Late Quaternary ostracods from Lake George, New South Wales

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Fossil ostracods from the uppermost 3m of core LG4 from Lake George all have modern living representatives. This part of the core is thought to represent deposition during the last 60,000 years (see Singh *et al*., 1981b) and the lake history is traced from a knowledge of the ostracod ecology.

The following distinct phases, and their respective timing, are postulated for Lake George (the timing of events should be considered with caution as few ^{14}C dates are available): water fresh and lake full for the periods of 10,200 — 12,000 yBP and 19,100 — 20,700 yBP; water fresh, ephemeral at times, for the periods of 3,200-4,000 yBP, 7,000 yBP, 7,500 yBP, 8,500-10,200 yBP, 12,000-13,500 yBP, 20,700-23,500 yBP, 23,800-27,600 yBP and at some stage between 27,000 and 60,000 yBP; ephemeral saline water for a few short episodes between 3,200 and 4,000 yBP and for the periods of 15,600-17,400 yBP and 23,800-27,600 yBP; lake definitely dry between 17,400 and 19,100 yBP.

Data obtained from the ostracods correlate reasonably well with those of lake level fluctuations based on the study of ancient shorelines by Coventry (1976) and others based on facies analyses and the record of plant microfossils by Singh *et al*. (1981b).

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OSTRACODS extracted from the upper 3m of core LG4 from Lake George represent faunas which lived during the last 60,000 years. Their study was carried out to determine the distribution of species through time in the lake and to reconstruct the lake history by reference to the known ecology of present day species. In addition, a check was made as to whether ostracods were readily preserved in the sediment of a large drainage basin which was known to have periodically dried up and undergone pedogenic processes (Singh *et al*., 1981b). Since the sequence of pollen and spores from an adjacent core is known, comparison of data from the aquatic vegetation and ostracods is presented to assess the type of information the study of ostracod remains can provide.

Lake George lies in a large internal drainage basin covering about 930 km^2 in the Southern Tablelands of New South Wales (Fig. 1). This tectonically formed half graben is bounded in the west by the north-south trending Lake George Fault which forms a sharp escarpment of about 250 m above the lake floor; the floor has an overall altitude of 673 m (see Fig. 1: section A-B). The present water level of the lake varies extensively. During major droughts it falls rapidly and, on several occasions, has been completely dry (Burton & Wilson, 1973; Jacobson & Schuett, 1979). Ancient shorelines up to 37 m above the lake floor have been studied by Coventry (1976). Above this height, the lake would overflow westwards through the 500 m wide Geary's Gap (Fig. 1). Fluctuation in water levels over the last 160 years have been reviewed by Burton & Wilson (1973) and Jacobson & Schuett (1979). Coventry & Walker (1977) have described the geomorphology, surficial sediments and soils of the Lake George Basin with particular attention to abandoned shorelines. Recently, Singh *et al*. (1981a) studied the fire and vegetation histories recorded in core LG2 (8.6 m) which covered the last 350,000 years. Singh *et al*. (1981b) have also described the Late Cainozoic history from B.M.R. Scout Hole No. 4 (72 m) and core LG4 (36 m) taken in the northwestern corner of the lake (Fig. 1). The upper 2.94 m of core LG4, taken by Singh *et al*. (1981b) for palaeomagnetic determinations, provides the basis for the present study of lake level fluctuations during approximately the last 60,000 years and comparisons with results from palynological and facies analyses (Singh *et al*., 1981a, 1981b), and abandoned shorelines studies (Coventry, 1976; Coventry & Walker, 1977).
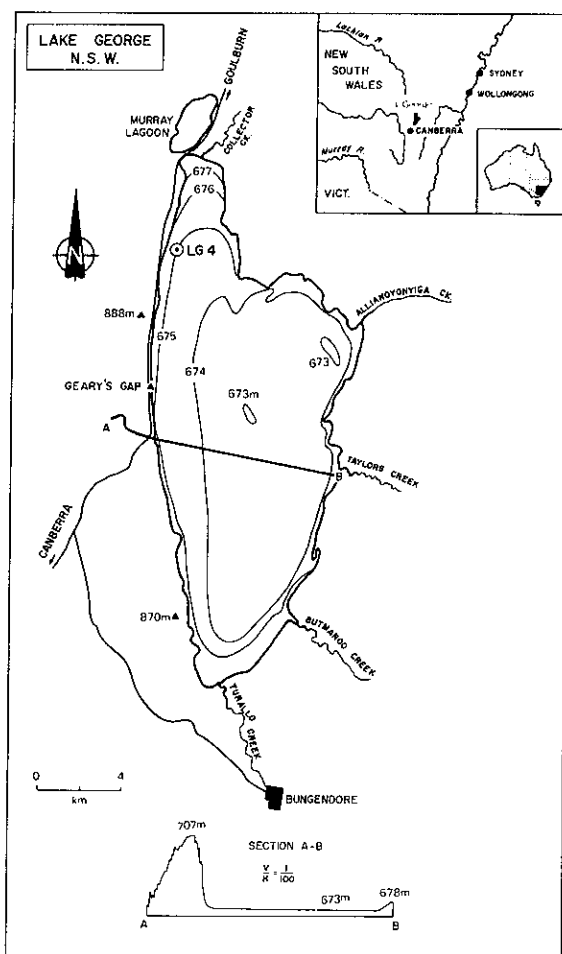
Fig. 1. Map showing the location of core LG4 in Lake George.

Methods

Because lithological changes in both cores LG2 and LG4 take place at the same depths (Singh, pers. comm.), all depths referred to in the present study correspond to the same levels in core LG2. Similarly, ^{14}C dates obtained for samples from various levels of core LG2 can be correlated with similar levels in core LG4.

One hundred and thirty-two samples, most weighing 10 g, were taken from the upper 2.94 m of core LG4 at 2 cm intervals; the core was cut into 50 cm sections. As the core consisted of grey, plastic to sandy or silty clay (Fig. 9), sediment compaction took place at some levels because of the coring procedure; fewer samples were taken from these intervals. Depth intervals for the samples were later adjusted so that all

samples would cover identical proportions of each 50 cm section of the core. This was done to allow more adequate correlation with core LG2 for which ^{14}C dates were available. All depths mentioned in Fig. 8 and in the text have been adjusted. Table 1 records the recovery in each core section and the adjustments required for each sample normally covering 2 cm. Numbering of the samples in the text refers to the upper limit of the sample in cm from the top of the core, preceded by the letters LG (e.g. sample interval 148-150.65 cm is labelled as LG148). All samples were treated with 10% H_2O_2 solution for approximately two months to dissociate clay particles because the core was dry and indurated when sampled for ostracods. Further procedures are identical to those mentioned in De Deckker (1982).

Ostracods, vertebrate and gastropod fragments, seeds and rootlets were recovered from the core. Information on the systematics and ecology of the ostracods (which all have living representatives) will be discussed separately, with additional information on the vertebrate fragments, prior to reconstructing the lake history. The gastropod fragments and seeds have not been identified but their presence is recorded in Fig. 8.

As many of the recovered ostracods were broken, valves could not be counted accurately. Estimates of the abundance of species is presented in Fig. 8. Compaction of sediment in parts of the core and drying out were the main causes of damage to the valves. The valves were not transported because there is no apparent sorting of valves into particular sizes (valves of adults and juveniles were most often found together).

Systematics and ecological information

All material illustrated in this paper is deposited in the ESCAP Collection held at the Bureau of Mineral Resources Geology & Geophysics, Canberra, under the repository numbers E880-E922.

Superfamily CYTHERACEA Baird 1850

Family LIMNOCYTHERIDAE Sars 1925

Subfamily LIMNOCYTHERINAE Sars 1925

Section of core (cm)	Length of core (cm)	Core recovery (cm)	Number of samples	Adjusted interval
top 0-50	50	48	24	Kept to 2 cm
50-100	50	48	24	Kept to 2 cm
100-149	49	49	25	Kept to 2 cm except bottom one is 1 cm
149-196	47	37	19	2.47 cm
196-244	48	30	15	3.2 cm
244-294	50	50	25	2 cm

Table 1. Recovery of samples from core LG4 and adjustments for compaction to standardize samples to a thickness of 2 cm.

LIMNOCYTHERE Brady 1867

LIMNOCYTHERE DORSOSICULA De Deckker 1981

1981a *Limnocythere   dorsosicula*   De Deckker, p. 43.

Ecology. Living specimens of this species have so far been collected in 4 localities: once at Lake Terangpom (2.03‰ salinity, pH 9.7) and once at South Nerrin Nerrin Lagoon (1.96‰ salinity, pH 9.2), both in Victoria, and a number of times at Lake Bathurst (where rare specimens were found between 2.7 and 3.3‰, pH 9 measured once) and The Morass, near Lake Bathurst (between 0.42 and 0.46‰, pH 8.2 measured once) in N.S.W., 25 km east of Lake George. *L. dorsosicula* is therefore indicative of fresh or slightly saline water (at least < 5‰). As a fossil, it has also been found in a core from Lake Bullenmerri, Victoria (De Deckker, 1981d). It seems to indicate permanent water conditions.

Superfamily CYPRIDACEA Baird 1845

Family   ILYOCYPRIDIDAE   Kaufmann 1900

ILYOCYPRIS Brady & Norman 1889

ILYOCYPRIS AUSTRALIENSIS Sars 1889 (Fig. 2)

1889 *Ilyocypris australiensis* Sars, p. 46.

Description. Rectangular and pitted shell which is occasionally covered with fine denticles especially along its periphery. Three main depressions on shell: a round one in centre, another above it just below the hinge line, and the vertically elongated third one starts in front just below the hinge line

and ends at mid-height between the other two. Greatest height at about one-fourth from anterior. Inner lamellae broadest anteriorly and selvage broad all along in both valves. 'Marginal ripplets' *sensu* Van Harten (1979) present in some specimens posteroventrally.

Remarks and ecology. The variability of the size, shape and ornamentation of *I. australiensis* valves has recently been documented and discussed in De Deckker (1981b). The ecological significance of these variations is not yet understood.

This species is present in temporary waters but has been found in low salinity lakes (4-7‰). The highest salinity record for the species is 10.37‰ measured once at Lake Kariah, Victoria. So far, *I. australiensis* has been found neither in deep lakes nor in permanent fresh lakes. As a fossil, this species has been found in a few samples from Lake Bullenmerri (De Deckker, 1981d) and in a trench dug 2 km west of the Walls on the lake floor of Lake Mungo, NSW.

Family CYPRIDIDAE Baird 1845

Subfamily   EUCYPRIDINAE   Bronstein 1847

MYTILOCYPRIS McKenzie 1966

MYTILOCYPRIS   PRAENUNCIA   (Chapman 1936) (Fig. 3)

1936 *Cypris praenuncia* Chapman, p. 298.
1978 *Mytilocypris praenuncia* (Chapman); De Deckker, p. 24.

Remarks and ecology. This species inhabits saline waters which are not necessarily ephemeral but which vary in salinity in different areas of Australia. In Victoria, the
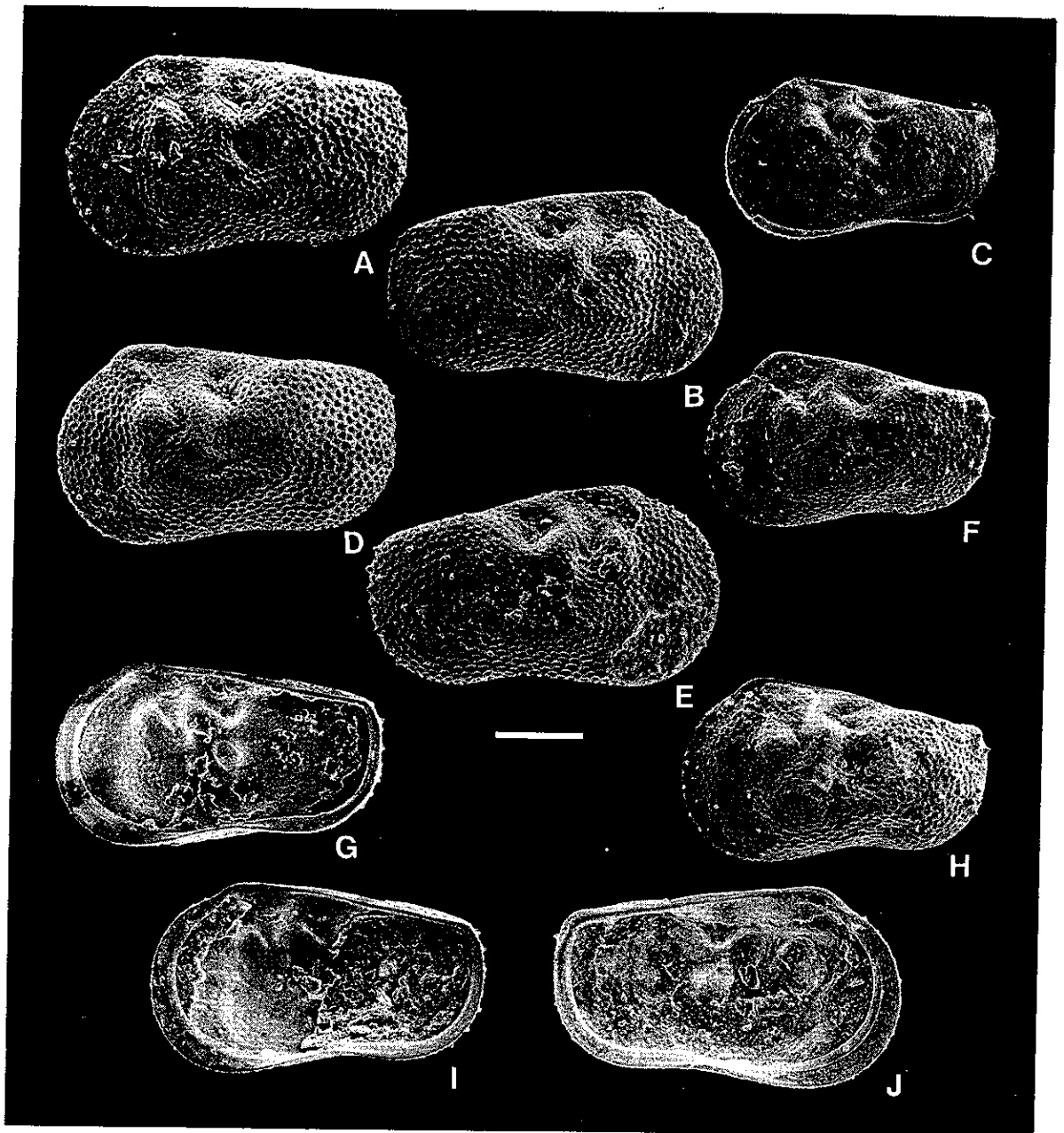
Fig. 2. Ilyocypris australiensis Sars 1894. A, LV external, LG173.7, E880. B, RV external, LG173.7, E881. C, juvenile RV internal, LG183.6, E882. D, LV external, LG188.5, E883. E, RV external, LG188.5, E884. F, juvenile LV external, LG188.5, E885. G, RV internal, LG183.6, E886. H, LV external, LG188.5, E887. I, RV internal, LG186.1, E888. J, LV internal, LG188.5, E889. Scale — 200μm. LG — Lake George, followed by adjusted depth in cm from top of core (see methods). LV, RV — left and right valves of carapace.

range in salinity is 7-42‰, whereas in South Australia, near the Coorong Lagoon, it is 12-35‰ with an additional record at 43‰ (De Deckker & Geddes, 1980).

Mytilocypris praenuncia was originally described from the Mallee area near the South Australian-Victorian border (Chap-man, 1936) and has since been found in a number of lakes in Victoria and South Australia. In some Victorian lakes, it can co-exist with *Platycypris baueri*, the latter then being found in low numbers. As a fossil, it is found in Holocene samples from Lakes Keilambete and Gnotuk in Victoria, where it

is associated on most occasions with *P. baueri* (De Deckker, 1981d). As the shell of this species is thin, complete valves are rare in the Lake George samples except for the specimens which became indurated with
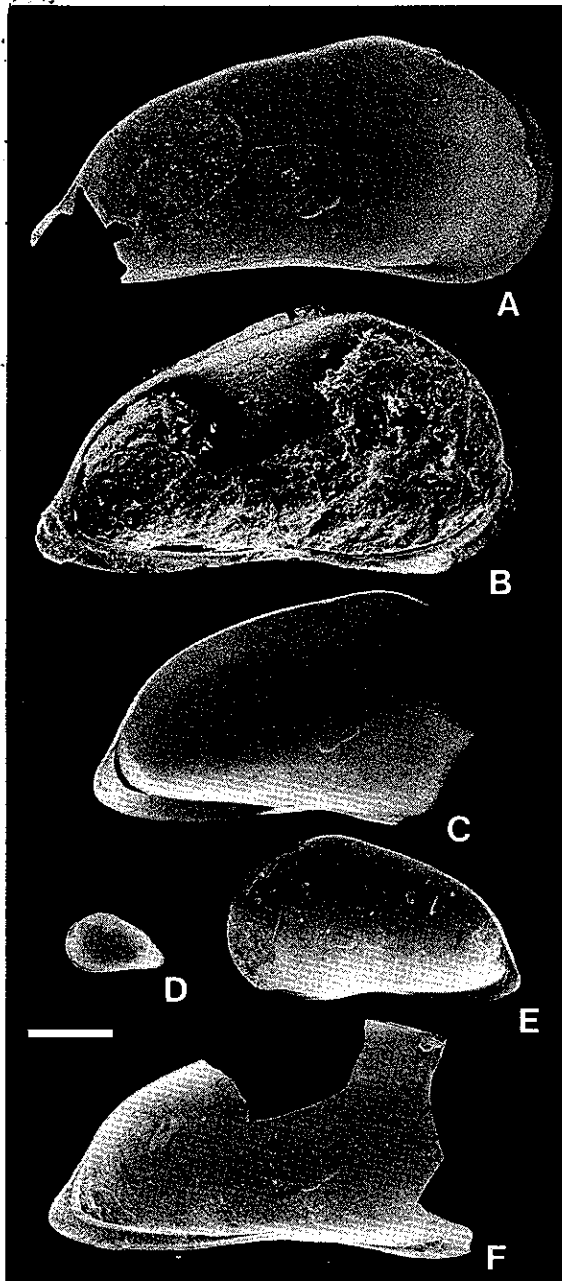

Fig. 3. *Mytilocypris praenuncia* (Chapman 1936). A, partly broken LV internal, LG173.7, E890. B, LV internal, LG134, E891. C, LV internal with anterior broken off, LG173.7, E892. D, juvenile RV internal, LG173.7, E893. E, juvenile RV internal, LG134, E894. F, LV internal with the anterior and dorsum broken off, LG173.7, E895. Scale — 500μm.

sediment and others on which a calcareous layer was precipitated. This phenomenon was also noticed for *P. baueri* which usually has a thin and brittle shell.

Subfamily PLATYCYPRIDINAE Hartmann & Puri 1974

PLATYCYPRIS Herbst 1957

PLATYCYPRIS BAUERI 1957 (Fig. 4).

1957 *Platycypris baueri* Herbst, p. 217.

Description. Valves smooth, very thin and oval to rectangular in shape. Greatest height at about two-thirds from anterior. Slightly concave ventrum at about one-third from anterior. Valves very narrow in dorsal view. Inner lamellae very small posteriorly and broader only anterodorsally. Central muscle field small. Juveniles usually circular to oval in shape as size increases. For these, shell still slightly concave at one-third from anterior in ventral region.

Remarks and ecology. This halobiont ostracod (*sensu* De Deckker, 1981e) inhabits waters with a broad salinity spectrum of 5-195‰ (De Deckker & Geddes, 1980). At low salinities, it is in low numbers but usually co-exists with *Mytilocypris* (either *M. splendida* or *M. praenuncia*). It is present in permanent and ephemeral saline lakes, is a good swimmer, but is also found on the lake floor crawling in soft mud. The presence of a few fossil carapaces in some samples seems to indicate that *P. baueri* is able to burrow into sediment, perhaps to avoid desiccation when the lake dries up, otherwise valves would separate after death.

Few valves were found complete except those which had become indurated or covered with secondary carbonate. In some samples, the ostracod shell has been dissolved away to uncover the indurated sediment (Fig. 4 G, H, J). These are still identifiable because they bear the characteristic flat ellipsoidal shell with a notch anterodorsally in front of the hinge line. Small fragments of *P. baueri* can also be recognized by the thin, narrow inner lamella combined with the very narrow vestibulum, as well as by the restricted central muscle
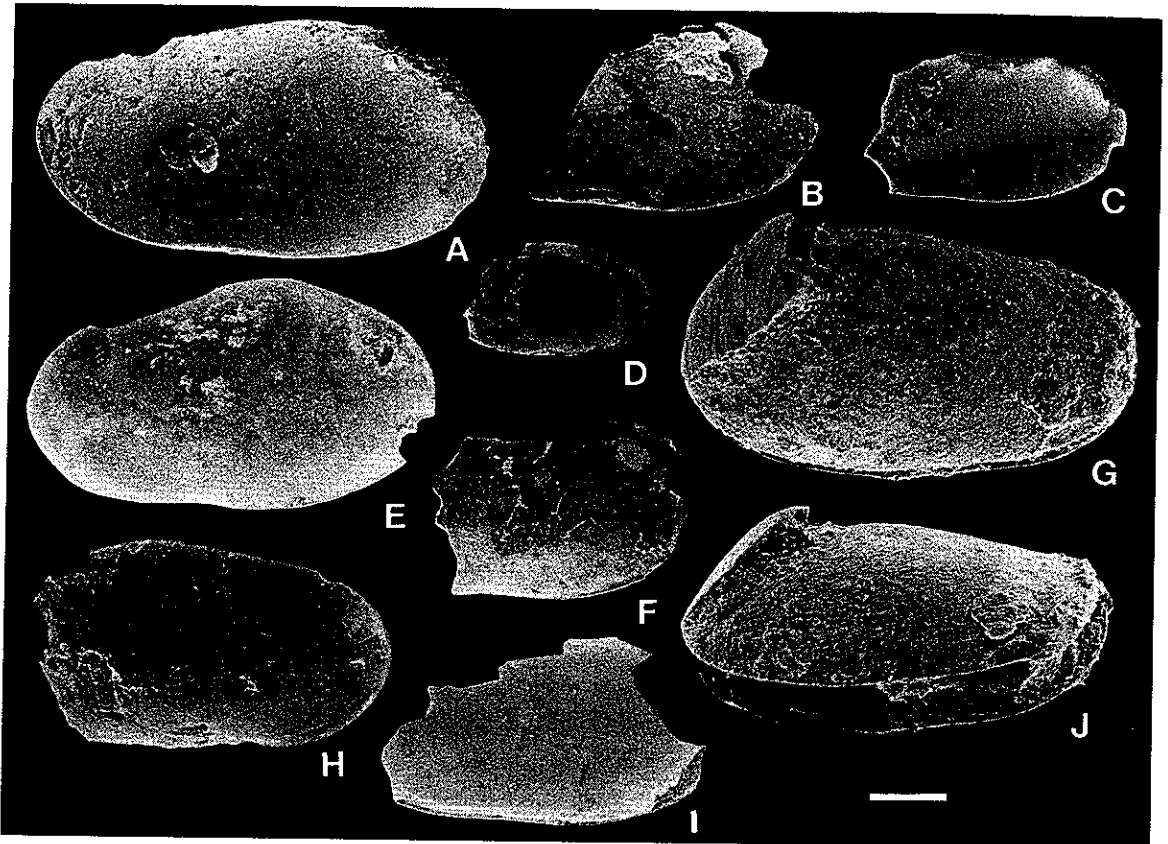
Fig. 4. Platycypris baueri Herbst 1957. A, LV internal, LG134, E896. B, LV internal fragment, LG128, E897. C, RV internal fragment, LG128, E898. D, LV internal fragment, LG128, E899. E, LV external LG134, E900. F, LV external fragment, LG128, E901. G internal mould of C showing right side and fragment of RV, LG134, E902. H, partly broken internal LV, LG134, E903. I, LV internal fragment, LG128, E904. J, same specimen as G but tilted to show lateroventral view. Scale — 250μm.

field area with its very small muscle scars. *P. baueri* has been recognized as fossil from Holocene sediments of Lakes Keilambete and Gnotuk in Victoria and Pillie Lake in South Australia (De Deckker, 1981d). The Victorian specimens are better preserved than those from Lake George because of the absence of desiccation or compression.

Subfamily DIACYPRIDINAE McKenzie 1978

RETICYPRIS McKenzie 1978

RETICYPRIS PINGUIS De Deckker 1981 (Fig. 5)

1981c *Reticypris pinguis* De Deckker, p. 93.

Remarks and ecology. R. pinguis has only been found living today in Lake George where it has been collected at different times in waters ranging in salinity from 4-35.4‰. It has not been found in fresh water pools adjacent to Lake George today nor in the nearby permanent 'fresh' Lake Bathurst (2.7-3.3‰) or The Morass (0.42-0.46‰), and is therefore euryhaline and unlikely to live (and reproduce) for a whole season in fresh water. *R. pinguis* has been found in association with *I. australiensis, I. viridulus* and *C. novaezelandiae* in samples taken in a trench dug 2 km west of the Walls on the lake floor of Lake Mungo, N.S.W. and given to me by Dr J.M. Bowler. Similarly, *R. pinguis* is found with *I. australiensis* and *I. viridulus* in 2 samples from Lake George and in one with *L. dorsosicula* (see Fig. 8). Care must be taken in interpreting this association because the presence of these ostracods together does not necessarily mean

that they co-existed in the lake. It is unlikely that they did because their salinity tolerances differ.

R. pinguis is rare in the Lake George samples. A number of specimens are broken and some even show signs of being reworked, a phenomenon likely to have been caused by the lake drying up after the death of the animals. This is not surprising as *R. pinguis* lives today in shallow water (down to 3 cm) in which wave action caused by winds can easily damage the empty ostracods shells lying on the lake floor (sheets of water almost 5 cm deep on the lake floor have been seen to move for 1 km or more in less than 1 hour).

Subfamily   HERPETOCYPRIDINAE Kaufmann 1900

ILYODROMUS Sars 1894

ILYODROMUS VIRIDULUS (Brady 1886) (Fig. 6)

1886 *Cypris viridula* Brady, p. 88.
1889 *Herpetocypris viridula* (Brady); Sars, p. 41.
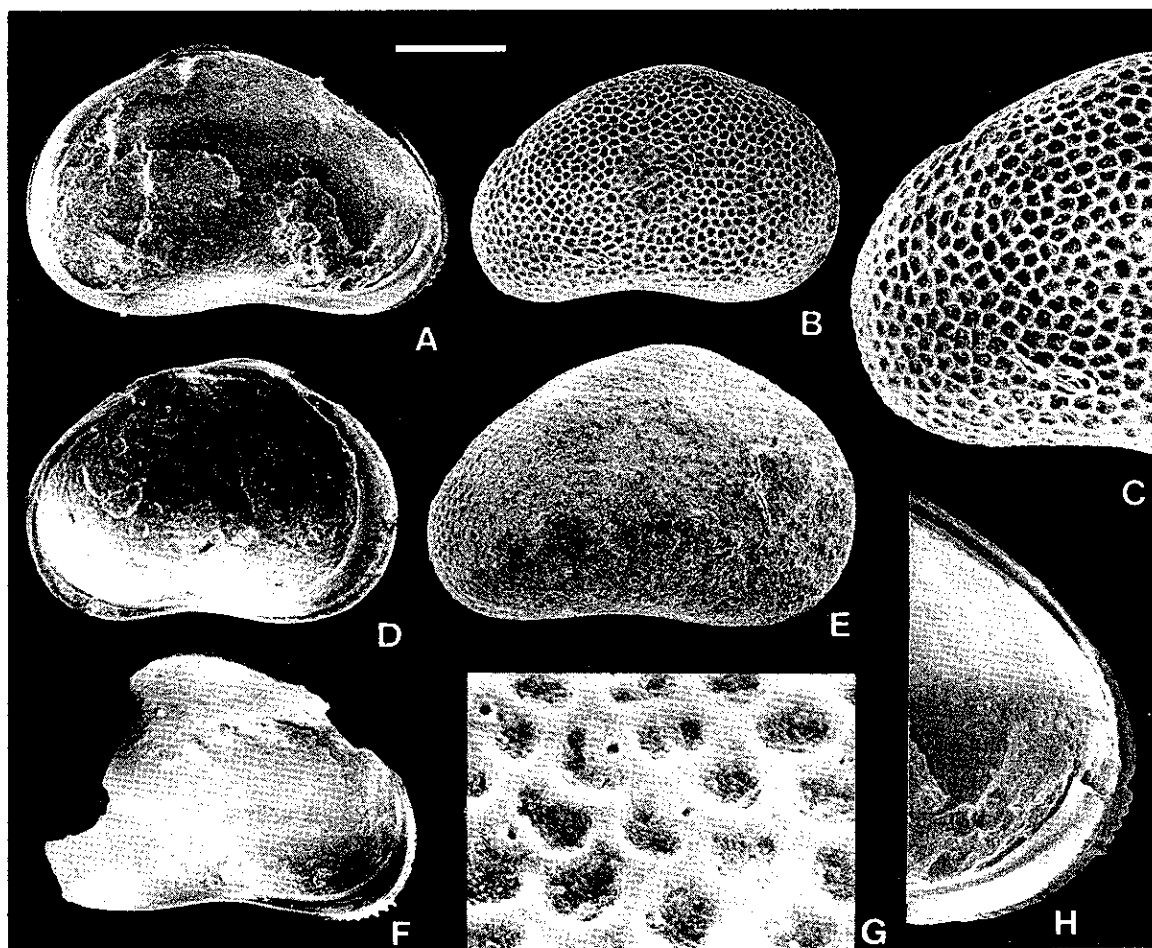1894 *Ilyodromus viridulus* (Brady); Sars, p. 39.

Fig. 5. Reticypris pinguis De Deckker 1981. A, RV internal, LG272, E905. B, RV external, LG30, E906. C, RV external showing posterior detail of B. D, LV internal, LG30, E907. E, RV external, LG272, E908. F, RV internal with the anterior and dorsum broken off, LG272, E909. G, RV external showing detail of B. H, RV internal showing posterior detail of A. Scale — 250μm.

Description. Smooth ellipsoidal to rec-
tangular shell with both ends broadly
rounded and dorsum almost horizontal in
hinge area. Ventrum slightly concave in
mouth region. Greatest height at about one-
third from anterior. Surface of shell oc-
casionally shows fine hexagonal grooves
anteriorly and posteriorly. Left valve slightly
larger all along. Shell narrow in dorsal view.
Internally, inner lamellae at least twice as
broad anteriorly. In left valve, selvage near
edge of valve anteriorly and often broad and
follows inner margin posteriorly and ven-
trally where it is broadest. In right valve,
selvage faint and peripheral all along except
posteriorly where it is placed at one-third of
inner lamella width from edge of valve.
Anterior inner lamella often faintly
reticulated. Juveniles more elongated than
adults.

Remarks and ecology. I. viridulus was raised
by Sars (1889) from dried mud from 2
freshwater localities near Rockhampton,
Queensland. It is considered to be a
freshwater species. So far, it has never been
found in slightly saline waters. As a fossil, it
is common in samples from a trench dug 2

km west of the Walls on the floor of Lake
Mungo, N.S.W.

The diagnostic feature of this species is its
overall shape with the almost flat dorsum
and the broad inner lamellae. A faint
reticulation of the shell is occasionally visible
on the external surface on some specimens
whereas others are smooth or faintly striated
longitudinally. These striations, typical of
most *Ilyodromus* species, are thought to act
as a strengthening feature for the shell which
is often very thin (compared with other
ostracods). In *I. viridulus*, such striations
may be unnecessary as the shell is rather
thick. On some living specimens striations
are usually restricted to the anterior and
posterior areas of the valves, although they
can cover the shell. *I. substriatus* Sars 1894,
from New Zealand, has a shell outline and
inner lamellae similar to those of *I. viridulus*
but further study of the soft parts is
necessary to determine whether or not the
species are the same.

Vertebrate fragments

Fish bones consisting of mostly vertebrae
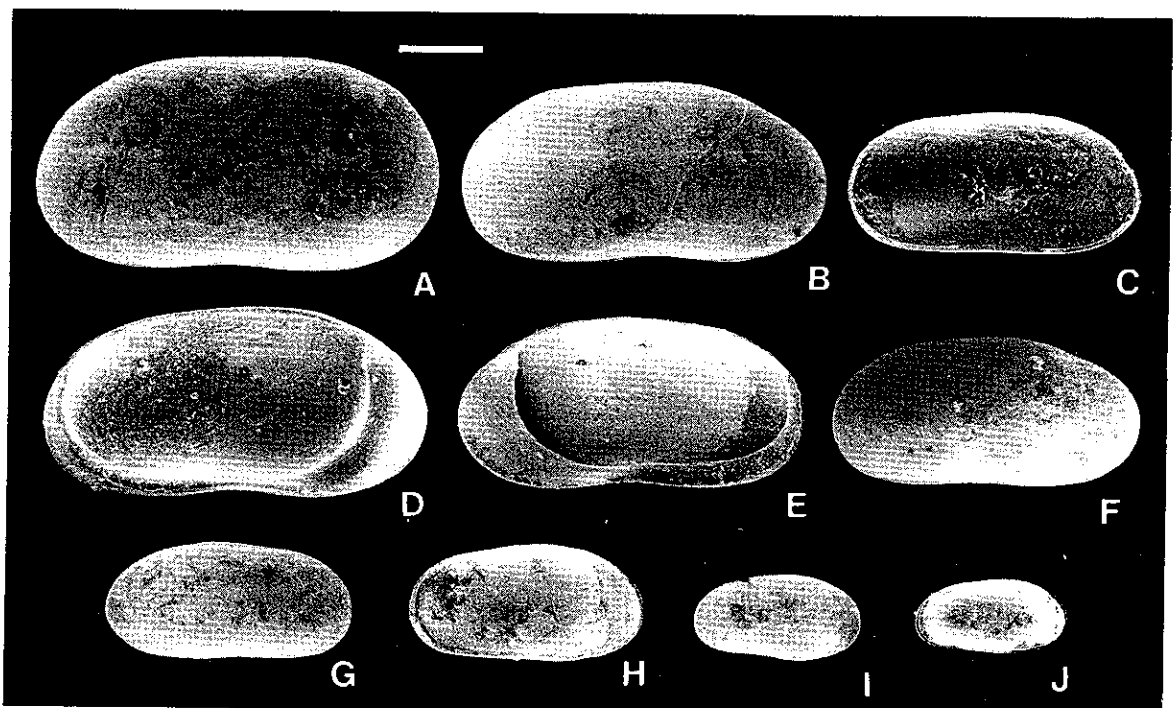but with rare jaw fragments (Fig. 7) were

Fig. 6. Ilyodromus viridulus (Brady 1886). A, LV external, LG149, E910. B, RV external, LG149, E911. C, juvenile
RV internal, LG149, E912. D, LV internal, LG149, E913. E, RV internal, LG149, E914. F, RV external, LG149,
E915. G, juvenile LV external, LG149, E916. H, juvenile LV internal, LG149, E917. I, juvenile LV external,
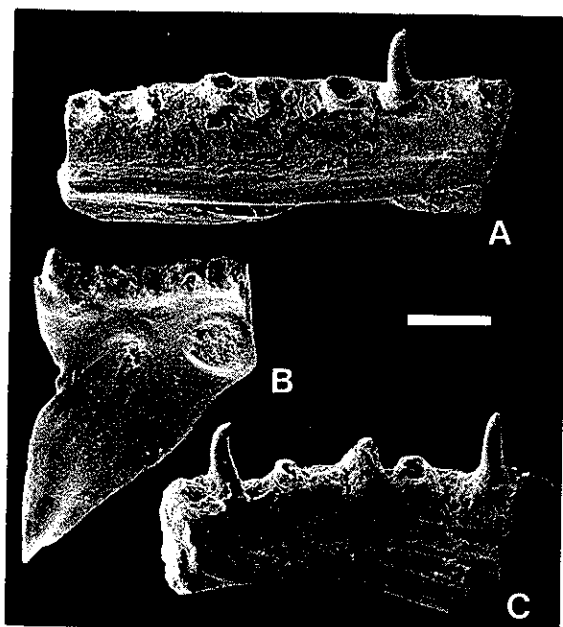LG149, E918. J, juvenile RV internal, LG149, E919. Scale — 250μm.

Fig. 7. Fish fragments. A-C, jaw fragments, LG114, E920-922. Scale — 500μm.

recovered in from a number of samples. Although the fish fragments indicate the existence of permanent water, these conditions can only be extrapolated for the immediate vicinity of the interval in which the fossils were found because in places there is evidence of reworking. Abundantly, mainly broken fish bones are present in sample LG114, which is interpreted as having been deposited at the shore of the lake.

Detailed study of the core

The zonation followed here is independent of the pollen zonation of Singh *et al.* (1981a), boundaries between the zones being placed where obvious changes in hydrological regime for the lake are detected through particular association of ostracod species and other fossils when ostracods are absent. The distribution of fossils is given in Fig. 8.

Zone 1 (0-20 cm = LG1-18). No ostracods were recovered. The presence of rootlets in most samples and of angular quartz grains in all samples indicates that the lake was either dry or ephemeral; the quartz grains could

not have been deposited during a deep water phase. Although it is known that lake level reached the coring site for short periods of time during the last 160 years (Jacobson & Schuett, 1979), the absence of ostracods in the core can be explained in three ways: valves have either been destroyed during dry phases, or transported (by winds deflating sediment from the lake floor or by wave action during a fluctuating lake level), or ostracods had insufficient time to become established in the lake during 'short' wet phases.

Zone 2 (20-92 cm = LG20-90). Ostracods are few in numbers and even absent in some samples. *I. viridulus* and *R. pinguis* are poorly represented and are rarely found together. They probably indicate ephemeral water for the lake, explaining the absence of vertebrate fragments in all samples except LG38 and 42. Water was saline when *R. pinguis* was present in samples LG20, 30, 34, 44, 50 and 52. The presence of *Mytilocypris* sp. in sample LG82 also indicates slightly saline water for that level. *I. australiensis* with *R. pinguis* in sample LG44 could point to slightly saline conditions as the former occurs today in water with a salinity of 7‰, with one extreme record at 10.37‰. Samples LG78 and 80, which yield substantial numbers of *I. viridulus* indicate a short, but definite, freshwater phase. This appears to also be the case for samples LG22-28 and LG70-72 where *I. viridulus* is found in smaller numbers.

Many fragments of large ostracods were recovered from a number of samples (see Fig. 8), but it is impossible to determine whether they belong to halobiont mytilocypridinid ostracods or large freshwater ostracods such as *Eucypris virens* (Jurine 1820) or *Heterocypris leana* (Sars 1896).

Secondary carbonate nodules in the middle (LG44, 46, 52 and 62) and lower parts of the zone (LG80-88) point to soil formation at some stages. The precise time of soil formation is not known because pedogenesis can affect older layers and destroy evidence of a lacustrine phase by leaching ostracod shells. Fragments of calcareous precipitates around stems (LG60, 66-74) cannot be fully explained, but could indicate carbonate-rich waters.

Zone 3 (92-112 cm = LG92-110). Abundant ostracods in the lower part of this zone (LG100-110) indicate that the lake was full,
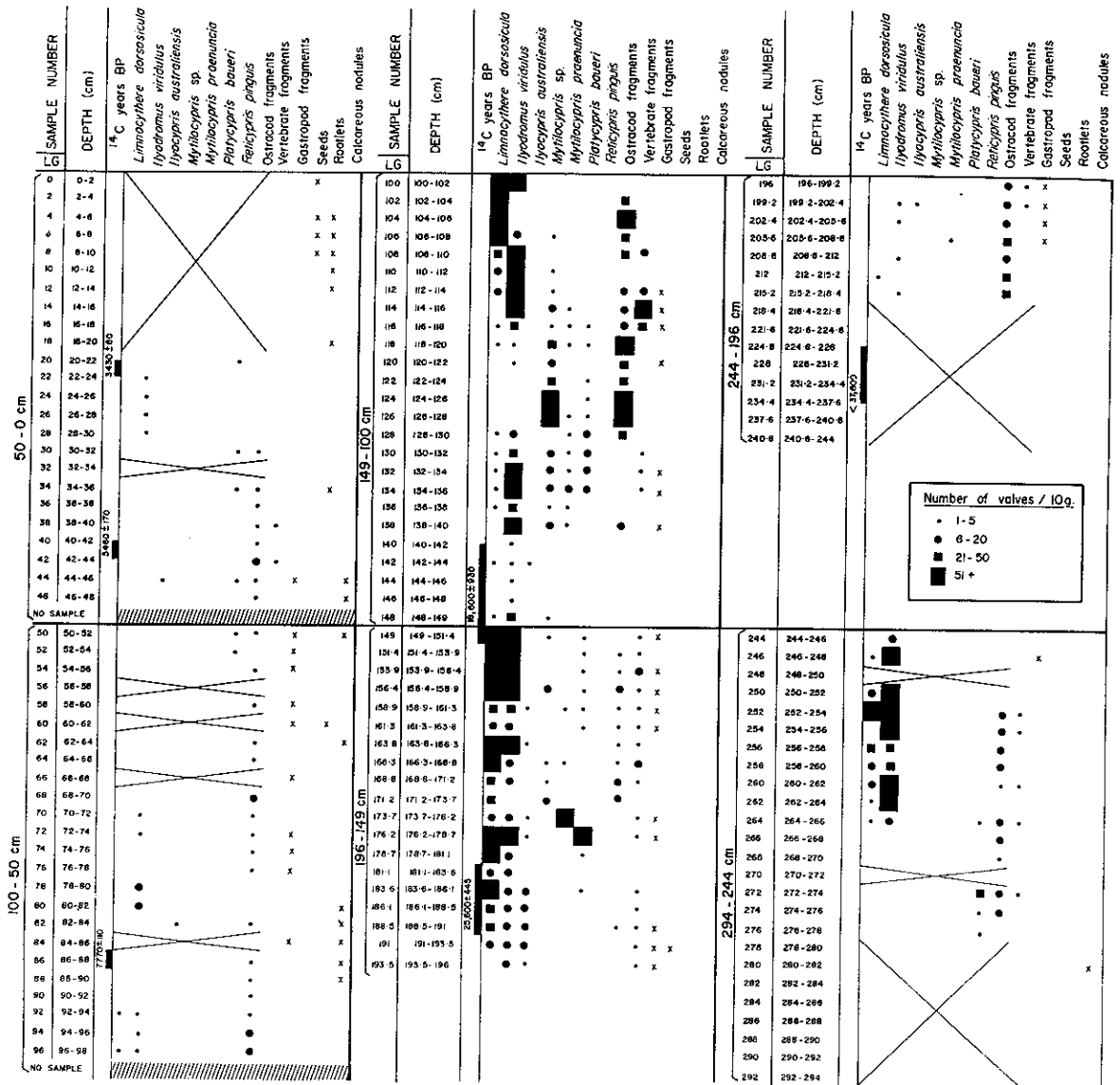
Fig. 8. Distribution of fossil ostracods and other remains obtained from core LG4 from Lake George. For sample distribution in the core, refer to Table 1. ^{14}C dates from Singh et al. (1981b). Small crosses indicate only the presence of remains in the samples and large crosses indicate the absence of any ostracods.

and there are sufficient adult and juvenile valves in these samples to be sure that reworking did not take place. Water salinity fluctuated between fresh and slightly saline as indicated by the co-existence of *I. viridulus* with juveniles of the halobiont *Mytilocypris* (LG106, 110). At other times, especially for samples LG100-104, 108, water was probably fresh. There is no evidence that water was permanent except for sample LG108 which contains vertebrate

fragments. An abundance of *L. dorsosicula* probably indicates permanent water.

Zone 4 (112-118 cm = LG112-116). This is a transitional zone between the freshwater one above and the saline one below. Faunal components typical of both zones are present in samples LG112-116, with faunal elements of zone 5 decreasing upwards and being replaced progressively by higher numbers of faunal elements typical of zone

3. Water was permanent, but it is likely that sample LG114 was located near the lake shore because of abundant vertebrate fragments, and the presence of only adult (sorted) valves of *I. viridulus*. A similar environment is postulated for sample LG116, although there are fewer ostracod valves and vertebrate fragments.

Zone 5 (118-130 cm = LG118-128). Water was ephemeral and saline as indicated by the presence of *M. praenuncia* and rare *P. baueri*. Water salinity could have reached 43‰. The absence of *I. australiensis* which can inhabit saline waters up to 7‰ probably indicates that salinity was above that value. Rare *I. viridulus* valves are juveniles and therefore they do not indicate a freshwater phase with certainty. The absence of vertebrate fragments does not necessarily indicate the ephemerality of the lake water. Fishes which can live in saline waters (for review see Chessman & Williams, 1974) probably did not reach the lake because there was no connection between Lake George and other major saline waters to allow for their introduction. The presence of freshwater fishes is easily understood as several small rivers are connected to Lake George.

Zone 6 (130-140 cm = LG130-138). The co-occurrence of the freshwater ostracod *I. viridulus* and the halobiont ostracods *M. praenuncia* and *P. baueri* indicates that water was permanent at times (LG130-134) and fluctuated between fresh and slightly saline. Surprisingly, *L. dorsosicula*, which is known to live in waters up to 4‰ salinity is rare in the samples. The bottom two samples of this zone (LG136, 138) probably represent a fresher phase because halobiont ostracods are rare.

Zone 7 (140-148 cm = LG140-146). Water was probably absent at most times and at others very likely ephemeral because ostracods are rare. Those present indicate freshwater conditions.

Zone 8 (148-196 cm = LG148-193.5). A high percentage of freshwater ostracods characterizes this zone. In some samples, halobiont species co-exist with freshwater ones but they are usually in very low numbers. Hence water was likely to have been fresh at most times. Exceptions include samples LG173.7 and 176.2 in which are found respectively, many *M. praenuncia* and *P. baueri*. A saline phase of up to 42‰ is

postulated for sample LG173.7, whereas fluctuation between fresh and saline water is inferred for LG176.2 because in the latter *P. baueri* occurs with freshwater species. Water was permanent at most times, except in LG171.2, 178.7-181.1, as indicated by the presence of vertebrate fragments.

Below sample LG176.2, water remained fresh, even though *I. australiensis* which can tolerate salinities up to 7‰ is present in most samples, because halobiont ostracods are absent or rare in all samples. Water level probably dropped when *I. australiensis* was present in the lower portion of the zone (LG183.6-193.5) as this species has never been found in deep lakes. This would explain the low numbers of *L. dorsosicula* in most samples.

Zone 9 (196-218.4 cm = LG196-215.2). Complete ostracods are rare but are found together with a number of broken valves belonging to unidentifiable large and small ostracods. The lake level rarely reached the coring site but when it did, ostracod valves were reworked. This is further suggested by the absence of vertebrate fragments below sample LG199.2. Water could have been saline for sample LG205.6, as indicated by the rare valves of *M. praenuncia*.

Zone 10 (218.4-244 cm = LG218.4-240.8). Ostracods are absent in this zone. The lake was either dry for the entire zone or pedogenesis at the top of the zone destroyed evidence of a wet phase.

Zone 11 (244-264 cm = LG244-262). The lake level reached the coring site and water was fresh. There is little indication that water was permanent except for samples LG250, 252 and 258. This is further substantiated by low numbers of *L. dorsosicula* in most samples. Sample LG248 is devoid of ostracods, indicating a lower lake level or a completely dry lake bed.

Zone 12 (264-278 cm = LG264-276). Ostracods are rare or absent in most samples, though *R. pinguis* in four samples indicates saline conditions. Water was ephemeral at most times except perhaps at levels LG264 and LG272 where vertebrate fragments are found with many ostracods (compared with other samples of this zone). The absence of ostracods at level LG270 probably represents a dry phase, but this is not completely certain as the ostracods could have been destroyed at a later stage.

Zone 13 (278-294 cm = LG278-292). No ostracods are found — the lake was either dry for the entire zone or pedogenesis at the top of this zone leached out evidence of a wet lacustrine phase by dissolving calcareous shells.

History of Lake George

Interpretation of the ostracod data

[14]C dates for six levels of core LG2 taken from Singh *et al.* (1981a) are transferred to corresponding levels in core LG4 (see Figs 8, 9). This transfer cannot be made below 200 cm because sedimentation rates are unknown, and there is evidence of pedogenesis. The history of the lake is given in schematic form in Fig. 9 and described below.

Between the present and ~ 3,200 yBP (= 0-20 cm) the lake was often dry and water was ephemeral.

~ 3,200- ~ 8,500 yBP (= 20-92 cm) the lake was characterized by ephemeral waters which were saline at various intervals (LG20, 30, 34, 44, 50, 52 and 82), but there were short freshwater phases at levels LG22-28 (~ 3,200- ~ 4,000 yBP), LG70-72 (~ 7,000 yBP) and LG78-80 (~ 7,500 yBP). Soil was formed on a number of occasions (LG44, 46, 52, 62 and 80-88).

~ 8,500- ~ 12,200 yBP (= 92-112 cm) water was present during the interval LG92-100 (~ 8,500- ~ 10,200 yBP), but the lake was full of fresh water between LG100-110 (~ 10,200- ~ 12,000 yBP) except for short periods of slightly saline water (LG106, 110).

~ 12,200- ~ 13,500 yBP (= 112-118 cm) this is a transitional zone between the mainly fresh one above and the saline one below. At levels LG114 and 116, the shoreline of the lake was near the core site at some stage.

~ 13,500- ~ 15,600 yBP (= 118-130 cm) water was ephemeral and saline (salinity could have reached 43‰).

~ 15,600- ~ 17,400 yBP (= 130-140 cm) water was permanent at all times and fluctuated between fresh and slightly saline. The bottom part of this zone (LG136-138) represents a fresh phase.

~ 17,400-19,100 yBP (= 140-149 cm) water was probably absent at most times near the core site and was ephemeral when present.

~ 19,100- ~ 27,600 (?) yBP (= 149-196 cm) water was likely to have been fresh and permanent at most times. The most diverse fauna in the core is present in the interval LG149-158.9. Water level was consistently high between ~ 19,100 and ~ 20,700 yBP, and for a short period around 21,600 yBP (LG163.8). Saline conditions prevailed for levels LG173.7 and 176.2 (~ 23,500-~ 23,800 yBP).

Dates for the events described below are not provided because only one ^{14}C date of > 37,800 yBP is available for level 230-240 cm (Singh *et al.*, 1981a). The approximate date of 60,000 yBP for the bottom of the core (294 cm) is postulated from the date of 720,000 yBP at 17.4 m in core LG4 where the Brunhes-Matuyama boundary is placed (Singh *et al.*, 1981b), and from the pollen record (Singh *et al.*, 1981a).

Between 196-218.4 cm the lake level rarely reached the core site, but water could have been saline for sample LG205.6; 218.4-244 cm — the lake was dry, with the level between 230-240 cm being dated as > 37,800 yBP; 244-264 cm — permanent fresh water was present at most times during levels LG250, 252 and 258, and the lake could have been dry at level LG248; 264-278 cm — water was saline at most times and was ephemeral except for indications of permanent water at LG264 and 272; 278-294 cm — the lake was either dry or pedogenesis destroyed the record of a lacustrine phase.

Comparison with previous work

Coventry (1976) and Coventry & Walker (1977) identified abandoned beaches from Lake George and were able to plot a water level curve for the lake for the last 27,000 years. Four major strandlines were recognized; the maximum lake level was registered sometime between 27,000 and 21,000 yBP and since then, the lake has been lower. Other high levels occurred at about 15,000, 5,500 and 3,500 yBP and probably about 8,000 yBP. These high stands, except the one at 5,500 yBP, are also recognized from the recovery of ostracods. The maximum lake level of Coventry (1976) and Coventry & Walker (1977) during the period 27,000-21,000 yBP corresponds with that postulated here between 19,100 and 27,600 (+ ?) yBP, the younger limit of the phase (down to ~ 19,000 yBP) being determined from the ostracod data, although limits of
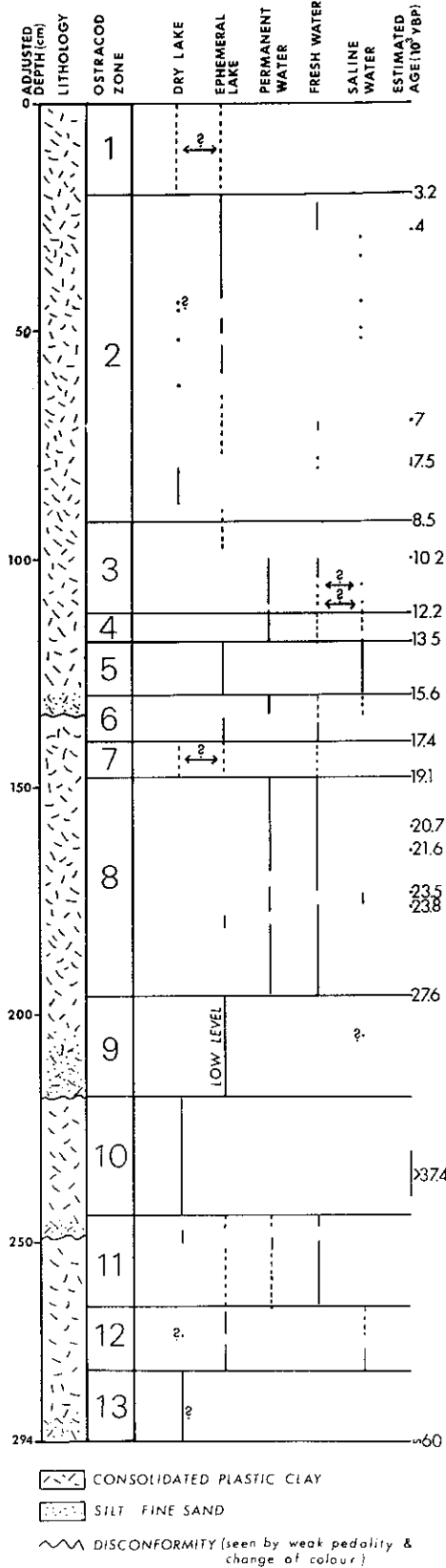
confidence of the ^{14}C dates could make this lower limit older by up to 1,000 years. No strandline was identified by these workers coinciding with that established between 10,200 and 12,000 yBP, for a fresh water phase based on the ostracod data; a strandline of that age could have easily been destroyed during a younger high water phase. The permanent fresh water phase identified here between 244-264 cm, for which no date is available but which is thought to be older than 37,000 yBP (as level 225-235 cm => 37,800 yBP), has also not been identified by Coventry & Walker.

Singh *et al.* (1981b), on the basis of facies analyses and records of plant microfossils from cores LG2 and LG4, identified a number of short phases of 'fresh water spells' and other longer fresh water intervals which all correspond reasonably well to those identified here. Those identified by Singh *et al.* (1981b) as calculated from their diagrams, are as follows: short spells of fresh water around 3,500, 5,000 and 13,500 yBP; long fresh water phases between 5,500-6,500, 7,500-10,000, 19,000, 21,000 and 23,000-31,000 yBP. The long fresh water phase between 5,500 and 6,500 yBP with the short spell of ephemeral water is not recognized in the present study; similarly part of the 23,000-31,000 yBP fresh water phase cannot be identified from the ostracod data, which instead indicate rare wet phases which reached the coring site and even a slightly saline phase — all these older than ~ 27,600 yBP. The permanent fresh water phases based on ostracod information for the ~ 10,200-~ 12,000 yBP and ~ 15,600-~ 17,400 yBP periods are supplemented by the algal record of *Botryococcus*, an indicator of open water conditions (Singh *et al.*, 1981b). The other phases distinguished by Singh *et al.* (1981b) closely coincide with those recognized here. Even the permanent fresh water phase indicated by the ostracod data between levels 244-264 cm falls within the boundaries of a large fresh phase described by Singh *et al.* (1981b). The slight discrepancies in the timing of some fresh water phases obtained from the different

Fig. 9. Diagram showing the lithological log of the upper 2.94 m of core LG4, the position of the 13 ostracod zones in relation to the adjusted depths and presenting the history of Lake George for the last 60,000 years. Timing of events is estimated from ^{14}C dates from Singh *et al.* (1981a).

studies will have to be checked by supplementary ^{14}C dates, but this might prove to be a difficult task, unless more cores are taken, because little organic matter is present in the sediment.

Conclusions

The present study shows that data derived from ostracods lead to conclusions similar to those obtained by Coventry (1976) and Coventry & Walker (1977) from dated stranded beach lines of the lake, and by Singh *et al*. (1981b) from facies changes and plant microfossils. Ostracods can indicate broad changes in water quality (fresh to saline) and the type of water body (ephemeral or permanent) within a lake. Consistently high water levels coincide with a high diversity of ostracod species because of the increased availability of 'niches'. Low water levels lead to the reworking of sediments and of ostracods and cause sorting and breakage of ostracod valves. One problem that still remains unsolved is an explanation of the absence of ostracod valves in some samples — were they absent because the lake was dry, or were they originally deposited during a lacustrine phase and later dissolved by pedogenic processes?

Acknowledgements

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