Large Australian lakes during the last 20 million years: sites for petroleum source rock or metal ore deposition, or both?

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SUMMARY: Three basic 'regimes' of large lakes are recognized: (1) deep lake, (2) lake with ephemeral (and shallow) water, and (3) dry lake. The characteristics of these three lake types are discussed with regard to the composition of their water and sediment chemistry, but also to their potential for the production and preservation of organic matter, as well as the adsorption and accumulation of metals. Large Australian lakes, some with a sedimentation record spanning the last 20 million years, are examined in line with the above concept. Because of the low sedimentation rates in those lakes and the present-day water chemistry predominantly leading to the precipitation of gypsum and halite (especially in the groundwater below the lakes), it appears that any organic matter that would have been produced in the lakes during their carbonate phase in Miocene time would have been consumed by bacterial activity mainly in the groundwater. It is therefore suggested that the search for sites of metalliferous accumulation may prove more rewarding than will exploration for oil within sediments deposited since the early Miocene. As a comparison with large lakes on other continents, suggestions are presented as to what would have happened if sedimentation rates were much greater and if the lakes were in proximity to volcanism.

Introduction

In recent years there has been increased interest in the economic aspects of large lakes. Not only have the evaporites received much attention, but there is now ample recognition that lake basins can host significant quantities of petroleum source rocks as well as being sites for metalliferous deposits of economic importance. Already, a number of models have been proposed on lacustrine sedimentation associated with petroleum source rocks (Demaison & Moore 1980; Friedman 1980; Bauld 1981; Dean 1981; Kirkland & Evans 1981; Eugster 1985) and ore deposits (Renfro 1974; Eugster 1985).

The data presented here looks at the situation of Australian lakes and their deposits spanning the last 20 million years to ascertain their economic importance with regard to petroleum and metalliferous deposits. Because of the prescribed short length of this article, emphasis is placed on a series of schematic diagrams describing the conditions under which organic matter and metal ions occur in lakes and also those circumstances under which they can be preserved and become economically important. Although all the examples presented here are based on Australian sites, conditions encountered on other continents (viz. high sedimentation rates and proximity to volcanism, neither of which occur in Australia), are discussed with reference to petroleum source rocks and metalliferous deposit potentials.

Three basic lake types

De Deckker (1987) distinguished three lake types (which, accordingly, relate to hydrological regimes) in his description of the biological and sedimentary features characteristic of Australian salt lake facies. The first type is a *permanent* lake because it retains perennial water; the second occasionally fills up and therefore retains *ephemeral* water; and thirdly, there is the lake which continuously remains *dry*. For brevity, those three lake types are mentioned throughout the text and are referred to graphically in a basic triangle (Fig. 1). Respective characteristics of these lake types are also presented on triangular diagrams (Figs 1, 4, 5). For example, an increase in aridity (viz. an increase in the evaporation/precipitation (E/P) over the lake) will change the status of a lake, from permanent to ephemeral, and with further increase in E/P the lake will finally become dry (see Fig. 1). In addition, permanent lakes are usually characterized by minimal physico-chemical changes in comparison to those witnessed in ephemeral lakes. Nevertheless, in the case of permanent lakes, some parameters do change over time like oxygen levels, temperature etc. Accordingly, this can have significant implications for the aquatic biota. Some organisms will have to withstand the rapid changes affecting their host environment; some may barely survive through these changes, whereas others will require these changes during their life cycle (e.g., to hatch in low salinity water and later on thrive and reproduce in high salinity water). On the

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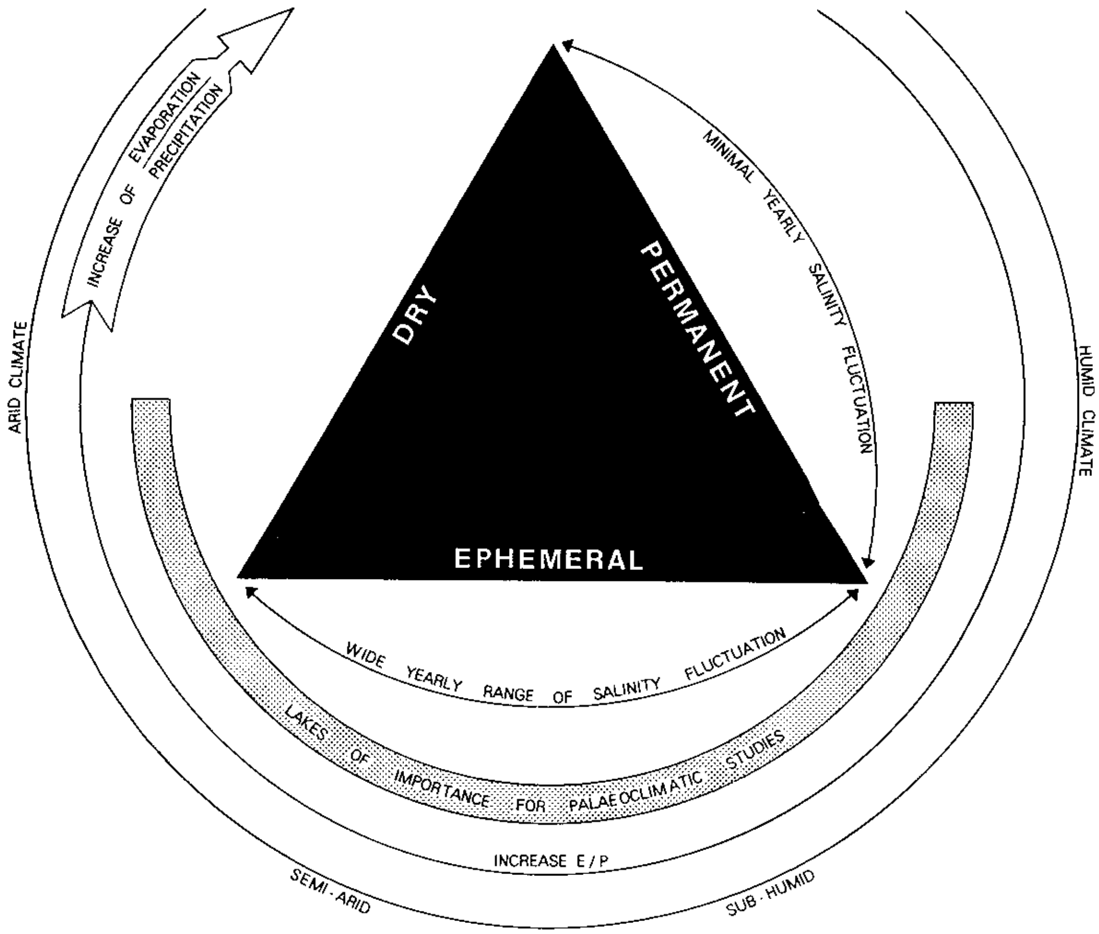


FIG. 1. Schematic triangular diagram showing the relationship between the three basic lake types and climatic conditions and salinity fluctuations (the latter summarizing other physico-chemical conditions like dissolved oxygen levels, temperature etc.).

other hand, organisms living in ephemeral water would tend to require particular and constant physico-chemical conditions to live and reproduce, and consequently would be unable to tolerate dramatic changes of their environment. However, it is more than likely that only a few species will be found inhabiting both permanent and ephemeral systems. Since a variety of organisms can be linked to the production and accumulation of organic matter and their association to metals in lakes (see below), it is necessary to identify the lake types in which those organisms live, and also where they occur in the lakes.

Facies and biota which help recognize the three different lake types are documented at length in De Deckker (1987). They will not be discussed here except for the biota of deep lakes which were not sufficiently documented in De Deckker (1987).

Figure 2 shows the distribution of organisms which readily fossilize in deep lakes [either fresh ($<3‰$ salinity) or saline ($>3‰$)] and where they can be transported by phenomena like turbidity flows/undercurrents. For more details on the latter see Sturm & Matter (1978). Ooids also deserve a mention here because they help recognize lake shore facies. Note also that calcareous organisms can become dissolved or partly etched in the hypolimnion if waters are undersaturated in calcium carbonate. Evidence of deep water may therefore disappear if calcareous fossils have dissolved. Calcareous nannoplankton (see Kelts & Hsü 1978, p. 297 and Dean 1981, p. 219) are not represented in this diagram since they are not restricted to any particular facies.

There are few differences between either a fresh or a saline deep-water lake since the major biological groups which fossilize are usually equally represented. However, with regard to diversity, differences do occur: in saline lakes,

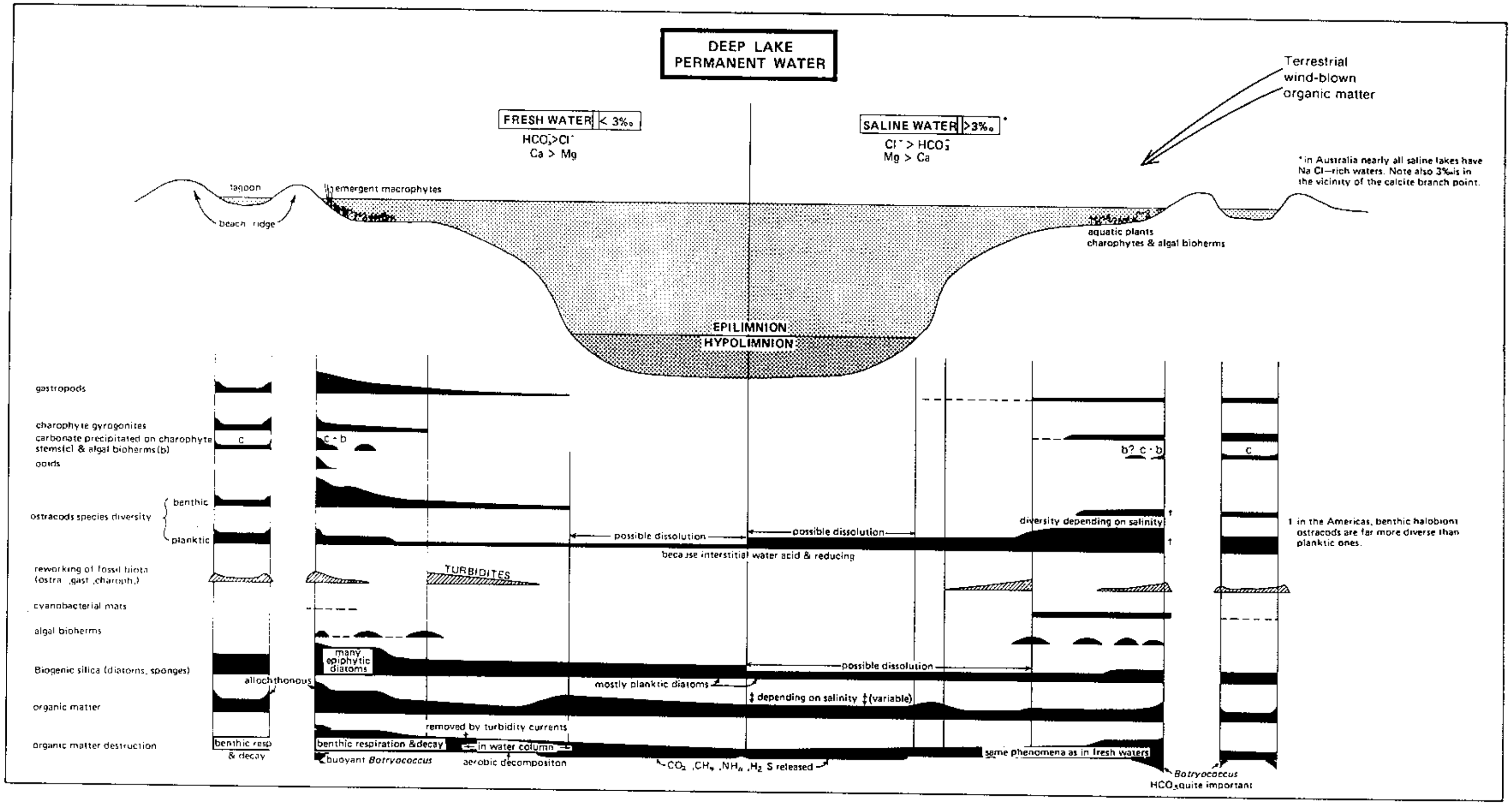


FIG. 2. Diagram showing the distribution of organisms (with remains which can potentially preserve as fossils) in a deep lake situation, with either fresh or saline permanent water. The reworking of organism remains is also indicated. The location and relative abundance of organic matter in the lake is presented together with information on the likelihood of its preservation and decomposition.

species diversity is generally much lower, but population density of some species may be extremely high. This applies to the flora, especially the algae, as well as the fauna. The former is of interest here because of its potential to become a source for petroleum. Note also the representation on Fig. 2 of where organic matter is produced, sometimes partly transported (in the case of turbidity flows etc.), and finally preserved or decayed. For more details on these phenomena refer to Dean (1981). Of note also is the influx of wind-blown terrestrial organic matter into lake systems, especially into saline lakes which occur in desertic regions. Galat *et al.* (1981), for example, have estimated that 50% of a tumble weed standing crop adjacent to Pyramid Lake in Nevada would be transported into it, thus contributing an input of over 2000 kg C yr^{-1} to the lake budget. Such input cannot be ignored.

Chemical characteristics: water and sediments

Nearly all saline lakes in Australia share a particular characteristic; Na and Cl are the dominant ions in their waters. They all belong to pathway II of Eugster & Hardie (1978) and, therefore, the most common salts precipitated from their waters, with an increase in water concentration, are $CaCO_3$, $CaSO_4 \cdot 2H_2O$ and NaCl. This chemical 'uniformity' in Australian waters, as already discussed in De Deckker (1983), is related to the stability of the Australian continent, as well as to the absence of active volcanism and rift-type sedimentation (and associated mineral springs), which otherwise would supply a greater variety of ions and minerals.

Before discussing the chemical properties which characterize the three lake types, it is important to note that nearly all lakes are the above-ground component of a hydrological basin. When the water table is below the lake floor, the lake remains dry, unless its surface (or near surface) is sealed by a hard layer (like indurated clay- or carbonate-band) for example and water enters the lake from a river or directly from rainfall. When the lake is dry, aeolian processes are most active and deflation of sediments and organism remains may occur, and more importantly oxidation of organic matter is extensive.

When the regional groundwater is obviously of different density from the brine pool below the lake, a Ghyben-Herzberg interface will occur (Freeze & Cherry 1979) (Fig. 3). As a consequence of this, potential flow lines converge towards the edge of the lake. This results in a marginal seepage-spring zone. There, a number of processes operate: they include evaporative pumping in the upper capillary fringe (see Hsü & Siegenthaler 1969), thus causing the formation of efflorescent salts (some of which may turn later into gypsum clay pellets, see Bowler 1973), polygonal cracking and associated with these are teepee structures and brecciation (see Muir *et al.* 1980; Warren 1982; De Deckker 1987).

The near-surface occurrence of the groundwater will also stimulate microbial activity resulting in cyanobacterial (algal) mat growth (Bauld 1981; De Deckker in press). Below these mats, bacterial sulphate reduction usually occurs (Teller *et al.* 1982, Skyring *et al.* 1983) and organic carbon is consumed in the process.

Permanent lakes (Fig. 4) most characteristically have carbonate-rich waters; this type of water chemistry also applies to the ephemeral coastal lakes in Australia, among which the lakes associated with the Coorong are the best known (von der Borch 1965). Some permanent lakes are also saline (>3‰ salinity) and have a more varied water chemistry, but, under the present-day (climatic) conditions in Australia, most permanent saline lakes have NaCl-dominant waters. If the lakes are of volcanic origin, like the well-studied maar lakes in Western Victoria (see Williams 1981), they will also have bicarbonate-rich waters. In any case, most permanent lakes are characterized by carbonate precipitates, some of which may form interstitially (Muir *et al.* 1980; De Deckker 1987).

Ephemeral lakes (Fig. 4) are usually characterized by the predominance of NaCl-rich waters and with gypsum and halite in their sediments. Interstitial precipitation of gypsum and halite also occurs as a result of groundwater concentration in association with evaporation, especially within the capillary fringe. Erosional phenomena are also commonly associated with the drying phase of these ephemeral lakes. Mechanical destruction of sedimentary structures, including algal mats (for more details see Walter *et al.* 1973; De Deckker 1987), formed under subaqueous conditions, commonly follows during the dry phase. Aeolian activity and associated phenomena (e.g., deflation, formation of clay lunettes) play a significant role with increasing aridity. Note, however, that aeolian deposits which originated from lakes may later act as reservoir rocks, hence it is important to recognize and locate them.

In the case of continuously *dry* lakes (Fig. 4) efflorescence of some salts operates, especially around the seepage zone when the groundwater is close to the surface (and also in association with a Ghyben-Herzberg interface). If the groundwater reaches saturation with respect to NaCl or $CaSO_4 \cdot 2H_2O$, and if there is little loss through the aquifer (viz. the basin being hydro-

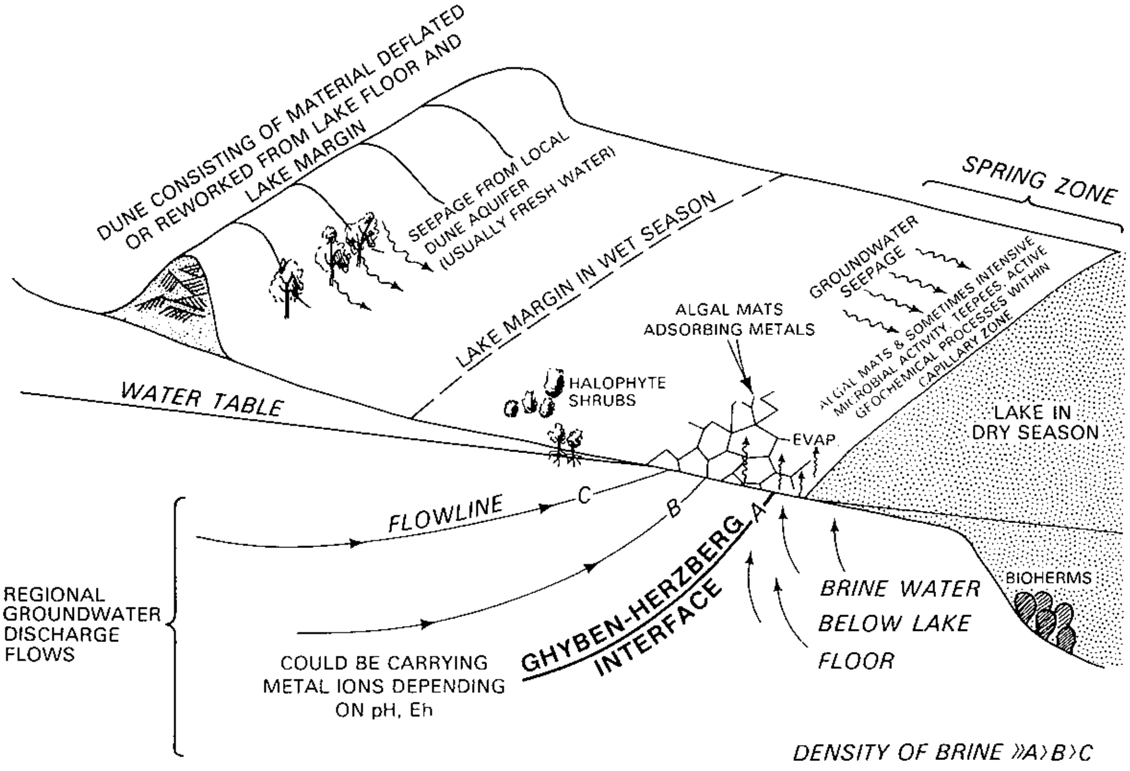


FIG. 3. Diagram representing a typical saline lake affected by the brine-water pool below it. In this particular case, a Ghyben-Herzberg interface operates between the regional groundwater and the brine pool, thus forcing both waters to converge towards the lake surface near the lake shore in an area characterized by seepage and springs. There, a number of processes operate, including the growth of algal mats which, in turn, could adsorb metal ions if they were transported there via the groundwater.

logically closed), a salt crust can form, thus preventing any further substantial sediment loss through deflation. Nevertheless, microbiological activity may continue below the salt crust, especially in regard to algal growth and bacterial activity.

Organic matter and metals in lakes

Phytoplankton productivity is usually very diversified in fresh and *permanent* lakes. An increase in salinity has an adverse effect on productivity except under certain circumstances when some algae grow under 'bloom' conditions. The alga *Botryococcus* is one of the best known examples, and is of interest here, because it contains high amounts of hydrocarbons (Hillen & Wake 1979). Accumulation of *Botryococcus*, along the shores of lakes or within lagoons connected to lakes, results from the positive buoyancy of this alga (Bauld 1983). In Australia, gelatinous deposits of *Botryococcus* are called Coorongite but elsewhere have received a variety of names (e.g., Balkashite, N'hangellite). Substantial accumulation of this alga, if adequately preserved, such as by rapid burial (e.g., during flash floods associated with adjacent alluvial fans), have the potential to form rich petroleum source rocks and oil shales.

Conditions favouring preservation of organic matter in deep lakes are highly variable. In general, with the lowering of water level in a deep lake, there is less likelihood of stratification within the lake. This prevents the occurrence of anaerobic conditions at the sediment/water interface. Thus the potential for organic matter preservation decreases. Similarly, as soon as a lake becomes *ephemeral* (or in the shallow parts of a deep lake) the potential for organic matter preservation is minimized because of mechanical erosion and transport during receding water levels, but also because benthic respiration and decay (caused by microbial organisms) are intensified during those circumstances (see Fig. 2 and Dean 1981).

Cyanobacterial (algal) mats, on the other hand, are best developed in *ephemeral* lake systems. They usually thrive under extreme physicochemical conditions (Bauld 1981) where they can

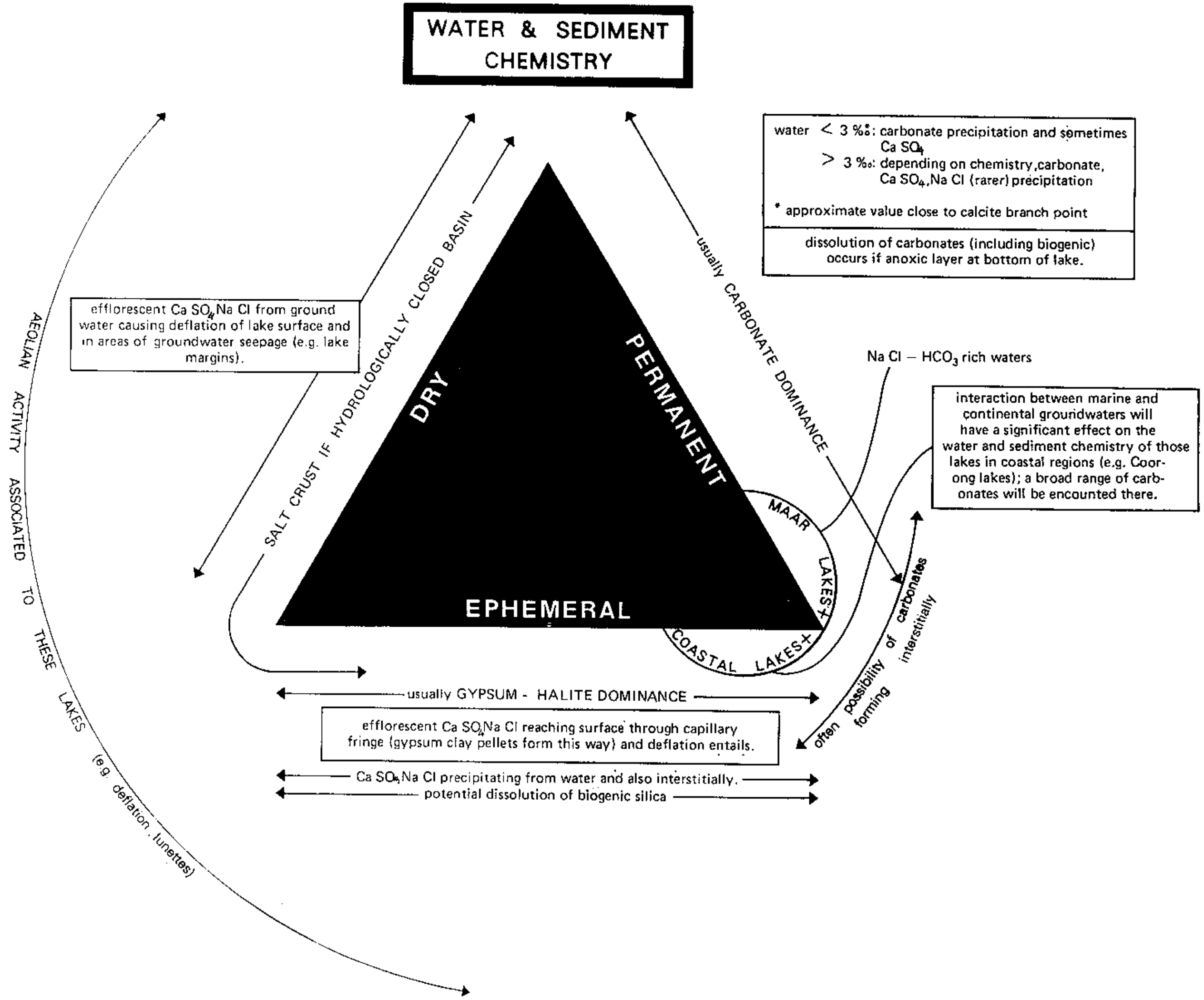


FIG. 4. Schematic triangular diagram showing the relationship between the three basic lake types and water and sediment chemistry for modern Australian lakes.

be less subject to grazing by organisms. They are also often aerially exposed and easily survive exposure. Note also that in hypersaline permanent water conditions, some cyanobacteria can grow to form larger bioherms (see De Deckker 1987) (up to several metres high and wide). Significantly, these bioherms may become potential hydrocarbon sources if they are adequately preserved. Specific conditions are indeed necessary for bioherm preservation since below algal mats sulphate reduction normally occurs with anoxic conditions and this causes the consumption of organic carbon (Bauld 1981, Skyring *et al.* 1983). An equilibrium between rate of sedimentation and conditions for (optimal) algal growth is therefore necessary to prevent the biological or mechanical (e.g., erosion by wave action) destruction of algal mats.

As mentioned earlier, algal mats are commonly found on the edge of lakes, especially in the areas associated with a Ghyben-Herzberg interface where a continuous, or near continuous, seepage of groundwater occurs (Fig. 3). They even commonly occur and grow below salt crusts or in association with teepee structures. The best documented example in Australia of large stromatolitic structures associated with polygonal cracking at Marion Lake in South Australia is published in von der Borch *et al.* (1977) and Warren (1982). There, the structures are well preserved but there is no organic matter left. A significant additional phenomenon is observed in association with cyanobacterial mats: commonly the latter can trap metal ions which become adsorbed on organic matter. This phenomenon was demonstrated experimentally by Disnar (1981) who showed the capability of cyanobacteria to select particular metal species under specific Eh and pH conditions. This is particularly relevant here because, as mentioned earlier, mats do grow along groundwater seepage zones where waters are often highly concentrated in many elements, and therefore may be relatively enriched in some metal ions. Degens & Ittekkot (1982) have also pointed out the common formation of metal–organic complexes in association with the growth of authigenic sulphide, phosphate, oxide and carbonate minerals. One of the processes which they described is the natural staining of organic matter by metals (best described by these authors as a kind of 'scavenging of metals from the environment by organics'). This could eventually lead to the possible formation of stratabound ore deposits. Already, Draper & Jensen (1976) have documented the close association between Mn and the presence of algal mats on the floor of the large playa Lake Frome. However, it must be noted that once some metals have been adsorbed by organic matter, they will not necessarily remain at the site of fixation. They can be remobilized depending on changing chemical conditions. This is the common case in Australia with uraniferous solutions from groundwater which eventually contribute to carnotite mineralization (see Arakel & McConchie 1982). Further, sulphides which also concentrate below algal mats as a result of bacterial activity (Skyring *et al.* 1983) may accumulate sufficient quantities of metals worthy of economic interest.

All the above mentioned phenomena are summarized in Fig. 5. It is important to know that petroleum source rocks are basically linked to *deep* lake systems and that *Botryococcus*-rich deposits probably originate in shallow water and perhaps *ephemeral* and slightly saline systems. Metalliferous deposits on the other hand are linked to *ephemeral* and *dry* lake systems, provided groundwater discharge areas occur and are enriched in metal ions. Association with algal mats is also necessary in the latter case. Nevertheless, it is important to realize that a close association exists between organic matter and metals in lacustrine systems.

Australian lakes, sites for hydrocarbon or metal deposits, or both?

Compared to the situation on other continents, some Australian lakes have been in existence for a long time. In fact, some lakes have been sites of sedimentation since the early Tertiary. For example, the elongated playa lakes in Western Australia which occupy ancient drainage systems have existed since the mid-Miocene (van de Graaf *et al.* 1978). In central Australia there are also mid-Miocene lacustrine carbonate sediments below Lakes Eyre and Frome (Callen 1977) and Eocene lacustrine sediments below Torrens (Johns 1968) (for more details see De Deckker 1983). Also, Lake George in eastern Australia has a well documented record of sedimentation that started in early Miocene (Singh *et al.* 1981).

Since the early Miocene, the Australian tectonic plate has moved northward, away from the Antarctic plate, across about 5–8° of latitude (see Fig. 6). Unfortunately, there are insufficient data to determine the climatic changes which occurred during the last 20 million years in Australia to postulate what would have happened to the large lakes. Nevertheless, there is evidence from lacustrine carbonate sediments and from the fossil biota recovered in the vicinity of Lake Frome that a warm, high rainfall climate prevailed during mid-Miocene time (Callen 1977). This is quite different from today, because now the lakes occur in the arid portion of Australia

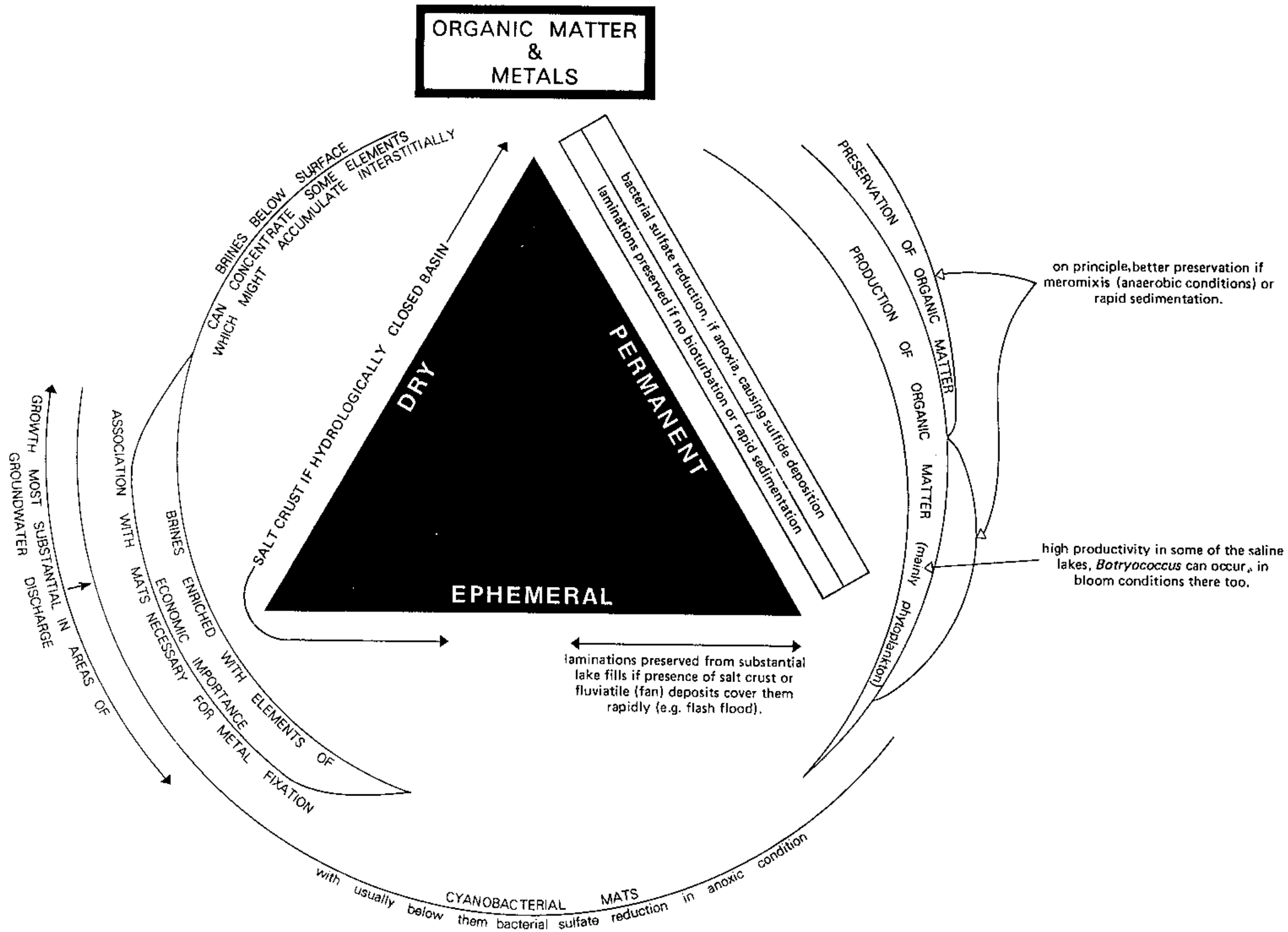


FIG. 5. Schematic triangular diagram showing the relationship between the three basic lake types and the presence of organic matter and metals, including their respective preservation.

and are the sites of gypsum and halite sedimentation.

An examination of the position occupied by most known Australian lakes on the basic triangle referring to water and sediment chemistry for three periods of the geological time scale (early Miocene, late Miocene and Present) (see Fig. 7) points to the following: nearly all lakes changed position (or would have if they had been in existence during the last 20 million years, e.g., the crater lakes and Lake Corangamite formed by damming of a lava flow are much too young) on the triangle and moved in an anticlockwise fashion. This, therefore, indicates that the lakes' water/sediment composition changed through time. Some lakes, however, remained groundwater-seepage areas (e.g., Lakes Amadeus and Napperby in central Australia) and would therefore only be sites of metal accumulation, but not hydrocarbons. The lakes which changed composition, and which would have been sites for hydrocarbon formation and storage (e.g., Lakes Eyre, Torrens and Frome: see Fig. 7), have undergone dramatic chemical changes through time, especially in the groundwater pool below them. Since the composition of the groundwater below most of these lakes is sulphate-rich today (and has been for some time), intense bacterial activity would have destroyed any organic carbon-rich sediments. However, the metals which originally were adsorbed by organic matter could have remained within the sediments, even if organic matter disappeared at a later stage. But they may also have been subsequently transported elsewhere by leaching processes via the groundwater.

As a consequence of the changes which occurred in Australia, especially as a result of an overall increase of aridity since the Miocene, the search for metals in large-lake sediments is likely to be more rewarding for the exploration geologist than the search for hydrocarbons.

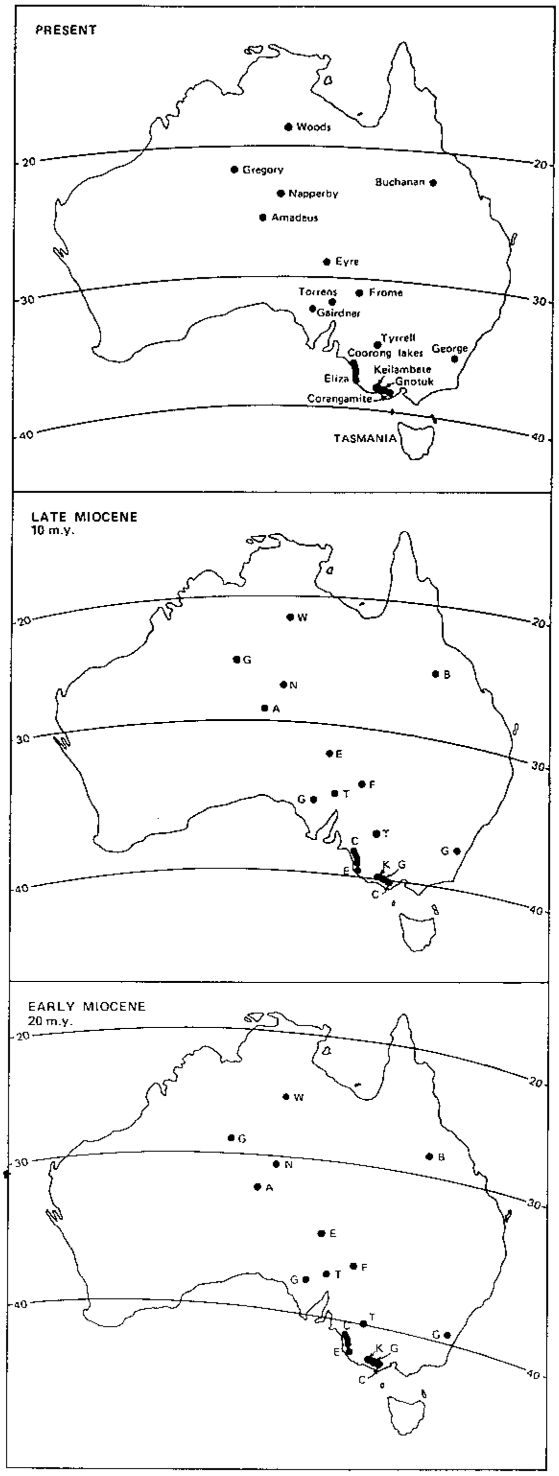


FIG. 6. Maps of Australia showing the location of the lakes mentioned in the text and in Fig. 7, and their respective latitudinal positions for three periods: early Miocene, late Miocene and Present.

Conclusions

Figure 8 provides a summary of the concepts presented in this article. The left hand portion of the diagram shows the evolution of a lake under Australian conditions with an increase in aridity (in an upward sequence on the diagram) with regard to water and sediment conditions. It shows the transition from sediment deposition to sediment deflation, and how this would favour either organic matter or metal preservation and accumulation. All the above phenomena relate to a system with low sedimentation rates. Water chemistry in Australian lakes which evolved

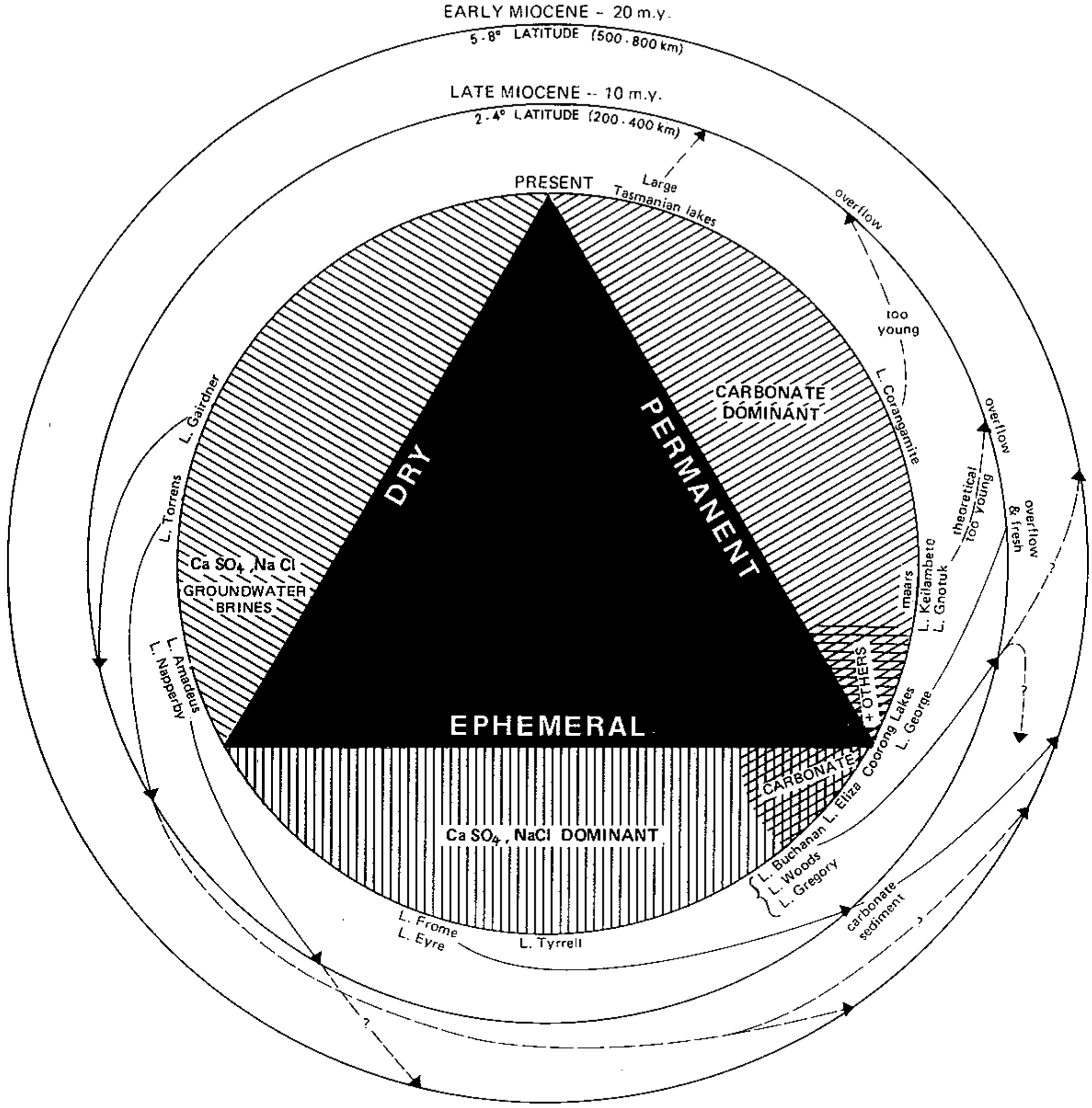
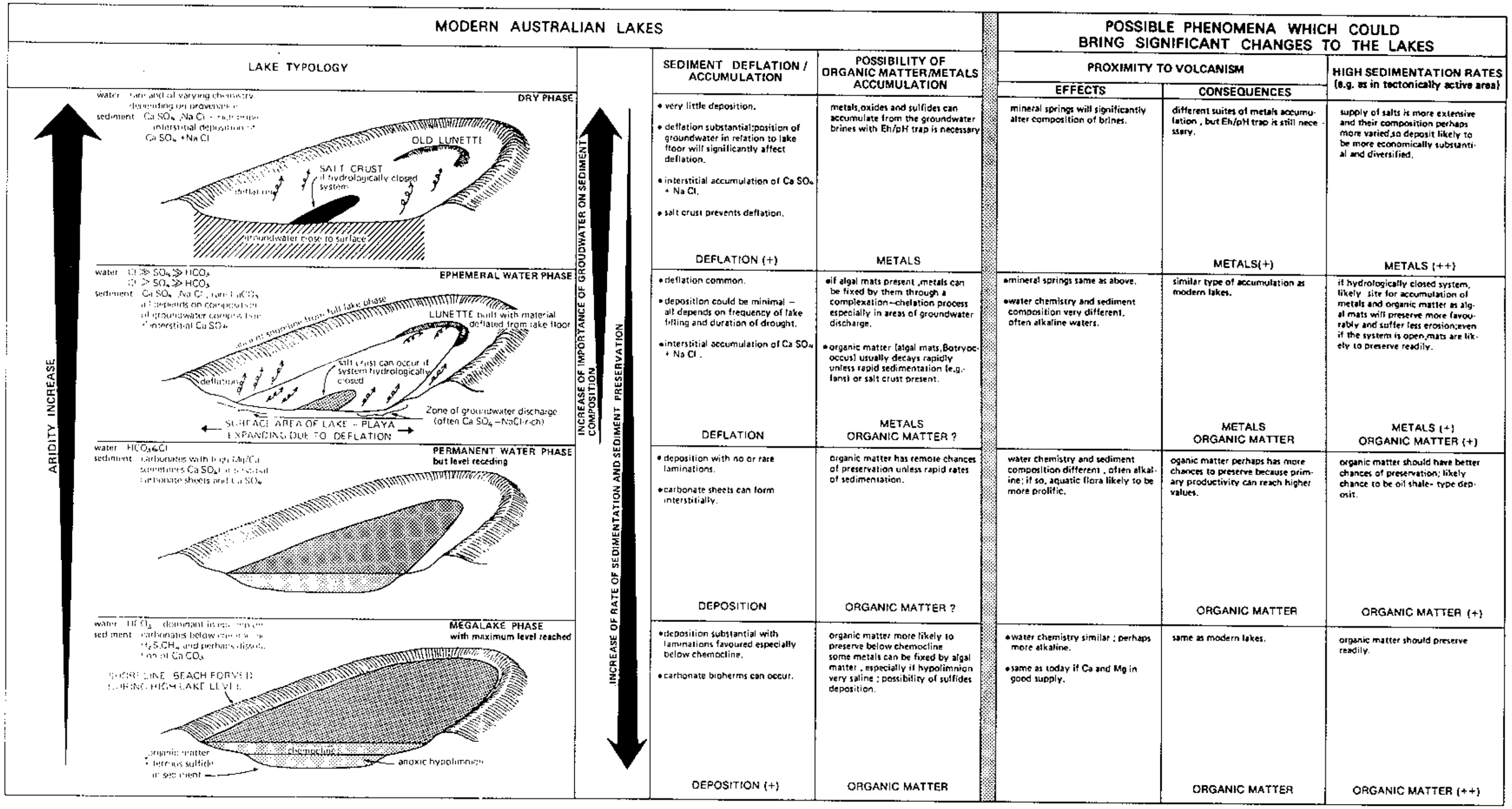


FIG. 7. Schematic diagram representing the three basic lake types and the position Australian lakes have today, but also had (or would theoretically have had if they were in existence then) during the early Miocene and late Miocene. Note also that since early Miocene, Australia has shifted 5–8° in latitude (=500–800 km) and since late Miocene, it has moved 2–4° in latitude (or some 200–400 km).

through the $CaCO_3$–$CaSO_4$–NaCl pathway, and which underwent an overall change during the last 20 million years from carbonate to gypsum–halite dominant sedimentation, has thus favoured the potential accumulation of metals and the destruction of organic matter.

Elsewhere on other continents, the proximity to volcanism, and high sedimentation rates due to high tectonic activity, would engender conditions favourable to the production and preservation of organic matter and accumulation of metalliferous deposits. By examining the right hand portion of Fig. 8, which fully documents those possibilities, it becomes obvious that high sedimentation rates are necessary for the preservation of organic matter, especially in a deep-lake situation with an anoxic hypolimnion. Thus, in general, a lake in a tropical region would become more favourable to organic matter preservation than in a temperate one because commonly deoxygenated waters occupy a much greater portion of the water column in tropical lakes (see Beadle (1974) for tropical African lakes and Kohzov (1963) for a comparison with Lake



SEDIMENT DEFLATION / ACCUMULATION	POSSIBILITY OF ORGANIC MATTER/METALS ACCUMULATION	PROXIMITY TO VOLCANISM		HIGH SEDIMENTATION RATES (e.g. as in tectonically active area)
		EFFECTS	CONSEQUENCES	
• very little deposition. • deflation substantial;position of groundwater in relation to lake floor will significantly affect deflation. • interstitial accumulation of Ca SO₄ + Na Cl. • salt crust prevents deflation. DEFLATION (+)	metals,oxides and sulfides can accumulate from the groundwater brines with Eh/pH trap is necessary METALS	mineral springs will significantly alter composition of brines.	different suites of metals accumulation , but Eh/pH trap is still necessary. METALS(+)	supply of salts is more extensive and their composition perhaps more varied,so deposit likely to be more economically substantial and diversified. METALS (++)
• deflation common. • deposition could be minimal – all depends on frequency of lake filling and duration of drought. • interstitial accumulation of Ca SO₄ + Na Cl . DEFLATION	• if algal mats present ,metals can be fixed by them through a complexation–chelation process especially in areas of groundwater discharge. • organic matter (algal mats,Botryococcus) usually decays rapidly unless rapid sedimentation (e.g.-fans) or salt crust present. METALS ORGANIC MATTER ?	• mineral springs same as above. • water chemistry and sediment composition very different, often alkaline waters.	similar type of accumulation as modern lakes. METALS ORGANIC MATTER	if hydrologically closed system, likely site for accumulation of metals and organic matter as algal mats will preserve more favourably and suffer less erosion;even if the system is open,mats are likely to preserve readily. METALS (+) ORGANIC MATTER (+)
• deposition with no or rare laminations. • carbonate sheets can form interstitially. DEPOSITION	organic matter has remote chances of preservation unless rapid rates of sedimentation. ORGANIC MATTER ?	water chemistry and sediment composition different , often alkaline; if so, aquatic flora likely to be more prolific.	oganic matter perhaps has more chances to preserve because primary productivity can reach higher values. ORGANIC MATTER	organic matter should have better chances of preservation; likely chance to be oil shale- type deposit. ORGANIC MATTER (+)
• deposition substantial with laminations favoured especially below chemocline. • carbonate bioherms can occur. DEPOSITION (+)	organic matter more likely to preserve below chemocline some metals can be fixed by algal matter , especially if hypolimnion very saline ; possibility of sulfides deposition. ORGANIC MATTER	• water chemistry similar ; perhaps more alkaline. • same as today if Ca and Mg in good supply.	same as modern lakes. ORGANIC MATTER	organic matter should preserve readily. ORGANIC MATTER (++)

FIG. 8. Summary diagram showing on the left the possible evolution of a large Australian lake with an increase in aridity (from bottom of diagram to top). Information is given on sediment deflation and deposition in those systems, and also with regard to the possibility of organic matter and metals accumulation under the conditions operating today in Australia. Summary information is given in capital letters in the bottom portion of the boxes with the signs (+) or (+ +) indicating increasing degrees of amelioration of the conditions. On the right hand side, possible phenomena which may affect the lakes favourably with regard to metals and organic matter accumulation are presented. These apply to lakes outside Australia in volcanic provinces and tectonically active areas.

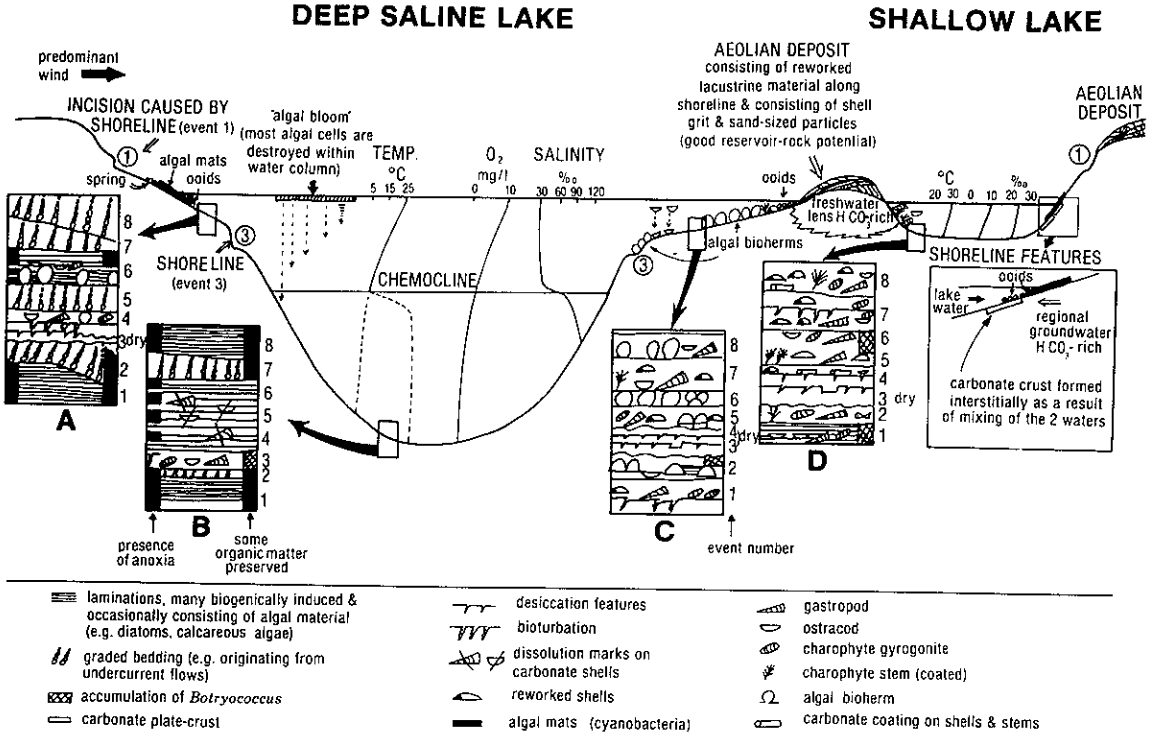


FIG. 9. Schematic diagram illustrating two adjacent lakes; one is a deep saline lake and the other is shallow and less saline. Distinctive physico-chemical characteristics of these two lakes (dissolved oxygen, temperature, salinity) are shown graphically along a depth profile. Sedimentological and palaeontological features which characterize facies within these two lakes are graphically presented and their association through a series of eight sequential, synchronous events, but operating in different parts of the lakes, are shown in four schematized stratigraphical columns (A–D). These events are briefly described below. *Event 1* (represented at the bottom of every column) relates to a phase during which both lakes were connected, thus with the larger lake margins forming an incision high up in the landscape. Extensive beach ridges also indicate (high) lake levels. The hypolimnion is enlarged during this phase at sites A and B and its presence favours the preservation or organic matter not decomposed or destroyed through the oxygenated part of the water column. *Botryococcus* blooms from the entire lake, due to the predominant winds, may accumulate in the shallower part of the large lake at site D. This hydrocarbon-rich alga should be preserved there if sedimentation rate is also rapid, thus preventing its decomposition by bacterial activity. During *event 2*, water level recedes and the lakes separate; stratification still occurs in the large lake and organic matter can preserve at sites A and B; in the former because of the high sedimentation rate related to undercurrent flows, and at site B because of anoxic conditions and the substantial supply of sediment from the turbidity flows. Note that the graded bedded sequences can act as hydrocarbon reservoirs especially along the margins of the lake due to their high porosity. *Botryococcus*-rich beds may accumulate along the right margin of the lake in among algal bioherms. The latter, if they are substantial (this is principally controlled by water depth) and lithified (most often by a carbonate matrix) they can act as both source rocks and reservoir rocks (the latter because of the large number of cavities they have). During *event 3*, lake level dropped to such an extent that stratification vanished in the large lake. Incision along the lake margin was substantial and this is visible below water level of the present lake (= represented by event 8). The shallow lake dried up and pedogenic phenomena destroyed evidence of past sedimentary structures down to a certain depth; fossil shells were also destroyed. If salinity is adequate for *Botryococcus* to bloom in the lake, it could accumulate at site B. Site C also suffered erosion, and material from this site as well as from site D is deflated and reworked, so as to become redeposited along the margins of the lake (on the right hand side of both lakes as controlled by the direction of the predominant winds). Some reworked material also accumulates there during the rise of water level during subsequent events. As lake level rises, anoxia reappears intermittently at site B and shells from oxygenated phases become partially dissolved during the anoxic ones. This intermittence of oxic–anoxic events causes the destruction of organic matter even in the deep parts of the lake. Elsewhere in the lake during that phase, and subsequent ones, one can see repetition of the events described previously. (Diagram modified from De Deckker (1987) and re-interpreted regarding the presence of organic matter in the two lakes.)

Baikal), but naturally there are exceptions to this rule. Demaison & Moore (1980) discuss this concept at length. Lakes in tectonically active areas, associated to mineral springs and high rates of erosion and weathering, would be more naturally propitious for the accumulation of metalliferous deposits, and in addition they may be sites of hydrocarbon source rocks.

To sum up, Fig. 9 provides a schematic view of the possible facies which can be recognized in association with a *deep* (and also *permanent*) lake, and a *shallow* (and occasionally *ephemeral*) lake, adjacent to one another. Four stratigraphic columns (A–D in Fig. 9), detailing schematically the evolution and changes of facies which might occur in both lakes during a series of eight events, relate to fluctuations in lake level and consequently to fluctuations of other physico-chemical parameters (e.g., presence or absence of anoxia, salinity changes). All these features are examined so as to distinguish the facies which are favourable for the production of organic matter and its preservation. Refer to the caption of Fig. 9 for a detailed description of the eight synchronous events relating to the evolution of both lakes. Figure 9 should also be examined while paying attention to the common association of metals to organic-rich sediments (as caused by the natural adsorption of metals to organic matter), and also to the presence of some conditions in lakes (like anoxia) which favour the formation of metalliferous sediments.

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