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Sea level change and environmental evolution of coastal lakes in Vestfold Hills, Antarctica

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Abstract Ecological and palaeoecological studies were carried out in a series of lakes in the Vestfold Hills (68°38′S, 78°06′E) on eastern Antarctic continent. Dynamics types of the lakes in environmental geomorphology and physic-chemistry, as well as features of biological community structures in different lakes were analyzed. Marine macro- and micro-fossils collected from the terraces and beaches surrounding these lakes and determined in ^{14}C radiocarbon ages to be the Late Pleistocene, were used as evidences to show the evolutionary processes of the lakes after sea level changes and transgressions since 18000 a B. P.. Basic modals of evolution for the lakes given in the paper could be regarded as not only explaining the history of environmental and ecological changes in VH lakes, and also reflecting of local environmental evolution in Antarctic region and global climate changes from past to present time.

Key words sea level change, Antarctic continent, environment of the lakes, ecological evolution.

1 Introduction

Evidence of global sea-level variation during the Quaternary has been found in coastal zones in many places around the world (Shi and Wang 1981; Liu 1982). The main causes of global sea level change were that of extending and retreating of polar ice sheets and continental glaciers of the world in large scale resulted from global climate variance (Zhang 1985). The ice sheet which covered Antarctic continent 18000 a ago, was much larger than present, and it's edge might reach to the margin of the continent (Hughes *et al*. 1980). Coastal line of Antarctic continent used to be moved several times due to ice sheet and sea level variations (Clark and Lingle 1979; Thomas 1979). The Vestfold Hills (VH), which is an ice free area today, was far away from the coast and was covered with ice by up to 160 m (Zhang 1985). Abundant instances have been found in circum-Antarctic coastal zone that the ecological changing is related to sea level and Antarctic continental environment variations (Berkman 1997). The result of ^{14}C age determination on bivalve, foraminifer and diatoms fossils obtained from VH indicates that the transgressions in Antarctic continent did happen in the time of the interstadial at the end of Pleistocene age (Zhang and Peterson 1984). And it much more affected modern ecosystem of Antarctic lakes directly that the transgression took place in the climatic optimum of the Holocene at about 7500 – 3200 a B. P. (Zhang 1985).

The geomorphology of Vestfold Hills is strongly influenced by geological structure. Several linear valleys were glacially excavated with prominent lineaments occupied by fjords and scarps. Basins and ends of fjords, as well as some arms of sea bays here became lakes and catchments after the processes of ice sheet retreat and marine transgressions (Peterson *et al*. 1988). The geologists have discovered abundant Palaeo-biological proofs, which shows the palaeo-environmental evolution in marine deposits and sedimentation in terraces and beaches of VH lakes. Meanwhile, biologists have done a number of work on limnology and ecology studies in lakes (Wright and Burton 1981; Burke and Burton 1988a, b; Bayly 1986; Franzmann *et al*. 1987, 1988; Volkman *et al*. 1988; Laybourn-Parry *et al*. 1992, 1995, 1997; Wang 1992; Wang and Eslake 1997). The results of studies indicate that the ecological structures of present lakes in VH have common properties and distinctive differences as well. Actually, there is an interrelationship between environment and bio-communities in lakes. The correspondence of bio-structure with the circumference produced progressively in historic process of environmental evolution. So far, it lacks that of systematic studies on biological evolution of lakes in correspondence with marine derived lake's environmental change. In this paper, the authors try to rebuild the processes of ecological succession related to lake environmental evolution, which could be probably a stronger proof to explain that of global climate change and Antarctic environmental variance.

2 Material and method

During the years of 1983 – 1991, field investigations were carried out several times including overwinters in 1984, 1986 and 1987 in the Vestfold Hills (VH). Biological and chemical samples were taken from a series of lakes and near bays in VH. The methods and equipment for biological sampling and analysis were used as done by Bayly (1986) and Wang (1992). However, some microbial samples were obtained from water sampler. Physical-chemical sampling and analysis methods were used as done by Deprez and Frazmann (1985) and Wang (1995). During the same period, some samples of micro-palaeobiology fossils collected in terraces and beaches of the lakes for ^{14}C age determination, and part of materials and data in same area by other colleagues were used as well.

3 Results and discussion

3.1 Present marine ecological features of lakes in VH

In present area of VH, there are hundreds of lakes and catchments, which can be divided into salt system and fresh system. The former is at 62% of total lake number in VH, and mostly in location towards the sea, and the latter is at the rest, and in location of closing the ice sheet. So far, evidences of last transgression, which took place about 6000 a ago, can be observed in geomorphology between the east and west sides in someway near the mid-part of VH. The east is characterized by relatively fresh, unweathered rock and rugged relief, whereas the west is characterized by subdued relief, intensely weathered rock. In Figure 1, a salt line from north-eastern to south-western with 100 m wide, sketched briefly by Adamson and Pickard (1986) is reflecting past transgression. It can be seen clearly that the front of transgression went over the mid-part of present VH. The end of salt line in the south is close to old Sørsdal glacial, which covered over the Crooked Lake in present location. The middle of salt line is at a distance of 5 – 10 km from ice sheet, and the north part of line is only 5 km away from ice sheet. In fact, the lakes in VH spread out evidently in distribution as two different groups of fresh and salt water with their common boundary of the salt line, which extends from the end of Long Fjord in mid-north of VH, down to Croocked Fjord in South-West of VH. There is Druzhby drainage system, a largest fresh system in Antarctic continent, including several large fresh lakes, such as Crooked and Druzhby (Bronge 1996). The lakes located in west of the salt line are mostly saline lakes related to marine transgression. However, it should be mentioned that some marine derived lakes near by the salt line have been diluted by this fresh system in long historic evolution process, such as Watts Lake, it has been finally changed into an entire fresh water (Pichard *et al*. 1986).

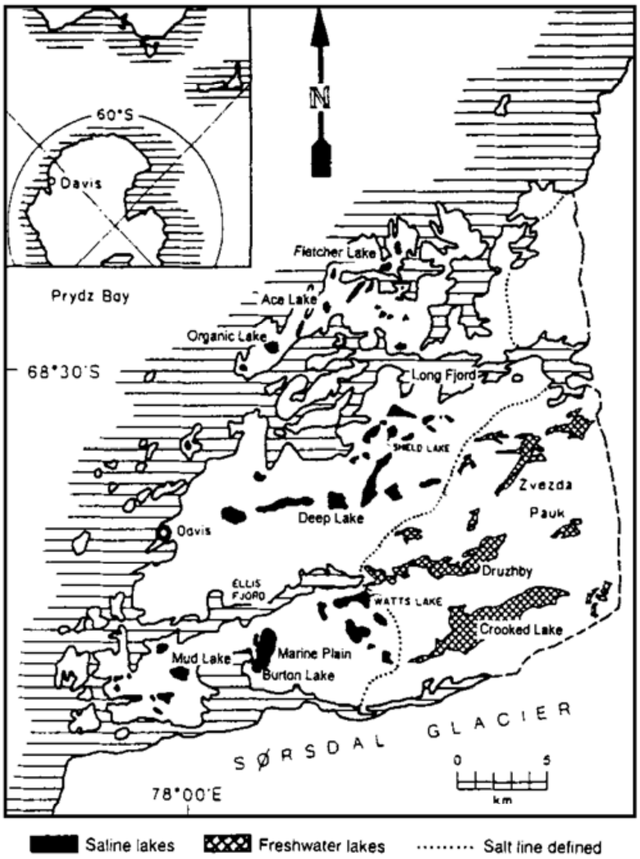

Fig. 1. Location of lakes and salt line in the Vestfold Hills (after Adamson and Pichard 1986).

In despite of a long historic evolution process, most of saline lakes preserved marked properties of their basic chemical components as marine water (Burton 1981; Wang and Deprez 1998). Meanwhile, main physical-chemical factors of salt lakes are distinguishable from those of fresh lakes, concentration of many ions, such as Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-} and so on, is much higher than that of fresh lakes except of the salinity (see Table 1).

Table 1. Comparison of chemical components between salt and fresh lakes in VH and sea water

Lakes	Depth /m	Oxyl. /m	Temp. /℃	Sal. /‰	pH	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	PO_4^{2-}	TN
Sea water (average)				33.5	8.0	10760	4030	1300	4100	19350	2710		
Fresh lake													
Croocked	150		+2.1	6.7	0.1	375	14	19	17	442	38.5	0.02	0.02
Watts	35		+4.8	2.2	6.9	670	35	31	29	510	55	0.02	0.01
Salt lake													
Deep	36	19	+8.5	222	7.4	67900	4210	12580	2400	165000	2550	0.57	0.65
Fletcher	11	6	−1.2	55	8.1	14550	4640	1950	620	30100	2150	0.21	–
Burton	18	8	+0.5	38.5	7.5	9800	1280	1220	450	18300	2080	0.24	0.45
Shield	37.6	19	+10.0	115	7.1	27800	1170	3110	820	91700	2800	0.41	–
Organic	7.5	4	+6.1	105	7.0	25300	1007	3648	940	90680	2730	–	1.10
Ace	24	10	+6.0	29.5	7.6	7350	300	960	140	13400	410	0.15	0.34

Depth: max depth; Oxyl.: Oxylimnion; Temp.: Temperature; TN: Total nitrogen.

The results of ecology studies of VH lakes show that there were basic differences in ecological structures and biological species compositions between salt and fresh systems. So far, more than 20 species of photosynthetic bacteria, such as sulphate-reducing bacteria, and hundred species of phytoplanktonic algae including Diatoms, Dinoflagellates, Chlorophyceae and Chrysophyte had been determined from salt lakes in VH lakes. In the data by Roberts and Mcmine (1999), 68 specie of diatoms have been recorded, and 56 specie of them could be found in lakes related to this studies (see Table 2). 11 species of zooplankton, which dominated by copepod crustaceans and

Table 2. Distribution of main micro-diatoms in lakes of VH, Antarctica

Species	Fle	Ace	Abr	Shl	Org	Bur	Watts
Achnanthes abundans							+
A. brevipes	+			+	+	+	+
Amphora veneta	+		+	+			+
Berkeleya adeliensis						+	
Cocconeis costata				+	+	+	+
C. fasciolata	+			+	+	+	+
C. pinnata				+			+
C. sp.	+					+	+
Diploneis splendida							+
D. sp.						+	
Entomoneis kjellmanii						+	
Fragilaria construens	+		+		+	+	
F. sp.	+			+	+	+	+
Fragilariopsis angulata				+			+
F. cueta.	+	+		+	+	+	+
F. cylindrus	+	+		+	+	+	+
Gomphonemopsis sp.	+			+		+	+
Gyrosigma subsalsum							+
Hantzschia virgata	+	+	+	+			+
Navicula adminii	+	+	+	+	+	+	
N. cf. *cancellata*				+			+
N. collersonii			+				
N. cryptotenella	+	+	+	+	+	+	
N. cryptotenelloides		+	+	+	+	+	+
N. cf. *detenta*	+	+	+				+
N. directa	+	+	+	+	+	+	+
N. glaciei	+			+	+	+	+
N. mutica	+		+	+	+	+	+
N. perminuta	+					+	+
N. cf. *salinarum*	+	+	+	+		+	+
N. cf. *seminulum*	+						
N. sp.		+	+				
Nitzschia lecointei	+	+	+	+		+	+
N. perminuta	+	+	+	+	+	+	+
N. sp.							+
Pinnularia cymatopleura			+	+			
P. lundii		+		+			
P. microstauron				+	+		+
P. quadratarea var. *Constricta*							+
P. cf. *quadratarea* var. *Constricta*						+	+
P. viridis	+		+	+			
P. cf. *viridis*			+				
Pleurosigma sp.		+				+	
Stauroforma inermis						+	+
Stauroneis salina		+					
S. sp.	+	+	+	+	+	+	+
Synedra cf. *Ulna*						+	
Trachyneis aspera	+			+			+
Tryblionella marginulata		+	+			+	+
Asteromphalus hyalinus					+		
Chaetoceros sp.		+		+	+	+	
Eucampia antarctica	+					+	
Porosira glacialis						+	
Thalassiosira antarctica			+	+		+	+
T. gracilis						+	
T. sp.	+						+

Fle: Fletcher; Shl: Shield; Org: Organic; Abr: Abraxas; Bur: Burtun. Data after Roberts and McMinn(1999).

ctenophora coelenterates, were recorded in VH salt lakes. Most of species in above could be found as common species in nearly sea waters. Over 50% of bacteria and 56% of algae in above are marine property organisms. Some diatoms like *Achnanthes brevipes*, *Navicula glaciei* and *Cocconeis fascilata* and so on are widely distributed even in east Antarctic area as far as near Zhongshan Station (Zhu *et al*. 1995). In the other, *Mesdinium rubrum*, an auto-trophic ciliata found in VH salt lakes (see Table 3), is original pelagic protozoa species (Fenchel 1987). Morst of zooplankton species, such as copepoda *Drepanopus bispinosus*, and ctenophora *Cydipida* sp. are typical marine invertebrates (Wang and Eslake 1997). The results of many studies show that the biological communities in all of saline lakes in VH have marked marine characteristics (Perriss and Laybourn-Parry 1997) except in Watts Lake, which is an entire fresh (salinity < 3.0 ‰) in location nearby the salt-line. However, it can be seen clearly that, so far, there are many remains of palaeooceanic tubeworm polychaeta on surface beach of the lake. This genus of polychaeta is alive tubeworm in adjacent waters near present VH. In other hand, population structure of diatoms in Watts Lake is similar to that of in other salt lakes (see Table 2), but in rest of fresh lakes (Eslake *et al*. 1991; Wang and Deprez 2000). This supports that the lake did experience transgression and diluted by ice melted water afterwrads (Pichard *et al*. 1986). Some fresh water species, such as copepoda *Acanthocyclops mirnyi*, Cladocera *Daphniopsis studeri* and ciliata *Strombidium viride* replaced original marine grazers, which were not alive in fresh at all (Wang and Deprez 2000).

Table 3. Distribution and ecological properties of the Zooplankton in lakes of VH

	Fle	Ace	Abr	Shl	Org	Deep	Bur	Watts	Adj. bays	Res.
Ciliata										
Mesodinium rubrum	+	+		+			+		+	(2)
Srombidium viride								+		(1)
Anthomedusae										
Rathkea lizzioides							c		c	
Ctenophora										
Cydippida sp.	+						a		c	
Cladocera										
Daphniopsis studeri								c		
Copepoda										
Drepanopus bispinosus	c						a		a	
Paralabidocera antarctica	+	c	c				+		c	(1)(4)
Acartia sp.		+								
Amphiascoides sp.			c						c	
Harpacticus furcatus	+								c	(1)
Idomene sp.	+								+	
Oithona similis	+								c	
Oncaea curvata	+								c	
Acanthocyclops mirnyi								+		
Amphipoda										(1)
Paramoera walkeri							+		a	

Fle: Fletcher; Shl: Shield; Org: Organic; Abr: Abraxas; Bur: Burtun; +: present; a: abundant; c: common.
(1) This study; (2) Perriss *et al*. 1995; (3) James *et al*. 1994; (4) Wang and Eslake 1997.

3.2 Palaeooceanic ecological features of the lakes in VH

Fossils of paleooceanic diatoms, foraminifer, bivalve, even some bones of marine mammals (such as dolphin) have been discovered in some valleys and beaches of lakes from coastal area to inland in VH. For example, marine bivalve fragments of *Laternula elliptica* have been found on the beaches of Lake Cemetery, Mud and Burton, and Marine Plain as well (Fig. 2a). ^{14}C age determinations of bivalve fossils give an age of about (31000 ± 474) a B.P., which belongs to late Pleistocene (Li 1985). However, samples

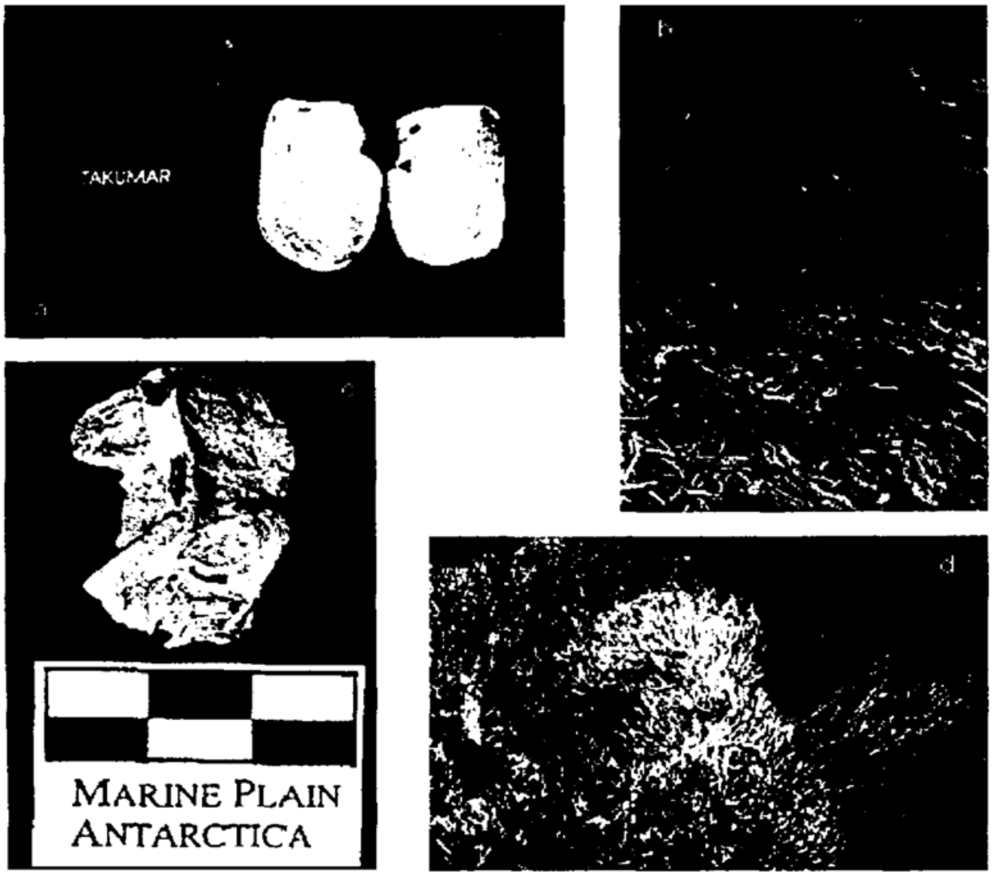

Fig. 2. Some bivalve fragments and polychaeta tube remains at terraces near the lakes and polychaeta tube worms at present seawater near Davis Staion in the Vestfold Hills, Antarctica.
a. Bivalve *Laternulla elliptica* shells at the beach of Burton Lake (photo by Quilty);
b. Polychaeta tube remains at terraces at the beach of Watts Lake (photo by Campbell);
c. Polychaeta tube remains at terraces at Marine Plane (photo by D. Crawford);
d. Polychaeta tube worms at present sea water near Davis Station (photo by R. Besso).

from different strata in the same area also give an age of about (6100 ±108) a B. P., which belongs to Holocene (Li 1985). Meanwhile, samples from different strata of Watts, Mud and Deep Lakes, indicate an age of (6100 ±108) a B. P. and (3325 ±474) – (4030 ±80) a B. P. respectively (Lan 1985). ^{14}C measurements of foraminifera fossils from Watts and Deep Lakes gives the age of about (6100 ±108) a B. P. and (4030 ±80) – (6632 ±118) a B. P. respectively (Li and He 1985). Tube fragments of polychaeta (^{14}C age (6150 ±95) – (7680 ±120) a B. P., Pickard *et al*. 1986) are seen at Lake Watts (Fig. 2b). Other marine fossils have been found including bivalve fragments of *Latesnula elliptica* near Watts Lake and Cemetery Lake, and tube fragments of polychaeta (^{14}C age (6150 ±95) – (7680 ±120) a B. P., Pickard *et al*. 1986) at Lake Watts. The compositions of fossil fauna along a tropical rocky coast (Laborel and Laborel-Deguen 1995) and along the Antarctic coastal zone (Berkman 1997), have been used as biological indicators for Holocene sea-level and climate variations. Based on those fossil remains which appeared in different strata in VH, we suggest that the terraces around the lakes can been distinguished into three geological age-groups (see Fig. 3):

(1) Mud Lake-Marine Plain-Burton Lake, marine sediments of age about 25000 –

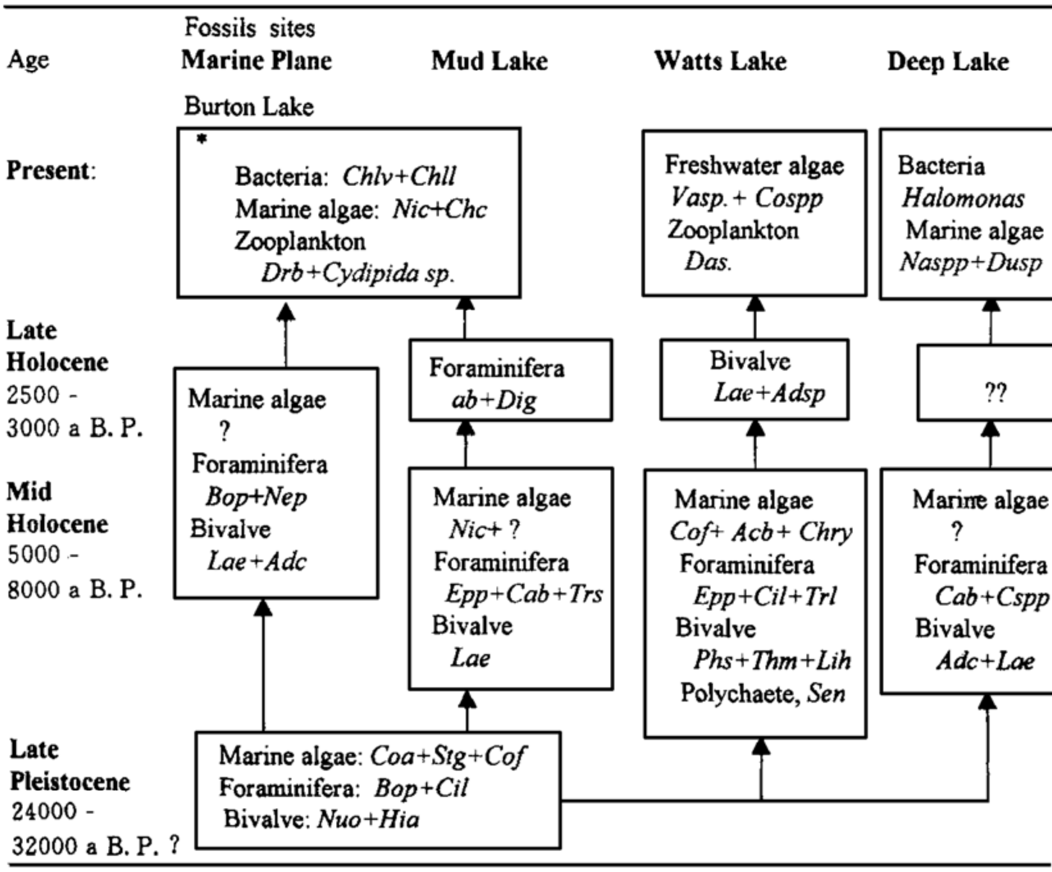

Fig. 3. Comparative bio-composition succession from late Quaternary to present day in some maritime strata in the Vestfold Hills, east Antarctica (after Li and He 1985; Lan 1985; Li 1985; Pichard *et al*. 1986; Burke and Burton 1988a, b; Quilty 1988).

Freshwater algae

Vasp: *Vaucheria* sp.; *Cospp*: *Cosmarium* spp.

Bacteria

Chlv: *Chlorobium vibriofome* Plesh; *Chll*: *Chlorobium limiola* Nadson

Marine algae

Stg: *Stephanopyxis grunowii* Gr. et St.; *Coa*: *Coscinodiscus asterompholus* Ehr; *Cof*: *Cocconeis fasciolata* (Ehr.) Brown; *Acb*: *Achnanthes brevipes* Ag.; *Naspp*: *Navicula* spp.; *Nic*: *Nitzschia curta* (V.H.) Hasle; *Dusp*: *Dunaliella* sp.; *Chc*: *Chaetoceros compressus* Lander; *Chry*: *Chrysophyta* spp.

Foraminifera

Bop: *Bolivina pseudopuncutala* Höglund; *Cab*: *Cassidulina biora* Crespin; *Cil*: *Cibicides lobatulus* (Walker and Jacob); *Dig*: *Discorbis globularis* d' Orbigny; *Epp*: *Epistominella potagonica* (d' Orbigny); *Trl*: *Triloculina lamellidens* Parr; *Trs*: *Trochammina squamata* Parr; *Pac*: *Patellina corrugata* Williamson; *Nep*: *Neogloboquadrina pahyderma* (Ehrenberg)

Bivalve

Nuo: Nucula obliqua Larmarck; *Lh*: Limatula hodgsoni Smith; *Phs*: *Philobrya sublaevis* Pelseneer; *Thm*: *Thracia meridionalis* Smith; *Lae*: *Laternula elliptica* (King and Broderip); *Adc*: *Adamussium colbecki* Smith; *Hia*: *Hiatella arctica* Linne

Polychaete

Serpula narconensis

Zooplankton

Drb: *Drepenopus bispinosus* Bayly; *Das*: *Daphniopsis studeri* R•be.

50000 a, and older than any other, could be Early Pliocene;

(2) The transgression was through over Mud Lake-Marine Plain-Burton Lake to Watts Lake-Deep Lake, terraces of age about 3000 – 8000 a could be Mid – Late Holocene;

(3) The present lake beaches.

It is clear that the valleys related to present raised beaches/terraces were once parts of bays in palaeoocean, resulting in variation of biological structure from the late Quaternary. Distinct palaeo-biological successions appeared in corresponding strata of some lakes (Fig. 3) and this suggests that marine derived lakes in VH had probably endured different sea level fluctuations since the Late Pleistocene. An general thread of communities succession in saline lakes in VH undergoing from Late Pleistocene to Holocene and Present time is shown in Fig. 3. Megabenthos bivalve (*L. elliptica*) and tubeworm polychaeta (*Serpular narconensis*) used to be main populations in this area, disappeared during the period of 3000 a after last transgression in Mid-Holocene. Marine foraminifer *Bolivina psedopuncutala*, *Cassidulina biora* were extinct nearly in the same period. The succession of Palaeo-communities resulted in ecological structure changing, in which, community composition of Planktonic Crustacean + Algae + Microorganisms was replaced by that of Bivalve+ Tube-polychaeta+ Planktonic crustacean+ Algae.

The data of Oxygen isotopic age determination on palaeo-vertebrate fossils in Marine Plain by Quilty (1990) recorded the time of Antarctic environmental evolution shifted to 3.5 − 4.5 Ma ahead. However, Eric (1991) affirmed that thransgressions did occur in VH during the period of 10000 − 6000 a in Holocene.

3.3 Evolution model related to environmental types of lakes

Based on historic causes of formation, the lakes in VH can be generally divided into marine derived and ice eroded lakes. In present time, some of lakes still have water exchange with near bay through the channels or certain connective ways, but the rest is not. Thus, it could be distinguished into two environmental types: stable and/or unstable environments. This way is more perceivable to reflect evolution processes of the lakes. In geographical features and main physical-chemical factors (such as temperature, salinity and dissolved oxygen), and biological structures as well, it is markedly different between stable and unstable lakes (Wang and Deprez 1998).

In factor, what is called stable is in relative less variant state since the lakes would be influenced by local climate change and variable by ice melting, evaporating and water leaking. Positive water budgets and associated salinity decreases have apparently been the cases for sometimes in the Hills resulting in low salinity, for example in Ace and Abraxas (20 ‰) Lakes. The flow of fresh water from melted snow and ice has diluted the original marine water from the Watts Lake, and in Deep Lake normal salty became a higher after long historic evolution with negative water budget increasing (Pichard *et al*. 1986; Wang and Deprez 1998). Despite the fact that there is a limited water exchange between Burton Lake and near bay, by a shallow channel only in the summer, it does not result in large seasonal changes in physical-chemical properties of lake water (Wang 1992), therefore, it should still be regarded as stable case here. Extreme salinity in some lakes like Watts and Deep restricts much strongly the marine organisms to survive in the lakes. Salinity in most of stable lakes (20 ‰ − 40 ‰) is favourable to marine original organisms survival, for example in Burton lake (38 ‰), 55 marine species survival. Moreover, after 6000 a environmental evolution, 28 marine microorganisms and 2 zooplankton copepod species still exist in Abraxas Lake, which is completely cut off from the sea, and the water level is 10 m higher than sea level.

Fletcher Lake, situated in the northern sector of VH, is a typical case of unstable (or variable) catchments. The water budget for the lake was negative for part of it's history, that resulted in high salinity. Conversely, tidal input has increased in recent 20 a in this lake. Salinity has decreased from 66 ‰ in 1978 to 48.5 ‰ in 1985, which is a suitable condition for marine organisms survival. It is clear that the lake is still evolving in an unstable and variable way. Species number of zooplankton, in the lake by tidal running has been increased from 1 in 1982 to 8 in 1989 (Wang and Eslake 1997). Meanwhile, 22 species of diatoms and 11 species of other marine organisms have been recorded in recent years.

In Fig. 1, the salt line shows that the tendency of front zone of last transgression in VH coincided with ice sheet moving about 6000 a ago (Quilty 1988; Wang 1998). The formation of main valleys running from east to west and relative lakes in there in present VH could be explained as follows: In the process of ice sheet retreat, isostatic uplift and last transgression. (1) Northern part of VH (north of Long Fjord) outcropped and some marine derived lakes, such as Ace and Organic Lakes, were formed gradually; (2) Long Fjord is drowned in water till now; (3) Broad Peninsula outcropped above the sea surface and, at some low-lying places and catchments on glaciated valley in the middle of the peninsula marine derived lakes were formed. In Deep Lake, as a representative case, salinity of the lake was concentrated due to negative in water compensation and over evaporation, and freeze point dropped down (Ferris and Burton 1988), so as to make lake surface opening and evaporating under Antarctic continental strong windy climate; (4) The south-west part of Broad Peninsula once drowned in sea water is the present Ellis Fjord, and the east part of the Peninsula (east of salt line) was never flooded by sea water, but it was recharged by ice melting fresh water in a long period, being a part of Druzhby drainage system; (5) Mule Peninsula and Marine Plain cropped out, and marine derived lakes such as Burton Lake were formed, and a series of marine derived lakes and catchments on the east of Marine Plain and near the salt line, were diluted by ice melting water in a long period, being fresh lakes finally such as Watts Lake (Pichard *et al*. 1986). Moreover, on the west part of salt line, the land was never suffered from transgression and was becoming Crooked Lake as fresh.

Based on above analysis, evolution models of VH lakes are given in Figure 4. Due to the facts that of global climate becoming warmer, ice sheet of Antarctic continent retreating and sea level rising since 18000 a (see Fig. 4- iv), subsequently, transgression took place with isostatic uprising since 6000 a (see Fig. 4- iv iv). Four types of present marine derived lakes (see Fig. 4- iv iv iv and ⑼iv) have gradually developed after undergoing a process of environmental evolution for thousands of years:

(1) Fig. 4- iv iv iva, lake is completely cut off from sea bay, and becomes finally a higher saline lake due to water of the lake in negative increasing for a long time with less ice melted water input as well as over evaporation, in Deep Lake, as the case, higher organisms were extinct in this lake.

(2) Fig. 4- iv iv ivb, lake is completely cut off from sea bay and becomes finally a fresh water due to salinity diluted by much positive increase of water form melted ice, in Watts Lake, as the case, fresh organisms are instead of original marine organisms.

(3) Fig. 4- iv iv ivc, lake is completely cut off from sea bay and water budget of the lake is someway in balance, in Ace Lake, as the case, salinity of the lake is close to or less than sea water, some original marine organisms exist still in the lake.

(4) Fig. 4- iv iv ivD and iv (九) lake was cut off from sea bay in historic period, and mostly original marine organisms were extinct due to high salinity. Water exchange happens again by tidal flooding in recent years, for instance in Fletcher Lake, marine organisms return to the lake when the salinity is decreasing.

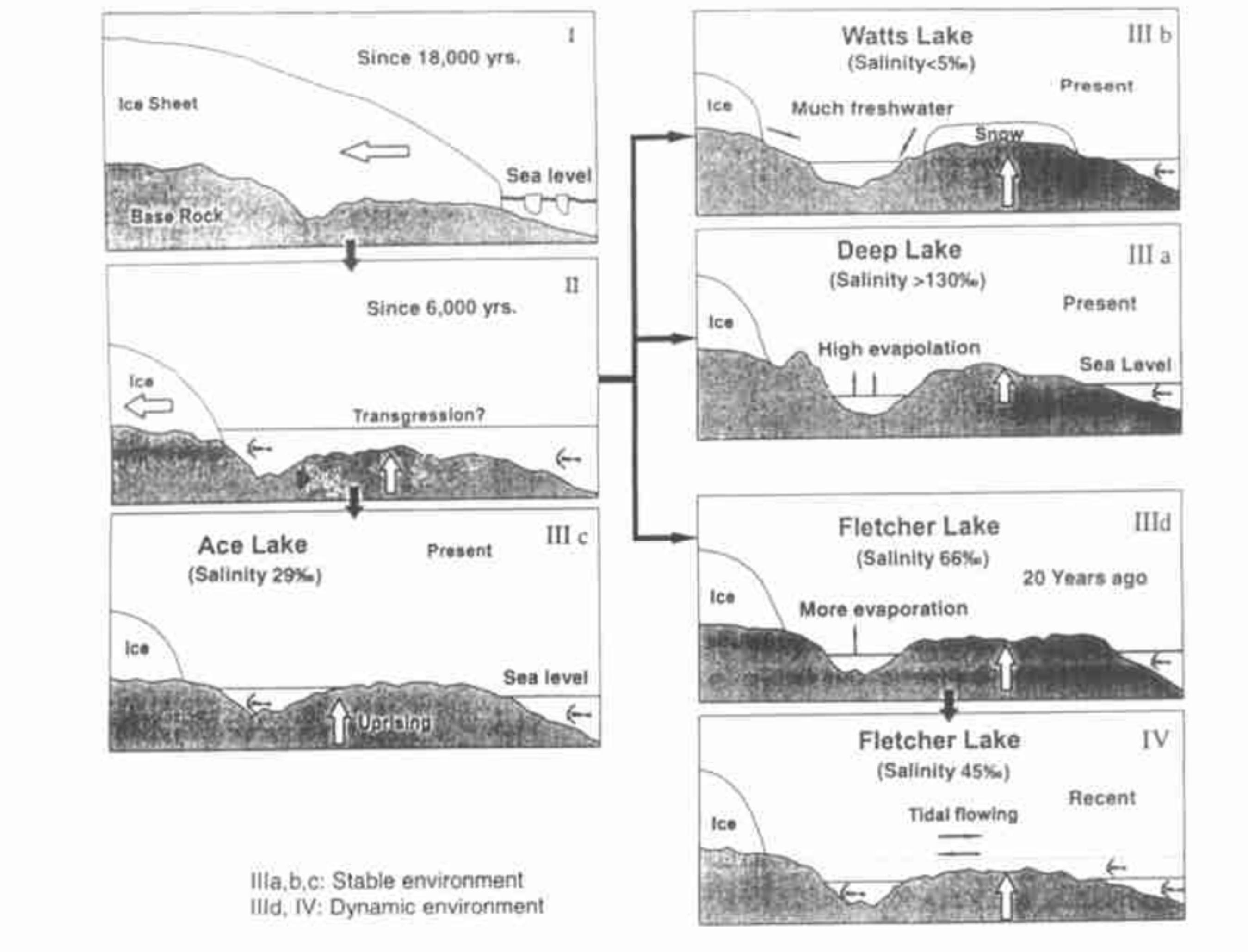

Fig. 4. Illustration of the evolution in different types of marine derived lakes.

4 Conclusion

(1) Great environmental variances of VH in geography and geomorphology are related directly to global sea level change since 18000 a B. P.; despite of many differences between present community structures and palaeo-ecological structure in VH lakes, there are very marked evidences of ecological evolution between past and present times.

(2) The coincidence between ecological structure and environmental type of VH lake should be regarded as a result by organisms adapting to environmental evolution; variations of bio-diversity and community structure in VH lakes should be regarded as important parts of Antarctic local environmental changes. Thus, the study in this respect is much valuable for understanding Antarctic environmental changes.

(3) Marine derived lakes of VH in Antarctic coastal zone, are products directly by Antarctic local climate changes as well as global ocean and climate variances in long period; environmental evolution of the lakes reflects a synthetic process of multi-factors variances in geology, geography and climate in Antarctica areas, and it could be incarnated as

present 4 types of VH lake.

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