figure 9, magnetite is plotted against depth in the cores. Cr, Al and Mg vary slightly from cycle to cycle. Within each cycle, Cr and Al both trend inversely to calculated Fe<sup>+3</sup>; a similar relationship can be seen between Fe<sup>+2</sup> and Mg.

**Table 6**  
*Electron microprobe analyses and unit cell contents of amphibole in samples selected from DDH C4*

Depth in metres	Cycle 1					Cycle 2					Cycle 3					Cycle 9		
	225.86	224.94	224.33	224.18	222.81	224.18	222.81	221.74	220.68	220.09	219.46	219.30	219.25	217.48	188.67	189.45	186.08	
SiO <sub>2</sub>	53.92	56.82	54.37	57.54	55.54	57.54	55.54	54.48	53.92	54.32	48.90	47.18	47.12	47.99	54.45	57.35	50.07	
TiO <sub>2</sub>	0.24	0.08	0.20	0.07	0.05	0.07	0.05	0.18	0.29	0.28	0.91	0.88	0.84	0.50	0.32	0.14	0.55	
Al <sub>2</sub> O <sub>3</sub>	4.53	2.29	4.83	0.96	2.50	0.96	2.50	5.00	4.71	4.73	12.79	12.55	10.05	10.24	4.67	0.84	6.73	
Cr <sub>2</sub> O <sub>3</sub>	0.30	0.08	0.24	0.09	0.04	0.09	0.04	0.26	0.35	0.14	0.04	0.04	0.05	0.01	0.13	0.23	0.25	
FeO†	4.79	3.92	4.51	3.76	4.11	3.76	4.11	4.60	5.32	5.56	7.86	8.80	12.49	11.41	4.62	2.81	5.04	
MnO	0.14	0.16	0.15	0.17	0.30	0.17	0.30	0.17	0.15	0.14	0.45	0.41	0.42	0.52	0.19	0.14	0.16	
NiO	0.11	0.04	0.15	0.10	0.06	0.10	0.06	0.12	0.23	0.18	0.09	0.01	0.06	0.08	0.17	0.19	0.09	
MgO	21.38	22.52	21.25	21.84	21.87	21.84	21.87	21.63	20.59	20.26	16.12	16.01	14.74	14.26	19.73	23.35	22.71	
CaO	13.71	14.33	13.53	14.26	14.39	14.26	14.39	13.01	13.95	14.00	11.73	12.88	12.97	14.01	14.42	14.59	13.32	
N <sub>2</sub> O	N.D.	0.22	0.50	0.18	0.33	0.18	0.33	0.65	0.89	0.74	1.43	1.59	1.30	1.09	0.91	0.24	1.34	
K <sub>2</sub> O	0.03	0.04	0.33	0.04	N.D.	0.04	N.D.	0.31	0.28	0.19	0.31	0.39	0.34	0.52	0.05	0.52	0.52	
Total	99.15	100.50	100.06	99.01	99.19	99.01	99.19	100.41	100.68	100.54	100.63	100.79	100.38	100.45	100.13	100.13	100.81	

	Number of ions on the basis of 23 oxygens																						
	7.410	7.669	7.407	7.860	7.616	7.394	7.361	7.414	6.721	6.569	6.709	6.789	7.453	7.746	6.880								
Si	590	331	593	140	384	606	630	586	1279	1431	1291	1211	547	134	1091								
Al <sup>IV</sup>	146	34	184	014	020	195	639	141	795	630	397	499	207										
Al <sup>VI</sup>	025	008	021	030	005	018	119	029	113	920	090	053	033	014	057								
Ti	551	443	515	429	471	522	607	632	904	1039	1487	1369	529	317	580								
Fe	033	008	026	010	005	028	038	015	004	008	008	001	015	024	027								
Cr	017	007	017	020	035	020	017	016	052	049	051	062	022	016	019								
Mn	012	004	016	011	007	013	025	020	010	001	007	009	019	020	010								
Ni	4380	4529	4320	4446	4474	4375	4190	4121	3302	3322	3130	3007	4025	4740	4657								
Mg	2019	2072	1978	2087	2114	1892	2041	2047	1728	1922	1979	2123	2115	2112	1961								
Ca	005	057	133	048	087	171	236	195	382	430	360	299	242	063	357								
Na	005	064	056	007	007	054	049	033	055	069	062	061	091	008	091								
K	63.1	64.3	63.4	63.8	63.4	64.4	61.3	60.6	55.7	52.9	47.5	46.3	60.4	67.1	64.7								
Mg	7.8	6.3	7.6	6.2	6.7	7.7	8.9	9.3	15.2	16.5	22.5	21.1	7.9	3.0	8.1								
Fe	29.1	29.4	29.0	30.0	29.9	27.9	29.8	30.1	29.1	30.6	30.0	32.6	31.7	29.9	27.2								
Ca	0.888	0.911	0.894	0.912	0.905	0.893	0.874	0.867	0.785	0.762	0.678	0.687	0.884	0.937	0.889								
Mg/(Mg + Fe)	0.112	0.089	0.107	0.088	0.095	0.107	0.127	0.133	0.215	0.238	0.322	0.313	0.116	0.063	0.111								
Fe/(Fe + Mg)	0.126	0.098	0.119	0.970	0.105	0.119	0.145	0.153	0.274	0.313	0.475	0.455	0.131	0.067	0.125								

† All iron as FeO Analyst: W. R. Morgan, W.A.I.T.

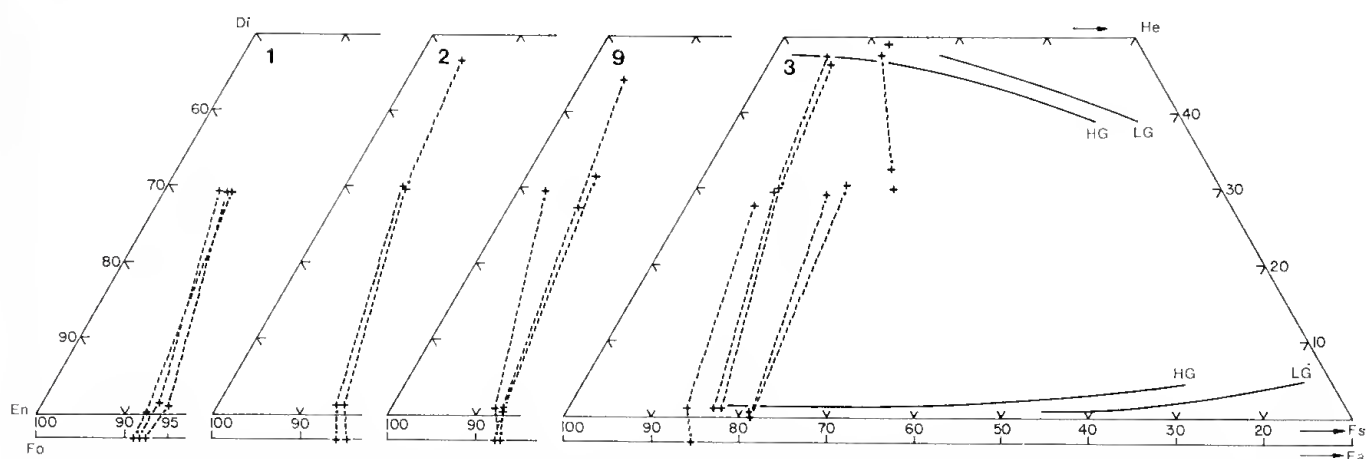


Figure 7.—Composite Ca-Mg-Fe diagram on which the Kondinin pyroxenes, amphiboles, and olivines are plotted. 1, 2, 9, 3 refer to cycles. HG: "higher grade" and LG: "lower grade" pyroxenes of Quairading and Broken Hill.

Table 7

Electron microprobe analyses and unit cell contents of plagioclase in samples selected from DDH CA

Depth in metres	Cycle 3				
	219.46	219.30	219.25	218.08	217.48
SiO <sub>2</sub> ....	43.24	43.17	43.50	43.28	43.09
Al <sub>2</sub> O <sub>3</sub> ....	36.62	35.79	35.98	36.22	36.50
Fe <sub>2</sub> O <sub>3</sub> * ....	0.35	0.46	0.22	0.43	0.41
MgO ....	N.D.	0.10	0.11	0.12	0.07
CaO ....	20.24	19.74	19.81	20.00	20.49
Na <sub>2</sub> O ....	0.42	0.61	0.49	N.D.	0.35
K <sub>2</sub> O ....	0.02	0.02	0.01	0.01	N.D.
Total ....	100.83	99.24	99.66	100.10	100.94

Number of ions on the basis of 32 oxygens

Si ....	7.964	8.029	8.058	8.019	7.944
Al ....	7.955	7.852	7.862	6.967	7.939
Fe ....	.049	.064	.030	.060	.057
Mg ....	.....	.028	.030	.032	.019
Ca ....	3.994	3.934	3.932	3.970	4.172
Na ....	.151	.219	.176	.....	.124
K ....	.004	.005	.002	.002	.....
An ....	96.3	94.6	95.7	99.9	97.0
Ab ....	3.6	5.3	4.3	.....	3.0
Or ....	0.1	0.1	.....	0.1	.....

\*All iron as Fe<sub>2</sub>O<sub>3</sub>. Analyst, W. R. Morgan

### Temperature-pressure estimate

#### Temperature

Temperature estimates, using the method of Wood and Banno (1973) were calculated for the four pyroxene pairs in the lherzolite and its associated rocks. These are listed in Table 10. Compared with the granulite-facies pyroxenes given by Hewins (1975), which include the Quairading pyroxene pairs (Davidson 1968), the data of Jayawardena and Carswell (1976), the estimates are high, and range between 856°C and 1034°C. These data support the evidence of igneous equilibration modified by a metamorphic environment.

#### Pressure

Mineralogically, the Kondinin rocks have the following assemblages:

- Olivine + orthopyroxene + tremolite ± clinopyroxene
- Orthopyroxene + hornblende + plagioclase
- Hornblende + plagioclase + clinopyroxene ± orthopyroxene
- Clinopyroxene + plagioclase ± hornblende

The rocks clearly fall into the plagioclase-peridotite facies. From this, and using the range of temperatures referred to above, together with O'Hara's (1967) pressure-temperature grid, pressure is estimated as less than 6 kb. This is in agreement with an estimate of 3-6 kb made from Herzberg's (1978) clinopyroxene alumina solubility grid of the lherzolite facies, using the data of samples 281.08 m and 217.48 m (Table 5). Obata's (1976) calculations on the solubility of alumina in orthopyroxene suggests pressures of less than 8 kb (from samples 219.47 m and 219.30 m; Table 4).

### Discussion

#### Evidence of igneous emplacement

Petrographically, the lherzolite and its associated plagioclase-bearing rocks show a rhythmic cyclic modal variation with no reversals. The bulk rock chemistry of the lherzolite samples is tholeiitic rather than komatiitic. In Figure 10 Al<sub>2</sub>O<sub>3</sub> is plotted against (FeO + Fe<sub>2</sub>O<sub>3</sub>)/(FeO + Fe<sub>2</sub>O<sub>3</sub> + MgO); Archaean tholeiitic and komatiitic rocks occupy sharply defined fields (Naldrett and Cabri 1976). In this diagram, the Kondinin rocks trend from lherzolite in the tholeiitic field to hornblende and clinopyroxene-plagioclase rocks in the komatiite field, showing an enrichment in Al prior to Fe-enrichment. This is, in fact, due to the amphiboles becoming more aluminous prior to their enrichment in Fe.

The cyclic rhythm from olivine-rich to olivine-poor rocks indicates that the lherzolite was emplaced by repeated pulses of magma with some crystallization and crystal settling after each injection. Because none of the cycles shows a complete differentiation series it follows that magma must also have been expelled from the chamber at the same time as crystallization, in the manner proposed by Mathison (1967) for the Somerset Dam intrusion, Queensland.



**Table 8**  
*Electron microprobe analyses and unit cell contents of magnetite in samples selected from DDH C4*

Depth in metres	Cycle 1			Cycle 2			Cycle 3			Cycle 9						
	225.86	224.94	224.33	224.18	222.81	221.74	220.68	220.09	219.46	219.30	219.25	218.08	217.48	188.67	187.45	186.08
Al <sub>2</sub> O <sub>3</sub>	1.12	0.74	0.36	1.63	1.15	2.05	2.96	2.19	4.52	1.46	1.50	0.14	0.14	1.77	1.56	1.84
Cr <sub>2</sub> O <sub>3</sub>	7.18	3.32	4.23	5.95	3.08	9.17	8.57	10.09	0.14	0.11	0.20	0.38	0.50	6.88	7.28	6.76
Fe <sub>2</sub> O <sub>3</sub>	59.74	64.63	63.34	59.16	62.67	57.99	56.55	53.89	61.95	65.21	66.09	67.05	66.27	58.90	59.03	59.50
FeO*	28.97	28.97	29.31	28.45	28.54	27.39	27.51	29.05	28.08	28.70	29.37	29.13	28.99	28.43	28.45	28.50
MgO	0.78	0.81	0.44	0.81	0.70	2.07	1.91	0.46	1.51	0.59	0.46	0.36	N.D.	1.06	1.10	1.22
Total	97.79	98.47	97.68	95.19	96.14	98.67	97.50	95.68	96.20	96.07	97.62	97.06	95.90	97.04	97.42	97.82

Number of ions on the basis of 32 oxygens	
Al	.405
Cr	1.741
Fe <sub>3</sub>	13.783
Fe <sub>2</sub> **	7.503
Mg	.359

\* FeO and Fe<sup>2+</sup> calculated, assuming ideal stoichiometry. Analyst: W. R. Morgan, W.A.I.T.

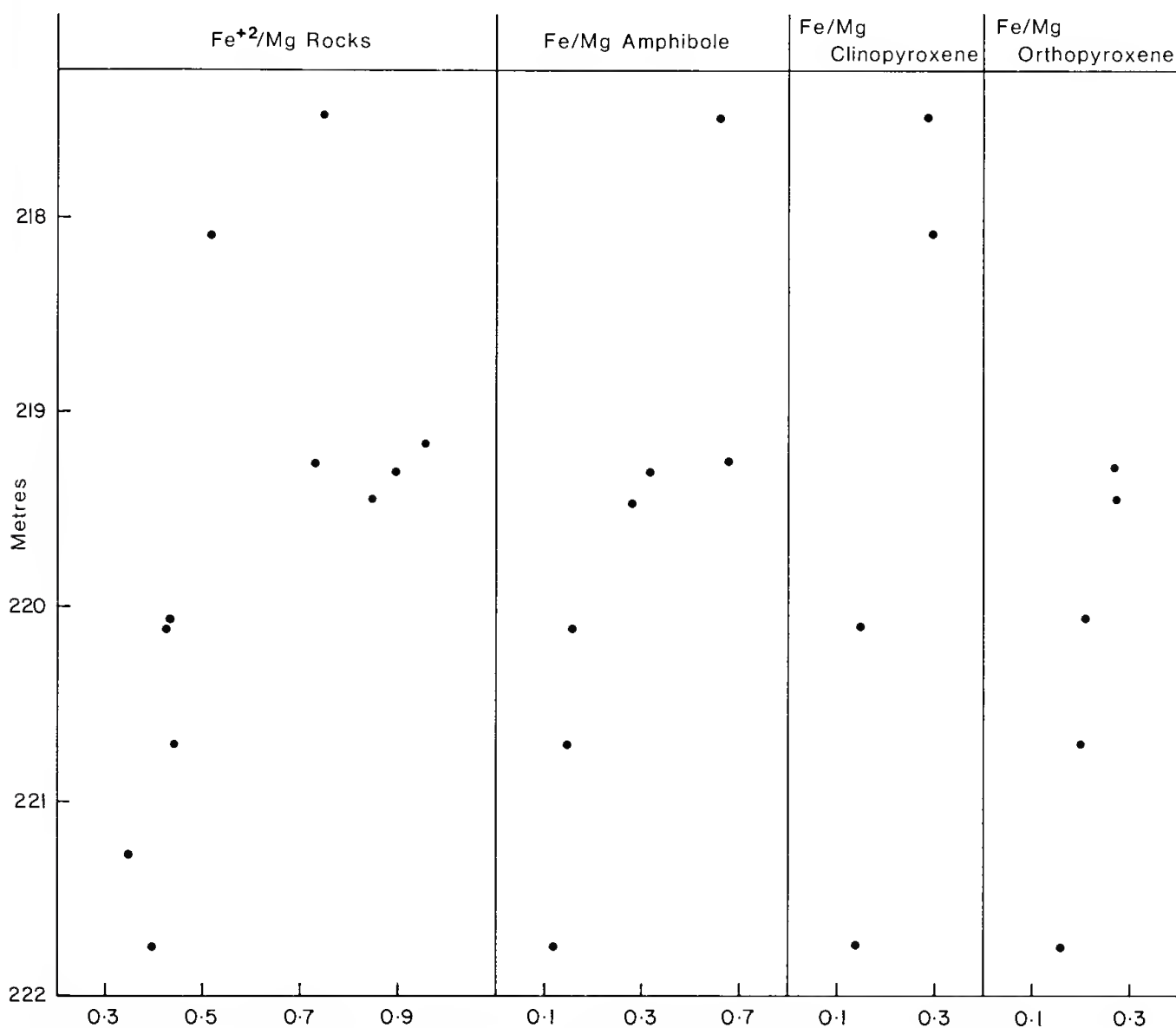


Figure 8.—Cycle 3: The Fe/Mg ratios of rocks, amphiboles, clinopyroxenes, and orthopyroxenes plotted against depth.

Table 9

*Fe-Mg distribution coefficients in samples selected from DDH C4*

	Cycle 1			Cycle 2		Cycle 3					Cycle 3			
Depth in metres	225.86	224.94	224.33	224.18	222.81	221.74	220.68	220.09	219.46	219.30	217.48	188.67	187.45	186.08
$K_D$ $\frac{\text{Fe/Mg opx}}{\text{Fe/Mg amph}}$	1.1	1.6	1.4	1.7	1.6	1.3	1.4	1.4	1.0	0.8	....	1.1	2.7	1.1
$K_D$ $\frac{\text{Fe/Mg opx}}{\text{Fe/Mg ol}}$	1.1	1.2	1.2	1.0	0.9	1.0	....	....	....	....	....	1.0	0.9	1.0
$K_D$ $\frac{\text{Fe/Mg opx}}{\text{Fe/Mg cpx}}$	....	....	....	....	1.6	....	1.5	1.4	....	....	....	....	....	1.6
$K_D$ $\frac{\text{Fe/Mg ol}}{\text{Fe/Mg amph}}$	1.0	1.4	1.2	1.7	1.7	1.4	....	....	....	....	....	1.1	2.2	1.5
$K_D$ $\frac{\text{Fe/Mg opx}}{\text{Fe/Mg amph}}$	....	....	....	....	1.0	....	....	1.0	....	....	0.6	....	....	0.7

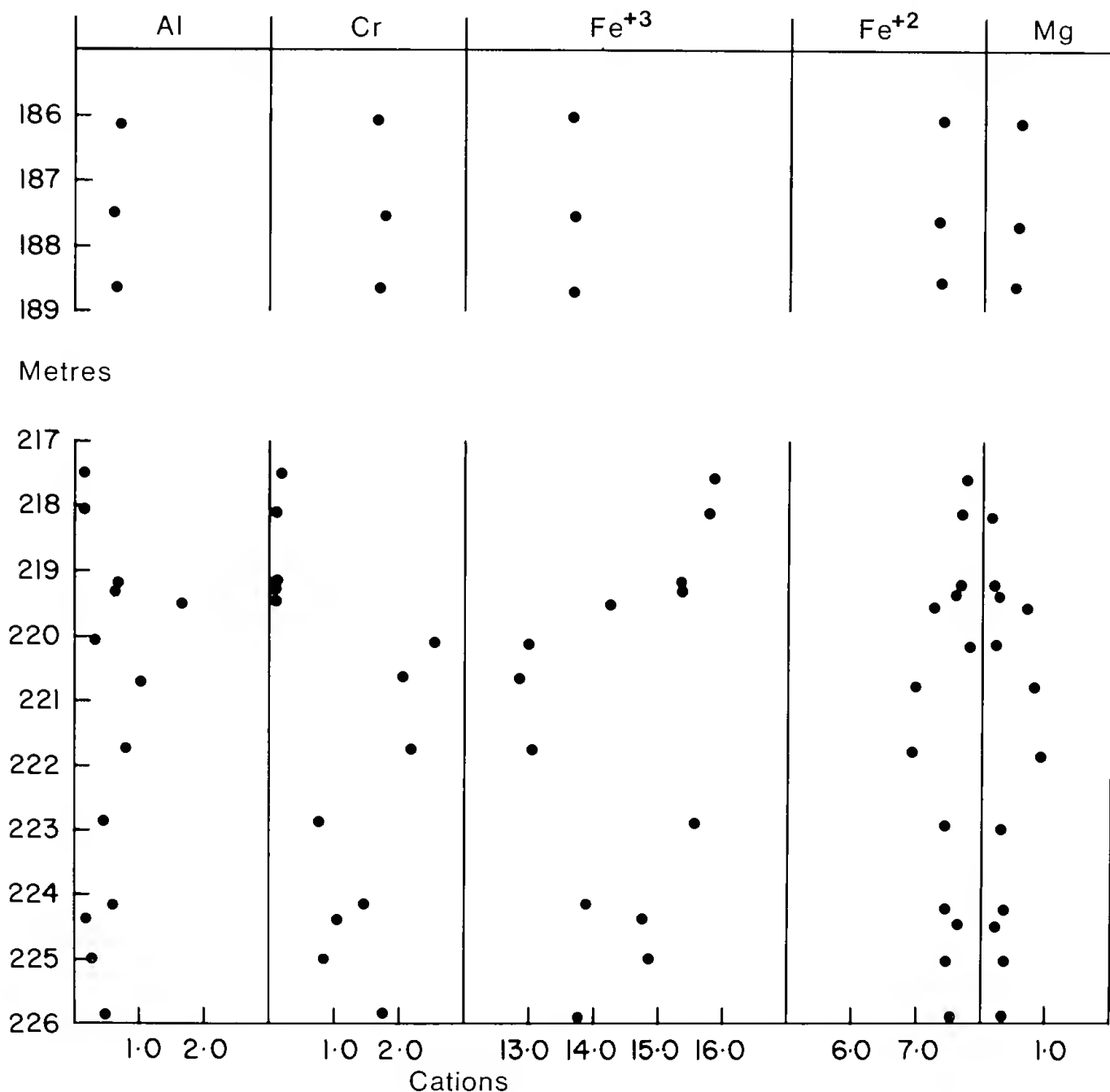


Figure 9.—Compositional variation of magnetite with depth in DDH C4.

Table 10

Temperature estimates (Samples from DDH C4)

Depth in metres	Cycle	Temperature
222·81	2	976°C
220·68	2	856°C
220·09	3	965°C
186·08	9	1034°C

*Evidence of metamorphism*

The time of emplacement of the ultramafic in relation to the stages of tectonism and metamorphism of the surrounding gneisses is hard to assess. The

rocks have crystalloblastic textures and their mineralogy suggests a granulite-amphibolite transition equilibrium perhaps at a slightly lower grade than the mafic gneisses surrounding the body. Figure 1 shows a general lensoid outline of the body, as delineated by the magnetic anomaly; it is elongated parallel to the regional strike as though the body represents a large block tectonically emplaced within the gneisses. These factors would suggest that the ultramafic body, including the lherzolite, was emplaced prior to the tectonism and metamorphism affecting the gneisses.

On the other hand, other features suggest post-tectonic emplacement of the ultramafic. Thus in spite of their crystalloblastic textures the lherzolite and associated rocks show no foliation, tectonite



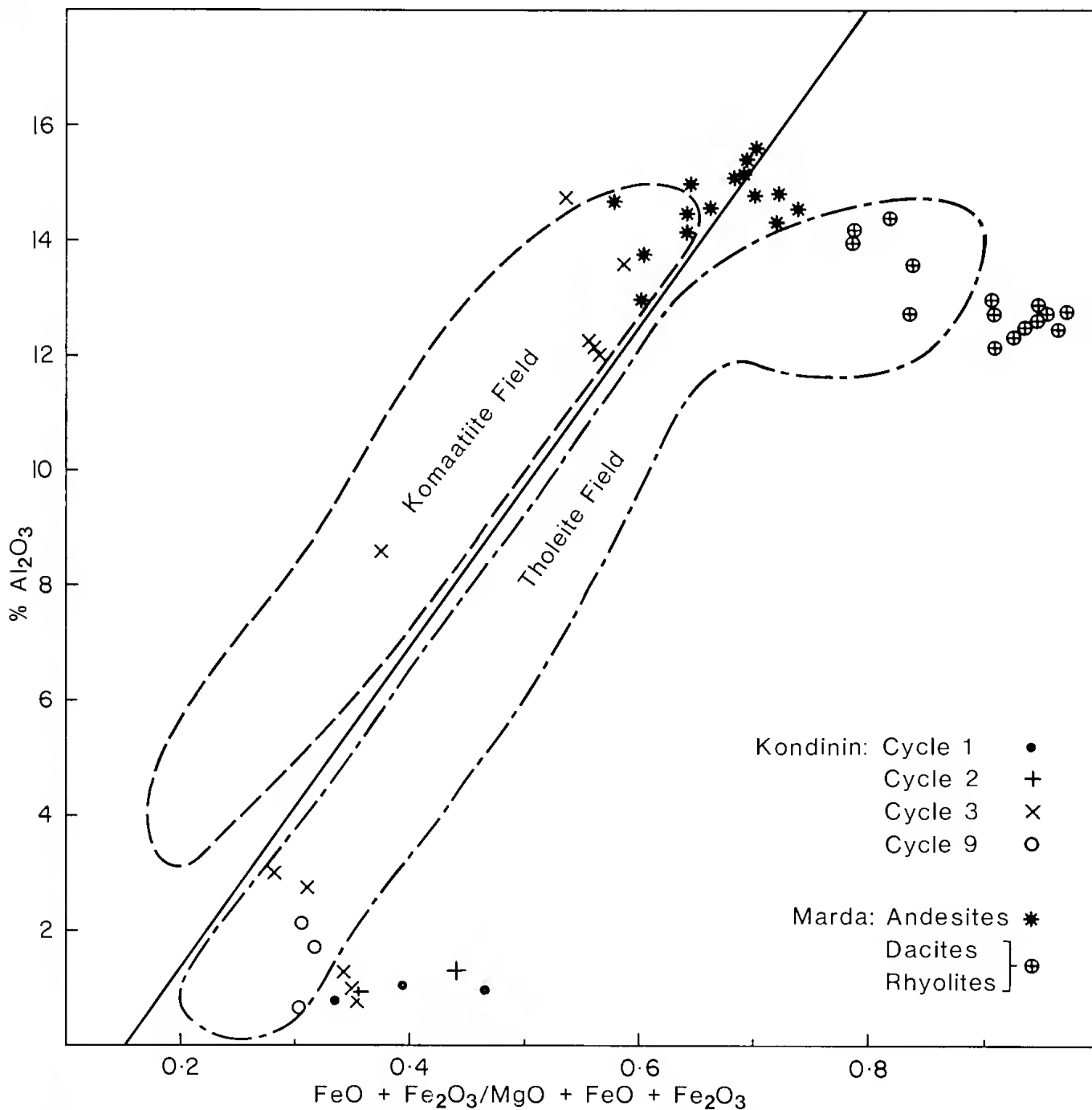


Figure 10.—Plot of Al<sub>2</sub>O<sub>3</sub> against (FeO + Fe<sub>2</sub>O<sub>3</sub>)/(MgO + FeO + Fe<sub>2</sub>O<sub>3</sub>), after Naldrett & Cabri (1976). Dashed lines: komatiite field. Chain dash line: tholeiite field. Kondinin rocks: • cycle 1; + cycle 2; x cycle 3; o cycle 9. Marda Volcanics (after Hallberg, *et al*, 1976 b) \* andesite; ⊕ dacite and rhyolite.

fabric or kinking of grains. In addition the orthopyroxene megacrysts of the harzburgite unit referred to earlier are increasingly deformed in the more northerly drill holes but are not deformed in DDH C3 at the south-west corner of the body. At this location, if the ultramafic body was emplaced as a tectonic block, one would expect more extreme deformation of the megacrysts here than further north. The megacryst is more likely to be a relict primary structure due to emplacement of the harzburgite as an igneous intrusion (Morgan, in prep.).

Electron Microprobe X-ray imagery (Fig. 11) of magnetite in the lherzolite shows no zoning of Fe and Cr. Thus there has not been reaction of the magnetite with surrounding silicate phases, as reported by Bliss and MacLean (1975) in chromites from metamorphosed ultramafics in Canada. Indeed, although the Kondinin rocks are enclosed within granulite facies metamorphics, it is evident from the analyses (Table 8) that the magnetite is not of spinel composition; Mg and Al are extremely low even in the hornblende and plagioclase-bearing rocks

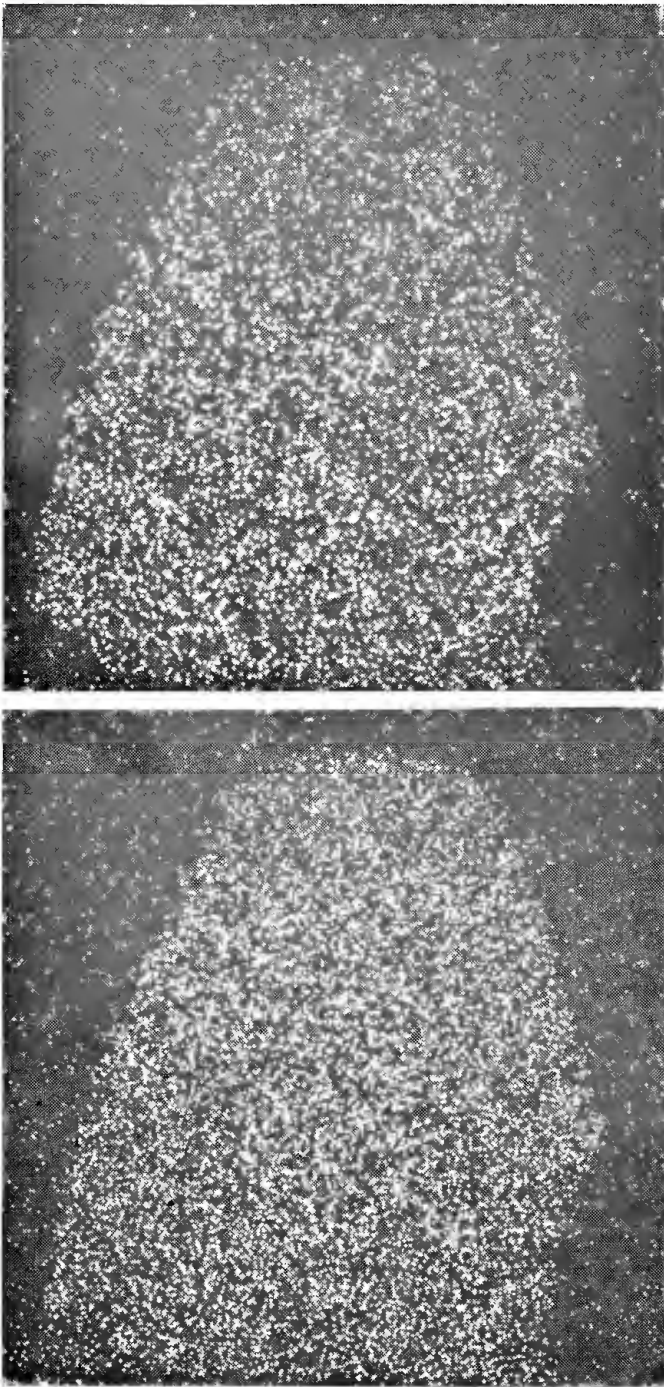


Figure 11.—Electron probe micrographs of a magnetite grain from 225.86 m. (DDH C4), showing lack of zonation in (top) Fe and (bottom) Cr. The grain is approximately 0.5 mm in diameter.

of cycle 3. Evans and Frost (1975) described progressive compositional changes in chrome spinel with increasing metamorphic grade in ultramafic rocks from magnetite to MgAl-spinel. Hence, the lack of zoning and the low Mg and Al support the possibility that the magnetite formed by magmatic crystallization rather than by metamorphic recrystallization.

Thus the evidence suggests that the ultramafic was emplaced during the waning stages of the metamorphism perhaps after the tectonism.

### Tentative petrogenesis

If this postulate is correct the repetitive injection, crystallization and expulsion of magma would have taken place during waning metamorphism. Calciferous amphibole crystallized and recrystallized from co-existing pyroxenes and olivine. In cycle 3, the hornblende and thus the rocks are strongly iron-enriched, possibly because hornblende was crystallizing in an amphibolite-granulite environment.

The two samples at 219.47 m and 219.30 m each contain about 50% hornblende. At 219.25 m there is 75% hornblende (Fig. 3). In the hornblende, and the rocks containing them, the Fe/Mg ratios rise sharply up the hole. If the hornblende results from magmatic crystallization, then it would have controlled the Fe/Mg ratio of the remaining liquid perhaps producing calc-alkaline magma, as suggested by the experimental work of Green and Ringwood (1967, 1968). Perhaps we have preserved here a magma chamber into which tholeiitic magma was being repeatedly intruded and from which differentiated tholeiite-like magma and even calc-alkaline liquids were expelled. With the latter in mind, Archaean calc-alkaline volcanics from the Marda Complex, Western Australia (Hallberg *et al.* 1976) have been plotted on Figure 10. Hallberg *et al.* believe the volcanics to be of Andean type (Miyashiro 1974; Morgan 1974) derived from the base of the Archaean crust. If there is any significance in Figure 10 it is the continuance of a "trend" from the Kondinin hornblende and clinopyroxene plagioclase rocks to the Marda andesites and rhyolites.

The fact that the analysed cycles have slightly different modal and chemical compositions suggests the arrival of batches of magma of slightly differing compositions, each batch cooling and settling crystals prior to expulsion of residual magma. Following from this we may imagine that this body represents just one of a nexus of staging places for such magma, with slight differentiation taking place at each stop.

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Contents

	Page
The association between the mealybug, <i>Pseudococcus macrozamia</i> , ants and the cycad <i>Macrozamia reidleyi</i> in a fire-prone environment. By June M. Dolva and John K. Scott .....	33
Seasonal activity of hexapods in woodland and forest leaf litter in the south-west of Western Australia. By J. D. Majer and L. E. Koch .....	37
Geomorphology and Holocene history of the tidal flats, King Sound, north-western Australia. By V. Semeniuk .....	47
A layered ultramafic intrusion in Archaean granulites near Lake Kondinin, Western Australia. By W. R. Morgan .....	69

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## Floristic ecotone between Quaternary sandridges and Jurassic sedimentary rocks near Mowla Bluff, Great Sandy Desert

by Ralf Buckley

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### Abstract

There is a well-defined floristic ecotone between Quaternary sands and exposed Jurassic sedimentary rocks at the north-western margin of the Great Sandy Desert. Within the dune-fields there is a dune-swale floristic gradient similar to that on central Australian sandridges, though different species are involved. The soil catena is also similar.

### Introduction

There are few detailed quantitative descriptions of Australian arid sandridge vegetation (Wiedemann 1971, Fatchen and Barker 1979, Buckley 1981a, b), and none of the north-western Great Sandy Desert at a scale closer than that of Beard and Webb (1974) and Beard (1979). Vegetation pattern on sandridges at the edge of the Great Sandy Desert was therefore analysed to help fill this gap. In addition, the ecotone between Quaternary sandridges and Jurassic sedimentary rocks was examined as a step in elucidating the control of plant distribution by environmental factors. Since such factors are tightly correlated on the sandridges themselves (Buckley 1981b, 1982), their individual effects on plant distribution can only be separated by experimental manipulation in field or glasshouse, or by using atypical or marginal habitats such as this as "natural experiments".

Approximately 180 km south of Derby (Fig. 1), the dune-fields of the Great Sandy Desert terminate abruptly in steep, gullied and broken slopes and cliffs, 40 m high, in the Jarlemai Siltstone (Casey 1958). The area 8 km southeast of Ardjorie station (123° 43'E, 18°46'S) was studied in August 1979. The site is shown in Figure 2, drawn from the 1967 1:80 000 aerial photograph (Mount Anderson E51-11 CAF 4040, run 7, photo 1385) and ground observations. Beard and Webb (1974, p. 45) on shallow sandridges area: *Eucalyptus brevifolia* - *Triodia intermedia* tree steppe on the scarps, *Acacia pachycarpa* - *Grevillea refracta* - *Triodia pungens* - *Triodia intermedia* shrub steppe on the sandy plateaux on top of the Edgar Ranges, and *Owenia reticulata* - *Triodia pungens* tree steppe on the desert sandridges. This site bears *Grevillea refracta* - *Triodia pungens* shrub steppe of Beard and Webb (1974, p. 45) on shallow sandridges over siltstone, with no *Owenia reticulata* in the immediate vicinity. The vegetation patterns described below are, of course, representative only of a small sector of these dune-fields: elsewhere in the Great

Sandy Desert, species such as *Velleia connata*, *Calytrix longiflora* and *Brunonia australis*, occur on different types of terrain and *Triodia pungens* is largely replaced by *Plectrachne schinzii* (J. S. Beard, pers. comm.).

### Methods and results

Vegetation patterns were analysed firstly using two belt transects, and secondly by mapping the overall distributions of individual species on dune, swale and rock. The first transect ("sandridge") ran between the sandridges as marked on Figure 2. The second ("ecotone") ran from the first and perpendicular to it, to the head of the main gully. Each transect comprised a belt of contiguous 5 m square quadrats. Presence or absence of each species was recorded for each quadrat. These quadrat data were clustered by unconstrained hierarchical polythetic agglomeration using euclidean distance and the error sum of squares and followed by relocation (cf. Buckley 1981a). Soils from 0.1 m and 2.0 m depth on ridge crest and central swale were analysed for organic carbon and total nitrogen concentrations, extractable phosphorus, sodium, potassium and calcium and pH by the methods described in Buckley (1982). Floristic patterns were then related to substrate features as far as possible. Results are shown in Figure 3 and Tables 1 to 4.

Within the sandridge transect there is a clear floristic division between the swale assemblage on the one hand and the dune flanks and dune crests on the other. This is well-demonstrated by the binary frequency ratio tabulations for the two-cluster stage in Table 1. These indicate that 16 of the 27 species in the sandridge transect are entirely absent from the swale zone. Only one, *Dampiera candidans*, is entirely confined to the swale, but four more (*Eragrostis eriopoda*, *Goodenia scaevolina*, *Gonocarpus eremophilus* and *Mirbelia viminalis*) are distinctly more frequent in the swale than on the flanks or crests.

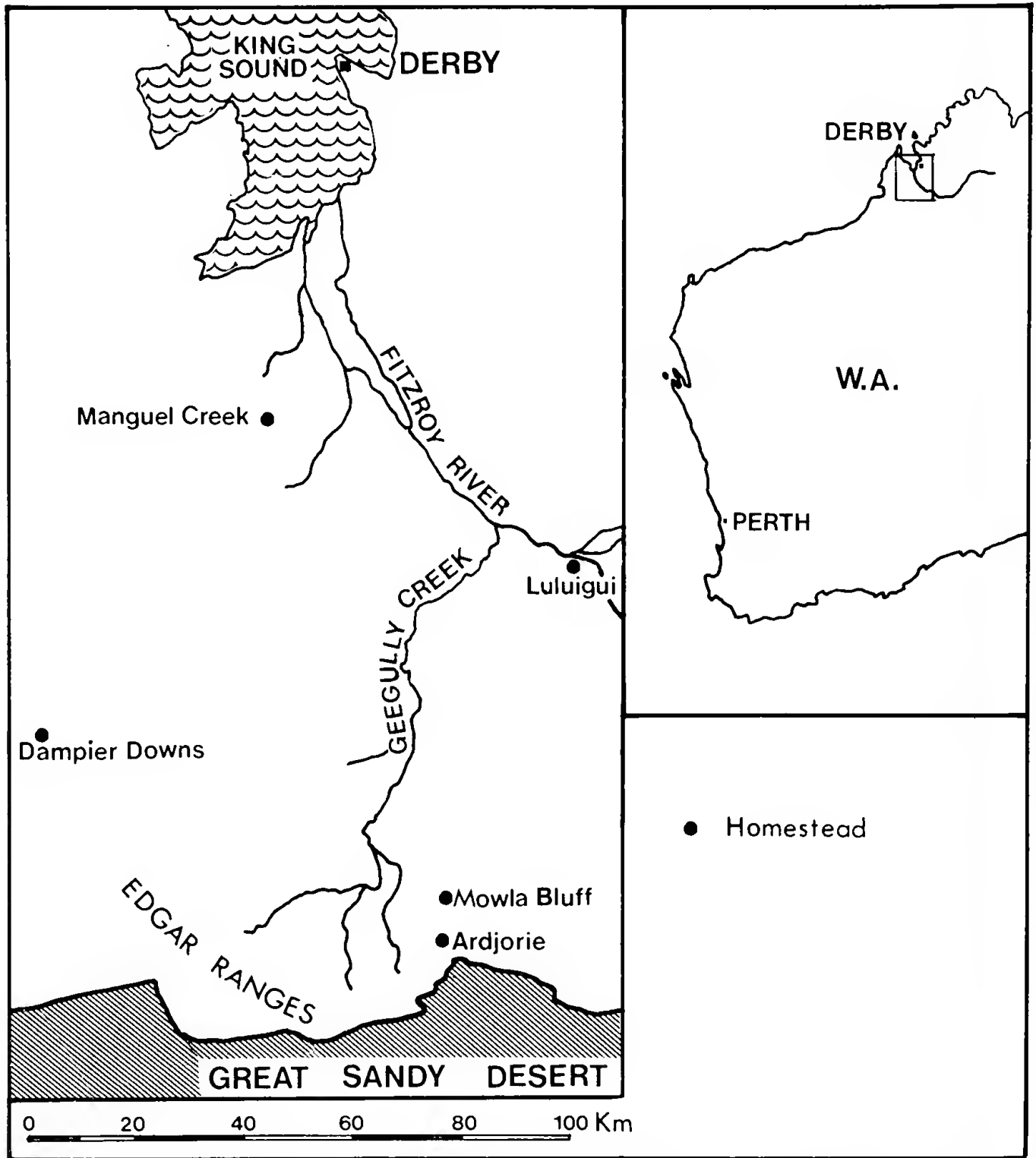


Figure 1.—Site location. Shaded area is Great Sandy Desert *sensu* Beard (1979); *Owenia reticulata*-*Triodia pungens* tree steppe between sandridges. Sandridges north of shaded area bear pindan. Site shown in Figure 2 is 8 km southeast of Ardjorie.



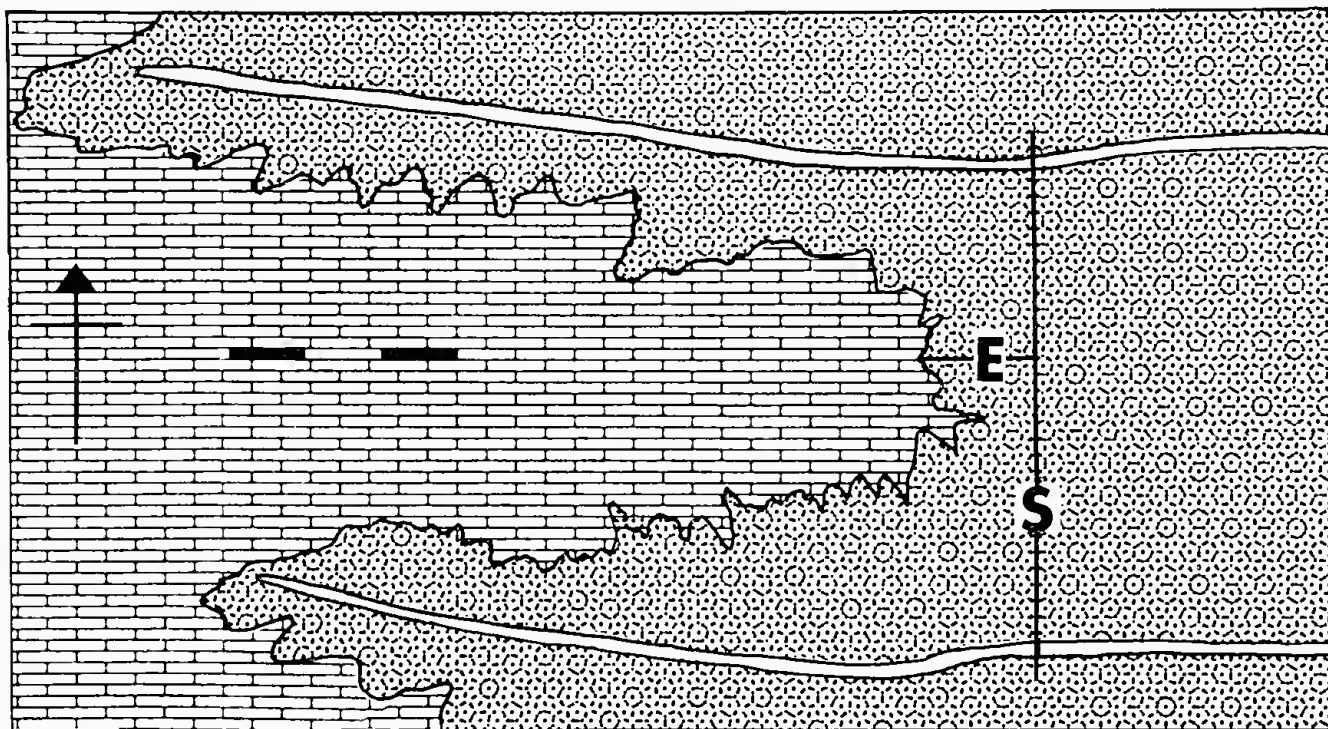


Figure 2.—Site plan showing open dune crests (white), vegetated flanks and swales (stippled), and heavily gullied Jurassic Jarlemai Siltstone (blocked), together with sandridge (S) and ecotone (E) transects. Scale bar 300 m.

Table 1

Cluster statistics for sandridge transect (to be read in conjunction with Fig. 3)

Species	Collection No.	Main Transect: BFRs					
		4-cluster stage				2-cluster	
		SW (15)	FL (79)	ND (10)	SD (18)	SW (17)	FD (105)
<i>Triodia pungens</i> R.Br.	4074	1.0	1.0	1.0	1.0	1.0	1.0
<i>Aristida browniana</i> Henr.	4082	1.2	1.2	0.9	.....	1.0	1.0
<i>Eragrostis</i> sp.aff. <i>eripoda</i> Benth.	4064	0.7	.....	11.1	.....	2.0	0.9
<i>Dampiera candidans</i> F.Muell.	4048	7.1	.....	1.5	.....	7.1	.....
<i>Goodenia scaevolina</i> F.Muell.	4049	6.1	0.4	.....	.....	5.4	0.3
<i>Gonocarpus eremophilus</i> Orchard	4058	3.4	0.9	.....	.....	3.0	0.7
<i>Mirbelia viminialis</i> (A.Cunn.) C.A. Gard.	4055	2.7	1.0	.....	.....	2.4	0.8
<i>Acacia hilliana</i> Maiden	4072	0.9	1.2	.....	0.8	0.8	1.0
<i>Grevillea refracta</i> R.Br.	4039	1.4	1.1	1.0	0.4	1.4	0.9
<i>Halgania solanacea</i> F.Muell.	4053	0.7	1.0	2.2	0.6	0.7	1.1
<i>Fimbristylis squarrosa</i> F.Muell.	4059	0.6	1.0	0.9	1.6	0.6	1.1
<i>Acacia difficilis</i> Maiden	4043	.....	.....	.....	6.8	.....	1.2
<i>Synaptantha tillueacea</i> (F.Muell.) Hook.f.	4069	.....	.....	.....	6.8	.....	1.2
<i>Tephrosia nematophylla</i> F.Muell.	4067	.....	0.5	.....	4.9	.....	1.2
<i>Burtonia simplicifolia</i> F.Muell. ex Tate	4041	.....	1.0	.....	2.6	.....	1.2
<i>Ptilotus fusiformis</i> (R.Br.) Poir.	4052	.....	1.0	.....	2.3	.....	1.2
<i>Jacksonia aculeata</i> W.V.Fitzg.	4047	.....	1.2	.....	1.7	.....	1.2
<i>Hibiscus solanifolius</i> F.Muell.	4068	.....	0.5	4.1	2.3	.....	1.2
<i>Eucalyptus setosa</i> Schau	4040	.....	0.9	2.4	1.4	.....	1.2
<i>Borreria australiana</i> Specht	4066	.....	1.2	3.1	.....	.....	1.2
<i>Sida</i> sp.aff. <i>virgata</i> Hook.	4071	.....	0.8	6.1	.....	.....	1.2
<i>Didymotheca tepperi</i> H.Water	4060	.....	.....	12.2	.....	.....	1.2
<i>Gardenia resinosa</i> F.Muell.	4063	.....	1.6	.....	.....	.....	1.2
<i>Calytrix longiflora</i> F.Muell.	4017	.....	1.6	.....	.....	.....	1.2
<i>Olax</i> sp. nov.	4050	.....	1.6	.....	.....	.....	1.2
<i>Velleia connata</i> F.Muell.	4030	.....	1.6	.....	.....	.....	1.2
<i>Brunonia australis</i> Sm.	4054	.....	1.6	.....	.....	.....	1.2

Table shows binary frequency ratios (BFRs) for each species in each cluster at the 4- and 2-cluster stages respectively. SW, swale; FL, flank; ND, north dune; SD, south dune; FD, flank and dune. Figures in brackets below abbreviations are total numbers of quadrats in each cluster. The number in the swale cluster changes between 4- and 2-cluster stage owing to relocation of two quadrats.

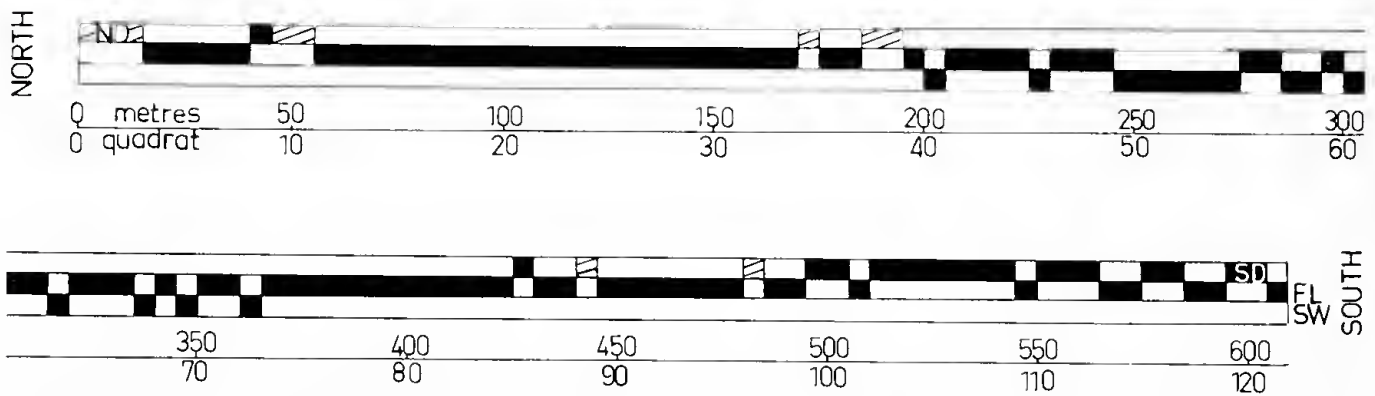


Figure 3.—Ground plot of sandridge-transect quadrat-clusters at four-cluster stage (split into two sections). Top bar shows quadrats in north-dune cluster (shaded) and south-dune cluster (solid); centre bar shows quadrats in flank cluster, and bottom bar those in swale cluster.

Table 2

Species distribution in ecotone transect, with collection numbers of voucher specimens

Species	Collection No.	(west) . . . Metres . . . (east)			
		0	50	100	150
<i>Triodia</i> sp.aff. <i>pungens</i> R.Br.	4075	**			
<i>Hibiscus leptocladus</i> Benth.	4077		*****		
<i>Eragrostis eriopoda</i> Benth.	4076		*****	*	**
<i>Grevillea wickhamii</i> Meissn.	4042		*****	*	*
<i>Grevillea refracta</i> R.Br.	4039	**	*****	*****	*****
<i>Fimbristylis squarrulosa</i> F.Muell.	4059	*	*****	*****	*****
<i>Dampiera candidans</i> F.Muell.	4048			*****	*****
<i>Ptilotus calostachyus</i> (F.Muell.) F.Muell.	4080				*****
<i>Ptilotus kenneallyanus</i> Benl.	4078		*		
<i>Pterigeron odorus</i> (F.Muell.) Benth.	4079		*		
Quadrat No.		0	10	20	30

A further four (*Acacia hilliiana*, *Grevillea refracta*, *Halgania solanacea* and *Fimbristylis squarrulosa*) have similar frequencies in each cluster, and *Triodia pungens* and *Aristida browniana* are uniformly abundant. The swale quadrats are not all contiguous (Fig. 3), so the vegetation gradient is not as clearcut as the above might suggest, but they are confined to a narrow zone in the topographic swale.

Examining the flank-crest complex in more detail the binary frequency ratios for the four-cluster stage (Table 1, Fig. 3) show that a broad flank cluster can be separated from two smaller dune clusters, which are themselves substantially different in floristic composition, and correspond respectively to the northern and southern dunes in Figure 2. Again, the clusters overlap somewhat on the ground, but quadrats bearing the dune floristic assemblages are confined to the topographic dunes indicating a real floristic gradient between dune and swale. Five species, none common, are confined to the flank assemblage and three of the more abundant species, present in both swale and flank assemblages, are entirely absent from both dune groups. Of the 19 species in the dune assemblage as a whole, only six are present in both the north dune and the south dune cluster, a remarkably clear floristic separation. Many are shared with the flank assemblage and only *Acacia difficilis*, *Synaptantha tillaeacea* and *Didymotheca tepperi* are confined to one or other of the dune assemblages, the first two species to the southern and the third to the

northern dune. Hence, cluster analysis of the sandridge transect demonstrates a dune-swale floristic gradient comparable to that on the sandridges of the Simpson and Gibson Deserts (Buckley 1981a, b).

Table 3

Additional species recorded from site but not transects, with collection numbers of voucher specimens.

Gullies	
<i>Acacia monticola</i> J. M. Black	4085
<i>Triumfetta plumigera</i> J. M. Black	4084
Dunefields east of area in Figure 2	
<i>Ptilotus polystachyus</i> (Gaud.) F. Muell.	4091
<i>Codonocarpus cotinifolius</i> (Desf.) F. Muell.	4086
<i>Acacia stipuligera</i> F. Muell.	4088
<i>Comesperma sylvestre</i> Lindl.	4089
Dunes shown in Figure 2	
<i>Plechrachne</i> sp.aff. <i>pungens</i>	4073
<i>Psoralea pustulata</i> F. Muell.	4090
<i>Dodonaea coriacea</i> (Ewart et Davies) McGillivray	4046
<i>Rulingia loxophylla</i> F. Muell.	4056
<i>Halgania glabra</i> J. M. Black	4057
<i>Newcastelia spodiotricha</i> F. Muell.	4045
<i>Dampiera cinerea</i> Ewart et Davies	4044

The shorter ecotone transect, from the centre swale of the sandridge transect to the head of the main gully, contains five species not found in the sandridge transect: *Hibiscus leptocladus*, *Grevillea wickhamii*, *Ptilotus calostachyus*, *Ptilotus kenneallyanus* and *Pterigeron odorus*. With the exception of the uncommon *P. odorus* all these species were also

Table 4

Soils, Mowla Bluff dunes

	Organic carbon*	Total nitrogen*	Extractable phosphorus*	Extractable potassium*	Extractable calcium*	1:5 pH*
Dune, 5-10 cm	825	75	9	33	14	6.55
Dune, 100 cm	390	40	2	40	41	6.75
Swale, 5-10 cm	1 400	130	5	85	39	6.57
Swale, 100 cm	750	80	13	55	21	6.50

\* Units are ppm.

recorded from within the gullies as were the five species shared with the sandridge transect: *Triodia pungens*, *Eragrostis eriopoda*, *Grevillea refracta*, *Fimbristylis squarrolosa* and *Dampiera candidans*. Of these latter five, only *Dampiera candidans* is a swale species the others being widespread in this area. Though short, the ecotone transect (Table 2) shows a floristic gradient from the swale soils to increasingly shallow skeletal sandy soils over siltstone. Table 3 lists additional species common in the gullies but not found in the dunefields, and dunefield species present at the site but not in either transect.

The distributions of a number of species, e.g. *Grevillea refracta*, take the form of oval patches with their major axes along the main gully centre-line, reaching west along the gully margins and east a short distance into the swale, in association with the shallower soils. Combined with the transects, this evidence therefore indicates two major substrate-controlled floristic gradients: firstly, from dune to swale as on sandridges throughout arid Australia; and secondly, from the red clayey swale sands through increasingly shallow sandy soils over sandstone to the Jurassic sandstone gullies. Substrate factors associated with this gradient were not investigated in any detail, since plants in the gullies are rooted in narrow cracks and it was not feasible to extract soils for analysis. Analyses of dune and swale soils (Table 4) indicate that dune-swale ratios for total carbon and nitrogen, extractable phosphorus, potassium and calcium, and pH are comparable to those for the central Australian sandridges (Buckley 1982), save that the dune-swale nitrogen gradient is less pronounced on the relatively low Mowla Bluff dunes. Actual values for organic soil carbon and total soil nitrogen contents at Mowla Bluff are not significantly different from those on the central Australian sandridges, given the overall variability and the low relief at Mowla Bluff; in contrast to the homogeneous crest sands on the higher central Australian ridges; however, carbon and nitrogen levels at Mowla Bluff are significantly higher at 5-10 cm depth than at 1 m. Both central Australian and Mowla Bluff sandridges lack pronounced dune-swale catenary variation in extractable phosphorus, potassium or calcium content, but absolute values are consistently lower at Mowla Bluff than in the Gibson or Simpson Deserts, being around 10-40% of the central Australian mean for phosphorus, 20-55% for potassium, and 2.5-8% for calcium; pH values, however, are very similar. Sample numbers were insufficient to test whether these latter differences between the Great Sandy Desert and the central Australian deserts are consistent; if they are, they could perhaps account in part, together with climatic patterns and phyto-

geographic history, for the floristic differences between the two regions. On the central Australian sandridges the dune-swale floristic catena is associated with corresponding patterns in soil texture, moisture relations and nutrient status (Buckley 1982). These were not studied in such detail at Mowla Bluff, but the textural patterns are similar and the evidence presented above indicates that the soil nitrogen catena, a major factor in central Australia, is similar at this site on the north-western margin of the Great Sandy Desert. Hence it appears probable that similar processes operate to control the dune-swale floristic catena.

### Conclusions

The following conclusions may be drawn: (a) there is a floristic ecotone between the red clayey sands of the dunefield swales and the Jurassic sedimentary rocks exposed in gullied cliffs at the north-western margin of the Great Sandy Desert dunefields; (b) there is also a floristic catena on the sandridges themselves, comparable to that on the central Australian sandridges; (c) this catena is associated with corresponding patterns in soil texture and nitrogen status, as on central Australian sandridges.

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- Acknowledgements.*—Fieldwork was funded by a grant from the Australian Biological Resources Study, and analyses were completed under a Rothmans Research Fellowship at the Department of Biogeography and Geomorphology, Australian National University. I should also like to thank J. S. Beard, A. Hopkins and A. E. Cockbain for constructive criticism.
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## Misapplication of the Aboriginal name "Gungurru" to *Eucalyptus caesia* Benth. and notes on the species' distribution

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### Abstract

Examination of voucher specimens of "Gungurru" collected by R. Helms in 1891 near the Fraser Range established that this Aboriginal food plant is *Eucalyptus woodwardii*, not *E. caesia* as claimed by Mueller and Tate (1896) and subsequent authors. The known geographical distribution of *Eucalyptus caesia* in south-western Australia is outlined and erroneous distribution records from the Murchison River, Fraser Range and the central wheatbelt are noted.

### Introduction

This paper addresses a number of misconceptions regarding the vernacular name and geographical range of *Eucalyptus caesia* Benth. The species occurs in small, widely scattered populations on granite rocks in the Western Australian wheatbelt (Hopper *et al.* 1982). Although quite rare in the wild, it is a well known and widely cultivated ornamental eucalypt.

In 1978-81, one of us (S. D. H.) conducted a systematic field survey to assess the range, abundance and conservation status of *E. caesia*. Figure 1 shows the known range of the species based on this survey, in which 15 major populations were located. However, the survey failed to locate the reported occurrences of the species from the Murchison River (Maiden 1917) and the Fraser Range (Mueller and Tate 1896; Chippendale 1973; Gardner 1954).

An examination of the relevant literature and herbarium specimens confirmed that the Murchison River and the Fraser Range records were inaccurate. They also revealed that *E. caesia* was not the Aboriginal food plant known as Gungurru (cf. Gardner 1954).

### The type collection

The first known collection and type specimen of *E. caesia* was Supplement No. 36 of James Drummond's 5th Collection (Bentham 1867). This collection was made during the spring or early summer of 1847 in the "Mullean", a region of large granite rocks including Mt. Caroline and Mt. Stirling in the central wheatbelt of Western Australia (Erickson 1969). Maiden (1917) mistakenly claimed that the type specimen had come from the Murchison, perhaps confusing it with Drummond's final (6th) Collection from the Murchison River to Dandaragan.

Bentham (1867) provided the original description of the species, giving it a name derived from the Latin *caesius* which means bluish-grey (Sharr 1978). This describes the powdery grey appearance of the branchlets, leaves, buds and fruits. Unfortunately,

the type specimen lacked flowers and this must have contributed to some early confusion (see below) over the identity of *E. caesia*.

### The collection of "Gungurru"

In 1891, Richard Helms was the naturalist with the Elder Scientific Expedition exploring the arid regions between the Everard Range in South Australia and the Fraser Range in Western Australia. While in the Fraser Range area, Helms met an Aboriginal tribe from the Hampton Plains. These Aborigines pounded the roots of a *Eucalyptus* species they called "Gungurru" to produce a food powder. Helms' specimen of this species (Fig. 2) collected at Camp 63 of the expedition, was identified as *Eucalyptus caesia* (Helms 1896, p. 325; Mueller and Tate 1896, p. 358). The location of Camp 63 was about 80 km south-west of Queen Victoria Spring (see Fig. 1).

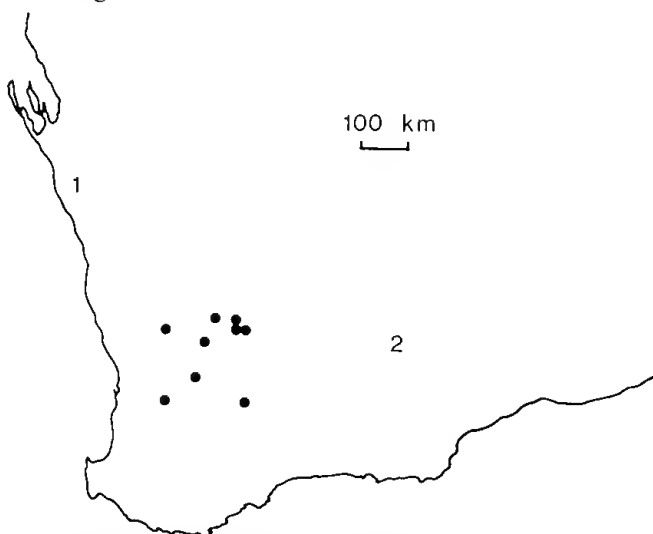


Figure 1.—Distribution of *Eucalyptus caesia* in southern Western Australia and the locations of two inaccurate records. ●—Confirmed localities. 1.—Murchison (Maiden 1917). 2.—Camp 63 (Mueller and Tate 1896).

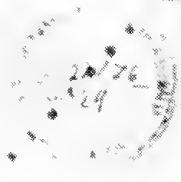


CSIRO Division of Botany  
This is insufficient material for  
probably a close relative of  
and *E. georgei* Brooker sp. nov.  
1976

STATE HERBARIUM OF SOUTH AUSTRALIA  
ADELAIDE

~~EXCELST~~

ELDER EXPLORING EXPEDITION.  
Name *Gunguru*  
Loc. *near ...*  
Coll. *E. Helms* Date *...*



Leg. Collector's No. Date

Figure 2.—Helms' herbarium specimen of Gunguru housed at the State Herbarium Adelaide. The determinavit slip of M.I.H. Brooker's dated 9 December 1976 reads "this is insufficient material but probably is close to *E. woodwardii* and *E. georgei* Brooker sp. nov".

Mueller and Tate (1896) described the Gungurru specimen, particularly its flowers, in some detail. Maiden (1917) suggested that this description might apply to *E. woodwardii* Maiden rather than *E. caesia* but did not examine Helms' specimens.

There are three *Eucalyptus* specimens from Camp 63 housed at the State Herbarium Adelaide, National Herbarium Melbourne and National Herbarium Sydney respectively. Both the Melbourne specimen (G. Chippendale pers. comm. 1980) and the Sydney specimen (D. Blaxell pers. comm. 1980) have been identified as *E. woodwardii*. The specimen housed at Adelaide (Fig. 2) lacked flowers and fruits so that it could not be identified with certainty. M. I. H. Brooker (pers. comm. 1980) and one of us (S. D. H.) considered that it was most likely to be either *E. woodwardii* or *E. georgei* Brooker et Blaxell.

Aside from these identifications there are two independent lines of evidence that the Lemon-flowered Gum, *E. woodwardii*, is Gungurru rather than the other two eucalypts mentioned above. First, *E. woodwardii* is known to occur in large stands in the Camp 63 area (Chippendale 1973). The verified geographical range of *E. caesia* (Fig. 1) is well removed from there and it seems unlikely in any case that the species' small populations of slender mallees could have provided a significant food source for the Aborigines. *E. georgei*'s known range is also some distance to the west from Camp 63 (Brooker and Blaxell 1978).

Secondly, *E. woodwardii* matches Mueller and Tate's (1896) description of Gungurru in all respects. However, *E. georgei* differs in several characters, for example in its smaller flower buds (11-13 mm long rather than 17-25 mm long) and its lack of a distinct beak on the operculum. *E. caesia* also lacks the distinctly beaked operculum that characterises Gungurru and differs in having kidney-shaped anthers rather than the cuneate-ellipsoid anthers of Gungurru. Gardner (1954) adopted Helms' aboriginal name for *E. caesia* but misspelt it "Gungunnu". Both versions of the common name are well known although the original spelling is favoured in more recent publications (e.g. Chippendale 1973; Gardner 1979).

#### Other distribution records

G. M. Chippendale (pers. comm. 1980) and M. I. H. Brooker (pers. comm. 1981) have confirmed that a specimen at the British Museum (collected by H. F. Broadbent, No. 1371, 11/9/1953) labelled "Fraser Range" is *E. caesia*. However, the entire Fraser Range was surveyed at low altitude in a light aircraft by one of us (S. D. H.) in company with A. S. George on 13 October 1979. No *E. caesia* plants were seen, nor have any specimens been collected from this locality in recent years. It is possible that Broadbent's specimen was actually collected from Fraser Rocks, located 40 km north-north-east of Beacon and 80 km north-west of known *E. caesia* localities at Yanneymooning Hill and Walyahmoning Rock. The Fraser Rocks locality deserves investigation.

*E. caesia* has most frequently been reported from Mt. Caroline and Mt. Stirling, the first of which still harbours relatively large populations of the species. Collection details on specimens housed in the Western Australian Herbarium (Perth) indicate that they were all collected within the species, known range

illustrated in Figure 1. However, the following recorded localities have not been confirmed.

1. Uberin Hill (Gardner 1954).
2. Warren Double Cunyan (Gardner 1954).
3. 25 miles north of Mukinbudin (A. N. Maddock 20/5/1960: PERTH).
4. Karlgarin (J. P. Stafford 3/6/1970: PERTH).

The first two localities are quite specific and do not have *E. caesia* populations now. Warren Double Cunyan has a small population of *E. crucis* Maiden, which could have been mistaken for *E. caesia*. Uberin Hill may have been mistaken for a nearby granite rock which does have an *E. caesia* population. The other two localities cannot be pinpointed but a fairly thorough search failed to locate *E. caesia* in those areas. It is possible that any of the localities listed above may have contained populations which are now extinct.

#### Conclusion

Gungurru is clearly not *Eucalyptus caesia* and there is little doubt that its true identity is *E. woodwardii*. Because "Gungurru" is inappropriate as the vernacular name for *E. caesia*, we favour "Caesia", an alternative vernacular name that is already fairly widely used.

This investigation illustrates the importance of keeping good herbarium specimens and accurate descriptions to substantiate new records. Had Helms not collected voucher plant specimens and Mueller and Tate not described these specimens in some detail, the misapplication of the name Gungurru to *E. caesia* would have gone unnoticed and the erroneous location of Fraser Range for the species would have become perpetually entrenched in the literature.

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## The marine environments of the Dampier Archipelago

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### Abstract

The Dampier Archipelago is an inundated landmass similar in topography to the present hinterland. A gently rising undulating submerged plain now occurs 5-20 m below mean sea level (e.g. Mermaid Sound). Inundated hills and ridges rise up from this plain, the lowest forming subtidal rocky reefs, the highest forming the numerous islands of the archipelago. Inundated valleys form the embayments, straits and channels of the archipelago.

Much of the coastline is igneous rock of Precambrian age. Pleistocene limestone is locally plastered onto this rock. Overlying all rock types is a veneer of varying thickness of sand, gravel or mud deposits. Each of these substrate types occurs in a range of locations which vary according to height above or below mean sea level, topographical configuration and exposure to waves and currents. Consequently there is a wide range of geomorphic units within the archipelago which include intertidal and subtidal rocky shores, intertidal and subtidal limestone pavements, intertidal flats, intertidal beaches and subtidal plains.

Habitats are intimately linked to geomorphic units and each habitat type supports its own characteristic assemblage of marine organisms. Biotic assemblages have been broadly grouped into categories based on the most common or noticeable species within the group. These assemblages are: oyster-barnacle, coral, mangal, *Notocallista*-echinoderm, demersal fish-echinoderm-crustacean, *Donax*-crustacean, *Uca*-cerithid, *Mictyris*, *Uca-Macrophthalmus*, xanthid-sponge, *Ocypode*, seagrass, algae, embayment fish, pelagic fish-plankton.

### Introduction

The coastal environment of the Dampier Archipelago (Fig. 1) is largely undescribed. The area is mentioned in a number of regional survey reports (Jutson 1950; Burbidge and Prince 1972) and portions of the coral reefs of the outer archipelago have been studied previously by the Western Australian Museum (Wilson and March 1974). Recent research in the area has provided data on natural history aspects of the region and this paper presents some of the results. As such the paper provides both the background for a series of papers currently in preparation which will describe each of the major habitat/biotic assemblages and sedimentology in greater detail.

In this study the Dampier Archipelago is placed in its regional context. The basic habitats and biotic assemblages of the archipelago are described and related to a framework of geology, geomorphology, stratigraphy, substrates and oceanography. The distribution of the habitats and biotic assemblages is shown to be highly variable because of the stratigraphy, the distribution of geomorphic units, aspect (exposure to wave climate), surface processes (e.g. sedimentation versus erosion) and oceanography.

### Methods

A variety of methods was used and a range of sites was studied to collect data for this paper. The regional coastal environment and selected small areas were studied by use of aerial photographs and supplementary on-ground surveys. Within the Dampier Archipelago, study sites and transects were located to sample as wide a range as possible of variation in habitats and biotic assemblages.

Subtidal transects (Fig. 2A) along rocky shores were established by a weighted line (marked in 5 m intervals) which extended from the tidal zone to offshore for 100-125 m. Observations on geology, substrate and biota were made by diving and data were recorded on waterproof data sheets supplemented by photography. Intertidal rocky shores and intertidal flat areas were selected for detailed mapping of morphology, habitats and biota (Fig. 2B); within these areas, transects and sampling sites were established to document geology, substrates and biota; observations were recorded on data sheets supplemented by photography. At numerous sites on the intertidal flat, the shallow stratigraphy also was explored by cores (up to 2 m) and auger.

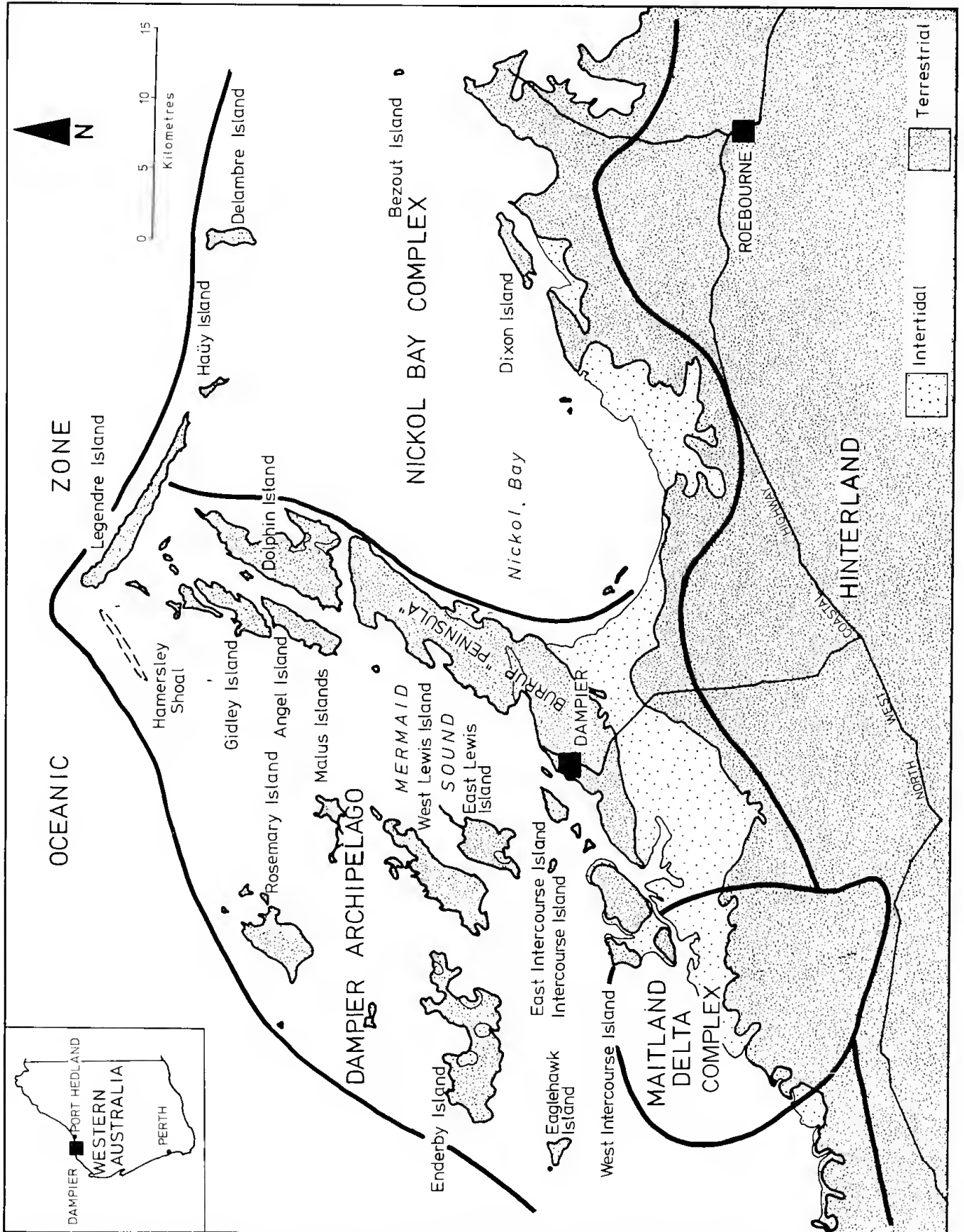


Figure 1.—Map showing location of Dampier Archipelago and its regional relationship to adjoining coastal units. The main geographic locations mentioned in the text are shown (Fig. 2D shows additional locations mentioned in the text.)

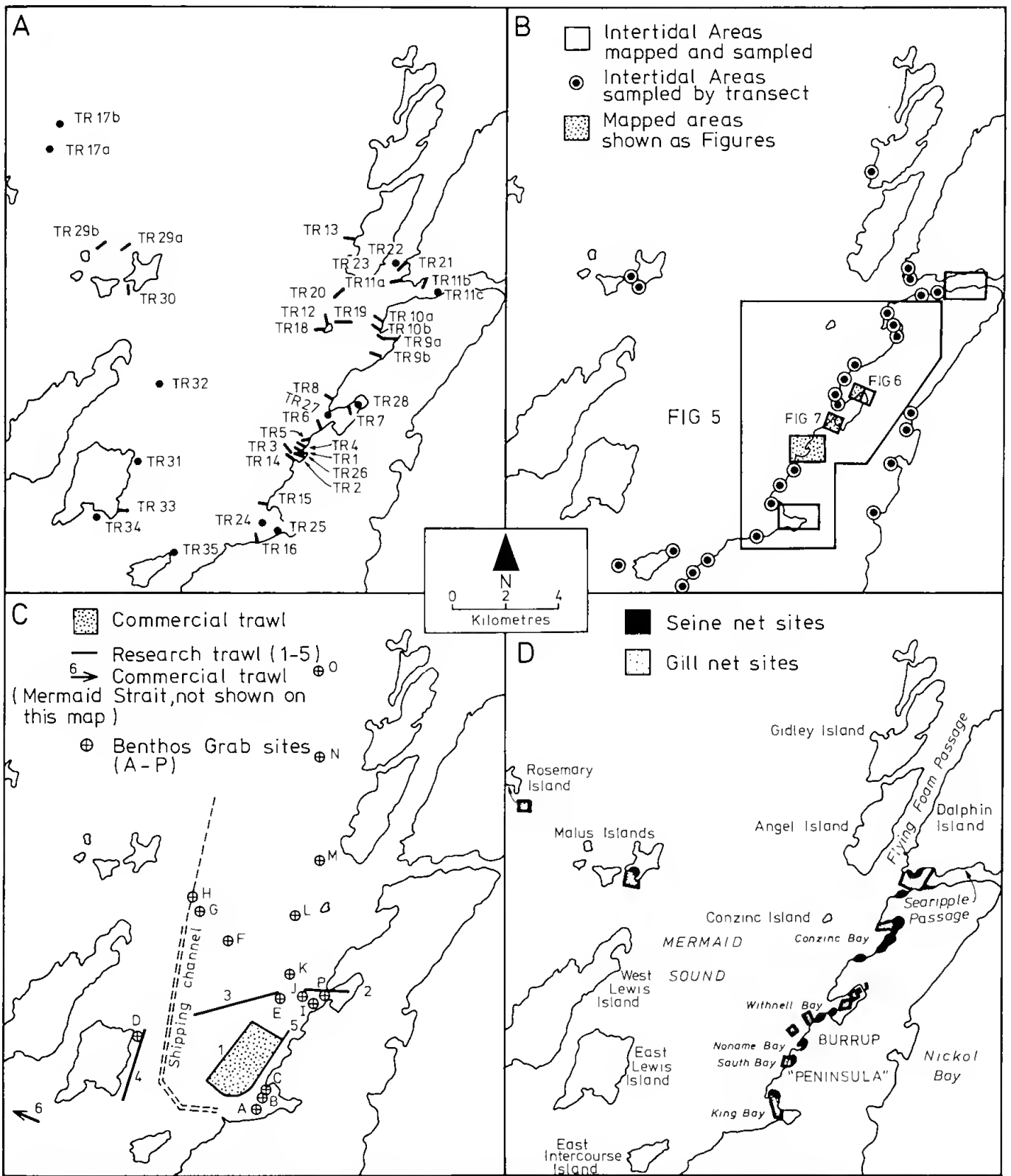


Figure 2.—Sampling sites. A.—Location of subtidal transects. B.—Location of intertidal areas mapped and sampled. C.—Location of trawls and benthic grabs. D.—Location of fish netting sites.



Deep subtidal offshore areas were investigated by commercial trawls, research trawls, benthos grabs and by underwater inspection (Fig. 2C). In August 1978 the catches of a commercial prawn trawler were examined on 2 nights to determine species diversity in the benthic fauna. This information was supplemented by collecting fauna from a small trawl (mouth aperture 5.2 m, mesh 5 cm) towed behind a research vessel. A Van Veen benthic grab was used to collect sediment and biota samples (five or more replicate samples per site) from various subtidal sites (Fig. 2C).

Fish were collected by gill nets, seine nets (Fig. 2D) and by underwater observation. The gill nets were designed to sample fish of all sizes on both the surface and the sea floor. Seine netting was carried out in a number of different habitats (viz exposed beaches, protected beaches, low tidal flats). Underwater observation of fish also was carried out mainly on coral reef environments.

Most of the biota samples have been lodged with the Western Australian Museum. Sediment (substrate) samples were visually described by binocular microscope and routinely sieved for granulometric analyses. Selected samples were thin-sectioned for petrographic analyses.

### Regional setting

The Dampier coastline is situated in the Pilbara region, termed Pilbaraland by Jutson (1950). It is unique in that the coastal area borders a hinterland that is situated in an arid climate. The distinctive landforms of the Pilbara form the architecture of the nearshore marine environment. The combination of tidal regime, wind-generated waves and archipelago-style coastal geomorphology also makes the area distinct oceanographically.

### Climate

The climate of the Pilbara region is tropical and arid (Gentilli 1972). Table 1 presents relevant climatic data. The area is also subject to periodic cyclones during the period December to April. Coleman (1970) shows that a cyclone passes within 100 km of the coast every 2-3 years. These cyclonic disturbances are responsible for heavy rainfall as well as increased wave action in coastal zones.

### Regional coastal units

The coastline around Dampier can be conveniently divided into five main regional units based on general geomorphology and oceanography (Fig. 1). These units are:—

Hinterland, Oceanic Zone, Nickol Bay Complex, Maitland Delta Complex and Dampier Archipelago.

Throughout this paper the above names are used to denote the designated coastal unit and not geographic localities.

*Hinterland.*—The hinterland is the landmass which borders the marine complexes. It is composed of rocky hills, ridges, colluvial slopes, alluvial flats, river courses, sandplains and subaerial portions of deltas. The bedrock geology of the hinterland consists of folded metasedimentary and metavolcanic rocks and irregularly ovoid domes of granite (Geological Survey of Western Australia 1975). Regional topography is controlled by jointing and fracture systems. Thus landforms reflect trends of the geological grain of the country as well as the weathering and erosion of fracture systems. Low plains consist of sand, alluvial wash and in situ soil. Hills and ridges are flanked by slopes of boulder and coalescing colluvial fans. Locally, along the coast, the hinterland is composed of aeolian sand formed by shoreward transport of inner-shelf marine sand. Few major rivers drain the Pilbara region; these flood only sporadically for short periods. The rivers contribute alluvium to the extensive plains and form deltas at their mouths.

The margin of the hinterland with marine geomorphic units is locally sharp and delineated by steep slopes or dune lines. In other areas it is irregular and diffuse where low-lying supratidal flats, extensive high tidal salt flats, alluvial valleys and deltaic lobes form a broad zone of contact.

*Oceanic Zone.*—The Oceanic Zone, characterized by deep open oceanic waters (> 20 m), forms the inner part of the north-west shelf. It is sharply demarcated from the Dampier Archipelago and Nickol Bay Complex by a steep slope where the seafloor descends to depths of 30 (and more) metres. This junction is often delineated by a line of submerged rocky reefs or coral reefs, or shoals that locally protrude above water surface, e.g. Hamersley Shoal and Legendre Island. Regional bathymetric charts indicate that

Table 1

Mean monthly climatic data for Dampier †

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Daily Maximum Temperature (°C)	35.0	37.1	36.0	33.6	29.2	26.3	26.3	26.8	29.7	32.6	34.6	35.3
Daily Minimum Temperature (°C)	26.3	26.4	25.8	22.0	17.8	15.1	14.0	14.9	16.5	19.5	22.1	25.4
Rainfall (mm) ....	29	57	41	14	70	62	14	10	*	0	2	16
Raindays (No.) ....	4	3	6	1	4	5	4	2	0	0	1	3
Evaporation (mm) ....	354	311	325	283	224	198	193	228	291	348	379	384

† Data from Bureau of Meteorology (1975).

\* Value is between 0.1 and 1.0



within the Oceanic Zone there are several large-scale platforms or terraces demarcated by relatively steeper slopes. Locally rocky islands and coral reefs protrude above the shelf surface. The seafloor physiography and substrate is one of flat, featureless limestone pavements, terraces and sand/gravel veneers (Woodside Petroleum Development 1978).

**Nickol Bay Complex.**—Nickol Bay is a large, shallow marine embayment (35 km x 20 km) and is a coastal portion of the north-west shelf. Bathymetric charts indicate a uniform gentle seafloor inclination; the seafloor is 20 m deep at the north margin and progressively shallows to intertidal at the south. Few islands or rocky reefs break this monotonous surface (e.g. Haüy and Delambre Islands to the north). The shoreline components of the Nickol Bay Complex include mudflat embayments, rocky shores, limestone pavements, sand beaches and mangal flats. The Nickol Bay Complex is separated from the Dampier Archipelago by the chain of islands which includes Burrup "Peninsula"\* and Dolphin Island.

**Maitland Delta Complex.**—The Maitland Delta Complex is a deltoid coastal lowland; it is a drowned sand-plain system (which has locally been overlain by alluvial wash and tidal sediments) interspersed with tidal mud deposits and sand ridge systems. The delta area appears to be underlain by a widespread sheet of Pleistocene limestone.

The entire lowland system has formed as a result of deltaic sedimentation during the Quaternary. The interplay between tidal sedimentation (mud), alluvial input, sand bar/ridge sedimentation, tidal erosion and sand plain degradation has developed a variety of tidal and marine habitat types that are unique to this delta complex.

**Dampier Archipelago.**—The Dampier Archipelago is a system of islands, rocky reefs, coral reefs, shoals, channels and straits. It also forms the coastal portion of the north-west shelf. This unit is treated in detail in the next section.

### Dampier Archipelago

#### *Oceanography and meteorology*

The coastline of Dampier Archipelago has large semidiurnal tides (Easton 1970). Mean spring range is 5.6 m; mean neap range is 1 m (Australian Tide Tables 1981). Tidal currents in embayments locally reach a maximum speed of 50 cm/sec during spring tides, but for the most part data on tidal currents are sparse.

Meteorological and oceanographic characteristics of the Dampier Archipelago are not well known but limited data (Woodside Petroleum Development 1978) show that the environment has variable waves. Long period swell from north, north-west and west impinges mainly on the exposed portions of the outer islands. Southerly facing coasts, embayments, straits and passages between islands are protected from

swell. Most waves are generated by local winds and wave direction follows wind direction, coming mainly from north-east, east, south-east and north-west during winter and from south-west, north-west and south-east during the summer. Wind-generated waves are small, generally less than 1.3 m height. Water circulation patterns are not known in detail but it appears that mixing is dominated by tidal currents, waves and winds (Woodside Petroleum Development 1978).

The open waters of the Dampier Archipelago show normal oceanic salinity and supersaturation with oxygen. Coastal and nearshore areas of the archipelago exhibit the same average values of salinity and dissolved oxygen as the offshore areas. However there is marked variation in the salinity and dissolved oxygen levels of the interstitial and ponded waters of tidal flat areas. Water temperatures on the north-west shelf and adjacent Pilbara coast are highest in summer and lowest in winter (ranging from between 19°C to 32°C) in response to intensity of solar radiation.

The turbidity of the water has been observed to be variable in time and place. Turbidity is due to suspended particulate sediment, organic detritus and plankton; the relative importance of each component depends on tidal cycle, wave action, season and location. At some times of the year, notably spring to summer, plankton blooms contribute locally to turbidity. There is also contribution from the Maitland River during floods, and Nickol Bay during spring tides.

#### *Morphology*

The Dampier Archipelago is a large marine area characterised by groups of islands, rocky reefs, coral reefs and shoals that rise from a general deep-water plain. The Dampier Archipelago may be subdivided into several morphological units characterised by depth, general physiography and component materials (rock and sediment). These units form the framework for broad scale classification of types of coastline. The units are: submarine plains, islands, rocky reefs, coral reefs and shoals, and channels and straits.

**Submarine plains.**—The submarine plains occur in deep water and form approximately 60% of the Dampier Archipelago. Bathymetric charts indicate that on a regional basis the plains are gently sloping features about 5 m deep below ILWS near the hinterland and 15-20 m deep at the northern margin. The seafloor is underlain either by extensive pavements of limestone, or vast sheets of shell gravel, sand and muddy sand/gravel.

**Islands.**—Rising above the general level of the submarine plain are partly inundated hills and ridges. These comprise the numerous islands that form some 15% of the surface area of the archipelago. The disposition, geometry and composition of the islands reflect regional geological lithology and fracture patterns (Fig. 3). Major north-east trending rock units form resistant ridges, flanked by valley systems developed on the more weathered rocks; marine inundation has resulted in north-east-trending chains of islands of essentially similar rock types.

\* The term "Burrup Peninsula" is used by Lands and Surveys of Western Australia, but technically the "peninsula" is an island. Several causeways now join the Burrup area to the mainland (hinterland), but in the past access to the island was across tidal flats (which now underlie solar salt-production ponds) and at high tide the area was cut off totally from the hinterland.

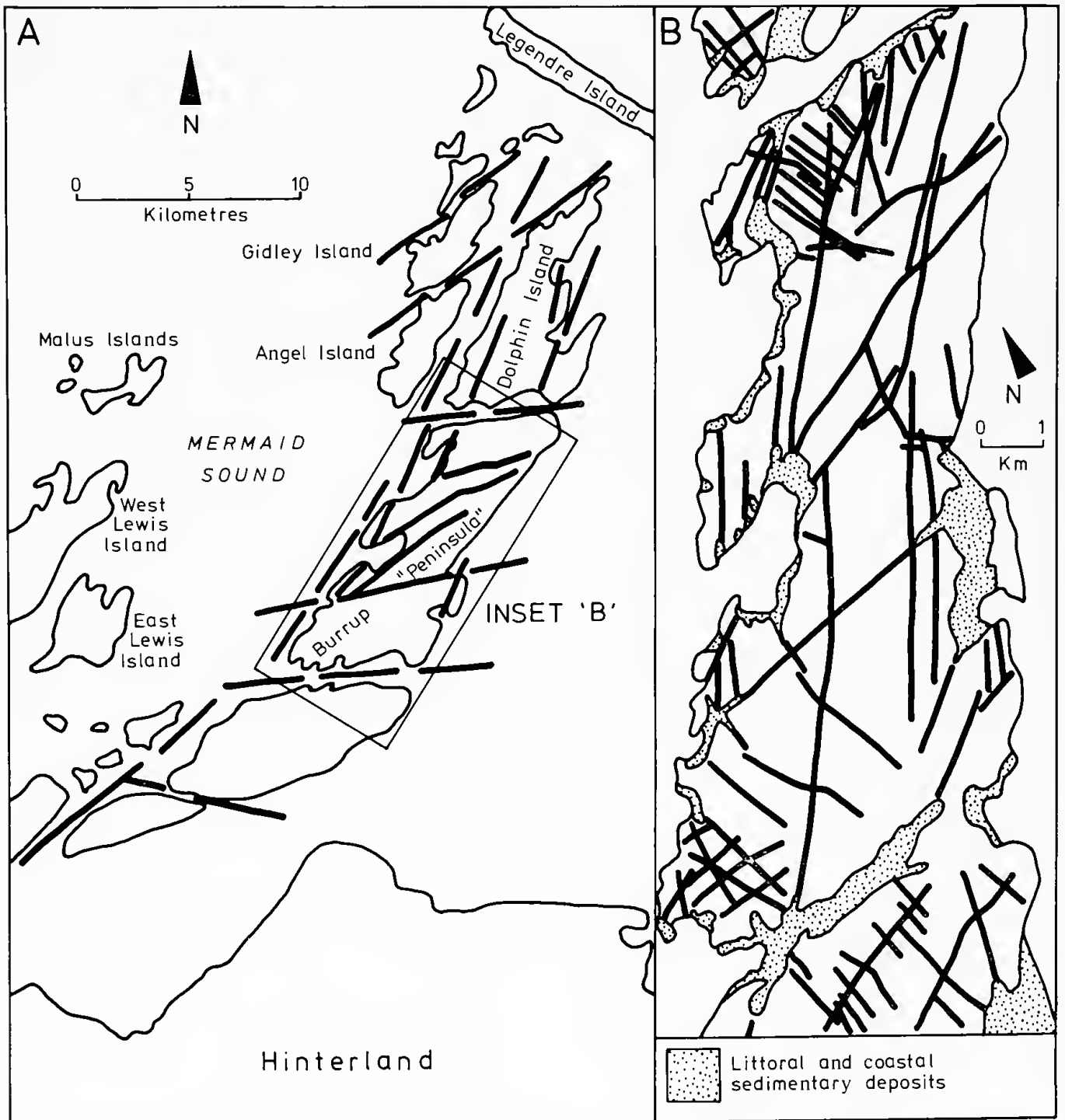


Figure 3.—A.—Major fracture patterns that determine the geometry and disposition of islands, passages and straits. B.—Detailed map showing major fracture patterns that determine shape and orientation of embayments.

Islands essentially have 3 terrestrial and 4 marine components. The terrestrial components are similar to the hinterland and include rocky terrains, valley systems and sand dunes. The marine components are rocky shores, protected embayments, exposed embayments and submarine slopes. Rocky shores are the dominant marine components. The protected embayments are the modern tidal flats and shallow subtidal bays that occur as discrete units along the margins of islands. Exposed embayments are the modern sandy (beach) coves. The slopes adjoining islands descend from low tide levels down to subtidal depths

of 5 to 10 m, frequently with a moderately steep inclination. Submarine slopes of islands are similar to sub-aerial slopes of hills and ridges in inclination, components (boulders, pebbles) and disposition, and probably represent inundated subaerial scree deposits.

*Rocky reefs, coral reefs and shoals.*—Submerged to tidally-submerged hills and ridges rising up from the submarine plain are the present rocky reefs. Some are colonised by corals to form coral reefs. The disposition, geometry and composition of rocky reefs also reflect regional lithology and fracture patterns.



Shoals are the shallowly submerged accumulations of sand and gravel derived by breakdown of both modern coral reefs and older limestone, and comprise about 15% of the surface area of the archipelago. They frequently form connections between the islands and coral reefs of the archipelago, occurring on the leeward side of islands or as aprons around islands. Locally shoals are sediment accumulations on shallowly submerged rocky reefs or limestone pavements. Many shoals become partly emergent on a falling tide and their surface is mobile during flood and ebb tide.

*Channels, straits and embayments.*—Channels, straits and embayments are inundated valleys and lowland systems. These can be traced into present terrestrial drainage systems whose disposition also largely is controlled by either the regional fracture (or joint) trends (Fig. 3) or location of weathered dolerite dykes which intruded these fractures (Geological Survey of Western Australia 1980). The regional fracture trends are oriented north-west, east-north-east and north-north-west and have resulted in major valley systems that segment the terrain into its component islands and embayments (Fig. 3). All islands, straits and embayments reflect this regional pattern to some extent.

The inundated valleys, embayments or straits are filled with sedimentary materials to varying degree. The King Bay embayment is largely filled with soils, limestone and marine sediments to levels of high tide and low supratidal; in contrast Searipple Passage is filled by limestone to levels of low neap tide, and Flying Foam Passage appears unfilled.

#### *Substrate materials of the Archipelago*

Geological materials comprise the substrate types that differentiate the various geomorphic units. Substrates also play a large role in determining distribution of habitat and determine the composition and distribution of the biota. The main geological materials of the Archipelago are: igneous rock, limestone, sand/gravel and mud. The stratigraphic array of these materials is summarised in Figure 4 and their distribution is summarised in Table 3. This shows that a variety of Holocene sediment types overlies Pleistocene and Precambrian rock units.

Precambrian igneous rock forms the core structure of islands and rocky reefs. In the marine environment it is hard, crystalline, smooth and not readily destructible. The rock forms large smooth surfaces, or creviced fissured surfaces. It also forms bouldery accumulations (boulder frame with interstitial sand and/or mud) on slopes. Limestone also may comprise the material of islands and rocky reefs typically as an external or peripheral plaster to a core of igneous rock. It also forms extensive pavements in tidal zones and deep-water plains. As a rock type it is a bedded and laminated, semi-indurated quartz skeletal sand. In the marine environment it erodes readily to thick slabs and boulders, and forms creviced, honeycombed, irregular to hummocky surfaces upon which there may be a patchy mobile veneer of unconsolidated sand.

Sand and gravel are derived by breakdown of rocks and calcareous skeletons of biota. The sediments occur as extensive veneers over vast areas of igneous

rock and limestone sea bottoms in deep water. Additionally these sediments occur as (1) offshore mound-like shoals, (2) subtidal to intertidal sheets, (3) shoreline ribbon deposits (beaches, bars, spits), (4) shoreline wedges in embayments and (5) small deltaic accumulations in shallow water. Gravel is either granule- to pebble-sized calcareous skeletal or granule- to boulder-sized lithoclast debris; sand and mud may occur interstitial to the gravel frame. Sand consists mainly of fine- and medium-size fractions. These sands range from quartz/lithoclast/skeletal types to dominantly skeletal types; mud also may occur interstitial to the sand grains and thus sandy sediments range from cleanly washed in high energy environments to muddy on tidal flats and subtidal plains.

Mud is transported into the marine environment by fluvial processes, or is eroded from older sedimentary deposits, or is biogenically generated. It occurs as sheet-like veneers in deep water over igneous rocks and limestone, and when mixed with sand also forms wedge-shaped to ribbon-shaped shoreline accumulations.

#### *Geomorphic processes*

The large scale coastal morphology was developed by subaerial arid-zone weathering prior to the Quaternary marine transgressions. Following the post-glacial transgression, today various parts of the archipelago are undergoing either erosion or sedimentation. These processes are developing the wide range of geomorphic surfaces (and units). Marine erosion is dominant in developing the small scale structure of most coastline types either by causing retreat or by exhuming buried stratigraphic units. Sedimentation is less important and has resulted in only localised accumulations. Sites that are not the result of either erosion or sedimentation usually are relic surfaces. These are gravel pavements or bouldery slopes that are marine-inundated terrestrial surfaces (valley alluvium, sheet colluvium and scree slopes).

*Erosion.*—There are 5 main geomorphic features that are the result of coastal erosion: cliffed shores, eroded limestone pavements, undercut and collapsed mangrove trees, eroded salt flat, and exhumed stratigraphic units.

Cliffs cut into limestone and igneous rock are a dominant feature of the shoreline of the Dampier Archipelago. The cliffs are formed by wave attack, biological erosion, undercutting and mass wasting. Marine erosion also is a major factor in developing the widespread limestone pavements. By a combination of tidal scour, wave attack, biological erosion and solution the limestone is degraded to an irregular to hummocky, internally honey-combed pavement that is covered by a sand/gravel veneer (itself the product of the eroding limestone).

Tidal scour and tidal-creek headwater erosion are resulting in degradation of high-tidal salt-flat surfaces. There is development of small cliffs, residual high-level mesaforms (< 30 cm high) and shallow channels. Tidal scour and wave attack progressively has exposed mangrove roots and has undercut mangrove trees along the seaward edge of many mangrove belts. As a result there has been a slow but net coastal retreat. Continued long-term erosion in many

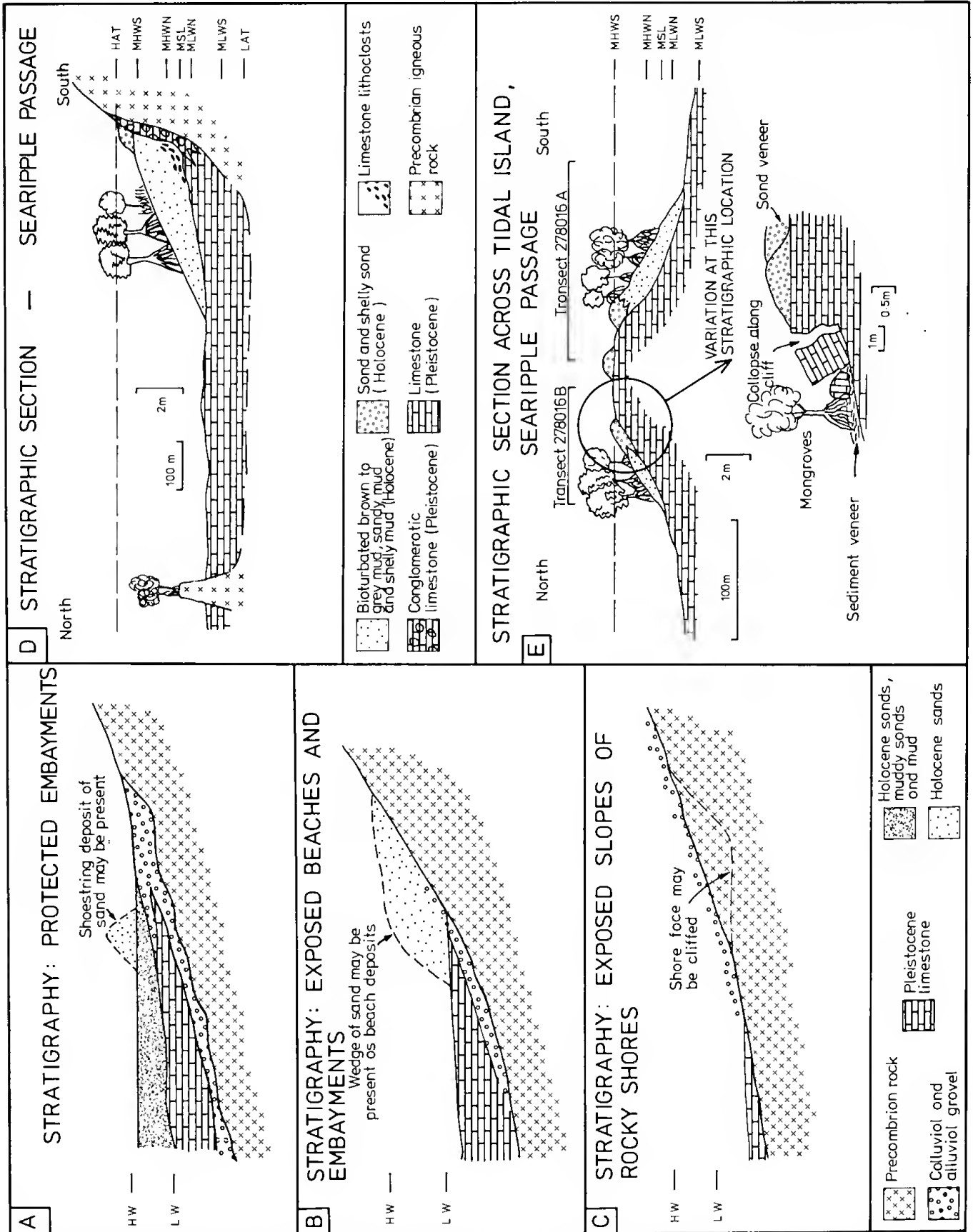


Figure 4.—A, B, C.—Summary of stratigraphic relationships in Dampier Archipelago. These relationships have formed as a result of erosion or sedimentation. The range of stratigraphic material in the profile determines the variation in substrates. D, E.—Details of stratigraphic relationships at two localities in Searipple Passage.



areas has resulted in removal of Holocene sedimentary deposits and the tidal zones now expose exhumed unconformity surfaces and Pleistocene stratigraphic units: these include gravel pavements (colluvial gravel sheets or alluvial gravel deposits) and calcreted limestone pavements.

*Sedimentation.*—There are 5 major sites of sedimentation in the Dampier Archipelago. These are: tidal flat accumulations and associated spits within embayments, beach-dune deposits, coral reefs and associated shoals, subtidal plain deposits, and supratidal/high-tidal deposits. Some of these accumulations have resulted in development of a shoaling stratigraphic sequence. Other deposits merely occur as a veneer on an unconformity.

Sedimentation within embayments has resulted in a wedge-shaped tidal deposit whose internal stratigraphy reflects progradation (Figs 4 and 6). Low tidal flat sediments are overlain by bioturbated and root-structured mud and muddy sands formed under mangrove cover, and this is overlain by salt-flat deposits. Depending on location relative to headlands, a sand or shelly sand spit (or chenier) may overlie landward parts of the tidal-sediment wedge. These tidal deposits typically rest on a shallowly buried unconformity surface cut into Precambrian rock, or colluvial soil, or Pleistocene limestone.

Sediment locally accumulates in exposed (beach) coves and embayments. Generally the accumulation is laterally limited by adjoining headlands. The deposits typically pass upslope into beachridge and dune deposits. Most beach/beachridge/dune accumulations typically overlie Pleistocene limestone at shallow depth.

Coral reefs locally have built up substantial deposits in the outer part of the archipelago. These reefs are encrusting on either Precambrian rock or Pleistocene limestone foundations. More typically, coral reefs form only thin encrustations on bedrock substrates; the larger coral reefs are associated with substantial build-ups of sand (shoals) derived from the coral and underlying rocks.

Deeper water subtidal-plain surfaces (usually limestone pavement) are covered by sand, shell gravel and mud. These deposits are accumulating by in situ biota contribution, redistribution of relic sediments, breakdown of limestone and fall-out of suspended mud. The deposits usually are thin (< 1 m).

Tidal erosion and dispersion as well as wet season sheet wash of the sand plain sediments along the supratidal zone results in a sheet of sand distributed over the upper edge of high tidal flats.

#### *Geomorphic units*

Numerous geomorphic units are differentiated within the Dampier Archipelago mainly on substrate type, geometry and substrate surface and tidal level. The units have developed by a combination of factors which include: erosion versus sedimentation, underlying stratigraphic sequence, tidal level, wave action and ancestral (pre-Holocene) physiography. The geomorphic units are: (1) Intertidal rocky shore, (2) Subtidal rocky shore, (3) Intertidal limestone pavement, (4) Subtidal limestone pavement, (5) Intertidal flats, (6) Intertidal beaches, (7) Subtidal shoals, and (8) Subtidal plains.

A description of the geomorphic units, their distribution and their occurrence within regional coastal morphology types is presented in Table 2. These

**Table 2**

*Geomorphic units and their distribution*

Unit	Description	Distribution	Relationship to physiographic units
Intertidal rocky shore	steep, cliffed shore cut into igneous rock; cliffs and sloping pavements alternate with bouldery shores; zone is inundated by tides	developed along exposed portions of islands; elsewhere developed as headlands within embayments of islands	margins of islands: both exposed shores and embayments
Subtidal rocky shore	as above; bouldery slopes more common; zone extends from low water to 8 m depth	as above	subtidal margins of islands, slopes and reefs; some embayments
Intertidal limestone pavement	gently to moderately inclined limestone pavement inundated by tides; cliff may be developed at about HWM	developed locally along rocky portions of embayments of islands	along margins of embayments of islands
Subtidal limestone pavement	gently inclined limestone surface extending from low water to over 5 m depth	developed in embayment of islands as subtidal extensions of tidal limestone pavement	subtidal margins of channels, embayments and islands
Intertidal flat	gently inclined surface underlain by muddy to sand sediment and exposed by tides	developed in protected parts of embayments of islands	within protected embayments of islands
Intertidal beach	moderately inclined surfaces underlain by sandy to gravelly sediment and exposed by tides	developed in exposed embayment and coves of islands	within exposed embayments and coves of islands
Subtidal shoal	large-scale hummocky to featureless subtidal mounds of sand	developed in northern parts of the archipelago	comprise the shoals
Subtidal plain	extensive, featureless subtidal surface occurs at water depths of 0–20 m, more usually 5–15 m; gradually deepening to north	developed in deep water of straits and shallow to deep subtidal of embayments	comprise the submarine plains and subtidal parts of embayments

Table 3

*Habitats within geomorphic units*

Geomorphic unit	Habitat	Substrate
Intertidal rocky shore	cliffed shore fissured rock pavement or slope bouldery shore	igneous rock and their bouldery deposits
Subtidal rocky shore	fissured rock pavement or slope bouldery shore gravel pavement	igneous rock and bouldery deposits
Intertidal limestone pavement	limestone cliff limestone pavement	limestone
Subtidal limestone pavement	limestone pavement	limestone
Intertidal flats	salt flats sand flat gravel pavement muddy sand flat shoal tidal creek spit	sand gravel muddy sand mud
Intertidal beach	beach ridge beach	sand
Subtidal shoal	sand flat	sand
Subtidal plain	(muddy) sand/gravel sheet locally limestone pavement	sand gravel muddy sand limestone

geomorphic units may be further subdivided into habitat types on basis of detailed geometry and substrate differences (Table 3).

#### *Habitats*

The term "*habitat*" as used here refers to space which abiotic factors determine as suitable for colonisation by biota. These factors primarily include substrate types and tidal levels. Other factors related to tidal levels include light attenuation, turbidity and salinity. Thus, the combination of substrate type and tidal oscillation provides a range of habitats for benthic organisms. The prism of marine water also is a habitat for a variety of nektonic and planktonic organisms.

The physiography and its configuration largely determine for example, whether a coastline is exposed or protected, eroding or advancing, or composed of plains or ridges and islands; substrates may vary from well oxygenated, mobile, clearly washed sand and gravel in high energy, exposed, beach environments to poorly oxygenated, muddy and bioturbated sediment in low energy, protected, mid-tidal environments; there may be a gently shelving sea-floor, or a steeply plunging cliffed shoreline; or the submarine environment may be one of shallowly submerged irregular rocky areas or relatively deeply submerged flat plains.

Numerous habitat types occur within any given geomorphic unit. For example, within intertidal-flat units there can be distinguished a low-tidal muddy sand habitat, a low-tidal clean sand shoal habitat, a high-tidal mud (to muddy sand) salt-flat habitat. On rocky shores there can be distinguished cliffed shore habitats, bouldery shore habitats, fissured rock

pavements, etc. The subdivision of geomorphic units into these habitats for biotic assemblages is summarised in Table 3 but the details form the basis for further papers that deal with specific biotic assemblages.

#### *Biotic assemblages*

Biotic assemblages are groups of organisms which occur in recognisable habitats; their grouping together is for convenience of description. There is a large range of habitat types, and with a given variation in physiochemical conditions such as wave action, salinity, sediment mobility, there is a corresponding large number of biotic assemblages that inhabit the marine environment of the Dampier region. Most of the biota are markedly restricted to habitat type so that maps of habitats broadly represent boundaries and areas of assemblages.

Defining assemblages, however, can be problematic in that component species vary in abundance locally and one species dominant at one locality may be subordinate in abundance to another elsewhere, yet the overall composition and trophic relationships are essentially the same. The overlap of zones of animals and plants also make it difficult to assign a group of organisms to a particular assemblage. Barnacles, for instance, occur in a mid-tidal zone of encrusting organisms but also extend down to the lower-tide levels of the adjoining assemblage. Thus, boundaries may be gradational or diffuse.

For purposes of this paper the biota of the archipelago has been aggregated into broad assemblages which tend to recur on, and are characteristic of, the broad categories of habitat.

Table 4

*Benthic biotic assemblages and habitats*

Assemblage	Geomorphic unit	Habitat	Tidal level
Oyster-barnacle	intertidal, rocky shore and intertidal limestone pavement	cliffed shore, fissured pavements or slopes, bouldery shore, limestone cliff and limestone pavement	intertidal
Coral	subtidal, rocky shore and subtidal limestone pavement	fissured rock pavement or slope, bouldery shore, limestone pavement	subtidal to depths of 10 m
Mangal	intertidal flat less commonly intertidal rocky shore	muddy sand flat, banks of tidal creeks, edges of spits, boulder shore	mid to high tidal
<i>Notocallista</i> -echinoderm	intertidal flat	sand flat and muddy sand flat	low tidal
Demersal fish-echinoderm-crustacean	subtidal plain	muddy sand/gravel sheet	subtidal
<i>Donax</i> -crustacean	intertidal beach	beach	mid to low tidal
<i>Uca</i> -cerithid	intertidal flat	salt flat	high tidal
<i>Mictyris</i>	intertidal flat	shoal, sand flat	low tidal
<i>Uca-Macrophthalmus</i>	intertidal flat	muddy sand flat	low tidal
Xanthid-sponge	intertidal, limestone pavement	low tidal limestone pavement	low tidal
<i>Ocypode</i>	intertidal beach	high tidal sand	high tidal
Seagrass	subtidal plain, intertidal flat	sand/gravel sheet, sand flat	subtidal, low tidal
Algae	shoal, embayment plain, subtidal rocky shore and limestone pavement	sand flat, sand/gravel sheet, bouldery shore, fissured pavement, limestone pavement	subtidal

The more widespread and important assemblages are: (1) oyster-barnacle, (2) coral, (3) mangal, (4) *Notocallista*-echinoderm, (5) demersal fish-echinoderm-crustacean, (6) *Donax*-crustacean, (7) *Uca*-cerithid, (8) *Mictyris*, (9) *Uca-Macrophthalmus*, (10) Xanthid-sponge, (11) *Ocypode*, (12) seagrass, (13) algae, (14) embayment fish and (15) pelagic fish-plankton.

A summary of the distribution of benthic biotic assemblages in relation to habitats is presented in Table 4. Figures 5, 6, and 7 present typical distribution patterns for these assemblages for several selected areas along the west coast of Burrup "Peninsula".

*Oyster-barnacle assemblage.*—This encrusting assemblage occurs on hard substrates such as igneous rock, limestone and mangrove roots and trunks in the intertidal zone (rocky shore and limestone pavement). The assemblage is zoned with different species and groups of species occurring at different heights. At the top of the intertidal zone an algae slick covers the rocks; at lower levels there is a narrow band of the milky oyster, *Saccostrea* sp. The coral rocky oyster, *Saccostrea cucullata*, forms a broader band below the milky oyster. Barnacles, *Tetraclita porosa* and *Chthamalus* sp. become more abundant below the oyster level and form a distinct zone. The worm-like vermetids form a zone at the lowest level of the intertidal zone. An algae turf occurs at the lower edge of this assemblage. Associated with the oysters and barnacles are a wide range of other molluscs such as bivalves, gastropods and chitons as well as crabs, polychaetes, amphipods and some small fish. Most of these species occur in the crevices in the rocks or the oyster clumps.

This assemblage, with variations, extends throughout the Dampier Archipelago. The major difference in the assemblages between Mermaid Sound and the outer islands of the archipelago is the replacement of the milk and coral rock oyster by the ocean oyster (*Saccostrea commercialis?*).

*Coral assemblage.*—The coral assemblage is totally subtidal occurring predominantly in water of 0-10 m depth. It is an encrusting assemblage on subtidal rocky shores and limestone pavements.

Corals are conspicuous and dominate this assemblage, but there is also a wide range of other fauna, such as seawhips, anemones, echinoderms, crustaceans, reef fish and molluscs including encrusting bivalves, infaunal bivalves and vagile gastropods. Sponges become more abundant where the assemblage is developed on limestone pavement.

Although there are no distinctly different coral assemblages in the various parts of the archipelago, some species of corals are confined to either the seaward reefs or to the more inshore reefs of the archipelago. There is some vertical zonation of the coral species, but it is not sufficiently pronounced that coral assemblages differentiate with depth.

However, the size of coral colonies, their abundance and the associated fauna do vary locally within the assemblage. The most marked variation is that between the assemblage on flat limestone pavement and the assemblage on sloping rocky shores. On the sloping substrates, the coral colonies reach a large size and are closely packed. In contrast, on flat limestone pavements the coral colonies are small and interspersed with a variety of other sessile invertebrates such as sponges, seawhips, zoanthids and anemones.



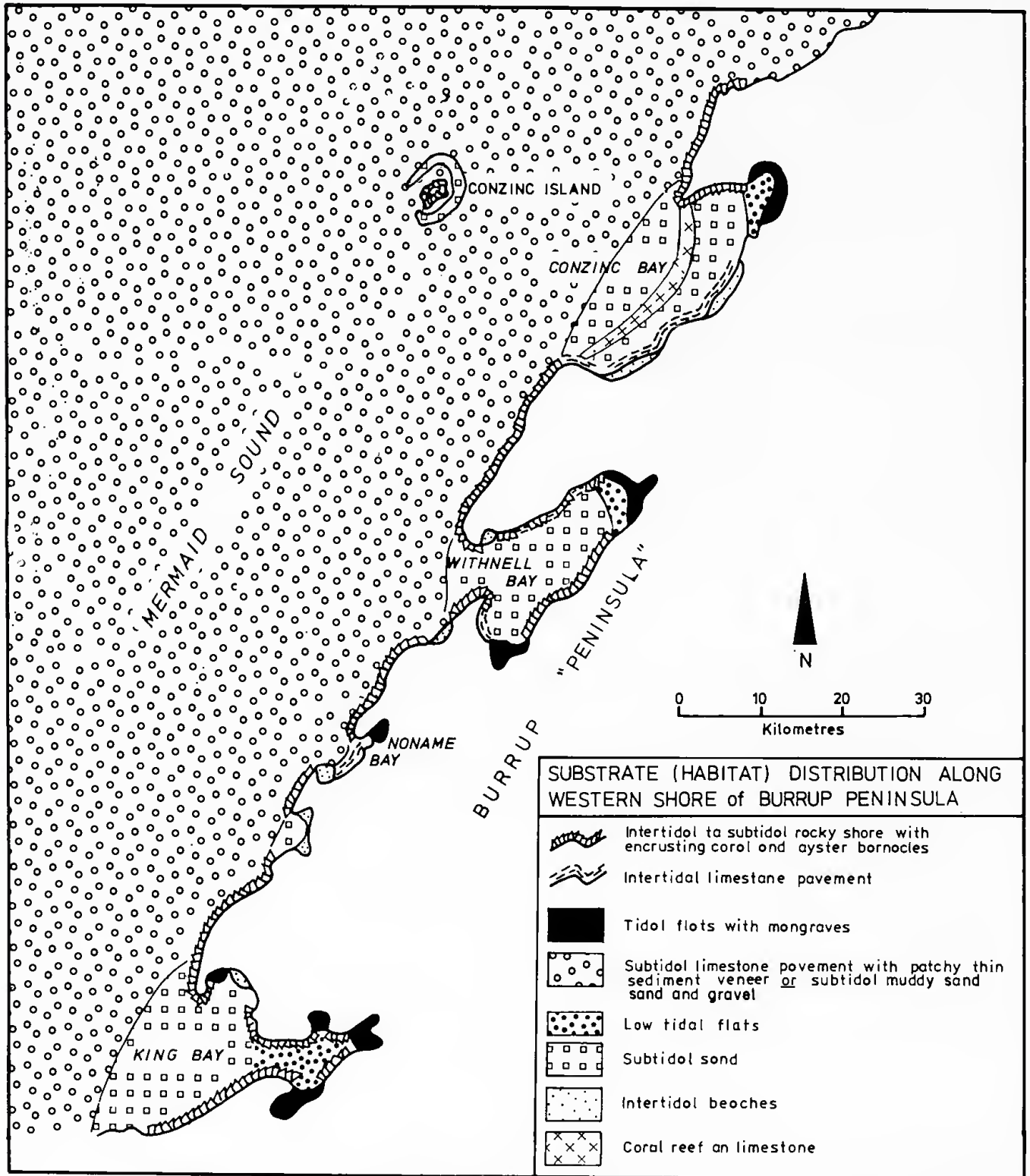


Figure 5.—Distribution of substrates and habitats (biotic assemblages) along the western shore of Burrup "Peninsula".

*Mangal assemblage.*—The mangrove vegetation assemblage is termed a mangal (MacNae 1968). Within this are mangrove trees and shrubs and a benthic fauna. The assemblage mostly inhabits intertidal flats of embayments between mean sea level and high water, though in some locations it occurs on rocky shores in embayments. Mangals vary from being wide tidal formations as at Searipple Passage

and King Bay to narrow fringing formations as at Withnell Bay. In areas exposed to waves, mangals become progressively narrower (1 or 2 trees wide) and finally absent. The most luxuriant mangals occur at the inner portions of embayments where a combination of low-energy conditions and sedimentation provide a gently sloping tidal flat.





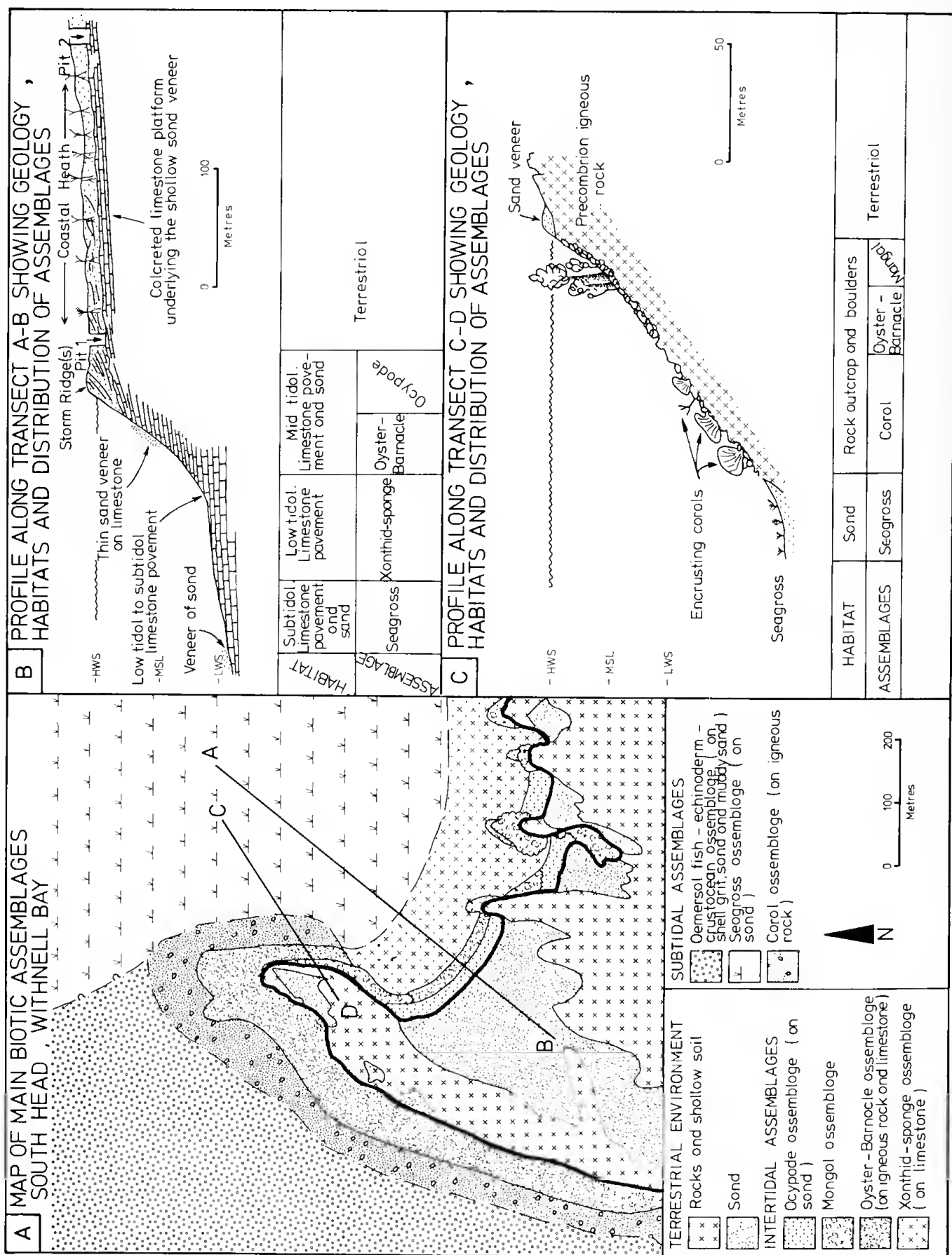


Figure 7.—A.—Distribution of biotic assemblages south head, entrance Withnell Bay; B, C.—Profiles showing distribution of substrate types and biotic assemblages.

Within the mangal there is a pronounced zonation of biota in response to tide levels, salinity and substrate types. *Avicennia marina* forms parklands and shrublands at about mean sea level. Interior parts of the mangal are closed forests of *Rhizophora stylosa* or mixed *Rhizophora*, *Avicennia* and rarer *Bruguiera exaristata*. Landwards parts of the mangal at about high-water spring level are shrublands of *Avicennia* with *Ceriops tagal*. In areas where there are spits, *Bruguiera* occurs with *Ceriops* and *Avicennia*.

Animals in the mangal include crustaceans (*Uca* spp., *Sesarma* spp., *Macrophthalmus*, alpheid shrimps, *Thalassina anomala*, *Epixanthus*, *Scylla serrata*); burrowing worms, vagile gastropods (*Terebralia*, *Cerithidea*, *Telescopium*, *Littorina* and *Nerita*); encrusting organisms (barnacles, bivalves and limpets), and miscellaneous biota such as gobioid fish and chitons. These animals occupy a variety of microhabitats in the mangal. A substantial proportion of the fauna are burrowing.

*Notocallista*—*echinoderm assemblage*.—This benthic assemblage colonises sand, muddy sand and gravel substrates in (low tidal) intertidal flats. It is composed almost entirely of infaunal elements such as bivalves (*Notocallista*, *Anomalocardium*, *Circe*, *Fragum*, *Pinctada*, *Pinna*, *Placamen* and *Modiolus*), crustaceans, worms, brachiopods, burrowing anemones, and echinoderms. On the surface are the gastropods *Natica*, *Cerithium*, *Epitonium*, *Rhinoclavis*, *Cominella* and *Strombus*. Algae and gastropods (*Morula*, *Trochus*) may occur scattered on rocks or larger shells.

The sediment which these organisms colonise is thoroughly bioturbated. During high tide demersal fish and embayment fish invade the habitat which supports this assemblage and feed on the benthos.

*Demersal fish-echinoderm-crustacean assemblage*.—The demersal fish-echinoderm-crustacean assemblage inhabits substrates in water depths of 5-20 m deep in subtidal embayment plains, e.g. Withnell Bay, King Bay and Mermaid Sound. The assemblage is composed of a wide range of demersal fish (such as flatheads, flounders, catfish, eels and rays), echinoderms, polychaetes, crustaceans, gastropods and bivalves. Some of the fish from this assemblage probably move onto the intertidal flats during high tide. Much of the gross variation within the assemblage can be related to substrate types and future work may result in further division of this assemblage.

*Donax*—*crustacean assemblage*.—Exposed beaches occurring in small embayments and tombolo settings support an infaunal assemblage of crustaceans and bivalves (mainly *Donax*) and surface gastropods. On such beaches there is zonation within the assemblage in relation to tidal level. Mid-low tidal zones have the crabs *Scopinera* and *Mictyris*, polychaetes, surface gastropod *Nassarius dorsata* plus infaunal bivalves (*Donax*); low tidal zones have the crabs *Matuta* and, in more oceanic settings, *Callapa*.

*Uca*—*cerithiid assemblage*.—This assemblage inhabits high-tidal salt flats shoreward of mangroves on intertidal flats. The surface of the substrate may be caked with a film of blue-green algae. Fauna includes the burrowing crabs *Uca* spp., *Metopograpsus* and *Sesarma*, and, in addition, the gastropod *Cerithium* sp.; salt bushes occur on higher parts of the flat.

*Mictyris assemblage*.—This is a benthic assemblage dominated by the soldier crab *Mictyris* which inhabits low-tidal sand shoals on intertidal flats. Bivalves, brachiopods, echinoderms and the sand-bubbler crab *Scopinera* form a minor component.

*Uca*—*Macrophthalmus assemblage*.—This assemblage is dominated by crabs *Uca* spp. and *Macrophthalmus*, and occurs on low-tidal muddy-sand flats and shoals of intertidal flats. Bivalves, echinoderms and worms form a minor part of the assemblage.

*Xanthid-sponge assemblage*.—The xanthid-sponge assemblage occurs on low-tidal limestone pavements in embayments. The assemblage includes several species of xanthids (*Pilumnus*, *Atergatis*), encrusting to erect sponges, tube worms, gobioid fish, bivalves (*Tridacna*, *Barbatia*), scattered corals and algae.

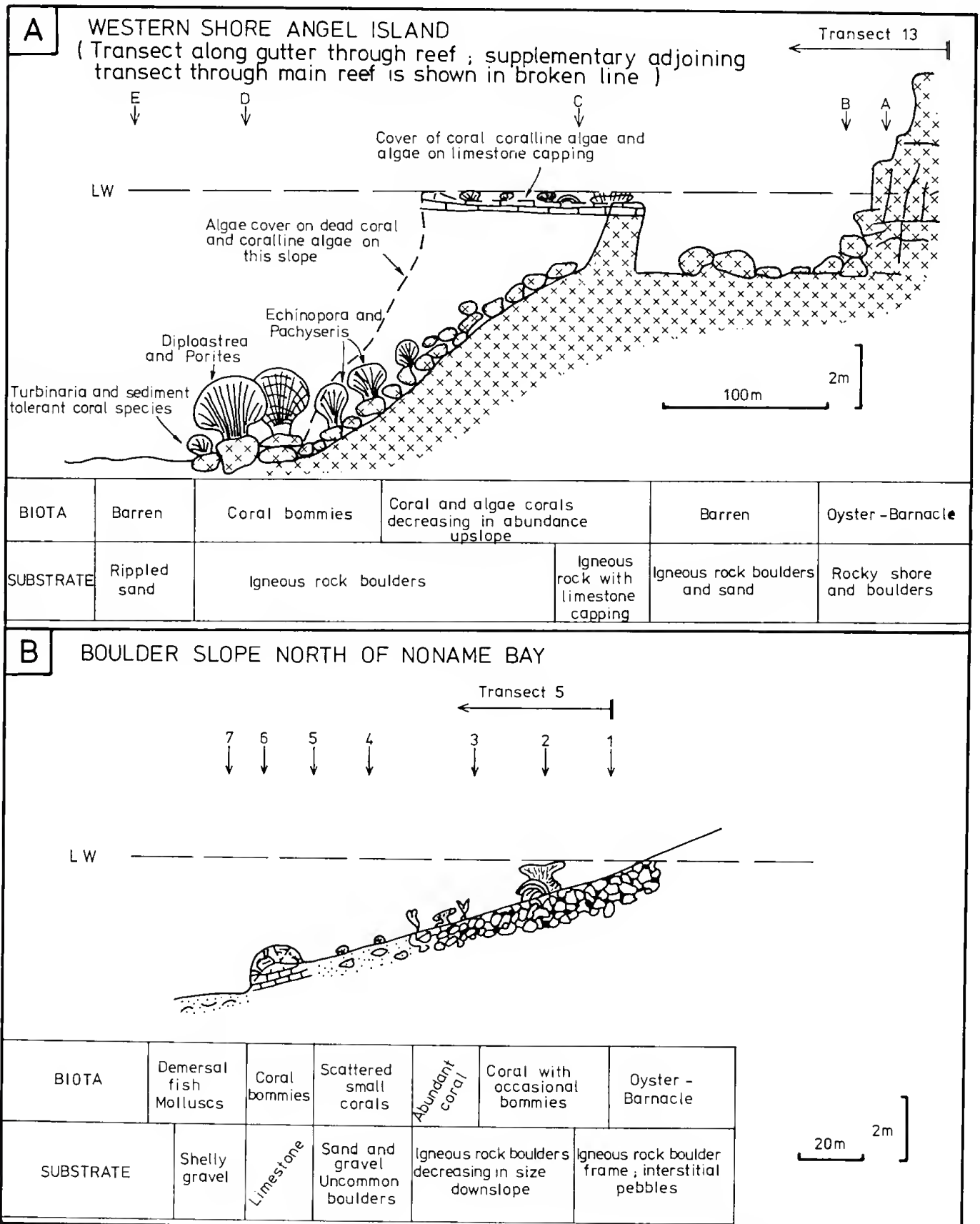
*Ocypode assemblage*.—The *Ocypode* assemblage occurs on high-tidal to supratidal parts of sandy beaches and spits. Fauna includes the ghost crab *Ocypode*, hermit crabs *Coenobita* and amphipods.

*Seagrass assemblage*.—This assemblage occurs on low-tidal sand flats and shallow subtidal embayment plains with substrates of sand and mud-sand; the assemblage typically occurs in the larger bays of Burrup "Peninsula". The seagrass *Halophila* (*H. ovalis*, *H. decipiens* and *H. spinulosa*) is sparse, but occurs throughout this assemblage. In some areas of shallow water, green algae are abundant during winter. Invertebrates (including echinoids, holothurians, molluscs, crabs) and demersal fish are locally abundant.

*Algae assemblage*.—Macroscopic algae colonise various types of subtidal substrates in the shallow waters of the archipelago. These substrates include sand/gravel sheets of embayment plains as well as shoals, bouldery shores and limestone pavements. The species, diversity, abundance and distribution of algae within the archipelago varies markedly in response to habitat, abundance of herbivores and seasonal and sporadic phenomena (such as cyclones). At a later stage with more detailed work this assemblage may be further subdivided.

The shoals of the outer archipelago contain the greatest diversity, and amount of algae of any of the areas examined. However, these characteristics were not consistent throughout this habitat. In places, brown algae were the most abundant algae group with the genus *Dictyopteris* being most frequently observed. The green algae were dominated by the articulated corallines. *Halophila spinulosa* was the most abundant species of angiosperm. Whilst algae were the main biotic components on shoals, areas of barren sand ridges occurred in places. Other organisms which occurred in the algal assemblage on shoals included molluscs, corals, echinoderms, crabs and fish.

Elsewhere plant cover was less and brown algae, whilst still abundant and diverse, were dominated by fucoid species. Similarly, amongst the red algae, the non-corallines were more abundant. In other places on limestone pavements where there was no sand veneer the algae were dominated by crustose corallines and algal turf (*Jania* sp.).





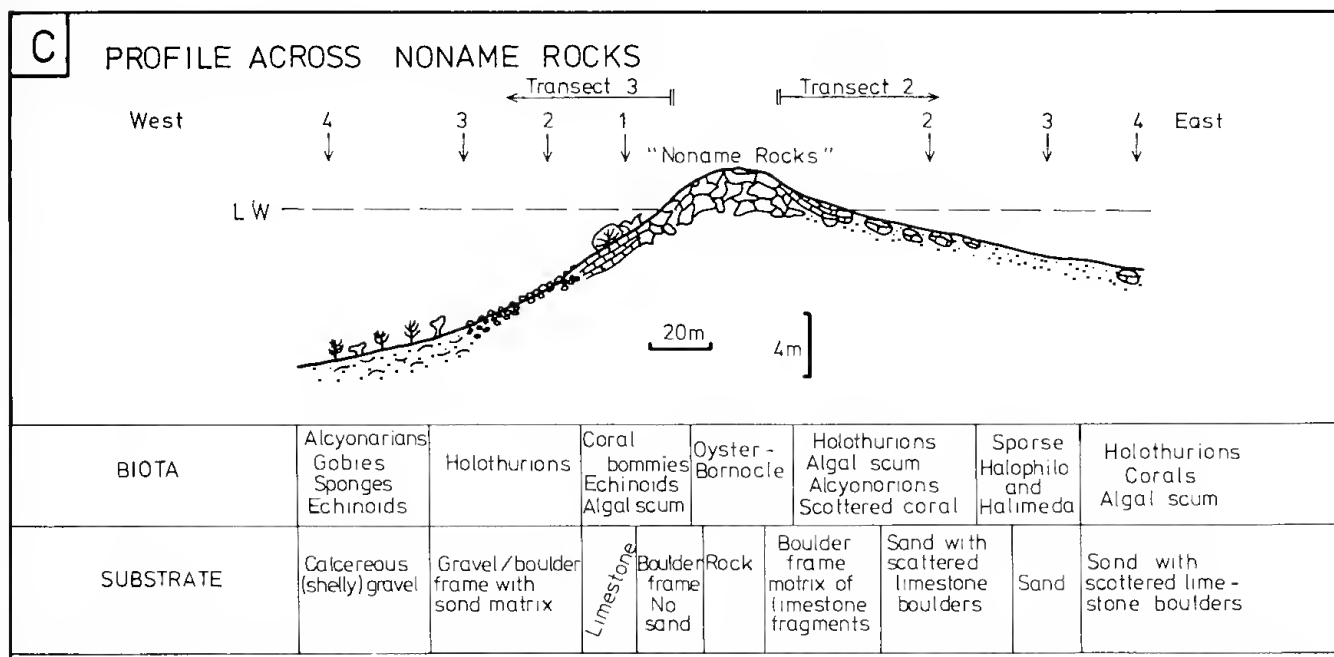


Figure 8.—Profiles (along transects 2, 3, 5 and 13; see Fig. 2A) showing distribution of substrates and biota.

The algal assemblage which occurred in protected embayments such as Conzinc Bay was also dominated by the brown algae; *Sargassum*, *Dictyopteris* and *Padina* being the more abundant genera. Other genera of brown algae (*Zonaria*, *Dictyota* and *Turbinaria*) occurred in minor abundance.

*Embayment fish assemblage.*—The embayments along Burrup “Peninsula” support an abundant and diverse assemblage of fish. Although these fish move between embayments and are consequently also found outside the embayments, they are most abundant, and appear to spend a substantial amount of their time within the embayments. The composition of the fish assemblage varies to some extent depending on whether the embayment is small, exposed and has a sandy beach, or is large and protected with extensive sand-mud flats and mangroves.

More fish occurred on the sand-mud tidal flats around the margins of the larger bays than on the sandy beaches of the small, exposed bays. This is probably because the sand-mud flats and mangrove-based detritus of the larger bays supported a rich benthic fauna which in turn provided a food source for fish.

Additionally the larger bays supported a greater total number of fish because of their greater area. Most juvenile fish also occurred in the shallow waters of the larger embayments. The shallow waters of the embayments also provided a refuge for the embayment fish from larger predatory fish.

*Pelagic fish-plankton assemblage.*—The open water areas of the Dampier Archipelago contain fast-swimming predatory fish such as sharks, mackerel, cobia, trevally and queenfish. Small baitfish were also plentiful in the surface water. Mackerel were either

planktivorous or piscivorous depending on the food sources present in the open water. However, most of the other tidal fish of open waters moved onto the sand-mud tidal flats of the embayments during high tides and these shallow water areas probably provided the food source for many fish. The other major component of this assemblage is the plankton. Phytoplankton which are present in low densities throughout the year, are particularly obvious when blooms occur. Blooms of dinoflagellates are responsible for producing “red-tides” which occur periodically through the spring, summer and autumn.

*Distribution in the archipelago*

The biotic assemblages and habitats in the archipelago have been mapped both extensively at the regional level and intensively at the local level. Distribution of the broad habitats and their associated assemblages are illustrated in Figure 5. This shows most habitats/assemblages are widespread along the shore of Burrup “Peninsula”. Virtually every shoreline in the archipelago has exposed and semiprotected settings within which are tidal and subtidal (rocks, limestone, sand/gravel and muddy) substrates. More detailed distribution of habitat/assemblage is illustrated in maps and transects of selected areas and these are typical representations of the regional picture (Figs. 6-8). These areas show a complex distribution pattern in the nearshore and tidal environments.

This variability reflects firstly the heterogeneity of soils and landforms that existed prior to the post-glacial Holocene transgression, and secondly the types of physical processes (erosion versus sedimentation) that are operating at present along the nearshore and shoreline environments.

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## Notes on the biogeographical regions of Australia

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### Abstract

Ever since Tate published his paper in 1887 on the biogeographical regions of Australia and designated the arid interior as the Eremian, zoologists and botanists have defined a wide range of regional zones resulting in an increasingly complicated system of nomenclature. A review of numerous papers indicates a general acceptance of the central arid region, but a diversity of views as to the number and demarcation of the peripheral zones. No evidence has been found to support the substitution of "Eremean" or "Eremaean" for Tate's original spelling "Eremian".

### Introduction

Ever since Professor Ralph Tate (1887) presented his paper "On The Influence of Physiographic Changes in the Distribution of Life in Australia" and divided the continent into three major regions, biologists have questioned the legitimacy of the regional boundaries and the appropriateness of the nomenclature used. Tate (1887, p. 315) defined his regions as follows:

1. Euronotian (lit. south-east wind) dominant in the south and east parts of the Continent.
2. Autochthonian (lit. of the original race) restricted to the south-west corner of West Australia, and approximately co-inciding with the rain-fall limit of twenty inches.
3. Eremian (lit. desert) dominant in the dry region, which has its centre in the Lake Eyre Basin."

Hedley (1894) and Baldwin Spencer (1896) gave general support to Tate's regions, but Spencer divided the Euronotian into the Torresian (northern tropics) and the Bassian (cool south) subregions and used the word Eyrean (after Lake Eyre in South Australia) to include Tate's Eremian and Autochthonian Regions (Serventy and Whittell 1948).

### Australia

As knowledge of animal and plant distribution increased it became clear that the early biogeographical regions did not fit all circumstances and that while certain basic subdivisions could accommodate most disciplines the exact lines of demarcation between the different areas and the numbers of subregions would depend largely upon the groups studied (McMichael and Iredale 1959). For instance Serventy and Whittell (1948) working on birds do not agree that South-western Australia as defined by Spencer is typically Eyrean and produce convincing evidence, confirmed by numerical computer analysis (Kikkawa and Pearse 1969), to show that the region is a blend of Eyrean and Bassian elements. Littlejohn (1967) working with frogs supported this view, but Tyler (1976,

p. 185) studying the same group saw no reason to modify Spencer's boundaries. However, he did acknowledge that "No scheme of provinces is going to satisfy all zoologists and the situation occurring in the south of the continent is a prime example of the problem that exists."

Key (1959, p. 207) working with grasshoppers stated "The distribution and taxonomic relationships of the Australian Acridoidea certainly suggest relative discontinuities in the vicinity of Spencer's boundaries. However, grasshoppers are more sensitive to the environment than Serventy and Whittell's birds (being poikilotherms of lower vagility), so that it is understandable that the significant ecological cliffs should be more numerous..."

Whitley (1959) recognised nine subdivisions as appropriate to Australian freshwater fishes and stated that these are supported by other freshwater fauna, including tortoises, crustacea etc. His subdivisions are based mainly upon drainage systems and include a central Sturtian region (which includes much of the Eremian) and a northern Leichhardtian region which incorporates a large portion of Spencer's Torresian subdivision.

Sloane (1915) working on beetles recognised ten subdivisions, but another entomologist, Paramonov (1959) working with Diptera recognised only two major "subregions"—*Australica deserta* and *Australica sylvatica*, although he distinguished three subdivisions of *sylvatica*. McMichael and Iredale (1959) studying molluscs defined seven areas and Campbell (1943) working with birds described twelve separate zones.

Pianka (1969) specialising on lizards (*Ctenotus*) divided the central desert (Eremia) into 13 subdivisions or provinces and Doing (1970), by calling the Eremian the Central Australian Subkingdom and the remaining periphery the Eucalyptus Subkingdom, recalls Paramonov's two major subdivisions. However, Doing goes much further with his regions or provinces and recognises 25 subdivisions in all.



Although the lines of demarcation used in the different systems do not coincide there is basic acceptance of a large central desert region and a variable number of peripheral zones. Furthermore there is increasing support by zoologists for Whitley's (1959, p. 141) warning against regarding "our division of Australia into areas... as hard and fast outlines." Serventy and Whittell (1948, p. 47) studying birds have shown that "instead of thinking of fixed regions it is necessary to think of fluid faunas." The range of these faunas may expand or contract in response to geological and climatological changes and they are particularly sensitive to alterations in rainfall and vegetation types.

### Western Australia

At the State level the study of biogeographical regions has received most attention in Western Australia and the earliest work was done by Mueller (1867) who stressed the specialised nature of the South-west flora. Diels (1906) recognised a South-west botanical province and the dry Eremaean (sic), and with some modifications this was supported by Gardner (1942), who divided the State into a South-west Province, a Northern Province (including the Pilbarra) and the Eremaea (sic).

Clarke (1926, p. 118) divided the State into 15 natural regions which "should be in harmony with the distribution of distinctive plant associations" and determined the subdivisions by the simultaneous consideration of topography, geology, rainfall and vegetation. Burbidge (1960) divided the continent into three "Principal Floristic Zones"—the Tropical, the Temperate and the Eremaean, but her major divisions differ little from those of most other workers and her treatment of Western Australia is in broad agreement with the earlier work of Gardner and Bennetts (1956).

Beard (1980) draws attention to the fact that regional maps of Australia suffered in the past from small scale and inadequate basic information, but adds that while preparing vegetation maps at the 1:1 000 000 scale covering the greater part of Western Australia he came to appreciate the reality of the "ecological regionalisation" of both Clarke and Gardner. Beard (1980, 1981) accepts the major provinces of Gardner (1942) and of Burbidge (1960), but divides the Eremaean into 11 districts and excludes much of the Pilbarra (Fortescue district) from the Northern Province. He makes certain other boundary adjustments based upon the increased topographical and botanical information now available from aerial photography and expresses the hope that "the system now becoming available... be of use to workers in other fields as well." (Beard 1980, p. 47).

It will be many years before the distribution of the major zoological groups has been mapped in the detail which now applies to vegetation. As a result of the "Bird Atlas" study now being conducted by the Royal Australasian Ornithologists' Union knowledge of bird distribution will be improved greatly in the near future, and it is to be hoped that this will not lead to a spate of new zoogeographic terms and boundaries. Already Davies (1979) writing on the breeding seasons of birds has introduced another element by adapting the subdivisions used by the

Commonwealth Bureau of Meteorology, but as may be expected these areas show important similarities with several other systems, including Spencer's (1896) and Clarke's (1926).

### Discussion

The present review has shown that almost all specialists can produce plausible reasons to support an individual set of geographical subdivisions appropriate to their particular interests. On the other hand the wide acceptance of Spencer's major regions together with appropriate subregions could meet the main requirements of many biogeographers and reduce the confusion which now exists in this field.

However, Moore (1961) warns that in their efforts to delimit zoogeographical areas in Australia no one has set out a clear basis for recognising a zoogeographical region and although this is often assumed to be obvious it is not. He does not question the validity of the major zoogeographical divisions of the earth with Australia and some nearby islands as a single region. He sets out four criteria which may be used to test the validity of a zoogeographical region or subregion and these are summarised as follows:

1. A zoogeographical region must have boundaries which can be determined with a moderate degree of precision.
2. A zoogeographical region should have fauna markedly different from that of the adjacent zoogeographical region.
3. A significant proportion of the fauna of the zoogeographical region should have ranges approximately co-extensive with the region.
4. A zoogeographical region should be an area isolated at the present time or during its past for a sufficient period of time to have allowed the faunas to differentiate.

Moore also suggests that zoogeographical regions should have other attributes, if possible, such as applicability to many groups.

Using Moore's (1961) criteria "we can recognise a distinct zoogeographical region in the south-west, but the rest of the continent cannot be divided in any satisfactory manner." He contends that the wide support for the conventional zoogeographical regions in Australia "comes... more from the zoogeographers than from the fauna." The Australian frogs seem to support his views and he counters the argument that the details of distribution for many frogs are not yet known by claiming that "better data are required for establishing the reality of a zoogeographical region than for questioning its validity."

### Nomenclature

Almost as much discussion has hinged around the nomenclature used for the various subdivisions as the demarcation of the actual boundaries. The terminology of Tate (1887) was not accepted by Spencer, who extended the Eremian to include Tate's Autochthonian and divided Tate's Euronotian into the northern Torresian and the southern Bassian. Nicholls (1933) criticised the term "Autochthonian" on the grounds that each area could have its own autochthonous elements and suggested the "Hesperonotian" (western) as more appropriate.



Paramonov (1959, p. 180) criticised such words as "Autochthonian" and "Euronotian" and said "the use of such terms only overburdens our minds with new words." He then added further to the confusion by suggesting two new subdivisions—Australica deserta for the arid centre (Eremian) and Australica sylvatica (wooded) for the periphery. This he divided further into Australica westralica, Australica bor-orientalis and Australica merorientalis.

The word Eremia, first used by Tate (1887) has aroused considerable discussion based upon its derivation and spelling. Diels (1906) gave no explanation for changing the spelling to Eremaea and this form was used by Burbidge (1960) and Beard (1980). However, Gardner (1942) used the spelling Eremaea, also without explanation and this form was retained by Gardner and Bennetts for their work on toxic plants in 1956. Tate's original spelling was used by Harrison (1926), Nicholls (1932) and Moore (1961) although most zoologists have avoided the issue by following Spencer's terminology and using the word Eyrean for the dry interior.

It has been suggested that Diel's use of the term Eremaea to replace Tate's earlier Eremia may have been based on Lindley's spelling of *Eremaea* for a genus in the family Myrtaceae. Another suggested explanation is that, as Webster's Third New International Dictionary defines Eremian as a division of the Palaearctic region, including the North African and Asiatic deserts, a different spelling should be used for comparable regions elsewhere. However, in the absence of any evidence to support these suggestions they carry little weight. There seems little doubt that the correct spelling is Eremia, as the word comes from the Greek meaning a solitude, a wilderness or a desert. It has given the English language the word hermit—a hermit and is the basis for several scientific names including *Eremiornis carteri* for the spinifex bird or Carter's desert-bird and *Eremianthus* for another genus of inland birds.

### Conclusion

The current state of knowledge gives a fairly clear indication of why the boundaries of biogeographic regions do not meet the strict criteria proposed by Moore (1961). Indeed, it would be strange if it were so, because the biota is clearly of two origins with forms of each origin adapted to past climates, with the consequence that each worker will produce a different biogeographic classification depending on the component or components of the biota which he chooses to use. The biota closely adapted to broad climatic factors clearly yields a classification like that of Baldwin Spencer, while one which recognised the original components of the biota would clearly recognise Autochthonian regions. Future biogeographic studies need to recognise that different groups of plants and animals have different capacities to handle climatic fluctuations, and hence their distribution will reflect this. Moreover, the old and newer components of the biota may be restricted in terms of climate or minor habitats, and it would seem to be reasonable for future workers to try and unravel the likely past history of the group or groups being used in biogeographic studies, so that the assumptions about the suitability of the group for distinguishing biogeographic boundaries become explicit.

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Contents

	Page
Floristic ecotone between Quaternary sandridges and Jurassic sedimentary rocks near Mowla Bluff, Great Sandy Desert. By Ralf Buckley (communicated by Angas Hopkins) .....	87
Misapplication of the Aboriginal name "Gungurru" to <i>Eucalyptus caesia</i> Benth. and notes on the species' distribution. By Barbara L. Rye and Stephen D. Hopper .....	93
The marine environments of Dampier Archipelago. By V. Semeniuk, P. N. Chalmer and I. Le Provost .....	97
Notes on the biogeographical regions of Australia. By C. F. H. Jenkins .....	115

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## *Austroassiminea lethae*, gen. nov., sp. nov., a rare and endangered prosobranch snail from south-western Australia (Mollusca: Prosobranchia: Assimineidae)

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### Abstract

A few isolated freshwater seepage areas between Turner Brook north of Augusta and Ellen Brook north of Margaret River in the south-west corner of Western Australia support populations of *Austroassiminea lethae*, which is described as a new genus and species of the prosobranch family Assimineidae. Anatomical structures differentiate it from previously described assimineids and suggest strongly that it is a phylogenetic relict. Pleistocene fossils are known from several places on the coast, as far east as Point d'Entrecasteaux. Each of the three known living populations is small and in danger of destruction from agricultural or other human activity. Efforts are needed to preserve this important relict component of the Western Australian fauna.

### Introduction

Subfossil specimens of a small "terrestrial" prosobranch were taken first at Cosy Corner by Barry R. Wilson in 1963. Subsequent collections by Anne Paterson (Brearley) from Turner Brook in 1971 and by Shirley Slack-Smith from Ellen Brook in 1975, have been supplemented by further collections in 1980 by Shirley Slack-Smith, George W. Kendrick and Mike Ellis. Materials adequate for description and tentative classification are now available.

Assimineids are common in South-east Asia and Indonesia through New Guinea and onto the Pacific Islands, but this is the first anatomically studied species for the family in Australia. A salt-marsh species from Tasmania and New South Wales, "*Assiminea*" *tasmanica* Tenison Woods, 1876, is placed correctly in the family Assimineidae; generic assignment must wait publication on its anatomy by Dr W. F. Ponder. The features of the new taxon, *Austroassiminea lethae*, combine characteristics of the two generally recognized subfamilies of the Assimineidae, and no closely related extralimital genera could be identified. There is a long history of exotic organisms having been introduced to Australia. Therefore, considerable efforts were made to compare this species with extralimital taxa. The occurrence of *Austroassiminea lethae* in presumed Pleistocene fossil soils from the south-western coast of Western Australia (Fig. 13) is additional strong evidence for it being an endemic faunal element.

The present study is a cooperative effort with different primary responsibilities: Alan Solem provided the systematic descriptions, comparisons, SEM analyses and photographs, and did much of the dissection work and supervision of the illustrations; Elizabeth-Louise Girardi worked extensively with illustrator Elizabeth Liebman and Alan Solem on the anatomical structures and interpretations; Shirley Slack-Smith is

primarily responsible for the data on ecological occurrence and field collections; and George W. Kendrick did much of the fossil collecting and provided data on the geology and interpretation of the deposits.

All specimens used in this study are presently located in the collections of the Western Australian Museum (WAM) and the Field Museum of Natural History (FMNH).

### Ecological occurrence

All collections of active individuals have been in actual seepage films or splash zones by small freshwater streams near the coast. Fissured rocks or talus through which the water can trickle are present. Aestivating and recently dead individuals have been taken on logs, leaves and rocks immediately adjacent to such areas. These findings probably represent wide-foraging individuals stranded by increasing dryness. The main reservoir of the populations would be inside the boulder fissures or talus, where either a minor flow of water or very high humidity would prevail even in mid-summer drought. The source of this water is runoff and percolation from areas lying further up the drainage basin of each stream. In all cases the water drains from areas of limestone and, in some, directly from the contact zone between the limestone and the underlying granitic rock. The Turner Brock site involves present or proposed agricultural areas that are subject to chemical spraying and/or fertilizer applications. The effects of such chemicals on amphibious snails are not known. They are highly unlikely to be beneficial, and probably are quite harmful. The limited extent and thus small size of this population does not provide a margin for experimentation as to such effects. The immediate steps necessary to minimize the possibility of extinction occurring would be to ban chemical applications on the few hectares immediately involved in seepage drainage through the known live snail area.

Although the snails are clearly associated with freshwater seepage areas, the lack of any gill remnant, and the fact that they will at least temporarily seal to a log, leaf or rock, indicates that they are marginally terrestrial. All known live occurrences of *Austroassiminea lethia* are well above tidal or ocean spray influence. These snails are best considered to be amphibious in the same sense as the North American *Pomatiopsis* (see Dundee 1957). The limited and spotty distribution of *Austroassiminea lethia* is typical of such taxa, and also reflects the limited number of suitable habitat sites in south-western Western Australia.

### Systematic review

The most recent reviews of the Assimineidae (Thiele 1927, 1929) provide a framework for generic reference. Abbott (1958) produced an excellent review of the Philippine members of the genus *Assiminea*, which gives entry to the widely scattered literature on this group. Known habitats range from mudflats through amphibious situations to dry upland forest areas. Habitat occurrence does not correlate with the admittedly form genera currently used. The most obvious anatomical features differentiating assimineids from members of the hydrobioid groups are their pectinate marginal tooth, relatively simple lateral teeth and general lack of basal denticles on the rachidian tooth of the radula. Unfortunately, few assimineids have been dissected in detail, so that only limited anatomical comparisons can be made with other genera.

#### Family Assimineidae

##### Genus *Austroassiminea* gen. nov.

**Diagnosis:** The simple snout without an accessory cape, absence of accessory basal plates for the lateral teeth, lack of basal denticles on the rachidian radular tooth, pectinate single marginal tooth, paucispiral operculum without posterior protrusions, retention of long tentacles, huge penis with bifurcate tip and internal vas deferens but no lateral protrusions, and simple female system combine aspects of the family-level units Assimineinae (= Syncerinae) and Omphalotropidinae as delineated by Abbott (1949, p. 262) and Tutuilanidae of Hubendick (1952). Most genera traditionally referred to these complexes are known from shell and operculum only. Radular cusps, shape of the verge, and external features of the head region have been recorded for a few taxa, but details of the internal anatomy equivalent to those presented here are not recorded in the literature. The form genera *Assiminea* Fleming 1828, *Paludinella* Pfeiffer 1841 and *Omphalotropis* Pfeiffer 1851, with which *Austroassiminea lethia* might be associated, differ in most of the above characters (see Abbott 1949, 1958).

**Description:** Foot not divided, a prominent lateral groove extending from mantle cavity to head. Tentacles long, with raised eyespots lateral to base. Snout of moderate length, no cape or shield present, terminating in two lips reaching slightly beyond mouth, which is a vertical slit. Operculum paucispiral, corneous, nucleus acentric, no trace of calcareous deposits. Radula taenioglossate. Rachidian tooth without basal denticles; normally 7 denticles on upper edge, central largest. Laterals multicuspid; inner with greater variation in denticle size, weak

protrusions on inner side of base which is shovel-shaped. No accessory basal plates. Outer lateral with flatter, tapering base, sharply recurved denticles. Marginal tooth fan-shaped, pectinate, with minute recurved denticles. Male with enormous verge having a bifurcated tip and internal vas deferens. An unusual release valve from the vas deferens enters the hindgut. Suprapallial structures of male system relatively simple. Female with small spermatheca, seminal receptacle a kinked area in upper oviduct; pallial oviduct large, U-shaped, with vaginal orifice near anus.

**Type species:** *Austroassiminea lethia* n. sp.

**Remarks:** Intertidal, supratidal, freshwater and terrestrial species of similar conchological mien from most continents have been referred to the Assimineidae and to the form genera *Assiminea* Fleming 1828, and *Paludinella* Pfeiffer 1841. Recorded data on these species consist mostly of shell and opercular features that are notoriously subject to convergent simplicity. Occasional outlines of radular denticles and the upper parts of the basal plates, or of the extended head and foot, plus an outline of the cephalic verge complete most available data. Abbott (1958) monographed the Philippine Islands *Assiminea*, greatly extending our knowledge of structure, although he was (p. 224) "...unable to satisfactorily work out the female genital system." In an earlier paper, Abbott (1949) described several new assimineids from the Mariana Islands and provided expanded definitions of the subfamilies Assimineinae (under the name Syncerinae) and Omphalotropidinae, even hinting that they might be separate families. Turner and Clench (1972) recorded some data on *Omphalotropis nebulosa* Pease 1872 and *Pseudocyclotus levis* (Pfeiffer 1855) from the Solomon Islands.

The level of recorded knowledge for extralimital taxa is thus meagre, which makes meaningful comparisons difficult. Since *Austroassiminea* agrees with the Assimineinae in snout and operculum, but with the Omphalotropidinae in length of eye stalk and pectinate marginal tooth on the radula, doubt is cast on the reality of current suprageneric categories in the Assimineidae. We choose to ignore the subfamily and tribal names of Thiele (1927, 1929), since they appear to be artificial pigeonholes based on inadequate evidence, and classify *Austroassiminea* only to family level. It is quite possible that monographic revisions will split the family or attach sections to other family units. Consideration of such changes is well beyond the scope of this study.

Data on the anatomy of some Pacific island taxa are given by Abbott (1949, 1958). Quick surveys of Melanesian and Polynesian assimineids in the alcohol collections at Field Museum of Natural History showed a pattern of these species having both a proboscis cape and a deep posterior slit on the foot, characters that Abbott (1949, 262) used as subfamily features for the Omphalotropidinae. Both of these features are absent from *Austroassiminea lethia* (see Fig. 12). While some of the Pacific island taxa have similar-appearing shells, the above differences in external anatomy alone are sufficient to exclude congeneric classification of *Austroassiminea* with any of the genera based on Pacific island taxa that Abbott (1949) included in the Omphalotropidinae (*Omphalotropis* Pfeiffer 1841, *Paludinella* Pfeiffer 1841, *Electrina* Gray 1850, *Quadrasiella*



Moellendorff 1894, *Garrettia* Paetel 1873, *Allepithema* Tomlin 1931, *Thaanunnella* Clench 1946, or *Wrayanna* Clench 1948). The pectinate marginal teeth of the radula in *Austroassiminea* are a major difference from the situation in *Assiminea* Fleming 1828, *Acmella* Blandford 1869, *Turbacmella* Thiele 1927, and *Conacmella* Thiele 1927, taxa that although lacking the proboscis cape and posterior foot slit, have much shorter eye-stalks and non-pectinate marginal teeth on the radula.

It is quite possible that these characters considered by Abbott (1949, 1958) as indicative of suprageneric categories will be shown to be less important when the family is revised, but such a revision cannot be undertaken at this time.

The combination of features listed for *Austroassiminea* in the diagnosis is very different from the combinations recorded for any of the above genera. This, combined with the extreme geographic isolation of *Austroassiminea* from potential relatives (see diagnosis of the species for comparisons), makes description of a new genus necessary.

The name *Austroassiminea* refers to both its geographic position and taxonomic relationship to the assimineid complex.

*Austroassiminea lethae* sp. nov.

(Figs. 1-12)

*Type locality*: Cosy Corner, Hamelin Bay, near Augusta, Western Australia, ca. 34° 15' 05" S, 115° 01' E, under tussocks of grass on granite cliffs near coast wet by seepage from limestone-granitic rock contact above.

*Holotype*: WAM 71.80, adult shell, probably a female. Collected by Anne Paterson (Brearley), 8 July 1971.

*Paratopotypes*: WAM 778.66, WAM 472.80, WAM 477.80, WAM 478.80, WAM 479.80, WAM 699.80, FMNH 200985, FMNH 200986.

*Paratypes*: Deepdene Cliffs, near Augusta, from seepage area, moss and *Agonis* leaf litter, foot of cliffs, ca. 34° 15' 09" S, 115° 03' E, WAM 476.80, FMNH 200987; Deepdene Cave area near Lakes Rat Hole, Cave 3, 0-0.1 m, WAM 1175.69, subfossil; Turner Brook near Deepdene Cliffs, ca. 34° 15' 09" S, 115° 03' E, WAM 475.70, WAM 694.80, FMNH 200989; entrance to Meekadorabbie Cave, Ellen Brook, 33° 54' 36" S, 114° 59' 40" E, Leeuwin-Naturaliste National Park, WAM 693.80, WAM 695.80, WAM 696.80; upstream from Ellensbrook homestead, under logs, 2-3 m above water level, WAM 700.80, WAM 701.80; below dam on Ellen Brook, WAM 697.80, WAM 698.80, FMNH 200988; Ellen Brook, ca. 33° 54' 10" S, 114° 59' 30" E, WAM 473.80; Sta. WA.284, banks of Ellen Brook, east of homestead, FMNH 200598. Fossil at: on the coast west of Strongs Cave, south end of North Point, 34° 09' 41" S, 115° 01' 23" E, WAM 68.385, WAM 81.19, FMNH 198759; Donnelly River mouth, ca. 0.5 m (0.8 km) south-east of the river mouth, ca. 34° 29' 24" S, 115° 40' 38" E, WAM 70.2691, WAM 70.2692; ca. 0.5 m (0.8 km) north of Windy Harbour townsite, quarry on south side of track to Salmon Beach, 34° 49' 14" S, 116° 00' 52" E, WAM 70.895, WAM 70.897, WAM 70.898.

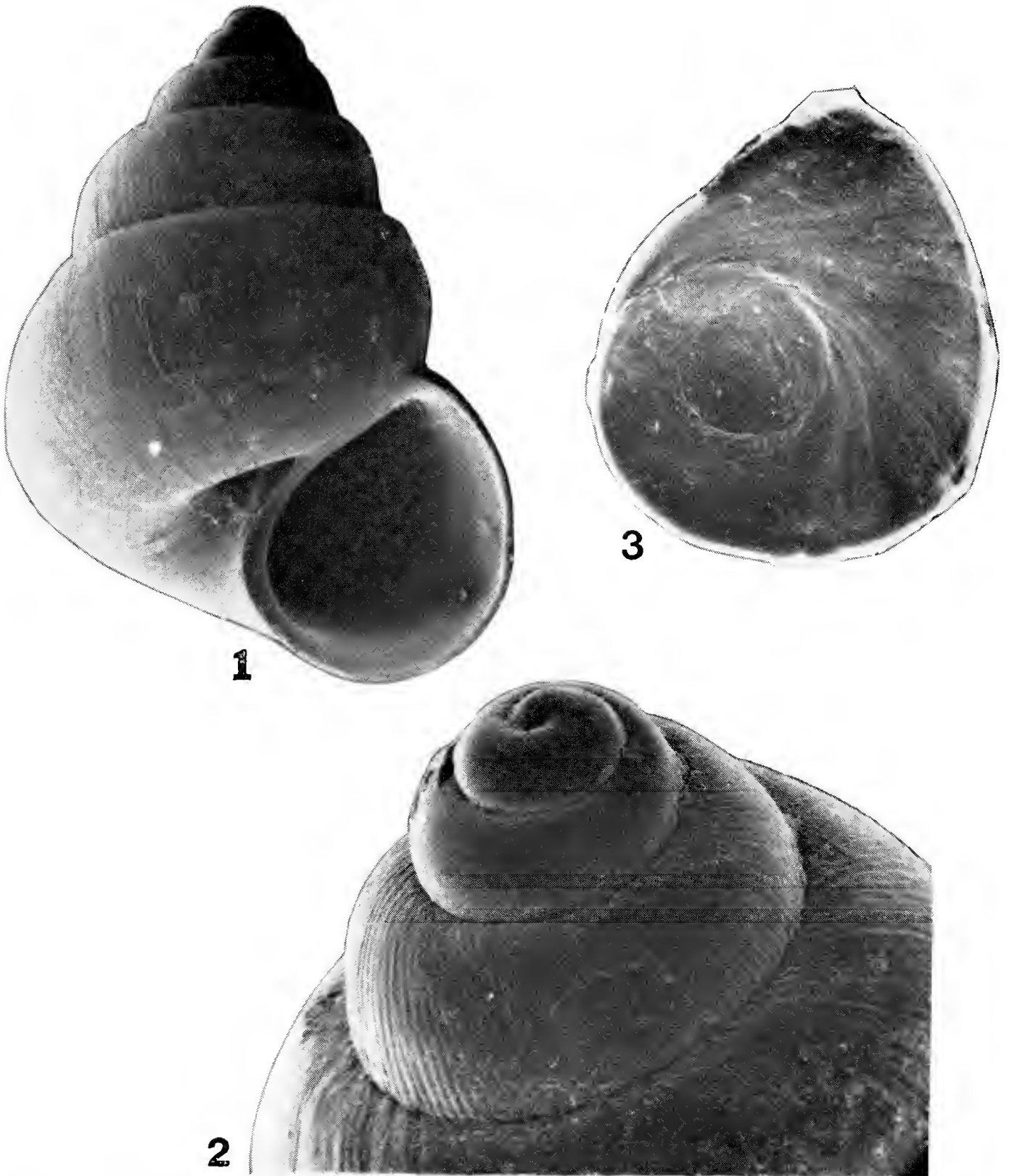
*Diagnosis*: The combination of smooth apex, moderate radial ribbing on the upper spire, frequent presence of peripheral spiral cords and weak spiral cords on the shell base, relatively open umbilicus of the shell; paucispiral corneous operculum without posterior projections; absence of basal denticles on the central tooth of the radula, comblike marginal tooth with clear slits; extremely large bifurcated penis without lateral protrusions, small spermatheca, and long tentacles effectively differentiate *Austroassiminea lethae* from geographically nearby taxa. *Hydrococcus graniformis* Thiele (1928, p. 374-5, 380, pl. 8, figs 10, a), described from the Swan River, Western Australia, has a multispiral operculum with central nucleus and posterior projection; a hydrobiid, rather than an assimineid radula; and a globose, rather than elongated, shell. "*Assiminea*" *tasmanica* Tenison Woods 1876, reported from Tasmania north to Queensland (Hedley 1906, p. 527-8, Figs 27-30; Iredale and McMichael 1962, p. 43), and also south-western Australia (*teste* Ponder), has a generally banded shell without radial ribs, a nearly closed umbilicus, more acentric paucispiral operculum with posterior projection, and quite different lateral teeth on the radula. The New Zealand species, "*Assiminea*" *vulgaris* (Webster 1905) and *Suterilla neozelanica* (Murdoch 1899), as summarized by Powell (1933), obviously differ in radula, nearly closed umbilicus, lack of shell sculpture and in basic habitat. Both are marine or strand line in association.

The long tentacles, lack of any lateral protrusions on the male verge, absence of basal denticles on the radular central tooth, open umbilicus, radial ribbing on the spire and freshwater habitat, effectively eliminate the possibility that *Austroassiminea lethae* might be based upon introduced examples of the British *Assiminea grayana* Fleming 1828.

*Description*: Shell variable in shape, from squat ovate-conic to elongate-conic, spire angle generally uniform, H/D ratio 1.23-1.55 (mean 1.38). Males often smaller and squatter than females. Shell height 3.45-5.39 mm (mean 4.50 mm), diameter 2.60-3.78 mm (mean 3.26 mm). Apex (Fig. 2) smooth, upper spire with fine radial ribs that become irregular to absent on lower spire and body whorl (Fig. 1). Whorls 4 7/8- to 6 1/8- (mean 5 1/2-). Sutures well impressed, whorls evenly rounded, a weak (Fig. 1) to prominent spiral keel visible on periphery of penultimate and body whorls, sometimes weak spiral cords on shell base. Umbilicus narrowly open, without carina or keel. Lip of adults expanded, noticeably thickened on columellar and parietal walls (Fig. 1). Based on 227 adult specimens.

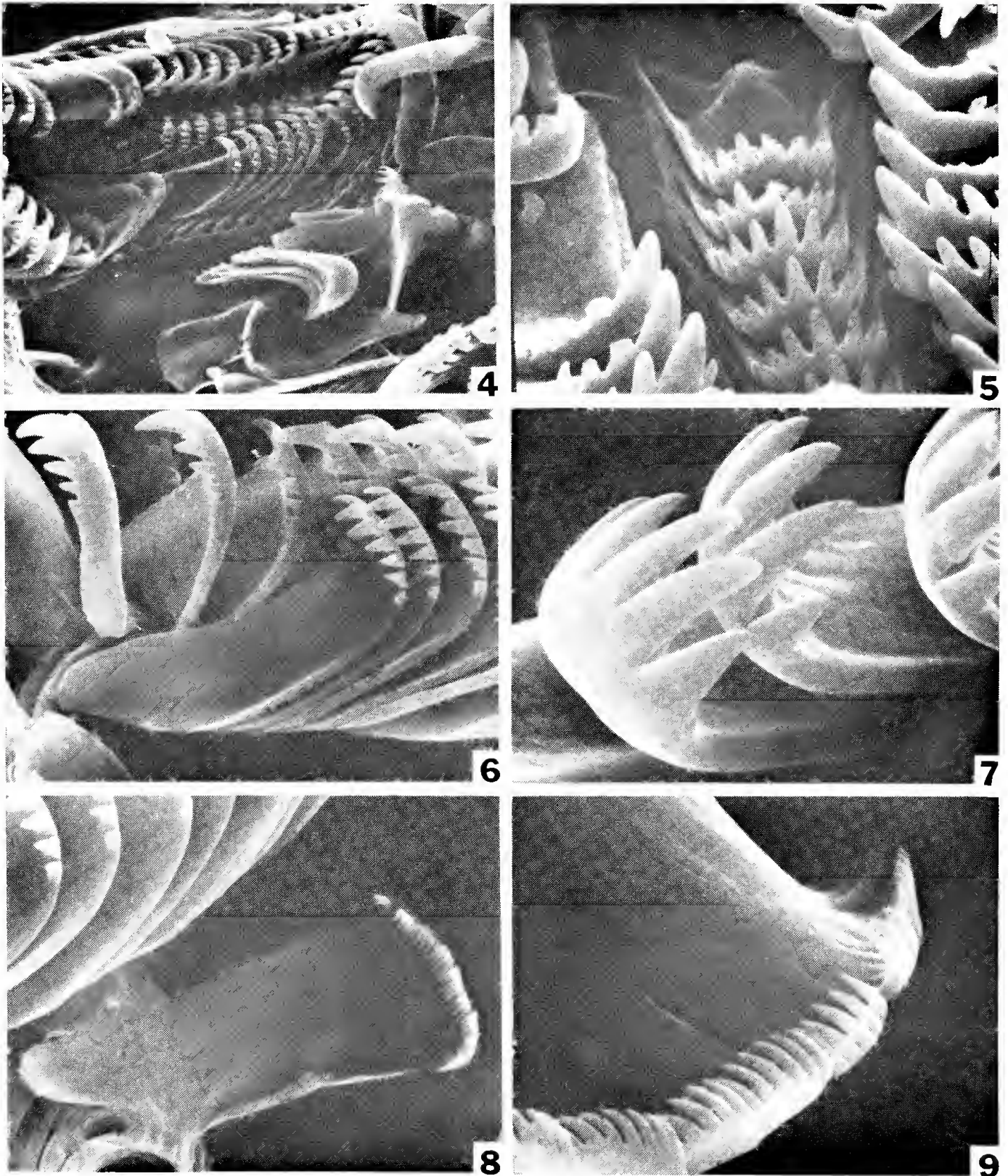
Operculum (Fig. 3) corneous, paucispiral, nucleus slightly acentric, without calcareous granules or posterior projections. Head of animal (Fig. 12) without unusual features. Eyespots (EY) lateral to base of tentacles (TE). Snout (SN) relatively short, ending in two expanded superior lobes (L) that extend in front of mouth (M). Edge of snout marked by a groove (BG) from mantle cavity. Foot (F) undivided, truncated in front, tapering posteriorly. Operculum (OP) mounted on a raised flap.

Radula taenioglossate, 7 teeth per row. Rachidian tooth (Figs 4, 5) normally with 7 cusps, median cusp slightly enlarged, sides of tooth with weak bumps, but no developed denticles. Centre base of rachidian



Figures 1-3.—*Austroassiminea lethata* sp. nov. 1—side view of Holotype WAM 71.80, x20.9. 2—spire of holotype, x54.3.  
3—operculum of paratype, WAM 472.80, x42.2.





Figures 4-9.—*Austroussiminea lethia* sp. nov. Radula of paratype WAM 472.80. 4—partially fragmented radula, x400. 5—central teeth, x1,335. 6—lateral teeth, x1,110. 7—side view of outer laterals, x4,000. 8—single marginal tooth, x1,270. 9—edge of comb marginal, x3,960.



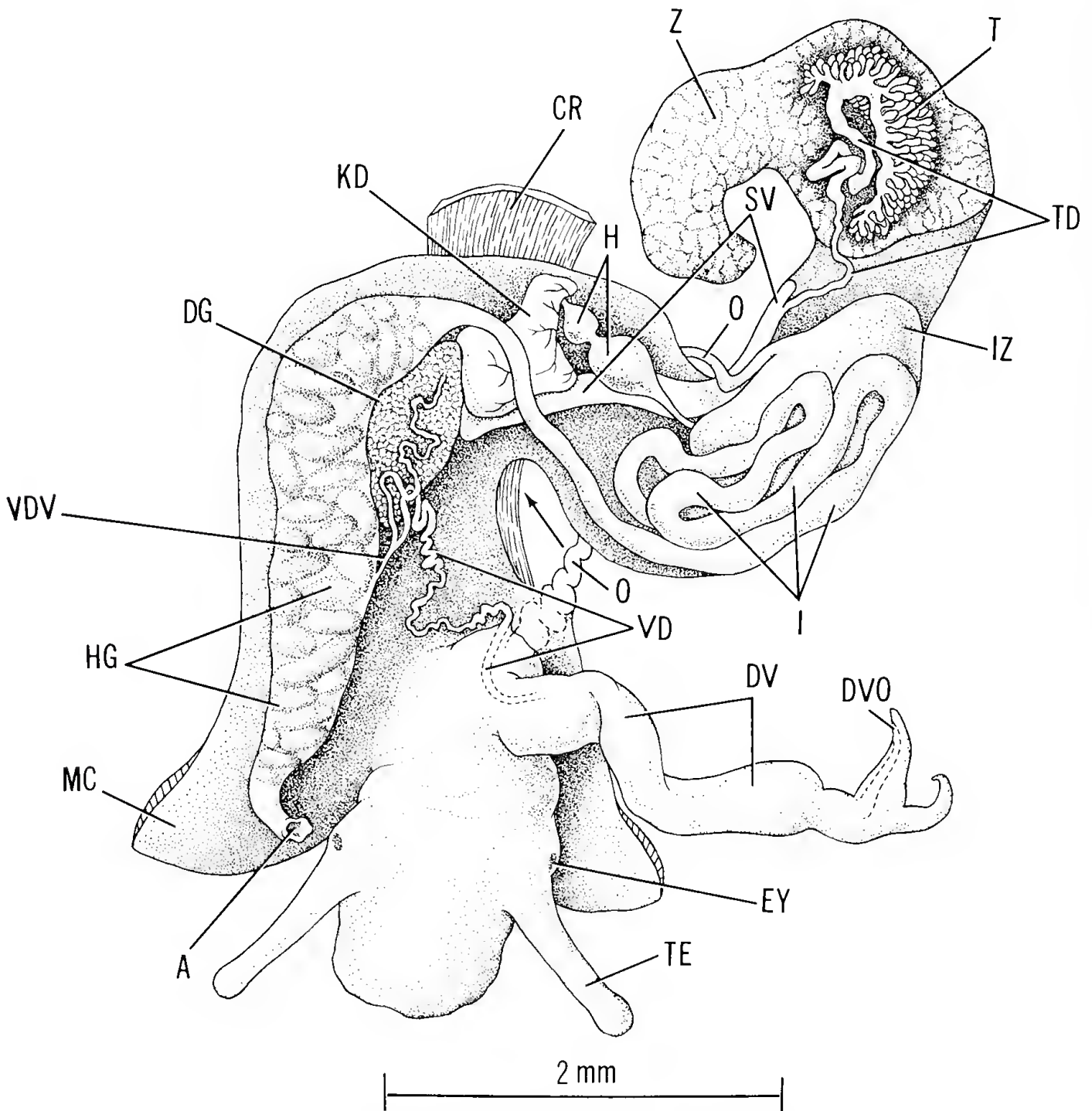


Figure 10.—*Austroassiminea lethia* sp. nov. Paratype WAM 472.80. Gross anatomy of male. Arrow indicates apex of mantle cavity. Drawing by Elizabeth Liebman. See Table 1 for explanation of labels.

slightly protruded, but without denticles. Inner laterals (Figs 4-6) with concave, shovel-shaped base; inner side of tooth with a row of low protrusions (Fig. 5, left), denticles asymmetrical with largest 2nd from inner side, gradually reduced in prominence outward, normally totalling six. Outer laterals (Figs 6-7) with base less concave, clearly tapered; sides of tooth without bumps or accessory denticles; upper

margin sharply recurved (Fig. 7) and bearing normally seven denticles that are less differentiated in size than those of the inner laterals. No accessory basal plates on either lateral tooth. Marginal (Figs 8-9) broad, relatively flat, base tapering as in outer lateral; edge split 7-8 times and thus pectinate, each pectination edge with sharply recurved, minute denticles, 4-7 in number.



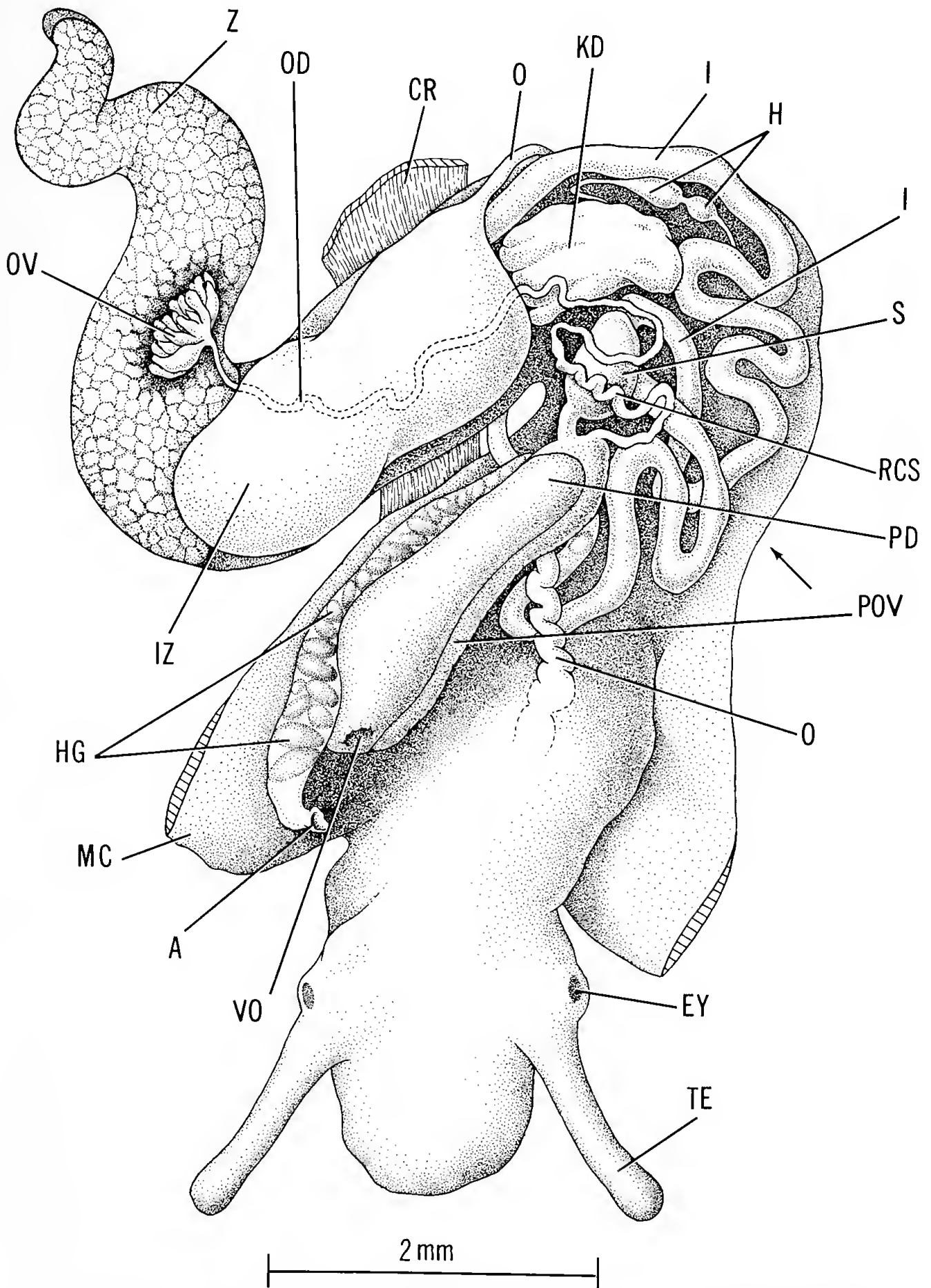


Figure 11.—*Austroassiminea lethae* sp. nov. Paratype WAM 472.80. Gross anatomy of female. Arrow indicates apex of mantle cavity. Drawing by Elizabeth Licbman. See Table 1 for explanation of labels.

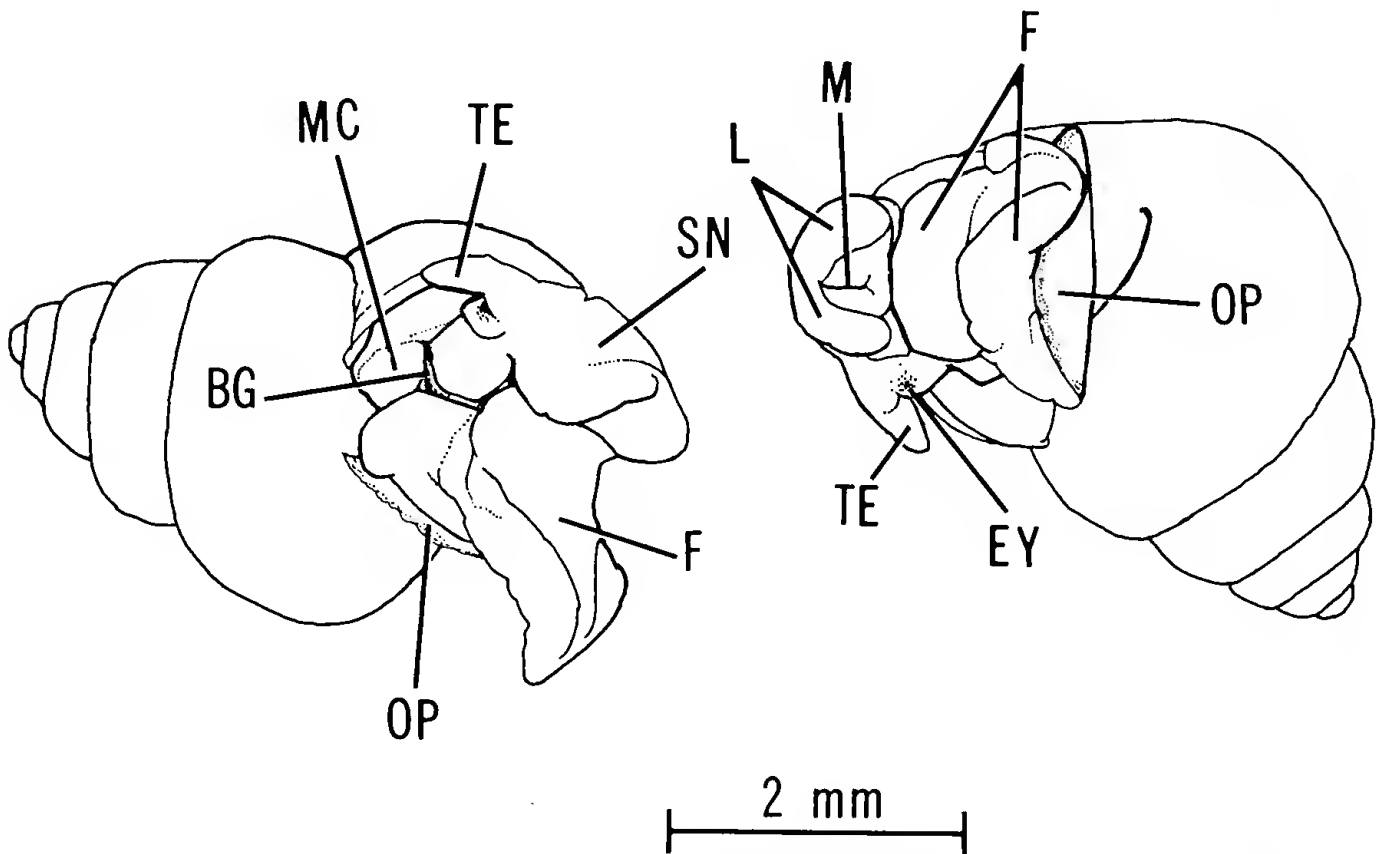


Figure 12.—*Austroassiminea lethra* sp. nov. Paratype WAM 694.80. Head and foot of preserved animal. Drawing by Linnea Lahlum. See Table 1 for explanation of labels.

Table 1

Explanation of anatomical labels

A	anus	OD	oviduct
BG	back groove	OP	operculum
CR	columellar retractor muscle	OV	ovary
DG	prostate gland	PD	dorsal lobe of oviduct
DV	verge	POV	ventral lobe of oviduct
DVO	external pore of verge	RCS	seminal receptacle
EY	eye spot	S	spermatheca
F	foot	SN	snout
H	heart	SV	seminal vesicle
HG	hindgut	T	testis
I	intestine	TD	testis duct
IZ	stomach	TE	tentacle
KD	kidney	VD	vas deferens
L	snout lobes	VDV	escape valve of vas deferens
M	mouth	VO	vaginal orifice
MC	mantle collar	Z	digestive gland
O	oesophagus		

Oesophagus (O) entering stomach medially in male (Fig. 10), anteriorly in female (Fig. 11). Looping of intestine (I) also differing, aligned with stomach (IZ) in male (Fig. 10), linearly anterior to enlarged stomach in female (Fig. 11). Hindgut (HG) normally filled with faecal pellets, opening near anterior margin of mantle collar (MC) through a raised anal pore (A) (Figs 10, 11). Digestive gland (Z) distinctly larger in female (Fig. 11) than male (Fig. 10). Details of heart (H) and kidney (KD) not worked out.

Nervous system not studied because of limited material.

Male genitalia (Fig. 10) simple. Testis (T) with branched tubules along an apically running collecting duct, buried in base of digestive gland. Testis duct (TD) kinked apically, wider at first, narrowing after leaving digestive gland, entering seminal vesicle (SV) subapically. Seminal vesicle (SV) a narrow strip of tissue attached loosely to body wall, running just below kidney to enter prostate (DG), which is a mass of acinar tissue lying at apex of pallial cavity next to hindgut (HG). Collecting tubule of prostate zig-zags anteriorly, emerging as vas deferens (VD) at anterior margin of prostate. Branching of vas deferens occurs almost immediately. A slender "escape valve" (VDV) continues anteriorly to enter hindgut and the posteriorly directed main branch of the tube leads to the verge (DV) after complex coiling. Verge massive, located on back of neck, tip bifurcated with opening of vas deferens (DVO) through larger arm of bifurcation. Shaft of verge without bumps or other structures, exact internal passage of vas deferens through verge not determined.

Female genitalia (Fig. 11) simple. Ovary (OV) a single clump of large acini near base of digestive gland (Z). Oviduct relatively narrow and uncoiled down to level of seminal receptacle (RCS), which appears as an area of tight kinking in the oviductal tube. After one major curve, this enters apically into the pallial oviduct (PVO). Latter U-shaped, with a dorsal (PD) and ventral (POV) lobe. Vaginal orifice (VO) slightly posterior to anus (A). Spermatheca small, globose, on short duct.

The holotype, probably an adult female, is 5.00 mm in height, 3.59 mm in diameter, H/D ratio 1.39, with 5 1/2 whorls. Although collected alive, it had dried out subsequently.

*Remarks:* The name *letha* comes from the Greek *lethos*, referring to forgetting or escaping notice, an appropriate name for this rare and well-hidden species.

The dissected material from Cosy Corner (WAM 472.80) provided the impression that male shells were smaller and slightly squatter than females. This could not be documented by measurements as parts of the shells had been chipped away prior to study by Solem and thus could not be measured. The other live-collected and well-preserved set from Turner Brook (WAM 694.80) had most specimens retracted sufficiently that they could not be sexed without damaging or destroying the shell. Dried out materials from Cosy Corner and Deepdene could not be sexed. Thus, comparative measurements (Table 2) are based on lumped samples. Data is recorded only as mean and range for each area. The actual sex ratios and size differences are unknown.

Adult specimens were defined as those with both thickening of the basal lip and a beginning of irregular, gerontic growth visible behind the palatal lip. This gerontic growth may continue for more than an eighth of a whorl and in the very old and large specimens from Cosy Corner, the inside of the aperture has a substantial callus built up on all walls. All measurements were made with an ocular micrometer at x16, height and diameter accurate to within 2%, and whorls to within 1/8th accuracy. Differences among the samples are summarized in Table 2.

Specimens from Turner Brook below Deepdene Cliffs (WAM 694.80), collected 3 July 1980, are smallest in size and slightly lower in whorl count. They show the shortest area of gerontic growth and may well represent younger examples, rather than indicating a smaller "adult" size for that population. Specimens collected live, but aestivating, and freshly dead in September, October and November from Deepdene Cliffs (WAM 476.80), Ellen Brook (WAM 697.80, WAM 698.80), and Meekadorabbie Cave,

Ellen Brook (WAM 696.80) are distinctly larger in size and with noticeably greater thickening to the shell lip. The differences among these populations are not significant. The Cosy Corner samples, nearly all collected dead and many in bleached condition, are large (Table 2) and many show much greater thickening of the shell lip and noticeably longer gerontic growth. We cannot say if this population actually is larger, or if biased samples of mainly gerontic individuals have been taken.

Living specimens of *Austroassiminea letha* are known from three localities just north of Augusta. They are Turner Brook near Deepdene Cliffs, Cosy Corner, and Ellen Brook just north of the Margaret River. At Turner Brook they have been found in seepage areas at the base of limestone cliffs, or in litter near the creek banks in an area located only a few hundred metres from the creek mouth. Near the base of Deepdene Cliffs they were on rocks splashed by a miniature waterfall and on the ground above, a seepage area draining from the high limestone on the southern side of Turner Brook. At Cosy Corner they have been taken in grass tussocks on granite cliffs wet by seepage from the limestone-granitic rock contact above and located less than 200 metres from the beach. Dead shells are common in what we presume to be Holocene deposits, but live material has been found in an area of only a few square metres. At Ellen Brook, live material was taken in algae growing on the sides of concrete and wooden troughs carrying flowing water from Ellen Brook to the Ellensbrook homestead. The snails were in algal growth above the water line in the troughs. This site was several hundred metres from the stream mouth and significantly more elevated than the small sandy delta of Ellen Brook. Additional field work along Ellen Brook in September and October 1980 found specimens alive or freshly dead adjacent to the dam at Ellensbrook homestead and on moss and algal covered limestone forming the sides of the waterfall at the entrance to Meekadorabbie Cave and the banks of the brook above it. Specimens on soil, leaves and twigs were aestivating or recently dead. All of these localities, although near the ocean, are well above storm water marks and are not subject to sea water inundation.

Table 2

Size and shape variation in *Austroassiminea letha*

Locality	No. of adults measured	Mean (and range)			
		Shell Height (mm)	Shell Diameter (mm)	H/D ratio	Whorls
Turner Brook, below Deepdene Cliffs	20	3.94 (3.48-4.67)	2.91 (2.60-3.39)	1.35 (1.23-1.47)	5¼- (4¾-5½+)
Deepdene Cliffs	25	4.39 (4.01-5.33)	3.20 (2.96-3.68)	1.39 (1.31-1.55)	5¾- (5-5¾)
Cosy Corner	120	4.76 (4.08-5.39)	3.42 (2.99-3.78)	1.39 (1.29-1.49)	5¾- (5½-6¾-)
Ellen Brook	31	4.24 (3.45-5.16)	3.12 (2.70-3.52)	1.36 (1.27-1.47)	5¾- (5+-5¾)
Meekadorabbie Cave, Ellen Brook	31	4.14 (3.49-4.97)	3.08 (2.63-3.62)	1.34 (1.23-1.48)	5¾- (5-5¾)



Several visits to the Deepdene and Cosy Corner sites since 1963 demonstrate that the populations persist within very small areas. Extensive searches in similar-appearing habitats along the Deepdene Cliffs and near Cosy Corner have failed to reveal additional populations. At both Cosy Corner and Deepdene, ground areas remain moist even during the middle of summer, and live snails have the option of retreating into deeply fissured rocks back to the retracted water trickle that eventually forms the basal ground soak. All localities would be subject to heavy morning dews, another dependable source of water in this area of coast. Living specimens have been taken only at times when flowing water was in the seepage zones, but this may only be indicative of an extended foraging zone bringing them out into areas accessible to prying fingers of scientists. While water associated, they are in damp terrestrial habitats that are close to the water margin.

Because of the very limited populations observed, collections have been restricted mainly to samples of dead shells. Some early collections were dried and the anatomical data recorded here are based upon material from Cosy Corner (WAM 472.80) collected 22 June 1980 specifically for this review.

#### Fossil records

Evidence that *A. lethae* is an endemic relict comes from three fossil occurrences on the lower southwest coast of Western Australia. On the southern side of North Point (34° 09' 41" S, 115° 01' 23" E), a 25 m sea cliff of Tamala Limestone (Playford *et al.* 1976) rises on a basement of Precambrian gneiss. It shows a sequence of four prominent, brown fossil soils, separated by units of paler aeolian calcarenite. A thin gneiss-calcrete conglomerate underlies the lowest fossil soil and is itself underlain at about HWM by a poorly exposed, marine shelly limestone; the limestone-gneiss contact is partly obscured by an apron of fallen boulders.

The lowest fossil soil, up to 2.3 m thick, lies in the splash zone and is being eroded vigorously. It is a brown, friable clayey to silty calcarenite, without obvious bedding structure and with thin bands of calcareous cementation; rhizoconcretions occur near the top and in the lower part occur pebbles and cobbles of near-black calcrete. This fossil soil contains a sparse land snail assemblage of four species—*Austroassiminea lethae*, *Bothriembryon* sp. and a species each of the Charopidae and Punctidae. Of the first mentioned, 15 specimens (WAM 68.385, WAM 81.19, FMNH 198759) have been collected, of which the largest has a height of 4.84 mm. This species has been found only in the lowest fossil soil and mainly within 0.6 m of its base. Numerous shells of other land snails, notably *Bothriembryon* sp., occur in the overlying fossil soils.

The section at North Point, including the basal marine unit, resembles others from the Cape Leeuwin-Cape Naturaliste coast described by Fairbridge and Teichert (1953) and Fairbridge (1953). The marine units were noted by Lowry (1967) and assigned a late Pleistocene age. All snails from the North Point fossil soils represent living species, which is consistent with a relatively "late" Pleistocene age. The presence of *Austroassiminea lethae* only in the lowest fossil soil indicates that the species last inhabited the

site during the accumulation of that unit. By analogy with modern occurrences of the present species, it seems likely that the site incorporated a freshwater discharge at the gneiss-limestone contact, which became buried beneath mobile aeolian sands early in the regression following the "Last Interglacial" of the Late Pleistocene. Other land snails were able to maintain populations on the sandy terrains that resulted from this episode of dune building, but not *Austroassiminea lethae*, which became extinct locally. With the return of sea level to its modern position about 6000 years ago (Mörner 1976), wave erosion established the fresh cliff section visible today.

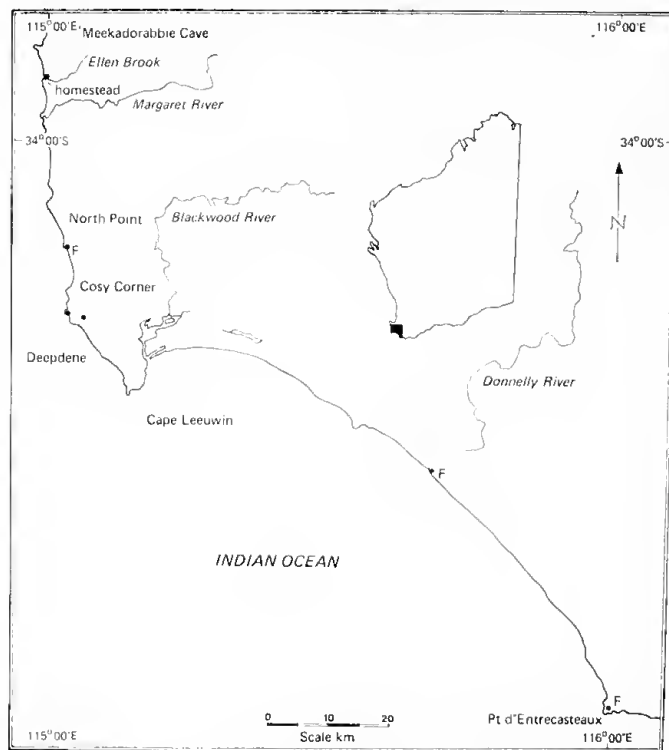


Figure 13.—Part of southwestern Australia with localities of *Austroassiminea lethae* sp. nov. shown by •. F denotes fossil locality.

A calcareous, sandy fossil soil, reported to lie at about 2.5 m above sea level is exposed within a coastal cliff of aeolian calcarenite behind a sandy beach about 0.8 km SE from the mouth of the Donnelly River (34° 29' 24" S, 115° 40' 38" E). Five shells of *Austroassiminea lethae* (WAM 70.2691, 70.2692) were collected from this deposit, the height of the largest being 5.07 mm. Other land snails present included species of *Succinea*, *Bothriembryon*, Charopidae and Punctidae. All of these species appear to be extant and a Late Pleistocene age is probable. We have not examined this isolated locality and are unable to comment on the presence or otherwise of any freshwater discharge, past or present, at the site.

The elevated limestone headland of Pt d'Entrecasteaux (35° 50' 32" S, 115° 59' 40" E) features several exposures of lithified fossil soils with land snail shells (Kendrick 1978). The assemblage includes species of Charopidae and Punctidae, two extinct species of *Bothriembryon* and *Austroassiminea lethae* (WAM 70.895, 70.897, 70.898), height of the largest 4.47 mm. These fossil soils are

probably of Pleistocene age and their snail assemblage suggested to Kendrick (1978) "a humid, well-vegetated, probably forested environment . . ., in contrast to the exposed coastal heath that presently characterizes the area". The deposits lie about 100 m above sea level and overlie a substantial thickness of porous, sandy limestone. They are dispersed over several square kilometres of open terrain, with no evidence of concentrated freshwater discharge or seepage, such as those associated with modern populations of *A. lethia*. This association of *Austroassimineia lethia* with forest litter snails is puzzling. We are not agreed as to whether *A. lethia* was either dispersed more or less generally on the leaf litter of a forest floor, under conditions of higher and more sustained levels of humidity than now prevail in the area (Kendrick), or washed in from nearby localities featuring its current habitat (Solem). Of the three fossil localities reported here, only Pt d'Entrecasteaux contains extinct species and we conclude from this that it is the oldest geologically. A more precise dating of this deposit within the Pleistocene is not possible at present. We suggest that the Pt d'Entrecasteaux records of *A. lethia* antedate, wholly or in part, the events which led to the severe fragmentation of the species' modern range.

### Conclusions

The recent and fossil distribution data indicate that *Austroassimineia lethia* had a more extensive range in the geologically recent past. Three of the six known occurrences are fossil only and indicate a high rate of local extinction by natural processes. It is now relatively abundant at each of three localities in areas of only a few square metres. Human activities could easily extinguish each extant colony. We thus consider it to be both a rare and endangered species.

The absence of any other amphibious or terrestrial assimineid from Australia is remarkable in view of the wide distribution that terrestrial members of the family have from South-east Asia into Polynesia. We can offer no reasons for the lack of representation in northern and eastern areas of the continent. The presence of a species in the south-western tip of Australia suggests that it is a Gondwanic relict. The fact that the anatomical features of this species combine aspects of both recognized subfamilies of the Assimineidae, may have major phylogenetic implications. If the characters used by Abbott (1949) to delineate subfamily units are significant, the combination in *Austroassimineia lethia* of features from both subfamilies may indicate that it is close to the ancestral condition, a phylogenetic relict as well as geographic. It is also possible that the selection of subfamilial characters is in error, but until modern revisions of the Indonesian to Polynesian taxa are available, this question cannot be settled.

Regardless of its exact phylogenetic position, *Austroassimineia lethia* represents a significant addition to the fauna of Western Australia, and is a species reduced to remnant populations that can be wiped out by man unless they are afforded protection from environmental pollution and habitat destruction.

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## The distribution of *Lepidogalaxias salamandroides* and other small fresh-water fishes in the lower south-west of Western Australia

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### Abstract

A survey of small native fishes in the lower south-west of Western Australia indicates that most native species in the area with the possible exception of *Nannatherina balstoni*, are relatively common.

The distribution of *Lepidogalaxias salamandroides* is restricted but the species is common within the area of its occurrence. Its distribution was found to correlate with 'coloured waters', high in organic matter, arising in non-forested areas of low open woodland, herbland, scrubland and heaths which typically occur to the south of the main forest area. The species occurred most frequently in small pools, often seasonal, with a muddy bottom and which were clear of overhanging vegetation. The water in which they occurred was typically of low pH with a high chemical O<sub>2</sub> demand. They were frequently found in association with other species of small fish.

The fish species collected showed a tolerance to a fairly wide range of pH and some, *Edeia vittata* and *Bostockia porosa* in particular, appeared to be tolerant of moderately high salinities.

### Introduction

First collected in 1959 the diminutive fresh-water fish, *L. salamandroides* has since created world wide interest amongst zoologists. Its describers, Mees (1961) originally included it in the Galaxiidae, a group of salmoniform fishes, some of which *L. salamandroides* superficially resembles. Its inclusion in that family was subsequently disputed by Scott (1966). Later during a search for a clear indication of the species true relationship (Rosen 1974), it became evident that the classification of salmoniforms was in a confused state. In an extensive review and comparison of salmoniform anatomy, Rosen proposes an entirely new phylogeny for the salmonids and related groups. He suggests that *L. salamandroides* is not a galaxiid, a group he places in the salmoniforms, but an esocoid, a related northern hemisphere group, including the pike of which *L. salamandroides* is now the sole southern hemisphere representative. This classification presents intriguing problems which leads Rosen to speculate further in the wider area of zoogeographic problems in relation to fishes.

Consequently, *L. salamandroides* has become an important species not only in its own right but also because it occupies a unique position as a key piece in the puzzle of phylogeny and zoogeography of the worlds teleost fishes.

The future of this little fish is currently a subject of concern amongst conservationists. The type locality is described by Mees (1961) as, "a very small creek in heavy forest of mixed karri and

jarrah, *E. diversicolor* F. V. Mueller and *E. marginata* Sm.". Much of this type of forest occurs within the marri chipwood licence area (Anon. 1977) and is due to be clear felled and regenerated over the next few decades. Other collections of *L. salamandroides* have been made since its original discovery, and the majority have been from within the chipwood licence area. Because of this, concern has been expressed that forest operations may endanger the species.

In order to determine the present status of the species, a survey of its distribution in the lower south-west was carried out during the summers of 1978 and 1979. During the survey it was also attempted to relate the occurrence of the species to site-vegetation type, water quality and other site characteristics.

Information on the distribution of other species of small fishes and crustaceans was also obtained during the survey.

### Methods

Preliminary collections and examination of Museum records suggested that *L. salamandroides* was confined to the lower south-west where it had a sub-coastal distribution. Accordingly, the survey was designed to include the middle and lower reaches of the major river systems in this area and extended between the Blackwood river in the west to the Hay river in the east. Sampling points included small streams, rivers, lakes and other bodies of water, both natural and man made such as roadside ditches and drains.

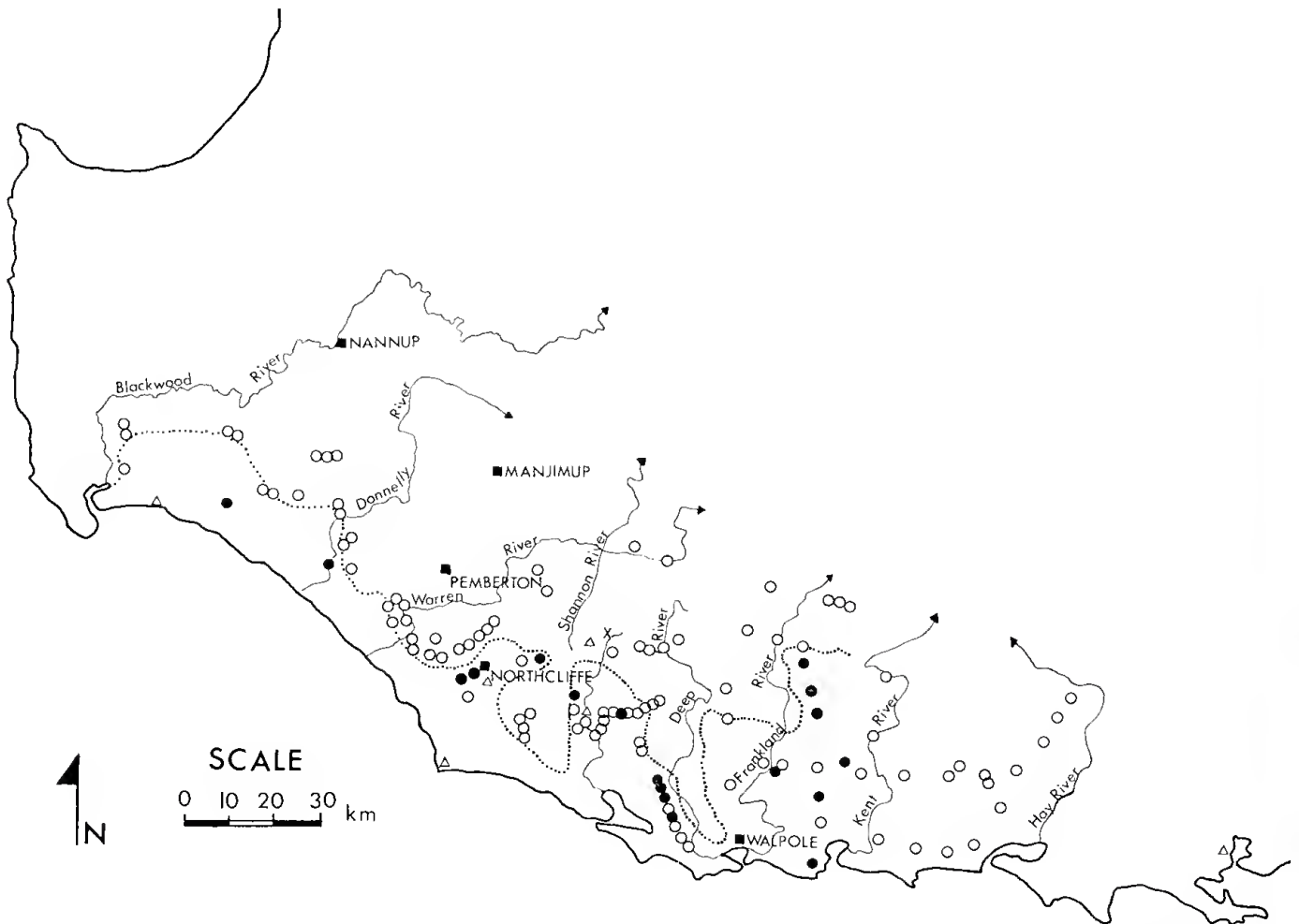


Figure 1.—Map of the lower south-west showing the distribution of *L. salamandroides*.  $\Delta$  Museum records of *L. salamandroides* collections X Original collection of *L. salamandroides* (Mees 1961) O Sample point  $\bullet$  Sample point with *L. salamandroides* ..... Approximate northern extent of southern hermland, scrubland, heath and low open forest and woodland communities.

Sampling was carried out by means of a scoop net. Scooping was continued at each sample point until no new species of fish were caught. Numbers and species of fish and crustaceans netted were recorded and representative samples from each sampling point were sent to the Western Australian Museum for identification.

A total of 120 sampling points (Fig. 1) were visited during January and February in 1978 and 1979. At this time of the year water in the streams is low, making sampling easier and more effective. At each sampling point a measure of the abundance and frequency of the major plant species growing in the immediate vicinity was obtained using a qualitative five point scale of frequency to give a cover value for each species (Havel 1975). In addition to the vegetation data, ten parameters relating to sample site characteristics, and six to water quality were recorded at each sampling point. (Appendix 1.)

Principle components analysis was used to achieve ordination of the sampling points, based on vegetation data, using the programme FACVA (Havel 1975). This programme combines the loadings of the vegetation species on the component axes with their cover values at individual points to obtain scores which can be used as point co-ordinates. A sampling points co-ordinate (score) on any component axis is the sum, for all species, of the products

of their loadings on that component, and the deviation of their cover value on that point from their mean cover value in the study as a whole. Varimax rotation was used to obtain best alignment of the component axes. Square root transformation was employed to achieve the best possible separation of the data. Data on the occurrence of fish species as well as those relating to sample site characteristics and water quality were examined in relation to sampling point distribution within the principle component matrix in order to identify any trends in the various parameters relating to the distribution of fish species.

## Results

### *Lepidogalaxias salamandroides*

*Lepidogalaxias salamandroides* with a frequency of occurrence of 16.7%, was not one of the most frequently netted species but it is relatively abundant in waters to the south of the main karri forest area and was collected in reasonable numbers at most sampling stations where it was found (Appendix 2.)

Almost all of the sampling points where it was caught fall within the area of non-forested low open woodland, hermland, scrublands and heath in the high rainfall areas to the south of the main forest belt (Fig. 1).

Results of ordination suggests a pattern of distribution which is related to the major vegetation associations of the area. Ordination of the streamside vegetation resulted in three quite distinctive groupings (Fig. 2); a southern jarrah forest streamside vegetation type (1), a karri forest streamside vegetation type (2) and a non-forest vegetation type (3). Ordination of the sampling points using plant species loadings achieved good separation on factors 1 and 2, these two factors representing 22.4 and 10.4 percent of the total variance respectively. However, no attempt was made to interpret the principal component axes, these were used merely as a framework within which to identify trends in the recorded parameters relating to fish species occurrence.

The sampling points at which *L. salamandroides* was collected mostly occur towards the negative end of the factor 1 axis in the southern jarrah and non-forest associations (Fig. 3a). Using the CHI square test *L. salamandroides* was found to be positively associated with plant species typical of these non-forested areas and southern jarrah associations and negatively associated with plant species of the karri forest (Table 1).

Further CHI square tests also revealed significant correlations between *L. salamandroides* occurrences and some of the recorded site characteristics and measures of water quality. It was found to be positively correlated with waters of <pH 5.0\* and > 100 gm/l suspended solids\* and small pools < 1 m across\*\*\*. There was a negative correlation with the presence of aquatic vegetation\*. (\*Signif. 0.05 level; \*\*\*Signif. 0.001 level.)

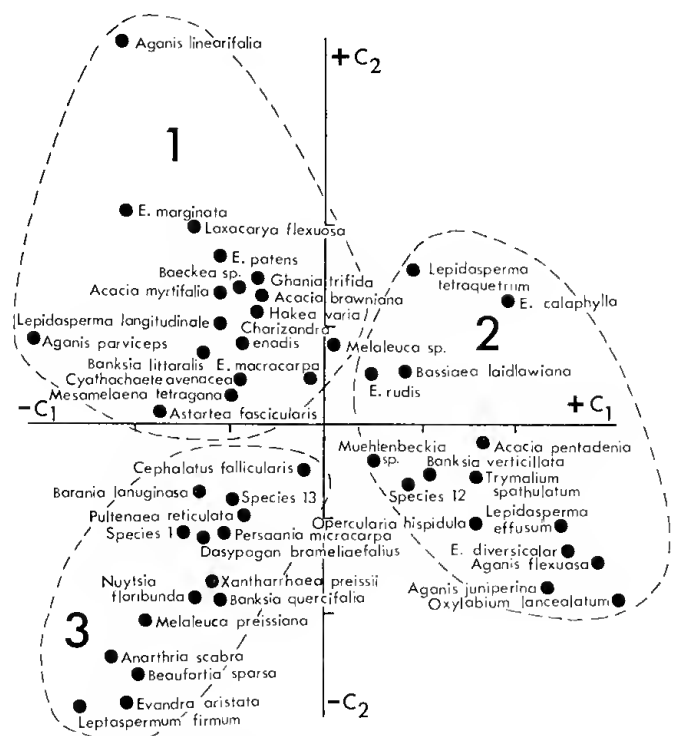


Figure 2.—Distribution of 48 individual plant species recorded at 120 points within component space derived by P.C.A., Components 1 and 2. (Square root transformation was used.) Note the separation of three major forest streamside plant communities; 1 = Southern jarrah forest 2 = Karri forest 3 = Southern hermland, scrubland, heath and low open forest and woodland communities.

Table 1

Plant species significantly\* correlated with the presence of *L. salamandroides* and other small fish in the study area  
\*correlation signif. at 0.05 level (CHI sq. test)

Plant species, "associations"	Fish species			
	<i>Bostockia porosa</i>	<i>Edelia vittata</i>	<i>Galaxiella munda</i>	<i>Lepidogalaxias salamandroides</i>
<b>1. Southern Jarrah Forest Associations</b>				
<i>Acacia myrtifolia</i> ....	+		+	
<i>Acacia strigosa</i> ....	+			
<i>Agonis parviceps</i> ....				+
<i>Cyathochaete avenacea</i> ....				+
<i>Eucalyptus patens</i> ....			+	
<i>Hakea varia</i> ....			+	
<i>Lepidosperma longitudinale</i> ....			+	
<i>Mesomelaena tetragona</i> ....				+
<b>2. Karri Forest Associations</b>				
<i>Agonis flexuosa</i> ....			-	-
<i>Agonis juniperina</i> ....		+		
<i>Banksia verticillata</i> ....	+	+		
<i>Eucalyptus diversicolor</i> ....		+		
<i>Eucalyptus calophylla</i> ....		+		-
<i>Lepidosperma effusum</i> ....		+		-
<i>Opercularia hispidula</i> ....		+		+
<i>Oxylobium lanceolatum</i> ....		+		-
<i>Species 12</i> ....		-		
<b>3. Southern Flats Associations</b>				
<i>Banksia quercifolia</i> ....				+
<i>Beaufortia sparsa</i> ....				+
<i>Dasypogon bromeliaefolius</i> ....			+	
<i>Evandra aristata</i> ....				+
<i>Leptospermum firmum</i> ....				+
<i>Persoonia microcarpa</i> ....				+
<i>Species 1</i> ....			+	+



The water at sampling points in the sector of the component space in which most *L. salamandroides* occurrences were recorded was found to have a tendency towards low pH, high colouration and a high permanganate equivalent. The latter being a measure of chemical O<sub>2</sub> demand which in most cases is indicative of the organic matter content of the water (Fig. 4).

*Other species*

The distribution of the other species of small fish netted during the survey was examined in a similar manner to that of *L. salamandroides*.

*Edelia vittata* with a frequency of occurrence of 40.8 percent was the most common species and shows a slight tendency to occur at sampling points within that sector of the component space characterized by the karri forest associations (Fig. 3b). This trend is supported by positive correlation with plant species typical of these associations (Table 1). The second most common species *Bostockia porosa*, frequency 33.8 percent exhibits no clear trends in its

distribution (Fig. 3c) and is correlated with very few plants species (Table 1). The distribution of *Galaxiella munda* with a frequency of 30.8 percent, is most similar to that of *L. salamandroides*, showing a tendency to occur at sampling points in the jarrah and non-forest associations (Fig. 3d). This trend is supported by positive correlations with plant species from these associations.

The other small fish species *Galaxias occidentalis*, *Nannatherina balstoni* and *Galaxiella nigrostriatus*, occurred at frequencies too low to allow any assessment of their preferred habitat. *Galaxias occidentalis* with a frequency of 10.8% may be more common in the study area, but it is a strong swimming species which prefers the larger streams and it may well have escaped the net on occasions.

In addition to the above, two small fingerling brown trout (*Salmo trutta*) and a young ammocoete stage lamprey (*Geotria australis*) were netted in a small tributary of the Warren River. The trout were observed swimming rapidly in fast flowing

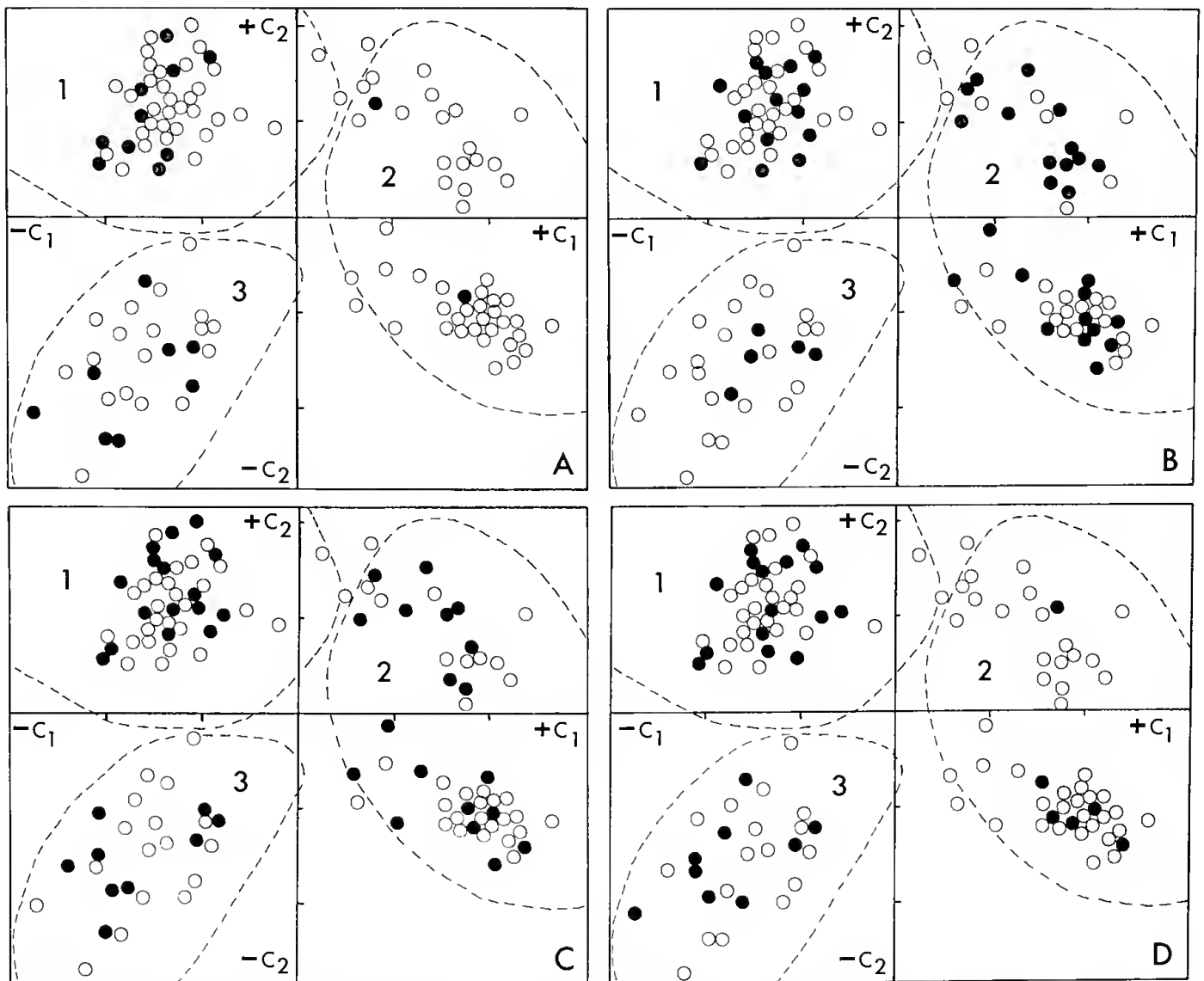


Figure 3.—Distribution of *L. salamandroides* and other small fishes from 120 sampling points within component space derived by P.C.A., of vegetation species data, Components 1 and 2. (Square root transformation was used.) 3 (a) *L. salamandroides* 3 (b) *E. vittata* 3 (c) *B. porosa* 3 (d) *G. munda*, O = sample point • = sample point with fish.

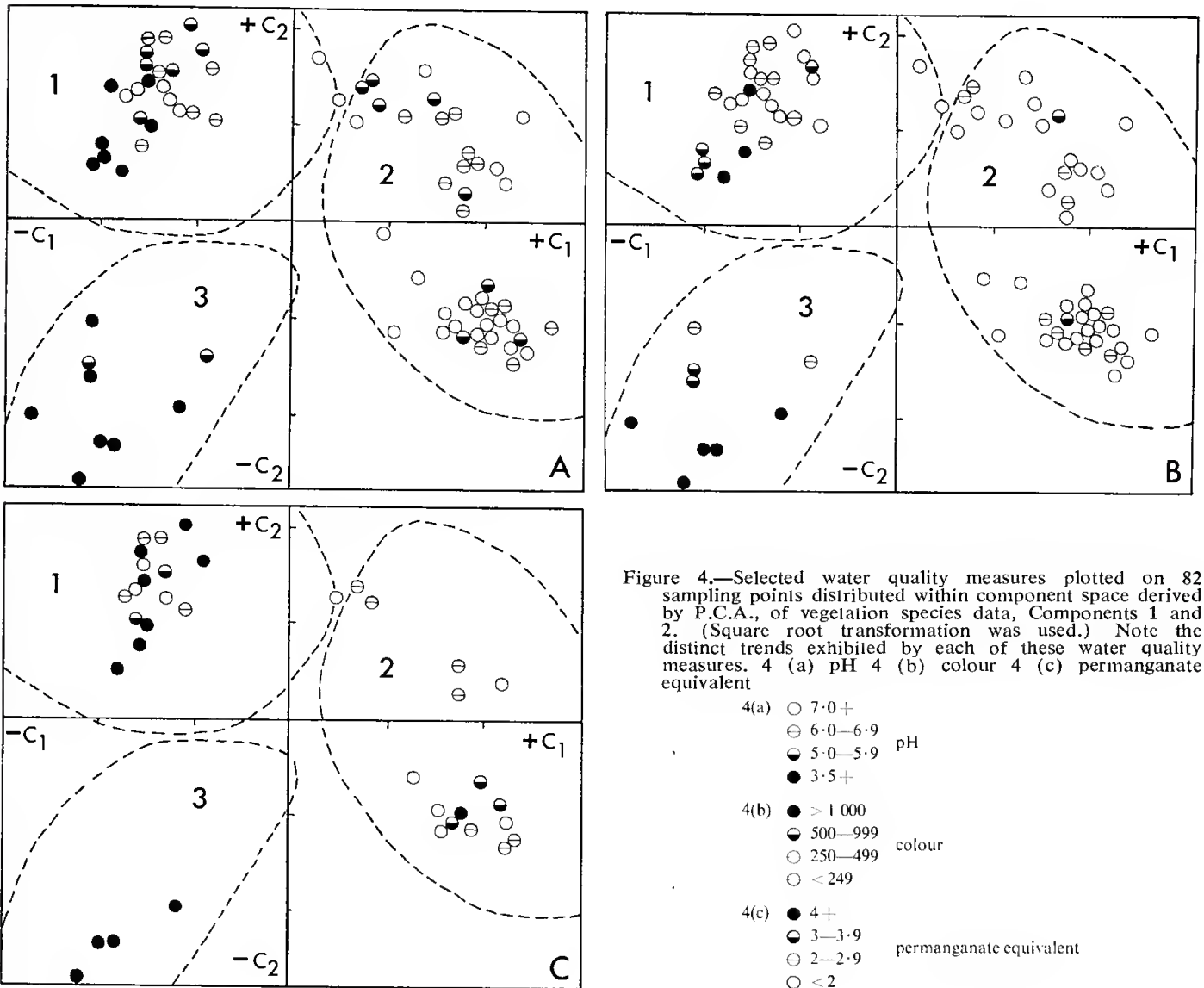


Figure 4.—Selected water quality measures plotted on 82 sampling points distributed within component space derived by P.C.A., of vegetation species data, Components 1 and 2. (Square root transformation was used.) Note the distinct trends exhibited by each of these water quality measures. 4 (a) pH 4 (b) colour 4 (c) permanganate equivalent

- 4(a) ○ 7.0+  
 ⊖ 6.0–6.9  
 ● 5.0–5.9  
 ● 3.5+ pH
- 4(b) ● > 1000  
 ● 500–999  
 ○ 250–499  
 ○ < 249 colour
- 4(c) ● 4+  
 ● 3–3.9  
 ⊖ 2–2.9  
 ○ < 2 permanganate equivalent

cold water in a sandy creek bed. Seventeen *Gambusia affinis*, the only specimens of this species caught during the survey, were netted at one sampling point on the Frankland River. *Nannatherina balstoni* was netted at only four points and *Galaxiella nigrostriatus* at only two.

### Discussion

*Lepidogalaxias salamandroides* has a restricted range but it is comparatively abundant in the pools in which it does occur. The waters of the streams within the area of occurrence of *L. salamandroides* arise in non-forested areas of low open woodland, herblands, scrublands and heaths as defined by Smith (1973). These vegetation associations all occur on peaty sandy soils. Around Denmark, these soils are typically leached sands or black peaty sands of the Kwilalup and Plantagenet peaty sands series of Hosking and Burvill (1938). In the west they are similar sands of the Chudalup and Blackwater associations of McArthur and Clifton (1975). Drainage on these sands is impeded and low lying areas are subject to prolonged winter flooding and waterlogging Smith (1973). The waters of this area are characteristically brown in colour, stained

with the exudates of organic matter, they have a low pH and a high chemical oxygen demand, probably a consequence of the high organic matter content.

Whether *L. salamandroides* is collected from the streams and waters within areas of southern jarrah forest or in the non-forested areas themselves it is in these dark stained waters in which it most frequently occurs. During summer they are most often located in small pools or slow flowing small streams in association with other species but in winter they may also be found widespread over the herblands and scrublands which are under water at this time (Pusey 1981). The pools in which the fish occurred most often were clear of overhanging vegetation, had a muddy bottom and were never clean sand or rock. They were often seasonal, supporting the findings of Pusey (1981) that the species aestivates over summer. The absence of water weed and the freshwater shrimp *Palaemonetes australis* appears to be another characteristic of these waters.

The area sampled did not include the known easternmost occurrence of *L. salamandroides*. There is a W.A. Museum record (P 25693.001 coll.

J. Allen 1976) from Lake Powell east of Albany. The area surrounding this lake is low open woodland and sedgelands similar to those in the survey area. It is likely that this record is close to the species eastern limit of distribution since the climate and vegetation change markedly further to the east. Similarly it seems unlikely that the fish will be found within the jarrah forests to the north of the karri forest area. Collections within the karri forest itself are infrequent and appear to be associated with waters which arise in peaty heathland areas which occur within the southern portion of the karri forest. Such is the case with the collection made at point 34 on this survey and also the original collection (Mees 1961) which appears to have been made in a stream originating in low open woodland on grey peaty sands in the vicinity of Gobblecannup swamp to the northeast of Shannon.

No two fish species were found to be significantly associated although several species were usually netted together at most sampling points (Appendix 2). The most frequently collected small fishes in the survey area were *Edelia vittata*, *Bostockia porosa* and *Galaxiella munda*, all occurring at more than 30 percent of the sampling points. *Edelia vittata* was collected from both still and running water including rivers, lakes, small creeks, ponds and roadside drains. Its occurrence was found to be significantly correlated (.001 level) with the presence of aquatic vegetation. *Bostockia porosa* and *Galaxiella munda* occurred most frequently in smaller streams, pools and roadside drains. The latter species was the only one of the small fishes, with the exception of *L. salamandroides*, which showed a distinct distribution pattern (Fig. 3) very similar to that of *L. salamandroides*. It is significant that this species, like *L. salamandroides* has a very limited distribution (McDowall 1978; McDowall and Frankenbury 1981). With the exception of one outlying population near Gin Gin, to the north of Perth, the species is restricted to the high rainfall areas of the southern forests.

The other species of small fishes, *Galaxias occidentalis*, *Nannatherina balstoni* and *Galaxiella nigrostriatus*, all occurred at comparatively low frequencies. *Galaxias occidentalis* is widely distributed in the area but infrequently caught probably because it is a fast moving fish inhabiting the larger pools, and faster flowing streams and rivers. *N. balstoni* appears to be comparatively rare despite the fact that the survey area covered a major portion of its known range between Two Peoples Bay and the Blackwood River, Coy (1979). *Galaxiella nigrostriatus* likewise is uncommon but the survey area may represent only the western extremity of this species range which Coy (1979) gives as Esperance to Albany, although McDowall (1978) lists a collection from Wye plains southeast of Shannon.

There was considerable difference in preference for pH ranges shown by native fish species. This ranged from *G. occidentalis* which preferred the more neutral waters to *L. salamandroides* showing a distinct preference for more acidic waters (Fig. 5). The range of tolerance shown by all species is comparatively wide. At least four of the fish, *E. vittata*, *B. porosa*, *G. munda* and *G. occidentalis* appeared to have some tolerance to salinity. All occurred together in a pool on the Tone River (No. 56)

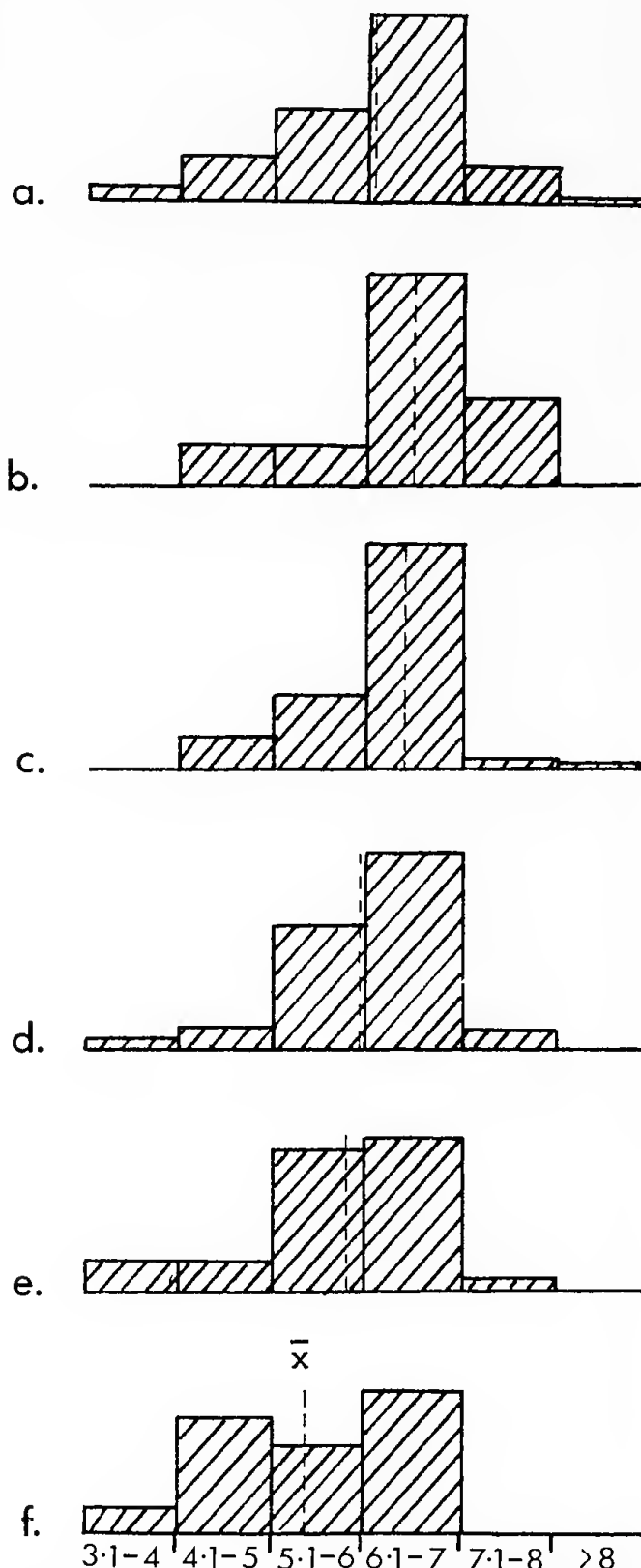


Figure 5.—Percentage frequency distribution in pH of waters inhabited by small native fish species collected during the survey.

- 5 (a) pH distribution  $\bar{x}$  6.06, range 3.7-8.4,  $n = 83$ .  
 5 (b) *G. occidentalis*  $\bar{x}$  pH 6.48, range 4.4-7.6,  $n = 9$ .  
 5 (c) *E. vittata*  $\bar{x}$  pH 6.39, range 4.2-8.4,  $n = 35$ .  
 5 (d) *B. porosa*  $\bar{x}$  pH 6.05, range 3.9-7.6,  $n = 34$ .  
 5 (e) *G. munda*  $\bar{x}$  pH 5.79, range 3.9-7.6,  $n = 24$ .  
 5 (f) *L. salamandroides*  $\bar{x}$  pH 5.40, range 3.7-6.8,  $n = 13$ .



with a conductivity of 5202, equivalent to 3620 T.D.S. (Hatch 1976). *E. vittata* and *B. porosa* both occurred together in a small creek on the Denbarker Road (No. 59) with a conductivity of 7159, (equivalent T.D.S. = 4992) and *E. vittata* was collected at one point on the Frankland River (No. 78) with a conductivity of 8129 (equivalent T.D.S. = 5672). *L. salamandroides* appears to be less tolerant. The highest conductivity, 644 (equivalent T.D.S. = 425), recorded for water in which this species occurred was at point 82, a small creek on Middle Road in the Bow river catchment.

The five most frequently collected fish, *E. vittata*, *B. porosa*, *G. munda*, *L. salamandroides* and *G. occidentalis* were all collected in streams and pools on cleared farmland areas. A total of 10 sampling points out of 16 on farmland in the Nornalup, Barlee Brook, Denbarker, Denmark, Scott River, Northcliffe and Muir Highway areas contained fish in reasonable numbers. Their frequency was consistent with the overall frequency of the species. Thus *E. vittata* and *B. porosa* occurred at 7 points, *G. munda* at 4 and *L. salamandroides* and *G. occidentalis* at one each. Many of the sample points were in areas which have been cleared for some time and dense growths of green algae and water weed were often present. How long populations of native fishes can continue to survive under such conditions is not known.

Many of the small streams and waters of the south arise and flow within state forest and here their future would seem to be secure. The water remains fresh and there is no indication that forest operations such as for example those associated with the woodchip industry, have affected the quality of the regions water resources to any level which provides a basis for concern (Anon. 1980). A more likely threat than mans activities in this area is that of introduced competitors.

The capture of the small introduced fish *G. affinis* at only one sampling point, on the Frankland river, confirms the comments of Coy (1979), that this species is not common in many of the south-coastal streams. With this exception and a record from the Warren river Mees (1977), this species appears to be absent from the streams of the forested area between the Blackwood and the Hay river. There is a strong possibility that it may spread through this area in the future.

Several authors Coy (1979), Mees (1977) and Sarti and Allen (1978) have expressed fears that the presence of this fish leads to the extinction of species of small native fish. There appears to be no evidence from Western Australia to substantiate such claims. *Gambusia affinis* is known to occur in association with native species at several localities Mees (1977), Sarti and Allen (1978) and Forests Department (unpublished data). However no records exist to indicate what species were present at these localities prior to the introduction of *G. affinis*. In the absence of such data, any suggesting that the fish fauna has become impoverished, remains speculative. Nevertheless until proven otherwise it would be prudent to regard the species as a threat to small native fishes in the area.

In conclusion it seems unlikely that *L. salamandroides* is threatened by any of mans activities. There

is no evidence to suggest that forestry practices pose any problems, in addition the waters in which the species occurs most often arise and flow through areas of non-commercial forest not subject to logging activities. Agricultural clearing is not likely to be a problem since there is little uncommitted land outside National Parks and State Forests in the area. Likewise mans activities would seem to pose no problem to other species of small fish in the area.

The most obvious threat to any of these native fishes would appear to be *G. affinis*. This however remains to be demonstrated and field ecology studies are urgently needed on all species to answer this question. The indication that some species may be able to co-exist with *G. affinis* and that some appear reasonably tolerant to changes in water quality such as salinity, are encouraging. The genera *Lepidogalaxias*, *Bostockia* and *Nannatherina*, the species of galaxiids and *Edelia vittata* are all endemic to the south-west and deserve more attention than they have had in the past.

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### Appendix 1

Data recorded at each sampling point.

1. The main plant species at each sampling point were scored on a five point scale of frequency; (Havel 1975).  
 0—Absent  
 1—Very rare, seen only after careful search  
 2—Present, observable, but in small numbers  
 3—Common locally, but not uniform over the whole area  
 4—Common over the whole area  
 5—Completely dominating the undergrowth
2. Numbers of each species of fish and crustaceans caught at each point was recorded and samples were collected and sent to the W.A. Museum for identification.
3. Site characteristics,
  1. Pool size (diam.) < 1 m, 1-2 m, 2-4 m, > 4 m.
  2. Natural or man made i.e. dozer scoop, ditch etc.
  3. Degree of overhead shade 0 = open 1 = ½ shade  
2 = fully shaded
  4. Running water or still.
  5. Sample point—0 = small flat, 1 = medium sized flat,  
2 = extensive flat, 3 = non-forest area, 4 = small stream,  
5 = stream, 6 = river, 7 = lake.
  6. Forest type,  
1 = jarrah 2 = blackhutt 3 = marri  
4 = cleared farmland 5 = River gums (*Eucalyptus rudis*) 4 = karri
  7. Presence of aquatic vegetation—largely *Chara* or *Nitella* sp.
  8. Streamside soil 0 = rock 3 = peat  
1 = sand 4 = clay  
2 = loam
  9. Stream bottom 0 = rock 3 = peat  
1 = sand 4 = clay  
2 = silt
4. Water quality, Samples were collected and tested in the laboratory for the following; (Only done on sample points 1-84)
  1. pH
  2. Conductivity
  3. Suspended solids (ppm)
  4. Colour (pt—Co units)
  5. Permanganate Equivalent (meP-1).

### Appendix 2a

Fishes and crustacea collected at 120 sampling points

Sample Point Number	<i>Bostockia porosa</i>	<i>Edelia vittata</i>	<i>Galaxiella nigrostriata</i>	<i>Galaxias occidentalis</i>	<i>Galaxiella munda</i>	<i>Lepidogalaxias salamandroides</i>	<i>Nannatherina balstoni</i>	<i>Geotria australis</i>	<i>Gambusia affinis</i>	<i>Salmo trutta</i>	<i>Cherax preissi</i>	<i>Cherax quinquecarinatus</i>	<i>Palaemonetes australis</i>
1	...	1	...	...	...	...	...	...	...	...	2	...	...
2	...	...	...	...	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...	...	...	...	...
4	...	4	...	...	...	...	...	...	...	...	...	...	...
5	7	6	...	...	...	8	...	...	...	...	7	...	...
6	...	11	...	...	1	8	...	...	...	...	...	...	...
7	...	5	...	...	...	...	...	...	...	...	...	...	...
8	1	...	...	...	...	...	...	...	...	...	...	...	...
9	...	...	...	...	...	...	...	...	...	...	2	...	...
10	...	...	...	...	...	...	...	...	...	...	1	...	...
11	...	...	...	...	...	...	...	...	...	...	...	...	...
12	...	...	...	...	...	...	...	...	...	...	2	...	...
13	...	...	...	...	...	...	...	...	...	...	...	...	...
14	2	15	...	...	3	...	...	...	...	...	4	1	...
15	...	...	...	...	2	6	...	...	...	...	9	...	...
16	...	...	...	...	...	...	...	...	...	...	...	...	...
17	...	3	...	...	...	...	...	...	...	...	2	...	...
18	...	...	1	...	...	3	...	...	...	...	24	...	...
19	...	...	20	...	...	...	...	...	...	...	10	...	...
20	7	6	...	...	...	...	...	...	...	...	13	1	6
21	...	...	...	...	...	4	...	...	...	...	12	...	...
22	1	...	...	...	...	2	...	...	...	...	9	...	...
23	9	2	...	...	...	11	...	...	...	...	24	...	...
24	4	4	...	...	7	...	...	...	...	...	7	...	...
25	1	...	...	...	...	...	...	...	...	...	14	...	...
26	...	...	...	1	...	...	...	...	...	...	5	...	...
27	...	1	...	...	...	...	...	...	...	...	...	...	...
28	3	...	...	...	1	...	...	...	...	...	6	...	...
29	1	...	...	...	39	...	...	...	...	...	7	...	...
30	...	...	...	...	...	...	...	...	...	...	...	...	...
31	...	2	...	2	...	...	...	...	...	...	1	7	...
32	...	1	...	...	...	...	...	...	...	...	...	...	...
33	...	7	...	...	...	...	...	...	...	...	2	...	...
34	...	...	...	...	...	2	...	...	...	...	16	...	...
35	...	...	...	...	...	...	...	...	...	...	19	...	...
36	...	...	...	...	9	...	...	...	...	...	...	...	...
37	...	...	...	...	...	...	...	...	...	...	11	...	...
38	...	2	...	...	...	...	...	...	...	...	15	...	8
39	2	1	...	...	...	...	...	...	...	...	...	1	...
40	...	...	...	1	...	...	...	...	...	...	1	...	1

Appendix 2a—continued

Sample Point Number	<i>Bostockia porosa</i>	<i>Edelia vittata</i>	<i>Galaxiella nigrostriatus</i>	<i>Galaxias occidentalis</i>	<i>Galaxiella munda</i>	<i>Lepidogalaxias salamandroides</i>	<i>Nannatherina balstoni</i>	<i>Geotria australis</i>	<i>Gambusia affinis</i>	<i>Salmo trutta</i>	<i>Cherax preissii</i>	<i>Cherax quinquecarinatus</i>	<i>Palaemonetes australis</i>
41	6	2	...	3	...	...	...	...	...	...	24	...	...
42	11	6	...	...	...	...	...	...	...	...	3	...	...
43	...	...	...	...	...	...	...	1	...	...	12	...	1
44	...	...	...	...	...	...	...	...	...	2	...	...	...
45	4	...	...	...	...	...	...	...	...	...	7	...	...
46	...	1	...	...	...	...	...	...	...	...	...	...	...
47	1	2	...	1	13	...	...	...	...	...	3	...	...
48	2	1	...	1	...	9	...	...	...	...	9	...	...
49	3	...	...	...	5	...	...	...	...	...	3	...	...
50	...	...	...	...	...	...	...	...	...	...	...	...	...
51	2	1	...	...	...	...	...	...	...	...	...	...	...
52	...	...	...	...	...	...	...	...	...	...	5	...	1
53	12	1	...	...	9	...	...	...	...	...	1	1	12
54	...	...	...	6	40	...	...	...	...	...	10	...	...
55	6	...	...	...	30	...	20	...	...	...	2	...	...
56	1	3	...	1	1	...	...	...	...	...	6	...	10
57	...	...	...	...	...	...	...	...	...	...	...	...	...
58	...	...	...	...	...	...	...	...	...	...	6	...	50
59	2	1	...	...	...	...	...	...	...	...	17	...	...
60	...	...	...	...	...	...	...	...	...	...	21	...	...
61	3	2	...	...	3	...	...	...	...	...	10	...	...
62	...	...	...	...	2	...	...	...	...	...	...	...	...
63	2	...	...	...	...	...	...	...	...	...	...	...	...
64	5	9	...	1	5	2	...	...	...	...	6	...	...
65	5	11	...	...	...	...	...	...	...	...	2	...	...
66	...	7	...	...	...	...	...	...	...	...	6	...	...
67	13	...	...	...	1	...	...	...	...	...	3	...	...
68	25	4	...	...	9	...	...	...	...	...	3	...	...
69	...	1	...	...	...	...	...	...	...	...	11	...	...
70	6	6	...	...	...	...	...	...	...	...	8	...	...
71	...	...	...	...	...	...	...	...	...	...	...	...	...
72	...	...	...	...	...	...	...	...	...	...	...	...	...
73	...	...	...	...	...	...	...	...	...	...	8	...	...
74	...	...	...	...	1	2	...	...	...	...	24	...	...
75	...	...	...	...	...	...	...	...	...	...	8	2	...
76	...	2	...	...	...	...	...	...	...	...	1	3	...
77	1	3	...	...	4	...	...	...	...	...	24	1	...
78	...	1	...	...	...	...	...	...	...	...	...	...	2
79	...	...	...	...	...	4	...	...	...	...	8	...	...
80	5	...	...	...	...	...	...	...	...	...	7	...	...
81	4	...	...	...	7	...	...	...	...	...	7	...	...
82	...	...	...	...	2	4	...	...	...	...	16	...	...
83	5	6	...	...	3	...	...	...	...	...	9	1	...
84	18	...	...	...	45	...	...	...	...	...	11	...	...
85	...	2	...	...	...	...	...	...	...	...	2	...	...
86	...	13	...	...	4	...	...	...	...	...	...	...	...
87	10	5	...	...	...	...	...	...	...	...	8	...	...
88	...	...	...	...	20	...	...	...	...	...	1	...	...
89	...	...	...	...	1	2	...	...	...	...	...	...	...
90	9	2	...	...	1	1	...	...	...	...	...	...	...
91	...	...	...	...	...	...	...	...	...	...	1	...	...
92	10	...	...	...	30	...	...	...	...	...	26	...	...
93	52	90	...	...	82	...	...	...	...	...	...	...	...
94	...	...	...	...	...	...	...	...	...	...	10	...	...
95	...	...	...	...	...	...	...	...	...	...	2	...	...
96	...	5	...	...	...	...	...	...	...	...	...	...	...
97	...	...	...	...	...	...	...	...	17	...	1	...	3
98	...	...	...	...	...	...	...	...	...	...	10	...	...
99	...	8	...	1	12	13	...	...	...	...	6	...	...
100	...	...	...	...	...	1	...	...	...	...	3	...	...
101	...	...	...	...	...	12	...	...	...	...	20	...	...
102	...	...	...	...	1	...	...	...	...	...	1	...	...
103	...	...	...	...	1	5	...	...	...	...	50	...	...
104	...	...	...	...	...	...	...	...	...	...	4	...	...
105	...	11	...	...	5	...	1	...	...	...	5	...	...
106	10	...	...	...	...	...	...	...	...	...	6	...	...
107	2	1	...	...	...	...	...	...	...	...	3	...	...
108	...	...	...	...	...	2	...	...	...	...	20	...	...
109	...	...	...	...	...	...	...	...	...	...	4	...	...
110	...	...	...	...	...	...	...	...	...	...	1	...	...
111	3	4	...	1	...	...	...	...	...	...	2	...	...
112	20	...	...	...	...	...	20	...	...	...	...	...	...
113	2	1	...	...	...	...	1	...	...	...	2	...	...
114	...	2	...	...	...	...	...	...	...	...	2	...	...
115	12	6	...	...	20	...	...	...	...	...	6	...	...
116	...	...	...	...	...	...	...	...	...	...	1	...	...
117	2	...	...	...	15	...	...	...	...	...	6	...	...
118	...	...	...	1	...	...	...	...	...	...	12	...	...
119	1	...	...	...	4	...	...	...	...	...	9	...	...
120	...	...	...	...	...	...	...	...	...	...	...	...	...
Total	313	291	21	22	438	101	42	1	17	2	750	20	94
Presence	46	49	2	13	37	20	4	1	1	1	88	10	10
% frequency	33.8	40.8	1.7	10.8	30.8	16.7	3.3	0.8	0.8	0.8	73.3	8.3	8.3
Abundance	6.8	5.9	10.5	1.7	11.8	5.1	10.1	1.0	17.0	2.0	8.5	2.0	9.4



## Appendix 2b

## Description of Sampling Points

R = River	M.P. = Man-Made Pool
C = Creek or stream	C.F. = Cleared Farmland
L.F. = Large Flat*	J = Jarrah
M.F. = Medium Flat	J/M = Jarrah/Marri
S.F. = Small Flat	K = Karri
P = Pool	K/M = Karri/Marri

\* Flat = Area of non-forested sedgeland

1. Ant Pool, J.	116°24'E, 34°44'S
2. M.P., Nelson Road, S.F.	116°22'E, 34°46'S
3. C, Nelson Road, J.	116°23'E, 34°43'S
4. C, Nelson Road, L.F.	116°21'E, 34°43'S
5. C, Nelson Road, L.F.	116°31'E, 34°41'S
6. C, Nelson Road, K.	116°30'E, 34°42'S
7. C, Off Nelson Road, K.	116°29'E, 34°42'S
8. C, Off Nelson Road, J.	116°26'E, 34°43'S
9. M.P., Dog Road, S.F.	116°26'E, 34°43'S
10. C, Dog Road, S.F.	116°25'E, 34°43'S
11. Shannon River, Dog Road, K.	116°25'E, 34°43'S
12. P on Nelson Road, S.F.	116°24'E, 34°43'S
13. C, Nelson Road K.	116°24'E, 34°44'S
14. C, Deeside Road, K.	116°20'E, 34°42'S
15. C, Deeside Road, K.	116°20'E, 34°41'S
16. Deep River, S.W. Hg/wy, K.	116°38'E, 34°59'S
17. C, S.W. Hg/wy, K.	116°36'E, 34°58'S
18. C, S.W. Hg/wy, L.F.	116°35'E, 34°56'S
19. C, S.W. Hg/wy, L.F.	116°35'E, 34°56'S
20. Inlet River, S.W. Hg/wy, J.	116°34'E, 34°55'S
21. C, S.W. Hg/wy, L.F.	116°34'E, 34°54'S
22. C, S.W. Hg/wy, S.F.	116°33'E, 34°53'S
23. P, S.W. Hg/wy, L.F.	116°32'E, 34°48'S
24. C, S.W. Hg/wy, J.	116°30'E, 34°46'S
25. C, S.W. Hg/wy, K.	116°30'E, 34°44'S
26. Weld River, S.W. Hg/wy, K.	116°31'E, 34°41'S
27. Shannon River, S.W. Hg/wy, K.	116°24'E, 34°35'S
28. Quininup Brooke, Cripple Road, K.	116°17'E, 34°30'S
29. C on Wheatley C. Road.	116°15'E, 34°26'S
30. C, Gardner River Road.	116°12'E, 34°43'S
31. Una Brook, Gardner River Road, K.	116°12'E, 34°44'S
32. Buldonia Creek, Gardner River Road, J/M.	116°13'E, 34°46'S
33. Boorara Brook, Boorara Road, J/M.	116°12'E, 34°41'S
34. East Brook, Boorara Road, K.	116°17'E, 34°37'S
35. Boorara Brook, Middleton Road, K.	116°13'E, 34°37'S
37. Dombakup Brook, Vasse Hg/wy, K/M.	116°04'E, 34°35'S
38. C, Barker Road, K/M.	115°54'E, 34°31'S
39. Lake Yeagerup, Coastal J.	115°52'E, 34°32'S
40. Lake Yeagerup, Coastal J.	115°53'E, 34°32'S
41. C, Lake Road, J/M.	115°53'E, 34°31'S
42. C, Ritters Road, K.	115°53'E, 34°30'S
43. C, Lewin Road, J/M.	115°55'E, 34°36'S
44. L, Lewin Road, J/M.	115°54'E, 34°36'S
45. C, Richardson Road, J/M.	115°57'E, 34°36'S
46. C, Off Richardson Road, J/M.	115°58'E, 34°37'S
47. C, Richardson Road, J.	115°59'E, 34°38'S
48. C, Richardson Road, J.	116°05'E, 34°38'S
49. C, Thompson Road, J.	116°42'E, 34°40'S
50. C, Thompson Road, L.F.	116°42'E, 34°44'S
51. Flsie Brook, Thompson Road, J/M.	116°43'E, 34°51'S
52. C, Bevan Road, S.F.	116°35'E, 34°35'S
53. Deep River, Bevan Road, K.	116°33'E, 34°35'S
54. C, Bevan Road, J.	116°32'E, 34°35'S
55. C, Bevan Road, K.	116°30'E, 34°35'S
56. Tone River, Muir Hg/wy, J.	116°53'E, 34°24'S
57. M.P., Meribup Arboretum, L.F.	116°30'E, 34°23'S
58. C, Denbarker Road, J.	117°33'E, 34°41'S
59. C, Denbarker Road, C.F.	117°29'E, 34°45'S
60. C, Denbarker Road, J.	117°27'E, 34°39'S
61. Mitchell River, Denbarker Road, J/M.	117°24'E, 34°50'S
62. C, Denbarker Road, J/M.	117°23'E, 34°55'S
63. C, Summer time track, L.F.	116°04'E, 34°44'S
64. Meerup River, Gurnsey Road, J.	116°04'E, 34°41'S
65. C, Rifle Range Road, J.	116°01'E, 34°37'S
66. C, Rifle Range Road, K.	116°01'E, 34°37'S
67. C, Rifle Range Road, J.	116°03'E, 34°36'S
68. C, Rifle Range Road, K.	116°03'E, 34°35'S
69. Barlee Brook, Vasse Hg/wy, C.F.	115°45'E, 34°13'S
70. C, Vasse Hg/wy, J.	115°46'E, 34°18'S
71. Donnelly R., Vasse Hg/wy, C.F.	115°46'E, 34°19'S
72. C, Jasper Road, J/M.	115°47'E, 34°22'S
73. C, Jasper Road, J/M.	115°46'E, 34°23'S
74. C, Pneumonia Road, L.F.	115°44'E, 34°25'S
75. Carey Brook, Jasper Road, J.	115°48'E, 34°26'S
76. Weld River, Beardmore Road, K/M.	116°34'E, 34°37'S
77. Deep River, Beardmore Road, J/M.	116°35'E, 34°48'S
78. Frankland River, Caldyaning Road, K.	116°48'E, 34°39'S
79. C, Boronia Road, L.F.	116°50'E, 34°39'S
80. C, Boronia Road, M.F.	116°51'E, 34°39'S
81. C, Middle Road, M.F.	116°57'E, 34°50'S

82.	C, Middle Road, M.F.	116°57'E, 34°52'S
83.	Bow River, Middle Road, J/M.	116°58'E, 34°55'S
84.	C, Break Road, J/M.	117°03'E, 34°51'S
85.	Barlee Brook, Steward Road, J/M.	115°42'E, 34°19'S
86.	C, Steward Road, J/M.	115°42'E, 34°19'S
87.	M.P., Black Pt. Road, L.F.	115°40'E, 34°18'S
88.	M.P., Fouracres Road, L.F.	115°35'E, 34°18'S
89.	M.P., Fouracres Road, L.F.	115°35'E, 34°18'S
90.	M.P., Fouracres Road, C.F.	115°31'E, 34°18'S
91.	M.P., Scott Road, C.F.	116°16'E, 34°12'S
92.	M.P., Scott Road, C.F.	115°16'E, 34°11'S
93.	M.P., Scott Road, C.F.	115°16'E, 34°10'S
94.	C, Steward Road, J.	115°32'E, 34°11'S
95.	C, Steward Road, J.	115°35'E, 34°12'S
96.	M.P., Myalgelup Road, L.F.	116°43'E, 34°33'S
97.	Frankland R., Myalgelup, J.	116°51'E, 34°33'S
98.	M.P., Nornalup Road, C.F.	116°57'E, 34°35'S
99.	C, Nornalup Road, J.	116°57'E, 34°39'S
100.	M.P., Nornalup Road, S.F.	116°57'E, 34°44'S
101.	C, Nornalup Road, J.	116°57'E, 34°44'S
102.	Kent R., Basin Road, J.	117°03'E, 34°46'S
103.	C, Nornalup Road, J.	117°00'E, 34°50'S
104.	C, S.W. Hg/wy, C.F.	117°04'E, 34°58'S
105.	Kordabup Rd., S.W. Hg/wy, C.F.	117°09'E, 34°59'S
106.	C, S.W. Hg/wy, C.F.	117°12'E, 34°59'S
107.	C, S.W. Hg/wy, C.F.	117°18'E, 34°59'S
108.	C, S.W. Hg/wy, L.F.	116°53'E, 35°01'S
109.	M.P., Muir Hg/wy, C.F.	116°50'E, 34°28'S
110.	C, Muir Hg/wy, C.F.	116°57'E, 34°29'S
111.	C, Muir Hg/wy, C.F.	116°58'E, 34°29'S
112.	C, Muir Hg/wy, C.F.	116°59'E, 34°30'S
113.	Kent R. Bevan Road, J.	117°06'E, 34°41'S
114.	P, Kockelup Road, J.	117°08'E, 34°47'S
115.	Denmark R. Kockelup Road, K.	117°13'E, 34°47'S
116.	C, Kockelup Road, J.	117°14'E, 34°46'S
117.	C, Stan Road, J.	117°21'E, 34°48'S
118.	C, Stan Road, J.	117°21'E, 34°51'S
119.	C, Court Road, K.	115°56'E, 34°20'S
120.	M.P., Glouster Road, K.	116°08'E, 34°21'S





## Chromosome numbers of Western Australian Apiaceae

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### Abstract

Chromosome numbers for 37 species of Apiaceae are given, including new generic records for *Chlaenosciadium*, *Homalosciadium*, *Pentapeltis*, *Platysace*, *Schoenolaena* and *Xanthosia*.

### Introduction

The Apiaceae (Umbelliferae), although one of the largest dicotyledon families is sparsely represented in Western Australia, where approximately 90 species occur. These species are often small herbs, and have been poorly collected and are generally little studied. This paper presents chromosome number determinations for 92 populations of 37 species of the family. Studies on the cytology of the family are continuing, and will be extended to cover Eastern Australia during the next phase.

Counts were made on pollen mother cells in all cases. Buds were fixed in Bradley's (1948) chloroform-acetic acid-alcoholic fixative, then stained in Snow's (1963) acid-alcoholic carmine for 4-7 days and squashed in 45% acetic acid. Voucher specimens for all counts are lodged in PERTH or Kings Park.

### Results and Discussion

Details of the new chromosome number determinations are given in Table 1. Previous counts for the other genera are given in Table 2. The counts for

Table 1

New chromosome number determinations for Western Australian apiaceae

Taxon	n	Locality	Voucher
<i>Actinotus glomeratus</i> Benth.	10	10 km N of Walpole	GK 676
	10	Crestwood, Perth	GK 1313
	10	13 km S of Bunbury	GK 103
<i>A. humilis</i> (F. Muell. et Tate) Domin.	10	Karridale	GK 1384
	10	Newdegate to Lake King	GK 359
	10	80 km E of Lake King	GK 3422
<i>A. leucocephalus</i> Benth.	10	Cannington	GK s.n.
	10	Mimegarra Rd, Cataby	GK 2095
	10	Cockleshell Gully	GK 579
<i>A. omnifertilis</i> F. Muell. ex Benth.	10	Scott River	GK 598
<i>A. superbus</i> O. H. Sargent	10	cultivated	no voucher
<i>Apium annuum</i> P. S. Short	11	20 km E of Esperance	GK 453
<i>A. prostratum</i> Labill. ex Vent.	11	Augusta	GK 1884
	11	Guildford	GK 1492
	11	Molloy Isld, Augusta	G.K. s.n.
<i>Chlaenosciadium gardneri</i> Norman	10	Tarin Rock	GK 334
	10	21 km N of Narebeen	GK 448
	10	Newdegate to Lake King	GK 3527
<i>Daucus glochidiatus</i> (Labill.) Fisch., C. A. Meyer et Ave-Lall.	22	1 km N of Lake Cave	GK 348
	22	Mt Holland	GK 1088
	22	Yanchep	GK 2129
	22	Seamore Downs Station	GK 542
	22	Queen Victoria Rocks	GK 386
<i>Eryngium pinnatifidum</i> Bunge	14	Trigg Island	GK s.n.
<i>E. pinnatifidum</i> "var"	14	67 km E of Perth on York Road	GK 486
<i>E. sp.</i>	14	Cape Leeuwin	GK 1885
<i>Pentapeltis peltigera</i> (Hook.) Bunge	5	1 km W of Dell, Mundaring	GK 2904
	5	Brockman Highway, Augusta	GK s.n.
<i>Platysace</i> sp.	8	32 km N of Walpole	GK 96
<i>Schoenolaena juncea</i> Bunge	5	Cannington	GK 4004
	5	Yornup	GK 990
	5	Molloy Isld. Rd,	GK 1551
	5	8 km E of Porongorups	GK 349
	22	John Rate Lookout, Walpole	GK 1413
<i>S. tenuior</i> Bunge	22	10 km W of Pemberton	GK 1414
	22	41 km E of Augusta	GK 346
	22	Denmark	GK 1412
	22	Nornalup	GK 2153
	22	15 km N of Pemberton	GK 2154
<i>Trachymene anisocarpa</i> (Turcz.) B. L. Burtt.	22		

Table 1—continued

Taxon	n	Locality	Voucher
<i>T. bialata</i> (Domin.) B. L. Burtt.	11	242 km N of Seemore Downs Stn. Great Victoria Desert	GK 552
<i>T. caerulea</i> Grah.	11	Rottneest Island	GK s.n.
	11	Garden Island	GK s.n.
	11	City Beach	GK s.n.
	11	11 km S of Mandurah	GK 2198
<i>T. caerulea</i> var. <i>leucopetala</i> F. Muell.	11	Kalbarri	Young 485
<i>T. croniniana</i> F. Muell.	11	7 km W of Forrestiana	GK 1661
	11	45 km E of Lake King	GK 435
	11	Newdegate to Lake King	GK 358
	11	10 km N of Mt Ridley	GK 417
	11	100 km E of Lake King	GK 409
	11	117 km W of Balladonia	GK 1719
<i>T. aff. croniniana</i>	11	22 km S of Laverton	GK 507
<i>T. glaucifolia</i> (F. Muell.) Benth.	11	43 km E of Laverton	GK 523
	11	Python Pool	GK 772
<i>T. oleracea</i> (Domin.) B. L. Burtt.	20	Salmon Beach, Esperance	GK 493
<i>T. pilosa</i> Sm.	20	Ruabon	GK 2177
	20	Welshpool Road, Perth	GK 2053
	11	19 km W of Meekatharra	Del 74886
<i>T. sp. I</i>	11	Pharoah's Well	Demarz 3841
<i>T. sp. I</i>	11	Ruabon	GK 600
<i>T. sp. II</i>	11	Darlington	GK s.n.
<i>T. sp. II</i>	11	Lake Cave, Augusta	GK 345
<i>Xanthosia atkinsoniana</i> F. Muell.	10	13 km N of Manjimup	GK 923
	10	Darlington	GK 2890
	10	10 km N of Walpole	GK 678
	10	Kojonup area	GK 448
	10	7 km W of Toodyay	GK 1050
	10	2 km S of Witchcliffe	GK 687
<i>X. ciliata</i> Hook.	10	Yoongarillup	GK 212
	10	7 km W of Toodyay	GK 1051
	10	Abbey, Stirling Range	GK 1143
	10	20 km S.E. Eneabba	GK 587
	10	18 km S of Busselton	GK 1386
	10	Cannington	GK 2102
	10	Karridale	GK 2165
	10	38 km S of Nannup	GK 2166
	10	170 km N of Perth on Brand Highway	GK 97
	10	Eneabba	GK 1338
<i>X. huegelii</i> ssp. nov.	20	46 km W of Ravensthorpe	GK 104
	20	Nannup	GK s.n.
	20	Mt Lofty Ranges, Adelaide	GK 2248
	20	Cape Le Grand	GK 653
	20	32 km N of Walpole	GK 81
	20	Inlet River	GK 351
	20	24 km S of Manjimup	GK 78
	10	Gull Rock, Albany	GK 2697
<i>X. rotundifolia</i> DC.	10	Mt Hassell, Stirlings	GK 443
	10	Chester Pass Road, Stirlings	GK 444
var. <i>rotundifolia</i>	10	4 km N of Cockleshell Gully	GK 482
<i>X. rotundifolia</i> DC.	10	8 km E of North Bullsbrook	GK 2096
var. <i>hypoleuca</i> Diels.	10	Hostellers, Stirling Range	GK 1123
<i>X. tomentosa</i> George	10		
<i>X. sp. I</i>	10		
<i>X. sp. II</i>	10		

Table 2

Previously recorded chromosome numbers for Apiaceae of the Australasian region

Species	n	2n	Reference	Area
<i>Trachymene adenoides</i> Buwalda	22		Constance <i>et al.</i> (1971)	Papua
<i>Trachymene anisocarpa</i> (Turcz.) B. L. Burtt.	66		Constance <i>et al.</i> (1971)	cultivated
<i>Trachymene australis</i> Benth = <i>anisocarpa</i> (Turcz.) B. L. Burtt.		44	Wanscher (1933)	Australia
<i>Trachymene arfakensis</i> (Gibbs) Buwalda	22		Constance <i>et al.</i> (1971)	New Guinea
<i>Trachymene caerulea</i> Grah.		22	Wanscher (1933)	Australia
<i>Trachymene caerulea</i> Grah.	11		Constance and Bell (1960)	cultivated
<i>Trachymene cyantha</i> D. E. Boyland	11		Boyland (1972)	Queensland
<i>Trachymene humilis</i> Benth.		22	Wanscher (1933)	Australia
<i>Trachymene saniculaefolia</i> Staff.	44		Constance <i>et al.</i> (1971)	Borneo
<i>Trachymene saniculaefolia</i> Staff.		44	Borgman (1964)	Mt. Wilhelm New Guinea
<i>Trachymene tripartita</i> Hoogl.		44	Borgman (1963)	Mt. Wilhelm New Guinea
<i>Actinotus helianthii</i> Labill.		20	Smith-White (1955)	South East. Australia
<i>Apium annuum</i> P. S. Short	11		Short (1979)	South Australia
<i>Apium prostratum</i> Labill.		22	Short (1979)	Australia

the genera *Chlaenosciadium*, *Homalosciadium*, *Pentapeltis*, *Platysace*, *Schoenolaena* and *Xanthosia* are believed to be new generic records.

*Actinotus* in Western Australia is uniformly  $n = 10$ , supporting Smith-White's (1955) count on the Eastern *A. helianthii*. Moore (1971) however, cites *Actinotus* as  $n = 20$ , and states the genus is a paleopolyploid. This is obviously incorrect, as there is no current evidence of polyploidy in the genus.

*Xanthosia*, *Chlaenosciadium*, *Actinotus*, *Pentapeltis* and *Schoenolaena* all appear closely related on vegetative and floral morphology. The finding of  $n = 10$  for *Actinotus*, *Chlaenosciadium* and *Xanthosia* supports this association, while the records of  $n = 5$  (very large chromosomes over twice the size of *Xanthosia* in *Pentapeltis* and *Schoenolaena* chromosomes) supports their segregation from *Xanthosia* s.s., where Bentham (1867) had placed them.

The monotypic genus *Homalosciadium* has  $n = 12$ , which provides evidence for a close relationship to *Hydrocotyle* ( $n = 8, 9, 10, 11, 12$ ; Moore 1971) in which it was once placed.

*Platysace* with  $n = 8$  appears cytologically very distinct from *Trachymene* ( $n = 11$ ), within which several species were once placed. Further studies are needed on this large genus, which has proved cytologically extremely difficult.

*Trachymene* is relatively uniform on  $n = 11$ , with extensive polyploidy being reported elsewhere in the perennial species (Table 2). A small degree of aneuploidy ( $n = 20$  in *Trachymene pilosa*) has been found.

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## Oniscoidea (Crustacea: Isopoda) from Rottnest Island, Western Australia

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### Abstract

Eleven species of Oniscoidea are recorded from Rottnest Island and notes on their distributions are provided. Seven species, including three of Palaeartic origin, represent new records for the island.

Two of the Palaeartic species, *Halophiloscia couchi* and *Porcellio lamellatus*, are recorded from Australia for the first time. The possible transfer of other Palaeartic species to Rottnest Island is discussed.

### Introduction

During 1980, a study of island biogeography of terrestrial Isopoda (Suborder Oniscoidea) was made on small, limestone islets and stacks around Rottnest Island. These islets provide an excellent system for the investigation of various aspects of insular biogeography and they have been used in studies of plants (Abbott 1977; Abbott and Black 1980) and lizards (Coster 1977).

Prior to this study at least four different species of Oniscoidea have been recorded from Rottnest Island. *Buddelundia cinerascens* Budde-Lund, *Deto* sp. and *Philoscia* sp. were recorded by Budde-Lund (1912). Wahrberg (1922) recorded *Deto marina* (Chilton) and *Laevophiloscia perlata* Wahrberg. *Haloniscus searlei* Chilton was reported from salt lakes on the island by Ellis and Williams (1970). Although terrestrial isopods form a common element of the invertebrate ground fauna, they have received little attention in Western Australia. Much of the published information is in papers by Budde-Lund (1912), Wahrberg (1922) and Vandel (1973). These comprise mainly descriptions of species and lists of localities, and none is written in English.

The purpose of this paper is to present an updated list of Oniscoidea from Rottnest Island. Details of the distribution of species on the limestone islets and stacks will be published elsewhere.

### Methods

Nine visits were made to Rottnest Island, from February to October, 1980. Most of the samples were collected around the rocky shoreline and on beaches but several inland sites, near lakes and swamps, were also sampled. A map of Rottnest Island, showing the sampling locations, is given in Figure 1.

Isopods were collected by hand from beneath rocks, mats of succulent vegetation (predominantly *Rhagodia baccata*, *Threlkeldia diffusa* and *Scaevola crassifolia*) and other cryptozoic refuges. Specimens for identification were preserved in 70% ethyl alcohol. Reference specimens have been lodged in the Western Australian Museum, Perth, and the Tasmanian Museum, Hobart.

**Table 1**

*Species of Oniscoidea recorded from Rottnest Island. Catalogue numbers of specimens lodged in the Western Australian Museum (WAM) are also listed.*

Species	WAM No.
Indigenous species	
Family SCYPHACIDAE	
<i>Deto marina</i> (Chilton, 1884)	119/80
<i>Alloniscus (Alloniscus) nicobaricus</i> Budde-Lund, 1885	120-122/80
Family PHILOSCIIDAE	
<i>Laevophiloscia perlata</i> Wahrberg, 1922	123-125/80
<i>Laevophiloscia karrakattensis</i> Wahrberg, 1922	126/80
Family undetermined: close to SCYPHACIDAE and PHILOSCIIDAE	
<i>Haloniscus searlei</i> Chilton, 1920	—
Genus <i>Haloniscus</i> was placed originally in Family Oniscidae <i>s. lat.</i> Due to a restriction of the Oniscidae, the position of <i>Haloniscus</i> needs to be reviewed.	
Family: PLATYARTHRIIDAE	
<i>Trichorhina australiensis</i> Wahrberg, 1922	127-129/80
Family TRACHELIPIDAE?	
An unidentified species	130-131/80
Family ARMADILLIDAE	
Subfamily BUDELUNDIINAE	
<i>Buddelundia cinerascens</i> Budde-Lund, 1912	132-135/80
Introduced species	
Family HALOPHILOSCIIDAE	
<i>Halophiloscia couchi</i> (Kinahan, 1858)	—
Family PORCELLIONIDAE	
<i>Porcellio lamellatus</i> Uljanin, 1875	138/80
<i>Metoponorthus pruinosus</i> (Brandt, 1833)	139-140/80

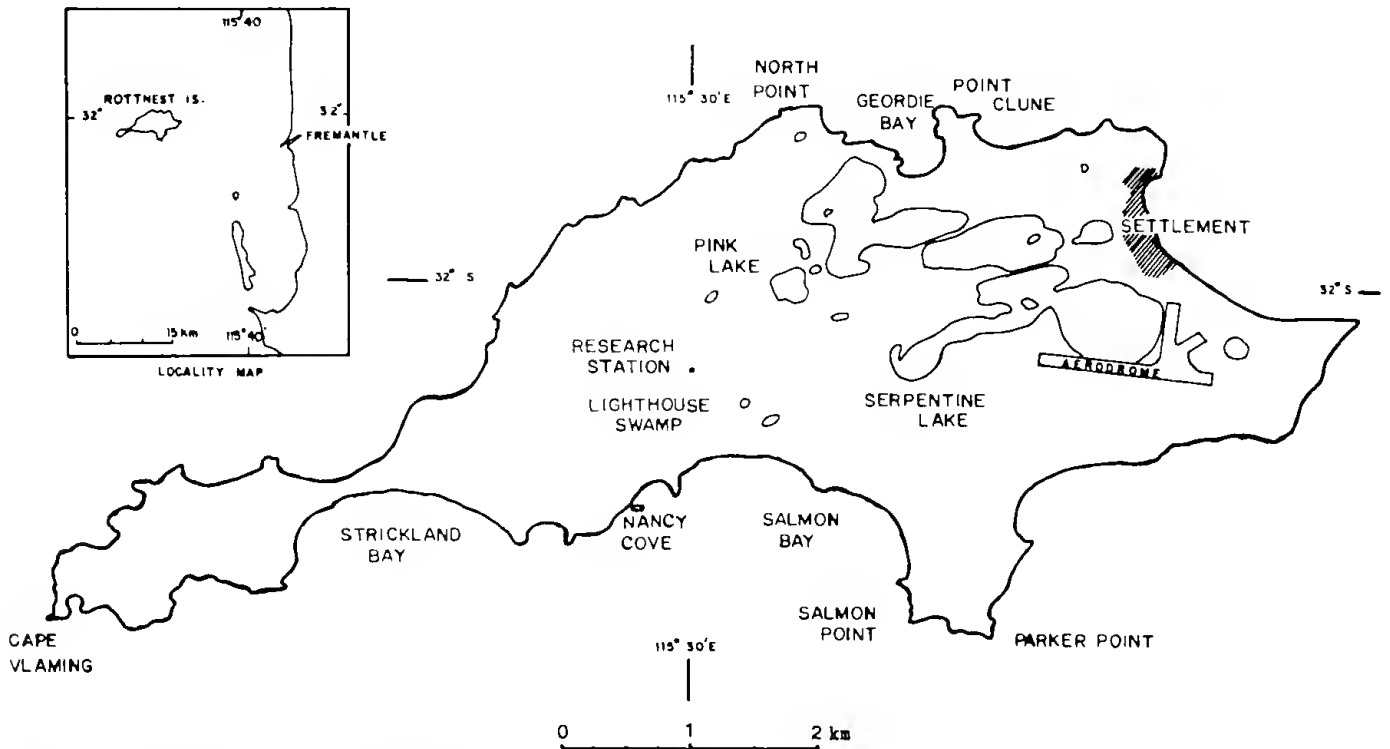


Figure 1.—Sampling locations on Rottnest Island.

Table 2

Distribution of Oniscoidea on Rottnest Island

	Parker Point	Salmon Point	Salmon Bay	Nancy Cove	Strickland Bay	Cape Vlaming	North Point	Geordie Bay	Point Clune	Lighthouse Swamp	Research Station	Pink Lake	Serpentine Lake
<i>Deto marina</i> .....	*	*	*	*	*	*	*	*	*				
<i>Alloniscus nicobaricus</i> .....	*	*	*	*	*	*	*	*	*			*	*
<i>Laevophiloscia perlata</i> .....	*	*	*	*	*	*	*	*	*			*	*
<i>Laevophiloscia karrakattensis</i> .....	*	*			*	*	*	*	*			*	*
<i>Haloniscus searlei</i> .....													*
<i>Trichorhina australiensis</i> .....				*			*						
Trachelipidae? sp. ....		*	*	*	*	*	*		*				
<i>Buddelundia cinerascens</i> .....	*	*	*	*	*	*	*	*	*	*		*	
<i>Halophiloscia couchi</i> .....		*		*	*		*		*				
<i>Porcellio lamellatus</i> .....			*						*				
<i>Metoponorthus pruinus</i> .....	*						*	*	*	*	*		

In the preparation of this paper, the contributions of the two authors were as follows:

Stuart Bunn carried out the field work for the project and assessed the situation on Rottnest Island. Except where stated otherwise, the isopods studied were collected by S. Bunn.

Alison Green identified the specimens and provided information on taxonomic matters and on distributions elsewhere.

**Results**

Eleven species of Oniscoidea, including three introduced species, were collected from Rottnest Island during the present study (Table 1). The distributions of these species throughout the sampling sites are shown in Table 2.

**Indigenous species**

Family Scyphacidae

*Deto marina* (Chilton)

Green (1974, p. 235) reported *Deto marina* as a halophilic species which inhabits stony parts of the supralittoral zone. Recorded from Rottnest Island by Wahrberg (1922, p. 86), *D. marina* has been obtained from "various localities" in Western Australia (Nicholls 1933, p. 128) and on the southern and eastern coasts of Australia, as well as Tasmania. On Rottnest Island the species is abundant in supralittoral habitats, mostly beneath broken rock. In some areas, the island's shoreline consists entirely of vertical cliff faces of weathered limestone and little broken rock material is available. In such

places the species is present infrequently in narrow crevices above the high tide level. At Parker Point, on 23 September 1980, animals were observed beneath rock debris, submerged in tidal pools.

*Alloniscus (Alloniscus) nicobaricus* Budde-Lund

Budde-Lund (1912, p. 40) identified isopods from North Fremantle, W.A., as *Alloniscus nicobaricus* Budde-Lund, 1885. Specimens of *Alloniscus* found on Rottneest Island are likely to be conspecific with the former animals. Arcangeli (1960, p. 40) divided the genus *Alloniscus* into two subgenera and included *A. nicobaricus* in the subgenus *Alloniscus*. The specimens from Rottneest Island also belong to this subgenus. They agree with Budde-Lund's (1885, p. 226) description of *A. nicobaricus*; however, the latter is brief and it might apply to more than one species.

In the present paper, Budde-Lund's use of the name, *A. nicobaricus*, for the species of *Alloniscus* collected at North Fremantle, will be followed. However, it is not taken for granted that these isopods from southern Western Australia are conspecific with the type material of *A. nicobaricus* from the Nicobar Islands. A comparison of specimens from the two localities would be of interest. *A. nicobaricus* has not been recorded from other parts of Australia.

In this survey of Rottneest Island, *A. nicobaricus* was found in pockets of soil in the rocky, supralittoral zone and beneath rock slabs higher on the marine shore. It was also collected on the shores of Pink Lake and Serpentine Lake. The latter is in the centre of the island and its water is strongly hypersaline.

Family Philosciidae

*Laevophiloscia perlata* Wahrberg

*L. perlata* is endemic to Western Australia; it has been recorded from 14 localities, including Rottneest Island, by Wahrberg (1922, p. 126), and from Pelican Point, Crawley, and Walpole Inlet by Bowley (1935, pp. 58, 60). In the present study it was found in the upper supralittoral zone beneath mats of succulent vegetation (in particular, *Scaevola crassifolia*). *L. perlata* is a very agile species which rapidly burrows through loose sand and organic debris when disturbed. Apart from the supralittoral area, it was also found beneath rocks in moist soil near Lighthouse Swamp and Pink Lake.

*Laevophiloscia karrakattensis* Wahrberg

*L. karrakattensis* has been recorded previously only from the Perth suburb of Karrakatta (Wahrberg 1922, p. 130). On Rottneest Island it was found in similar microhabitats to *L. perlata*.

Family undetermined (close to Scyphacidae and Philosciidae)

*Haloniscus searlei* Chilton

*H. searlei* was found submerged in the hypersaline water at the edge of Serpentine Lake. It has been recorded previously from Government House Lake, and five other localities on Rottneest Island, by Ellis and Williams (1970, p. 52). *H. searlei* also occurs in salt lakes in South Australia, Victoria and Tasmania.

Family Platyarthridae

*Trichorhina australiensis* Wahrberg

*T. australiensis* was recorded by Wahrberg (1922, p. 189) from Woorloo and Gooseberry Hill, W.A. This species was collected at Blackwall Reach, Perth, W.A., in 1973, by Mrs J. Lowry (Green unpub. data) but it has not been found beyond Western Australia. *T. australiensis* seems to have a limited distribution on Rottneest Island (Table 2). However, its small size (4.5 mm or less) makes it difficult to detect so the actual distribution may be greater.

Family Trachelipidae?

An unidentified species

An unnamed oniscoid species was found beneath rocks and mats of vegetation, high on the shore of Rottneest Island. This is probably conspecific with one of the species present in Tasmania, which Green (1974, p. 232) referred to Family Trachelipidae. Other examples of what is thought to be the same species have been collected on 14 islands in the Furneaux and Kent Groups, Bass Strait, in 1972-1979, by Mr J. S. Whinray, and in Adelaide and near Moorlands, South Australia, in 1975, by Mr T. N. Petney and Mr C. Wilson respectively (Green unpub. data). In Tasmania and eastern Bass Strait these isopods have been found only near the coast or on islands but they occur further inland in South Australia. The specimens do not correspond with any oniscoid species described from Australia to date.

The unnamed isopods from Tasmania, S.A. and Rottneest Island have been referred, tentatively, to the Trachelipidae because they appear to have pseudotracheae in the exopodites of the pleopods. These isopods have other characters in common with an African genus, *Niambia* Budde-Lund, 1904, which is currently placed in Family Platyarthridae. Members of this family, typically, do not possess pseudotracheae. However, there is some difference of opinion, in literature, as to whether some of the species placed in *Niambia* do or do not have respiratory structures in the pleopods. Further study of the Australian isopods, and of genus *Niambia*, is needed to resolve the present uncertainty. In the mean time, the species found on Rottneest Island will be referred to as Trachelipidae? sp.

Family Armadillidae

Subfamily Buddelundiinae

*Buddelundia cinerascens* Budde-Lund

*B. cinerascens* was recorded from Rottneest Island by Budde-Lund (1912, p. 27) and from Carnac Island, W.A., by Wahrberg (1922, p. 231); it has not been recorded elsewhere. This is the only oniscoid species which can readily be located on Rottneest Island during the summer months. It is the only native species, found so far, which is able to conglobate. *B. cinerascens* occurs in cryptozoic retreats throughout the entire island.

Introduced species

The following three species have been introduced to Australia. Their descriptions have been published by Vandel (1962).



Family Halophilosciidae

*Halophiloscia couchi* (Kinahan)

*H. couchi* is a halophilic species which occurs on marine coasts and on the shores of brackish waters. It has a wide distribution in Europe, Asia Minor, North Africa and on North Atlantic islands (Vandel 1962, p. 480). It has been introduced to Virginia, U.S.A., and Bermuda (Schultz 1972, p. 86) and to Argentina (Reca 1972, p. 407). The species has not been recognized previously in Australia. In this study *H. couchi* was found amongst rock rubble in the supralittoral zone. The first collection was made at Strickland Bay, in early August, 1980.

Family Porcellionidae

*Porcellio lamellatus* Uljanin

*P. lamellatus* is a Palaearctic species which has not been recorded previously from Australia. It is native to the Mediterranean and Black Sea shores, the Atlantic shores of Spain and Portugal, and to some North Atlantic islands (Vandel 1962, p. 744). *P. lamellatus* has been introduced to Cuba and Bermuda (Schultz 1972, p. 93), Argentina (Reca 1972, p. 409) and Saint Helena (Vandel 1977, p. 393). According to a key constructed by Vandel (1962, p. 742), the specimens from Rottneest Island belong to subspecies *lamellatus*, form *oceanicus*. *P. lamellatus* is a halophilic species which remains near the coast. On Rottneest Island one small population was found at Salmon Bay, on 6 May 1980, on the sandy beach beneath rocks.

*Metoponorthus pruinus* (Brandt)

*M. pruinus*, a Palaearctic species which is now cosmopolitan, has been recorded from 15 localities in Western Australia (Budde-Lund 1912, p. 39; Wahrberg 1922, p. 157; Vandel 1973, p. 16). It also occurs in South Australia, New South Wales, Queensland and the Northern Territory. Its distribution on Rottneest Island coincides closely with human habitation. On the shore *M. pruinus* was found beneath rock slabs on sandy beaches. It has been recorded from similar situations in Bermuda (Schultz 1972, p. 91).

Discussion

Many of the species recorded in the present study are not common in cryptozoic retreats during the harsh summer conditions. In February and early March *Buddelundia cinerascens* was the only species easily located. Some specimens of *Laevophiloscia perlata* and *Metoponorthus pruinus* were also taken at this time, but only from microhabitats in damp soil near Lighthouse Swamp. By May, all but one of the recorded species were present; *Halophiloscia couchi* was first located in early August. During the cooler months, from May to September, most species of terrestrial Isopoda were readily found in their cryptozoic microhabitats.

In *Buddelundia cinerascens* there are pseudotracheae in the exopodites of the 1st-4th pairs of pleopods (the 5th pleopods are hidden and lack pseudotracheae). The 2nd-4th exopodites are grooved so that they and the 1st exopodites fit together instead of loosely overlapping each other, as is the case in other Oniscoidea. This unusual adaptation of the respiratory organs may be related to the tolerance of drier conditions by *B. cinerascens*.

Most of the oniscoid species require a cool, moist microhabitat, especially those, such as *Deto marina* and *Alloniscus nicobaricus*, which rely on branchial respiration by the pleopods. Hot, dry conditions would also be particularly harsh for the small isopods such as the Trachelipidae? species and *Trichorhina australiensis*, where a high surface-area-to-weight ratio would imply rapid desiccation. To escape such conditions the isopods presumably migrate from their cryptozoic niches to subterranean ones. Consequently a survey of terrestrial isopods conducted during the summer months would reveal only those species which are adapted to drier conditions.

The low number of species recorded in previous papers cannot be attributed to this seasonal activity. Budde-Lund (1912) reported on isopods from Rottneest Island which were collected during September. Most species of Oniscoidea are abundant at this time. Unfortunately, Wahrberg (1922) did not mention the collecting dates of his specimens from the island.

The three Palaearctic species, which were not represented in previous collections, may have arrived on the island subsequently. The distribution of *Metoponorthus pruinus* closely follows human habitation, occurring notably near the new settlement regions at Point Clune and Geordie Bay, and near Lighthouse Swamp and the Research Station. The other two species are particularly interesting records for Rottneest Island because neither has been recognized previously in Australia.

Three other introduced species are known to occur on the adjacent mainland but they were not collected on Rottneest Island during the present survey. *Porcellio scaber* Latreille, 1804, *Porcellio laevis* Latreille, 1804, and *Armadillidium vulgare* (Latreille, 1804), together with *Metoponorthus pruinus*, are common in damp places in gardens throughout Perth metropolitan area (Bunn unpub. data). The main settlement at Thompson Bay on Rottneest Island was not included in this study and it is possible that these species are present there. If not, their arrival on the island might be expected in the near future, especially with the recent increase of building activity at the new areas of settlement. Materials used for buildings on the island are transported from the mainland.

Specimens of *Armadillidium vulgare* (Family Armadillidiidae), collected at Nedlands on 19 April 1980, represent the first record of this species from Western Australia. *A. vulgare* has been recorded previously from south-eastern Australia and Tasmania.

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## Beach-width variation at Scarborough, Western Australia

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### Abstract

An analysis of beach-width changes occurring over sixteen years, from 1965 to 1981, on Scarborough Beach, in the Perth metropolitan area identifies long-term cyclic beach changes. A strong seasonal cycle of shoreline fluctuation, with the shoreline ranging up to 25 m, is superimposed on a steadier progradation of approximately 3 m per year. Other important cyclic components include a biannual component with ranges approximately 20% of the annual component and weaker 3.5 and 7 year oscillations. The several periodic components combine to cause a beat effect with a period of the order of 10 years.

### Introduction

The nature of beach change on the coast of the Perth metropolitan area north of Fremantle (Fig. 1) is a matter of growing concern to State and local government authorities responsible for management of public utilities in the coastal zone. Two sets of problems are evident. Sand drift, resulting from frontal dune instability and destruction, is common in all local government areas. Car parks, roadways, parklands and buildings are occasionally buried by sand drift. Second, shoreline retreat endangers private and public property on some beaches, notably at Cottesloe, City Beach, and Floreat. The two sets of problems are related to changes in beach-width in time and space, and hence to sediment exchange between the subaerial and subaqueous beach zones. Assessment of long-term (measured over sixteen years) and cyclic variation in beach-width at Scarborough Beach is reported in this paper.

Beach profile and hence beach-width changes on open ocean sandy beaches essentially involve onshore-offshore and alongshore shifts of sand associated with changes in wave regime. Individual profile configuration alters from a berm to bar type pattern and the beach-width decreases as the wave regime alters from swell to storm wave conditions, low to high wave steepness, or reflective to dissipative wave conditions. Such changes have been examined for a variety of time scales ranging from short period duration associated with semi-diurnal tide cycles, through spring to neap tide cycles to longer period changes such as annual variations associated with seasonal weather conditions.

Beach-width also varies systematically along sandy beaches in accordance with the rhythmic topography of the nearshore zone. The rhythmic topography is linked to the beachface morphology via the nearshore water circulation system so that giant cusp

horns are frequently tied to sand bars at rip catchment divides, and cusp embayments are tied to rip channels. Along a beach with rhythmic topography, beach-width changes as the pattern of rhythmic topography switches state. This occurs with variation in the wave regime or as rip currents and bars migrate along the beach.

Strategies for examining these complex beach changes have been suggested by Sonu (1969), who argued that the dynamics of beach change are best explained in terms of the collective responses of sediments associated with sand bars migrating alongshore or in onshore-offshore directions. These changes have temporal and spatial components which can be separately analysed. Temporal components may be analysed by time series analysis involving application of least squares or Fourier transform techniques (Doornkamp and King 1971; Eliot and Clarke 1980) while characteristic modes of spatial variability are identified by empirical orthogonal function, eigenfunction, analysis (Winant *et al.* 1975; Dolan *et al.* 1977; Aubrey 1979; Aranuvachapun and Johnson 1979; Bowman 1981).

### *Winds, waves, currents and tides*

Several major weather systems determine the wind regime of the Perth Metropolitan coastal region. These have been described in detail by the Bureau of Meteorology (1969) and Gentilli (1971). Prevailing weather conditions are largely determined by a belt of anticyclonic, high pressure systems that is periodically displaced by tropical and mid-latitude cyclonic depressions or locally modified by sea breeze activity. The belt of anticyclones is seasonally displaced, alternating between latitudes 35° to 45°S in summer and 26° to 34°S in winter. The prevailing coastal winds at Perth therefore are dominantly offshore in summer and onshore in winter. This basic seasonal rhythm is modified by the other

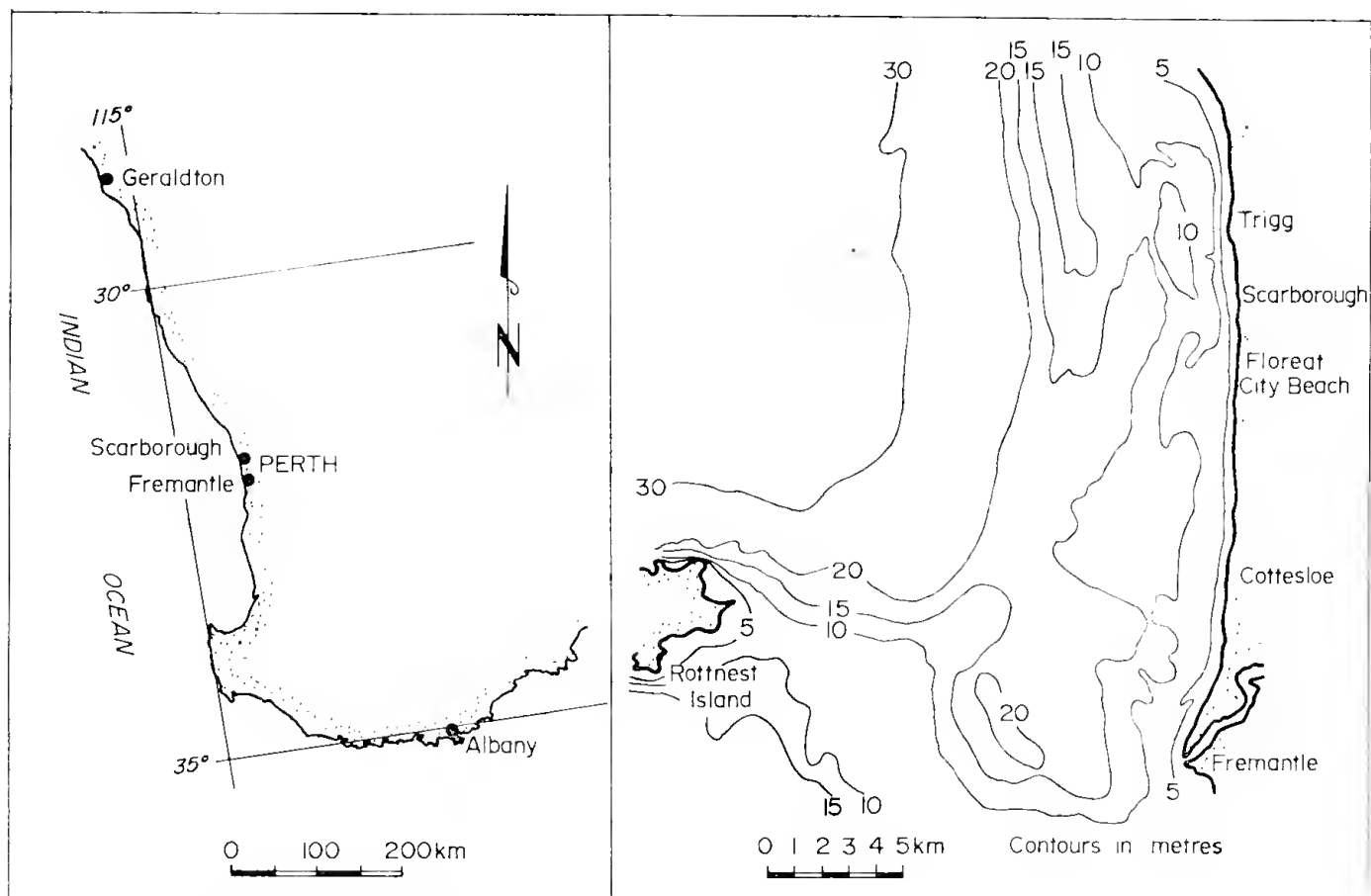


Figure 1.—Scarborough Beach: Regional Setting.

weather systems; particularly by afternoon sea breezes which blow onshore for approximately 60% of summer days (Hounam 1945). The strong seasonality of the weather regime directly affects the regional wave climate.

The coast of the Perth metropolitan area is, thus, dominated by a low to moderate energy, deep water wave regime characterised by persistent south to south-west swell (Davies 1972; Silvester 1976). The offshore wave climate has been described by Riedel and Trajer (1978) from wave data obtained in 40 m of water seaward of the Five Fathom Bank off Cockburn Sound (Fig. 1). They note that the offshore wave climate is mild, with an average significant wave height of 1.5 m. Wave heights of more than 4 m are likely to be exceeded on less than 1% of the time while heights of less than 1.0 m occur more than 80% of the time. There is little variation in the low wave energy from year to year for the summer to autumn period (December through May). However, the wave climate is more severe during the winter to spring period, with large variations possible between successive years.

Closer to shore the swell is refracted by offshore reef systems and greatly attenuated by shoaling in the inner continental shelf and nearshore environments. The reefs are discontinuous and complex wave refraction patterns develop, resulting in zones of wave convergence and divergence along the shoreline. These determine the location of large scale water circulation systems similar to those described

for Californian beaches by Shepard and Inman (1950), and the development of cusped forelands (Silvester 1976). Small shifts in wave direction, such as occur during seasonal phases of storm wave activity, cause alongshore migration of the wave convergence zones and are associated with short term reversals in the nearshore current field.

A highly variable wind-wave climate is superimposed on the swell regime. It is dominated by northwesterly storm waves during early to mid-winter, and by the wave field associated with strong, southwesterly summer sea breezes. Wave spectra for storm conditions have been described by Riedel and Trajer (1978). Storm waves in the 8 to 9 second band were superimposed on a background swell component having periods of 11 to 14 seconds. Typical spectra for sea breeze wave conditions are shown in Fig. 2.

The mixed tides of this coast have been described by Bennett (1939), Hodgkin and di Lollo (1958) and Radok (1976). Semi-diurnal constituents are dominant in the neap tide phases when tidal ranges may be less than 0.1 m, while diurnal constituents dominate the spring tide phase. Spring tidal ranges occur up to 0.9 m. Because of the relatively low range of the tide, it is frequently over-ridden by barometric pressure effects on sea level. These effects may also generate long wave activity on the continental shelf, particularly during storm conditions (Petruševics *et al.* 1979; Allison and Grassia 1979; Allison *et al.* 1980).



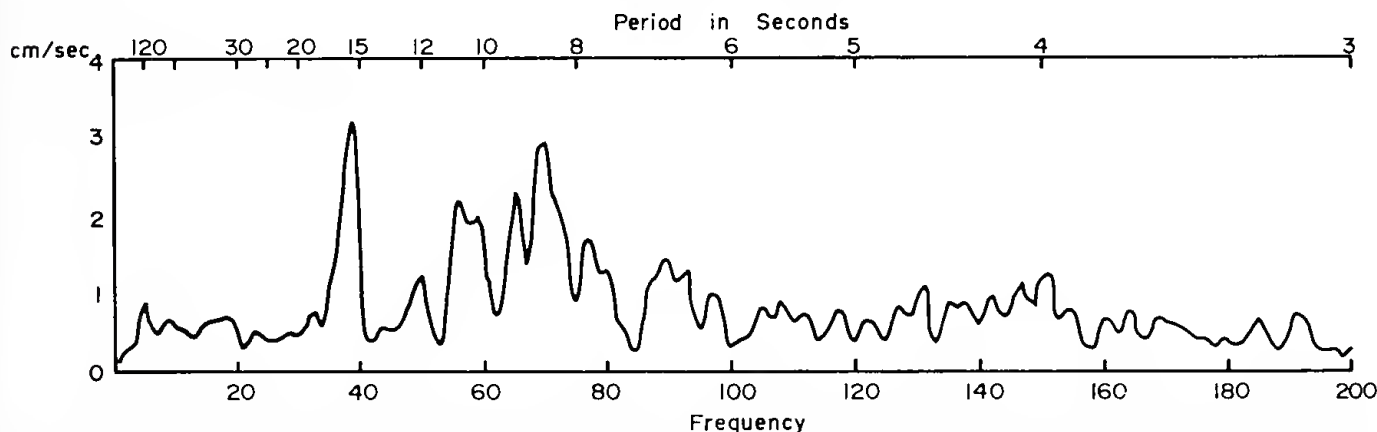


Figure 2.—Typical wave spectrum for sea breeze conditions. Amplitude spectrum for 10 minutes of bi-directional flowmeter record. Measured immediately seaward of the breaker zone at City Beach. Time 1300 hours on 21 March, 1981. Linear trend =  $-2.93$  cm/sec over 10 minutes. Mean =  $-1.65$  cm/sec indicating net onshore flow.

*Scarborough Beach*

Scarborough Beach is a salient on a large sandy beach extending 11.5 km from calcarenite headlands and reefs at North Cottesloe to similar rock outcrops at Trigg Island. The long beach is generally linear in plan form but has a rhythmic shoreline with meander wave lengths of approximately 1.2 km. Scarborough Beach is approximately 600 m long and straddles a major promontory of the rhythmic shoreline. Inshore and foreshore morphology at Scarborough is closely linked with the nearshore water circulation system, particularly with meandering alongshore currents and rips. The beach exhibits a variety of morphologic states dominated by forms similar to those described by Wright *et al.* (1979) for low wave energy conditions on New South Wales beaches. A reflective beach mode, with wide berm, steep beachface and deep inshore zone is common during summer while complex arrangements of transverse and alongshore bar patterns occur more frequently in winter. Beach sediments comprise medium to coarse grained, quartz sand with calcareous lithoclastic and skeletal material. Their composition and distribution has been described by Searle and Logan (1979).

**Data collection and analysis**

Beach-width has been measured at Scarborough Beach monthly since 9 August 1965, and before then intermittently since 20 May 1931. The measurements were made by chain survey of beach-width from a fixed mark seaward to the mid-swash zone for six stations spaced at 100 m intervals along the beach (Fig. 3). They provide a record of net shoreline change and cyclic fluctuation in beach-width over the sixteen years of survey. The time series of beach-width changes for profile station 4 is illustrated in Fig. 4.

The sixteen year record, 1965 to 1981, has been analysed to identify the variability and long-term change in beach-width for the six profile stations. Specifically, the following information was determined:

- i The long-term trend measured over the sixteen years of observation.
- ii Cyclic fluctuations thought to occur in response to seasonal variation in the wave regime and sea level elevation.

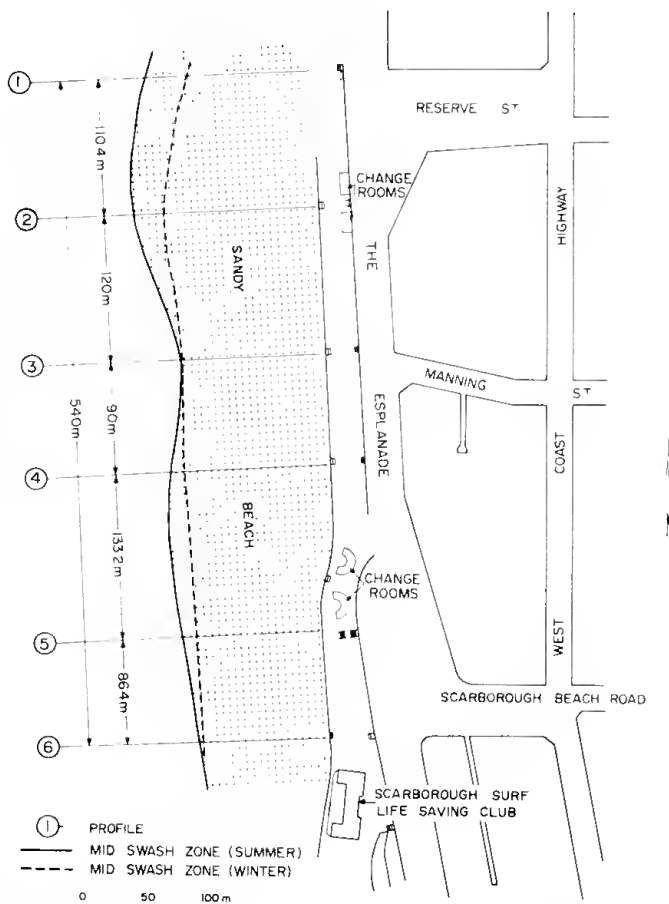


Figure 3.—Profile stations for beach-width measurement at Scarborough.

The methods of analysis used have been described previously by Eliot and Clarke (1980). They have their antecedents in work reported by Doornkamp and King (1971). The steps used in decomposition of each of the time series curves are as follows:

- i The long-term trend is calculated separately for each station record by linear regression techniques. The difference between the measured trend and a state of zero net change is tested for significance in each instance.

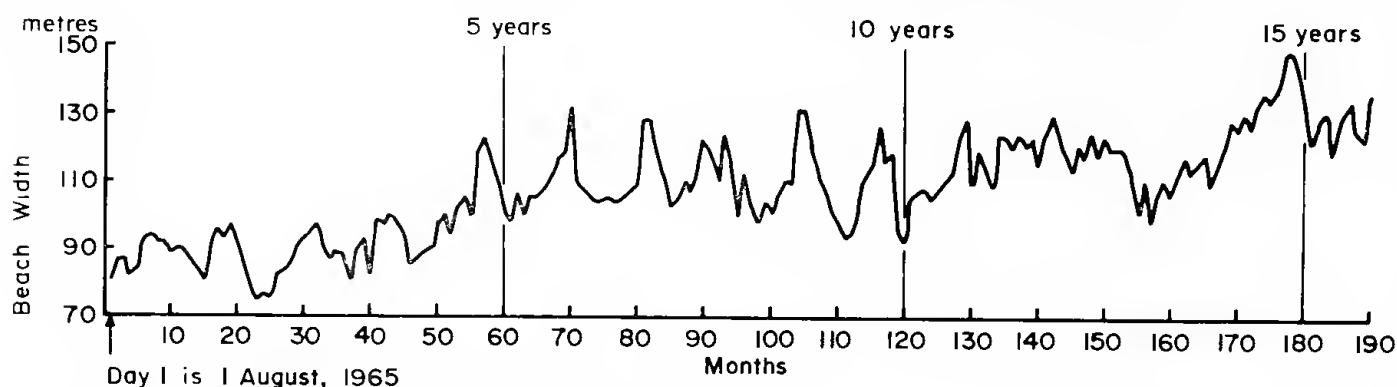


Figure 4.—Beach-width changes on profile 4, Scarborough Beach.

- ii Cyclic components are then calculated by detrending the data and analysing it with Fast Fourier Transform (FFT) techniques.

**Results**

Long-term changes, measured as the trend of the data for each of the six stations, confirm Kempin's (1953) observation that the beach is 'building up'. Indeed, the shoreline is prograding rapidly with accretion rates ranging from 2.4 m per year on the southern end of the study area (near Scarborough Surf Life Saving Club) to 3.3 m per year at the northern end, near Reserve Street (Table 1). The mean accretion rate for all profile stations is 3 m per year.

Periodic and aperiodic variations in beach-width are superimposed on the long-term trend. The annual (seasonal) component dominates the time series with the record for each station showing a slight asymmetry. The peak beach-width is recorded in late February to early March while minimum widths are recorded in mid-August. The range of the seasonal oscillation for each profile station is listed in Table 2. It is least at Station 4, between Scarborough Beach Road and Manning Street, and increases north and south of this station. The maximum range is recorded immediately south of Reserve Street, on Station 2.

**Table 1**

*Trend of beach-width change monitored over sixteen years, from 1965 to 1981*

Profile station	Beach-width change 1965-1981 (metres)	Metres/year
1	93-146	3.3
2	89-143	3.3
3	86-133	2.9
4	87-130	2.7
5	85-128	2.7
6	90-129	2.4

Two other periodicities were evident in the record: a six monthly oscillation with ranges approximately 20% of the annual component (Table 2), and weaker 3.5 and 7 year oscillations. The biannual oscillation is probably a byproduct of the asymmetry of the annual component. However, further analysis, relating beach change to process information is necessary to test this proposition.

**Discussion**

Long-term progradation (measured in decades) of Scarborough Beach was postulated by Kempin (1953) and is confirmed by the 16 year trend of beach-width change on all profile stations. It raises important questions concerning the source of sediment. In this respect beach changes at Scarborough need to be set in the wider context of shoreline change between North Cottesloe and Trigg Island. Unfortunately little is known about the coastal sediment budget of this long beach. Searle and Logan (1979) have identified the principal sedimentary units but exchanges between and within these units are largely undefined. At present, the coast between North Fremantle and Trigg Island receives little, if any sediment from beaches south of Fremantle, according to Searle and Logan (1979). Sand supplied to the metropolitan beaches north of Fremantle therefore is locally derived from reworking of coastal sand dunes and from nearshore biogenic sources. North of Cottesloe the net littoral drift is northwards toward Scarborough and Trigg (Kempin 1953; Silvester 1976; Searle and Logan 1979).

Progradation in the vicinity of Scarborough Beach may be balanced by erosion in the southern sector of the Cottesloe to Trigg beach complex. However, the direction of sediment movement at Scarborough cannot be inferred from analyses reported to this paper. The spatial pattern of progradation, with progradation rates increasing in a northerly direction, is consistent with sediment accumulation on the up-drift side of a shoreline obstacle, on the lee side of a major shoreline salient, or with alongshore

**Table 2**

*Amplitudes and phases of the annual (seasonal) and biannual components of beach width variation*

Profile station	Amplitude of seasonal component (metres) <sup>1</sup>	Phase (degrees) <sup>2</sup>	Amplitude of biannual component (metres)	Phase (degrees)
1	12.1	147	2.8	35
2	12.8	147	2.3	21
3	9.0	149	2.1	5
4	6.0	152	1.7	-2
5	6.4	139	1.9	29
6	6.9	147	1.3	5

<sup>1</sup> Maximum beach-width occurs at approximately 27 February while the minimum occurs near 27 August each year.

<sup>2</sup> Phase is relative to 1 October 1965.

migration of a large shoreline meander. Additionally, the long-term trend (measured in decades) may be part of much longer period, low amplitude shoreline oscillations, similar to those postulated by Stevenson (1980) for beaches of New South Wales.

An annual variation in beach-width was anticipated from a previous study of beach change on Perth metropolitan beaches by Kempin (1953). Our results confirm this expectation. The annual cycle is generally attributable to seasonal changes in coastal weather conditions, particularly with periods of strong sea breeze activity and storm onset, and with associated changes in the nearshore wave regime. Similar beach changes have been described from New South Wales by Short and Wright (1981). The contribution of particular weather systems, wave regime changes and nearshore current activity to shoreline fluctuation is subject to ongoing investigations.

The time series of beach-width change at Scarborough also has some interesting features that were not anticipated from the earlier studies. The annual cycle is slightly asymmetric with a late summer peak and a variable, mid to late winter low. It is the dominant of several periodic components superimposed on the long-term trend. The several components (12 monthly, 6 monthly and longer period oscillations) combine to cause a beat effect on the amplitude of beach change from year to year. The beat is apparent in the original data. It has a period of the order of 10 years. The amplitudes of beach change were lowest in 1967 to 1969 and again in 1977 to 1979. They were highest between 1974 and 1975.

Storm impacts on beaches are frequently identified in time series data from beach environments. Eliot and Clarke (1980) distinguished aperiodic beach changes, those related to storm impact and intermittent change in the nearshore water circulation pattern, from a five year record of beach profile data for Warilla Beach. They concluded that many aperiodic events occurred at higher frequencies than the fortnightly sampling period and produced aliasing effects in the time series. Satisfactory description of the aperiodic changes therefore, was not possible from the Warilla data. Irregularities, possibly related to aperiodic events are discernible in the time series from Scarborough Beach. However, the sampling density used was sparser than that used at Warilla and it was not possible to statistically separate aperiodic events from the longer period, cyclic beach changes. Our results indicate that monthly beach measurements do not facilitate description of the impact of storms and other aperiodic events.

### Conclusions

The analysis of beach-width change over 16 years on Scarborough Beach provides quantitative description of previous expectations regarding long-term (measured in decades) and seasonal shoreline change. A strong seasonal cycle of shoreline fluctuation, with the shoreline ranging up to 25 m is superimposed on a steadier progradation of approximately 3 m per year. These changes also interact with other cyclic components and with aperiodic events, such as storm impacts and rip current migration along the beach. Other important

cyclic components include a biannual component with ranges approximately 20% of the annual component, and weaker 3.5 and 7 year oscillations. Further work examining the relationship of these fluctuations to other environmental changes, particularly mean sea level variation, is in progress.

Spatial constraints limit discussion of beach change to consideration of the low frequency changes in beach-width. Effects due to the passage of particular storms cannot be clearly identified from the data. This has ramifications for the design of future studies examining beach changes associated with storm events. In circumstances such as the low energy environment of the Perth metropolitan area, high frequency (at least every second day) sampling is necessary to establish individual storm effects on beach-width variation.

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Contents

	Page
<i>Austroassiminea lethae</i> , gen. nov., sp. nov., a rare and endangered proso-branch snail from south-western Australia (Mollusca: Prosobranchia: Assimineidae). By Alan Solem, Elizabeth-Louise Girardi, Shirley Slack-Smith and George W. Kendrick .....	119
The distribution of <i>Lepidogalaxias salamandroides</i> and other small fresh-water fishes in the lower south-west of Western Australia. By P. Christensen .....	131
Chromosome numbers of Western Australian Apiaceae. By G. J. Keighery	143
Oniscoidea (Crustacea: Isopoda) from Rottnest Island, Western Australia. By Stuart E. Bunn and Alison J. A. Green .....	147
Beach-width variation at Scarborough, Western Australia. By I. G. Eliot, D. J. Clarke and A. Rhodes .....	153

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