PILLIE LAKE, EYRE PENINSULA, SOUTH AUSTRALIA: MODERN ENVIRONMENT AND BIOTA, DOLOMITE SEDIMENTATION, AND HOLOCENE HISTORY

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Summary

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The small, ephemeral, carbonate-depositing Pillie Lake is located in coastal calcarenite dunes at the southern end of Eyre Peninsula. Characteristics of surface sediments, microbial mats, aquatic biota and water chemistry are reported together with a reconstruction of the lake's history. The floor of Pillie Lake consists of a central zone with polygonal fissures, surrounded by a broad band of surficial microbial mats which is, in turn, bordered by a marginal lithified platform. The surface sediments consist of aragonite with minor calcite and halite. A core (62 cm long) from the centre of the lake floor was examined for variation in mineralogy and fossil remains. Changes in the composition of the associated invertebrate fauna, particularly ostracods, indicate that dolomite once formed in the lake under permanent water cover and at salinities below that of sea water. However, dolomite was also formed, at a later stage, during a period of both gradual freshening of the lake water and increasing frequency of desiccation. These phenomena appear to be associated with a progressive fall of sea level in the area over approximately the last 5000–6000 years.

KEY WORDS: Palaeolimnology, dolomite, charophyte, microbial mats, Ostracoda, Holocene, sea level.

Introduction

Pillie Lake is a small, ephemeral, carbonate lake situated about 10 km south of Port Lincoln at the southern end of Eyre Peninsula (Fig. 1). The lake, which is about 1 km long by 0.5 km wide, occupies an isolated depression within Quaternary calcarenite dunes about 1 km from the embayment of Port Lincoln Proper. It lies below the 10 m contour relative to sea level.

Pillie Lake was visited in November 1979, during a reconnaissance survey of salt lakes of Eyre Peninsula (Bauld, Burne, De Deckker, & Ferguson in prep.). The objective of our investigations was to provide information about the extant biota of the lake, the mineralogy of its sediments and the fossils present in them. Our findings for Lake Pillie are presented here, together with an interpretation of the Holocene history of the lake and a comparison with other, better known, coastal lakes of the Coorong region.

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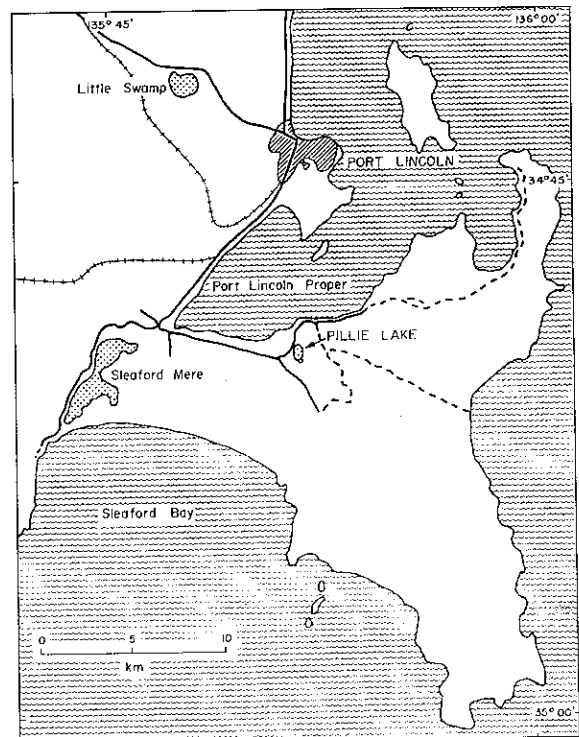‡ Baas Becking Geobiological Laboratory and Bureau of Mineral Resources, Canberra.

Fig. 1. Map showing location of Pillie Lake, Eyre Peninsula.

Methods

A PVC (=polyvinyl chloride) pipe of the type described by Tratt & Burne (1980) was used to obtain a 62 cm long core from near the centre of Pillie Lake. Sixteen samples (referred to as LP1 to LP16) were taken at predetermined intervals in the core (their position is indicated in Fig. 8). A portion of each sample was crushed to a powder and analysed by X-ray diffraction. The remainder of each sample was treated with dilute hydrogen peroxide, and then sieved and dried for the recovery of ostracods and other fossils. The presence and relative abundance of fossil species in each sample examined was recorded.

Three horizons in the core (0–5 cm, 45–50 cm and 55–60 cm) were sampled for ^{14}C dating of bulk carbonate sediment. Samples were crushed to powder and analysed by Dr G. Stipp, without additional treatment, in the laboratories of Beta Analytical, Florida. $\delta^{13}C$ values were determined by mass spectrometry (Craig 1957) and were used to correct the ^{14}C data for isotopic fractionation. No environmental correction factors were applied to the dates obtained.

Samples for microbiological examination (designated PIL–1 onwards) were preserved with 4% formaldehyde (final concentration) in lake water. In addition, samples of dried mat were collected for later recovery of living cyanobacteria. Wet mounts of samples were examined using bright-field or phase-contrast microscopy. Photosynthetic pigments were extracted overnight (at 4°C) into 90% acetone. After centrifugation to remove debris, spectral scans were made using a Varian Techtron 635 spectrophotometer.

Fauna were collected from the lake water with a fine (150 μm) plankton net and later preserved in alcohol (70% v/v). Macrophytes found on the lake floor, mostly in the fissures, were preserved in 10% formaldehyde.

Samples for water chemistry were taken in the fissures (see Fig. 2b) and stored in polyethylene bottles until analyses were performed by AMDEL in Adelaide.

Results and Discussion

1. *The modern lake and its extant biota.*
1a. Setting.

Pillie Lake lies in a depression surrounded by vegetated calcarenite dunes (Fig. 2a) and has a small catchment area relative to the area of the lake floor. The lake is fed mainly by rainfall and by groundwater discharge.

On the first visit to the lake (10.xi.1979) a thin (<1 cm) sheet of water covered several hundred m² of lake floor. Three days later, the water level had fallen slightly and the surface water had retreated to a small patch in the southeastern area of the lake floor. The water table appeared then to be just beneath the lake surface as evidenced by the water levels present in polygonal fissures (Fig. 2b,c) of the south-central, lower area of the lake floor. Such fissures are considered by von der Borch & Lock (1979) to be the location of major discharges of groundwater into lakes during the wetter, winter months when the water table rises. Additional groundwater discharge may also occur in the zone of lithified polygons along the eastern margin of the lake.

1b. Surface sediments

The lake floor is bordered by a lithified platform. A wide belt of surficial microbial mats grades into this lithified platform through an intermediate zone showing varying degrees of induration. The inner edge of mat development merges into a wetter zone which supports occasional stranded macrophyte growth. The lowest, south-central area of the lake floor is characterized by polygonal fissures up to 20 cm wide and 50 cm deep (Figs 2b,c). Away from the central zone, these fissures have been filled by sediment, but the polygonal network is still visible, and is often marked by the growth pattern of charophytes and microbial mats (Fig. 3).

The lake floor consists of white carbonate mud. Particle size analysis shows that 99% of this sediment has a grain size less than 45 μm. The coarsest (> 180 μm) fraction, which consists of skeletal remains, comprises only 0.2% of the sediment. X-ray diffraction analyses reveal that the clay-sized fraction consists mainly of aragonite with minor halite and low magnesian calcite.

The slightly higher marginal platform of the lake exhibits increasing induration and lithification of the sediment with increasing dis-

Fig. 2. Pillie Lake. (a) setting in Quaternary calcarenite with Port Lincoln Proper background left. View to east. (b) characteristic fissures in lake floor (south central) containing water. Note growth of charophytes within fissure and polygonal growth pattern of same on surface sediments (see also Fig. 3). (c) vertical view of fissure and floating "skeins" of carbonate particles. Diameter of coin in (b) and (c) 23 mm.

tance outwards. X-ray diffraction analyses of lithified samples demonstrate the presence of dolomite and aragonite. The degree of ordering of this dolomite has not been determined.

On the eastern side of the lake the lithified platform is broken up into a 5 m scale network of polygonal plates. Tepee structures occur along some polygon margins. Carbonate mounds (up to 40–60 cm high and 1 m across) are associated with this zone. The surfaces of these mounds are grey and compact but their interiors are white and consist of porous tufa. The mounds are composed of aragonite, dolomite and calcite. Similar mounds of porous tufa are found associated with areas of groundwater discharge around the shores of the permanently filled nearby lagoon, Sleaford Mere (Fig. 1). Human, bird and other animal footprints are preserved on the surface of the lithified terrace.
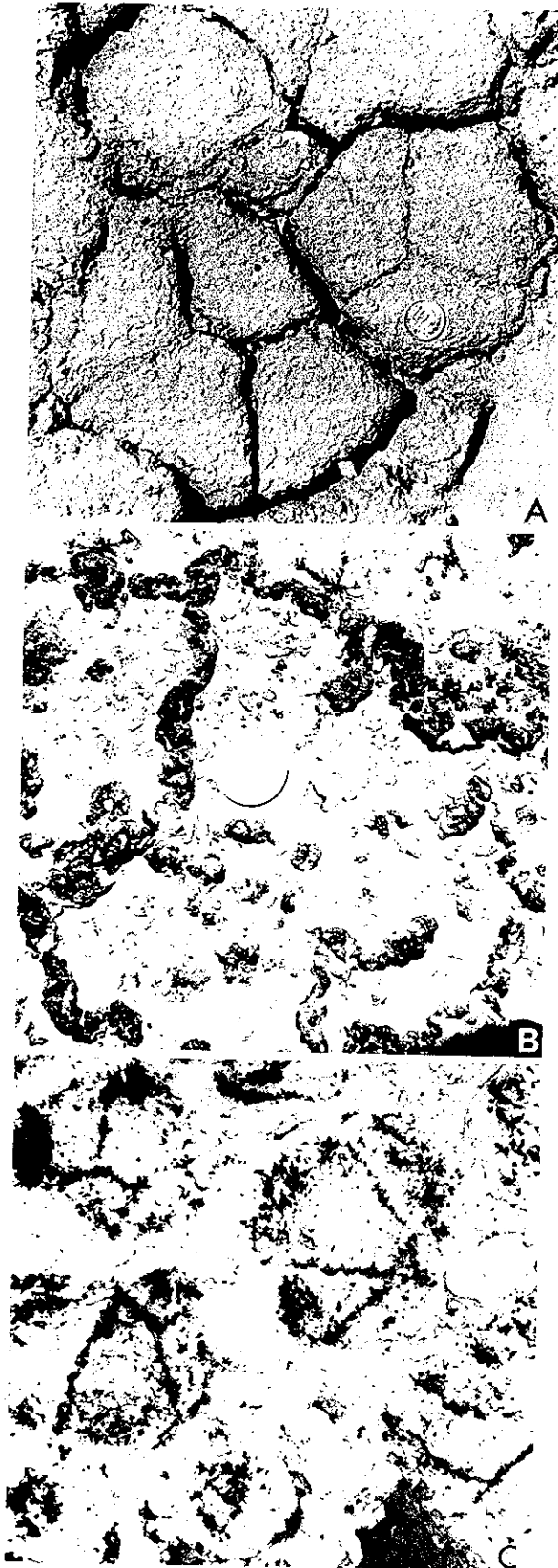
1c. Aquatic biota.

Charophytes and other aquatic macrophytes were present. The best development of charophytes was observed in the lower, south-central area of the lake. Healthy charophytes occurred both within polygonal fissures and along the tops of old polygonal cracks now filled with carbonate sediment (Figs 2b,c). Charophyte growth formed a distinctive pattern tracing the margins of former small-scale polygonal plates. (Figs 2b, 3). In shallower areas, where water remained only in the fissures, charophytes and other aquatic macrophytes grew mostly in the polygonal fissures.

The charphyte was identified as *Lampro-thamnium papulosum*, a common inhabitant of ephemeral saline lakes in South Australia (Burne *et al.* 1980). At the time of our visit the plants bore oogonia, antheridia, and starch storage organs. The plants were generally short (1–2 cm) (Figs 2b, 3), even when fully mature, presumably because of the very shallow water cover. Gas evolution by the charophytes indicated oxygen production due to photosynthetic activity. Photosynthetic activity and growth of this charophyte at seawater salinities (Pillie Lake TDS = 36.24‰) would be consistent with earlier field observations and experimental work (Burne *et al.* 1980).

Healthy aquatic macrophytes, some with flowering organs, identified as *Ruppia* sp., were also present in the fissures.

The ostracods *Mytilocypris praenuncia* and *Diacypris spinosa* were most commonly found swimming among the charophytes and the *Ruppia* plants, in the fissures filled with water. The cladoceran *Daphniopsis pusilla*, which is also a halobiont organism, was as common as the ostracod. On the other hand few specimens of the amphipod *Austrochiltonia australis* and the copepod *Mesochra baylyi* were collected. The diversity of the fauna is low compared with that for other salt lakes (e.g. lakes of the Coorong region; De Deckker & Geddes 1980) and is also lower than would be expected from the measured salinity. This low species diversity probably results from a rapid increase in salinity during the later stages of desiccation, which could prevent hatching and/or maturation. Depletion of the fauna would be assured if this were a recurring phenomenon as very few organisms would be able to complete their breeding cycle.

1d. Microbial mats and microbiology.

Microbial mats occupied a broad zone surrounding an area of extensive charophyte development and bounded by the belt of shoreline lithification. At the time of sampling the lake water had retreated from the zone of mat colonization. The shoreward margin of the mats was dry and formed a hard crust.

The distribution of mat types appears to be controlled by the pattern of polygonal desiccation cracks beneath them (see Figs 3a, 3b). Generally the polygon tops were covered by flat mat (Fig. 3b; Table 1, PIL–7) while the original crack areas were colonized by a mat of raised and crenulate appearance (Fig. 3b; Table 1, PIL–9).

The marginal development of mats in Pillie Lake is consistent with microbial mat colonization of other ephemeral saline lakes (Bauld 1981a). The lack of mat accretion, or of preservation detectable as buried laminated organic matter indicated that colonization during wetting periods is followed by desiccation and subsequent aeolian erosion, which

Fig. 3. Polygonal cracks control growth pattern of charophytes and microbial mats. (a) polygonal cracks in carbonate floor of lake. (b) an area of colonization by microbial mats. Coin rests on flat mat; crenulate mat (see Table 1) grows along and over the now filled-in cracks. (c) charophytes appear to preferentially colonize filled-in polygonal cracks. Coin used for scale 23 mm diameter.

TABLE 1. *Description of microbial mats, Pillie Lake.*

Sample	Location and description	Microorganisms	Photosynthetic pigment
PIL-1	Carbonate crust, shoreline. Lithified surface, soft and crumbly underneath. Thin blue-green layer (*ca.* 0.2 mm) 0.5–1.0 mm beneath surface (endolithic?). Diffuse, salmon-pink layer above this.	Occasional narrow (<5 μm) filaments, often encased in carbonate. More frequent short narrow trichomes. Identification not possible.	Below detection limits.
PIL-7	Desiccated flat mat, top-centre of polygon (early stages of induration?). Very thin carbonate coating covers pale salmon-pink layer. A *ca* 2 mm thick, bright blue-green layer occurs *ca.* 1 mm below surface. Small, black irregular colonies occur on surface.	Blue-green layer: Carbonate grains host single-trichome filaments with thin, hyaline, closely appressed sheaths. Some trichomes encased in carbonate. Cells *ca.* 11–12 μm long x 2 μm wide. (Figs. 4 and 5) *Phormidium hendersonii* (*sensu* Golubic & Focke 1978). Black colonies: Most organic material without discernible structure. *Calothrix*-like filaments and colonial, coccoid cells with dark brown stained sheaths (*Chroococcus*).	Chlorophyll *a* (see Fig. 7).
PIL-8	Marginal tufa head. White, lithified surface; when broken reveals variety of endolithic colonies, irregularly distributed within *ca.* 5 mm of surface.	Bright blue-green; appears to be chasmolithic, mat-like growth. Filamentous cyanobacterium (*Phormidium*?) entangled with cocci (*Chroococcus*?) (see Fig. 6).	Chlorophyll *a*
	Colonies have bright blue-green (possibly chasmolithic), pale brown to tan, and diffuse salmon pigmentation. 10–20% of lithified surface covered with black "colonies", which appear green to yellow-brown when crushed.	Possible *Nostoc*. Black "colonies" contain unidentified filamentous cyanobacteria.	Chlorophyll *a*
PIL-9	Raised crenulate-like mat from polygon margin, contiguous with flat mat. Black "colonies"/concretions $\leqslant1$ mm across and partly submerged in flat mat (PIL-7). Black crust continuous on crenulate ridges.	Black "colonies" contain *Chroococcus turgidus* (colonial, coccoid). Filaments of *Calothrix* sp. present.	Chlorophyll *a*

would remove these surficial mats (Bauld 1981a, 1981b).

The microorganisms constructing and present in the mats are given in Table 1. The desiccated condition of the mats and the poor state of microorganisms, combined with their low populations relative to detritus and carbonate sediment/cement (Figs 4, 5), made identification difficult. Prolonged wetting of dried mat samples under laboratory conditions enabled some microorganisms to grow. This
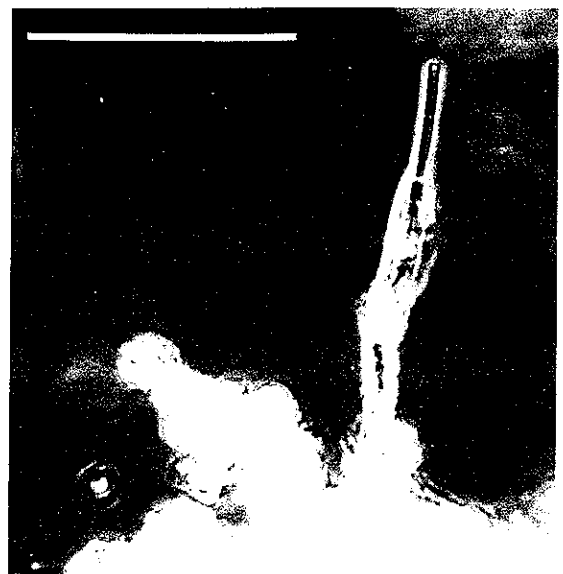

Fig. 4. Photomicrograph (phase-contrast) of filamentous cyanobacterium, identified as *Phormidium hendersonii*, from the blue-green layer of flat mat (PIL-7), cells of the trichome protrude beyond the end of the sheath, which appears to be coated with carbonate or some other inorganic material. Scale bar 50 μm.

demonstrated their presence in the field mats but not necessarily their relative dominance in the constructing population.

Endolithic microorganisms (Fig. 6) were detectable in the lithified carbonate mounds (PIL-8, Table 1) which occur along the lake margin. Blooms of purple bacteria (photosynthetic sulfur bacteria) were observed in the bottom waters of some of the polygonal fissures. Their occurrence indicates anoxic conditions, most likely resulting from decomposition of organic matter. The occurence of photosynthetic microorganisms in mats, lithi-
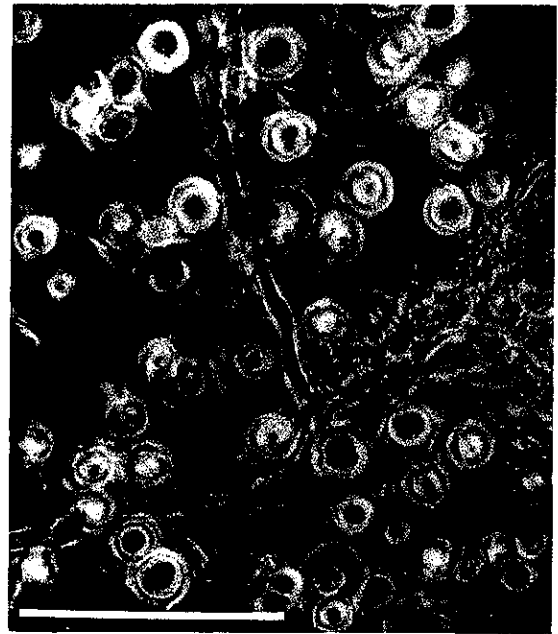

Fig. 6. Photomicrograph (phase-contrast) showing filamentous cyanobacterium (*Phormidium?*) and coccoid organism (*Chroococcus?*) from mat-like chasmolithic growth (PIL-8). Scale bar 50 μm.

Fig. 5. Photomicrograph (phase-contrast) of *P. hendersonii* from PIL-7 showing binding effect of the ensheathed trichomes on carbonate grains in the mat. Cell can be seen protruding beyond end of sheath at right. Scale bar 50 μm.

fied carbonate and other environments was confirmed by extraction of the photosynthetic pigments chlorophyll *a* and bacteriochlorophylls *a* and *c*. (Table 1 and Fig. 7).

1e. Water chemistry.

The field pH of Lake Pillie water was 8.55, a value close to that (8.6) determined later by AMDEL. The water had a conductivity of 46 388 μS cm^{-1} and contained 36 235 mg 1^{-1}. Total Dissolved Solids (TDS) comprising the following (in mg 1^{-1}); Ca^{2+}, 93; Mg^{2+}, 1236; Na$^+$ 11 980; K$^+$, 275; CO$_3^{2-}$, 39; HCO$_3^-$, 339; SO$_4^{2-}$, 3819; Br$^-$, 49; Cl$^-$, 18 550; F$^-$, 6; NO$_3^-$, <5; SiO$_2$. 7.6; B, 882. Total alkalinity as CaCO$_3$ was 343 mg 1^{-1}.

2. *Holocene record*

2a. Sediment type

Three zones are recognized in the core (Fig. 8). The upper zone (0–43 cm) consists of uniform white mud with scattered skeletal grains. The intermediate zone (43–50 cm) comprises olive grey mud with layers of coarse carbonate sand and one horizon of root fibres. The lower zone (50–62 cm) contains purple brown mud with white clay lenses and streaks, and scattered fine carbonate sand grains. There
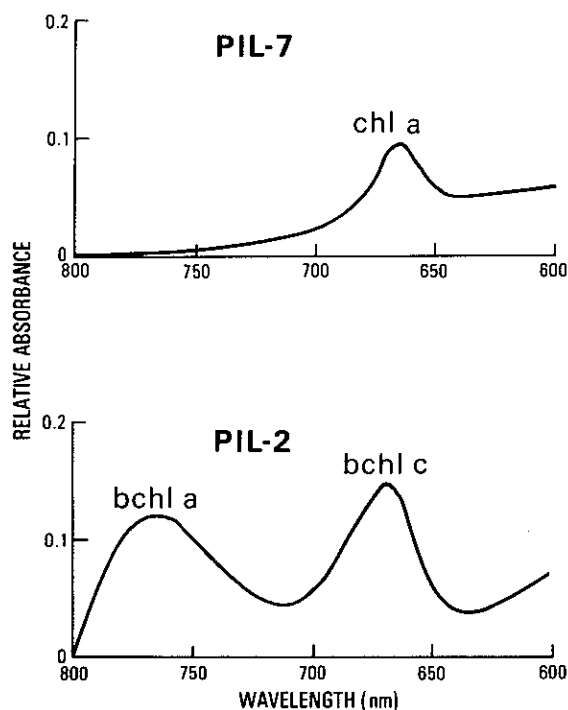
Fig. 7. Absorption spectra of photosynthetic pigments (acetone extract) from (a) flat mat (PIL-7) constructed by *Phormidium hendersonii* (see Figs. 4 and 5), and (b) bloom of photosynthetic bacteria (PIL-2) in bottom of water-filled fissure. λ_{max}: chl$a$ = 664 nm; bchl$a$ = 770 nm; bchl$c$ = 670 nm. The bchl$c$ peak indicates the presence of green sulfur bacteria with the bloom of purple sulfur bacteria (bchl$a$).

are no signs of diagenetic cementation or nodule formation.

2b. Mineralogy

X-ray diffraction analysis of bulk samples for carbonate minerals revealed only the presence of aragonite, low magnesian calcite and dolomite (sample LP7 was not analysed). The relative abundance of each mineral, determined according to the methods of Chave (1952) is presented for each sample in Figure 8. Halite was also recorded from quite a number of samples (see Fig. 8) but no gypsum was found. Ostracod shells were not separated from the samples prior to X-ray diffraction analyses and are thought to be the major source of the calcite present throughout the core.

X-ray diffraction analysis shows that LP15 contains dolomite which is stoichiometric (strong peak at 2.89Å) and well-ordered (strong peaks at 2.48Å (221) and 2.07Å

(111)). Sample LP15 consists of 32% dolomite, 62% aragonite and 6% low-Mg calcite, and a similar composition is assumed for the dolomite throughout the lower portion of the core (50–62 cm).

2c. Fossils

Ostracods, isopod fragments, foraminifers, gastropods and charophyte oogonia were recovered from some of the core samples (Fig. 9). They are discussed separately.

2c(i). *Ostracoda.*

The ostracods found in the core are all halobiont species (*sensu* De Deckker, 1981a). They are listed below together with the most recent references on relevant taxonomic and ecological information.

1. *Cyrideis australiensis* Hartmann, 1978 = *C. westraliensis* McKenzie, 1978 (Hartmann 1978; De Deckker 1981c), Fig. 9: 21, 23–24, 28, 31–33.

2. *Diacypris compacta* Herbst, 1958 (De Deckker 1981c), Fig. 9: 37–29.

3. *Diacypris spinosa* De Deckker, 1981 (De Deckker 1981b). Fig. 9: 9–11, 20.

4. *Leptocythere lacustris* De Deckker, 1981 (De Deckker 1981d), Fig. 9: 7–8.

5. *Limnocythere mowbrayensis* Chapman, 1914 (De Deckker 1981b, 1982a), Fig. 9: 1–3.

6. *Mytilocypris mytiloides* Brady, 1886 (De Deckker 1978, 1981c), Fig. 9: 12–13.

7. *Mytilocypris praenuncia* Chapman, 1936 (De Deckker 1978, 1981c), Fig. 9: 17–18, 25.

8. *Platycypris baueri* Herbst, 1957 (De Deckker & Geddes 1980; De Deckker 1982b), Fig. 9: 26–27.

2c(ii) *Isopoda.*

Only very brittle exoskeletal fragments of the isopod *Haloniscus searlei* Chilton, 1920 were recovered. They consist mainly of elongated cones which are slightly arched and hollow (Fig. 9: 5–6). The ecology of this isopod is discussed by De Deckker & Geddes (1980) and De Deckker (1981c).

2c(iii) *Foraminifera.*

Tests of *Elphidium* sp. (Fig. 9: 4) Cann & De Deckker 1981, which can live in non-marine waters, were rarely encountered. The
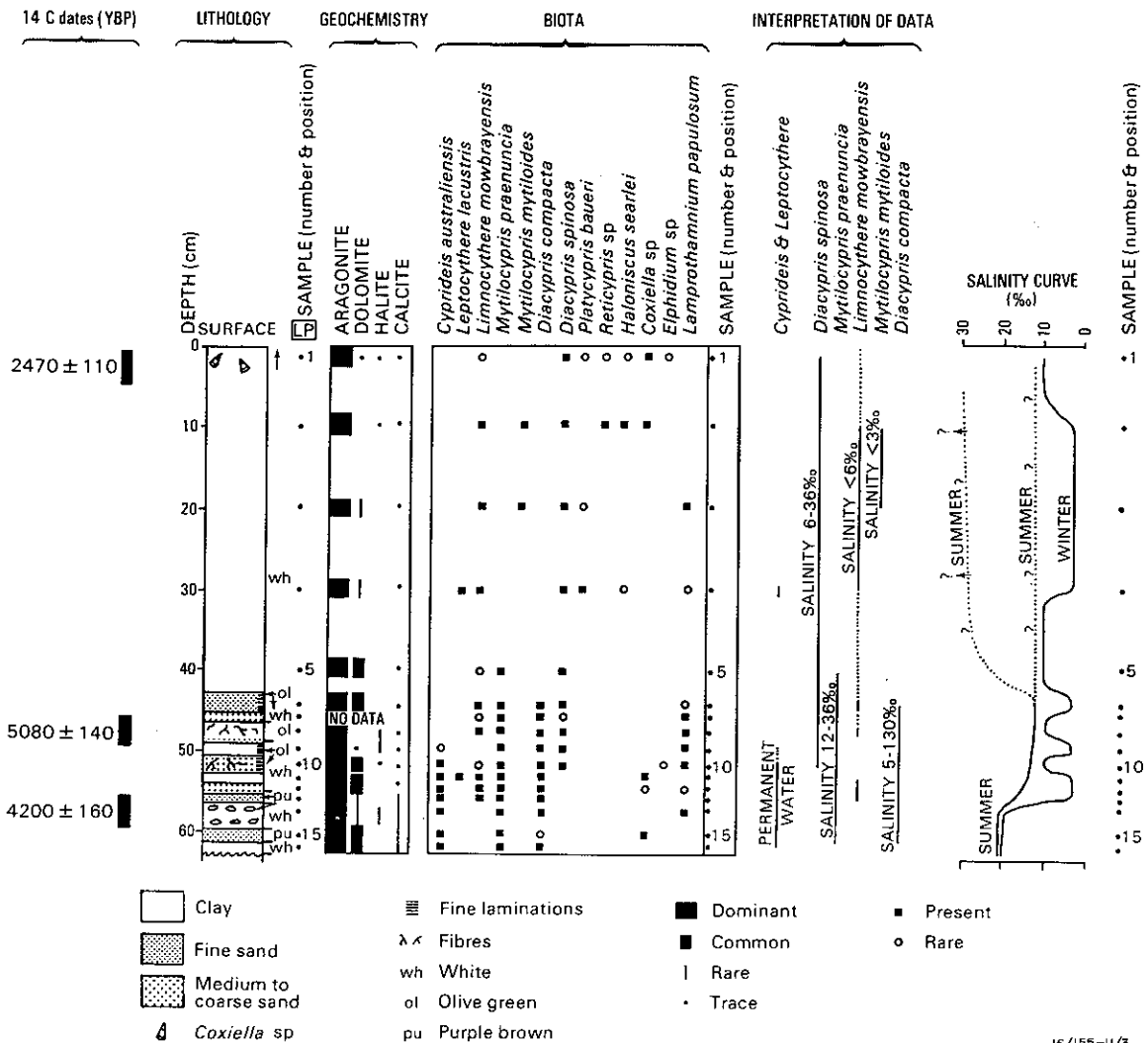
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Fig. 8. Lithology, geochemistry, fossil ostracods and other fossil remains recorded from Pillie Lake core, together with past salinities of the lake inferred from fossil ostracod data.

Fig. 9. 1–3: *Limnocythere mowbrayensis* —1, ♂, LV external, LP2; —2, ♀, RV external, LP2; —3, ♂, C, dorsal, LP5. 4: *Elphidium* sp., side view, LP16. 5–6: *Haloniscus searlei*, —5, fragment of distal segment of posterior appendage, LP2; —6, fragment of spine attached to telson, LP2. 7–8: *Leptocythere lacustris*, —7, LV external, LP11; —8, LV internal, LP11. 9–11, 20, 22 *Diacypris spinosa*, —9, juvenile, RV external, LP10; —10, juvenile, RV external, LP10; —11, LV internal, LP10; —20. LV external, LP10; —22, RV internal, LP10. 12–13: *Mytilocypris mytiloides*, —12, LV external, LP2; —13, RV internal, anterodorsal area broken off, LP2. 14–16, 19: *Coxiella* sp., —14, juvenile, dorsal view, LP1; —15, juvenile, apertural view, LP1; —16, juvenile, ventral view, LP1; —19, apertural view, part of aperture broken off, LP1. 17–18, 25: *Mytilocypris praenuncia*, —17, juvenile, LV internal, LP10; —18, RV internal, LP10; —25, LV external, LP5. 21, 23–24, 28. 31–33: *Cyprideis australiensis*, —21, juvenile, RV external. LP15; —23, juvenile, LV external. LP15; —24, ♂, RV internal, LP15; —28, ♂, LV external, LP15; —31, ♀, C, dorsal, LP15; —32, ♂, C, dorsal, LP15; 33, ♀, LV external, LP12. 26–27: *Platycypris baueri*, —26, RV external, dorsum distorted and partly broken off, LP4; —27, LV internal, dorsum broken off, LP4. 29–30: *Reticypris* sp., —29, RV external, LP2; —30, RV internal, LP2. 34–36: *Lamprothamnium papulosum*, oogonia, all side views and all LP10. 37–39: *Diacypris compacta*, —37, LV dorsal, LP14; ~~—38, LV external, LP14;~~ —38, LV external, LP14; —39, RV internal, LP14. C—carapace: LV. RV = left and right valves. Scales: 1: 200 μm for 1–4, 7–8. 2: 500 μm for 5–6, 12–16, 19. 3: 500 μm for 9–11, 20, 22, 34–36. 4: 250 μm for 26–27; 500 μm for 17–18, 25. 5: 500 μm for 21, 23–24, 28. 31–33. 6: 200 μm for 29–30, 37–39.
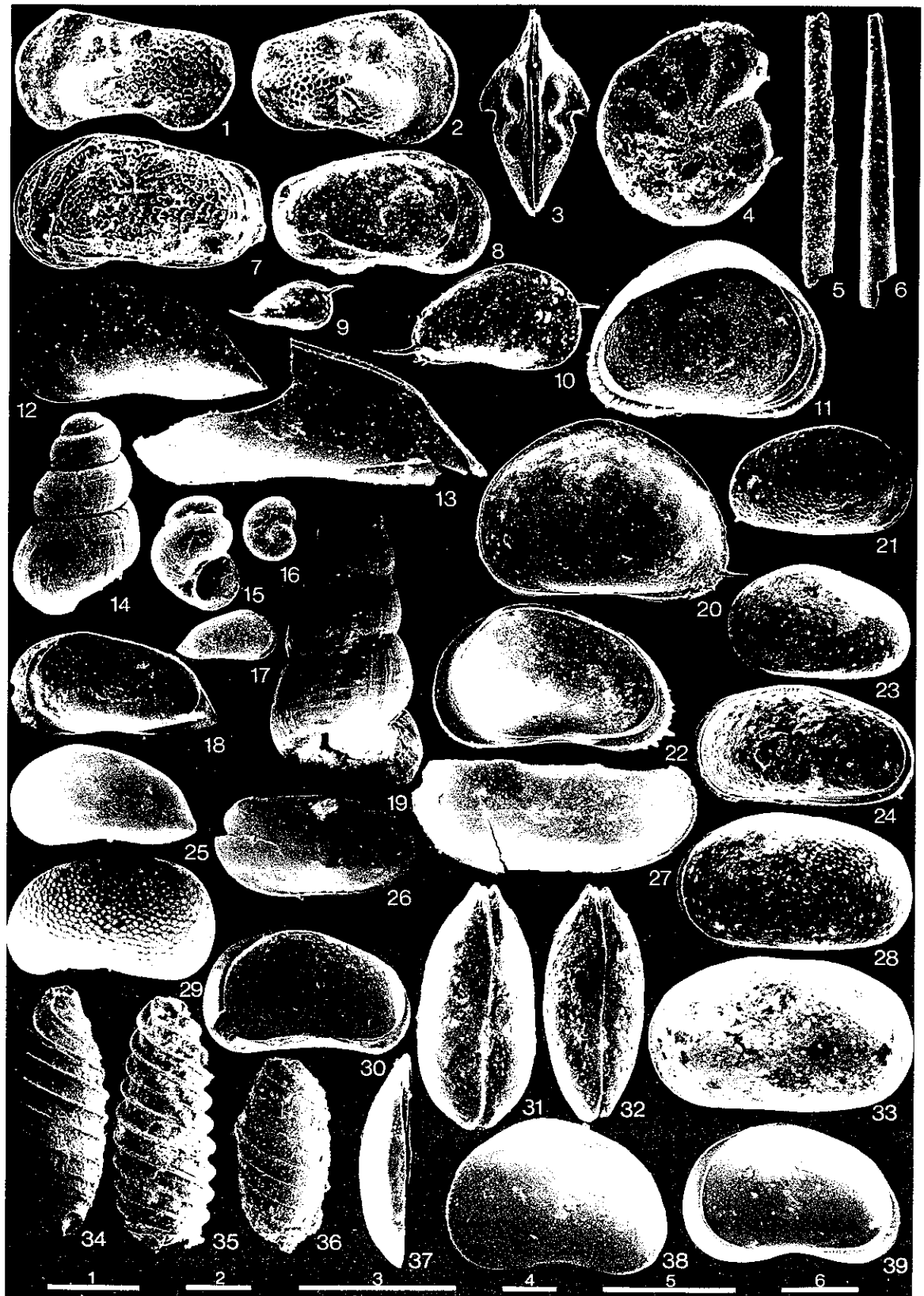
TABLE 2. *Carbon-14 dating of Pillie Lake sediments.*

Core interval (cm)	BMR code	LAB code	XRD mineralogy*	D^{14}C (‰)	δ^{13}C (‰)	Age yBP
0–5	323	β1841	A,H,c,d	−264.7 ± 9.1	+1.6	2470 ± 100
45–50	323A	β1844	A,H,c,d	−468.7 ± 9.2	+1.6	5080 ± 140
55–60	323B	β1843	A,C,D,H	−407.2 ± 11.7	+0.5	4200 ± 160

* Upper case—abundant
Lower case—trace
A—aragonite
C—calcite
D—dolomite
H—halite

taxonomy and ecology of this foraminifer have been described by Cann & De Deckker (1981).

2c(iv) Gastropoda.

Shells of the halobiont gastropod *Coxiella* sp. (Fig. 9: 14–16, 19) were found in the upper levels of the core.

Specimens were not identified at the species level because the taxonomy of *Coxiella* is in a confused state (Mellor 1979[1], De Deckker & Geddes 1980). However the morphology of the specimens from the core fit the variation of the species labelled *C. striata* by De Deckker & Geddes (1980) collected from lakes adjacent to the Coorong Lagoon. The salinity range for those specimens was 6–124‰. *Coxiella* spp. can withstand periods of desiccation although they do not occur in lakes which remain dry for a number of years (e.g. as in Central Australia).

2c(v) Characeae.

The oogonia recovered from the Pillie Lake core are thought to belong to *Lamprothamnium papulosum*. Although their shape may vary extensively (Fig. 9), *L. papulosum* oogonia are very elongated and narrow (Fig. 9: 34–36) compared to other charophyte oogonia found in the southeast of Australia.

Until the report of Burne *et al.* (1980) the presence of fossil charophyte oogonia in sediments was considered to indicate the presence of fresh water. However, these authors demonstrated that *Lamprothamnium papulosum* grows in saline waters and that photosynthetic CO_2-fixation in this species occurs at salinities up to two times that of sea water. Thus the

presence of oogonia in the core does not preclude seasonally saline or hypersaline conditions, (Burne *et al.* 1980).

2d. Dating

Since there was insufficient material to enable samples of skeletal carbonate to be concentrated for ^{14}C analysis, bulk carbonate samples were analysed. The results (Table 2) indicate an age of 2470 ± 100yBP for the uppermost sediments. Since no detrital carbonate from the surrounding calcarenites was found within the core sediments, it is thought that all the carbonate minerals have formed within the lake basin.

The apparent age reversal for the 45–50 and 55–60 cm layers suggests either that the carbonates of the lower sample could have undergone diagenetic alteration, possibly as a result of "ageing" of the dolomite (McKenzie 1980), or that the overlying sample contains a proportion of old carbon not present in the lower sample.

We consider the date of 5080 ± 140yBP to indicate a maximum possible age for the 45–50 cm sample, and we recognise the possibility that the 55–60 cm sample may be slightly older than this date.

3. Holocene History of Pillie Lake
3a. Deduction of palaeosalinity and water level.

De Deckker (1981a) has demonstrated that some ostracods can be used as sensitive indicators of water salinity and, furthermore, sometimes provide information about water level variation in saline lakes. The presence of fossil representatives of these species in the Pillie Lake core may therefore be used to indicate the palaeosalinities and determine whether or not the lake was permanently filled.

The presence of *Cyprideis australiensis* valves in samples LP10 to LP16 (and also their rare occurrence in LP9) indicates that

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[1] MELLOR, M. (1979) A study of the salt lake snail *Coxiella* (Smith, 1894) *sensu lato*. B.Sc. (Hons) thesis, University of Adelaide (unpubl.).

water was permanent in the lake at the time of deposition of levels LP16 to 10 and perhaps LP9.

At some stage during the periods when *Limnocythere mowbrayensis* was p r e s e n t (levels LP2–4, 6, 8 and 11–12), salinity of the lake water must have been below 6‰ and water was probably permanent at some stage for these levels. Both phenomena are less certain for other samples where the species is rare i.e. LP1, 5, 7, 10 and in LP13 where only juveniles have been recovered.

The elongated specimens of *Mytilocypris mytiloides* in samples LP2–3 indicate salinities below 3‰. The shorter specimens belonging to the same species in sample LP3 indicate that salinity could have reached 25‰. The record of *Diacypris spinosa* in samples LP1–10 indicates that during winter months salinity was likely to be below 20‰.

The presence of *Haloniscus searlei*, and other fossils, in the upper part of the core shows that the lake was subject to desiccation. However, while *H. searlei* can withstand desiccation, it is known to require frequent re-wetting, usually at yearly intervals, for it to survive and reproduce. (De Deckker & Geddes 1980; W. D. Williams, in prep.).

On the basis of these data the Holocene history of Pillie Lake is interpreted as follows (See Fig. 8):

Water was permanent between LP16 and 10. The average winter salinity[2] was of the order 20‰ until LP13 when salinity dropped to ≤6‰ where it remained until LP11. It is likely that salinity was higher at other times because *M. praenuncia* is also present in these samples (the lowest salinity tolerated by this species is 12‰).

For LP9, and younger layers, water was probably not permanent and salinity fluctuated although it remained generally low (<10‰) in winter. It was definitely <6‰ at some stage for LP8 and LP4–2 as shown by the presence of *L. mowbrayensis*. For the other samples it was below 20‰ in winter because *D. spinosa* found in them requires such salinities in winter. An exception probably occurs for samples LP7 and 5 where *D. spinosa* is rare. Timing of these events cannot be defined accurately because of the anomalous ^{14}C dates (Table 2).

3b. Dolomite formation.

Since Pillie Lake possesses a relatively small catchment area, it is likely to be filled not by surface run-off, but by rainwater falling directly on the lake floor and by groundwater discharge into the lake. It can be deduced from the fossil ostracod record of the lake sediments that the evolution of Pillie Lake from a permanent to an ephemeral status was associated with a progressive decrease in salinity. These changes possibly indicate a progressive decrease in marine groundwater influence, and are accompanied by changes in sediment type. They are therefore consistent with a fall in sea level affecting the groundwater regime. [14]C dating indicates an approximate age of 5000yBP for sediments in the lower portion of the core. This is concordant with the last high sea level stand in the adjacent areas of north eastern Spencer Gulf and the Coorong area (ca. 6000y BP; Burne 1982; von der Borch *et al.* 1975; von der Borch 1976) and it supports our explanation for decreasing salinity concomitant with the transition from permanent to ephemeral water.

A comparison of ostracod distribution with the occurrence of carbonate minerals in the Pillie Lake core led us to conclude that dolomite is found in sediments that formed under both permanent and ephemeral conditions (Fig. 8). Precipitation of dolomite under the latter conditions is similar to dolomite formation in the Coorong area (von der Borch 1976) where it occurs in ephemeral lakes fed solely by evaporitically modified continental groundwater without the influence of marine brines. This process of dolomite formation has also been invoked (von der Borch 1981) for a salt lake near Naracoorte which is considerably further inland (85 km) than lakes near the Coorong Lagoon and thus removed from possible influence by sea water.

On the other hand, the occurence in the lower layers of the Pillie Lake core of abun-

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[2] All the salinity values discussed here refer to winter values. The work of De Deckker & Geddes (1980) suggests that the presence of ostracods is controlled by the effect of salinity on hatching during the winter months. Furthermore, as the catchment area of Pillie Lake is small and the lake lies in a small depression, the lake could never be very deep. It is therefore easier to predict winter salinities rather than the summer ones since the latter are likely to fluctuate extensively from year to year. Additionally, a sudden retreat of the water table in summer could cause the lake to dry up without salinity reaching high levels.

dant well-ordered dolomite, associated with organisms which live under permanent water cover in an environment of fluctuating salinity, suggests that a different mechanism of dolomite formation occurred. Folk & Land (1975) proposed that an important method of precipitating dolomite was to dilute either evaporitically concentrated brines or sea water with fresh water. The sites suggested for the formation of dolomite by these means are shallow lagoons experiencing rapid fluctuations between hypersaline and nearly fresh water conditions, or a phreatic groundwater zone where sea water is diluted by mixing with a lens of meteoric water. Either of these could acount for the dolomite in the lower levels of the Pillie Lake core but, because the dolomite appears to be a primary lake sediment and dolomitic nodules or other obvious diagenetic textures are absent, we favour the former model.

Conclusions

1. Palaeoenvironmental conditions during the Holocene were deduced by the presence of various fossil ostracods, which are used as both indicators of salinity and indicators of whether the lake retained permanent or ephemeral water.

2. A general decrease in water salinity was recorded and is thought to be related to a fall of sea level during the past 5,000–6,000 years.

3. Our investigation provides evidence for the formation of dolomite under permanent water cover ca 5000y BP and, later, under ephemeral water conditions.

4. The formation of dolomite under permanent water conditions contrasts with the well documented occurrence of dolomite precipitation under evaporitic conditions in lakes near the Coorong Lagoon.

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