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Ecology features of coastal saline lakes related to environmental evolution in the area of Antarctic continental ice edge

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Abstract An investigation has been made on the ecology of some saline lakes in the Vestfold Hills (60°38′S, 78°06′E), East Antarctica. The results indicate that changes of natural environment and physico-chemical factors, as well as the variation and evolution of biological species do occur in some lakes. This can be attributed to seasonal and local climate changes and geographic differences in this regions. These findings are believed to be indicative to the effects from the processes of globle climate change, ice sheet retreat, and isostatic uplift, are presently occuring, and a study of the chemistry and biology of these Antarctic lakes may be a significant means of monitoring effects of global climate change in the Antarctic.
Key words environmental evolution, ecology in saline lakes, Antarctica.

1 Introduction

The Antarctic coastline is affected by the retreat of the ice sheet which began around 18000 a B.P.. Ice free areas, such as the Bunger Hills, Vestfold Hills, and South Victoria Land on the Antarctic continental margin, formed particularly during processes such as global climate change and ice sheet retreat, subsequent flooding of areas by sea water and isostatic uplift raising since 6000 a B. P.. A numbers of coastal lakes and catchments with salt and freshwater developed during these period of processes(Zhang 1985; Peterson *et al.* 1988). These ice free areas are being influenced by both of marine and continental ice sheet. In comparison with open water, the lakes, fjords and bays consist of mostly are closed or semi-closed water bodies, and are affected by climate change and other local environmental physico-chemical factors. Salinity of the lakes depends entirely on their water budgets at any given time. These are more important factors restricting the life activities of organisms in the lakes, including their reproduction, community structure and succession (Wang and Eslake 1995; Burton 1981; Bayly 1986; Wang 1992). The results from this study indicate changes in geomorphological environments and ecological variability in many of the saline lakes in the Vestfold Hills. This paper reports the results of combinated studies of late Quaternary geological data in these area and present chemical and biological data for some of the lakes. The relationship between ecological variations in the lakes, regional environment evolution and the global climate change is discussed.

2 Materials and method

Based on the expeditions in the Vestford Hills during the period 1983 – 1990, geographic situation and environmental factors were measured and biological samples were made in Lakes Burton, Fletcher, Ace, Organic, and Deep, and in the Taynaya Bay and Ellis Fjold. All of the methods has been explained in Wang (1989, 1995) (environmental factors), Deprez and Franzmann*, Bayly (1986), Wang and Eslake (1995), Wang (1992).

3 Results and discussion

3. 1 Evolution in morphology of the area in Antarctic continental ice edge and the proofs in palaeontology

Evidences of global sea-level variation during the Quaternary have been found in coastal zones in many places around the world. For example, the sea level declined largely in the period of last Pleistocene, due to the enlargement and increase in thickness of ice sheet in both north and south polar and high latitude area in the North hemisphere. The range of sea level changing was much different in different places. Sea level declined 155 m in East China Sea, and 100 – 105 m in the Atlantic and the Indian Oceans. In East Antarctic, sea level in that time could be 100 – 150 m lower than the present (Zhang 1985; Liu 1982). The ice sheet which covered the Antarctic continent 18000 a ago, was much larger than present, and the edge may have reached the margin of the continent up to 67°S (Hughes *et al.* 1980). It had an estimated thickness of 300 m higher than today's ice shelf in West Antarctica (Thomas 1979). The Vestfold Hills which is an ice free area today, was far away from the coast and was covered with ice by up to 160 m at that time (Zhang 1985). Therefore, coastal saline lakes found there today must have formed at a later, more recent stage.

Sea level changes are mostly related to polar ice sheet retreat or extension. Retreat of ice sheet most probably resulted in sea level rising, as well as in isostatic uplift. Zhang (1985) believes that there were two transgressions in the Vestfold Hills from last Pleistocene. The second transgression was larger than the first in scale and took place in the climatic optimum of the post glacial period at 7500 – 3200 a B. P.. Sea level rose about 25 m, and pushed the coastline back about 75 km (Clark and Lingle 1979). As isostatic uplift took place, part of coast appeared as land, and some arms of sea became trapped and formed saline lakes in the South Victoria Land, Bunger Hills and the Vestfold Hills (Quilty 1988).

The Vestfold Hills is a rocky ice free area with generally lower hills, run from west to east or from south-west to north-east. There are many lakes and catchments

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* Deprez and Franzmann (1985): Aspects of the Biological Sulphur Cycle in Limmological Ecosystems in the Vestfold Hills, Antarctica. ANARE Scientific Report.

in the Hills. Fossils of diatoms, chlorophytes, foraminifers and bivalves, as well as bones of dolphin have been discovered in the valleys and lake beaches, where the strata are characterized as marine deposits. More marine paleobiological remains can be found including bivalve fragments of *Laternula elliptica* near Lake Cemetery, tubeworm fragments of polychaeta at Lake Watts. The results of age determination in bivalve fossils obtained from different strata of the terraces in Marine Plain, Lake Watts, Lake Mud and Deep Lake, show that various remains appeared in different strata from animals that existed in different paleoocean environments in relation to depth and age of the deposits (Zhang 1985). The terraces in the Hills are distinguished by four geological age-groups (Quilty 1988):

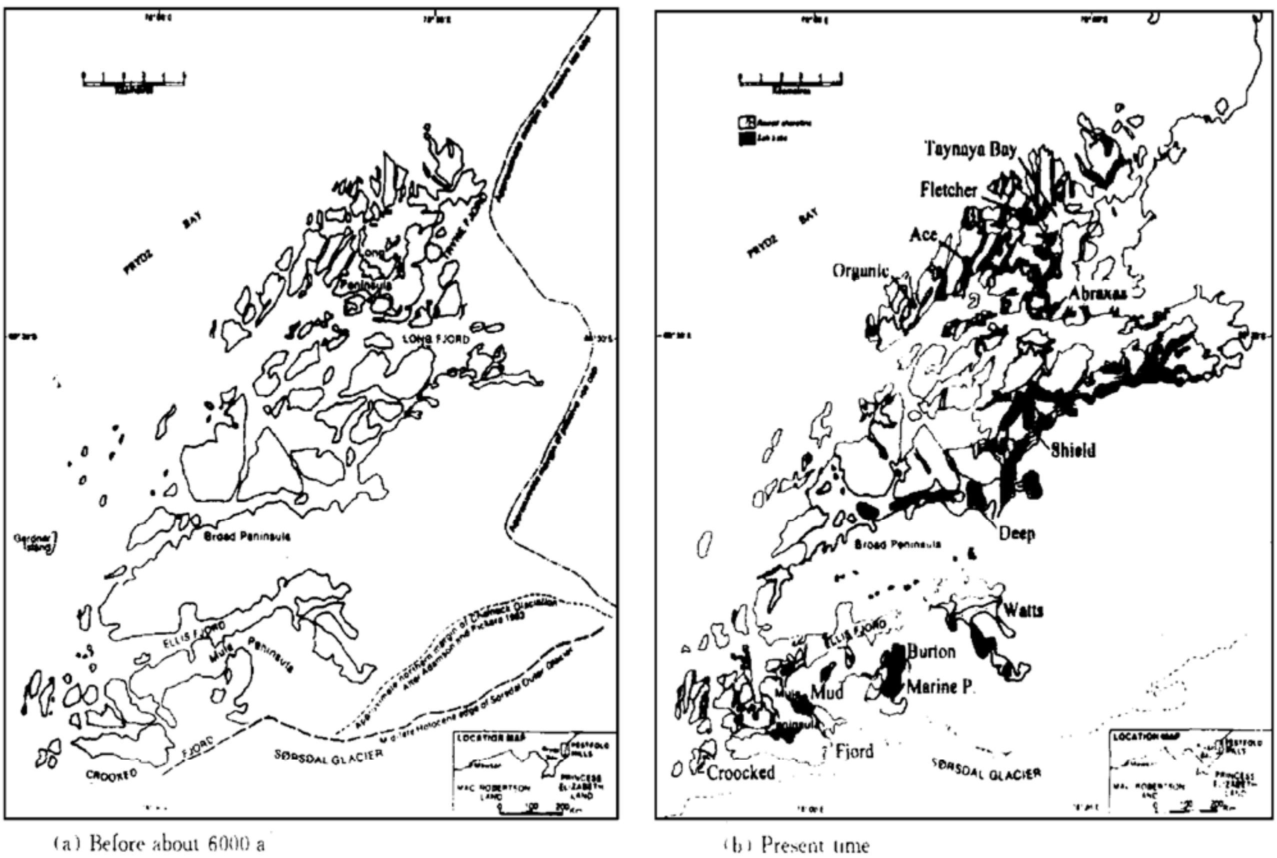
(1) Marine Plain immediatly on the east of Burton Lake, marine sediments of age older than any other, could be Early Pliocene;

(2) Death Vally Lake System, cosisting of an irregular series of lakes just on the south of Long Fojld, in age about 5000 – 500 a;

(3) Laternula Lake System in the west of Mule Peninsula between Ellis and Crooked Fjords with an age of 2500 – 3500 a;

(4) The present marine system.

Thus, it is apparent that the exsisting raised beaches in the valleys were part of palaooceanic bays. The ends and arms of those bays became lakes as a result of the ice sheet retreat, isostatic uplift and sea level movement (Fig. 1).



(a) Before about 6000 a (b) Present time

Fig. 1. Evolution of periglacial landforms in the Vestfold Hills.

3.2 Comparison of natural environment, physical and chemical features between the lakes

Because of their geographical locations, geomorphological processes and experiences under local climate changes, there are many differences in natural condition, such as water volume and depth, among those coastal saline lakes of the Hills (Table 1). Distances of lakes from nearby fords and bays, and their existing water levels are more important to the process of water exchange between lake and sea. Deep Lake is 50.4 m lower than the present sea level, and Abraxas Lake is 10 m higher and Burton Lake is at sea level. Apart from Burton Lake, which is connected by a shallow channel to the sea via the Croocked Fjord, the other lakes are completely cut off from the sea. Fletcher lake for example, is completely cut off from the Taynaya Bay by 80 m distance.

Table 1. Comparison of natural environment in lakes of the Vestfold Hills

		Depth		Aear /km^2	Level /m	Distance to the bay /m
		Max/m	Mean/m			
Saline lakes	Fletcher	11	5	0.38	+0.27	80
	Ace	24	9.2	0.46	+7.8	152
	Shield	37.6	19	0.48		1100
	Organic	7.5	3.1	0.29	+2	135
	Abraxas	24	11	0.35	+10	150
	Deep	36	14.2	0.64	−50.4	1640
	Burton	18	7.2	1.36	0	8
	Watts	35		0.51	−4.4	
Bays	Taynaya	65	15	>6.5		
	Ellis	50	30	>0.35		

Table 2 shows the main physical and chemical factors of the lakes and nearby Taynaya Bay and Ellis Fjord. Generally, it appears that the larger and deeper the lake, the warmer the water regardless of seasonal variation. Salinity is another one of the factors influencing water temperatures in the lake. Temperatures could drop down to very low level in some high salinity lakes, for example in Deep (S=105‰) and Organic Lake (S=222‰), it is 8.5 ℃ (depth of 6 m) and 6.1 ℃ (depth of 3 m) in summer, and −11 – −16 ℃ in winter respectively. Comparing with these, in Fletcher Lake (S=55‰), the range of temperature variation in seasons is as smaller as −2.5 – +2.9 ℃. It was −1.9 ℃ only in Burton Lake (S=38.5‰). The pH in the lakes is not related to salinities. It is a little higher in Fletcher lake than others (Table 2a). Evident differences in distributions of dissolved oxygen have been observed from respective lakes, which have respective physical and chemical factors of depth, salinity, productivity of sulphide, and the density of phytoplankton as well. In most of lakes the oxyliminion separates lake water into two levels: the upper being oxygen rich and the lower being oxygen deficeint and sulphide rich. The oxyliminion fluctuates remarkably following seasonal phytoplankton blooms. In some high salinity lakes, Deep and Organic Lakes, for example (Table 2b), the content of dissolved oxygen is limited by both of lower productivity of phytoplankton and higher productivity of sulphide (DMS) (Franzmann *et al.* 1987, 1988).

Table 2a. Physical and chemical factors of some saline lakes in the Vestfold Hills (up the oxyliminion, Jan. – Feb.)

		Oxyliminion /m	Depth* /m	Temperature		Salinity /‰	pH	Dissolved O_2 /ml·L^{-1}	SO_4 /g·L^{-1}	H_2S /mg·L^{-1}
				Ts/℃	Tw/℃					
Saline lakes	Fletcher	6	4	−1.2	−2.4	54.5	8.1	13.1	1.7	0
	Ace	10	6.5	+6.0	+2.5	29.5	7.6	8.5	0.4	0
	Shield	19	10	+10.0	−8.5	115			4.4	0
	Organic	4	3	+6.1	−10.8	105	7.0	3.2	0.1	19.3**
	Abraxas	17.5	9.5	+7.1		19.0		16.8		0.5
	Deep		6	+8.5	−15.5	222	7.4	2.4	2.6	0
	Burton	8	5	+0.5	−1.7	38.5	7.5	5.0	2.8	0
	Watts	29	10	+4.8		<3.0	6.9	10.2	0.2	0
Bays	Taynaya		10.5	−0.7		40.6		5.6	0.1	-
	Ellis	42	10	−1.5		33.5		6.1	2.7	0

*: Measured depth; Ts: in summer; Tw: in winter (Jul. – Aug.); **: DMS(μg/L) (Franzmann *et al.* 1987).

Table 2b. Physical and chemical factors of some saline lakes in the Vestfold Hills (under the oxyliminion, Jan. – Feb.)

		Oxyliminion /m	Depth* /m	Temperature		Salinity /%	pH	SO_4 /g·L^{-1}	H_2S /mg·L^{-1}
				Ts/℃	Tw/℃				
Saline lakes	Fletcher	6	7	+2.9	−0.5	92	6.6	2.4	3.8
	Ace	10	13	+6.1	−1.2	30.2	9.5	0.4	5.5
	Shield	19	20	−3.7		126		6.0	3.0
	Organic	4	5	−5.0	−6.8	132.3	6.9	6.1	51.7**
	Abraxas	17.5	18	+6.5	+2.0	20.0			2.5
	Deep	20	−14	−15	223	7.5			
	Burton	8	9	−1.5	−1.7	40.5		3.0	4.1
	Watts	-	20	+4.2				0.23	2.3
Bays	Taynaya	21	−0.7		36				5.1
	Ellis	44	−2		34.9			2.8	4.2

*: Measured depth; Ts: in summer; Tw: in winter (Jul. – Aug.); **: DMS(μg/L) (Franzmann *et al.* 1987).

3.3 Environmental types of saline lakes and community structure

Based on their geographical features and three main physico-chemical factors (temperature, salinity and oxygen), saline lakes in the Hills could be distinguished into three main types in ecological environment.

(1) Extreme environments: Lake is cut off from the bay, without water exchange between lake and bay.

(a) High salinity (>100‰), evident seasonal differences in temperature (>17), lower oxygen content (<3.8) (such as Deep, Organic and Shield Lake).

(b) Low salinity (<5‰) and high oxygen content (Watts Lake).

(2) Stable environments: Lake is cut off from near bay, without water exchange between lake and bay. Salinities are close to sea water (28‰ – 40‰), lower seasonal variances in temperatures (<5.1), oxygen content>3.0 (Abraxas and Ace Lakes).

(3) Variable environments: There is limited water exchange between lake and near bay. Salinity is close to or over sea water (35‰ – 55‰), lower seasonal differences in temperatures (<3), oxygen content >3.8 (as in Fletcher and Burton Lake, and some other small lakes near the coast (Zhang 1985)).

The communities in marine saline lakes in the Hills consist of bacteria (4 families, 7 genera and 9 species)(Burke and Burton 1988a,1988b;Volkman *et al.* 1988), phytoplankton (12 families, 15 genera and 19 species)(Volkman *et al.* 1988; Heath 1988), and some zooplankton species including 1 medusa (Coelenterata) and 1 ctenophora, and 8 species of copepoda with high distribution densities in lakes(Wang and Eslake 1995; Burton 1981). The community structures and dominant species in different types of those lakes are shown in Table 3. In environment type 1, it has high salinity and lower oxygen content, or particularly in extreme low salinity (near freshwater), most of marine phytoplankton and animals are hard to survive, except a few species of bacteria and elementary algae. So that the biological diversity are lower in both cases. With adequate salinity levels, temperature and oxygen content in environment type 2, this provides optimal survival conditions for marine algae and animals (16 species as more, with diversity of 1.8) survival. In environment type 3, where water exchanges occur between lakes and fjords and bays, the physico-chemical conditions are closer to those of sea water and 25 marine species have been found, with the biological diversity as high as over 2.2. With constant water exchange, there is also a good variation in species composition. In Fletcher Lake for example, an increasing number of marine derived animals have been observed over winter since 1978(Wang and Eslake 1995). This seems to be indicative of an increasing level of favorable conditions for these organisms, such as salinity decreasing.

Table 3. Comparison of biological structures in different types of the lake

Types	Salinity	d*	Community structure	Dominant species
1a	>130	0.89	Bacteria+diatoms+chlorophyta	*H. elongaia*; *Dunaliella* sp.
1b	<5	0.78	Diatoms+chlorophyta	*Rhodomonas* sp.
2	20 - 40	1.79	Bacteria+diatoms +chlorophyta +copepoda	*C. vibrioforme*; *P. gelidicola*; *P. antarctica*
3	35 - 55	2.24	Bacteria+diatoms +chlorophyta +copepoda +ctenophora	*C. vibrioforme*; *C. compressus*; *D. bispinosus*; *Cydippida* sp.

d*: Biological diversity.

3.4 Changes in ecological structure related to the evolution of lake environment

Environment of marine derived lakes, in view of itself, is fragile and affected directly by variations in regional geographyical conditions and climate changes. As one of most important features to saline lake, the salinity status depends entirely on total water budgets viz. net result of water input from snow, streams, tides and precipitation, and of water loss by catchment over flow, leakage and evaporation. The water budget for some high salinity lakes, such as Deep, Organic and Fletcher Lakes, have been negative for part of their history. Positive water budgets and associated salinity decreases have apparently been the case for some time in the Hills, and result in low salinity, for example, in Ace and Abraxas Lakes. Zhang(1985) believes that because of global change, the precipitation by snow on Antarctic continent has remarkably increased since this century. On internal plateau (Dome C area in east Antarctica) snow accumulation increases 1.1 $g/(cm^2 \cdot a)$, and it increases 50% in Antarctic peninsula area in the same period. Therefore, more snow is blown to the coastal ice free area, and more melted water flows into the lakes. In Deep Lake, water level has been raised 1 m (Burton 1982). With decreasing surface salinity, the entire lake surface was frozen for the first time in 1982. The salinity in Fletcher Lake has decreased from 66‰ in 1978 to 48.5‰ at present (Wang and Eslake 1995). In Watts Lake, snow meltwater reduced salinity to as low as 2‰ (Burke and Burton 1988b). Also geomorphological phenomena have been observed recently, the Vestfold Hills is bing in the processes of isostatic uplift raising with mean rate of 1 - 2.5 m/a (Zhang 1985). The small lake on the Lake Island near the coast of the Hills, and Burton Lake as well, have been moving out from the transgression resently. In the other, the tides has been running more frequently into Fletcher Lake in the north part of the Hills in resent years. Thus, it is clear that those lakes are still being in unstable status. Fletcher Lake is a typical case of unstable catchment, in which the composition of community has changed considerably with changes to the lake environment since 1978 (Table 4). There were no any zooplankton in this lake with salinity of 66‰ in 1978. However in 1983, with a reduced salinity of 56‰, a few samples indicated the presence of a Calanoida copepoda, *Drepanopus bispinosus*, in existence there. An increased number of zooplankton, such as ctenophore, and other copepoda species *Oceaea curvata* and *Harpacticus furcatus* survive in winter in this lake as a result of reduced salinity (Wang and Eslake 1995).

Table 4. Community composition and variation of Zooplankton in Lake Fletcher (1978 - 1989)

Date	Salinity /‰	Community composition of zooplankton					
		D. b	O. c	P. a	H. f	Is	Cy
Nov. 1978	66	—	—	—	—	—	—
Dec. 1979	-	—	—	—	—	—	—
Dec. 1983	56	+	—	—	—	—	—
Sep. 1984	49.3	++	—	—	—	—	—
Dec. 1984	55.9	++	—	—	—	—	—
Dec. 1985	54	++	—	—	—	—	—
Apr. 1986	54	++	+	+	++	+	*
Jun. 1986	54	++	+	—	—	—	*
Jan. 1987	54	++	+	++	++	—	* *
Oct. 1987	54	++	+	—	—	—	*
Dec. 1989	48.5	++	+	++	++	—	*

—: 0/m³; +: 1 - 100/m³; ++: 101 - 500/m³; *: 1 - 10/m³; * *: 11 - 50/m³; P. a: *Paralabidocera antarctica*; D. b: *Drepanopus bispinosus*; O. c: *Oceaea curvata*; H. f: *Harpacticus furcatus*; Is: *Idomene* sp.; Cy: Cydippida (Ctenophora).

4 Conclusion

In the Vestfold Hills, the ecosystem of marine derived saline lakes is continuously influenced by environmental factors and ongoing evolution. The changes observed in biological composition and physico-chemical features of the lakes are a direct result of present environmental conditions, which in turn reflect global effects on the Antarctic environment. These indicators are regarded as very important in monitoring changes in the Antarctic environment. Ongoing studies, including monitoring, of these marine derived lakes is recommended as a way of observing greater processes such as global climate changes.

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