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22.1 The fossil record

22.1.1 Introduction

The broad-scale distribution of fossils within Victoria is controlled by general global patterns in the biological evolution of life on Earth, the local development and environmental evolution of habitats, and the occurrence of geological processes conducive to the preservation of fossil floras and faunas. Early Palaeozoic fossils are mostly marine in origin because of the predominance of marine sedimentary rocks in Victoria and because life on land was not significant during most of this time interval. Middle Palaeozoic sequences have both terrestrial and marine fossil records. Within Victoria, marine rocks are only very minor components of strata deposited during the late Palaeozoic, so that few marine fossils are known from this time period. A similar situation existed during most of the Mesozoic except towards the end of this era when marine conditions began to prevail in the Bass Strait region. During long intervals in the Cainozoic, large areas of Victoria were flooded by shallow-marine seas, particularly in the southern basins of Bass Strait, as well as in the northwest of the State (Murray Basin). Cainozoic sediments contain an extraordinary range of animal and plant fossils. During the Quaternary, the landscape of Victoria became, and continues to be, dominated by continental environments including, at times, extensive freshwater lake systems. Fossil floras and faunas from sediments deposited in these lake systems and from other continental sediments, as well as from Quaternary sediments deposited in marginal marine environments, collectively record a history of rapid fluctuations in climate and sea level.

22.1.2 Palaeozoic fossil assemblages

Cambrian

The oldest fossils found in Victoria are Cambrian. They are mostly found in shales and limestones, occurring as minor components of Cambrian sequences within two N–S fault-bounded belts known as the Heathcote Belt and Mt Wellington Belt (see Chapter 3). Shale of the Knowsley East Formation near Heathcote and Lancefield contains a rich diversity of hydroids, some siliceous sponges and a variety of trilobites. Along the Wellington River in east-central Victoria, the Cambrian Dolodrook Limestone Member, which comprises allochthonous blocks that have been re-deposited in the Garvey Gully Formation, contains various species of trilobites and brachiopods as well as rarer shelly fossils. The Knowsley East fauna is thought to be Middle Cambrian while the Garvey Gully Formation faunas are slightly younger, nearing the Middle–Late Cambrian boundary. The fossils so far found are mostly benthonic (bottom dwelling) and shallow-marine in origin, although the fauna of the Knowsley East Formation is probably from slightly deeper marine waters than those of the Dolodrook Limestone Member.

Ordovician

Fossiliferous Ordovician sedimentary rocks are widespread across central and eastern Victoria. There are three broad Ordovician palaeoenvironments in which fossils are preserved.

The first is the shallow-marine, carbonate-shelf palaeoenvironment of the Digger Island Marlstone at Waratah Bay in southeastern Victoria (Fig. 22.1) (see Chapter 4). Containing abundant trilobites, brachiopods, ostracods and algae, the marlstone is the only Ordovician rock with a diverse fauna of shallow-marine shelly fossils in Victoria, although more extensive comparable fossiliferous sequences occur to the south in Tasmania. Whilst it appears that the hinterland to the Ordovician sea lay in western Victoria, the limited extent of Lower Ordovician shelf deposits in Victoria suggests that the Early Ordovician continental shelf was relatively narrow in this region. The western landmass (Delamerian Highlands) was an actively eroding landscape. Eroding land surfaces were devoid of the stabilising effect of land plants, which were yet to evolve, and large quantities of detrital sediments were rapidly transported eastwards into deep-marine depositional basins. To the south, however, there was substantially less terrigenous sediment moving across the continental shelf, perhaps reflecting increased distance from the highlands. In this southeastern region, Early Ordovician sea-floor environments were suitable for the accumulation and preservation of carbonate-dominated, shallow-marine deposits such as the Digger Island Marlstone.

The second Ordovician palaeoenvironment in Victoria is a mostly dysoxic deep-water sea floor setting. This palaeoenvironment is represented by black...
shale sequences such as those in the Bendoc Group of eastern Victoria and the Romsey Group of central Victoria (Fig. 22.2). These sequences mostly contain fossils of planktonic (floating) and nektonic (swimming) organisms, with graptolites as the principal fossil type. Graptolites, extinct colonial and planktonic organisms, display an extensive array of biostatigraphically useful evolutionary trends within Victorian Ordovician sequences (see Chapter 26). After they died and sank to the ocean floor they together with nektonic (?) phyllocarid crustaceans, rare conodonts and coiled nautiloids, were well preserved in hemipelagic organic-rich mud. Very rare benthiic gastropods are also known from these sequences. At several levels in the Ordovician sequences there are cherts that are considered to be derived from accumulations of the siliceous remains of planktonic radiolarian tests. However, the tests are generally no longer recognisable because of diagenetic alteration.

The Castlemaine Group (Lancefieldian to Darriwilian) and the Sunbury Group (Late Ordovician) are thick submarine-fan turbidite sequences, in which graptolites are mostly limited to intercalated hemipelagic beds. The turbidites are largely unfossiliferous except for rare shelly fragments, probably transported from shelf regions.

In eastern Victoria, Upper Ordovician rocks are dominantly hemipelagic black shale and mudstone (Mount Easton Shale, Bendoc Group) which contain one of the richest and most diverse Late Ordovician graptolite successions in the world. The youngest Ordovician fauna in Australia occurs in the Darrawiet Guim Mudstone which, apart from an impoverished graptolite assemblage, contains a benthiic trilobite and several fossiliferous mudstones including a nautiloid and a small gastropod. Black hemipelagic mudstone dominates in the Upper Ordovician rocks and points to a persistent anoxic environment. Abundant burrows occur in Gisbornian rocks and reappear in the late Eastonian, becoming gradually more abundant until, by latest Bolindian time, burrowed rocks predominate.

**Silurian**

The Silurian sedimentary rocks of Victoria exhibit a temporal progression from the dominantly deep-marine palaeoenvironments in the Lower Silurian to more extensive shallow-marine and terrestrial palaeoenvironments in the Upper Silurian. In general, Silurian strata possess a broader range of shallow-marine shelly fossil assemblages than the preceding Ordovician strata. Silurian shallow-marine fossils are generally preserved in siliciclastic facies, although rare allochthonous fusuliniferous shallow-marine limestone blocks, redepoted into deeper marine settings, are also present. Indeed, many Silurian shallow-marine fossil assemblages in siliciclastic facies also appear to have been transported into deeper marine environments within mass gravity deposits such as turbidites. Trace fossils are common in some Silurian sequences.

Graptolites are less common than in the Ordovician, but remain important for correlation. This is particularly the case for the Lower Silurian units, such as the Springfield Formation, which yield characteristic Llandovery graptolite assemblages. Early and middle Silurian shelly fossils are uncommon, although transported assemblages are present in the Llandovery ‘Illeana’ band and Chintin Formation of central Victoria. Upper Silurian formations, such as the Dargile Formation and McIvor Sandstone, contain rich Ludlow fossil assemblages. These include graptolites, brachiopods and trilobites, as well as a diverse array of echinoderms which are commonly articulated, suggesting that they may have been transported and buried alive. Macrofossils of transported land plants occur in Upper Silurian shallow-marine siliciclastic sediments near the township of Yea in central Victoria. These are amongst the earliest fossil land plant occurrences known from anywhere in the world (see Chapter 26). They probably inhabited the transition zone between aquatic and terrestrial palaeoenvironments, perhaps living in marshes that were in close proximity to extensive shallow-marine realms.

The Late Silurian to Devonian transition within the Grampians Group of western Victoria is characterised by the occurrence of restricted marine fossil assemblages composed of lingulid brachiopods, ostracods and fish remains, as well as near-shore, trace-fossil assemblages.

**Devonian–Permian**

Lower Devonian strata include a wide range of shallow and marginal marine palaeoenvironments, which yield rich and diverse fossil assemblages. Graptolite fossils are rarer than in lower Palaeozoic strata, although when present they are useful indicators of geological age. Early Devonian graptolite faunas are known from the Wilson Creek Shale, which also possesses a rich and well-preserved flora of early vascular land plants. The influx of probable coastal-plain plants into marine sequences containing Late Silurian to Early Devonian graptolites is indirect evidence for the local expansion of nonmarine aquatic swamp and marsh habitats.

The most conspicuous fossil assemblages of the Lower Devonian of Victoria, however, occur within Pragian to Emsian carbonate sequences, such as those outcropping near Buchan in eastern Victoria. The lower part of the fossiliferous sequence in the Buchan district includes a carbonate nodule-bearing unit known as the Fairy Sandstone. The nodules yield brackish-water (?) fossil assemblages of charophytes, ostracods, conchostracans and fish remains, as well as abundant fragments of terrestrial plant material. This fossil assemblage perhaps provides early evidence of the colonisation of nonmarine habitats by previously exclusively marine invertebrate groups such as ostracods. Stratigraphically higher within the Buchan area is the Buchan Caves Limestone, a very shallow-marine carbonate unit with a rich assemblage of invertebrate fossils including brachiopods, stromatolites, Stromatoporidae, colonial and solitary corals, gastropods (mostly towards the base), crinoid ossicles and ostracods, amongst others.

There are slightly younger shallow-marine limestone sequences in the region. The Rocky Camp Member of the Murralind Limestone is an isolated carbonate-mound deposit with abundant crinoid, receptaculitid (calcareous algae) and trilobite fossils. The McLarty Member of the Murralind Limestone is a macrofossil-poor, organic-rich, lagoonal carbonate unit dominated by grains of fine carbonate mud derived from the mechanical disintegration of calcareous algae. Other carbonate units in the Buchan area, such as the
Taravale Formation, lack a diverse benthonic macrofossil fauna, but possess rich fossil assemblages of nektonic groups such as nautiloids and conodonts, in addition to the tentaculitids. The presence of conodonts in the deeper water Taravale Formation is important for the global biostratigraphical correlation of these carbonate sequences. Except for agglutinated foraminiferids, benthonic microfossils are not common in these deeper muddy carbonates, although the presence of probably neritic ostracods suggests that deposition took place within the photic zone.

The Tabberabberan Orogeny terminated the widespread occurrence of shallow-marine environments during the Early Devonian. Limited, predominantly nonmarine, Upper Devonian to Lower Carboniferous sequences are known from the Mansfield district and a few other localities in eastern Victoria (see Chapter 6). These siliciclastic ‘red bed’ sedimentary rocks contain common assemblages of fossil plant fragments, reflecting the greater spread of plants within terrestrial environments by this time. Other fossils within these sequences include age-diagnostic fish faunas and the track-ways of amphibians that reflect the beginnings of land colonisation by vertebrates. Trace fossils left by the activity of invertebrates are also common in these sequences.

No Late Carboniferous fossils are known from surface outcrops in Victoria. Permian rocks preserved in isolated fault blocks are of fluvioglacial origin with rare marine incursions. The fossil assemblages of terrestrial plants (Glossopteris and Gangamopteris; Figs. 22.3, 22.4) and associated palynological assemblages (Fig. 22.5) indicate an Early Permian (Sakmarian) age. Marine faunas are severely restricted, with only two horizons known. The lower, with brachiopods, indicates an early to middle Sakmarian age while the apparently higher, with conulariids and foraminiferids, indicates a late Sakmarian or slightly younger age. Late Permian fossils are unknown from Victoria.

22.1.3 Mesozoic fossil assemblages

Triassic sedimentary rocks in Victoria are extremely limited. However, fluviatile units containing Late Triassic plant fossils outcrop at Bald Hill, Bacchus Marsh (Council Trench Formation). No Triassic marine sediments or fossils are known from Victoria.

One of the most profound palaeoenvironmental events recorded in Victoria was the opening up of the rift valley between Australia and Antarctica during the Jurassic–Cretaceous. In Victoria, Jurassic sedimentary rocks are confined to the base of thick fluviatile sequences originally deposited in this rift valley. Known as the Casterton Beds (Upper Jurassic), they contain sparse fossil plant remains characteristic of their age. Continued deposition within the rift valley led to the accumulation of a vast thickness of Lower Cretaceous fluviatile sandstones, mudstones and coals known as the Otway Group in southwestern Victoria and the Strzelecki Group in southeastern Victoria. These sequences contain a suite of well-preserved plant macrofossils and microfossils. The Otway and Strzelecki groups have also yielded an internationally significant cool-climate dinosaur and Early Cretaceous mammal fauna. In addition, rare lacustrine deposits such as the

Koonwarra fossil bed in Gippsland enclose beautifully preserved fish and insect faunas, along with impressions of aquatic crustaceans and bird feathers.

During the Late Cretaceous, the sea flooded into the western end of the rift valley region in southern Victoria and deposited marine and estuarine mudstones and sandstones. These rocks are not exposed and fossils are known only from subsurface cores derived from the Sherbrooke Group. Fossil marine invertebrates/protozoans of the Upper Cretaceous include bivalves and foraminiferids, whilst the plant/algae record includes very abundant terrestrial spore and pollen grains, as well as marine dinoflagellates. These fossil assemblages record the earliest marine conditions in the Bass Strait region.

22.1.4 Cainozoic fossil assemblages

Cainozoic fossil floras and faunas and their associated palaeoenvironments are extremely diverse in southeastern Australia. This is largely a consequence of the extensive flooding of the failed rift valley between Victoria and Tasmania, which formed the Bass Strait seaway.

Paleocene strata are best exposed in coastal cliff sequences in the vicinity of Princetown in southwestern Victoria. Here, Upper Paleocene conglomerates and mudstones of the Pebble Point Formation unconformably overlie the Lower Cretaceous sediments of the Otway Group. A Late Paleocene molluscan fauna is known from the Pebble Point Formation at this locality, as well as sparse foraminiferid, shark tooth and ostracod faunas. These onshore exposures and offshore cores show both the Lower and Upper Paleocene portions of the Pebble Point Formation contain extensive marine dinoflagellate and terrestrial spore-pollen assemblages.

The Lower Eocene Dhyn Clay, which overlies the Pebble Point Formation in the Princetown region, yields rare moulds of marine invertebrate fossils and extensive assemblages of marine and terrestrial plant microfossils. Elsewhere in Victoria, Paleocene to Lower Eocene strata yield mostly terrestrial plant fossils. Strata with rich Late Eocene to Early Oligocene shelly fossils outcrop near Johanna River and Castle Cove along the western coast of Victoria. Here, the Browns Creek Clay and Castle Cove Limestone yield abundant bivalves, gastropods, foraminiferids, ostracods, coccoliths, bryozoans, corals, brachiopods and echinoids, to name only the more common groups. This diverse benthonic and planktonic biota is evidence of the earliest development of substantial well-oxygenated, offshore neritic conditions in the western Bass Strait region. At the eastern end of Bass Strait, more restricted marine conditions prevailed during this time, as indicated by the low-diversity assemblages (predominantly agglutinated foraminiferids and marine palynomorphs) of the Gurnard Formation.

In south-central Victoria, Paleocene and Eocene floras occur in the terrestrial Eastern View Formation, which includes the Deans Marsh and Anglesea coal measures, and which disconformably overlies Otway Group strata. Conformably overlying the Eastern View Formation is the Upper Eocene to Lower Oligocene Anglesea Sand. The Eocene–Oligocene boundary occurs in the non-calcareous Anglesea Sand outcropping near Point Addis. Within south-central Victoria, Eocene and Lower Oligocene facies are dominated by terrestrial plant microfossils with appreciable marine
Palynomorphs becoming significant around the Eocene–Oligocene boundary. This pattern is also evident in the onshore regions of Gippsland, where the Upper Eocene – Lower Oligocene ‘older’ coal measures occur over extensive areas of the Latrobe Valley (see Chapter 16). In regions of the Gippsland Basin with a more seaward palaeogeography, units such as the Lakes Entrance Formation possess calcareous faunas dominated by planktonic foraminiferids.

Uppermost Lower Oligocene calcareous units are known to extend subsurface across Bass Strait. The occurrence of foraminiferids and ostracods in these units marks the initiation of the Bass Strait seaway as a broad, well-oxygenated water mass connecting the Southern and Pacific oceans. Upper Oligocene formations with diverse shallow-marine calcareous fossils are very broadly distributed throughout Bass Strait and the adjacent onshore lowlands of Victoria. These units include the neritic Point Addis Limestone and Jan Juc Marl of western Victoria (sometimes together referred to as the Jan Juc Formation), and the neritic Longford Limestone and Wuk Wuk Marl (which are part of the Gippsland Limestone) of eastern Victoria. These formations yield rich fossil faunas including bivalves, gastropods, foraminiferids, ostracods, coccinolids, bryozoans, corals, brachiopods and echinoids. Hemipelagic bathyal calcareous facies of Oligocene age are also known from offshore regions of Bass Strait, these being dominated by planktonic foraminiferids.

Miocene strata of Victoria exhibit a very extensive range of palaeoenvironments, represented in both onshore outcrops and offshore oil well sections. Lowermost Miocene sediments are exposed in cliffs at Jan Juc Beach, where the Oligocene–Miocene transition is taken as the boundary between the Jan Juc Formation and the overlying Puebla Clay. The Puebla Clay and the (in part) correlative Zeally Limestone preserve evidence of a diversity of shallow-shelf habitats and include abundant molluscan, brachiopod, echinoid, bryozoan, ostracod and benthiic foraminifera faunas. Planktonic foraminiferids are reasonably abundant in the upper beds of the Puebla Clay. Biofacies of the mid-Miocene indicate a broad range of continental-shelf habitats for onshore outcrops and both shelf and continental-slope habitats for offshore regions beneath Bass Strait. Of particular note, the uppermost Lower Miocene to lowermost Middle Miocene marine sediments of southern Victoria (e.g. the Balcombe Clay) have probably the greatest diversity of marine invertebrate macrofossils and microfossils of any Cainozoic interval represented in southeastern Australia. This diversity reflects the generally high sea levels and extensive flooding of the Bass Strait hinterland at this time. Distinctly warm-water invertebrate faunas are conspicuous in some Miocene carbonate facies, e.g. the Batesford Limestone. The palaeobathymetric ranges indicated by latest Middle Miocene to Late Miocene biofacies are far less than for underlying Miocene intervals, reflecting the generally lower relative sea levels of the later Miocene.

Early Oligocene to early Middle Miocene nonmarine sequences, including the considerable thicknesses of the ‘younger’ coal measures of the Gippsland Basin, yield palynofacies that generally reflect warm, wet palaeoclimates. Late Miocene marine invertebrate biofacies indicate a substantial climatic cooling from a warm peak around the Early–Middle Miocene boundary.

Across the Late Miocene – Early Pliocene transition, there is a dramatic faunal changeover event across southeastern Australia. Within the Black Rock Sandstone, Moorabool Viaduct Sand and Jemmys Point Formation,
Rich but variable benthonic macrofossil and microfossil faunas (molluscs, echinoids, ostracods and benthonic foraminifers) indicate a range of shallow- and marginal-marine (estuarine and lagoonal) environments. Shallow-marine lags of invertebrate and vertebrate fossils are a conspicuous feature of outcrops of this age in southern Victoria.

Generally, Late Pliocene and Quaternary marine invertebrate fossil assemblages reflect episodes of relatively rapid sea-level changes. Sediments in coastal outcrops, in which these assemblages occur, predominantly accumulated in shallow, open marine, lagoonal or estuarine environments. Further, Quaternary floras and palynofacies from lacustrine (lake) and paludal (swamp) deposits in southern Victoria indicate rapid climatic change through this period. In northwestern Victoria, rapid palaeoenvironmental change is also evident in Quaternary sequences such as the Blanchetown Clay and the Bungunna Limestone. Of special note are invertebrate faunas dominated by freshwater ostracods, which indicate the existence of a large Pleistocene lake (Lake Bungunna) within the Murray Basin. Some smaller lake deposits formed by the damming of streams by basalt flows, such as those at Newham near Woodend, contain large concentrations of freshwater diatoms. Other small lacustrine deposits in southern Victoria, such as the Pleistocene Lara Limestone, are known for fossil assemblages of land vertebrates, in particular representatives of the marsupial megafauna.

Younger Pleistocene and Holocene formations, such as the Douutta Galla Silt of the Port Phillip district, contain hominid fossils marking the colonisation of Victoria by Homo sapiens.

### 22.2. Invertebrate fossils

#### 22.2.1. Introduction

Invertebrate palaeontology has made the prime contribution to the development of the Standard Geological Time Scale, as geological periods and epochs are largely based on the evolutionary history of marine invertebrate groups represented in the fossil record. During the 20th Century, invertebrate palaeontology has differentiated into many specialist subdisciplines. For instance, studies on early, middle and late Palaeozoic trilobite faunas are seen as separate areas of expertise by some because of the complexity of knowledge required to classify these fossils accurately. Similarly, local brachiopod faunas from different intervals in the Palaeozoic have mostly been considered in separate scientific works (e.g. Cambrian and Ordovician — Laurie, 1987; Brock & Talent, 1999; Silurian and Devonian—Talent, 1956a,b, 1964).

In Victoria, common macrofossils found in Palaeozoic marine sequences include stromatoporoids, corals, brachiopods, molluscs, trilobites, echinoderms and graptolites. Mesozoic terrestrial invertebrate faunas composed principally of insects are known from a few isolated localities throughout the State, such as near Koonwarra in Gippsland. Common Cenozoic macrofossil invertebrates include molluscs, brachiopods, echinoderms, corals and bryozoans, although the last require microscopic examination of fine features to differentiate genera and species.

In addition, there is an enormous abundance and diversity of microfossils preserved in Palaeozoic and Cainozoic strata throughout Victoria. Palaeozoic carbonate rocks commonly contain abundant calcareous ostracods (e.g., Warren & Talent, 1967; Tassili & Warnke, 1997), sporadic benthonic arenaceous foraminifers (Bell, 1996) and organic chitinozoans (Winchester-Seeto, 1993), as well as conodonts, a phosphatic fossil group now regarded as chordates. Conodonts have been critical in Victorian Ordovician to Devonian biostratigraphy. In Ordovician strata, their main application has been to provide correlations between the local Victorian graptolite-bearing Ordovician siliciclastic turbidite/black-shale sequences and shallow-marine successions elsewhere that are dominated by shelly faunas (I. Stewart in Cas & Vandenberg, 1988). It is, however, in local Devonian carbonate sequences that conodont biostratigraphy has been most extensively used (Mawson et al., 1992).

Microfossils have been employed particularly successfully in the correlation of Cainozoic strata. This is in part due to the evolutionary expansion of planktonic marine organisms in post-Jurassic world seas of the newly evolving Pacific, Atlantic and Indian oceans. Planktonic foraminifers from the Cainozoic strata of Victoria include globally distributed index fossils, the local occurrences of which provide important marker biohorizons. Benthonic foraminifers occur in great abundance in Cainozoic strata and have been extensively used in the evaluation of Cainozoic palaeoenvironments. Also significant amongst Cainozoic microbenthos are the marine and nonmarine ostracods. Ostracods have also been widely used in Cainozoic palaeoenvironmental analysis.

The radiolarians were probably an important source of silica for the Palaeozoic cherts found in Victoria. These planktonic organisms are also present in some southeastern Australian post-Palaeozoic sequences, although they have not been extensively studied.

The following sections on invertebrate taxa are not exhaustive of Victorian invertebrate palaeontology, but highlight the most common and widespread groups or introduce new findings of stratigraphical value.

#### 22.2.2 Early and middle Palaeozoic invertebrate fossils

**Trilobites**

The oldest trilobite known from Victoria is an Early Cambrian protoluid (P.A. Jell in VandenBerg & Wilkinson, 1982) from volcanogenic sandstone within the Mount William Metabasalt (Heathcote Volcanic Group) in the Heathcote district. In the overlying Knowsley East Formation, trilobite faunas of Middle Cambrian age occur at two horizons referred to as the Dineus (lower) and Amphoton (upper) bands, but few of the species present have been described (Chapman, 1917; Etheridge, 1896; Gregory, 1903c; Opik, 1949). The faunas were listed by Thomas & Singleton (1957, pp. 155–156) as including Peronopsis, Dineus, Kootenia, Amphoton and Centropleusa in the Dineus band, and Peronopsis, Dineus, Solenopana, Nepa, Drypyge, Amphoton and Fuchonia in the Amphoton band. The Dineus band fauna was correlated by Thomas & Singleton (1957, p. 161) with the European early Middle Cambrian Ptychagnostus gibbus Biozone. The earliest Late Cambrian trilobite faunas of the Dolodrook Limestone in the Dolodrook River area of east-central Victoria are also undescribed, apart from a few forms documented by Chapman (1911). These faunas, including Hypagnostus, Amathachit, Pseudagnostus, Phedagnostus, Blosnita, Bynuma, Trioceroplites, Corynecyclops, Eugnathoec and Aphelaspis (Singleton in Thomas & Singleton, 1957, p. 158; Shergold, 1973), were assigned by Opik (1967, p. 32) to the Midianyll and Ilidaean stages.

The diverse Early Ordovician trilobite fauna of the Digger Island Marlstone at Waratah Bay was described by Jell (1988), who gave the age as early Tremadoc (approximately equivalent to Lancefieldian zone L1). The fauna includes Micagnostus, Neagnostus, Shumardia, Panbythiscius, Leostegium, Onychopyge, Pseudokainella, Austrolophares, Landysia and Victoripina. Only one other trilobite is known from the Ordovician of Victoria, namely a species of Songexites from the late Bolinian (Rawtheyan) Darraweit Guinn Mudstone at Darraweit Guinn (Campbell, 1973; VandenBerg et al., 1984b).

No Early Silurian (Llandovery) trilobites have been formally described from Victoria, but faunas of this age are present in the Springfield Formation in the Keilor–Sydenham area, and in the overlying Chintin Formation in the Springfield and Kilmore areas (Rickards & Sandford, 1998). These faunas include fragementary specimens of Dicroproetus, Radnoria, Geanticammina, Trimorus, Conus?, Acastaspis and Dalmanites, as well as indeterminate Cheruiridae, Phacopidae and Odontopleuridae (Sandford, 1996). A distinctive genus in strata of Wenlock age in the Darraweit Guinn Province of the Melbourne Zone is the blind trilobite Thomastus (Opik, 1953; Sandford & Holloway, 1998), which dominates the fauna of the ‘Ilmaeus’ band of the Corderfield Shilstone in the Heathcote district. It also occurs in the Chintin Formation at Bylands (Fig. 22.6b) and the Anderson Creek Formation at Bulleen and North Balwyn. Other trilobites present in these faunas are Ananaspis, Dalmanites, Maunotarion and Trimorus in the ‘Ilmaeus’ band of the Corderfield Shilstone; Dicroproetus?, Ananaspis, Sinuaria?, Diacamus, and an unnamed genus of...
Fig. 22.6: Trilobites (a–d), brachiopods (e, h, j–l), bivalves (f, i) and a gastropod (g). (All specimens from Museum Victoria Collection; photographs by D. Holloway). (a) *Cromus cf. spryi* (Chapman), P136974, and *Raphiophorus jikaeensis* (Chapman), P134034 (small specimen on right); Melbourne Formation (Late Silurian, Ludlow), West Brunswick, x 2.7. (b) *Thomastus aops* Sandford & Holloway, P139969A, Bylands Siltstone (Silurian, Wenlock), Bylands, x 1.8. (c) *Gravicalymene angustior* (Chapman), P12675, Humevale Formation (Early Devonian, Lochkovian–Pragian), Lilydale, x 1.2. (d) *Odontochile formosa* Gill, P147848, Humevale Formation (Early Devonian, Lochkovian–Pragian), Kinglake West, x 0.7. (e) *Tjersella typica* Philip, P127684A, internal mould of dorsal valve, Boola Formation (Early Devonian, early Pragian), Tyers area, x 1.9. (f) *Panenka gipslandica* (McCoy), P104339 (upper) and P104340, Norton Gully Sandstone (Early Devonian, Emsian), Jordan River, x 0.5. (g) *Straparollus (Euomphalus) northi* (Etheridge), P42143, Lilydale Limestone (Early Devonian, middle–late Pragian), Cave Hill Quarry, x 0.6. (h) *Notoconchidium tasmaniensis* Etheridge, P59524, internal mould of ventral valve, Dealiba Sandstone Member, Mount Ida Formation (Late Silurian–Early Devonian), Heathcote district, x 2.3. (i) *Chenodonta (Praectenodonta) raricostae* (Chapman), P17419, internal mould of right valve, Humevale Formation (Early Devonian, Lochkovian–Pragian), Killara, x 1.4. (j) *Spinella buchanensis buchanensis* Talent, P127697, dorsal view; Taravale Formation (Early Devonian, latest Pragian?–Emsian), Buchan district, x 1.1. (k) *Boucotia australis* (Gill), P127615, internal mould of articulated valves, Humevale Formation (Early Devonian, Lochkovian–Pragian), Seville, x 4. (l) *Maoristrophia keblei* Gill, P14612, internal mould of ventral valve, Humevale Formation (Early Devonian, Lochkovian–Pragian), Mooroolbark, x 2.1.
The Ordovician graptolite record of Victoria is one of the most complete in the world (see Chapter 26), contrasting strongly with the impoverished and water biotopes (Cooper, 1992) is linked to a rapid evolution rate. These features, together with the continuous fossil record, allow reasonable estimates to be made of both the real (evolutionary) ranges of taxa and their evolutionary rates (origination, extinction, diversity change, etc.) in the Pacific Province. VandenBerg & Cooper (1992) calculated an average duration of 2.5 zones for each graptolite taxon, approximately equivalent to 5 million years each.

There are several main bioevents discernible in the Ordovician succession, each marked by the entry of one or very few species followed by very rapid diversification. 

*Reign*¹ of the anisograptids (Lancefieldian). 

*Reign* of the dichograptids and sigmoidograptids (Lancefieldian–Darriwilian). 

*Reign* of the isograptids (Castlemainian–Yapeenian). 

Interval of the glossograptids (mid-Castlemainian–Eastonian). 

*Reign* of the diplograptids and orthograptids (Darriwilian–Bolindian). 

Interval of the diconograptids (Gisbornian–Darriwilian). 

*Reign* of the monocograptids (Darriwilian–end Ordovician). 

The appearance of anisograptids also marks the base of the Lancefieldian stage² and the appearance of graptolites in the sequence. The first zone, L1a, contains a sparse fauna comprising two pelagic species of *Rhabdodiplograptus* (Fig. 22.7d) and two of *Anisograptus*, joined in the succeeding L1b zone by *Psigraptus*. By the start of the next zone, L2, these are replaced by a diverse fauna that includes *Anisograptus*, *Adelograptus*, *Paraeledograptus*, *Clonograptus* and *Kierograptus*. Of these, only *Clonograptus* survives into the Bendigonian, reaching its greatest diversity in Be1 but then declining rapidly. Only a single species survives into the Chewtonian.

### Reign of the dichograptids

Dichograptids make their first appearance in the Lancefieldian with species of three genera, *Didymograptus* (s.l.), *Tetragraptus* (s.l.) (Fig. 22.7b) and *Temnograptus*, present in both L2 and L3. An explosive radiation occurs at the beginning of the Bendigonian, where 28 dichograptid species grouped into ten genera and subgenera make their appearance in Be1: *Dichograptus*, *Didymograptus* (Didymograptus), *D. (Espansograptus)*, *D. (s.l.)*, *Loganograptus*, *Pandograptus*, *Temnograptus* (Schizograptus), *T. (Kellamograptus)*, *Pseudokellamograptus* and *T. (Tetragraptus)*. Especially striking is the diversity of the multibranched dichograptids. Only seven more genera and subgenera, *D. (Corymbograptus)*, *Mimograptus*, *Orthodicelograptus*, *Zygograptus*, *Trianograptus* and *Tidiosisgraptus* make their entry after zone Be1, most of them in the Bendigonian and Chewtonian, with *Pseudokellamograptus* making a very late appearance in the Darriwilian. The last surviving dichograptid occurs in the early Gisbornian.

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¹ *Reign* in this context means that this element is truly dominant in the time range; ‘interval’ means the element is a prominent component. 
² *Stages* in the Ordovician of Australasia are used in the sense of superzones defined solely by their graptolite content—see VandenBerg & Cooper (1992).
Cardiograptus taxa, all belonging to caduceus imitatus the Yapeenian and Darriwilian, and no isograptid survived into the Gisbornian. Only one, remained a group of relatively low diversity represented by six genera, of which appearance in the Darriwilian, but no sigmagraptid survived into the Gisbornian. Castlemainian. Two new genera, into rapid decline after the Chewtonian, with only four species persisting into the zone Be1. A further genus, in mind. The earliest member of the group, identity. Trends in diversity and succession are, therefore, to be read with this often too poorly preserved to establish their true generic, and hence familial, and no isograptid survived into the Gisbornian.

Interval of the sigmagraptids

Sigmagraptids are an important component of the Early Ordovician and show an expansion during the Castlemainian (Ca3) and in the succeeding zone is represented by four species. Sigmagraptids are an important element in the remainder of the Middle Ordovician, with three genera—Apiograptus, Cryptograptus, Pseudoaegriograptus—in the Yapeenian, joined by Glossograptus and Pseudograptus in the Darriwilian. Both survived the mass extinction event in the late Darriwilian, and the last glossograptid, Corynoides, first appears in the upper Gisbornian (Gi2), where it occurs in staggering abundance (thousands per square metre) on some bedding planes. Both Cryptograptus and Corynoides disappeared in the Eastonian.

Reign of the isograptids

While the isograptids were dominant in sheer numbers during their reign, they remained a group of relatively low diversity represented by six genera, of which only one, Isograptus, produced more than a single species. The appearance of the isograptids is gradual, with a single lineage, the Isograptus victorinae lineage (Fig. 22.7f), beginning with Isograptus primulus in the upper Chewtonian (Ch2) and continuing with increasing rhabdosome size through the Castlemainian and Yapeenian. In Ca3 there are still only two isograptids, I. victorinae maximus and I. caduceus imitatus, and only in Ca4 is there a diverse isograptid fauna with five taxa, all belonging to Isograptus. The remaining genera, Oncograptus (Fig. 22.7a), Cardiograptus, Pseudociagrapthus, Shiagraptus and Bergstroemograptus, evolved during the Yapeenian and Darriwilian, and no isograptid survived into the Gisbornian.

Interval of the glossograptids

The first glossograptid, Pseudograptus, made its appearance in the mid-Castlemainian (Ca3) and in the succeeding zone is represented by four species. Glossograptids are an important element in the remainder of the Middle Ordovician, with three genera—Apiograptus, Cryptograptus, Pseudoaegriograptus—in the Yapeenian, joined by Glossograptus and Pseudograptus in the Darriwilian. Both survived the mass extinction event in the late Darriwilian, and the last glossograptid, Corynoides, first appears in the upper Gisbornian (Gi2), where it occurs in staggering abundance (thousands per square metre) on some bedding planes. Both Cryptograptus and Corynoides disappeared in the Eastonian.

Reign of the diplograptids and orthograptids

In Victorian strata, biserial forms traditionally classified as ‘Climacograptus’ are often too poorly preserved to establish their true generic, and hence familial, identity. Trends in diversity and succession are, therefore, to be read with this in mind. The earliest member of the group, Hallograptus, makes its appearance in the Darriwilian (Da2). In Da3 it is joined by four species of Pseudoclimacograptus and the first Amplexograptus. Species diversity remains low in the Darriwilian: a total of eight species occur, belonging to three genera. This changes drastically in the Gisbornian, where five new genera make their appearance. They are Climacograptus, Orthograptus, Lasiograptus, Neurograptus and Ensigraptus, with a total of twelve species. Climacograptus bicornis, typical of...
the Gisbornian, often occurs in abundances of thousands of rhabdosomes per square metre (Fig. 22.7c). The greatest diversity is reached in the Eastonian, where 23 species occur. Genera that make their appearance here are Diplacanthograptus and Nymphograptus. The group is well represented in the lower three zones of the Bolindian, with fifteen species belonging to eight genera. Genera that appear in this interval are Appendispinograptus, Euchimacograptus, Orthoretiograptus, Paraorthograptus and Sinoretiograptus. However, none of the species of the group survives into the late Bolindian.

**Interval of the dicranograptids**

Dicranograptids make their appearance in the Gisbornian and are a prominent component of Late Ordovician faunas. Of the 30 described species present, 17 belong to Dicellograptus and 6 to Dicranograptus (Fig. 22.7e), with the remaining seven species divided amongst three other genera: Nemagraptus (1 species), Leptograptus (3), Pleurograptus (2) and Jiangxigraptus (1). Dicellograptus is well represented in the early Bolindian but disappears abruptly, together with the last Pleurograptus, within Bo3.

**Interval of the monograptids**

Only biserial monograptids occur in the Victorian Ordovician. They form a small but important faunal element in the upper part of the sequence. The first appearance of Undulograptus defines the beginning of the Darriwilian. Only three genera are represented, Undulograptus, Glyptograptus and Normalograptus, and in much of the time only one or two species are present. However, the family survived the mid-Bolindian extinction and became more abundant and important in the late Bolindian, heralding its explosive radiation in the early Llandovery.

**Silurian graptolites**

The lowest Silurian zone, that of Akidograptus acuminatus, is known from several localities low in the Deep Creek Siltstone, but their vertical distance above the highest Ordovician graptolites is uncertain because they occur in different structures (VandenBerg et al., 1984b). This is the only occurrence of Akidograptus in Australia, and its preservation is very fortuitous because most of the overlying rocks are unfossiliferous. Faunas from the remainder of the Deep Creek Siltstone have enabled recognition of the lower Llandovery triangulatus, magnus and leptotheca biozones (Rickards & Sandford, 1998). The Springfield Sandstone is the most graptolitic of the Silurian formations, with all of the mid- to late Llandovery graptolite zones represented. By contrast, the Wenlock and Ludlow record is poor and generally difficult to correlate, largely because of the complete absence of Cystograptus from Victoria.

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Fig: 22.7. Graptolites. (All specimens from Museum Victoria Collection; photographs by D. Holloway). (a) Oncograptus upsilon T. S. Hall, P13071, Early Ordovician (Yapeenian, Ya1), Yapeen, x 2.5. (b) Tetrograptus (Pendeograptus) fruticosus J. Hall, 3-branched form, P34278, Early Ordovician (Bendigonian), locality unknown, x 2.4. (c) Climacograptus bicornis bicornis (J. Hall), P134906 (left) and P56046, Late Ordovician (late Gisbornian), Wellington River, x 1.3. (d) Rhabdinopora scitulum (Harris & Keble), P31912, Early Ordovician (Lancefieldian, La1), Stauro Gully, Romsey district, x 2.4. (e) Dicranograptus hians T. S. Hall, P21936, Late Ordovician (Eastonian), Wellington River, x 1.4. (f) Isograptus victoriae Harris, P44059, Early Ordovician (Castlemainian, Ca2), Castlemaine, x 2.3.
The dearth of graptolites in the Silurian and Lower Devonian rocks appears to be largely due to the effects of burrowing organisms. Silurian seas were just as rich in graptolites as those of the Ordovician. This is demonstrated in a single black-shale bed 5 cm thick in the Yalmy Group, which has yielded a mid-Llandovery fauna with five biseriial monograptid species (including the only known Victorian representatives of *Petalographus*) and eight uniserial ones. This exceeds, both in number of taxa and abundance of graptolites, most Ordovician graptolite localities.

The youngest graptolites in Victoria occur in black shales in the Lower Devonian. Two species occur, 'Monograptus' thomasi and 'M. aequabilis notoaequabilis'. These two species span a time interval within the late Pragian and early Emsian that corresponds to the 'standard' *lyndonensis* Biozone.

**Stromatoporoids**

Stromatoporoids occur in Victoria in rocks of Late Silurian (Ludlow) and Early Devonian (Pragian–Emsian) ages. Silurian occurrences are in limestone bodies within the Gibbo River Siltstone in the Wombat Creek – Mitta Mitta River area (Chapman, 1912a), the Cowombat Formation in the Cowombat Flat – Limestone Creek and Bindii areas (VandenBerg et al., 1984b), and the Wirgenden Limestone (VandenBerg et al., 1992) in the Yalmy area (Talent et al., 1975). These faunas are poorly preserved due to recrystallisation of the limestones and have not been studied systematically.

The diverse Early Devonian stromatoporoid faunas of Victoria were first described by Rupger (1933, 1937a, 1937b, 1937c, 1938), and have been recently reviewed by Webby et al. (1993). The most diverse faunas are those of the Lylidale Limestone (middle to late Pragian), the Buchan Caves Limestone (latest Pragian–Emsian) and the Murrrindal Limestone (early Emsian) in the Buchan district. More restricted faunas are found in the Pragian Waratah and Bell Point limestones at Waratah Bay, the late Pragian limestones within the Norton Gully Sandstone at Loyola, the Pragian–earliest Emsian age Coopers Creek Limestone in the Tyers district, and the Emsian Tabberabbera Formation. Webby et al. (1993) recognised three biostратigraphically distinct assemblages:

- A Pragian assemblage, occurring in the Lylidale, Waratah and Coopers Creek limestones, with key elements such as *Pleurodictyum alutum*, *Aculatulatrama?*, *Schizostichyenia?* cylindriserenum, *Pseudoactinodictyon*, *Atelodictyon* champmani, *Stromatoporella cf. granulata*, *Tubuliporella calamosa*, *Amnisteotroma holmesc*, *Saliarella lylidalese*, *Syringostromella zinchenkovi*, *Habrostromella tyrensis*, *Collosomia lalattam* and *Dendrostroma?*
- A basal Emsian association in the Buchan Caves Limestone, with *Clathrodictyon? heathense*, *Pseudotrupetosicola buchense*, *Syringostromella cf. labyrintha*, *Coenosomata* and *Astrotomata distans*.
- An early Emsian association in the upper Murrrindal Limestone, with *Petrolisthesia delicatulam*, *Pseudotrupetosicola*, *Parallelopora ampla* and *Astrotoma*.

Many of the genera occurring in the Early Devonian assemblages of Victoria, such as *Pseudoactinodictyon*, *Stromatoporella*, *Stictostroma*, *Tubuliporella*, *Parallelopora*, *Pseudeotrupetosicola* and *Coenosomata*, are more characteristic of successions in Asia, Europe and North America that are Middle rather than Early Devonian in age.

**Corals**

At the species level, about 140 coral taxa have been reported from the Palaeozoic rocks of Victoria, all of them in Silurian or Early Devonian strata. No corals are known from lower in the Palaeozoic. Extensive marine rocks of Middle Devonian to Carboniferous age have not been recognised in the State and corals have not yet been reported from the cold-water Permian marine rocks. Modern approaches to taxonomy have reduced the overall number of species through recognition of numerous synonyms. All currently recognised taxa reported to species level, with their occurrences, are listed in Table 22.2 in Appendix 1.

**Silurian corals**

These are known from two main areas: the Melbourne Zone, and the Wombat Creek and Limestone Creek regions north and east of Benambra. Those from the Melbourne Zone, apart from the widespread tabulate coral *Pleurodictyum megastoma* McCoy (the first Palaeozoic coral to be described from Victoria) (Fig. 22.8e), are poorly known and preserved, and of little significance stratigraphically. They are mostly solitary, and have been referred to various species of *Lindstroemia* by Chapman (1925). The only compound rugosan is the doubtful *Columnaria flanigentomensis* Chapman. Most of these forms inhabited deeper-water, muddy-bottom biotopes.

In the northeast of the State, by contrast, corals occur in limestones at a number of levels in the Silurian. The oldest appear to be those from the Farquhar and Lobelia Limestone Members of the Towanga Formation, of late Llandovery age (Simpson & Talent, 1995), from which the genera *Phaulactis*, *Helodictyon*, *Protopora* and *favositids* are reported (Talent et al., 1975). These are amongst the oldest *Phaulactis* reported from Australia. Among the youngest limestones in the Enano Group are the McCarty's and Claire Creek – Stony Creek limestones, and these are studies as *Pleurodictyum megastoma* (late Ludlow, *crispa* Biozone) and a lens at Native Dog Flat (Pridoli), which have yielded *Mucuphyllum crateroides*, *Stylopleuna lilliformis*, *Flechsera densoidea*, tabulates, and a form reported as *Mazophyllum coumbeathensis* (Talent et al., 1975; Simpson & Talent, 1995). The latter (invalid name) is of interest as it is the youngest by far of the known occurrences of the genus (now *Labecchiella*).

**Devonian corals**

Limestones are rare in the earliest Devonian successions, and the oldest Devonian corals, of probable Lochkovian age, are reported from mudstones or small limestone bodies, possibly allochthonous (e.g. from a boulder in the Eildon Sandstone at Eildon dam; Hill, 1947). During the Pragian, however, major bodies of limestone were deposited, many of which have yielded abundant coral faunas. (Fig. 22.8a–d). The most significant faunas have been recovered from the Lylidale, Coopers Creek, Mansfield, Waratah Bay and Buchan areas. The Coopers Creek fauna is the most extensive, due largely to the thorough collecting and description by Philip (1962).

There is remarkably little overlap between the coral faunas of the major limestones, most of the shared species being long-ranging tabulates. A preliminary zonation of coral faunas for eastern Australia was set up by Philip & Pedder (1967b), providing eleven zones spanning the Early and Middle Devonian. Of these, the second (the *Linetaema chapmani* fauna) and the fourth (the *Chalidophyllum reesiana* fauna) have their type areas in Victoria, in the Coopers Creek Limestone and the Buchan Caves Limestone respectively. *Linetaema chapmani* also occurs in the Waratah, Lylidale and Loyola limestones, which therefore indicates that all the major Victorian coral assemblages fall into only two coral zones. However, the type species of the fifth coral zone, *Xystiphyllum Mitchelli*, is also reported from the much older Coopers Creek Formation (Philip, 1962) and the Murrrindal Limestone (Hill, 1950), which have a slight difference in age. The corals of the Murrrindal Limestone are perhaps the youngest Palaeozoic examples known from the State, and the presence of *X. Mitchelli* at that level is consistent with its distribution in New South Wales.

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5 The two localities that Rickards & Sandford (1998, figs 2 & 6) place in the Leptotheca Zone are from the Deep Creek Siltstone, not the Springfield Sandstone—see VandenBerg (1991).
Fig. 22.8: Corals (a–e) and echinoderms (f–g). (All specimens from Museum Victoria Collection; photographs by D. Holloway). (a, b) Tanjilasma meridionalis (Philip), transverse section P128606 and longitudinal section P128607, Coopers Creek Limestone (Early Devonian, Pragian–earliest Emsian), Tyers district; x 3.5 and x 2.3. (c, d) Loyolophyllum cresswelli Chapman, transverse section P138944 and longitudinal section P138946, ‘Loyola Limestone’ (Early Devonian, late Pragian), Loyola, x 4.6 and x 2.0. (e) Pleurodictyum megastoma (McCoy), P10875A, Cornella Member, Mount Ida Formation (Late Silurian – Early Devonian), Heathcote district, x 0.9. (f) sea star, Eoactis stachi (Withers & Keble), P49191, Melbourne Formation (Late Silurian, Ludlow), Melbourne city, x 0.8. (g) crinoid, Helicocrinus plumosus Chapman, P384, Melbourne Formation (Late Silurian, Ludlow), West Brunswick, x 1.3.
Zhen (1998), in an overview of all Australian Devonian rugosans, reduced the number of coral zones to four. For the Victorian faunas at least, the Philip and Pedder choice of zonal taxa is supported by the correlation of limestone units on the basis of conodonts (Mawson et al., 1992; Mawson & Talent, 1994; Wall et al., 1995), although the degree of precision using the microfossils is much greater than is afforded by current knowledge of fossil corals.

**Conodonts**

Conodont data obtained from Victoria, mainly over the past 15 years, have resulted in significant stratigraphic re-alignments for rocks of Ordovician through to Early Devonian age and better understanding of the transgression-regression pattern for the Silurian and Early Devonian. Pioneering work by G. M. Philip on Early Devonian conodont faunas using single-element nomenclature (e.g. Philip, 1965, 1966) has been revised in terms of multi-element taxonomy and expanded. Zonal schemes established on the basis of Northern Hemisphere sequences (Walliser, 1964; Klapper & Johnson, 1975; Klapper, 1977; Lane & Ormiston, 1979; Aldridge & Schönlaub, 1989; Klapper & Johnson, 1980; Jeppson, 1997) are readily applicable (e.g. Mawson, 1987; Mawson et al., 1988, 1992; Mawson & Talent, 1994; Simpson, 1995a,b; Simpson & Talent, 1995).

Biogeographic differentiation among mid-Palaeozoic conodont faunas, even on a global scale, is subtle. There are, however, a few Early Devonian conodonts occurring in Victoria that have limited distribution globally. These include three polygnathid conodonts: *Polygnathus trilinitatis* (Cooper, 1973; Mawson et al., 1992; Mawson & Talent 1994) (Fig. 22.10c), reported elsewhere only from Shishkat, Tajikistan (Bardashev, 1991; Bardashev & Ziegler, 1992); *Polygnathus zavarovianicus* (Mawson et al., 1992; Mawson & Talent, 1994; Mawson, 1998) (Fig. 22.10d) and *Polygnathus hindei* (Wall et al., 1995), reported elsewhere from both Zinzillab, Uzbekistan (Masikova & Apekins, 1980; Yolkin et al., 1989) and Shishkat. *Ozarkodina linearis*, first described from Buchan (Philip, 1966; Mawson, 1987), occurs elsewhere in the Yukon, and on Ellesmere Island, Canada (Fähareus, 1971), whereas *Ozarkodina prolata* described from Buchan by Mawson (1987) has been found otherwise only at La Grange, northwestern France (Bultynck, 1989). These restricted occurrences of conodonts during the latest Pragian and Emsian (*pireneae–rotinum zones*) suggest they were originally in close biogeographic proximity to each other and/or that long-distance current transport occurred between crustal blocks in southeastern Australia, Tajikistan and Uzbekistan, and the northeast margin of Alaska.

Conodont data have shown that the Silurian sequences of eastern Victoria, particularly in the region about the headwaters of the Indi, Buchan and Tambo rivers, span almost all intervals from early Llandovery, apparently *Dictododus combinatus* Zone (*sensu* Simpson, 1995b = approximately mid-D. *kentuckyensis* Zone of Fig. 22.9), through to *Pridoli* (Simpson et al., 1993; Simpson & Talent, 1995). Unequivocal mid-Llandovery faunas are represented. Late Llandovery *elloni* Zone and late Llandovery to earliest Wenlock *amphrophathoids Zone* conodont faunas have been obtained from several limestone bodies, notably the Lobelia and Fanquhar limestone lenses of the Towanga Sandstone in the Reedy Creek area in the upper Buchan Formation, possibly an extension of the Walhalla Group of the Walhalla Synclinorium, limestone clasts from debris flows and isolated limestone megaclasts suggest cannibalisation of the Waratag Bay Platform, a persistently emergent part of the Selwyn Block (VandenBerg, 1988a; Mawson & Talent, 1994; VandenBerg et al., 2000; Casey et al., 2002—see Chapter 5). Conodont data from limestone olistoliths in the Norton Gully Sandstone at Loyola, near Mansfield (Cooper, 1973; Mawson et al., 1992) are also dated as Pragian; palaeocurrent data indicate their source lay to the east (see VandenBerg et al., 2000). On the Waratag Bay Platform, three Devonian units outcrop. These are the Waratag and Bell Point Limestones — *Pragian, sulkatus, kindlei* and possibly *pireneae zones* (Talent, 1989; Bischoff & Argent, 1990; Mawson et al., 1992; Mawson & Talent, 1994) and the turbiditic Liptrop Formation, possibly an extension of the Walhalla Group of the Walhalla Synclinorium farther north.

Several carbonate horizons occur in the locally richly fossiliferous Wentworth Group, extending through Tabbereabbera (Talent, 1963), northwest of Bairnsdale. Conodonts recovered from these outcrops and from limestone clasts from the oldest unit in the Wentworth Group, the Wild Lime Formation, demonstrate that the sequence is late Pragian *Polygnathus pireneae Zone* and younger (Mawson et al., 1992).

Conodonts from the Buchan Group of eastern Victoria (Fig. 22.10g–j, l–p) have demonstrated that the group spans most of Emsian time (*dehissens to sevotinus zones*) and apparently much of the *pireneae Zone* as well (Mawson, 1987; Mawson et al., 1992). The Taravale Marlstone has produced important dacyroconarid faunas and late *dehissens Zone* peribonius Zone ammonoids (Erben, 1964, 1965; Mawson, 1987; Alberti, 1993). The presence of strata aligning with the *pireneae Zone* low in the Buchan Caves Limestone at Buchan and Bind is inferred from the widespread *pireneae Zone* transgression identified in analogous sedimentary sequences elsewhere in southeastern Australia. Amongst these is the Boulder Flat Limestone of far eastern Victoria where *pireneae Zone* conodonts have been identified (Mawson et al., 1992).

**Brachiopods**

The Silurian and especially Lower Devonian sequences of central and eastern Victoria tend to be dominated by brachiopods and, in carbonate facies, by coral–brachiopod faunas. Most of the brachiopod faunas have still to be described and evaluated for their chronological and palaeo-ecological significance. Some have chronological control from associated graptolite or conodont data (cf. Fig. 22.9), but there is a lack of tight chronological control for the late Ludlow to end-Lockhovian faunas indicated in Fig. 22.9. With the notable exceptions of the diverse faunas from the Buchan Group and small faunas from the Láyde, Bell Point and Coopers Creek limestones and limestone olistoliths in the Walhalla Synclinorium, most brachiopod faunas are preserved as moulds. This has acted as a disincentive to taxonomic study. Seven of the ten Ludlow to Emsian brachiopod-based faunal units proposed by Garratt & Wright (1988) were based on Victorian faunas. Important in this synthesis were notoanelliids and strophomenidines. Late Wenlock brachiopod faunas from the *Illawerus* band of the Costerfield Silstone (Opik, 1953; Talent, 1964; Edwards et al., 1998) are dominated by the smooth *Australina tyro* (Opik) with rare occurrences of *Leangella ino* Opik, small chonetidines and strophomenidines.

Brachiopod faunas of the Melbourne Formation consist of relatively rare and localised occurrences of coquinas with rynchonellidines (e.g. in Moonee
Ponds Creek. These have not been investigated since the days of Sir Frederick McCoy, about 150 years ago, when they were identified with European forms (summary in Chapman, 1914b). Associated forms include poorly known dalmanellidines, while higher (basal McIvor Sandstone) is a widespread level of sowerbyellids (prominent among which is Aegiria thomasi Talent) associated with occasional small rhyzochonellidines and rare strophoendontoids, in places forming a mappable interval in areas from Heathcote (Talent, 1964) southwards towards Melbourne (e.g. Williams, 1964).

Chronological alignments in the succeeding thick clastic late Ludlow–Lochkovian sequence of the Heathcote–Redcastle–Costerfield area are problematic. The generally poorly preserved brachiopod faunas higher in the McIvor Sandstone in the Heathcote–Redcastle area (Talent, 1964) are dominated by rhyzochonellidines with, at one locality only, the unusual Notocladium tasmanicum (Etheridge) (Fig. 22.6b). Associated with them are subordinate strophoendontoids, particularly Lepostrophiella and rare Maoristrophia, retzioids (especially Molangia), atrypidines (especially Australina), dalmanellidines resembling Salopina, small spiriferidines resembling Hovellia, genetically unidentified orthotetoids and strophomenidines including leptaenids and rare sowerbyellids.

The Cornella Member (Unit 1) of the Mount Ida Formation is characterised (Talent, 1964) by an assemblage of presently unidentifiable species of dalmanellidines including Salopina, and Lorthis (Tverskaya), the strophoendontoid Lepostrophiella, various cuboidal and non-cuboidal rhyzochonellidines, the retezooids Molangia and Athryrina, and the smooth
Fig. 22.10: Some key Silurian and Devonian conodont species (specimens with P numbers in Museum Victoria Collection; photographs provided by R. Mawson). (a, b) Eognathodus sulcatus Philip iota morph, upper and lower views respectively, Boola Quarry, Tyers, x 45. (c, d) Eognathodus kindlei Lane & Ormiston, upper and lower views respectively of P142156, Evans Quarry, Coopers Creek, from Mawson & Talent (1994, Fig. 16A, B), x 60. (e) Polygnathus trilinearis (Cooper), upper view of P142100, Boulder Flat, from Mawson et al. (1992, Fig. 9G), x 50. (f) Polygnathus zeravhanicus Bardashev & Ziegler, upper view of P142102, Boulder Flat, from Mawson et al. (1994, Fig. 9H), x 90. (g, h) Polygnathus dehiscens dehiscens Philip & Jackson, upper and lower views respectively, Buchan Caves Limestone, Slocombe’s Cave section, The Basin, x 40. (i) Polygnathus nothoperbonus Mawson, lower view, low Taravale Formation, Slocombe’s Cave section, The Basin, x 40. (j) Polygnathus pseudoserotinus Mawson, lower view of AMF 66049, East Buchan, from Mawson, 1987 (Pl. 25, fig. 11), x 60. (k) Icriodus steinachensis Al-Rawi et a morph, upper view of P143070, Tyers Quarry, from Mawson & Talent (1994, Fig. 9K), x 60. (l) Ozarkodina prolata Mawson, lateral view of P142122, Buchan Caves Limestone, Savpit Ridge section, Bindi, from Mawson et al. (1992, Fig. 10M), x 45. (m) Ozarkodina pseudolamiæ Mawson, lateral view, Buchan Caves Limestone, Slocombe’s Cave section, The Basin, x 45. (n) Pandorinellina exigua exigua (Philip), lateral view, Taravale Formation, Old Tara Road Cutting, South Buchan, x 45. (o) Ozarkodina buchanensis Philip, lateral view of P142157, Buchan Caves Limestone, Savpit Ridge section, Bindi, from Mawson et al. (1992, Fig. 12N), x 70. (p) Ozarkodina linearis (Philip), lateral view of P142146, Buchan Caves Limestone, Savpit Ridge section, Bindi, from Mawson et al. (1992, Fig. 12C), x 60. (q) Pedavis brevicauda Murphy & Matti, upper view of P143034, Boola Quarry, Tyers, from Mawson & Talent (1994, Fig. 6G), x 45. (r) Ozarkodina crispa (Walliser) beta morph, upper view of P137682, Cowombat Formation, Cowombat Plain, from Simpson et al. (1993, Fig 4N), x 50. (s) Ancoradella ploeckensis Walliser, upper view of P140261, unit 3, Claire Creek Limestone Member of Cowombat Formation, Stoney Creek, from Simpson & Talent (1995, Pl. 5, Fig. 3a), x 30.
Nearshore faunas dominated by bivalves tend to be replaced laterally and up-chronological alignments are imprecise, a broad biofacies pattern (Talent, Meadows area, southwest of Cobar and the Bogan Gate – Trundle area of and prior to major down-slope transport by turbidity currents. The Infrequent trilobites and molluscs are rarely complete and thus seldom ‘chaff’ with associated fragments of crinoids and rare solitary rugose corals. Biofacies tend to occur rarely, in generally thin intervals of comminuted shell athyrididines including Sandstone and from the Mt Ida Formation have much in common with the and the spiriferidines Howellella. Brachiopod fauna is monospecific, consisting of the nondescript inarticulate tasmaniense occurs in the Silverband Formation within the predominantly nonmarine autochthonous, but conceivably transported offshore attached to nekton. Formation has been documented. The indubitably Upper Silurian Clonbinane only a small proportion of the brachiopod faunas from low in the Humevale to be Silurian but first demonstrated to be substantially Early Devonian by Gill. 1994) — consists of Dolerictes percivalpila Philip, Parmorthina impensa (Philip), Iorthis (Tyersella) typica Philip (Fig. 22.6c), L. (Protozorcesthides) festiva Philip, Plectodonta bipartita (Chapman), Notoleptaena otophera Gill, Plectophorina (Quasiostrophiella) gypiplanica Philip, Rectarlastra thomsonensis Talent, Spirigerina (Spirigerina) supramarginalis sibirica Rashmonunskaya, Australina lenticulata (Philip), Bocoutia australis (Gill) and Notanoplia philipi Garratt. As well, there are species of the genera Daleysina, Schizophoria, Oquus and Myriospiner, chonetidines and poorly-known pentameridines referred to ‘Cypidula’.

The Boola Formation is overlain by suclatus Zone (but not earliest suclatus Zone) to early debiensis Zone limestones (Philip, 1965) of the Coopers Creek Limestone (Mawson & Talent, 1994). The lower limestones of this unit—suclatus to kindle Zones—have produced a small fauna with a few taxa co-occurring in the underlying Boola Silstone. These include Parmorthina impensa (Philip), Iorthis (Tyersella) typica Philip, Plectodonta bipartita (Chapman), Notanoplia philipi (Garratt) and Australina lenticulata (Philip), with species of Maoristrophia, rare large cuboidal rhynchonellidines, Myriospiner and small delthyrids. On the western side of Waratah Bay there are outcrops of two Pragian limestone units with ages constrained by conodont data (Talent, 1989; Bischoff & Argent, 1990; Mawson et al., 1992; Mawson & Talent, 1994). Impure limestones of early Pragian age (suclatus Zone) from the Waratah Limestone are coeval with the Coopers Creek Limestone. They have an undescribed low-diversity brachiopod fauna, notably at Robins Rocks, with a large cuboidal rhynchonellidines resembling Sphaerirhynchia, generally small delthyrids and a rare orthotetacean. The unconformably overlying Bell Point Limestone (later Pragian kindlei–pieneae zones) also has a low-diversity brachiopod fauna of Buchanathys westoni Talent, Athyris waanabahensis (Talent) and Spinella yassensis (de Koninck), similar to that occurring low in the Buchan Caves Limestone of eastern Victoria.

Brachiopods have been described from limestone outcrops of probable early Pragian and possibly late Lochkovian age (Mawson & Talent, 1994) in the Wurutwun Formation in Marble Creek and Deep Creek, east and southeast of Walhalla. These include species of Diarctesia, Leptagoria, Mesodowulina (Protoxytmagnostia?), Gypidula, various rhynchonellidines including Aspethynia and Taenmyrpha, with Rectarlastra thomsonensis (Talent), Atrypa spp. and species of Howellella including H. linata Talent (Chapman, 1903b; Talent, 1956b; Talent et al., 2001). Approximately coeval faunas from Norton Gulley Sandstone clastics at Loyola have produced Bouwitia hyloensis (Gill) and species of Leptanitona, Leptagoria? and various arthritines including Spinatrypa (Isopontatrypa) (Chapman, 1913). The sparsely occurring brachiopods in associated but stratigraphically higher limestone olistoliths of late Pragian – earliest Emsian age (Mawson & Talent, 1994) have not been described.

Conodont data from the Lilydale Limestone (Wall et al., 1995) demonstrate an age-span within the Pragian that includes the kindlei and pieneae zones. A small fauna of spiriferidines and rhynchonellidines brachiopods from within the kindlei Zone, associated with a rich fauna of tabulate and rugose corals, stromatoporoids and gastropods, has yet to be documented. Small, little-investigated brachiopod faunas are present in mudstones, calcareous mudstones and thin limestones in the highest levels of the Enano Group at Cowombat and Native Dog Plains in the headwaters of the Indi and upper Buchan rivers in eastern Victoria. They are in horizons known
from conodont data (Simpson et al., 1993; Simpson & Talent, 1995) to include the late Ludlow (prineae Zone) and extend into the Pfidolı eoeinhornerensis Zone. Atypidines are common, especially *Atrophyoea australis* (Mitchell & Dun) and *Coeolospira* (Talent, 1959b).

The shelly fauna of the basal unit of the Wentworth Group, the Wild Horse Formation, in the watershed of the Mitchell and Wentworth rivers, includes poorly preserved, broken brachiopod material. However, the occurrence of *Polygnathus prineae* in limestone clasts from this unit provides a maximum age of late Pragian (*prineae Zone*) for the base of the Wentworth Group and thus a maximum age for the faunas of the Dead Bull and Kilgower Members of the overlying Tabberabbera Formation (Talent, 1963). The Dead Bull fauna includes *Reefonia manwichi* (Allan), *Muriarella punctata* (Talent), ‘Adolfia’ *gylpta* Talent, *Houwella* aff. *textilis* Talent, and poorly preserved chonetidines and rychnonellidines. Brachiopod faunas from the Kilgower Member (Gill, 1949a; Talent, 1963; Johnson & Talent, 1967) are more diverse and inferred to be *prineae Zone* or perhaps as young as early as the *dehiscens* Zone. They are from a similar biofacies as the Boola and upper Humevale faunas and have a few species in common, notably *Reefonia manwichi* (Allen), *Pleodonta bipartita* (Chapman) and *Sphaerirhynchia globularis* Talent. However, the majority of the species, despite being referable to genera found in the Boola and upper Humevale faunas, are specifically distinct. These include *Murierella punctata* Talent, *Rugoleptaena undulifera* (Talent), *Nadiastra pauper* Talent, *Leptostrephella peli* (Gill), *Gymnostrophia bellangona* Talent, *Parachonetes burchanensis* (Gill), *Devonnagypa* *polyptia* (Gill), *Unimocina calathicina* Talent, *Eoglossinotoechia longispina* Talent, *Vittia? peflabella* (Talent), *Spinatrypa* (?*spinatrypa*) (Talent, *Houwella* *piger* (Talent), *H.? pinguis* Talent, ’Adolfia’ *gylpta* Talent, *Houwella* *textilis* Talent, *Phylocyrtina cooperi* Gill and *Altajelagia* *guyi* (Talent). These occur together with less readily characterised species of dalmanellidines, atherinidines, atypidines and spiriferidines. The youngest unit of the Tabberabbera Formation, the Roaring Mag Member, has produced sheared atherinidines resembling *Buchanathyris* and delthyrids possibly congeneric with *Spinella* (Talent, 1963; Talent et al., 2001), implying a fauna of similar biofacies but possibly postdating the Buchan Caves Limestone.

Three faunas can be discriminated in the Buchan Group (*prineae to serotinus zones*) of eastern Victoria. The oldest, the low-diversity fauna of the Buchan Caves Limestone (Talent, 1956a), is dominated by species of *Spinella* and *Buchanathyris*, with *S. buchanensis* Talent and *Howittia howittii* (Chapman) appearing near the top of the Buchan Caves Limestone. This fauna is best known from the upper half of the formation at Buchan, The Basin and Bindhi and is early in the *dehiscens* Zone. Essentially the same fauna extends down into the lower part of the formation to levels assumed to represent at least part of the *prineae Zone*, though this has been demonstrated with certainty at only one locality, low in the Buchan Caves Limestone at The Basin, northeast of Buchan. A smaller form of *Spinella* occurring at these levels may be *S. paraspinus* (de Koninck), better known from the Cavan Formation and lower units of the Taemas Limestone of southeastern New South Wales.

The lower Taravale Marlstone, as typically exposed in the entrance cuttings to the Buchan Caves Reserve and as the Pyramidal Member, is of late *dehiscens* Zone age. Salient brachiopods include *Dalejina philipi* (Chatterton), *Pachanoporites buchanensis* (Gill), *Prochonetes australis* (McCoy), *Coeolospira dayi* Chatterton, *Desquamatia* (?*Variatrypa*) *ectroistris* (Mitchell & Dun), *Athyris variatransiens* (Talent), *Ambocoelia? namogar* (Chatterton), *Quadrahydria allani* Chatterton, *Howittia howittii* (Chapman), *Rugoleptaena undulifera* (de Koninck), rare *H. multiplicita* (de Koninck) and *Spinella buchanensis* (Fig. 22.6g). Many of these forms occur in the uppermost bed of the Buchan Caves Limestone at Bindhi. *Septachonetes tiberalii* (Gill) is abundant in nodules at some horizons high in the Pyramidal Member. Brachiopods are very rare in the uppermost levels of the Taravale Marlstone (latest *dehiscens*, *inversus and venetius zones*; Mawson, 1987; Mawson et al., 1992).

The Murrindal Limestone faunas (late *dehiscens* and *perbonus zones*; Mawson, 1987 and unpublished data) are more diverse (J. Valentine, unpublished data) and some of the horizons are silicified. The faunas include many elements of the lower Taravale–Pyramids fauna, namely *Dalejina philipi* (Chatterton), *Pachanoporites buchanensis* (Gill), *Prochonetes australis* (McCoy), several atypidines including *Coeolospira dayi* Chatterton, *Desquamatia* (?*Variatrypa*) *ectroistris* (Mitchell & Dun), and the spiriferidines *Howittia howittii* (Chapman), *H. multiplicita* (de Koninck) and *Quadrahydria allani* Chatterton.

Among other elements are *Malhostrophia flabellicauda* Campbell & Talent (abundant in some horizons) and *Mesodinocardia* (Protoxynomorphia) *dickensi* (Chatterton), *Eosuchettellea murphyi* (Chatterton), several rychnonellidines undescribed from this unit including *Eoglossinotoechia? linki* Chatterton, several atypidines including *Pezzatrypa? penelopeae* (Chatterton) and several undescribed spiriferidines. The fauna has much in common with the faunas of the *Receptaculites and Warroo Limestone Members of the Taemas Limestone* (Talent & Philip, 1956) and *Actinopteria* from

**Molluscs**

**Bivalves**

The only bivalve recorded from pre-Silurian rocks in Victoria is a fragmentary specimen from the Knowles East Formation (Middle Cambrian) in the Heathcote district, tentatively assigned to *Gonimusya* by Chapman (1991).

The diverse bivalve assemblages in the Silurian – Lower Devonian sequences were first studied extensively by Chapman (1908), but most of the forms described have received no further attention and are in need of revision. The oldest Silurian bivalves he recorded are species of *Nuvela* and *Palaeoneilo* from the Chintin Formation (late Llandovery and/or Wenlock) in the Springfield area. From the Wenlock-age Anderson Creek Formation at Warrandyte he recorded only *Palaeoneilo*. In the Ludlow, he documented a rich fauna from the Melbourne Formation at South Yarra and Flemington, and a more restricted fauna from the Kilmore Silstone in the Kilmore–Wandong district. Genera present in these faunas include *Orthonota, Grammysia, Leptodomus, Palacanatina, Edmondia, Cardiola, Ctenodonta, Nuclites, Nuvela, Palaeoneilo, Parallelodén, Pterina*, *Arisalopecten, Modiolopsis, Goniophora and Paracyclus*.

**Silurian Zone**

Lower Devonian strata in the Heathcote district contain abundant bivalves (Opik, 1953; Talent, 1964) but poor preservation limits their identification. The lowermost unit with a significant fossil fauna, the ‘Baeros’ band (Wenlock), contains *Ctenodontia* (*Ctenodontia*), *Nuclites*, *Palaeoneilo?* and *Nuvela*. Higher in the sequence, the McIvor Sandstone (early Ludlow) contains *Ctenodontia* (*s.l.*) and *Ctenodontodina*. Ranging throughout the remainder of the sequence, in the McIvor Sandstone (Ludlow) and the overlying Mount Ida Formation (Ludlow) – early Lochkovian age), are *Leioteria, Actinopteria, Modiomorpha, Ctenodontia, Nuclites* and *Eschozoidus*. Also present are *Paracyclus, Leptodomus* and *Glosites* in the McIvor Sandstone, and *Nuvelalina*? *Cypricardia, Cypricardella, Amuleptes* and *Goniophora* in the Mount Ida Formation.

Elsewhere in the Darraweit Guim Province, Early Devonian bivalve faunas occur in the Humevale Formation (Lochkovian–Pragian) in the Lilydale–Killara and Kinglake districts (Fig. 22.11) and the Lilydale Limestone (middle–late Pragian). The Humevale Formation fauna includes *Hemyperilla, Grammysia, Ctenodontia* (Fig. 22.6a), *Nuclites, Nuclia, Palaeoneilo, Pterina, Actinodema, Mytiliana, Actinopteria, Leioteria, Glosites, Goniophora* and *Cypricardia* (Chapman, 1908; Gill, 1950a), while the Lilydale Limestone contains a much less diverse fauna with *Lucina* (?*Prohysia*), *Pterina, Ambonychia* and *Actinopteria* (Chapman, 1908; Pritchard, 1913).

In the Mount Easton Province, the earliest Devonian bivalve fauna is that of the late Lochkovian limestone in the Wurrutwun Formation at Marble Creek, Toongabbie, which contain *Rhombopteria, Actinopteria* and *Pterina* (Talent & Philip, 1956). In the Tyers district, Philip (1962) recorded *Actinopteria, Nuclites, Ctenodontia* (*Ctenodontia*), *Ctenodontia* (?*Phacotoclypeum*), *Cypricardia* from the Boola Formation (early Pragian), and *Actinopteria* from
the overlying Coopers Creek Limestone (Pragian–earliest Emsian age). The youngest fauna in the Mount Easton Province is that of the Norton Gully Sandstone (Emian) in the Loyola and Upper Yarra regions, which includes *Germysiosia*, *Pleuronema* (Fig. 22.6f), *Panacardium*, *Pseudomania*, *Lunulaticola* and *Actinopteria* (Chapman, 1908).

In the Buchan Caves Limestone (latest Pragian – early Emsian) in East Gippsland, bivalves are a rather subordinate faunal element (Talent, 1956a, p. 45) but are nonetheless diverse. Genera present are *Cypricardina*, *Pleurophora*, *Sanguinolites?, Nuculana, Eoschizodus, Schizodus, Glyptodus, Aviculipina*, *Cornellites*, *Actinopterella, Mytilacina, Actinopteria, Pterinoplax, Gonophora, Guenangaria* and *Panacardia* (Talent, 1956a; Johnston, 1993). The only bivalve reported from the Murrumbidgee Limestone (earliest Emsian), on the other hand, is "a small genus, possibly *Panacardium*" (Teichert & Talent, 1958). In the Tabberabbera district, a very diverse bivalve assemblage is present in the Tabberabbera Formation (Emian), from which Talent (1963) recorded *Pterinacea*, *Leziotera*, *Actinopteria, Ptychopteria, Leptodesma, Actinolycopeten* (Pterinoplax), *Mediomorpha, Goniophora, Sphenocysta, Ctenodonta, Palaeonella, Nuculana, Cypricardella, Nuezguelia, Cypricardina, Germysiosia (Germysiosiidae), Byssopteria?, *Pandelodon* and *Dolabula*.

**Gastropods**

In the Silurian of Victoria, gastropods have been described only from the Darraweit Guin Province of the Melbourne Zone. The oldest forms recorded are of Wenlock age, these being *Spinita?, Phygnolites, Tropididiscus, Bellerophon, Bucanella, Kokenospius?, Lophospira, Raphispira?* and *Loxonema* from the 'Ihlaen' band near Heathcote (Opik, 1953; Talent, 1964), and *Enopelphus* from the Anderson Creek Formation in the Melbourne district (Pritchard, 1944). Forms recorded from the Ludlow include *Tropididiscus?* and *Tichonema (Tichonemoporia?)* from the Dargle Formation at Heathcote, *Bucanella, Tenenodiscus?* and *Straparollus (Seripulopsis)* from the overlying McIvor Sandstone, and indeterminate bellerophonitids and loxonematids from both formations (Talent, 1964). The Kilmore Siltstone near Kilmore contains *Australonema*, *Bellerophon* and *Mourlonia* (Chapman, 1916; Tassell, 1980), while only *Capnita* has been recorded from the approximately contemporaneous Melbourne Formation in the Melbourne district (Chapman, 1929).

Gastropods in the Mount Ida Formation, which spans the Silurian–Devonian boundary in the Heathcote district, include *Straparollus (Staparollus), Platyceras (Orthonychia)*, and indeterminate loxonematids and plesiohorsids (Talent, 1964). Elsewhere in the Darraweit Guin Province, Early Devonian gastropods are recorded from the Humewale Siltstone (Lochkovian–Pragian) in the Lilydale–Kilalla district, and the Lilydale Limestone (middle–late Pragian). The Humewale Siltstone includes *Australonema, Tropididiscus, Bellerophon, Carinaporia, Phenomenia, Siluriphorus* and *Platyceras (Platystoma)* (Chapman, 1916; Tassell, 1977, 1980). The diverse gastropod fauna of the Lilydale Limestone has been the subject of several studies, the most recent by Tassell (1976, 1980), who described species of *Trematopus, Bellerophon (Bellerophon), Tropididiscus, Straparollus (Enopelphus)* (Fig. 22.6g), *Phanerotrema, Stenolon, Ortonista, Naticopsis (Naticopsis)*, *Murchisonia* (Murchisonia), *M. (Oxtonia), Michelia, Gyrodema, Scalaetrichus, Siluriphorus, Loxonema, Vallatotheca, Palaeocularia, Australonema, Anomphalus, Citronidae?* and *Subulites (Fuispina)*.

In the Mount Easton Province, the limestone bodies of late Lochkovian age in the Wurutwun Formation at Marble Creek, near Toongabbie, contain *Oxterina, Convurrella, Tiennatodus, Coelocaulus, Platyceras (Platyzena),* P. (Platystoma), *P. (Orthonychia)* and *Michelia* (Talent & Philip, 1956; Tassell, 1977). The limestone megastal fauna of similar age and in the same formation farther north in Deep Creek, east of Wallulla, includes *Platyzena (Platyzena), Ortonista* and *Sialtrotches* (Tassell, 1977). From the Booda Formation (early Pragian) of the Tyers area, Philip (1962, p. 136) recorded, but did not describe, *Straparollus, Orthonychia, a Loxemona-type gastropod, a large trochoform species probably related to *Sialtrotches*, and small bellerophonitids. Presumed olistostromal limestones of late Pragian age in the Norton Gully Sandstone at Loyola have yielded *Platyzena (Platyzena), P. (Pneumalic?)* and *Sialtrotches*, while the surrounding (Emian) clastics contain *Tropididiscus, Tenenodosus?, Straparollus (Staparollus) and Loxonema* (Tassell, 1977).

Gastropods are abundant in the Bell Point Limestone (Pragian) at Waratah Bay. The fauna was described by Tassell (1978), who recorded *Tropididiscus, Straparollus (Enopelphus), Ompteca, Bassetrocha, Mourlonia?, Gyrodena, Murchisonia (Murchisonia) and M. (Hormotomina). From the underlying Waratah Limestone, *Bellerophon, Coelocaulus and Loxonema* have been reported (Talent in Singleton, 1973c, p. 130).

In East Gippsland, gastropods have been recorded from the Buchan Caves Limestone (late Pragian–Emian) and the Tabberabbera Formation (Emian). Teichert & Talent (1958, p. 11) stated that gastropods are generally rare in the Buchan Caves Limestone, but they listed *Loxonema, Baylea, Mourlonia, Bellerophon* and either *Tichonema or Worthenia* from the formation. The fauna of the Tabberabbera Formation includes *Buchanopora, Protophytichus?, Tenenodosus, Tropididiscus, Straparollus*, *Benthexia?, cf. Urichospira*, *Platyzena (Orthonychia), Ortonista, Michelia* and *Loxonema* (Talent, 1963).

**Rostroconchs**

Though occurring widely in Victoria in strata of Late Silurian (Ludlow) to Early Devonian (Emian) age, rostroconchs are relatively uncommon and are typically represented at each locality by only a single species (Tassell, 1982). Most species were originally included in *Convorida*, but some of these were reassigned to *Hypocandia* by Tassell (1982), who recorded the latter genus from late Lochkovian limestones of the Wurutwun Formation in Deep Creek and Marble Creek in the Wallalla–Toongabbie area, from the Lilydale Limestone (middle to late Pragian) and, with question, from the Gibbo River Siltstone (Ludlow) in the Mitta Mitta River area and from the Humewale Formation (Pragian) at Seville East. *Brannia* was tentatively identified by Tassell (1982) from the Bell Point Limestone (Pragian) at Waratah Bay. In

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Fig. 22.11: Siltstones of the Humewale Formation (Lower Devonian), Middendorps Quarry, Kinglake West. Photograph by F. Holmes.
addition to these occurrences, Conocardiun has been recorded from the Melbourne Formation (Ludlow) at South Yarra (Chapman, 1908), the Coopers Creek Limestone (Pragan – earliest Emsian) in the Tyers district (Philip, 1962), the Stoddart Member of the Mount Ida Formation (Lochkovian) in the Heathcote district (Talent, 1964), the Tabberabbera Formation (Emsian) (Talent, 1963), and the Buchan Caves Limestone (latest Pragan – earliest Emsian; Talent, 1966a).

Cephalopods

Cephalopods are almost entirely absent from the Ordovician of Victoria. The only reported occurrences are undescribed orthoconic and cyrtoconic nautiloids in the Digger Island Marlstone (early Tremadoc) at Warratah Bay (Talent, 1966a, p. 17) and two coiled nautiloid specimens identified as Doxovania and Trocholitoceratina from Bendigonian Castlemaine Group slates in the Bendigo area (Thomas & Teichert, 1947; Talent, 1966a). A single orthoconic nautiloid has been found in early Eastonian shale from the Mount Easton Shale at Enoch’s Point (A. H. M. VandenBerg, personal communication, 2002).

In the Silurian and Lower Devonian of the Melbourne Zone, orthoconic nautiloids are relatively common but are generally too fragmentary and poorly preserved to be identified genetically. Genera identified by Teichert & Glenister (1952, pp. 735–736) include Doxovienia from the Melbourne Formation (Ludlow) in the Melbourne district and the Kilmore Shiststone (Ludlow) near Kilmore; Protodokiatina from the Melbourne Formation; Buchanoceras and Protokionoceras from the Humevale Formation (Lochkovian–Pragian) at Kinglake West; Dorothyceratina from the Lilydale Limestone (middle–late Pragian) at Lilydale; and Korniceratina, Donovニアceratina, Geisonocerina and Plagiotomceras from the Norton Gully Sandstone in the Upper Yarra district and near Mount Matlock. Anaptygotoceceratina was described by Talent (1964) from the Dargle Formation (earliest Ludlow) in the Heathcote district, and by Talent & Philip (1966) from late Lochkovian limestones of the Wurutwun Formation at Marble Creek near Toongabbie.

In East Gippsland, Spyc蔚来ceratina occurs in the Tabberabbera Formation (Emsian) at Tabberabbera (Talent, 1963). The nautiloid fauna of the Buchan Group was partly described by Teichert & Glenister (1952), who recorded Pectioceras, Pityobasmatina, Brachylomoceras, Mazonoceras, Buchanoceras, Scipitites and Michelionoceras from the Tabarvale Marlstone. Also present in the lower part of this formation are the ammonoids Talenticerata, Teicherticerata, Bautrites, Labobautrites and Anaceerata? (Teichert, 1948; Erben, 1965).

Ostracods

The only ostracod recorded from strata older than Silurian in Victoria is Beyr pérdia, identified by Eckardt (1987, p. 20) from the Darraweit Guim Mudstone (Ashgill–late Bolindian) near Darraweit Guim. In the Silurian and Devonian, ostracods occur widely but the faunas have not been extensively studied. The only Silurian fauna described is that of the ‘Illawera’ band (Wenlock) in the Heathcote district, but inadequate material and poor preservation make generic assignment of many of the species uncertain. Genera present are Velibeyrichia, Drepanellina, Gallitata, Arcmchina, Utchicha? Cienobolithina, Ogmomolomattela, Eosiuvia, Diibella?, ’Punctoprimitia’, Haskellprimitia, Cytherellina, Kayapia and Quadrilocollina (Opik, 1953; Talent, 1964). The only other Silurian ostracods recorded are Gallitata from the Kilmore Shiststone (Ludlow) near Kilmore (Chapman, 1903a; Opik, 1953; Talent, 1963), and unidentifiable forms from limestones within the Gibbo River Shiststone (Ludlow) in the Mitta Mitta River area (Chapman, 1920b, p. 191) and from the Silverband Formation (Ludlow?) in the Grampians Group (Talent & Spencer-Jones, 1963).

In the Lower Devonian, Velibeyrichia and other unidentified ostracods have been recorded from the Mount Ida Formation (early Lochkovian) in the Heathcote district (Talent, 1964), and Velibeyrichia and Gallatia from the Humevale Formation (Lochkovian–Pragian) at Kallara (Chapman, 1903a; Talent, 1963). However, evidence of a much more diverse fauna in the Humevale Formation was presented by Eckardt (1987, 1988), who identified Beyrichia (= Velibeyrichia), Hollinella, Kellettina, Egiykobby, Streptolites, Drepanellina, Arcmchina, Sigynus, Utchicha and Haskellprimitia from localities in the Lilydale and Kinglake districts. Philip (1962, p. 136) reported abundant unidentified ostracods towards the top of the Boola Formation (early Pragian) in the Tyers area. Diverse ostracod faunas of Pragian age have been described from the Bell Point Limestone at Warratah Bay, which contains Chapamnites, Bairdia, Kloeodega, Eiikloendena, Geisina, Kozlowskiella and Dhibolaina (Krommelbein, 1954; Prribyl, 1962), and from the Lilydale Limestone, with Lepedidiata, Pritrettata, Parapachites, Bairdia, Bairdina, Canadinea, Bairdiocystis and Microetella (Chapman, 1904; Willey, 1970). Ostracods are very common in the Buchan Caves Limestone and the Taravale Marlstone (latest Pragian – Emsian) in the Buchan district, but the fauna has not been fully described. Genera recorded are Apachites, Schmidtelia, Cavellina, Chapamnites, Sailella, Kloeendena and Kirkhynia from the Buchan Caves Limestone, and Apachites, Cavellina, Bairdiocystis and Renbeizychia from the Taravale Marlstone (Krommelbein, 1954; Reynolds, 1978). From the Murrindiland Limestone (early Emsian) only Batridia has been recorded (Krommelbein, 1954). In the Tabberabbera area, Velibeyrichia and other unidentified ostracods occur in the Tabberabbera Formation (Emsian; Talent, 1963).

Echinoderms

The uppermost Ordovician (Bolindian) to Lower Devonian (Lochkovian) sequences of the Melbourne Zone are rich in fossil echinoderms, occurring particularly in fine-grained clastics but also in sandstones and limestones. Classes represented include Crinoidea, Blastoida, Rhombiferida, Asterorhiza, Ophiuroidea, Ophiocidarida, Edrioasteroidea, Echinoidea, Soluta and Martata.

The Darraweit Guim Mudstone, dated by the graptolite Normalograpthus extraordinarius, the nominate species of the penultimate Ordovician biozone, yields the camerate crinoid Protocyathidium eliocae Ruta & Jell (1999a), which is interpreted as ancestral to the Allocystidae that spread across Gondwana in the Silurian and Devonian.

Throughout the Murrindindi Supergroup, disarticulated and unidentified echinoderm stem columns are common, but a relatively small number of species have been identified. The Upper Silurian (Ludlow) Melbourne, Dargo and Kilmore formations in the Melbourne, Heathcote, Kilmore, Clonbinane and intervening areas are rich in echinoderms, including the mitrates Victoriacrinus, Adoketocarpus and Notocarpus (Philip, 1981; Gill & Caster, 1960; Ruta & Jell, 1999b); the edrioasteroids Epipatia, Pyrgocyttus and Irenopha (Holloway & Jell, 1983); the asterozoans and ophiuroids Uromoa, Yarravina, Lepidaster, Boliactis, Esacites, Palasterina, Petaster, Pseumolapaeaster, Palllipsaster, Ulrichaster, Schucherta, Espondylus, Pacaster, Gregorius, Sturtcuna, Sturtaster and Lapworthoria (Witlers & Kehde, 1934a, b); the crinoids Dendrocrinus, Nasovicerina, Hapalocystus, Phoinocrinus, Clematocteurinus, Allocystus, Shintocrinus, Anthomocystus, Quadrataxocystus, Teichertocystus and Kopeocrinus (Jell, 1999).

Early Devonian (Lochkovian) echinoderm faunas are found in the Humevale Formation in the Mooroolbark–Lilydale and Kinglake districts and in comparable units in the Heathcote district. They include the blastoid Sphagoblastus (Jell, 1983); an undescribed echinoid (Museum Victoria collection); the ophiocidarid Gilbeycyttus (Jell, 1983); the rhombiferans Hilycystus and Henicoctyes (Jell, 1983); the solutarian Rutocyttus (Gill & Caster, 1960); the mitrate Adoketocarpus, Notocarpus, Victoriacrinus and Pseudovictoriacytus (Ruta & Jell, 1999b, c); the edrioasteroid Rhenopyrogus (Holloway & Jell, 1983); the ophiuroids Unastrella, Schucherta, Lapworthoria, Espondylus and Cephalopoma; and the crinoids Ophiocrinus, Holiopyrgus, Hexainctina, Eunicinerina, Nevronia, Clematocrinus, Capulocrinus, Phidocystus, Didicocteurinus, Dornocystus, Eucystus, Clematocteurinus, Frankocrinus, Ophcrinina, Dornocystus, Struvocrinus, Codaurina, Holmeinuax, Daraghocrinus, Kopeocrinus, Meristocristus, Anooycrinus, Ctenodactyloides, Dendrocrinus, Gerlichocystus, Shintocrinus and Koepocrinina (Jell, 1999).

A small crinoid fauna consisting of Eusalypctocerinus, Hexainctina and Thylocrinocteus is known from Lochkovian limestone in the Wurutwun Formation in the Toogabbie limestone quarries in the extreme east of the Melbourne Zone (Philip, 1961). Lenses of the ‘Loxley Limestone’ (Pragan, kindli Biozone) in the Norton Gully Sandstone, southwest of Mansfield, yield the camerate crinoid Eusalypctocerinus fonzi, that genus also being known in Queensland and New South Wales.
22.2.3 Late Palaeozoic and Mesozoic invertebrate fossils

Permian

Permian invertebrate fossils are rare in the glacially derived Lower Permian (Tastubian and Sterlitamakian) Bacchus Marsh Formation of the Bacchus Marsh district. A single brachiopod species, *Trigoneta victoriae* Archbold (1991a) and conulariid species referred to both *Noctsomulina* and *Paranomulina* are recorded (Garratt, 1969; Thomas, 1969). Recently a suite of arenaceous foraminifers, including species of *Hemidiscus*, *Hypoammina* and *Ammonidiscus* (Foster, Palmieri & McCann, personal communication), have been collected from the same locality as the *Noctsomulina* specimens referred to *N. inornata* (Dana) by Thomas (1969). The ages indicated by the sparse marine macrofossils were reviewed by Archbold (1998).

Cretaceous

Arthropods, Molluscs, Bryozoans and Annelids

Mesozoic invertebrate fossils are rare in Victoria. They include about half-a-dozen specimens of poorly preserved nonmarine bivalves, probably uniodids, known from a few scattered localities (McMichael, 1957), in addition to the classic insect fauna known only from one locality at Koonwarra.

The Koonwarra fossil beds in the Eumerralla Formation contain a diverse fauna of over 80 species of invertebrates preserved in sediments deposited in a shallow freshwater lake (Jell & Duncan, 1986). There are more than 70 insect taxa. The crustaceans include a conchostracan (*Cyzicus? banchoceanus*), a cypridoid ostracod, a syncarid (*Koonypides indistinctus*), an anostrocan and a daphnidi cladoceran. There are four arachnids (a limulid *Vitalium masqueri*, two spiders and a harvestman), bryozoan statoblasts, a possible uniodid bivalve, and possible oligochaete worms. The insects are represented by 12 orders dominated in terms of diversity by Hemiptera, Coleoptera and Diptera, but numerically by aquatic immature Ephemeroptera and Diptera. Many taxa can be recognised in both immature and adult stages and many can be referred to living families.

Marine invertebrates are known from bores in the Otway Basin. A single ammonite, *Haurerius angustos Yabe*, was recorded by Glaessner (1964) from the Comacian Belfast Mudstone Member of the Paaratte Formation in Flaxmans No. 1 Well between Warrnambool and Port Campbell. Other specimens of invertebrates occurring in other wells in the basin have not been described.

Foraminifera

Taylor (1964, 1971) described foraminiferids from subsurface Upper Cretaceous (Cenomanian, or Turonian to Maastrichtian) sedimentary units intersected in boreholes in the Otway Basin. These faunas are predominantly of benthonic forms, although planktonic species are reasonably well represented in the upper part of the Belfast Mudstone Member of the Paaratte Formation. Benthonic foraminiferids are most commonly arenaceous types. Foraminiferids were sufficiently common in the borehole samples examined by Taylor (1964, 1971) to form the basis of a biostratigraphical subdivision for these sequences. Genera recorded by Taylor (1964) include, amongst others, *Haplophragmoides* Cashman, *Textularia Debrance*, *Quinqueloculina d’Orbigny*, *Nodosaria Lamarck*, *Lenticulina Lamarck* and *Cibicides* de Montfort. Companion microfossil faunas of Ostracoda and Radiolaria have been reported from the upper interval of the Belfast Mudstone Member (Douglas et al., 1976).

22.2.4 Cainozoic invertebrate fossils and subfossils

Molluscs

Cainozoic marine molluscs are known from all the onshore basins in Victoria. The marine molluscan fauna is composed of four main elements:

1. Tethyan Indo-Pacific genera which have their major distribution in the Indo-Pacific region and represent northern or tropical influences.
2. Australian–New Zealand genera which may have originated in either New Zealand or Australia but are not known outside this region (these are generally temperate to cool-water genera and some have a relationship with species from southern South America and Antarctica).
3. Endemic genera known only from southern Australia or the deeper cooler waters of the east and west coasts of the continent (the proportion of this element has increased in southern Australia from the Paleocene to Recent).
4. Cosmopolitan genera, that is genera with a worldwide or nearly worldwide distribution.

The proportions of these four elements fluctuated throughout the Cainozoic era and thus give an indication of the climate during that time (Darragh, 1985). For example, at the time when the Indo-Pacific element is strongest, it is inferred that the sea temperatures were somewhat warmer than at present.

Molluscs are found in shelf sediments deposited at depths from just below low-tide level to about the mid-shelf. Molluscs living on rocky bottoms such as chitons, haliotids and turbinids are uncommon.

The earliest known fauna in southern Australia is of Late Paleocene age. Occurring in the Otway Basin, it contains about 90 species of molluscs of shallow-water origin, most of which are assigned to cosmopolitan genera such as the bivalves *Ledinia*, *Caualgia*, *Glycymeris*, *Pina*, *Pannamussium*, *Anomia*, *Pycnodonte*, *Bormia* and *Ponopea*; the gastropods *Calliotropis*, *Conomolinia*, *Cinochehus*, *Sasia*, *Cohobamus* (Fig. 22.13.c,d), *Proximitra*, *Acton*, *Tornatella* and *Spathidilus*; the scaphopod *Fussicidium*; and the nautiloid cephalopods *Eustrephoceras* and *Atuoredea* (Darragh, 1994, 1997a). There are very few endemic genera present and the fauna does not show any particular faunal affinity with other Palaeogene faunas of the southern hemisphere. Genera with a southern hemisphere affinity are the bivalve *Labillia* (Fig. 22.12.a,b), *Nelio* (*Australomelio*), and gastropods *Colposigma*, *Marshallaria* and *Zemasites*. The only undoubted endemic genera are *Eotroconia* (Fig. 22.12.a,b) and *Botellolites*. The composition of the fauna suggests that it lived in cool-temperate water.

By Late Eocene time, when the next youngest molluscan fauna of any significance lived, the basic compositional elements of the modern molluscan fauna had been established. Australian endemic genera (such as bivalves *Limarcus* and *Exosiperna,* and gastropods *Jettwoodia*, *Dennantia*, *Australothilia*, *Anillista*, *Antechilium*, *Ternovoluta*, *Notepephum*, *Eriusca* and *Notovoluta*) formed a significant part of the fauna and there had been an influx of immigrants from the Tethyan region (bivalves *Protulum*, *Semelangus*, *Myodora*, *Chlaenella*; gastropods *Baslicia*, *Belma*, *Liottia*, *Orthochetus*, *Atasorectith*, *Cypnadia*, *Chioreus*, *Cochlespinia*, *Bosoria* and *Conorbis*) and the New Zealand region (bivalves *Notogammenatom*, *Cosa*, *Notostrea*, *Hedicardium*, *Dosina*, *Hina*, *Fossacalista*; gastropods *Pairona*, *Spinocolpus*, *Archizeta*, *Protera*, *Ellatiria*, *Alecospinia*, *Waimatea*, *Waihoaia*, *Altheome*, *Omania*), though cosmopolitan elements were still important. This fauna lived in warmer water than that of the Paleocene, but not as warm as that of the Oligocene and Miocene. For example, at the time when the Indo-Pacific element is strongest, it is inferred that the sea temperatures were somewhat warmer than at present.

The Oligocene and Early to Middle Miocene faunas of the Otway Basin and Port Phillip Embayment are the richest in genera and species of the Victorian Cainozoic. They provide evidence for a significant warming across southern Australia, with a thermal maximum in the Middle Miocene marked by the presence of several Indo-Pacific genera such as *Crasatella*, *Solenotrema*, *Casidaria*, *Ficus*, *Ranella*, *Biplex*, *Conoc heelas*, *Tidicia*, *Personella*, and *Eudrilium* that are not found higher in the stratigraphic column. However, nowhere in the south could conditions be regarded as tropical. This warming event was not uniform across southern Australia. In the Eucla and St.Vincent Basins, faunas indicate even warmer water than in the southeast, leading to the recognition of two provinces — the Austral-Indo-Pacific Province in the Bremer, Eucla and St.Vincent Basins in Western Australia and South Australia and the Southeast Australian Province in the Murray, Otway, Bass and...
Fig. 22.12: Cainozoic invertebrate fossils; bivalves (a–k) and gastropods (l, m). (All specimens from Museum Victoria Collection; photographs by M. Darragh). (a) *Eotrigonia interstans* (Tate), P42504, right valve internal view, Upper Oligocene, Maude, x 1.1. (b) *Eotrigonia interstans* (Tate), P42504, right valve external view, Upper Oligocene, Maude, x 1.1. (c) *Grandaxinea ornithopetra* (Chapman & Singleton), holotype, P12465, right valve external view, Upper Oligocene, Bird Rock Cliff, Torquay, x 0.7. (d) *Grandaxinea ornithopetra* (Chapman & Singleton), holotype, P12465, right valve internal view, Upper Oligocene, Bird Rock Cliff, Torquay, x 0.7. (e) *Neotrigonia howitti* (McCoy), P47581, left valve external view, Lower Pliocene, Kalimna, x 0.8. (f) *Eucrassatella kingicolaides* (Pritchard), P127566, left valve internal view, Lower Pliocene, Kalimna, x 0.7. (g) *Eucrassatella kingicolaides* (Pritchard), P127566, left valve external view, Lower Pliocene, Kalimna, x 0.7. (h) *Lahillia australica* Singleton, P142916, right valve external view, Upper Paleocene, Pebble Point, x 0.6. (i) *Lahillia australica* Singleton, P142916, right valve external view, Upper Paleocene, Pebble Point, x 0.6. (j) *Proxichione subtilicostata* Darragh, P23822, left valve external view, mid-Miocene, Muddy Creek, x 0.8. (k) *Proxichione subtilicostata* Darragh, P23822, left valve internal view, mid-Miocene, Muddy Creek, x 0.8. (l) *Serratifusus craspedotus* (Tate), P26487, apertural view, mid-Miocene, Fossil Beach, Mornington, x 1.3. (m) *Serratifusus craspedotus* (Tate), P26487, abapertural view, mid-Miocene, Fossil Beach, Mornington, x 1.3.
Gippsland basins of Victoria. Genera characteristic of the Austral-Indo-Pacific Province include Veremolpa, Anodontia, Diastoma, Campanile, Strombus and Terebrulina. These are not known from Victoria.

The two provinces persisted through the Miocene into the Pliocene, but by latest Pliocene there seems to have been more uniformity across southern Australia with the establishment of a fauna that was essentially modern in its composition, owing to a gradual cooling through the Late Miocene and Pliocene.

Many genera characteristic of southern Australia first make their appearance in the Late Oligocene to Middle Miocene. These include the bivalves Populella, Scutella, Neotrigonia (Fig. 22.12e), Plethodon, Precociatropis (Fig. 22.12g,k) and Myochama, and gastropods Notohaliaxis, Lactifuntor, Eniunella, Nototritia, Umbilia (Fig. 22.13b,h), Austrocypraea, Austrotriton, Austrotrigonia, Terebratulina (Fig. 22.13a,b), Amoria and Livena.

In the Upper Miocene and Pliocene only shallow-water sediments outcrop. These harbour genera typical of shallower waters such as the bivalves Planam, and Basina, and gastropods Leioptyga, Bankivia, Sydaphera and Tylospina (Fig. 22.13c,f) appear for the first time. By the Pliocene, the fauna is essentially modern at the generic level. Only one genus, Zanitschekia, is known to have become extinct at the end of the Pliocene. A very few genera make their appearance in the Pliocene, the scallop Peten being the best known of these.

The faunas of the Pleistocene and Holocene deposits consist principally of very shallow-water species (Valentine, 1965), all of which, with one or two important exceptions such as Ninella torquata, are still living in the sea adjacent to the Victorian coast.


Nonmarine Palaeogene and Neogene molluscs are very little known. A few undescribed freshwater snails are found in freshwater limestones. The only other nonmarine Cainozoic macrofossil invertebrate known is an insect in amber.

**Corals**

Corals are found in all of the onshore Cainozoic marine basins. All corals are hermatypic and most are solitary. They mainly occur in marl and clay and these facies are a major limiting factor on their distribution. Most significant locality, the one with the greatest variation and quantity, is Torquay in the mid-Tertiary Jan Juc Marl (Figs. 22.14, 22.15a–d). Early works on the systematic classification of local Cainozoic corals include Dennant (1899a,b, 1902a,b, 1903, 1904). Modern, hermatypic coral genera are temperature- and depth-dependent. Where modern taxa have fossil relatives in the Victorian Cainozoic, that relationship can be used to interpret the depth and the temperature of the fossil forms’ environment of deposition (Table 22.3 in Appendix 1).

There are a total of 145 described species in 33 genera known from the Palaeogene and Neogene of Victoria. The majority of the genera have a wide distribution through both time and space. Only five genera, Holotrochus, Platytrochus, Tremaotrochus, Notophyllia and Pleuropholis, are endemic to the southern and eastern Australian regions.

**Echinoderms**

There are 84 echinoid generic taxa currently described from the Palaeogene and Neogene of Australia, of which 55 are known to occur in the onshore basins of Victoria. The ratio of irregular to regular forms is exactly 2:1. The earliest Cainozoic echinoids in Victoria occur in the Upper Eocene of the Aire district within the Otway Basin. Although nine genera have been recorded, only six can be verified from existing collections—Cystites (Fig. 22.15g). In the mid-Tertiary Jan Juc Formation, posses by far the most diverse echinoid fauna of the Upper Oligocene, having a total of 27 genera. Three of these genera, Apatopygus, Hemiaster and Orthopedia, may or may not be of Late Eocene age. This restricted fauna indicates a weak correlation with echinoids of a similar age in coastal basins of South Australia.

The Late Oligocene echinoid fauna of the Aire district strongly resembles the fauna recorded from elsewhere in the Otway Basin, both in content and overall diversity. On the other hand, the Upper Oligocene deposits of the Torquay Basin contain a diverse echinoid fauna having more in common with that of the southern Australian Eucla and St. Vincent basins. However, the Torquay Basin, with the highly variable lithology of the Jan Juc Formation, possesses by far the most diverse echinoid fauna of the Upper Oligocene, having a total of 27 genera. Three of these genera, Apatopygus, Hemiaster and Orthopedia, may or may not be of Late Eocene age. This restricted fauna indicates a weak correlation with echinoids of a similar age in coastal basins of South Australia.

The terebratellinid genera are Cudmorella from the Oligocene (Point Addis and Calder River limestones) and Miocene (Port Campbell and Bairnsdale limestones), Vorticithrix from the Miocene (Port Campbell, Gambier, Bairnsdale, Batesford and Gippsland limestones, and Rutledges Creek Member), and Desidrothyris, also Miocene (Batesford Limestone and Muckleberry Creek Marl).

The greater abundance and diversity of genera from the Miocene and later are due to the more uniform distribution pattern seen for Late Oligocene echinoids across southern Australia. A similar relationship is seen in the distribution of molluscs.
The southeastern Australian province itself became subdivided into western and eastern sectors during the Miocene. The Miocene of the Murray Basin (predominantly subsurface in Victoria) and of the Otway and Torquay basins possess similar faunal elements, giving them a distinct western Victorian character. The Port Phillip and Gippsland basins constitute an eastern sector, with the Western Port Basin left unassigned owing to the paucity of recorded material.

The Murray Basin, which forms the western limit of the southeastern Australian province, possesses the most diverse fossil echinoid fauna recorded in Australia. A total of 40 genera are known from the Miocene, five of which, *Hysteraster*, *Porterpygus*, *Cryptechinus*, *Menocidaris* and *Murravechinus*, have not been recorded elsewhere. The fauna has a close affinity with that of the Torquay Basin, with which it shares a total of 20 genera, 91% of the Torquay Basin’s Miocene echinoid fauna. The Otway Basin, the third basin of the western sector, contains 32 recorded genera, 17 in common with the other two basins. Nine of these, *Clypeaster*, *Corystus*, *Echinolampas*, *Eupatagus*, *Fibulata*, *Lovenia* (Fig. 22.15k), *Monostyctia*, *Comosideris*, and *Ortholophus*, are widely distributed throughout southern Australia, while one, *Actoperichaelum*, is endemic to these three basins.

In the eastern sector of the southeastern Australian province, 25 echinoid genera are recorded from the Miocene of the Port Phillip Basin, one of which, *Evechinus*, is endemic. The Gippsland Basin has a slightly less diverse fauna with only 18 genera recorded, twelve being shared with the Port Phillip Basin. Although none of these genera are restricted to the eastern sector, five of them, *Cyclaster*, *Schizaster* (*Schizaster*) (Fig. 22.15g), *Austrodistis*, *Deloidaris* and *Othioidea*, are restricted to the southeastern Australian province, while the others, *Clypeaster* (Fig. 22.15h), *Eupatagus*, *Lovenia*, *Monostyctia*, *Comosideris*, *Ortholophus* and *Phyllacanthus*, are widely distributed. One genus found in the Gippsland Basin, *Pseudechinus*, is otherwise known only from extant faunas.

Late Neogene faunas are poorly known, with only *Fellaster* being recorded from both eastern and western Victoria.

*Fig. 22.13:* Cainozoic fossil gastropods. (All specimens from Museum Victoria Collection; photographs by M. Darragh). *Atheta (Terrivoluta) subcrenulifera* Darragh, P22481, apertural view, Lower Miocene, Horden Vale, x 1.8. (b) *Atheta (Terrivoluta) subcrenulifera* Darragh, P22481, abapertural view, Lower Miocene, Horden Vale, x 1.5. (c) *Columbarium acanthostephes* acanthostephes (Tate), P16449, abapertural view, mid-Miocene, Fossil Beach, Mornington, x 1.3. (d) *Columbarium acanthostephes* acanthostephes (Tate), P16449, apertural view, mid-Miocene, Fossil Beach, Mornington, x 1.3. (e) *Tylospira coronata* (Tate), P135835, apertural view, Lower Pliocene, Hamilton, Victoria, x 1.3. (f) *Tylospira coronata* (Tate), P135835, abapertural view, Lower Pliocene, Hamilton, Victoria, x 1.3. (g) *Umbilia eximia* (G. B. Sowerby), P30274, dorsal view, mid-Miocene, Fossil Beach, Mornington, x 0.9. (h) *Umbilia eximia* (G. B. Sowerby), P302744, lateral view, mid-Miocene, Fossil Beach, Mornington, x 1.0.
Extant echinoid genera found in Australian waters total about 90 (Rowe & Gates, 1995), of which one third are known from the Palaeogene and Neogene echinoid faunas of southern and western Australia. The compositions of both these southern and western Australian fossil faunas show affinities to the extant fauna of the present-day southern Australian region. Within the modern Bass Strait province, 24 extant genera occur, of which four are known from Australian mid-Cainozoic localities, although only 10 are related to fossil recorded in adjacent Victorian onshore basins. While similarities exist between Oligocene–Miocene and Recent faunas, temperature preferences exhibited by extant genera show a very limited relationship to mid-Cainozoic distribution patterns. Seven of the genera recorded from Victorian basins, Brissopsis, Echinolampas, Echinonema, Lovenia, Pericosmus (Fig. 22.15i), Schizaster (Schizaster), and Euclidaris, are today restricted to tropical zones in northern Australia or to eastern zones, including the Tasman Sea, under the influence of the subtropical East Australian Current.

The proportion of extant tropical genera present in the fossil record increases from four in the Late Oligocene to eight in the Miocene. This represents a major compositional change in the Australian echinoid fauna. The period was marked by the first of a series of warming events (McGowan & Li, 1994) that probably influenced evolutionary trends. This compositional change is characterised by the extinction of genera such as Apoecystis, Meoma, Warinia, and Pentechinina, and the appearance of Actinocyclus, Brissus, Notoplites, Perapatangus, Schizaster (Dipteneus), 'Siomondia', Studeria, Austrodiadema, Menidiidina, Holocidaris and Marananchius.

Other echinoderms known from the Victorian Palaeogene and Neogene basins are restricted to segments of comatulids (free-swimming crinoids), stalked crinoids, asteroids, ophiuroids and dermal spicules of holothuroids. All are comparatively uncommon and undescribed.


**Decapods and Cirripedes**

Two groups of Cainozoic macroscopic crustaceans are well known—the crabs (Decapoda) and the barnacles (Cirripedia). The only crab that is relatively common locally is Ommatecanus conensis, which can be found in a comparably complete state preserved in burrows (Jenkins, 1975). Other Tertiary decapod remains are usually fragmentary and have not been described. Barnacles are common particularly in the Neogene or in faunas typical of rocky bottoms (Buckeridge, 1983).

**Bryozoans**

Bryozoa are exceptionally abundant and diverse in the marine Cainozoic of Victoria, in many places forming a significant proportion of the sediment fraction. Their importance as part of the fauna of the continental shelf has continued to the Recent, where bryozoan remains constitute a major fraction of the sediments off southern Australia.

Palaeogene and Neogene bryozoans have a long history of investigation in southeastern Australia (e.g. Tensm Woods, 1888; Waters, 1881, 1882, 1885; MacGillivray, 1895; Maplestone, 1901, 1904; Stach, 1935a,b; Brown, 1958; Wass, 1975; Bock & Cook, 1993a, b, 1995a, b, 1996, 1999, 2001, 2002). However, the use of scanning electron microscopy to show increased detail, and the systematic studies since 1983, have resulted in the systematics of many of the earlier bryozoan records being of little practical application. Many of the descriptions of new species by early workers were apparently based upon single fragments, or upon very small samples. It is clear that study of larger collections is necessary for a fuller definition of interspecific and intraspecific variation. In addition, the stratigraphic control of most of the early bryozoan papers was inadequate. While there is a general belief that the bryozoans are of little use in biostratigraphy, it would be more accurate to say that their biostratigraphic value has not yet been adequately tested.

Most of the bryozoan faunas that have been studied were separated from clay-rich sediments, in which the preservation is particularly fine. Bryozoans are mainly found in open-marine environments; estuarine bryozoans are generally poorly calcified, and are far less likely to be preserved. Mobile sandy substrates may support bryozoans, but these also are rarely preserved. A characteristic fauna of the modern shelf with a high diversity has been described as the 'sand fauna'.

This contains a large number of bryozoans with soft, cuticular rootlets, such as Sphaeropora and Mehornia (Cook, 1979). This fauna has some similarities with components of the faunas collected from Cainozoic clay-rich sediments, such as the Fyansford Formation. Many Cainozoic limestones also contain diverse and important colonial bryozoan skeletal remains which, for the most part, have not been studied in detail. The many studies of colony form distribution have shown that there are no easy answers in palaeoecology, although bryozoans have become an important tool in palaeoecological analysis (Hageman et al., 1998). A major assumption in interpreting current or wave activity from the type of bryozoan colony form is that the bryozoan colonies were attached to a rigid local substrate. However, it is clear that a large number of flexible, ephemeral substrates were also exploited, such as sponges, hydroids and uncalcified bryozoans. Delicate bryozoans can survive moderate wave or current activity when the local substrate can respond to the agitation.

The lack of recent revision of the fauna means that estimates of diversity must be very approximate. More than 500 species can be recognised from the existing literature on the Victorian Palaeogene and Neogene. While some of these will be recognised as synonyms, it is clear that revision will also result in recognition of many more undescribed species. A recent study of the group of modern and fossil 'lunuliform' (free-living, cap- or dome-shaped) bryozoans from the Cainozoic of Australia and New Zealand by Cook & Chimonides (1984a,b, 1985a,b,c, 1986, 1987) showed the high diversity of the fauna; subsequent studies have revealed further new species.

The Order Cyclolomata has colonies constructed from tubular zooid units, normally with a round terminal orifice. A few species are found in most samples, with some clay-rich samples containing many erect, fragile forms. Many species were described by the early workers, but there are no recent studies of Australian forms.

The highest diversity is found in the Order Chelostomata, in which the zooids are typically box-shaped. Family-level systematics are still being revised. Among the groups which are most significant in the Victorian Palaeogene and Neogene are the Family Adenoidea, with a large number of erect bivalvate species. The high diversity has continued to the modern fauna. The Family Leptolepidellidae has many fossil representatives, in the genera Collepsopora and Sphaeropora. Collepsopora is found as large colonies in some localities, such as the 'Collepsopora Beds' at Jan Juc Beach, and the limestone at Longford. Additional small colonies or fragments are encountered in other facies.

The Family Pholidoporidae is represented by a large number of erect fenestrate forms, mainly in the genus Retepora (once known as Retepony (Fig. 22.16e); a number of encrusting forms are known, but have not been revised recently. The Family Catenicellidae is one of the most diverse Recent and fossil Cainozoic bryozoan groups of Australia. Colonies are erect and bushy, and constructed of calcified units of one, two or three zooids (Fig. 22.16d). The uncalkified joints decay after the death of the colony, and so the small calcified units are found in the fine fraction of the sediment.
Fig. 22.15: Cainozoic invertebrate fossils; corals (a–d) (specimens from M. Grover private collection; photographs by M. Grover); echinoids (e–l) and brachiopods (m–o) (specimens from Museum Victoria Collection; photographs by M. Darragh). (a, b) Placotrochus magnus Dennant, profile and calice views, Upper Oligocene (Jan Juc Marl), Torquay, x 1.5 and x 2.0. (c, d) Flabellum pavoninum distinctum Milne, Edward & Haime, profile and calice views, Upper Oligocene (Jan Juc Marl), Torquay, x 2.3 and x 2.8. (e, f) Goniosigma singletoni (Philip), P102917, lateral and dorsal views, Upper Miocene (or lowermost Pliocene), Beaumaris, x 1.3 and x 1.1. (g) Schizaster sphenoides Hall, P53194, dorsal view, Middle Miocene, cliffs between Port Campbell and Sherbrook River, x 0.5. (h) Clypeaster gipslandicus (McCoy), F. Holmes Collection, dorsal view, Middle Miocene, McCrae’s Quarry, x 0.5. (i) Pericosmus quasimode McNamara & Philip, P302894, dorsal view, Middle Miocene (Bairnsdalian), Ingles Creek, x 0.4. (j) Corystus dysasteroides (Duncan), P78254, dorsal view, Upper Oligocene, Waurn Ponds, x 0.6. (k) Lovenia woodsi (Etheridge), P307045, dorsal view, Upper Miocene (or lowermost Pliocene), Beaumaris, x 1.3. (l) Cassidulus? florescens (Gregory), P143579, dorsal view, Upper Oligocene, Point Addis, x 1.1. (m, n, o) Austrothyris sp., P84723, profile, brachial valve and pedicle valve views, Middle Miocene, North Shore, Victoria, x 1.5, x 1.5 and x 1.5.
The Family Cellariidae forms erect bushy colonies, in which the calcified units are rod-shaped, composed of many zooids. Cellariids are also abundant and diverse in Victorian Palaeogene and Neogene sediments (Fig. 22.16b). The lunulitiform bryozoans are one of the characteristic components of the Cainozoic of Victoria, although they appear to be absent in the coarser limestone facies.

A great variety of unilaminar colonies are recorded; these are referred to a wide range of families, and many need revision. The Smittinidae are represented by few species in Victorian Palaeogene and Neogene sediments, in contrast to the modern ocean, where the family is highly diverse.

The Order Ctenostomata forms uncalcified colonies, which are unlikely to be preserved except for species that excavate openings in shell substrates. Boring bryozoans occur at Muddy Creek and further investigations should reveal more species. One group of ctenostomate fossils which has not yet been found from Victoria are the forms which are preserved by being entombed by an overgrowth of a calcareous organism (bioimmuration).

Sponges, annelids, spicules and trace fossils

Sponges
A few species of entire marine calcareous sponges have been recorded from the Cainozoic marine sediments of Victoria. Four species in three genera (two of which were new) from three localities were described by Hinde (1900). All species are of small size, generally less than 20 mm in diameter. A small Miocene limestone occurrence at Flinders contains numerous specimens of the species *Tetossilus pezica* Hinde.

Sponge and holothurian spicules
Siliceous sponge spicules are a common component of the fine-grained marine sediments, particularly the Miocene Balcombe Clay at Fossil Beach, Mornington. Monaxon, tetract, and tuning fork types are dominant. At the same locality, calcareous holothurian (echinoderm) spicules are a conspicuous component of the sediment.
Annellids
Polychaete fossils are generally extremely rare, but an exception is in the Miocene Port Campbell Limestone, in which abundant specimens of the calcareous tubes of the polychaete Dittyna wormbeiens is seen.

Trace Fossils
Fine-grained Cainozoic marine sediments, such as the Fyansford Clay, are often completely disturbed by bioturbation, indicating a diverse and active burrowing infauna extending to a depth of several centimetres below the depositional interface.

The principal identifiable trace fossils from the Cainozoic sediments are the anastomosing burrows of callianassid decapod crustaceans, often identified as the ichnogenus Ophiomorpha. These callianassid burrows are very well developed in the Paleocene Pebble Point Formation in the coastal exposures near Princetown, and are also found in the Black Rock Sandstone in the Beaumaris area. Callianassid burrows are indicators of intertidal or very shallow subtidal environments.

Foraminifera
Planktonic foraminiferids have been extensively used in Cainozoic biostratigraphic correlation throughout the globe, with a highly precise zonation developed for sequences deposited in warm, low-latitude regions (Berggren et al., 1995). Companion schemes have also been developed for cooler, high-latitude marine sequences (Jenkins, 1985). The spatial and temporal distribution patterns of southern high- and mid-latitude planktonic foraminiferal faunas as they relate to Victorian (and other) Tertiary sequences are discussed in Jenkins (1993) and McGowran et al. (1997).

In addition, a variety of local Victorian zonations have been developed (Carter, 1964; Taylor, 1965b; Jenkins, 1985; Mallett, 1978; Mallett & Holdgate, 1985; Moss & McGowran, 1993; McGowran & Li, 1993; Taylor in figure 9 of Bernecker et al., 1997, amongst others). Some of these, such as Mallett & Holdgate (1985) and Chaproniere (1988), used planktonic foraminiferids exclusively to establish biozones. Others, such as Carter (1964), McGowran & Li (1997) and Li & McGowran (1997) integrated planktonic and benthonic occurrences in order to define faunal units or assemblage zones that may be used for regional southeastern Australian correlation. Integrated biostratigraphic and sequence-stratigraphical or sea-level studies of Victorian Cainozoic sequences which utilise foraminiferal data include Mallett (1978), Mallett & Holdgate (1985), McGowran (1989), McGowran et al. (1997), Holdgate & Gallagher (1997), Gallagher et al. (1999) and Li et al. (1999).

Benthonic foraminiferids have often been utilised in biostratigraphical correlation of the marine outcrop of southern Victoria because of the plankton-poor nature of most of the shallow-marine carbonate and marl facies of the Bass Strait hinterlands (i.e. Carter, 1964). In offshore regions of Bass Strait, Upper Eocene to Pliocene facies were generally deposited in deeper-marine settings. As a result, they contain extensive successions of diverse and abundant planktonic foraminiferal faunas, which provide the main means for correlation and dating. Planktonic foraminiferids are the principal type considered here, although Tertiary marine mudstone facies of Victoria often contain extremely rich and diverse faunas of benthonic species (Fig. 22.18f-g). Examples of typical southeastern Australian Cainozoic fossil and Recent benthonic foraminiferal faunas were presented in Chapman (1907b, 1914c), Chapman & Parr (1926), Chapman et al. (1934), Chapman & Crespin (1928), Crespin (1943), Carter (1964), Collins (1974), Li & McGowran (1988) and Yasiini & Jones (1995), amongst others.

The foraminiferal faunas described by McGowran (1965, 1976) have provided critical evidence for the age of the oldest exposed Cainozoic deposits of southern Victoria — the Upper Paleocene portion of the Pebble Point Formation (Fig. 22.17) and the Lower Eocene Dilwyn Formation. The Pebble Point Formation foraminiferal faunas are dominated by benthonic species with planktonic species becoming conspicuous in the Dilwyn Formation (McGowran, 1965). A significant occurrence of a planktonic species is the presence of Pseudohastigerina pseudovita (Hornibrook) in the Rivermook Member of the lower Dilwyn Formation. In general, calcareous foraminiferal faunas, and in particular planktonic faunas, are very sparse in Victorian Lower Paleocene to Middle Eocene outcropping strata. However, some common benthonic foraminiferal occurrences in the Paleogene of southeastern Australia are of arenaceous forms belonging to the genus Cyclusminna Brady. Of particular note are the occurrences of Cylaminina-bearing facies in the Lower Eocene Dilwyn Formation and Middle Eocene Johanna River Sand.

Upper Eocene and lowermost Lower Oligocene strata in western Victoria, such as the Browns Creek Clay, Castle Cove Limestone and Glen Aire Clay, were deposited in well-oxygenated marine settings. Planktonic foraminiferal faunas in these formations have enabled quite precise international correlations. Of particular significance is the occurrence of Hantkenina primitiva Cushman & Jarvis in the Browns Creek Clay and Globigerinatheca index (Finlay) in the Castle Cove Limestone.

Outcrops of mid- to uppermost Lower Oligocene strata in southern Victoria rarely contain calcareous fossils. Exposures of the Upper Eocene to Lower Oligocene Anglesa Sand along the central Victorian coast include only arenaceous foraminifera belonging to the genera Cyclusminna Brady, Anomodiscus Reuss, Bathysiphon M. Sars and Distrothnia Plummer (Abele et al., 1976). However, calcareous foraminiferal faunas are known from throughout the Lower Oligocene in offshore drillhole sequences. They include the species Subbotina linaperta (Finlay), S. angigynoidea (Hornibrook) and Oligotextinella aubertii (Palmer).

Fossiliferous lowermost Upper Oligocene strata are known from one onshore cliff section where the uppermost Angahook Formation (sensu Reekman in Webb, 1995) is exposed at Bells Headland along the Bells Beach – Addiscott Beach coastline. The precise age of this Angahook Formation exposure is not known because it contains a paucity of planktonic foraminifera. However, according to Li et al. (1999), samples of the Angahook Formation from nearby borehole yield, among others, the planktonic foraminiferids Globigerinotubulina euganica (Jenkins), G. labatunensis (Jenkins), Cymbula triseriata (Terasu) and Oligotextinella aubertii. This assemblage suggests that the Angahook Formation is latest Early Oligocene at its base and earliest Late Oligocene at its top within the borehole sections. The fossiliferous outcrop exposures, which lie immediately beneath the Jan Juc Marl at Bells Headland, presumably correlate with the top of the Angahook Formation in the nearby boreholes. The isolated outcrop at Bells Headland is therefore likely to be equivalent to the lowermost part of the Upper Oligocene.

It was probably during the Oligocene that a broad open normal marine passageway became established across Bass Strait. In south-central Victoria, the Late Oligocene Jan Juc Marl and Point Addis Limestone overlie the Angahook Formation. Planktonic foraminifera are very rare in these two Late Oligocene formations, their age being inferred on the basis of Early Miocene index foraminiferids present in the overlying Puebla Clay and Zeally Limestone. Other Late Oligocene units include the Clifton Formation of southwestern Victoria, which at its type locality yields the planktonic foraminiferids Globigerinotubulina anguliformis (Bolli) Globigerina opibusensis Bolli and Tuberatitubulina buligreri (Bolli) (for discussion see Abele et al., 1976). Equivalent subfacies strata in southeastern Victoria include the Lower Oligocene portions of the Lakes Entrance Formation. In general, offshore regions of Bass Strait possess diverse Late Oligocene planktonic foraminiferal faunas.

The major marine inundation of the Bass Strait region continued into the Early Miocene and resulted in the deposition of the upper parts of the Clifton Formation and Lakes Entrance Formation. In south-central Victoria, the Jan Juc Marl and Point Addis Limestone are overlain by the Lower Miocene Puebla Clay and Zeally Limestone. Generally, the base of the Miocene in these sequences is taken as the first appearance of the foraminifer species Globorotalia dehiscens (Chapman et al., 1934). As outlined by Carter (1990) and more expansively by McGowran & Li (1993), the first appearance of this species is generally followed in Victorian Lower Miocene strata by the last appearance of Globigerinatubarotita euganica and the first appearances of the species G. woodi (Jenkins), G. omnivora (Jenkins) and Globigerinoides telolobus (Reuss).

The planktonic foraminiferid Praeobulina sicana (De Stephani) (Fig. 22.18a), diagnostic of a late Early Miocene age, makes its first appearance towards the top of the Zeally Limestone in south-central Victoria, within the Gellibrand Marl of the Otway Basin, and within the Gippsland Limestone of the Gippsland Basin. Within the biostratigraphical range of Praeobulina sicana in the Port Phillip Basin, the distinctively warm-water benthonic foraminiferid Lepidocyclina hochvinti Chapman & Crespin is a conspicuous component of calcareous facies. The classic locality for Lepidocyclina-bearing strata is the Batesford Quarry near Geelong.
Chapter 22 Palaeontology

In south-central Victoria, the first appearance of Praeorbulina glomerosa (Blow) (Fig. 22.18b) occurs subsequent to the disappearance of Lepidocythere boucheri, although odd specimens of the latter occur reworked into younger Neogene units of this region. Praeorbulina glomerosa marks the beginning of the Middle Miocene and, within south-central Victoria, it first occurs within the Fyansford Formation. It occurs in the Gellibrand Marl in the Otway Basin and in the Gippsland Limestone in the Gippsland Basin. Subsequent planktonic foraminiferal datums in these sequences define a number of relatively small time-slices within the early Middle Miocene. These include the successive first appearances of Orbilina rutulis Brönnmann, O. universa d’Orbigny and Neogloboquadrina mayeri (Cushman & Ellisor) (Fig. 22.18c) and the last occurrence of Globorotalia peripheronda Blow & Banner (Fig. 22.18d).

The younger part of the Middle Miocene is marked by the first appearance of Globotruncana nepenthos (Todd), with the beginning of the Late Miocene taken as the first appearance of Neogloboquadrina acostaensis (Blow) (Mallett & Holdgate, 1985). This fossil succession is developed in subsurface sections through the Fyansford Formation in the Port Phillip Basin, the Port Campbell Limestone of the Otway Basin and the Gippsland Limestone of the Gippsland Basin. Subsequent planktonic foraminiferal events include the first appearance of Globorotalia conomiozea (Kennett) in the Late Miocene and the first appearance of G. crassaformis (Galloway & Wissler) (Fig. 22.18e) around the base of the Pliocene. G. puncticulata (Deshayes) makes its first appearance slightly higher in the Lower Pliocene. Both G. crassaformis and G. puncticulata are represented in the Jenny’s Point Formation of the Gippsland Basin (Mallett, 1978). Carter (1990) has recorded G. spinoneomiozea Walbers from the upper Neogene strata of the offshore Gippsland Basin and reported its occurrence between the first local appearances of G. conomiozea and G. crassaformis. In the Port Phillip Basin, shallow-marine facies of the Wannanee Formation yield the first local appearances of the planktonic foraminifers G. viola Blow and G. hirsuta d’Orbigny. The co-occurrence of these two species, in the absence of younger index species, is taken as characteristic of the Late Pliocene (Mallett & Holdgate, 1985). The end of the Neogene is approximated by the first appearance of the planktonic foraminifer G. truncatulinoides d’Orbigny high in the Werrakoo Limestone of the Otway Basin and near the base of strata attributed to the Bridgewater Formation, in the Port Phillip Basin (Mallett & Holdgate, 1985).

**Ostracods**

Ostracods are found in great abundance in many Cainozoic marine sequences of Victoria, where they are useful environmental indicators (Fig. 22.19). In their life cycles, ostracod form and shed shells of various sizes which have different hydrodynamic properties. As a consequence, the analysis of fossil ostracod population–age structures enables the recognition of sorting and transportation by currents. In Palaeogene and Neogene marine sequences of southeastern Australia, allochthonous (transported) specimens are usually a small component of mid-shelf ostracod assemblages, but commonly a large component of outer-shelf and bathyal assemblages (Warne, 1987, 1993; Warne & Whatley, 1994; Warne & Idris, 1995). Inner-shelf assemblages have variable transported contents, but commonly show evidence of the winnowing of small juvenile specimens by wave action.

The Palaeogene and Neogene assemblages of southern Victoria exhibit profound changes that reflect a history of global sea-level fluctuations. In particular, changes in the number of time-equivalent, depth-related ostracod biofacies can be related to eustatic sea level changes. Intervals of maximum transgression onto the Bass Strait hinterland correlate with maximum ranges of synchronous shelf habitats and associated ostracod biofacies. An expansion in the number of shelf habitats is first apparent in the Late Eocene to Early Oligocene in the Otway Basin. However, it is especially in the Late Oligocene to Middle Miocene, when deposition occurred under conditions of high sea level and maximum accommodation space, that a wide diversity of biologically productive habitats, both neritic and bathyal, is apparent. The maximum number of these habitats occurred during the latest Early Miocene to earliest Middle Miocene. Similar expansions in the range of shelf habitats are less obvious during the major transgressive phases of the Pliocene because of a reduction in accommodation space in Bass Strait as a consequence of sediment inflowing and the slowing of subsidence and/or initiation of regional uplift. However, the

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**Fig. 22.17:** Pebble Point Formation (Late Paleocene) overlain by Dilwyn Clay (Early Eocene), Pebble Point, near Princetown, Otway Coast. Photograph by W. Birch.

**Fig. 22.18:** Planktonic (a–e) and benthonic (f–h) foraminifers. (All specimens from Museum Victoria Collection; photographs by M. Warne). (a) Praeorbulina srinaca (De Stephani), P210174 (C. Mallett Collection), Gibson’s Beach, Princetown, x 66. (b) Praeorbulina glomerosa curva (Blow), P210173 (C. Mallett Collection), Gibson’s Beach, Princetown, x 66. (c) Neogloboquadrina mayeri (Cushman & Ellisor), P210172 (C. Mallett Collection), Colquhoun Bore No.11, 500 ft, x 86. (d) Globorotalia peripheronda (Banner & Blow), P210178 (C. Mallett Collection), Gibson’s Beach, Princetown (Gellibrand Formation), x 105. (e) Globorotalia crassaformis (Galloway & Wissler), P210168 (C. Mallett Collection), Mangaa No.1 Oil Bore N.Z. (Hematite Petroleum), 8530 ft, x 75. (f) Textularia sp., P210180, Nepean 1 bore, 297.5 m, near Sorrento, (Fyansford Formation, lowermost Upper Miocene), x 25. (g) Spiroroculina sp., P210181, west end of Jan Juc Beach, near Torquay, (Jan Juc Formation, uppermost Upper Oligocene), x 67. (h) Siphonia sp., P210182, west end of Jan Juc Beach, near Torquay, (Jan Juc Formation, uppermost Upper Oligocene), x 91.
Miocene–Pliocene transition marks the beginning of a period, extending to the present day, during which abundant marginal-marine and nonmarine ostracod faunas are apparent within the Cainozoic fossil record of southern Victoria. The Miocene–Pliocene boundary perhaps approximates the most profound Cainozoic ostracod faunal turnover in southeastern Australia. It is around this time that many broad elements of the modern coastal ostracod microfaunas first become conspicuous in the fossil record of southern Victoria.

The Paleogene and Neogene record of fossil Ostracoda in southern Victoria shows strong links with several major characteristics of the Cainozoic palaeobiogeography of the broader southwest Pacific Ocean (Warne in McGowran et al., 2008). The first of these is the origination of endemic Paleogene clades in shallow-marine environments. In the southwest Pacific, this is associated with an environmental shift and deep-ocean colonisation as Late Cretaceous, Gondwanan, neritic clades were displaced from shelf regions and transported into, or invaded, deep Pacific environments. The second is the invasion of deep-sea ostracods into the Bass Strait region during major and rapid marine transgressions in the Early and Middle Miocene, which were times of intense global oceanic upwelling. The third is the Neogene and Quaternary migration of the ‘modern’ faunas of the neritic, Indo-Pacific realm into neritic environments of southern Australia.

In the following discussion, a small proportion of the total number of ostracod genera present in Cainozoic strata of southeastern Australia is used to illustrate important aspects of ostracod palaeoenvironmental distribution patterns and evolutionary history. A fuller perspective can be gained from Chapman (1914c, 1926), Chapman & Crespin, (1928), McKenzie et al. (1990, 1991, 1993), Neil (1994), Warne (1987, 1990a, b) and Whately & Downing (1983).

A key to understanding the evolutionary origins of southeastern Australian Cainozoic Ostracoda is to compare them with the Late Cretaceous ostracod faunas from shallow-marine facies in the Perth and Carnarvon basins, Western Australia. In these basins, numerous ostracod genera such as Pelocythere, Premunseyella and Paramunseyella make their earliest evolutionary appearances. The occurrence of a descendant Pelocythere species in the Paleocene Pebble Point Formation of southwestern Victoria is good evidence for evolutionary links between ostracods from the two regions and indicates that descendant species of this genus maintained shallow neritic habitats into the Paleogene (Neil, 1997). However, later species that arose within this genus mostly evolved to occupy deep-marine realms such as those of the southwest Pacific Ocean and, as a consequence, are not known from Victorian late Paleogene and Neogene shallow-marine strata.

Strong taxonomic links between Western Australian Late Cretaceous faunas and southeastern Australian Paleocene faunas are also reflected by the particular pectocytherid species groups prevalent in both provinces. For instance, some Munseyella species from the Pebble Point Formation have strong morphological affinities with Late Cretaceous species of Premunseyella and Paramunseyella from the Gingin Chalk and Toolonga Calcilutite, Western Australia (Neil, 1997). The palaeobiogeographical distribution of this endemic species group of pectocytherids strongly suggests the presence of a later Cretaceous to Paleocene shallow-marine passage-way extending from southwestern Australia along the southern continental margin to southeast Australia. The ostracod migration along this route was probably largely from west to east.

Similarly, species of the genus Bradleya (Fig. 22.19e–h) first appeared in Upper Cretaceous neritic facies and this genus seems to have originated in the new seaways that developed between the rifting fragments of Gondwana. Some descendant species groups, such as those of the subgenus Quasibradleya (Fig. 22.19e–f), maintained shallow-marine niches throughout their evolutionary history, these groups being mostly endemic to the Cainozoic of Australia. Other species groups of Bradleya evolved to occupy worldwide deep-sea habitats during the Cainozoic. The locus for migration of Bradleya species into the deep sea was the southwest Pacific Ocean (Whately, 1983). Bradleya (s.l.) species are extremely common in Eocene to Quaternary strata of southeastern Australia, with both shallow- and deep-marine species groups being represented in mid-Miocene sequences of southern Victoria. This reflects the significant diversity of palaeobathymetric settings within southern Victorian sedimentary basins at this time.

Examples of the evolution of new Palaeogene clades in Australasia are Anaxythere and Vandiemencythere. Anaxythere is a trans-Tasman genus with many neritic species known from the Cainozoic of New Zealand and southeastern Australia, as well as a significant group of deep-sea species in Upper Eocene to Holocene ocean-floor sediments of the southwest Pacific Ocean. Vandiemencythere seems to have evolved in the new seaways that developed in former rift valleys between southern Australia and Antarctica and between eastern Australia and New Zealand (Whately et al., 1982).

Vandiemencythere is a distinctive and endemic trans-Tasman genus that probably evolved from Anaxythere stocks. A single neritic species of Vandiemencythere is known to range from Upper Eocene to Middle Miocene strata in New Zealand and a different species is known from mid-Miocene deep-neritic facies of the Fyansford Formation in southeastern Australia. Other species are known from Pliocene sediments of the Marion Plateau, offshore southeastern Australia and from the Recent of the Coral Sea (Ayres & Warne, 1993). Vandiemencythere is a classic example of the marine palaeobiogeographical links between neritic southern Australian and neritic New Zealand Cainozoic faunas with diverging lineages in the two regions probably arising as early as the Late Eocene.

Examples of the evolution of new mid-Cainozoic clades in southeastern Australia are the first appearances of the genera Pontocythereis and Papillatabaridina in lower Miocene, shallow-marine facies of the Fyansford Formation of the Port Phillip Basin and Sherwood Formation of the Western Port Basin (Warne, 1987, 1993). Descendant species have retained a shallow-marine habitat, as well as remained restricted to the Australian – southwest Pacific Ocean region (Warne & Whately, 1996).

Importantly, ostracod faunas from offshore southeastern Australia and from the Recent of the Coral Sea (Ayres & Warne, 1993). The co-occurrence of sporadic and rare Legitmocythere specimens with continental-shelf taxa in some deep-neritic muddy units of the Fyansford Formation attests to the mixing of oceanic water masses at this time. In offshore regions beneath Bass Strait (Kingfish 8 well, Gippsland Basin), other deep-sea Ostracoda such as Zahlythocypris make their first appearance within Miocene benthal (continental-slope) facies. In modern seas, Zahlythocypris species have been found living only on deep ocean floors (>1000–6000 m). Zahlythocypris is perhaps one of the most ancient deep-sea faunal components of modern oceanic faunas. However, it appears to have occupied shallower continental-slope niches during periods of major oceanic upwelling or oceanic water-mass turnover, as exemplified by the relatively shallow-bathyal mid-Miocene occurrences of offshore Victoria.

The relatively warm climatic conditions of the mid-Miocene are reflected in the occurrence of ostracod species such as Triebelina vadum (Warne, 1986) in late Early Miocene neritic carbonate facies (e.g. Batesford Limestone) of southern Victoria. Most modern species of this genus inhabit warm shallow-marine environments. In contrast, distinctively warm elements are absent in the Victorian late Middle and early Late Miocene ostracod assemblages, suggesting a phase of climatic cooling.

The Miocene–Pliocene transition in southern Victoria is marked by numerous synchronous speciation events in different clades and by the migration into southern Victoria of ostracod genera or species groups that were previously unknown from the local fossil record. An example of speciation during the latest Miocene is seen in the shallow-neritic genus Neobuntonia Hartmann, a well-known clade from the Cainozoic of southern Victoria. This speciation event, which is observed in the Black Rock Sandstone of the Port Phillip district, is one manifestation of the major faunal turnover of continental-shelf ostracod faunas that occurred at this time in southeastern Australia. A regional unconformity and prominent uppermost Miocene phosphatic nodule bed at the base of the Black Rock Sandstone marks the start of this faunal turnover. Some ostracod species in the nodule bed suggest a minor warming event across southeastern Australia.

A conspicuous event of this time is the first occurrence of euryhaline taxa such as Ostriocythere haagwanathi (Chapman & Crespin) in the rich
22.3 Vertebrate fossils

22.3.1 Fish fossils

Victoria has an excellent record of fossil fishes that spans over 400 million years. Apart from some gaps in the late Palaeozoic and first half of the Mesozoic era, there is a continuity through time which demonstrates some of the major steps of fish evolution.

Palaeozoic fish faunas

The oldest fish fossil from Victoria is a partial body of an enigmatic teleostome called *Yaltpis douglasii* from the Upper Silurian beds near Yea that contain the Bangananthu–Monograptus cf. uncinatus association. It has small acanthodian-like scales but lacks the characteristic fin-spines of that group (Burrow & Young, 1999), so cannot be confidently placed in any known class of vertebrates at present.

Early Devonian fishes are known from limestones outcropping near Buchan and Walkerville. At Walkerville, the oldest remains are from the late Pragian Bell Point Limestone, which has yielded a lower jaw of the lungfish *kloenynas kunna*, described by Long et al. (1994). It is the oldest member of the Dipnot known from Australia. Other remains of placoderms and acanthodians come from the same rocks but have not yet been studied in detail.

Extensive Lower Devonian (Emsian) outcrops of the Buchan Group limestones, near Buchan, have yielded many kinds of fishes which inhabited the warm carbonate platform. The fishes are three-dimensionally preserved and can be etched from the limestone with acetic acid, mostly as isolated bones and rare articulated specimens. The fauna includes scales of the agnathan thelodont *Tunia cf. T. australitennis* (Barden, 1999); placoderms such as the acanthothoracid *Murrindalaspis wallacei* and *M. bairdi*; the petalichthyid *Wijdaispis waroensis* (Long, 1984b); the arthrodirines *Buchanostegus confertihelicalatus* (Hills, 1936a; Stensiö, 1945; Young, 1979), *Tiemnasosteus maclartienis*, *Arenipiscis wellsi* and *Errolosteus cf. E. goodadiagenesis* (Long, 1984b). Acanthodians (Fig. 22.20a) are known from isolated scales (e.g. Long, 1991) and one ischnacanthid, *Rockycampanacanthus milesi* (Long, 1986a) represented by a single gnathal bone. Osteichthyans are known from jaws of the lungfish *Dipnothyrus ussuralichi* (Thompson & Campbell, 1971) and undescribed bones and teeth of onychodontid fishes have been found in the underlying Fairy Formation.

A fauna of microvertebrates, of probable earliest Devonian age, is known from the Silverband Formation in the Grampians Group of western Victoria. Scans first thought to belong to sharks (Talent & Spencer-Jones, 1963) were redescribed by Turner (1986b) as belonging to the thelodont *Tunia fusina*.

Middle–Upper Devonian fluvialite and lacustrine deposits of central and eastern Victoria have yielded many fish fossils, the first of which were recorded from the Blue Range Formation (Marysville Igneous Complex) and from eastern Gippsland by Hills (1929, 1931, 1936b). A lungfish from the Blue Range Formation was named as *Eoctenodus microsoma* by Hills (1929) but was later referred back to the European genus *Dipterus* (Hills, 1931; Long, 1987b) re-examined this material and reinstated it as an endemic genus.

The most significant site in the Devonian of Victoria is on the banks of the upper Howqua River, near Mt. Howitt, where fish have been preserved whole in all stages of growth in lacustrine banded shales. The fauna is now regarded as the late Givetian age (Young, 1993a; Long, 1999) and includes *Bothriolepis gippslandiensis*, *B. fergusoni* (Fig. 22.20c), *B. cullodenensis* (Long, 1983a; Long & Wendelin, 1986), *Austrophylopsis richtae* (now known to be synonymous with *A. youngi*, Long, 1984b, 1999), *Goonlandaspis sp.* (Long, 1991), *Culmancanthus steuani* (Long, 1983a) and *Howittacanthus lentoni* (Long, 1986b). Osteichthyans from Mount Howitt include a very primitive palaeoniscoid, *Heuropalepis rostredens* (Long, 1988) (Fig. 22.20d) and several sarcopterygians, namely the lepidacanthid lungfishes *Howittipterus domae* and *Banwicchia domunda* (Long, 1992, 1993), the most primitive and earliest known coelacanth *Gavinia syrtis* (Long, 1999), the canowindrid osteolepiform *Belawonga patrichae* (Long, 1987a) and a rhizodontid *Mandenichthys longiplicatus* (Long, 1985). In addition, there are undescribed scales of a *Glyptolepis*-like pterolepidiform and another undescribed osteolepiform with rhombic, heavily ornamented scales.
Fig. 22.20: Fossil fish. (a) Scale of the acanthodian *Nostolepis* sp., Lower Devonian Buchan Group, eastern Victoria, x 200. (b) Miocene shark’s tooth, *Iurus hastalis* Agassiz, Beaumaris Beach, Melbourne, x 1. (c) Placoderm fish *Bothriolepis fergusoni* Long, Mt Howitt, Avon River Group, Middle Devonian (Givetian), x 0.4. (d) Palaeonisoid *Howqualepis rastiodens* Long, Mt Howitt, locality as for ‘c’, x 1. (e) Primitive teleostean fish *Wadeichthys oxyops* Waldman, Lower Cretaceous Koonwarra fossil bed (Strzelecki Group), south Gippsland, x 1. Photographs provided by J. Long.
Other Middle–Late Devonian fish faunas are known from the Lewis Farm Conglomerate near Tatong (Long & Werdelin, 1986), from the South Blue Range, near Mansfield (Hills, 1936b) and from within sediments of the Wellington Volcanic Group at Freestone Creek, near Briagolong. The Freestone Creek fauna contains several species in common with Mount Howitt, although much of the material remains undescribed. Long (1989b) described a new phylolepid placoderm, *Austrophyllolepis edwini*, from the South Blue Range (probably the Kevington Creek Formation), and regarded this fauna as the oldest of the Victorian Middle–Upper Devonian succession.

Carboniferous fishes are only known from the Snowys Plains Formation just north of Mansfield. Woodward (1906a) assigned all taxa to European genera, although later revisions of the fauna found that all of the species belong in endemic taxa, except for the acanthodian *Cynacthodes murrayi*, a genus widespread throughout Gondwana. Woodward identified another two acanthodians but both could be placed in the cosmopolitan genus *Acanthodes*, although not enough material has been found to confirm this identification. The fauna is dominated by osteichthyans, which include the palaeoniscoids *Mansfieldius sweeti*, *M. gibbus* and *Novogonatodus kazantziawe* (Long, 1988), the lungfish *Delatitia breviseps* (Long & Campbell, 1985) and the rhizodontid *Barameda decisionis* (Long, 1989a; Long & Ahlberg, 1999). Until recently *Banamedea* was the only rhizodontid described from articulated cranial remains and it remains one of the most primitive members of the group (Johanson & Ahlberg, 1998). Microvertebrate remains at this locality include teeth and scales of xenacanth-like sharks, which have yet to be described.

There are no Permian fish remains known from Victoria.

**Mesozoic fish faunas**

There are no Triassic or Jurassic fish remains known from Victoria. However, Early Cretaceous fish are well preserved in the Koonwarra fish beds (Eumeralla Formation) near Leongatha, in Gippsland, and are also known from isolated remains occurring elsewhere in the Strzelecki and Otway groups.

The Apter Koonwarra fish site contains whole fishes preserved in lacustrine shales. The fauna includes rare fragments of the lungfish *Ceratodus sp.*, the late surviving palaeoniscoid *Cacolepis woodwardii*, the archaenacid holostean *Wadeichthys oxyops* (Fig. 22.20e) and an early teleost *Leptolepis koowarr* (Waldman, 1971). In addition, excavations at the site by staff from Museum Victoria and the Australian Museum in the 1980s yielded some remains of other actinopterygian fishes not previously identified in the fauna.

Isolated fish remains from the coastal exposures of southern Victoria include several lungfish. These include a partial lower jaw toothplate of *Ceratodus avus* (Woodward, 1906b), isolated scales and toothplates of *Ceratodus sp.* (A. Kemp, 1991) and toothplates of an extinct species of the Queensland lungfish *Neoceratodus nungan* (A. Kemp, 1991).

**Cainozoic fish faunas**

Cainozoic fish remains from Victoria are known only as isolated teeth and bones which occur in marine deposits in the southern half of the State. Early works by Chapman & Pritchard (1904, 1907) and Chapman & Cudmore (1924) were the only descriptions of these isolated remains until otoliths (ear stones) were later studied by Frost (1928) and Stinton (1958, 1963). In recent years the sharks’ teeth faunas have been studied by N. Kemp (1991).

The Paleocene Pebble Point Formation, near the mouth of the Geelibrand River in the Otway Ranges, has yielded a sharks’ teeth assemblage including the lamniforms *Canthias cf. C. australis* and *Otodus obliquus*. Near Princetown, *Canthias sp.*, *C. macrurus* and a hexanchid shark, *Hexanchus sp.*, have also been recorded from the Rivermook Member, which is of similar or slightly younger (Early Eocene) age. A single, possibly Eocene tooth of *Otodus obliquus* has also been collected from a bore hole, Olney No. 1, in northeastern Victoria (N. Kemp, 1991).

Fish remains, mostly represented by sharks’ teeth, occur in the uppermost Oligocene Jan Juc Marl near Torquay, the Point Addis Limestone and the Waurin Ponds Limestone near Geelong. These faunas include abundant teeth of *Canthias taenus*, *Iurus desori* and rare *I. planus, and the very large teeth of *Cantharias angustidens*. *Cantharias totusserus* also occurs at Jan Juc and in several Lower Miocene units of Victoria.

Sharks’ teeth are abundant throughout the Miocene of Victoria. Early Miocene assemblages are well known from the Batesford Limestone in the Batesford Quarry near Geelong and at Muddy Creek and Grange Burn near Hamilton. Middle Miocene teeth are not as common but occur at a few sites, the most notable being at Muddy Creek, Hamilton and in the Fyansford Formation at Balcombe Bay near Morrington. Late Miocene – Early Pliocene teeth are found at Grange Burn, Hamilton, in the Black Rock Sandstone at Beaumaris beach and in the Jemmys Point Formation at Jemmy’s Point near Barndale and nearby areas in eastern Gippsland. Most of the species occurring in the Miocene of Victoria are wide-ranging and details of individual sites and their faunas can be found in N. Kemp (1991).

In general, the commonest teeth found in Miocene deposits around Victoria are the small spindly teeth of *Canthias taenus* (the extant Grey Nurse shark), large triangular teeth of an extinct mako, *Iurus hastalis* (Fig. 22.20b) and slightly smaller *I. retroflexus*, the extinct tiger shark *Galeocerdo adansii*, the small serrated teeth of the whaler *Cantharias sp.* as well as sporadic occurrences of the largest predatory shark that ever lived, *Carcharodon megalodon*, whose teeth are up to 15 cm high. Amongst the rarest shark fossils from Victoria’s Miocene are an associated dentition of *Panatodus sp.* from Batesford and a very rare occurrence of a tooth of *Panatodus cf. benedini* from Balcombe Bay, Morrington.

The modern Great White shark, *Carcharodon carcharias*, makes its first appearance in the Early Miocene and is common by the Pliocene. The only hexanchid shark known in Victoria’s Miocene is *Notorynchus primitivus* from Batesford and Hamilton. Rounded crushing toothplates of the extinct Port Jackson shark, *Heterodontus couchii*, are also found, as are teeth of the extinct eagle ray, *Myliobatis sp.*, and giant chimaerid toothplates of *Edaphodon sweeti*, *E. mitibus* and *Ichthyodus cf. I. doliei*. Details of the many other shark species known from the Miocene of Victoria can be found in N. Kemp’s (1991) comprehensive review of Australian fossil chondrichthyans.

Early Pliocene sharks’ teeth are known from the uppermost sediments at Grange Burn (Grange Burn Formation) near Hamilton. The fauna includes similar species to those found in the Miocene, but *Iurus hastalis*, *Canthias taenus*, *Galeocerdo adansii* and *Carcharodon carcharias* are particularly abundant. A very rare occurrence of a single serrated *Iurus* tooth assigned to *I. echi* is recorded from Grange Burn, and the extant hexanchid *Notorynchus cepedianus* occurs in the Lower Pliocene Jemmy’s Point Formation in the Gippsland Basin, also based on just one tooth.

Actinopterygians are known throughout the Palaeogene and Neogene of Victoria as isolated bones. These are difficult to identify apart from their otoliths, so very little taxonomic work has been done on the material at hand. Chapman & Pritchard (1907) identified a toothplate of an extinct wrasse *Nannomylus depressus*, as well as jaws of the tetradontiform (toadfish) *Diodon formosus* from the Upper Miocene Black Rock Sandstone at Beaumaris. Chapman & Cudmore (1924) described other isolated Miocene phanerogal tooth mills from labrids as the new species *Ophylognathus manni* and *Labrodon bartoniensis*.

The otoliths of teleostean fishes have been described from several sites in the Oligocene–Miocene of Victoria by Frost (1928) and Stinton (1958, 1963). These reveal a fish fauna similar, at the generic level, to that inhabiting southern Australian waters today, although most of the species are extinct. They include whiting (*Sillago*), flathead (*Platypocephalus*), bonnier (*Boumeresia*), red snapper (*Diplhysichthys*), ox-eye herring (*Megalepis*), hake (*Merluccius*) and marine eel (*Unovater, Astromontr, Munadius*), amongst many others. Unusual occurrences are the cod (*Gadus*), which now lives only in cold waters of the Northern Hemisphere, and the whiptail *Coelorhynchus*, which today inhabits very deep waters (250–900 metres).
22.3.2 Tetrapod fossils

The fossil tetrapod record of Victoria (Fig. 22.21) may be conveniently broken down into five divisions. These are Devonian amphibian footprints, late Early Cretaceous, Neogene, and Pleistocene terrestrial vertebrates, and Cainozoic marine vertebrates. The temporal gaps reflect the spotty nature of this record. What is not evident in this listing is how sparse most of the records are. Only the Pleistocene terrestrial vertebrate record can be regarded as anything like reasonably abundant and, even there, the record is based entirely on isolated bones and teeth rather than articulated skeletons. The greatest potential for significantly expanding knowledge of Victorian fossil tetrapods is to be found in the study of Cainozoic marine vertebrates. Vickers-Rich et al. (1991) is the most current source of information about Victorian fossil tetrapods, and it contains an extensive bibliography.

Devonian amphibian footprints

Warren & Wakefield (1972) described unquestioned Late Devonian (Frasnian) amphibian trackways from the Combyningbar Formation of far eastern Victoria. At that time, this was the oldest known record of tetrapods anywhere. Subsequently, Warren et al. (1986) recognised what they considered to be Early Devonian tetrapod trackways from the Grampians Group at Glenisla in western Victoria. If truly footprints, they are the oldest evidence of tetrapods on Earth. However, Clack (1997) regarded it highly questionable that these tracks are those of tetrapods.

Cretaceous terrestrial vertebrates.

The shore platforms forming the southern flanks of the Strzelecki and Otway ranges have yielded, respectively, early Aptian and early Albian assemblages of terrestrial vertebrates (Fig. 22.22). The specimens occur in the Strzelecki Group and the Eumeralla Formation of the Otway Group, respectively. The most refined dating of these units has been based on palynology corroborated by means of fission track dates (Constantine et al., 1998; Wagstaff & McEwen-Mason, 1989).

There are a number of clear biases in the fossil vertebrate assemblages from the Wonthaggi and Eumeralla Formations. In the first place, there are no large bones preserved intact. What evidence there is indicating the former presence of large dinosaurs the size of Allosaurus, for example, is based on the existence of a few small fragments of individual bones. These fragments are the smallest possible that can be identified to indicate the presence of the largest elements in the fauna. For example, specimens with a maximum dimension of 20 cm suggest the former presence of dinosaurs that stood five metres high.

A second bias is in the elements preserved. Teeth and femora of hypsilophodontids are overwhelmingly the most abundant fossils of all the dinosaurs found (Fig. 22.23b). This may or may not reflect true numerical dominance of hypsilophodontids in the former living assemblage. Certainly, since of hypsilophodontid skeletal elements alone, teeth and femora are highly favoured, caution is warranted before accepting that the hypsilophodontids were the most abundant vertebrates.

Except in the case of Leaellynasaura amicagraphica, the hypsilophodontids are represented solely by isolated bones and tooth rows. This means that it is difficult to assess how many different taxa of this family were present. Four have been named: L. amicagraphica, Fulgurotherium australis (also known from Lightning Ridge, New South Wales), Atlascopcosaurus loadsi and Qantassaurus interpedius but there are possibly as many as three more. Where they are known elsewhere, hypsilophodontids are usually rare. For example, there are only two genera of hypsilophodontids amongst about one hundred genera named from the Upper Jurassic Morrison Formation of the western USA. That hypsilophodontids constitute half the approximately twelve dinosaur taxa now known from Victoria may indicate that they were favoured in the polar latitudes where Victoria was located in the Early Cretaceous. Histological evidence (Chinsamy et al., 1998; Constantine et al., 1998) suggests that the hypsilophodontids were metabolically active year-round.

That is concordant with enlarged optic lobes on the brains of hypsilophodontids, suggesting they had enhanced visual ability, an adaptation that would have been useful for seeing under the low-light conditions of a polar winter (Chinsamy et al., 1998; Rich & Rich, 1989). Among dinosaurs, only hypsilophodontids and some closely related groups show histological evidence for continuous metabolic activity. That, coupled with enhanced visual ability, which is not seen in hypsilophodontids from lower palaeolatitudes, may well have been the key to their success in a polar environment.

The estimates of the climatic conditions that prevailed during the late Early Cretaceous in polar Victoria range from cool-temperate, based on...
assessments of the palaeoflora (Parrish et al., 1991), to frigid based on geochemical (Gregory et al., 1989) and sedimentological analysis (Constantine et al., 1998). Constantine et al. (1998) presented evidence from the Strzelecki Group of seasonally frozen ground just three metres stratigraphically below one of the principal fossil vertebrate sites (Flat Rock).

Many of the Late Early Cretaceous tetrapods of Victoria are either amongst the earliest or latest records of major groups. Early records include the dinosaurs ornithomimosaurs and protoceratopsians (Rich & Vickers-Rich, 1994) and oviraptorosaurs (Currie et al., 1996), as well as (arguably) placental mammals (Rich et al., 1997, 1999). These records of early occurrences could reflect a Gondwanan, if not specifically Australian, origin of these groups, which are far better known in the Upper Cretaceous of the Northern Hemisphere. However, it must be borne in mind that the knowledge of Aptian and Albian tetrapods worldwide is much richer than that for those with the Upper Cretaceous; Victoria has a Cretaceous record in that sparsely sampled interval.

Latest occurrences include the allosaurid dinosaurs (Molnar et al., 1981, 1985; Welles, 1983) and temnospondyl amphibians (Warren et al., 1997). In the case of the temnospondyl, it has been argued that the polar location of Victoria was a favourable refugium because the frigid temperatures in the Aptian prevented the morphologically convergent crocodilians from occupying the area. Crocodilians are known in the Albian of Victoria where there is no trace of the temnospondyls (Warren et al., 1997).

Rich et al. (2002) summarised the polar dinosaur assemblages of the world and assessed the Early Cretaceous tetrapods of Victoria in this context.

Neogene terrestrial vertebrates

Eight Victorian sites have yielded Neogene terrestrial vertebrates. Detailed summaries of each site listing the stratigraphic unit, age and the basis for that age assignment, together with a faunal list, are given in Rich et al. (1991).

By far the most prolific of these sites is the Early Pliocene Hamilton local fauna. Although composed almost exclusively of small mammals, the assemblage also contains a few of the larger diprotodontoids. Oddly, although more than 1000 small teeth, as well as about thirty jaws of small mammals are known, no other class of vertebrates is represented at this site by even a single bone. With the exception of Burramys, the Mountain Pygmy Possum, which lives today in the Victorian Alps, the total assemblage from the Hamilton local fauna suggests adaptation to a moist forest habitat, as in northern Australia today (Turnbull & Lundelius, 1970).

The Hamilton local fauna was collected from an unnamed lithic unit that was interpreted as a fossil soil by Gill (1957b). It overlies the Lower Pliocene Grange Burn Formation (Ludbrook, 1973) and underlies a basalt aged 4.46±0.1 Ma (Rich et al., 1991). As such, it is one of the most securely dated of all Australian Neogene land-mammal localities.

Another well-dated Victorian Neogene terrestrial vertebrate site is at the base of the Black Rock Sandstone at Beaumaris. Although fewer than a dozen fossils of land mammals have been recovered, they are quite significant for stratigraphic purposes because they have been assigned to three genera of diprotodontoids: Zygomaturus (Fig. 22.24b), Kolopsis and Palorchestes. Based on its content of marine macroinvertebrates (Singleton, 1941, amongst others), the Black Rock Sandstone is considered to be latest Miocene to Early Pliocene (Abele et al., 1976).

The Hamilton and Beaumaris local faunas are highly significant in biostratigraphic terms. As their ages in the Lyellian framework are well established, they are among the few Neogene assemblages of Australian land mammals that can be used as a basis for international correlation. While there is far more known about the Neogene land mammals of northern South Australia, the Northern Territory and northwestern Queensland, their correlation is dependent for the most part on the land-mammal assemblages themselves. This is done primarily by assessment of their overall ‘stage-of-evolution’, rather than superposition or correlation by other means. The exceptions are those central Australian terrestrial vertebrate assemblages that have mammals, particularly diprotodontoids, similar to those at Beaumaris and Hamilton (Rich et al., 1991).
Pleistocene terrestrial vertebrates

The Pleistocene terrestrial vertebrate sites of Victoria can be conveniently divided into caves and open sites. While numerous cave sites occur in the Glenelg and Buchan regions, there are also other occurrences, primarily south of the Great Dividing Range, between these two districts. Those in the Buchan region have formed in recrystallised Devonian limestones, whereas those in the Glenelg district occur in more friable upper Cainozoic calcarenites. Although most of the open sites also occur south of the Great Dividing Range, there are several sites to the north, particularly along the Murray River. Baird et al. (1991) and Horton (1984) list most Victorian Pleistocene terrestrial vertebrate sites.

One of the principal problems with the scientific assessment of Pleistocene terrestrial vertebrate sites is determining their ages (Miller et al., 1999). Thus far, it has not been possible to subdivide the Pleistocene of Australia, much less that of Victoria, on the basis of its land-mammal assemblages. This is in contrast to other continents, such as North America, where a three-fold division of the Late Pliocene–Pleistocene is well established. In the North American case, this was facilitated by the entry into the continent during that time of large land mammals from Asia. It is not intrinsically impossible for a similar set of terrestrial mammalian migrants to eventually be recognised in Australia. If this does eventuate, the group most likely to be useful in this way will almost certainly be rodents.

The only subdivision within the Victorian Pleistocene that has been possible thus far is based on $^{14}$C ages. The practical effect of this is to divide the Pleistocene sites into two categories, those within the range of $^{14}$C and those beyond it. About 98% of the Pleistocene lies beyond the limit of the radiocarbon method. It is quite conceivable that the great majority of the known Victorian Pleistocene fossil vertebrate sites beyond the range of $^{14}$C have ages that fall in the last 10% of that epoch.

One Victorian Pleistocene site beyond the range of $^{14}$C, the Portland local fauna, is constrained to the interval 0.73–1.66 Ma by a combination of
palaeomagnetic and biostratigraphic evidence (MacFadden et al., 1987). Some elements of this fauna stand apart from other Pleistocene assemblages in a striking way. The large diprotodontid *Zygometrum* is quite small, resembling not contemporaneous Pleistocene examples of this genus in size, e.g. *Zygometrunus* trilobus, but the Mio-Pliocene *Zygometrum* gilli from Beaumaris. On the other hand, there is an unusually large pseudocheirid in the assemblage, *Pseudokala cethysantamaria* (Archer et al., 1997). This is reminiscent of island faunas. Mammals on islands are often characterised by adult sizes quite atypical of mainland relatives. For example, giant hedgehogs and miniature elephants of late Palaeozoic age occur on various islands of the Mediterranean (Freudenthal, 1971; Shoshani & Tasey, 1996).

If there is a central problem in the study of Victorian Pleistocene terrestrial vertebrates and those of Australia generally, it is determining the mechanism which brought about the extinction of many large mammals such as *Diprotodon* (Fig. 22.24a) and *Sthenurus*, as well as the giant flightless bird *Genyornis*, all members of the Megafauna. Was it due to climatic change or brought about by humans, either directly through their hunting practices or indirectly by their alteration of the environment? The timing of that event, or events if the extinctions were not simultaneous, is critical to its resolution. Because a reliable framework of dated sites still remains a desideratum rather than a fact, the temporal information relevant to the resolution of this controversy has yet to be acquired (Baynes, 1995).

**Cainozoic marine tetrapods**

About half the Victorian coastline is formed of Cainozoic marine deposits. However, only a few marine fossil tetrapods, mainly whales and penguins, have been described from these coastal units (Fig. 22.23a). There are also a few inland sites, such as Warr Pond and Batesford Quarry (both in Batesford Limestone) near Geelong (Fordyce, 1991). This scarcity is no doubt in large part due to the fact that these fossils have never been extensively studied. However, the sea off the Victorian coast may have been a major centre of cetacean evolution once the Circum-Antarctic Current was established during the Oligocene (Fordyce, 1977). That the marine Cainozoic exposures along the Victorian coast may have a rich record of this key phase in cetacean evolution suggests that pursuit of a long-term field program and analysis of fossils from these rocks has great research potential. Rare fossils of seals and an albatross are also known from Victorian Cainozoic strata.

**22.4 Fossil plants**

### 22.4.1 Plant macrofossils

The plant associations that make up such an integral part of our environment had their counterparts in past ages and the rocks of Victoria provide a wonderful record of the development of this vegetation (Fig. 22.25). A wide spectrum of sedimentary rocks contains fossil plants, providing a readily discernible progression from the algal assemblages in the oldest marine beds to conifer and angiosperm giants of the modern forests.

The preservation of the whole plant organism is the exception rather than the rule. As a result, different binomial names are commonly bestowed on different portions of the same plant (leaves, wood, spore–pollen, fruiting bodies), because much of the original plant is unknown. Foliage, especially the leaf, is the most common visibly fossilised taxa distinguished on leaf morphology predominate. Heavier vegetative elements, such as wood, may be preserved *in situ* or transported before being coalified, silicified or otherwise preserved. These are also prominent in the fossil record.

Palaeobotany differs from animal palaeontology in another major respect. Microscopic reproductive units, such as spores of cryptogams5 and the pollen grains of advanced groups like the gymnosperms and angiosperms, are often widely dispersed in an endeavour to maximize reproduction, and are even more widely dispersed by the processes of sedimentation. The waxy outer surface of their cuticle (exine) facilitates preservation and such remains are a prime tool for the biostratigraphic subdivision of the rocks in which they are preserved. They are of such importance that their study is included as a discipline of its own, called palynology (palyn = pollen), dealt with in section 22.4.2.

**Early Palaeozoic**

From early in the Cambrian period to the middle of the Devonian, the marine environment predominated in eastern Australia. During the Cambrian there was a great explosion of life in the sea, but the only fossils with probable plant affinity of this age recorded from Victoria are thalloid remains attributable to algae (Douglas, 1981). Throughout the Ordovician and the Early Silurian, the land surface, not yet colonised by erect plants, would have presented expanses of sediment and rock interrupted by bodies of water and streams. The mantle of green was yet to appear. The occurrence of the vascular land plant *Baugwanathia longifolia* (Lang & Cookson, 1935) in Upper Silurian (Ludlow) beds near Yea, central Victoria (Garratt, 1978; Garratt & Rickards, 1984), provides dramatic evidence of the earliest appearance of plants visibly modifying the landscape (see also Chapter 26).

There has been no monograph on the 'Baragwanathia Flora' but the early descriptions by Cookson (1935) and Lang & Cookson (1930, 1935) have been supplemented by new species described by Douglas (1981, 1983), Tims & Chambers (1984) and Douglas & Jell (1985). Several other new forms are currently under investigation. In an unpublished work by Tims (1980) there are descriptions of eight new fossils adding substantially to the known diversity of the 'Baragwanathia Flora'. Many of the taxa are affiliated with long-extinct families, such as the *Xlyniaceae*, Zosterophyllaceae and Trimerophytaceae. Tables 22.4 and 22.5 give an idea of the size of plant remains attributed to algae (Douglas, 1981). Throughout the Ordovician and Silurian, extensive growths of thalloid marine plants are common in Victoria (Garratt, 1978). However, unfortunately for the student of early Palaeozoic terrestrial sedimentation, the Baragwanathia Flora is not very rich in terrestrial plants and presents a rather poor record of terrestrial vegetation.

**Late Palaeozoic**

From Middle Devonian time, after the Tabberabberan Orogeny, sedimentation was principally in large continental basins. However, in several localities (Table 22.6) fragmentary specimens attest to the introduction of other groups, for example the Filicales (ferns) and perhaps the Sphenopsida, a group no longer endemic to Australia but known in the northern hemisphere as ‘horsetails’.

Terrestrial sedimentation continued from the Late Devonian into the Carboniferous when a few better preserved specimens show the continued development of the *Lycopsida* (as *Lepidodendron*; Douglas, 1983). These are comparable to species dominant in the great Northern Hemisphere forests of the time. Extensive glaciation, which affected Gondwana in the Late Carboniferous – Early Permian, seems to have devastated the Devonian and Carboniferous plant assemblages, which were replaced by the readily distinguishable *Glossopteris* flora6.

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4 Cuticle is a chemically complex waxy layer or layers that exist as an external cover over photosynthesising parts of the plant, notably the leaf; it is extremely resistant to decay, and has specific anatomical features.

5 An old-fashioned, but useful term embracing primitive land plant groups such as ferns, mosses and liverworts.

6 *Glossopteris* is an easily recognisable broad-leaf genus of the late Palaeozoic found principally in the southern or Gondwanaland continents.
Well-preserved *Glossopteris* assemblages are prominent in the Permian coal measures of New South Wales and southern Queensland, but in Victoria are found in only a few isolated localities. Mortons Quarry (Bacchus Marsh Formation) near Bacchus Marsh is the type locality of *Gangamopteris obliqua*, *G. angustifolia* and *G. spatulata* (McCoy, 1875), and *G. douglasii* (Rigby & Chandra, 1990). Although the assemblage from this locality is represented in museum collections by only a few score of highly weathered leaf impressions in massive sandstone, it provides an invaluable link between Palaeozoic and Cretaceous floras.

**Triassic**

Occurrences of Triassic sediments are confined to a siltstone remnant in an adit near Yandout and a not-much-larger exposure of sandstone with conglomerate lenses near Bacchus Marsh. The latter has been designated the Council Trench Formation and occurs in a down-faulted block overlying the Permian Bacchus Marsh Formation at Bald Hill. A noteworthy aspect of plant fragments from the Yandout locality is their preservation with cuticular anatomy discernible under the microscope after treatment. These are the oldest Victorian fossils whose cuticle has been used to facilitate their determination, an approach that becomes vital in the examination of the plants of younger deposits. The age of the Council Trench Formation is based on highly weathered and fragmentary leaf and pinnule remains referable to Bennettitales, Sphenopsida, Filicales and Ginkgoales of Triassic aspect.

**Early Cretaceous**

There are no outcropping sediments regarded as Jurassic in age in Victoria, but a magnificent record of plant life throughout the Cretaceous is preserved in the Otway and Gippsland basins.

Knowledge of the Early Cretaceous floras is facilitated by a multitude of outcrop localities in the Otway and Strzelecki ranges and the Casterton area. In addition, bore core, particularly from the deep bores in the Otway Basin, has given access to a treasure-trove of dispersed cuticle. A plethora of plant remains has facilitated the biostratigraphical subdivision of a sequence regarded as difficult to subdivide lithostratigraphically.

The oldest (Table 22.7) or ‘Zone A’ assemblage (Douglas, 1969, 1986), known only from bore core obtained at about 2 400 m in the Planet Casterton Bore 1, consists essentially of several members of the Bennettitales, an order of cycad-like plants prominent in many Mesozoic assemblages, and nondescript Filicales.

The oldest outcrop, or ‘Zone B’ assemblage, is best observed in basin-margin deposits near Tyers in Gippsland. Here in the Boola Boola assemblage (Fig. 22.25c), the Bennettitales are again a dominant element, but there are also plentiful ‘Pteridosperm’ Coniferales and Filicales with minor cryptogams, Ginkgoales and Sphenopsida. It is possible that this assemblage represents, in part, plants derived from the uplands surrounding the enormous land-locked basin formed as an initial episode in the separation of Australia and Antarctica.

The ‘Zone C’ assemblage occurs over much of the Strzelecki and eastern Otway ranges. It is identified by an absence of Bennettitales and the prevalence of a new conifer suite and *Ginkgo australis*, along with numerous ferns. This record conveys a picture of a landscape dominated by conifers and *Ginkgo*.

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7 Up to the middle 1950s the Lower Cretaceous deposits of the Otway and Strzelecki groups were identified as Lower Jurassic largely because of a superficial resemblance of some of the plant fossils to taxa present in the Jurassic flora of Yorkshire, England.

8 Pteridosperm literally means ‘seed fern’, but the term has been bestowed on a great many completely unrelated taxa to which more precise nomenclature cannot be comfortably allocated.
The classic Koonwarra fish bed locality has been included in ‘Zone C’ (Douglas, 1969). This locality provides a splendid overview of the biota of 110 million years ago with fish, invertebrates (including insects) and birds (as feathers) fossilised in finely laminated weathered shales. Dinman & Chambers (1986) monographed the accompanying plant remains which, although principally preserved as impressions (and therefore lacking the anatomical detail to facilitate identification), are an important element of this great fossil locality. Koonwarra has provided much evidence for palaeoenvironment and palaeoclimate speculation. Waldman (1971) suggested that fish kills occurred after seasonal freezing and death was the result of anoxia. Douglas & Williams (1982) concluded that the laminae of mudstone, siltstone and fine sandstone lack the regularity of true varves, and that the strata suggest episodic fluctuations in fluvial discharge rather than marked seasonal changes of temperature.

‘Zone D’, sampled in western Otway Ranges outcrops, the Glenelg River cliffs south of Casterton and Port Campbell Embayment bore cores, displays a particularly marked floral contrast, reflecting the onset of marine inundation of much of the lowlands. The fern Ptilophyllum dentata (Cantrill & Webb, 1987) is a key species here and is often found fossilised en masse or with araucarian and podocarp conifers, liverworts and other ferns.

The very thick Lower Cretaceous section provides an excellent record of plant development over some 40 million years. The plants represent vegetation from a great variety of habitats, from constantly damp fern glades of deep forest gullies to sparsely covered barren uplands. These plant associations and associated fauna provided an impetus for controversy when palaeomagnetic calculations for the Albain Stage (‘Zone D’) (Schmidt & Embleton, 1981; Veevers, 1981) placed the depositional basins in subpolar and even polar latitudes. Such a site implies winters several months long with the sun beneath the horizon and raises many questions about those ancient ‘forests of the night’. The ability of plants, particularly trees, to photosynthesize, and the effect on the life cycles of any number of biota, have been the subject of investigation by Read & Francis (1992).

Most attention (e.g. in section 22.3.2) has been placed on the dinosaurs of those postulated forests and their environment under such a regime. Douglas & Williams (1982) postulated a reduced obliquity of the ecliptic as a mitigating influence facilitating the existence of biota functioning under milder, high-latitude conditions than the present day. Others (e.g. Axelrod, 1984) advocated the possibility of forest growth and development at high polar latitudes without recourse to such drastic change. It has also been pointed out that small discrepancies in the palaeomagnetic determinations could mean that the assemblages grew in more northerly palaeolatitudes, more consistent with our current experience of the forest environment.

Several Early Cretaceous assemblages from Victoria are important in elucidating the history of today’s dominant plant group, the angiosperms, or flowering plants. An isolated leaf or two high in the sequence had been noted by Medwell (1954), and angiosperm–like seeds and leaves attributed to aquatic dicotyledons described by Douglas (1963, 1965), added to a steadily increasing number of mid–Cretaceous discoveries from around the world. However, the description of “diminutive…leaves…bearing pistillate organs” by Taylor & Hickey (1990) attracted worldwide attention to the world’s oldest flower.

**Late Cretaceous**

Upper Cretaceous rocks do not outcrop, so our knowledge is restricted to bore core provided by extensive drilling in the Otway Basin. Some drill core contains hand specimens of plants; more common are bands of sediment packed with cuticular debris, which facilitates diagnosis, and plant microfossils (see section 22.4.2). For example, in the Port Campbell Bore 1 at 1740 m, the assemblage (known as the Waarre Flora because of its occurrence in the Waarre Formation) contains the youngest species of the primitive conifers known as the Ginkgoales yet documented from mainland Australia. Several other conifers also no longer appear in the fossil record, but the change in regime is perhaps best reflected by an influx of angiosperms, which began to make their mark on the landscape, although the conifers still dominated the skyline.

### Table 22.4: The Baragwanathia Flora — Silurian (Ludlow) assemblage; major localities in Melbourne Zone. Taxa with no accreditation are J. Douglas identifications. Location details for sites listed are as in Douglas (1983) and Holmes (1988).

<table>
<thead>
<tr>
<th>NAME</th>
<th>19- Frenchmans</th>
<th>Booda</th>
<th>Spur</th>
<th>Boola</th>
<th>Tortons</th>
<th>Coles</th>
<th>Miles</th>
<th>Chin</th>
<th>Melbourne</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Chin</td>
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<tr>
<td>B rangiana elongata Lang &amp; Cookein, 1935</td>
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<tr>
<td>B. sp 1 (described in Tims, 1980)</td>
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<td>B. sp (described in Tims, 1980)</td>
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<tr>
<td>Zosterophyllum sp 1 (described in Tims, 1980)</td>
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<td>Zosterophyllum sp 2 (described in Tims, 1980)</td>
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<tr>
<td>Zosterophyllum sp 3 (described in Tims, 1980)</td>
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<td>Zosterophyllum sp 4</td>
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<tr>
<td>Selaginella arenacea Times &amp; Chambers, 1984</td>
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<tr>
<td>Selaginella sp 1 (described in Tims, 1980)</td>
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<tr>
<td>Selaginella sp 2 (described in Tims, 1980)</td>
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<tr>
<td>Baragwanathia longifolia Lang &amp; Cookson, 1935</td>
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### Table 22.5: The Baragwanathia Flora — Devonian (Pragian) assemblage; major localities in Melbourne Zone, including 19-mile Quarry-type locality. A full species list is presented, but site information restricted to major, currently accessible localities. Taxa with no accreditation are J. Douglas identifications. Location details for sites listed are as in Douglas (1983) and Holmes (1988).

<table>
<thead>
<tr>
<th>Locality</th>
<th>Pelliophyta</th>
<th>Lycopoda</th>
<th>Psilophyta</th>
<th>Sphenophyta</th>
<th>Cordaitales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bindaree</td>
<td><em>Unidentified sp.</em></td>
<td><em>Zygozeps sp.</em></td>
<td>*</td>
<td>*</td>
<td><em>Unidentified sp.</em></td>
</tr>
<tr>
<td>Mansfield</td>
<td><em>Zelleria bushi</em></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td><em>Unidentified sp.</em></td>
</tr>
<tr>
<td>Arno River</td>
<td><em>Zelleria bushi</em></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td><em>Unidentified sp.</em></td>
</tr>
<tr>
<td>Freestyle Creek</td>
<td><em>Teossiales</em></td>
<td><em>Zelleria bushi</em></td>
<td><em>Unidentified sp.</em></td>
<td>*</td>
<td><em>Cordaitales</em></td>
</tr>
<tr>
<td>Ignassa Creek</td>
<td>*</td>
<td><em>Arborespinulina bouchetii</em></td>
<td><em>Sphenophyta</em></td>
<td>*</td>
<td><em>Cordaitales</em></td>
</tr>
<tr>
<td>Talbrumbiara</td>
<td>*</td>
<td><em>Arborespinulina bouchetii</em></td>
<td><em>Sphenophyta</em></td>
<td>*</td>
<td><em>Cordaitales</em></td>
</tr>
<tr>
<td>Combabah</td>
<td><em>Zelleria bushi</em></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td><em>Unidentified sp.</em></td>
</tr>
<tr>
<td>Genoa River</td>
<td><em>Baragwanathia</em></td>
<td>*</td>
<td>*</td>
<td>*</td>
<td><em>Unidentified sp.</em></td>
</tr>
</tbody>
</table>

### Table 22.6: Late Devonian or Early Carboniferous plant fossil localities in Victoria.
Little is known of the vegetation of the latter part of the Late Cretaceous, although the Paratte Flora from the cuticle-rich Belfast Mudstone Member of the Paratte Formation has been placed in the Senonian Stage (Dettmann & Douglas, 1976).

**Palaeogene**

The plant macrofossil record provides no data on the extinctions at the Cretaceous–Tertiary boundary, and a search through the pertinent section of the Geological Survey of Victoria core holdings in 1992 (J. G. Douglas, unpublished data) revealed no evidence for an iridium anomaly or any other discernible mineral layer. However, Partridge (1999a) has inferred the approximate position of this boundary from major changes in spore–pollen assemblages in oil-well sections of the Gippsland Basin. Despite extensive outcrops of probably Palaeogene fluvialite beds (Pebble Point Formation) on the western flanks of the Otway Ranges and a thick subsurface section in the Latrobe Group in the Gippsland Basin, no plant macrofossils have been recorded from undisputed Palaeocene sediments.

The oldest Palaeogene macrofossil plant remains recorded appear to be of Early Eocene age (Partridge, 1998b) in fluvial siltstone underlying basalt at the Brandy Creek mine, Hotham Heights. Impressions and compressions of leaves attributed to the Lauraceae, Proteaceae and Elaeocarpaceae are abundant with well-preserved dispersed cuticle facilitating determination. Conifers are represented as *Agathis* and *Dacrycarpus* and ferns are also present (Greenwood et al., 2000).

Brown coal deposits in the Demons Bluff Formation west of Melbourne (Wensleydale, Benwerrin and those currently exploited at Anglesea) provide an extensive record of the Eocene vegetation. Angiosperm leaves in “exquisite preservation” (Christophel, 1993) from the overburden of the Alcoa brown coal mine at Anglesea, represent a subtropical lowland riparian vegetation (Fig. 22.25d). Over 50 leaf taxa have been recorded from one of several clay lenses postulated as having been deposited in a meandering stream environment (Christophel et al., 1987). Families prominent include Proteaceae (Mangraevinae), Myrtaceae (but not *Eucalyptus*), Ebenaceae, Casuarinaceae and Lauraceae. In addition there are the gymnosperms *Dacrycarpus, Decussocarpus*, *Falcatifolium*, *Podocarpaceae, and Pseudotsuga* of the family Podocarpaceae and *Perotoma* and *Bouienia* of the Zamiaceae (cycads).

Although *Nothofagus* (Fagaceae) pollen is so prevalent as to suggest landscape dominance, its leaves have not been recognised here and are rare at other Victorian Palaeogene localities. This suggests that the genus may not have formed such an important element of the vegetation as previously thought.

Leisman (1986) described a silicified log of *Cryptocarya* sp. (Lauraceae) several metres long and a metre in diameter. It was found in gravel under an Eocene basalt flow at Jungle Creek near Buchan.

The best-documented Oligocene assemblage is from under basalt in a quarry at Berwick (Deane, 1902; Pole et al., 1993). The assemblage contains the oldest authenticated record of *Eucalyptus* leaves in Victoria (*E. hitomi* Deane), together with one of the rare records of *Nothofagus* (*N. maidenti* Deane) fossilised in leaf form. In addition to a new species of the conifer *Agathis*, undetermined leaves of the Lauraceae, Casuarinaceae, Cunoniaceae and Proteaceae were also recorded. This assemblage indicates that the rainforests of the time were in the process of being replaced by sclerophyllous plants.

The Calivil Formation in the ‘deep leads’ contains plant fossils commonly in the form of cuticular leaves that survived stream abrasion. Mueller (1874, 1883) first described these fossils from the central Victorian goldfields in classic studies that have been updated by Rozefelds & Christophel (1996) (Fig. 22.26). Several of these assemblages have been dated as Oligocene. The temporal ranges of Victorian Palaeogene macrofossil plant localities are summarised in Table 22.8.

**Neogene**

The Middle Eocene to Middle Miocene Latrobe Group brown coal measures are formed from immense deposits of plant remains, with the thickest seams being 100 metres or more. However, many of the fossil plants described, with the notable exception of coalified wood (Patton, 1958), have been obtained from the mainly Neogene overburden beds in the huge Yallourn, Morwell and Loy Yang opencuts.


The Maddingley Coal Seam (Werribee Formation) in a quarry at Bacchus Marsh contains myrtaceous leaves (but not *Eucalyptus*), *Elaeocarpus* fruits and conifer shoots, and many other undescribed forms.

The Sentinel Rock Clay, near the mouth of the Aire River, is probably Neogene and contains leaf remains that include *Aana* (Cookson, 1954a).

Among the youngest Neogene plant remains are leaves, including *Eucalyptus*, in dark, well-bedded shale in the Haunted Hills Formation overburden in the Morwell open cut. They are probably Pliocene in age (Greenwood et al., 2000). These authors also list over sixty plant-fossil localities, and provide the most up-to-date assessment of the Victorian Palaeogene and Neogene macrofloras. Temporal ranges of Victorian Neogene macrofossil plant localities are summarised in Table 22.8.
Quaternary

Douglas (1983) reported logs of *Eucalyptus, Casuarina* and *Melaleuca* that had been found in Coode Island Silt during bridge construction at King Street, Melbourne. *Eucalyptus canadensis* is listed from Lake Hindmarsh in the Mallee, and calcareous root and stem casts are common in Pleistocene coastal dunes.

The largest assemblage of Quaternary plants, however, seems to be leaf impressions and fruit compressions from ash and tuff beds on the shore of Lake Colac. These are regarded as Early to middle Pleistocene by Tickell et al. (1991), but require further study.

Summary

The brief outline above of the plant fossil record in Victoria provides food for thought and a plethora of research opportunity. Elucidation of the history of the southeastern Australian monocotyledons (grasses, etc.), of which we know virtually nothing, will necessitate a great deal more collection and investigation of fossil material. Extending and improving the scanty records of *Acacia* and *Eucalyptus* ancestors will provide a new dimension to knowledge of these genera that are so dominant in our present-day assemblages. Use of fossil plants as indicators of past climates will enhance our knowledge of climate change and its potential impacts in the future.

22.4.2 Plant microfossils

Plant microfossils (Fig. 22.27) have played a significant role in the dating and correlation of stratigraphic units of Victoria, particularly those of Mesozoic and Cainozoic age. They have also contributed to the development of the modern Australian flora. Notable among the plant microfossils are acid-resistant, organic-walled palynomorphs that include pollen of flowering plants and gymnosperms, spores (iso-, micro- and megaspores) of free-sporing land plants, and cysts of marine and freshwater phytoplankton. Amongst the phytoplankton are dinoflagellates (Dinophyta), acritarchs (uncelled protists of uncertain origin) and microscopic colonial algae (e.g. *Amoeba*, *Chlorophyta*, *Bryophyta*, *Pteridophyta*). Other acid-resistant microfossils found in sediments include fragments of leaf cuticles and woods and fruiting bodies, spores and hyphae of fungi. Plant groups represented by calcareous or siliceous microfossils, which require different methods of recovery from those used to extract palynomorphs, have been less studied, and consequently have a rather sketchy record. Most studied and best known are calcareous nannofossils (coccolithophorids and discoasters of the Chrysothyra), which make important contributions to the dating and correlation in Cainozoic sequences in Victoria (e.g. Rade, 1977; Siesser, 1979; Waythorn, 1989; Shafik, 1983, 1990, 1996).

Palaeozoic – early Mesozoic

Palynomorphs first recorded from Victorian sediments are also the oldest. Lang & Cookson (1938) figured and briefly commented on spores isolated from sporomorphs of the Silurian–Devonian lycocarpus *Baccharis lingulata*. Lang & Cookson (see section 20.3). Few palynomorphs have been recorded from younger Palaeozoic sediments of the Tasman Fold Belt, due principally to a lack of studies and, to a lesser extent, to the high thermal maturity of some of the rocks, rendering them palynologically barren. Late Palaeozoic records are from the uppermost Carboniferous *Urania* Formation from the subsurface in the Murray Basin and from the Lower Permian glaciomarine *Baccharis* *Marsh* Formation. The latter is known from outcrops in the Bacchus Marsh region, scattered localities through central Victoria, and from a bore in the Gippsland Basin (Douglas, 1964, 1969; Evans & Hodgson, 1964; Bowen & Thomas, 1988). For the early Mesozoic, the record is confined to the palynomflora associated with pteridophyta macrofossils and cuticular remains reported from Triassic strata at Old Nuggetty Gully, Yandoit (Douglas, 1969). Bisaccate pollen, possibly of cortosporites and referable to *Falsisporites*, dominate these palynomfloras.

Late Mesozoic

The main application of palynology to Victorian geology has been the use of fossil spore and pollen and microplanckton (dinoflagellate cysts and other microscopic algae) for dating and correlation of thick nonmarine to marginal marine sequences of Cretaceous and Cainozoic age in the Gippsland, Bass and Otway basins. The earliest studies of well-preserved spore–pollen microfloras confirmed a mostly Early Cretaceous age (latest Tithonian to Albian) for the extensive outcrops of the predominantly volcanoclastic Eumeralla Formation of the Otway and Strzelecki groups (Cookson & Dettmann, 1958, 1959; Dettmann, 1963). The first major study on fossil dinoflagellates in Australia established the presence of subsurface Upper Cretaceous sedimentary rocks on the southern margin of Australia (Baker & Cookson, 1955; Deflandre & Cookson, 1955). Since this early work, palynology has become established as the principal technique for correlation and dating of all Cretaceous sequences.

The Cretaceous spore–pollen zonation is an amalgam of the Early to mid-Late Cretaceous zones proposed largely on the basis of the palynofloral sequence in the Otway and Eromanga basins (Dettmann, 1963, 1986; Dettmann & Douglas, 1976; Dettmann & Playford, 1969), and the latest Cretaceous (Santonian to Maastrichtian) zones formulated for the Gippsland Basin (Stover & Evans, 1974; Stover & Partridge, 1973). Subsequently, Helby et al. (1987) modified several of the zone names and defining criteria when they established an Australia-wide palynological zonation framework for the Mesozoic. More detailed studies of the Otway Basin (Morgan et al., 1995) have since highlighted the difficulties associated with a broad approach to zonation. These relate to differing inter-basin species ranges, extreme scarcity of some index taxa particularly at their range limits, and differing species range concepts between palynologists. Notwithstanding these caveats there is broad consensus on the key defining characters and taxa of the zones (Tables 22.9 and 22.10).

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<tr>
<th>AGE ma</th>
<th>STAGE</th>
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<tr>
<td>0</td>
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</table>

Table 22.7: Megaplant zonation of Cretaceous sediments of Victoria.

22.4.2.1 Megaplant zones

The main application of palynology to Victorian geology has been the use of fossil spore and pollen and microplanckton (dinoflagellate cysts and other microscopic algae) for dating and correlation of thick nonmarine to marginal marine sequences of Cretaceous and Cainozoic age in the Gippsland, Bass and Otway basins. The earliest studies of well-preserved spore–pollen microfloras confirmed a mostly Early Cretaceous age (latest Tithonian to Albian) for the extensive outcrops of the predominantly volcanoclastic Eumeralla Formation of the Otway and Strzelecki groups (Cookson & Dettmann, 1958, 1959; Dettmann, 1963). The first major study on fossil dinoflagellates in Australia established the presence of subsurface Late Cretaceous sedimentary rocks on the southern margin of Australia (Baker & Cookson, 1955; Deflandre & Cookson, 1955). Since this early work, palynology has become established as the principal technique for correlation and dating of all Cretaceous sequences.

The Cretaceous spore–pollen zonation is an amalgam of the Early to mid-Late Cretaceous zones proposed largely on the basis of the palynofloral sequence in the Otway and Eromanga basins (Dettmann, 1963, 1986; Dettmann & Douglas, 1976; Dettmann & Playford, 1969), and the latest Cretaceous (Santonian to Maastrichtian) zones formulated for the Gippsland Basin (Stover & Evans, 1974; Stover & Partridge, 1973). Subsequently, Helby et al. (1987) modified several of the zone names and defining criteria when they established an Australia-wide palynological zonation framework for the Mesozoic. More detailed studies of the Otway Basin (Morgan et al., 1995) have since highlighted the difficulties associated with a broad approach to zonation. These relate to differing inter-basin species ranges, extreme scarcity of some index taxa particularly at their range limits, and differing species range concepts between palynologists. Notwithstanding these caveats there is broad consensus on the key defining characters and taxa of the zones (Tables 22.9 and 22.10).
Systematic studies

The spore–pollen assemblages of the Victorian Cretaceous sediments reflect a series of microfloras in which austral conifers (Podocarpaceae and Araucariaceae) were important and often dominant components. Based on present-day ecological parameters, combined with palaeotemperature and palaeolatitudinal data, these austral conifers are interpreted to have formed high-latitude forests, characterised by conically crowned, widely spaced trees with height:width ratios up to 4:1 (Specht et al., 1992). Superimposed on this long-lasting regional character of the forests is a progressive modification in the understory and fringing plant communities, reflected in the change from spore-dominated assemblages in the Early Cretaceous to angiosperm-dominated assemblages in the Late Cretaceous. The earliest appearance of the flowering plants (angiosperms) is in sediments of latest Barremian-Aptian age, but their pollen are low in diversity (average <10 species) and abundance (average <1%) in deposits older than mid-Santonian. A rapid increase in both abundance and diversity occurs through the succeeding Campanian and Maastrichtian.

The spore–pollen microfloras are grouped into superzones and zones (Helby et al., 1992). Superimposed on this long-lasting regional character of the forests is a progressive modification in the understory and fringing plant communities, reflected in the change from spore-dominated assemblages in the Early Cretaceous to angiosperm-dominated assemblages in the Late Cretaceous. The earliest appearance of the flowering plants (angiosperms) is in sediments of latest Barremian-Aptian age, but their pollen are low in diversity (average <10 species) and abundance (average <1%) in deposits older than mid-Santonian. A rapid increase in both abundance and diversity occurs through the succeeding Campanian and Maastrichtian.

The spore–pollen microfloras are grouped into superzones and zones (Helby et al., 1992). The oldest Microcachryidites Superzone correlates with macroplant zones A–C of Douglas (1969) and is of latest Jurassic – earliest Cretaceous to angiosperm-dominated assemblages in the Late Cretaceous. The earliest appearance of the flowering plants (angiosperms) is in sediments of latest Barremian-Aptian age, but their pollen are low in diversity (average <10 species) and abundance (average <1%) in deposits older than mid-Santonian. A rapid increase in both abundance and diversity occurs through the succeeding Campanian and Maastrichtian.

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The Hoegisporis uniforma Zone at the top of the Hoegisporis Superzone (Tables 22.9 and 22.10) is a replacement name for the modified concept of the Appendicisporites distocarinatus Zone adopted by Helby et al. (1987). The A. distocarinatus Zone was originally proposed by Dettmann & Playford (1969) with a reference section spanning the upper part of the type section of the Waarre Formation to the basal core assigned to the type section of the Flaxman Formation in the Port Campbell 2 well. More detailed palynological studies of this and adjacent wells have subsequently demonstrated that the immediately younger P. mawsonii Zone extends to the base of the Waarre Formation in the Port Campbell Embayment of the Otway Basin (Partridge, 1996a). The ramifications of this change are that all sections previously assigned to the A. distocarinatus Zone in the Otway Basin actually belong to the younger P. mawsonii Zone, and there is consequently little if any Cenomanian section in either the Otway or adjacent Gippsland basins. Therefore, to avoid possible future confusion between the many older references to the A. distocarinatus Zone and the more widely distributed Cenomanian portion, the Hoegisporis uniforma Zone is adopted as a replacement name for the modified concept of the A. distocarinatus Zone proposed by Helby et al. (1987).

All Upper Cretaceous sedimentary rocks identified in Victoria belong to the Turonian to Maastrichtian Proteacidites Superzone. Pollen of the austral conifers (Podocarpaceae and Araucariaceae) continue as prominent components of Late Cretaceous assemblages and are joined by pollen of forest canopy

Table 22.8: Range in time of Victorian Palaeogene and Neogene plant fossil localities.

<table>
<thead>
<tr>
<th>Superzone</th>
<th>Melbourne Area</th>
<th>Otway Basin</th>
<th>Gippsland Basin</th>
<th>Pliocene</th>
<th>Oligocene</th>
<th>Neogene</th>
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<tr>
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### Table 22.9: Latest Jurassic to early Late Cretaceous palynological zonal nomenclature applicable to Victoria. Million year ages and Stage designations on all figures are according to AGSO timescale (Young & Laurie, 1996). The three middle columns show main variations in zonation schemes with preferred scheme in right column. Diagnostic criteria for zone and subzones are provided by the first and last appearances of key species in far right column.

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<tbody>
<tr>
<td>95</td>
<td>LATE CENOMANIAN</td>
<td>Appendificosporites disstrictocarinitus</td>
<td>Appendificosporites disstrictocarinitus</td>
<td></td>
<td>Hoegisporis uniforma</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>ALBIAN</td>
<td>Phimopollenites pannosus</td>
<td>Phimopollenites pannosus</td>
<td>Upper C. paradoxa</td>
<td>Upper C. paradoxa</td>
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<tr>
<td>105</td>
<td>APTIAN</td>
<td>Coptospora paradoxa</td>
<td></td>
<td></td>
<td>Cyclosporites striatus</td>
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<tr>
<td>110</td>
<td>BARREMIAN</td>
<td>Cyclosporites hughesi</td>
<td></td>
<td></td>
<td>Hoegisporis uniforma</td>
<td></td>
</tr>
<tr>
<td>115</td>
<td>HAUTERIVIAN</td>
<td>Foraminisporis wonthaggiensis</td>
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<tr>
<td>120</td>
<td>NEOCOMAN</td>
<td>Microcachryidites Superzone</td>
<td></td>
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<tr>
<td>125</td>
<td>VALANGINIAN</td>
<td>Dicrytosporis speciosus</td>
<td>Cyclosporites hughesi</td>
<td>Upper C. australiensis</td>
<td>Upper C. australiensis</td>
<td></td>
</tr>
<tr>
<td>130</td>
<td>BERRIASIAN</td>
<td>Retitriletes watherooenisis</td>
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<tr>
<td>135</td>
<td>TITHONIAN</td>
<td>Retitriletes watherooenisis</td>
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<tr>
<td>140</td>
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<tr>
<td>145</td>
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Lagostrobus (Phyllocladidites mawsonii), Darydium (Darydiumites florini, Lystegopollenites balmi) and Wollenia (Dihynites spp.) in the lower part of the superzone. In the upper part of the superzone, pollen of Nothofagus (southern beech) and other angiosperms (Proteaceae) become common and are probably represented in the forest canopy. All these newly introduced taxa are believed to have origins in the southern high-latitudes of the circum-Antarctic. In the understorey and fringing communities, Gheicheniiales, Dicksoniales and Schizaeales are initially prominent but gradually decline and become much less prominent or, in some cases, may even become extinct (e.g. Appendificosporites disstrictocanatus, Cucurbitasporites/Ruffordiaspora) as the diversity and abundance of angiosperms increased rapidly from about the mid-Santonian. These Santonian to Maastrichtian assemblages are characterised by a diverse suite of angiosperm pollen superficially similar to Northern Hemisphere Normapolles pollen known from extinct Juglandales/Myricales. They also contain the oldest occurrences of pollen referable to extant families (Winteraceae, Eparidaceae, Gunneraceae, Trimeniaceae and Ranunculaceae).

Organic-walled microplankton are recorded in Victoria throughout the Cretaceous. However those from the Lower Cretaceous sequences are largely nonmarine lacustrine forms, whereas assemblages from Upper Cretaceous sedimentary rocks, although mostly marine, display varying degrees of endemism.

The Early Cretaceous sequences contain low-diversity but in places abundant assemblages of acritarchs (e.g. Microfassa evansi, Mischystudirum spp.), algal microplankton (e.g. Ovoidites spp., Sigmapollis spp.) and the distinctive Schizosporis reticulatus Cookson & Dettmann, now identified as probable resting eggs of rotifers (van Geel, 1998). These types are all considered diagnostic of lacustrine environments but lack a formal zonation framework. In contrast, marine microplankton recorded from the Lower Cretaceous sequences are restricted to a few extremely rare occurrences of Aptian to early Albian dinoflagellates in the westernmost Otway Basin (Padley et al., 1995). Other marine dinoflagellates cysts previously reported as coming from palynological assemblages at the top of the Eumeralla Formation and given a late Albian age (Dettmann & Playford, 1969: p.193) are now known to belong to the overlying Tuross Formation (Partridge, 1996a).

In the Australian-wide microplankton zonation framework proposed by Helby et al. (1987) for the Late Cretaceous (Table 22.11), the succession from the P. infusiosporus Zone to I. korojonense Zone was first recognised in the Otway Basin (Evans, 1966d; Partridge, 1975), while the M. dreggi Zone was initially identified in the Gippsland Basin (Partridge, 1976). The zones have a circum-Antarctic distribution and are recorded from the Antarctic Peninsula (Duane et al., 1992), New Zealand (Roncaglia & Schioler, 1999; Schioler & Wilson, 1998) and along the southern and southwestern margins of Australia (Marshall, 1984).

Assemblages recorded from the Otway Basin are largely cosmopolitan, but are less diverse than those from the Perth Basin. They are dominated by dinoflagellate cysts assigned to Heterosphaeridium and various peridiniaceous genera (Isabelidinium, Chatangiella, Nelsoniella etc.) or,
especially in the older part of the sequence, by the colonial alga Amosopollis cruciformis, which may exceed 25% of the total palynomorph count. The Cenomanian D. multispinum Zone at the bottom of the zonal succession is missing in the Otway Basin due to a break in the stratigraphic record, but is present farther west along the southern margin in the Dunroon and Bight basins (Powis & Partridge, 1980).

In contrast to the more cosmopolitan assemblages of the Otway Basin, the microplankton succession in the Gippsland Basin (Table 22.11) commences with a largely endemic suite of algal cysts described by Marshall (1989). These are here referred to the Turonian Isabelidinium Superzone and are interpreted as diagnostic of large and deep freshwater lakes (Partridge, 1996b). After a gap in the sequence, the succeeding Santonian to Campanian assemblages are represented by a mixture of cosmopolitan and probable endemic dinoflagellate cysts which are grouped under the Isabelidinium variabile Superzone, with the eponymous species typically dominating most assemblages (Marshall, 1988, 1990). The superzone is subdivided into older local zones based on probable endemic species (Chatangiella ponosa Range and Isabelidinium ponticum Interval Zones) and younger zones based on more cosmopolitan species (Nelsoniella semireticulata Interval, Satyrodinium haumuriense Interval and Isabelidinium korojonense Range Zones). Correlation with the zones in the Otway Basin is based on the observed ranges of both the cosmopolitan species and associated spore–pollen species. Early to mid-Maastrichtian deposits in the Gippsland Basin, represented by up to 1 km of continental and coastal plain sediments, lack diagnostic microplankton. However, the overlying sediments of latest Maastrichtian age are referable to the fully cosmopolitan M. druggii Zone.

### Cainozoic

The initial palynological studies of Cainozoic deposits in Victoria were mostly focused on the extensive brown coal deposits and those outcrops that lacked independent dating by other fossils. Early publications concentrated on documenting the fossil pollen record of selective modern families and genera, such as Daedycidium, Nothofagus and Proteaceae (Cookson, 1946, 1950, 1953a, 1957, 1959), or fossil dinoflagellate cysts and algae (Cookson, 1953b, 1956, 1965a,b; Deflandre & Cookson, 1953; Cookson & Eisenack, 1965a,b,c, 1967). Aside from the description by Cookson (1954b) of two successive spore–pollen assemblages in the Birregurra No.1 bore from the Otway Basin, there was little understanding of the biostratigraphic resolution of the microfossils.

The first formal spore–pollen zonation was proposed by Harris (1965) and was based on the Paleocene to Lower Eocene outcrops of the Wangarrip Group near Princetown in the Otway Basin. This scheme was subsequently expanded by the addition of Middle and Late Eocene zones (Harris, 1971). Concurrently, offshore petroleum exploration and the discovery of major oil and gas fields in the Gippsland Basin were the impetus for the independent proposal of a spore–pollen zonation by Stover & Evans (1974) and Stover & Partridge (1973). This zonation, which was based on better sampled sections of thick, near-continuous Upper Cretaceous to Cainozoic sequences, has since been adopted as the framework for the preferred spore–pollen biostratigraphy (Tables 22.12 and 22.13).

Formal description of Cainozoic microplankton zones has lagged behind the more widely applied spore–pollen zones. The framework of Paleocene and Eocene zones outlined on a stratigraphic table by Partridge (1976, fig.2)
Table 22.11: Comparison and correlation of Late Cretaceous microplankton zonal nomenclature applicable to Victoria. The zones recognised in the Otway Basin are largely cosmopolitan, whereas the zones recognised in the Gippsland Basin are fully endemic during the Turonian, partly endemic during the Santonian to Campanian and only become fully cosmopolitan in the Late Maastrichtian. Diagnostic criteria for identifying the zones are provided by first and last appearances of key species. The *Diconodinium multipinum* Zone does not occur in the Otway Basin, but is included on the diagram to facilitate comparison.

<table>
<thead>
<tr>
<th>Age</th>
<th>OTWAY BASIN MICROPLANKTON ZONES AND KEY EVENTS</th>
<th>GIPPSLAND BASIN MICROPLANKTON ZONES AND KEY EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td><em>Diconodinium multipinum</em></td>
<td><em>Rimosicysta &amp; Wuroia spp.</em></td>
</tr>
<tr>
<td>90</td>
<td><em>C. striatoconum</em></td>
<td><em>Rimosicysta</em></td>
</tr>
<tr>
<td>85</td>
<td><em>P. infusorioides</em></td>
<td><em>Manuilla druggii</em></td>
</tr>
<tr>
<td>80</td>
<td><em>Odontochitina porifera</em></td>
<td><em>Isabelidinium korojonense</em></td>
</tr>
<tr>
<td>75</td>
<td><em>Nelsoniella aceras</em></td>
<td><em>Isabelidinium korojonense</em></td>
</tr>
<tr>
<td>70</td>
<td><em>Isabelidinium cretaceum</em></td>
<td><em>Satyrodinium haumuriense</em></td>
</tr>
<tr>
<td>MAASTRICTHIAN</td>
<td>Manuilla druggi</td>
<td><em>Nelsoniella semireticulata</em></td>
</tr>
<tr>
<td>EARLY LATE CRETACEOUS</td>
<td>DIAGNOSTIC MICROPLANKTON SPARSE</td>
<td><em>Isabelidinium korojonense</em></td>
</tr>
<tr>
<td>LATE CRETACEOUS</td>
<td>MANUILLI DRUGGI</td>
<td><em>Isabelidinium korojonense</em></td>
</tr>
<tr>
<td>SANTONIAN</td>
<td><em>Isabelidinium korojonense</em></td>
<td><em>Satyrodinium haumuriense</em></td>
</tr>
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<td>CONIACIAN</td>
<td><em>Odontochitina porifera</em></td>
<td><em>Nelsoniella semireticulata</em></td>
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<td>TURONIAN</td>
<td><em>Isabelidinium korojonense</em></td>
<td><em>Isabelidinium ponticum</em></td>
</tr>
<tr>
<td>CENO-MANIAN</td>
<td><em>Diconodinium multipinum</em></td>
<td><em>Nelsoniella semireticulata</em></td>
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The Cretaceous spor–pollen succession is divided into six microfloras, which reflect major shifts or changes in the vegetation. There are nine assemblage zones and numerous informally named subzones defined on first and last appearance datums (Table 22.12). The oldest *Lygeipterolites* Microflora, which is mostly Paleocene and equivalent to the *Lygeipterolites baleni* Zone, starts at or close to the Cretaceous–Palaeogene boundary. Here there is a decline in diversity and numerous extinctions amongst the spores and angiosperm pollen, but less so or negligible amongst the gymnosperm pollen. Most notable is the extinction, or marked decline in abundance, of distinctive members of the austral Normapolles, including *Batteniopolis secalis*, *Forcipites longus*, *Quadratiplanus brosii* and *Gambierina* spp. The angiosperm–rich latest Cretaceous assemblages are replaced by assemblages dominated by gymnosperm pollen, in which there is the gradual introduction through the Paleocene of angiosperm pollen with affinities to modern families. Many of the new angiosperm pollen types are from wind-pollinating plants that become much more prominent later in the Cretaceous. They include *Notothofagidites* pollen of the modern *brevii*, *mensesi*, and *fusca* types (Dettmann et al., 1990) and pollen of the families *Casuarinaceae* (*Halangaidites harrii*), *Euphorbiaceae* (*Malacocarpus subtilis*), *Myrtaceae* (*Myrtacites parvus*) and *Restionaceae* (*Millokia homeoeocarpa*). In addition, late in the Paleocene, there are the oldest occurrences of pollen of the more tropical families *Oleaceae* (*Anacolosidites australis*) and *Sapindaceae* (*Cupanaceaides orthotichus*). The forest canopy was dominated by gymnosperms of *Podocarpaceae* (*Dacrydium*, *Lagarostrobos*, *Microcachrys*, *Podocarpus*), *Araucariaceae* (*Araucaria*), *Dacrydium* and *Podocarpus*). The Paleocene–Eocene boundary is marked by the loss of the last of the austral *Normapolles* (*Gambierina nudata* and *G. ehrendii*) and ancestral gymnosperms (*Lygeipterolites baleni*) and the introduction of the Early Eocene *Euphorbiaceae/Casuarinaceae* Microflora. This microflora, which is represented by the *Malacocarpus diversus* and *Proteacidites asperopolus* zones, is characterised by increased abundance of *Casuarinaceae* (*Halangaidites harrii*) and *Euphorbiaceae* (*Malacocarpus diversus* and *M. subtilis*), increased diversity and abundance of *Proteaceae* (notably *Prote acidites grandis* and *P. pachyphlos*), and a corresponding decline in podocarp conifers and *Notothofagus* pollen. Newly introduced taxa include the mangrove *Nyga*, *Tiliaceae*, *Santalaceae* and *Sapotaceae*. Marked successive
and horizontal changes in abundance of principal taxa in the assemblages indicate a more complex vegetation mosaic. This was presumably drier or more seasonal, as the principal rainforest indicator species show the greatest decline. Taxa identified indicate the presence of mangrove, levee, backswamp, woodland/shrubland and mega-mesophyll rainforest communities in the Gippsland and Otway basins during this time interval.

Early in the Middle Eocene there is another extinction event that is accompanied by an abrupt rise in abundance of *Nothofagus* pollen of the *brassii* type. Thereafter, this pollen dominated almost all southeastern Australian assemblages until the Late Miocene and constitutes the *Nothofagidites emarginatus* Microflora. The basal Middle Eocene extinction documented in the thicker and more complete sequences in the Gippsland and Bass basins appear to be local, as most of the species that disappear range into younger sediments in more northerly or westerly basins (e.g. Murray Basin and St. Vincent Basin). The *Nothofagidites emarginatus* Microflora is represented by the *Nothofagidites asperus*, *Proteacidites tuberculatus* and *Triporopollenites bellus* zones (Tables 22.12 and 22.13) (Fig. 22.28). Typical abundances of *Nothofagus* pollen increase abruptly from the *M. diversus* (1–3%) and *P. asperolus* (<7%) zones, into the Lower *N. asperus* Zone (average 25%), Middle and Upper *N. asperus* and major part of the *P. tuberculatus* Zones (>50%), before declining to <30% in the *T. bellus* Zone in the Gippsland Basin, but <20% in the same zone in the Murray Basin (Kershaw et al., 1994). This long interval, dominated by *Nothofagus brassii*-type pollen, signifies climatically optimum conditions for the parental sources, *Nothofagus* (*Bassopina*), which today are restricted to equable temperate rainforest of New Caledonia and the upland regions of New Guinea.

The *Nothofagidites asperus* Zone (early Middle Eocene to earliest Oligocene) also contains high frequencies of *Casuarinaceae* (probably including rainforest *Gymnostoma* known from contemporaneous macrofloras) and the ancestral Huon pine (*Lagastrobus*), as well as diverse and common Proteaceae and highly diverse associations of other angiosperm pollen. Turnover of taxa within the zone is not always contemporaneous in the separate basins. Introductions include a mix of rainforest and sclerophyll types, e.g. *Quintinia* (*Saxifragaceae*), epiphytic Loranthaceae, *Isoeagrom* (*Proteaceae*) and *Ungeria* (*Sterculiaceae*). Losses at the base of the zone in the Gippsland and Bass basins include mangroves (*Nypa*, *Tillia*), and several proteaceous pollen taxa. The compositional variations within and between the separate depositional basins may be related to variation in floristics of the mosaic of plant communities present in the separate regions (Macphail et al., 1994). Notophyll rainforests of high species diversity, with fringing wet and dry sclerophyll associates and restricted mangrove communities, appear to have been represented in the vegetation. The local extinction of many Proteaceae species, and marked decline in diversity at the base of the Upper *N. asperus* Zone, are interpreted to reflect temperature decline in the latest Eocene – earliest Oligocene related to the establishment of the circum-polar deep-water current (Kennett & Shackleton, 1976).

Assemblages of the succeeding *Proteacidites tuberculatus* Zone (Early Oligocene to Early Miocene) and *Triporopollenites bellus* Zone (Early to Late Miocene) are characterised by continued high frequencies of *Nothofagus*.

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<th>Stage Series</th>
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<th>MICROPLANKTON Zones &amp; Key Events</th>
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Table 22.12: Palaeocene to Early Oligocene palynological zonal nomenclature applicable to Victoria, based mainly on the more complete sedimentary record in the Gippsland Basin. Diagnostic criteria for identifying the zones and subzones are provided by first and last appearances of key species.
pollen of the brassii-type, with lower diversity angiosperm associations and increased diversity and representation of cryptogam spores. Several taxa were introduced into the region during Oligocene – Early Miocene times. These include the angiosperms Acacia (Acaciapollenites myriosporites), Embothrium (Granodiporites nebulosus), Epibolith (Corvisipollenites ephilbioides), Gaerttanda (Gaerttiardites viridens), Randia (Triporopollenites bellus) and the fern Lophosoria (Cyatheacidites annulatus). The vegetation of well-drained sites is interpreted as microphyll-notophyll Nothofagus rainforest with understory of angiosperms (herbaceous and shrubby) and cryptogams (terrestrial and epiphytic ferns and fern allies). Assemblages from the Latrobe Group (Oligocene – late Early Miocene) confirm lowland communities of podocarps (Lagarostrobos, Phyllocladus) associated with Cunoniaceae, Quintinia, Sapotaceae and Aquifoliaceae in and around coal swamps, whereas Myrtaceae and Elaeocarpaceae were prevalent during deposition of interseam sediments. Fire-prone heath/scrub included Dacrydium/Podocarpus, Eucaridaeae, Gleicheniaceae, Banksia/Dryandrea and Restionaceae (Kershaw & Sluiter, 1993; Martin, 1994; Kershaw et al., 1994). The succeeding M. lapis Zone contains only rare Nothofagus of the brassii type, but increased abundance of gymnosperms (Polecarpus, Darytidium and Darycarpus) indicative of cooler temperate podocarp rainforest. This zone is assigned an Early to mid-Eocene age in the Gippsland Basin and is considered equivalent to the combined Gymnosperm–Nothofagus phase and Upper Myrtaceae phase (Martin, 1994; Kershaw et al., 1994), and most of the Monotocidites galeatus Zone of Macphail & Truswell (1993) in the Murray Basin. The first T. pleistocenicus Zone is latest Pleistocene to Pleistocene and is characterised by Asteraceae pollen abundances of more than 20% and increased frequencies of Casuarinaceae, Myrtaceae and especially Eucalyptus pollen, indicating the emergence of more modern and familiar vegetation mosaics. In the lower part of the zone in the Gippsland Basin, Nothofagus of the menezii type occurs in persistent but low frequencies, indicating the continued presence of remnants of the once widespread Cenozoic rainforests.

The Cainozoic microplankton succession is represented by the Deflandrea Superzone (Paleocene to earliest Oligocene, Table 22.12), and the Operculodinium Superzone (Early Oligocene to Recent, Table 22.13). The Deflandrea Superzone is subdivided into a nearly continuous and extensively tested succession of fifteen zones, whereas the Operculodinium Superzone includes local untested zonal schemes proposed for the Oligocene to

### Table 22.13: Oligocene to Pleistocene palynological zonal nomenclature applicable to Victoria, based mainly on the better-studied sedimentary record in the Gippsland Basin. Diagnostic criteria for identifying the superzones, zones and subzones are provided by first and last appearances of key species.

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**Notes:**
- **First Appearances** are highlighted in red.
- **Last Appearances** are highlighted in blue.
- **Common to abundant** are highlighted in green.
- **Abundant** are highlighted in yellow.
- **Rare** are highlighted in brown.

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**Table 22.13 Notes:**
- The Operculodinium zone includes the main differentiation between the Oligocene and Miocene rainforests, with the Former having a more diverse angiosperm assemblage and the latter having a more diverse gymnosperm assemblage.
- The Operculodinium zone is characterised by the emergence of Eucalyptus pollen, indicating the development of modern forest communities.
- The Micropollenaceae assemblage is dominated by trees and shrubs, with a low abundance of gymnosperms.
- The Operculodinium zone marks the transition from the Oligocene to the Miocene, with a significant increase in the diversity and abundance of angiosperm pollen.
- The Operculodinium zone is characterised by the emergence of Eucalyptus pollen, indicating the development of modern forest communities.
Miocene of the Murray Basin (Martin, 1993) and the Late Miocene to Pleistocene of the Gippsland Basin (McMinn, 1992).

The Deflandrea Superzone is characterised by the common to abundant occurrence of peridiniacean dinoflagellates originally described under the cyst genera Deflandrea and Wetzeliella, but subsequently split between many genera (e.g. Apectodinium, Charlesdowniea, Gippslandica) within the subfamilies Deflandreoideae and Wetzelielloideae of the Order Peridiniales. Half of the diagnostic zone species come from these two subfamilies. The fifteen zones recognised comprise a mixture of acme, total range and interval zones.

The Paleocene microplankton succession commences with the Trithyrodinium evittii Acme Zone of Helby et al. (1987), followed by the new Palaeoperidinium pyrophorum, Alisocysta circumtabulata and Eisenackia trisitabulata interval zones, which are each defined by the successive last occurrences of the respective eponymous species. All four zones are recorded in the subsurface from the Gippsland and Otway basins, but the E. trisitabulata Zone is also identified in the basal two metres of the outcrop sections of the Pebble Point Formation in the Otway Basin (Cookson, 1965b; Cookson & Eisenack, 1965c). Following an interval that is left unzoned, the latest Paleocene is characterised by the oldest consistent and often abundant occurrence of the genus Apectodinium. The Apectodinium sp. nov. Acme Zone (formerly the Wetzeliella homomorpha Zone of Partridge, 1976) is characteristic of paralic environments interbedded with the coal measures in the Gippsland Basin and Torquay Sub-basin, but has not yet been recorded from the remainder of the Otway Basin. The succeeding Apectodinium
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*hypencanthum* Range Zone, which straddles the Paleocene–Eocene boundary, represents the most extensive Paleocene transgression in the three Bass Strait basins. It is best documented by assemblages described from outcrops of the Dartmoor Formation and Rivernook Member in the Otway Basin (Cookson & Eisenack, 1965b, 1967).

*Apertodinium homomorphum* is characteristic of most assemblages throughout the Early Eocene, but the *A. homomorphum* Interval Zone is restricted to the interval between the youngest occurrence of *A. hypencanthum* and oldest occurrences of *Hemotryphium tasmaniense* and the rarer *Rhombodium waipawaense*. The late Early Eocene is also characterised by environmentally widespread but erratically abundant occurrences of the chorate dinoflagellate cyst *Hemotryphium tasmaniense*, whose total range defines the *H. tasmaniense* Zone of Harris (1985). This interval can be further subdivided with great precision by short-ranging and distinctive species of the Wetzellidaceae subfamily, which are found in the most distally marine sections. The species *Rhombodium waipawaense*, *Wilsonidinium eratum*, *Charlesdovaria* sp. nov. cf. *C. coleophypta* and *Charlesdovaria edmundii* define individual range zones that do not overlap except where there has been demonstrable reworking. The zones occur in stratigraphic sequence and have their thickest and best expression in the Flounder Formation, which partly infills the Tuna–Flounder Channel in the Gippsland Basin. A few scattered occurrences of these index species are also reported from offshore exploration wells in the Otway Basin.

Microplankton assemblages representative of the early Middle Eocene interregnum in the Otway Basin (McGovern et al., 1997) have only been recorded from the offshore Gippsland Basin. Although this interval is poorly documented and not formally zoned, it can be subdivided by the last occurrence of the short-ranging acritarch species *Tintinities aeteri*, followed by the acme of the distinctive dinoflagellate cyst *Achomosphaeria ramulifera* (e.g. Marshall & Partridge, 1988).

The last sequences of the youngest four zones of the *Deflandrea* Superzone are found in the condensed and glauconitic Gurnard Formation in the Gippsland Basin, although the *Corrudinium inconstitutum* Zone is undoubtedly better preserved in the Browns Creek Clay in the Otway Basin (Cookson, 1965a; Cookson & Eisenack, 1965a). The *Enneadocysta partridgei* and *Deflandrea heterophlycta* zones are interval zones defined by the first occurrences of the eponymous species. The *Corrudinium inconstitutum* Zone is a total-range zone, while the *Phthanoperidinium commodum* Zone is characterised by an acme of the eponymous species just prior to its extinction in the Gippsland Basin. *Enneadocysta partridgei* Stover & Williams is a replacement name for the Southern Hemisphere dinoflagellate cysts previously considered conspecific with the Northern Hemisphere *Aressphaeridium diktyosplokus* (Klumpp). Its association in the Gippsland Basin with the species *Achomosphaeria ramulifera*, *Spongiphoria asymmetrical*, *Vezzheniokkia aperta* and *V. nitida* is considered diagnostic of the cool-water Transantarctic Flora for dinoflagellate cysts (Wrenn & Beckmann, 1982; Truswell, 1997). The original *Gipsplandica* (al. *Deflandrea*) extensa Interval Zone recognised by Partridge (1976) has subsequently been replaced by the *C. inconstitutum* Interval Zone of Harris (1985). Both eponymous species have the same range in the Gippsland Basin, with *G. extensa* abundant in the paralic sediments interbedded with coal measures in the onshore basin. *C. inconstitutum* is mostly restricted to the distal marine sediments of the Gurnard Formation in the offshore portion of the basin.

The *Operalolinidium* Superzone is coeval with widespread carbonate deposition in Victoria commencing in the Oligocene. It is characterised by assemblages dominated by a mixture of chorate dinoflagellate cysts with long processes, and spherical, morphologically simple proximate dinoflagellate cysts belonging to the Order Gymnodiniales. There is also a corresponding decline in the abundance of the dinoflagellate cysts belonging to the Order Peridiniidae that are so characteristic of the Paleocene and Eocene assemblages. The chorate cyst group is dominated by species belonging to the genera *Spiniferites*, *Achomosphaera*, *Operalolinidium*, *Nematophreopsis*, *Systemataphora*, *Hystrichokolpoma* and *Lingulodinium*, as well as a significant number of undescribed species referred to *Protoellipsodiaceae*. The proximate cyst group is represented principally by species belonging to the genera *Ptyxidinopsis*, *Tetradinidium* and *Impagidinium*.

In the Gippsland Basin, the oldest occurrences of *Tuberculodinium vancampoae* and *Melitasphaeridium chaoophorum* provide potential subdivisions within the earlier part of the *Operalolinidium* Superzone. However, their first appearances are not precisely tied to the stratigraphy, while the late Neogene was divided by McMinn (1992) into three interval zones and three subzones. These comprise the *Melitasphaeridium choaophorum* Zone, with a currently undefined base and top in the Early Pliocene, the mid-Pliocene to Early Pleistocene *Achomosphaera vulnifera* Zone, which is subdivided into a lower *Operalolinidium swarbricki* Subzone and a upper *Lingulodinium mackaerorum* Subzone, and the Early Pleistocene to Recent *Protoellipsodiaceae* Zone, which also has a lower *Boscartidinium tepikense* Subzone.

Additional local zones based on prominent species occurrences are recognised in the Murray Basin following Martin (1993), who proposed an Oligocene (or Late Eocene?) to Middle Miocene succession comprising the *Hystrichokolpoma* Zone, *Hystrichokolpoma* / *S. placacantha* Zone, *Systemataphora placacantha* Zone and *Enneadocysta uneformis* Acme Zone. Subsequently, Macphail & Kellett (1993) documented the characteristics of the microplankton assemblages from the Pliocene Bookpurnong Formation but did not erect a formal zone.