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Water Quality: Lakes of Schirmacher Oasis, Antarctica

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ABSTRACT:

The Antarctic continental margins are remarkably known for the diverse group of takes, ponds, and even streams. These water bodies may chemically range from distilled water of crystal clarity to salt-laden brines. Thirty-eight lakes out of a total of around hundred at Schirmacher Oasis, Antarctica were selected and surveyed during the austral summer (Jan. - Feb. 1999). These included (a) twenty-two glacier-fed and glacier-fed intermountainous lakes, (b) twelve intermountainous lakes, and (c) four grounding-line lakes.

Conductivity was found to be as low as 5.5 µS/cm in case of a glacier-fed lake just adjacent to continental ice and as high as 546.44 µS/cm in case of an inter-mountainous lake, a variation of about 100 times. pH ranged from 6-7.8, almost increasing with increase in conductivity. However, in one of the intermountainous lakes, pH was recorded to be as low as 4.8. Except one lake, turbidity was observed in the narrow range of 0.50 NTU - 1.60 NTU. Three fourth of the lake waters had turbidity <t NTU. However, in one of the glacier-fed lakes it was observed to be as high as 5.6 "NTU.

Spatial variation in total ionic composition was quite noticeable. It varied from 0.102 meq/L - 10,584 meq/L, a variation of about 100 times. Ca^{2}+ was found to be the dominant cation and HCO, - the dominant anion in majority of the glacier-fed lakes while in case of most of the intermountainous and all the grounding-line lakes Na+ and Cl- were the dominant cation and anion respectively. Waters of different Schirmacher lakes were found of sixteen water types. Among them Na+ - C1, and Ca^{2+} - HCO, types dominated. Considering the small area in which these lakes are situated, the variation in water types was quite significant. In > 50% of the lake waters analyzed (a) alkaline earths > alkaline metals, (b) strong acidic anions > weak acidic anions, and (c) non-carbonate hardness > carbonate hardness.

It could be concluded that perhaps no two natural waters are of the same characteristics. Even at a remote place like Schirmacher Oasis of only about 20 km in length and maximum width of only about 3.5 km, characteristics of unaltered, unpolluted polar lakes vary widely.

1. INTRODUCTION:

The fresh water lakes of Schumacher Oasis, Antarctica represent physical, chemical, and biological integration of particularly attractive ecological units for basic study. In spite of the hazardous climatic conditions, such isolated, unaltered, and unpolluted polar ecosystems have been investigated by many research workers. Some of these lakes harbour important fauna and flora of Antarctic continent. Available information indicate that major emphasis has so far been placed on their faunistic (Matondkar and Gomes, 1983; Ingole and Parulekar, 1987; Ingole et al., 1987; Verlencar et al., 1988; 96), and floristic aspects (Komarker and Ruzickal, 1966; Verlencar et al., 1988; 96). Some work has been done on water characteristics (Bardin and Leflat, 1965; Ghosh et al., 1997; Nair et al., 1998), nutrient status (Verlencar et al., 1988; 96), and presence of selective heavy metals (Ghosh et al., 1997; Nair et al.. 1998) in some selected lakes of the Schirmacher Oasis. During the present investigation, selected physical and chemical characteristics of water samples from thirty-eight lakes of Schirmacher Oasis were determined.

2. STUDY AREA:

Of all the continents, Antarctica is the fairest. It is white and unspoiled, spacious and austere, and fashioned in the clean, antiseptic quarries of an ice age. Thus, it is unique among continents. More than 98% of its surfaces is composed of a single mineral i.e. ice. It is the coldest, windiest, driest, thickest, most isolated, least known and most mysterious. It contains more than 70% of the world's fresh water. The combination of ice, cold and aridity is a lethal mix for most forms of life and only a few organisms are able to survive in this freezing desert. However, there are little patches during the summer, where temperatures rise above freezing and water flows over the rocks and soil. These are known as oases in a vast icy desert.

One such oasis on the periphery of East Antarctica with a large number of clear and blue lakes of different shapes and sizes is known as Schirmacher Oasis. It is about 70 km south of Prince Astrid Coast & forms a part of Dronning Maud Land. The physico-geographical conditions of the oasis have been described in detail by Simonov (1971). The Schirmacher Oasis has a maximum width of 3.5 km, & a length of about 20 km. It is oriented approximately in east-west direction. The coordinates of the oasis are: Lat. 70°44'33"S -70^{0}46'30"S; Long. 11°22'40"E-11^{0}54'00"E (Atlas Antarktiki, 1969; Richter, 1984). It consists of approximately 35 km^2 of solid bedrock, while fern and ice fields accounts for 27 km^2 & 3 km^2 respectively. Unlike the main mountain range. Schirmacher forms a group of low-lying hills of about 50 to 200 m high having glacial lakes ranging in size from 0.02 to 0.75 km^2 (Fig. 1), Its surface is undulating The gentle slopes and plain areas are covered with a mostly thin blanket of moraine. The average annual temperature is around -10^0C. The warmest and coldest months are January and July with average temperatures of approx. -1°C and -18^0C respectively. Extreme air temperatures recorded at Schirmacher vary from a minimum of -40^0C in winter to a maximum of -6°C in summer. The mean wind velocity is about 10 m/s. The most prevalent wind direction is east-southeast. The average precipitation in the form of snowfall is between 250-300 mm but most of it is blown by strong katabatic winds from easterly direction. The relative air humidity is about 50 percent. Monthly average of solar radiation values range from 0-34 $MJ\,m^{-2}\,d^{-4}$'.

At present, apart from Indian scientific research station, Maitree. a Russian station, Novolazharevskaya, is also located in Schirmacher Oasis at a distance of about 3.5 km east of Maitree.

3. SCHIRMACHER LAKES:

The snow, which covers large area of the Oasis in winter, partially melts off in summer. This melt water from snowfields along with the melted glacier water replenishes the water lost in the lakes due to evaporation and get accumulated in the depressions between the hills to form small pools. About 100 such lakes/pools exist in Schirmacher Oasis during the month of Dec. - Feb. However, even during peak summer, some part of the lake surfaces remain covered with ice. A continuous cycle of freezing and melting in winter and summer brings a large amount of changes in physico-chemical and biological properties of waters and bottom sediments. There are instances where the lakes are even subjected to drying in course of time as a result of negative water balance.

Scientists from Russia and India have named some of the Schirmacher lakes. Information about maximum depth of twelve of these was collected from Arctic and Antarctic Scientific Research Institute, Saint Petersburg, Russia. These names and depths have been indicated in Fig. 1. Names in Russian in Fig. 1 are based on special characteristic features of different lakes, mountain peaks, station etc.

Water for use at Russian research station, Novolazharevskaya and Indian research station, Maitree are drawn from lakes Verkhneye and Zub respectively. Verkhneye, a relatively small lake is situated close to ice edge at an elevation higher than Novolazharevskaya. A geographical barrier separates station and the lake. However, possibility of some used or treated water entering into another nearby lake Glubokoye which is situated at a much lower elevation compared to Novolazharevskaya is not completely ruled out. On the contrary, Maitree is situated in the catchment of lake Zub itself at a higher elevation. Possibility of seepage of used or treated water along with melt water to lake Zub is high.

Channels connect some of these fresh water bodies. For example, lake Smirnov situated at the southern boundary of Oasis near glacier is directly fed by glacier-melt water. A stream runs from Smirnov to Pomomik during summer and another channel from Pomomik to Glubokoye (Fig. 1).

4. MATERIALS AND METHODS:

Lakes were visited several times during the period from 17 Jan. - 27 Feb. 1999 and 38 lakes of widely diverse nature and sizes were selected for study. Lakes have been numbered as per the order of sample collection during the first sampling schedule (Fig. 1). These numbers have been indicated in the test. Water samples were collected and partially analyzed at Maitree. Rest of the analysis was done at Environmental Engineering Laboratory, Department of Civil Engineering, University of Roorkee, Roorkee. Samples were collected, handled, preserved, and analyzed in accordance with the procedures outlined in Standard Methods for the Examination of .Water-and Wastewater (APHA, 1998). In case of alkalinity, hardness, and Chloride, titration was carried out by diluting the titrants and taking a larger sample size than specified as very low values were expected. Correctness of analyses of different lake water samples using the observed values of pH, conductivity, total dissolved solids, and major anionic and cationic constituents was carried out as per methods prescribed in Standard Methods for the Examination of Water and Wastewater (APHA, 1998). Analyses were found to be acceptable.

5 RESULTS AND DISCUSSION:

Weather data (hours of visibility of sun, average temperature, average wind chill, gust, average wind speed, average pressure) collected during the period of study from 17 Jan. to 27 Feb., 1999 is given in Fig. 2. Sun did not set upto 28th Jan. and thereafter hours of visibility of sun gradually reduced to 15 hours and 54 minutes by the end of sampling schedule. Average daily air temperature throughout the study period was almost observed to be below zero and water temperature of lakes varied from 0.5 to 1.5"C. Weather data for the period (17 Jan. - 27 Feb., 1999) during which Schirmacher lakes were visited for the sample collection is summarized in Table 1.

Table 1. Weather Data for the Period: 17 Jan. - 27 Feb., 1999

Parameters	Value/range
Average daily air temperature (range), °C	+2.5 to-7.1
Maximum recorded air temperature, °C	+8
Minimum recorded air temperature, °C	-10
Average daily wind chill (range), °C	-5 to -23
Average daily wind speed (range), km/h	3.7 to 70.4
Maximum gust (range), km/h	22.2 to 111.1
Average daily pressure (range), hPa	978.8 to 1000.9

Lakes were initially surveyed for their physical features and were broadly divided into three categories namely, (1) glacier-fed/glacier-fed intermountainous lakes, (2) intermountainous lakes, and (3) grounding line lakes. Based on physical features like location, size, and depth, thirty-eight representative lakes were selected which included lakes from all the three above-mentioned categories. A brief description of these lakes along with their water quality is discussed below:

5.1 Glacier-fed/Glacier-fed Intermountainous Lakes

This category of 22 lakes, based on their location could be classified into following sub-groups: (i) Those situated just on the edge of continental ice like Zapadnoye (22), Iskristoye (33), Sbrosovoye (36), Predlednikovoye (18), Podprudnoye

(17), Smirov (2), Pomornik (4), Verkhneye (37) etc. During summer, when ice melts. water immediately enters into these lakes without coming in contact of moraine/parent rocks. Due to proximity with ice edge, there are no distinctly marked incoming water channels, (ii) Those situated away from continental ice like Dlinnoye (12), Zub (I), Glubokoye (3) etc. These lakes have channel(s) feeding melt water into them and taking out. In some of the lakes these inlet and outlet channels were quite distinctly marked like Zub (1), and Glubokoye (3). During sampling surface area of the lakes of first sub-group was found to be more frozen, and in some cases they were completely frozen.

During summer, from most of the lakes adjacent to ice edge, water flows out through channels to glacier-fed intermountainous lakes. For example, lake Smimov (2) situated on the boundary of continental ice is fed by ice melt water. A stream runs from Smimov to lake Pomomik (4) during summer. Another stream of more than a km in length connects Pomomik to lake Glubokoye (3). From Glubokoye water flows out towards the ice shelf. Another example of inter connecting glacier-fed intermountainous lakes having incoming and outgoing channels is flow of water during summer through Zub (1), lake 8, lake 6, than to a series of smaller lakes and finally to ice shelf.

Some of the physical (conductivity, turbidity) and chemical (pH) characteristics of lake waters are given in Fig. 3 in order of increasing conductivity values. Conductivity ranged from 5.5 µS/cm to 56.81 µS/cm, a variation of about 10 fold. An interesting observation on comparison of conductivity values (Fig. 3) and location of lakes (Fig. 1) is that conductivity of water increases as it travels from one lake to another. For example, conductivity of water of lake Smimov (2) whose southern boundary is defined by continental ice edge, was found to be 5.5 S/cm. Conductivity of water of lake Pomomik (4) was found to be 6.15 µS/cm while lake Glubokoye (3) had conductivity of 10.73 µS/cm. A similar increasing trend was also observed for another series of connecting lakes i.e. 1, 8, and 6 with conductivity values of 13.97, 14.39, and 26.26 uS/cm respectively. Starting lakes of these two sets of lake in series i.e. Lakes Smimov (3), and Lake Zub (1) had conductivity values of 5.5 µS/cm, and 13.97 µS/cm respectively. This difference is most probably due to the fact that in the Smimov water immediately enters after melting while in case of Zub, it travels through rocky terrain before entering (Fig. 1). Smirnov falls in sub-groups (i): Glacier-fed while Zub in sub-group (ii): Glacier-fed intermountainous lake. pH of lake waters was also found to be increasing more or less on the same lines as conductivity (Fig. 3). Turbidity was found to be ranging from 0.51 NTU to 5.60 MTU, 75% of the lakes having turbidity < 1 NTU. Lake 31 had much higher turbidity (5.6 NTU) than other lakes. Reason for the same could not be ascertained.

Using the parametric values as obtained by the analysis, the ionic composition for water from each lake was determined and presented diagrammatically in Fig. 4 (a tob).

A visual comparison of the different bar graphs revealed the following:

(a) Total ionic composition varies spatially. The range of variation for both cations and anions was found to be from 0.038 to 0.508 meq/L, a variation of over 13 fold.

(b) Dominant cation and anion are given in Table 2.

Table 2. Dominant Cation and Anion in Different Glacier-fed Lake Waters

Dominantion		Lake Number
Cations	Calcium	16,31,17,32,34,3,29,30, 21,1,24,36,33,22,12,37,18
	Magnesium	2,4,3,11,8,12,
	Sodium	6
Anions	Bicarbonate	2,16,34,3,29,30,1,36,12,18
	Sulfate	31,32,21,24,33,22
	Chloride	4,17,11,8,6,37

Calcium was judged the dominant cation in majority of the lakes, and bicarbonate the dominant among anion.

Two right-angled isosceles triangles (Fig. 5) were used for plotting cations and anions essentially for classification of lake waters. The three sides of each triangle, divided into 100 equal parts, represent the percentage reacting values of cation and anion groups. The cation and anion triangles are sub-divided into 7 sub fields each, representing the types of waters given in Table 3.

Table 3. Criteria for classification of Waters Based on Major Cations and Anions

Subfields : Types of Waters		Criteria
Cation triangle		
C1 :	Calcium type *Water Quality:*	Ca^{2}+ > 50%
C2 :	Magnesium type	Mg^{2+} > 50%
C3 :	Sodium type	Na^{+} > 50%
C4 :	Sodium-Calcium type	Na^{+} & Ca^{2}+ each 25-50% Mg^{2+} < 25%
C5 :	Calcium magnesium type	Ca^{2}+ & Mg^{2}+ each 25-50%, Na^{+} < 25%
C6 :	Sodium-magnesium type	Na^{+} & Mg^{2+} each 25-50%, Ca^{2+} < 25%
C7 :	Calcium-magnesium-sodium type Anion triangle	Ca^{2+}, Mg^{2+} & Na^{+} each 25-50%
A1 :	Bicarbonate type	HCO_3^- > 50%
A2 :	Sulphate type	SO_4^{2-} > 50%
A3 :	Chloride type	Cl^- > 50%
A4 :	Chloride-bicarbonate type	Cl^- & HCo_3^- each 25-50% SO_4^{2-} < 25%
A5 :	Bicarbonate-sulphate type	HCo_3^- & SO_4^{2-} each 25-50% Cl < 25%
A6 :	Chloride-sulphate type	Cl^- & $SO4^{2-}$ each 25-50%, HCo_3^- < 25%
A7 :	Bicarbonate-sulphate-chloride type	HCo_3^-, SO_4^{2-} & Cl each 25-50%

The proportion of principal cation and anion, in terms of percentage reacting values, were plotted in each triangle & the type of lake water was found out on the basis of position of plotting in respective fields (Fig. 5, Table 4).

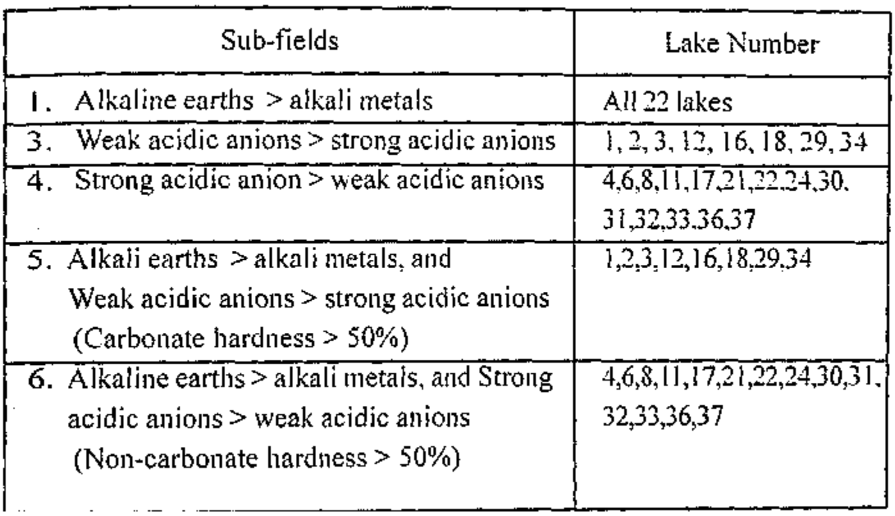
Table 4. Classification of Different Glacier-fed Lake Waters

Water Type	Criteria
$Ca^{2+} - HCO^{3-}+$	1, 16, 341
$Mg^{2+} - HCO_{3-}$ +	3, 29, 18
$Ca^{2+} - SO_4^{2+}$	2, 31, 33
$Ca^{2+} - Mg^{2+} - Cl^-$	4, 11, 8
Ca^{2+}.- Cl^-	17
$Ca^{2+} - Mg^{2+} - SO_4^{2-}$	32
$Ca^{2+} - Mg^{2+}\ HCO_3^- + SO_4^{2-}$	30
$Ca^{2+} + SO_4^{2-} - Cl^-$	21
$Ca^{2+} - HCO_{3-} - SO_4^{2-}$	24, 22
$Ca^{2+} - HCO_3^- - SO_4^{2-}$ Cl-	36
$Ca^{2+} - Mg^{2+} - Na^+ - HCO_3^-$	12
$Ca^{2+} - Na^+ - Cl^-$	6
$Ca^{2+} - Na^+ - HCO_3^- + Cl^-$	37

The data in Table 4 reflect a very wide distribution of water types although $Ca^{2}-HCO_3$ type dominated. Considering the small area in which these lakes are situated i.e. Schirmacher Oasis, this variation is all the more significant.

In Fig. 6, the difference in milli-equivalent percentage between alkaline earths (calcium + magnesium) and alkali metals (sodium + potassium), expressed as percentage reacting values, is plotted on x-axis, and the difference in milli-equivalent percentage between weak acidic anions (carbonate + bicarbonate) and strong acidic anions (chloride + sulphate) is plotted on the y-axis (Chadha, 1999). The rectangular fields in Fig. 6 describe the overall character of different lake waters (Table 5).

Table 5. Overall Character of Glacier-fed Lake Waters



Sub-fields	Lake Number
1. Alkaline earths > alkali metals	All 22 lakes
3. Weak acidic anions > strong acidic anions	1, 2, 3, 12, 16, 18, 29, 34
4. Strong acidic anion > weak acidic anions	4,6,8,11,17,21,22,24,30, 31,32,33,36,37
5. Alkali earths > alkali metals, and Weak acidic anions > strong acidic anions (Carbonate hardness > 50%)	1,2,3,12,16,18,29,34
6. Alkaline earths > alkali metals, and Strong acidic anions > weak acidic anions (Non-carbonate hardness > 50%)	4,6,8,11,17,21,22,24,30,31, 32,33,36,37

In the lake waters analyzed (a) alkaline earths exceeded over alkali metals in all the lake waters, (b) strong acidic anions exceeded in > 50 % of the lake waters, and (c) although both temporary hardness and permanent hardness were found to be present in all the lake waters, however, non-carbonate hardness exceeded in > 50 % of the lake waters.

5.2 Intermountainous Lakes

Twelve such lakes were surveyed during present investigation. Compared to lakes of category 1, these lakes are relatively smaller in size except lake Diatomovoye. shallower in depth except lake Diatomovoye (which is 8 m of depth) but have much bigger catchment areas. Almost each of these lakes is situated in a bowl like natural formation. During winter some drifted snow accumulates on Frozen lake surfaces, which feeds them when they partially melt during summer Ice from side slopes also melts during summer and enters into an adjoining lake flowing, through rocky terrain, and/or polygon channels. The loss of water appears to be only through evaporation as there are no outlet channels due to natural barriers on almost all sides. Conductivity, pH and turbidity values are given in Fig. 3. Conductivity varied from 133.44 µ Sem to 546.44µ S/cm, a variation of about 4 times. Variation of pH was observed to he in a narrow range of 7-7.8 except for lake 26 for which pH was found lo he 4.8. Turbidity ranged from 0.54 to 1.50. Compared to lakes of category 1, these had higher conductivity & pH values while turbidity was almost of the same order. Compared to conductivity of lakes of category

1 (5.5 µS/cm - 56.81 µS/cm), conductivity of intermountuinous lakes (133.44 µS/cm - 546.44u S/cm) was observed to be much higher. Lowest value of 5.5 µS/cm was observed for lake Smirnov while highest of 546.44 uS/cm was recoided for take 27, a very significant variation of ~ 100 times. A briefdescription of the mechanism of the formation of polygons, a very special feature of'Schirmachcr landmass. which most probably contributes towards increase in conductivity in intermouutainous lakes follows.

The landscape of Schirmacher Oasis, Antarctica is marked by a very special landform known as stone nets, (Also known as sorted polygons, stone polygons, frost polygons, and polygonal ground or soil). Permafrost overlain by active layer has resulted in conversion of land surface into a maze.c of polygonal patterns. Stone nets involve severe rearrangement of rock fragments with coarser material pushed outward to the edges of the polygons. These are basically three - dimensional soil structures having centres chiefly of clay, silt, and gravel and roughly circular (diameter approximately 2 m) or polygonal borders of coarse stones.

Initially, heterogeneous rock debris of all sizes from clay to boulders of glacial origin must have accumulated over the surface. Over the years this inhomogeneous debris underwent inhomogeneous freeze and thaw. Areas of line material acted as pressure centres because they contained more water and were able to draw moisture from surrounding materials as they froze. On freezing the stones and adjacent fines were shoved upward and outward from the pressure center or area of concentrated fines. On thawing the fines contracted and were pulled back further then the stones owning to greater mutual cohesion. This left the stones in a new position relative to the surrounding material and repetition of the process eventually produced the sorting now observed in stone nets in Schirmacher Oasis. Although, not apparently visible. the process of sorting is believed to be always active. A higher proportion of fine-grained sediment probably promoted this type of sorting because water is held longer without refreezing in fine sediments.

Sorted polygons are preserved over the years because seasonal flowing water, which ultimately flows into different intermountainous lakes, permeates the coarse network of polygonal boundaries without eroding the fine sediments from the cores of the polygons. Stone nets are found upon flat or nearly flat ground all throughout Schirmacher Oasis.

Ionic composition of 11 different lakes was determined and presented in Fig. 7(a,b). Cationic and anionic balance for lake 5 could not be completed due to some logistic problems. A visual comparison of different bar graphs revealed the following:

a) Spatial variation in total ionic composition is quite noticeable. It varied from 2.549 meq/L to 10.584 meq/L, a variation of over four times.

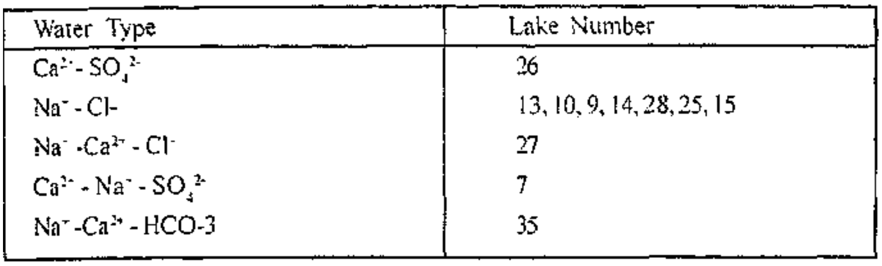
(b) Sodium and chlorides are the dominant cation and anion respectively (Table 6).

Table 6. Dominate Cation and Anion in Different Intermountainous Lake Waters

Dominant Ion		Lake Number
Cations	Calcium	35,26
	Sodium	7,13,10,9,14,28,25,15,27
Anions	Bicarbonate	35
	Sulfate	26,27
	Chloride	7,13,10,9,14,28,25,15

Major cations and anions were plotted in cationic and anionic triangles (Fig. 5). Type of lake water was evaluated based on the position of points in two triangles (Table?)

Table 7. Classification of Different Intermountainous Lake Waters



Water Type	Lake Number
Ca^{2+} - SO_4^{2-}	26
Na^{+} - Cl-	13, 10, 9, 14, 28, 25, 15
Na^{+} -Ca^{2+} - Cl^{-}	27
Ca^{2+} - Na^{+} - SO_4^{2-}	7
Na^{+} -Ca^{2+} - HCO-3	35

In majority of the lakes, water was found of Na^{+} - Cl^{-} type. Based on the ionic data of these eleven lakes as plotted in Fig. 6, different waters were classified as given in Table-8.

Table 8. Overall Character of Intermountainous Lake Waters

Subfields	Lake Number
1. Alkali earths > alkali metals	7.26,27,35
2 Alkali metals > alkali earths	9,10,13,14,15,25,28
3. Weak acidic anions > strong acidic anion	3 5
4. Strong acidic anion > weak acidic anions	7,9,10,13,14,15,25,26,27,28
5. Alkali earths > alkali metals, and Weak acidic anion > strong acidic Anions (Carbonate hardness > 50%)	35
6. Alkali earths > alkali metals, and Strong acidic anion > weak acidic anions (Non-carbonate hardness > 50%)	7,26,27
7. Alkali metals > alkali earths, and Strong acidic anions > weak acidic anions (Non-carbonate hardness > 50%)	9,10,13,14,15,25,28

In lakes of this category (a) alkali metals exceeded alkali earths in > 50% of the lake waters (b) strong acidic anions exceeded weak acidic anions in almost all the lakes, and (c) Non-carbonate hardness exceeds > 50% in all the lakes except one.

5.3 Grounding Line Lakes

Lakes situated on the ice shelf adjacent to Schirmacher Oasis were grouped under this category. They all has water level at the same elevation as of sea level and most of them are much bigger in size compared to glacier-fed and intermountainous lakes. Lakes Zigzag and Azhidaniya are 150 m deep, deepest among lakes of Schirmacher Oasis. Due to their location on ice-shelf, these lakes remain almost completely frozen around the year. Water flowing from continental ice/glaciers through different connecting lakes in Schirmacher Oasis ultimately flows into these lakes. During the present investigations, water from four such lakes was collected for the analysis.

Variation of some physico-chemical water quality parameters is given in Fig. 3. Conductivity varied from 74.66 µS/cm to 126.5 uS/cm while variation of pH and turbidity was recorded in very narrow ranges of 6.2-6.4, and 0.50 NTU to 0.65 NTU respectively. Ionic balance of these lakes is given in Fig. 8. Due to logistics, complete ionic balance could not be carried out for lake 23. A visual comparison of different bar graphs revealed the following:

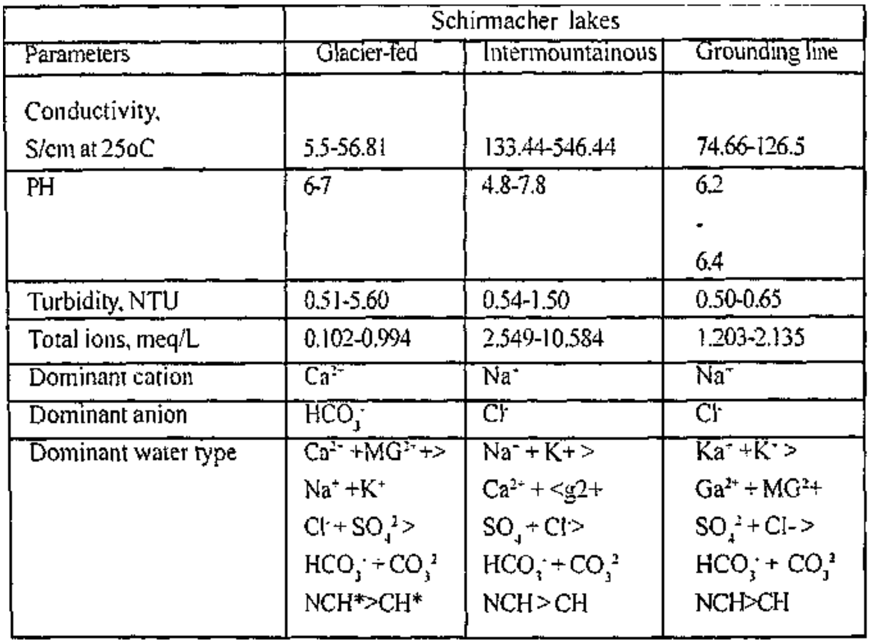
(a) Σ (cation + anion) varies from 1.203 meq/L to 2.135 meq/L.
(b) Sodium and chloride are the dominant cation and anion respectively in all the lakes.

Based on the plotting of cations and anions in different triangles (Fig. 5), waters of all the three lakes were judged to be Na^+- Cl^- type. Major ions were also plotted in Fig. 6 and in lakes of this category (a) alkali metals exceeded alkali earths, (b) strong acidic anions exceeded weak acidic anions, and (c) non-carbonate hardness exceeded carbonate hardness.

6. CONCLUSION:

Water samples of thirty-eight unpolluted Schirmacher lakes were characterized. Lakes are situated in a small area of about 20 km in length and about 3.5 km of maximum width. These polar lakes were found to have widely different characteristics (Table 9).

Table 9. Water Quality of Schirmacher Lakes : Summary of Results



	Schirmacher lakes		
Parameters	Glacier-fed	Intermountainous	Grounding line
Conductivity, S/cm at 25oC	5.5-56.81	133.44-546.44	74.66-126.5
PH	6-7	4.8-7.8	6.2 - 6.4
Turbidity, NTU	0.51-5.60	0.54-1.50	0.50-0.65
Total ions, meq/L	0.102-0.994	2.549-10.584	1.203-2.135
Dominant cation	Ca^{2+}	Na^{+}	Na^{+}
Dominant anion	HCO_3^{-}	Cl^{-}	Cl^{-}
Dominant water type	$Ca^{2+}+MG^{2+}$+> $Na^{+}+K^{+}$ $Cl^{-}+SO_4^{2}$ > $HCO_3^{-}+CO_3^{2}$ NCH*>CH*	Na^{+} + K+ > Ca^{2+} + <g2+ SO_4+Cl^{-}> $HCO_3^{-}+CO_3^{2}$ NCH > CH	$Ka^{+}+K^{+}$ > $Ga^{2+}+MG^{2+}$ SO_4^{2} + Cl- > $HCO_3^{-}+CO_3^{2}$ NCH>CH

* CH and NCH - Carbonate hardness and non-carbonate hardness respectively.

It could be concluded that all natural waters possess their unique characteristics. It is almost impossible to find two natural waters of the same quality.

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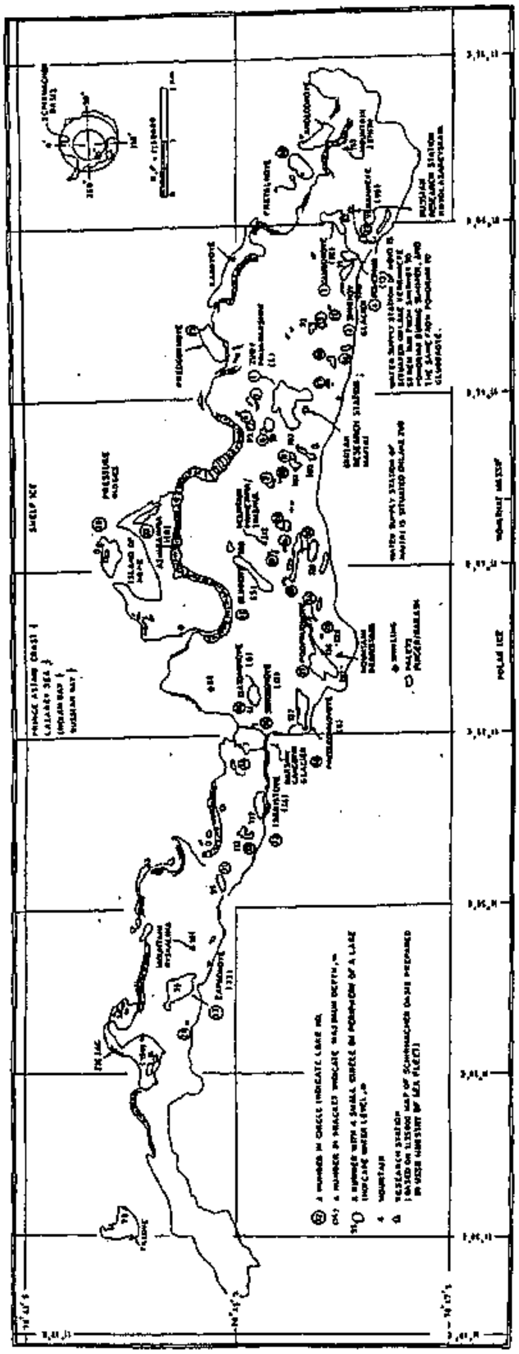
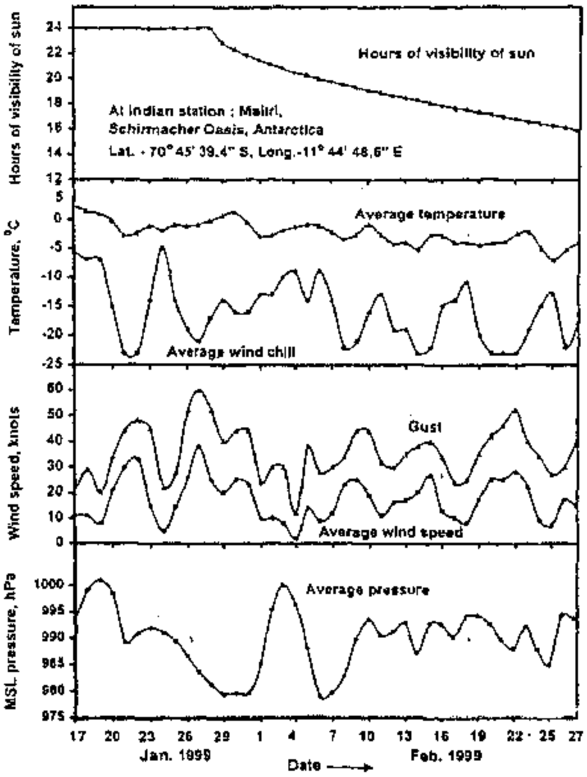


FIG. 1 STUDY AREA SHOWING THE LAKES SURVEYED IN SCHIRMACHER OASIS, ANTARCTICA



Fig, 21 Weather data (or th» period (17 Jan.- Z7 Feb., 1999) during which Schirmacher lakes were surveyed for sample collection.

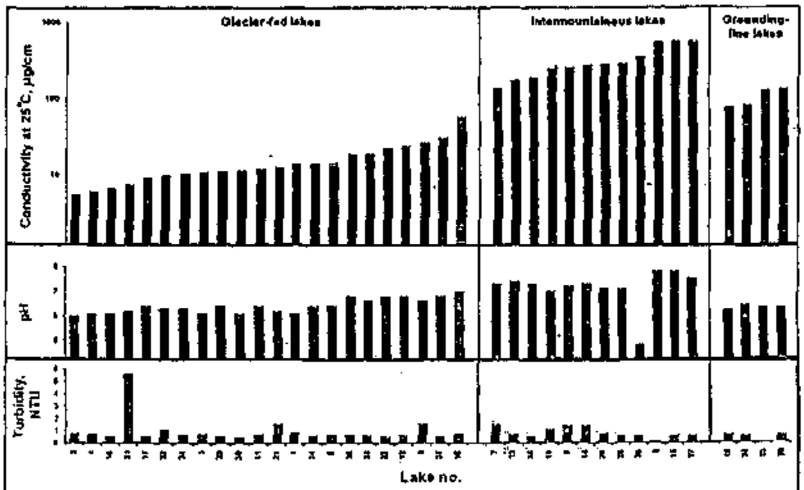


Fig.3 Some of the physical - chemical characteristics of Schirmacher Lakes

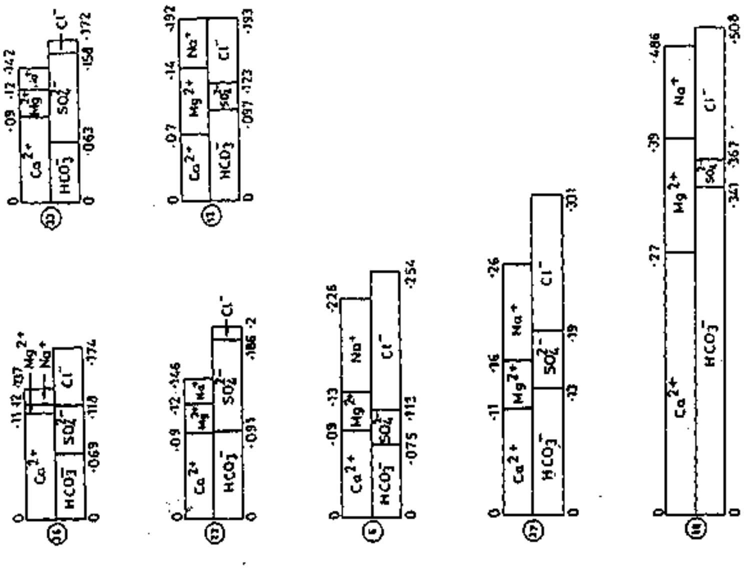


Fig. 4 (b). Ionic Composition of Glacier-Fed Lakes (All Values in mequiv/L)

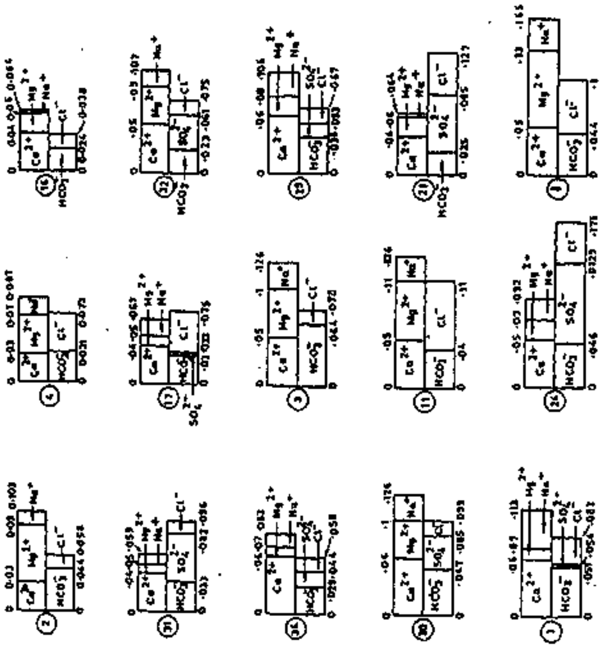


Fig. 4 (a). Ionic Composition of Glacier-Fed Lakes (All values in mequiv/L)

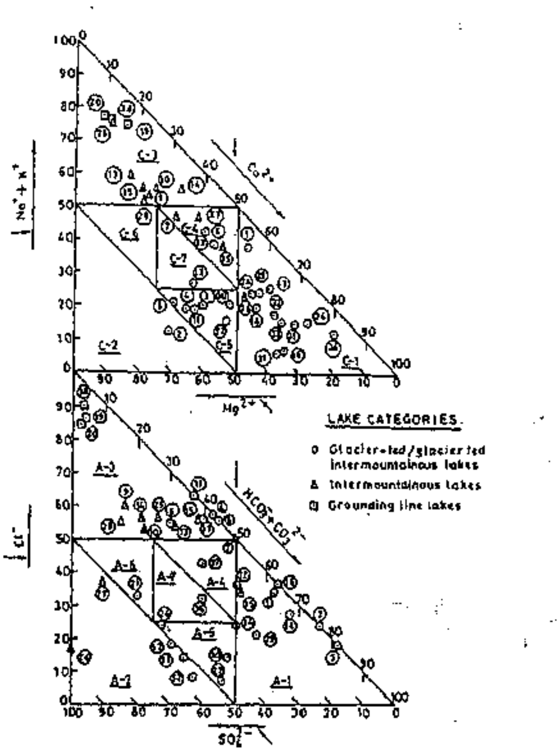


Fig. 5 Mojor-Ion Chemistry of 38 lake Water: from Schirmocher Oasis Represented in the Form of Trilinear Cation-Anion Triangles

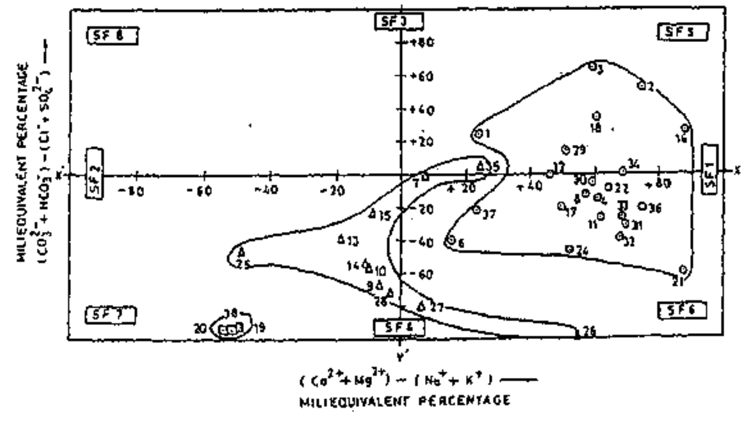


Fig. 6 Rectangular Ionic Field Describing the Overall Character at 38 Lake Waters from Schirmacher Oasis, Antarctica

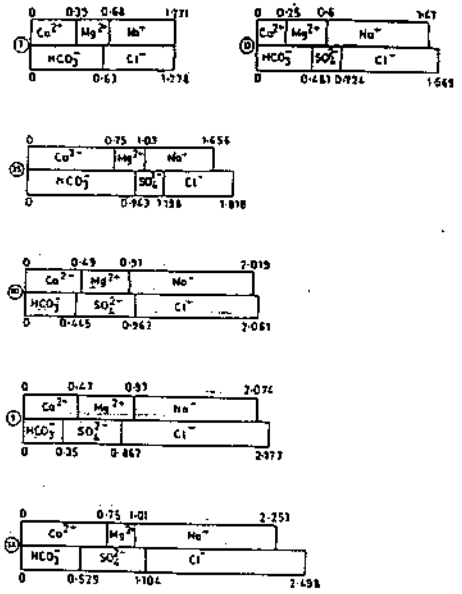


Fig: 7 (a). Ionic Composition of Intermountainous Lakes
(All Values in mequiv/L)

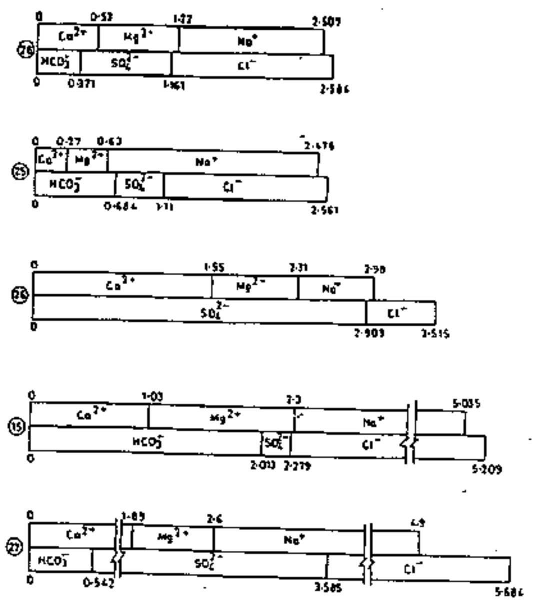


Fig. 7 (b). Ionic Composition of Intermountainous Lakes
(All Values in mequiv/L)

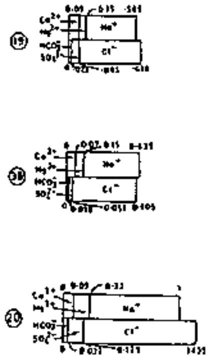


Fig. 8 Ionic Composition of Grounding Line Lakes
(All Values in mequiv/L)