# A PHYSICAL, CHEMICAL AND BIOLOGICAL INVESTIGATION OF SOME FRESH-WATER POOLS ON SIGNY ISLAND, SOUTH ORKNEY ISLANDS

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ABSTRACT. Physical, chemical and biological investigations were carried out on a series of fresh-water pools at Signy Island to obtain a day-to-day record of the state of the pools. Water temperatures showed large and rapid fluctuations, and a maximum of +17° C was recorded. The chemical composition of these pools has been shown to differ from the expected dilute sea-water composition, and it is suggested that this is due to differential rates of leaching of inorganic ions in snow drifts during winter and spring, and the anomalous composition of the precipitation. Qualitative work has been done on the biological samples, and the copepod and anostracan present in the pools have been identified as *Pseudoboeckella silvestri* Daday and *Branchinecta gaini* Daday, respectively.

PAAL HARBOUR (Fig. 1) is situated on the east coast of Signy Island, between Polynesia Point and Rethval Point. There are pools of fresh to brackish water on the three rock promontories (Fig. 2) which project from the shore of Paal Harbour. On the southernmost there are eight semi-permanent pools, six of which were studied in detail during the summers of 1964–65 and 1965–66. Water samples were taken for chemical analysis, physical measurements were made *in situ* and biological material was collected from the pools for subsequent identification of the species present.

## TOPOGRAPHY

Paal Harbour is an east-facing drowned cirque. At the northern end the ground rises from Polynesia Point to Observation Bluff (110 m.), and the rim of the cirque continues from there to Rusty Bluff (210 m.) never dropping lower than 60 m. above m.s.l. The northern walls of the cirque consist of cliffs and steep scree slopes, with some permanent snow beds, falling to a narrow rocky area a few metres wide at the base of the cliffs. The western walls are also steep

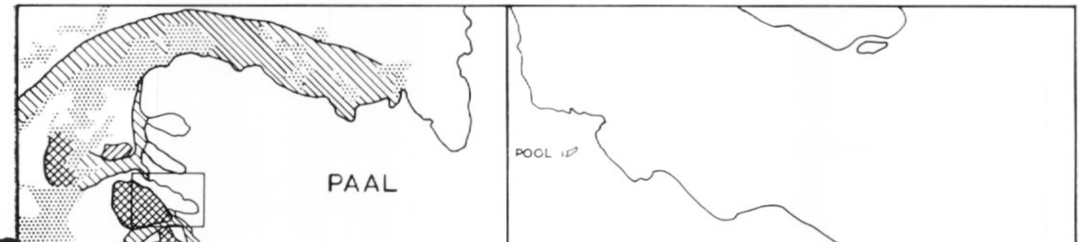

Fig. 1. A. Sketch map of Paal Harbour, Signy Island, showing areas of vegetation, scree or beach, and semi-permanent snow.
B. Sketch map of part of Paal Harbour, showing the location of the fresh-water pools investigated.

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Fig. 2. Oblique view of the promontories in Paal Harbour, looking south-east.

but they are rather higher and there is an extensive flat area at their base. This is at two levels, a higher one close to the cliffs from 6 to 30 m. above m.s.l., and a pebble and boulder beach at sea-level. Short slopes of loose rock and scree connect the two levels.

The promontories, which project about 100–150 m. from the shore and attain a maximum height of about 5 m. above m.s.l., are formed by quartz-mica-schists (Matthews and Maling, 1967) overlain by occasional loose rocks and moss patches. At the shoreward end of the two northern promontories there are areas of drift and scree, but at the shoreward end of the southernmost peninsula there is a steep moss bank rising about 30 m. up the lower slopes of Rusty Bluff.

## FLORA AND FAUNA

The flora and fauna of this area were not sampled but some general observations can be made. Three "sub-formations" (Holdgate and others, 1967, p. 63) were found in the Paal Harbour area:

i. Lichen-moss sub-formation of exposed rocky ground.
ii. Moss turf sub-formation of steep well-drained slopes.
iii. Moss mat sub-formation of wet ground.

Fig. 1A shows the approximate areas of the various formations.

P. J. Tilbrook (personal communication) considers that the arthropod fauna is probably typical of the island as a whole and he has provisionally identified some mites which appear to be common to both terrestrial and fresh-water samples.

## POOLS AND THEIR IMMEDIATE SURROUNDINGS (Table I)

*Pool 1* is in a depression between two large rocks, the ends of the pool being dammed by mineral detritus and scree. The south-east margin of the pool is a rock wall 0·5 m. in height, while the north-east edge is a gentle rock slope. The pool is surrounded by bare rock with some

TABLE I. COMPARISON OF SOME MORPHOMETRIC PARAMETERS OF THE FRESH-WATER POOLS TOGETHER WITH HEIGHTS ABOVE MEAN SEA-LEVEL AND DISTANCES FROM THE SEA

| *Pool number* | *Distance from sea* (m.) | *Height above m.s.l.* (m.) | *Surface area* (m.$^2$) | *Volume* (l.) |
|---|---|---|---|---|
| 1 | 5 | 1·5 | 1·7 | 300 |
| 2 | 13 | 3 | 4·8 | 1,100 |
| 2A | 19 | 3 | 1·8 | 280 |
| 2B | 17 | 3 | 1·9 | 280 |
| 3 | 4·5 | 2 | 1·9 | 380 |
| 4 | 4 | 3 | 2·1 | 480 |

patches of lichen and there is very little organic detritus on the bottom of the pool. This was the only pool that appeared to receive any contamination from elephant seals during the summers of 1964–65 and 1965–66.

*Pool 2* is in a rock basin, with the edges partly covered by moss banks. The bottom of the pool has shallow patches of organic detritus, 2–3 cm. in thickness, interspersed with areas of rock and small stones.

*Pool 2A* is the smallest pool. The bottom is covered with a layer of organic detritus 2–3 cm. thick and the edges of the pool are covered by moss banks.

*Pool 2B*. The north-west side of this pool is a 0·5 m. high rock face, while the south-eastern side consists of a luxuriant moss bank. This pool had the thickest layer of organic material on the bottom, being up to about 10 cm. in depth.

*Pool 3* is in a rock basin. There are no adjacent moss banks but the surrounding rocks are crusted with lichens and small patches of moss. The layer of organic debris on the bottom of the pool was about 3 cm. thick.

*Pool 4* is in a rock basin which had a 3 cm. layer of organic debris on the bottom. The north-west side of the pool is formed by a rock wall about 0·5 m. in height, while the south-east is half rock and half moss bank. The pool has an overflow at the south-west end.

## EFFECT OF WEATHER ON THE POOLS

Weather is the most important of the factors affecting the pools. It controls the water budget, as the volume of melt water available in the spring depends on the depth of snow accumulated during the winter; during the summer the water intake is restricted to precipitation and spray. The amount of water removed from the pools by evaporation also depends directly on the weather. It has an important influence on the ionic budget as well, for all forms of precipitation and spray contain ions which affect the composition of the pools. The water temperature in the pools depends on the duration and intensity of sunshine and on the air temperature. Solar radiation can cause a rapid increase in water temperature, while the air temperature causes slower changes. Precipitation and influxes of sea-water also affect pool temperatures.

Information for this section was obtained from the *Annual meteorological tables* of the British Antarctic Meteorological Service and from the meteorological records of the scientific station at Signy Island.

### *Air temperature and radiation during the summer*

The duration of the summer at Signy Island is variable. A summer month is defined here, for purposes of comparison, as one in which the mean temperature is greater than $-1·5°$ C (Table II). Using this definition, the mean length of summer for the period 1947–66 was 5·4 months. Summers of 4 months' duration occurred six times in this period, 5 months five

TABLE II. MEAN AND EXTREME TEMPERATURES (° C) FOR THE MAIN WINTER AND SUMMER MONTHS FOR THE PERIOD 1947–66

| | *Winter months* | | | | | *Summer months* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. |
| Mean monthly temperatures | −6·2 | −8·0 | −10·5 | −9·3 | −4·9 | −2·5 | −1·3 | −0·2 | +0·8 | +0·7 | +0·2 | −2·3 |
| Maximum monthly means | 0·0 | −0·8 | −5·8 | −3·6 | −1·8 | +0·2 | +0·1 | +1·2 | +2·4 | +3·2 | +1·8 | +1·0 |
| Minimum monthly means | −14·3 | −13·1 | −17·2 | −14·1 | −10·0 | −7·1 | −3·9 | −1·6 | −0·3 | −1·6 | −1·4 | −8·6 |
| Absolute maxima | +7·8 | +8·3 | +6·3 | +7·2 | +8·6 | +10·6 | +11·7 | +13·9 | +13·8 | +13·6 | +11·3 | +11·3 |
| Absolute minima | −32·2 | −32·7 | −34·4 | −34·8 | −31·1 | −23·9 | −16·0 | −6·1 | −5·0 | −7·8 | −10·0 | −20·6 |
| Mean daily sunshine (hr.) | | | | | | 2·1 | 2·2 | 1·9 | 2·3 | 1·7 | 1·2 | 1·0 |

times, 6 months five times and 7, 8 and 9 months once each. February 1954, which had a mean temperature of −1·6° C, has been included as a summer month as it occurred in a spell of milder weather, January, March and April having mean temperatures of +0·1, −0·1 and −0·2° C, respectively.

The frequencies of sunshine for the summers 1962–66 are given in Fig. 3.

Recorded pool temperatures range from 0° to 17° C with a mean of 4·5° C. The maximum air temperature that has been recorded on Signy Island is 14° C, and it can be seen from Table III that air temperatures seldom rise above 5° C. This indicates that radiation plays the major part in producing high water temperatures. However, high air temperatures and rainfall have more influence than radiation on the processes of thawing, presumably because of the high albedo of a pool full of ice and snow. Examples of this are pools 2 and 2B which thawed out between 23 December 1965 and 3 January 1966; from 23 to 30 December there was a total of 18·2 hr. of recorded sunshine (12 hr. on 29 December), while the mean daily air temperatures were −1·8° C on 23 December and −1·0, +0·2, −0·4, −0·8, −0·2, +0·1 and +1·1° C on succeeding days. In this period only slight thawing took place in pool 2, although the water temperature rose to +7° C on 30 December. However, air temperatures for the next 4 days were +2·4, +1·6, +3·2 and +4·4° C. A total of 6·3 hr. of sunshine was recorded during these 3 days, but 5·7 hr. were recorded on 3 January and pool 2B had completely thawed on this date. On 30 December, pool 2 had started to thaw but by 3 January this pool was 90 per cent clear. At this time, pool 1 had also started to thaw but this was probably due mainly to a melt stream flowing through the basin of the pool.

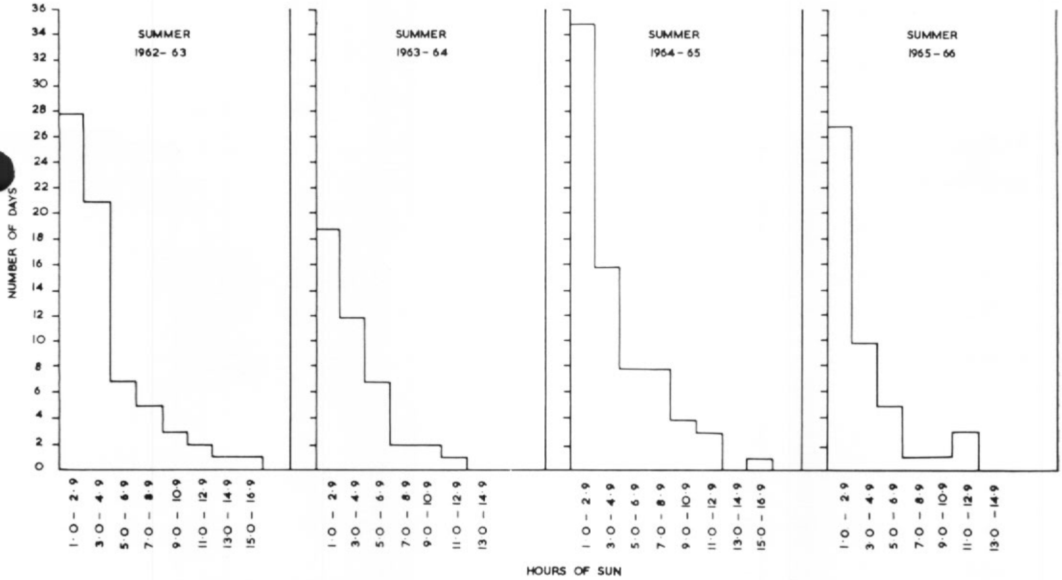

Fig. 3. Frequencies of sunshine (hr./day) for the summers of 1962–66.

In a partly or wholly ice-free pool, however, solar radiation has a considerable effect on the water temperature. Table IV gives air temperatures, pool temperatures and amounts of sunshine for the period 25 November 1965 to 24 February 1966. The air temperatures for the period 26–31 January will have had some warming influence but it is clear that they cannot wholly account for the observed water temperatures. The considerable amount of sunshine recorded during this period was mainly responsible for raising the water temperatures. Similarly, on 16 December, pools 3 and 4 were partly free of ice and, although very little further thawing took place, the water in the pools attained temperatures of 12·5° and 12·0° C,

TABLE III. FREQUENCY OF DAYS OF HIGH MAXIMUM TEMPERATURE FOR THE SUMMER MONTHS

| *Year* | *Month* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | October | November | December | January | February | March | April | May |
| 1948–49 | — | — | 0 | 1 | 1 | 5 | — | — |
| 1949–50 | — | — | 0 | 3 | 8 | 1 | — | — |
| 1950–51 | — | 1 | 3 | 2 | 4 | 6 | 6 | — |
| 1951–52 | — | — | 2 | 5 | 5 | 5 | — | — |
| 1952–53 | — | 1 | 2 | 3 | 5 | 3 | — | — |
| 1953–54 | — | — | 7 | 3 | 6 | 0 | 5 | — |
| 1954–55 | 2 | 4 | 0 | 7 | 14 | 4 | 4 | — |
| 1955–56 | 5 | 0 | 0 | 1 | 3 | 15 | 8 | 1 |
| 1956–57 | — | 2 | 1 | 3 | 7 | 12 | 2 | — |
| 1957–58 | — | 10 | 0 | 2 | 2 | 1 | — | — |
| 1958–59 | 6 | 4 | 1 | 3 | 4 | 5 | — | — |
| 1959–60 | — | — | 2 | 4 | 5 | 4 | — | — |
| 1960–61 | — | — | 4 | 9 | 3 | 3 | — | — |
| 1961–62 | — | — | 3 | 9 | 4 | 6 | 8 | — |
| 1962–63 | 3 | 2 | 8 | 14 | 13 | 5 | 4 | — |
| 1963–64 | — | — | 8 | 9 | 11 | 10 | — | — |
| 1964–65 | 7 | 2 | 5 | 15 | 14 | 11 | 1 | 4 |
| 1965–66 | — | 4 | 5 | 9 | 7 | 6 | — | — |

A day of high maximum temperature is defined as one on which the maximum temperature exceeds +5·0° C.

— Signifies that this was not a summer month according to the definition given on p. 3.

respectively. This was due to 6 hr. sunshine on that day and in spite of mean air temperatures of −0·8° C on 14 December, and +0·3 and −0·4° C on the following days. On 3 January which had nearly 5·7 hr. of sunshine and a mean air temperature of +4·4° C, the following water temperatures were recorded: pool 1 0·3° C, pool 2 3·0° C, pool 2B 11·5° C, pool 3 12·1° C, pool 4 9·0° C. But pool 1 is comparatively cold and pool 2 actually shows a drop in temperature between 30 December and 3 January. These apparent anomalies may be explained as follows: pool 1 had only just started to thaw and had a melt stream running through it, while pool 2 had undergone an almost complete thaw in this period, during which about 700 kg. of ice had melted. The latent heat required to melt this amount of ice probably prevented the water temperature from rising.

These observations indicate that low temperatures in the pools can be caused by the influx of melt water or by the melting of ice in the pool. They can also be caused by low air temperatures and by precipitation. Air temperatures affect the water temperatures slowly, for example, during 18–26 January (Table IV). Lowering of pool temperatures by precipitation probably occurred between 4 and 8 February (Table IV) but, as it was coincident with a fall in air temperature, the effect was masked.

TABLE IV. POOL TEMPERATURES (° C) WITH MEAN DAILY AIR TEMPERATURES (° C) AND AMOUNTS OF SUNSHINE (hr.)

| *Date* | *Temperatures* (° C) | | | | | | | *Sunshine* (hr.) |
|---|---|---|---|---|---|---|---|---|
| | *Mean daily air* | *Pool number* | | | | | | |
| | | 1 | 2 | 2A | 2B | 3 | 4 | |
| *1965* | | | | | | | | |
| 25 November | −1·5 | — | — | — | — | +3·3 | +4·2 | 0·1 |
| 28 | −0·9 | — | — | — | — | — | — | 0·0 |
| 1 December | −2·0 | — | — | — | — | +2·4 | +0·8 | 0·4 |
| 4 | +1·4 | — | — | — | — | +8·0 | +8·0 | 2·0 |
| 5 | −1·0 | | | | | | | 0·1 |
| 6 | −1·8 | | | | | | | 0·0 |
| 7 | −2·1 | — | — | — | — | +2·1 | +2·6 | 0·0 |
| 16 | −0·4 | — | — | — | — | +12·5 | +12·0 | 6·1 |
| 19 | −1·4 | — | — | — | — | +6·0 | +5·0 | 0·0 |
| 23 | −1·9 | — | — | — | 0·0 | +3·0 | +2·0 | 0·0 |
| 27 | −0·6 | — | — | — | +3·0 | +5·6 | +8·5 | 2·4 |
| 30 | +0·8 | — | +7·0 | — | +7·0 | +7·8 | +7·1 | 0·0 |
| *1966* | | | | | | | | |
| 3 January | +4·5 | +0·3 | +3·0 | — | +11·5 | +12·1 | +9·0 | 5·7 |
| 6 | 0·0 | +0·3 | +4·0 | — | +6·0 | +6·0 | +5·0 | 0·5 |
| 10 | +2·0 | +0·5 | +7·0 | — | +7·4 | +8·0 | +8·5 | 0·0 |
| 14 | 0·0 | +1·1 | +4·9 | — | +6·3 | +5·9 | +5·0 | 0·1 |
| 18 | +1·0 | +2·5 | +5·8 | — | +7·5 | +6·4 | +6·8 | 5·2 |
| 19 | +1·1 | | | | | | | 0·7 |
| 20 | +1·2 | | | | | | | 2·7 |
| 21 | +0·4 | | | | | | | 3·9 |
| 22 | −0·3 | +4·1 | +4·3 | +2·1 | +5·5 | +5·4 | +4·2 | 0·0 |
| 23 | +0·1 | | | | | | | 0·1 |
| 24 | −0·2 | | | | | | | 0·0 |
| 25 | −0·9 | | | | | | | 0·8 |
| 26 | −1·0 | +2·2 | +1·9 | +0·6 | +2·1 | +3·2 | +2·0 | 0·0 |
| 27 | −3·0 | | | | | | | 2·2 |
| 28 | +0·3 | | | | | | | 0·0 |
| 29 | +1·3 | | | | | | | 0·3 |
| 30 | +2·1 | | | | | | | 11·3 |
| 31 | +3·2 | +8·4 | +8·3 | +8·0 | +11·2 | +10·5 | +8·2 | 4·6 |
| 4 February | +3·4 | +5·3 | +6·0 | +6·2 | +6·5 | +6·3 | +5·3 | 0·1 |
| 5 | +2·5 | | | | | | | 1·1 |
| 6 | +0·6 | | | | | | | 0·0 |
| 7 | −1·2 | | | | | | | 0·4 |
| 8 | −3·7 | +1·2 | +1·1 | — | +0·2 | +1·0 | +0·9 | 0·1 |
| 12 | 0·0 | +2·8 | +4·0 | +3·4 | +4·3 | +3·5 | +3·0 | 0·0 |
| 16 | 0·0 | — | — | — | +1·6 | — | — | 0·0 |
| 20 | 0·0 | +1·5 | +2·0 | +2·2 | +3·0 | +2·3 | +0·5 | 1·6 |
| 24 | −4·5 | — | — | — | — | — | — | 0·0 |

### *Air temperature and radiation during the winter*

During the winter the pools are frozen and covered with a layer of snow. Tilbrook (1967) has shown that a snow layer is highly effective as an insulator and this ameliorates the temperature regime for organisms at the bottom of the pool, because temperatures at the bottom of the snow layer do not generally fall below about −7° C when the snow cover is in excess of 20 cm. The rate of snow accumulation during the autumn varies considerably from year to year, but pools 2, 2A and 2B usually have the thickest snow cover and the minimum cover during the coldest weather is probably about 0·5 m. for all the pools.

### *Precipitation*

There is little information on the amounts and composition of precipitation at Signy Island. Holdgate and others (1967, table II) have quoted figures for amounts of precipitation at

Laurie Island in the South Orkney Islands, and they considered that these provide a good indication of the amount of precipitation at Signy Island. Allen and others (1967) have carried out chemical analyses on precipitation samples collected at Signy Island during the 1964–65 summer but, as these samples were collected over a period of only 1 week, they cannot be used as more than a general guide to the quantities of ions in precipitation (Table V).

TABLE V. CHEMICAL ANALYSIS OF PRECIPITATION (Allen and others, 1967)

| | *Concentrations* (mg./l.) | | | |
|---|---|---|---|---|
| | $Na^+$ | $K^+$ | $Ca^{++}$ | $Mg^{++}$ |
| Rain | 28·5 | 1·4 | 2·64 | —* |
| Snow | 5·8 | 0·30 | 0·47 | 1·34 |

* Not determined because of insufficient sample.

### *Wind*

Although the pools are in a sheltered area, the wind can cause contamination by sea-water. In general, strong north to north-easterly winds coupled with spring tides are most likely to cause contamination.

In autumn and in winter when the sea is open, spray is deposited on the snow, affecting the composition of melt water in the spring. The amount of spray depends on the local ice conditions and the frequency of strong winds.

## METHODS OF SAMPLING AND ANALYSIS

### *Sampling*

The small size of the pools precluded elaborate sampling techniques; for collecting water samples a polythene bottle was rinsed out with pool water and then immersed carefully in the pool, the lid being replaced under water. A small hand net was used for samples of zooplankton, while a dessert spoon was found to be suitable for collecting samples of bottom debris.

Water samples were taken once every 4 days on average although, owing to the exigencies of routine at the station, this interval could not be adhered to rigidly. Normally, sampling involved the measurement of pH and temperature *in situ* (using a pocket pH meter (Analytical Measurements Ltd.) and a mercury-in-glass thermometer, respectively), the removal of 50 ml. of water from each pool for chemical analysis and the collection of a biological sample from an unnumbered pool. Every third or fourth sampling was more elaborate, 600 ml. of water being collected from each pool together with biological samples.

### *Methods of analysis and laboratory procedure*

Water samples were brought back to the laboratory for analysis within 1 hr. of collection and if 600 ml. samples had been collected the following procedure was carried out:

i. Samples were filtered to remove suspended matter and returned to their respective bottles.
ii. Aliquots for $PO_4^{---}$ determinations were removed and placed in glass flasks.
iii. Aliquots for $NO_3^-$ determinations were evaporated to dryness on a water bath and the flasks sealed.
iv. Portions of each sample were put in polythene bottles in a thermostatic bath at 25° C.
v. The alkalinity titration was performed according to the method described by Mackereth (1963, p. 24).
vi. The conductivities of the samples already set aside (iii) were measured with a Mullard conductivity bridge at 22·5° C. Bright platinum electrodes were used.

vii. Four methods were tried for the estimation of $Cl^-$; the ion exchange method (Mackereth, 1963, p. 31), the Volhard titration, titration with $Hg(NO_3)_2$ as described by the American Public Health Association and others (1960, p. 79) and the Mohr titration. The concentration of $Cl^-$ in the sample was too large for the satisfactory use of the ion exchange method. The Volhard titration was found too time-consuming and results from titration with $Hg(NO_3)_2$ were not significantly more accurate than from the Mohr titration, although this was probably due to an inadequate amount of time being spent on familiarization with the technique. Consequently, the Mohr titration was used, and all the $Cl^-$ results for the summer of 1965–66 were obtained by this method. The experimental procedure was as recommended by the American Public Health Association and others (1960, p. 78), except that only 0·5 ml. of the $K_2CrO_4$ indicator solution was used, because of the small size of the sample.

viii. The concentration of strong acid salts was determined using the method described by Mackereth (1963, p. 25).

ix. An analysis for $PO_4^{---}$ was carried out. Only orthophosphate was determined as the sample size did not permit an additional determination for total phosphate. The method of analysis was the reduction of molybdophosphoric acid with $SnCl_2$ solution. An extraction procedure was not employed. The colour development was carried out for 11 min. at 25° C and the resulting blue colour was measured with a Unicam SP600 spectrophotometer at 690 m$\mu$. The detailed procedure was as described by the American Public Health Association and others (1960, p. 202).

x. $Ca^{++}+Mg^{++}$ was determined by titration according to the method of Mackereth (1963, p. 32).

xi. $NO_3^-$ samples were re-dissolved and analysed by the method of Mackereth (1963, p. 45) but employing pre-treatment of the sample with $Ag_2SO_4$ to remove $Cl^-$ by precipitation. The yellow coloration was measured spectrophotometrically at 410 m$\mu$.

xii. $Na^+$ was determined with an EEL flame photometer. All samples were diluted to within the range 0–5 mg. $Na^+$/l.

xiii. $K^+$ was determined in the same manner as $Na^+$.

xiv. Estimation of $Ca^{++}$ by titration with EDTA was attempted using the method of Mackereth (1963, p. 34), but the amount of $Ca^{++}$ in the sample was not generally sufficient to allow a satisfactory determination, so a flame-photometric method was used, all samples being diluted to within the range 0–20 mg. $Ca^{++}$/l.

xv. $Mg^{++}$ was calculated from the results obtained in stages (x) and (xiv).

For the analyses of the 50 ml. samples, only the following steps were carried out: i, iv (the entire sample was placed in the thermostatic bath), vi, vii, x, xii, xiv and xv.

### *Chemical interference in analysis*

Iron was not present in detectable concentrations in the samples; one set of analyses was performed using the phenanthroline method for the determination of iron (American Public Health Association and others, 1960, p. 140) but no measurable concentration was found.

Samples stored in polythene bottles show significant changes in $PO_4^{---}$ concentration after a few hours (Heron, 1962), so aliquots for $PO_4^{---}$ determinations were transferred to glass flasks within 1·5 hr. of collection. Similarly, portions of the samples removed for $NO_3^-$ determinations were evaporated to dryness within about 2 hr. of collection to minimize any effect from bacterial action. The presence of $Cl^-$ in excess of 10 mg./l. interferes chemically with the determination of $NO_3^-$, so samples were treated with the equivalent amount of $Ag_2SO_4$ solution before analysis to remove $Cl^-$.

A series of experiments was carried out on the flame photometer to determine the extent of the mutual interference of $Na^+$, $K^+$ and $Ca^{++}$ and the effect of $PO_4^{---}$ on $Ca^{++}$ over the range of concentrations found in the analysed solutions. It was found that $K^+$ and $Ca^{++}$ had no effect on the determination of $Na^+$, and $Ca^{++}$ had no effect on the determination of $K^+$, whereas $Na^+$ had a slight effect. $K^+$, $Na^+$ and $PO_4^{---}$ were all present in sufficient amounts in the analysed solutions to cause interference with $Ca^{++}$ determinations, so calibration curves were constructed from experimental data obtained with the equipment at Signy Island, and the appropriate corrections were applied to the $Ca^{++}$ results. No allowance was made for the effect of $SO_4^{--}$ on the measurement of $Ca^{++}$.

## PHYSICAL FACTORS AND CHEMISTRY

### *Water and ionic budgets of the pools*

Under normal summer conditions, the water sources of the pools are limited to the collection of precipitation and sea spray from the catchment areas. At the end of winter, however, each pool and its drainage basin is full of snow and ice, ensuring that it will be full of water at the start of the summer. At the beginning of the 1965–66 summer, pool 1 also received water from a melt stream for 2 or 3 days. Precipitation amounts to about 3 cm./month during the summer and, except for certain isolated occurrences, the volumes of sea-water received are small. To balance this low water intake, water losses are small; temporary removal can be caused by the formation of ice. The only ways in which water can be lost permanently are by overflow, uptake by vegetation and evaporation from the pools themselves or from saturated areas of moss adjoining the pools. As the pools are on impervious rock, there is no water loss from seepage. H. L. Penman (personal communication) has estimated that the rate of evaporation from a free-water surface on Signy Island is about 1–2 mm./day, which roughly balances the input from precipitation of about 1 mm./day, collected by a drainage basin of approximately twice the size of the pool. In a warm summer the pools can lose large volumes of water. For example, by 13 March 1965, pools 2A and 2B had dried out completely, while pool 2 contained only 300–400 l. of water, about half its usual volume. Monthly mean temperatures for the 1964–65 summer were as follows: October −0·6° C; November −1·0 °C; December +0·6° C; January +2·4° C; February +2·8° C; March +1·8° C; April −0·8° C; May −1·1° C. These temperatures may be compared with the corresponding mean monthly temperatures in Table II. Fig. 3 and Table III also show that this summer was exceptionally mild with more than average amounts of sunshine. It seems that the effect of water uptake and evaporation from the saturated moss mats in the area of pool 2 has a considerable influence on the water budget of this group of pools, since over the same period pools 3 and 4 remained relatively full of water.

During the course of the summer, ions are added to the pools by precipitation, sea spray and biological contamination, and they are removed by biological uptake and overflow. Comparison of Figs. 4–8 with the results of an analysis of precipitation (Table V) shows that precipitation usually acts as a diluent, and a permanent diluent if the pools overflow. Wind-blown spray brings in small volumes of sea-water, and biological contamination in the form of bird and seal excreta will add significant amounts of phosphates and nitrate.

The amount of ions removed by biological activity is presumably small compared with the total quantities of ions in the pools, and overflow is the main cause of ionic depletion. At the beginning of the summer, when the pools are starting to thaw, there is a possibility that they may be flushed out with melt water.

### *Classification of the pools*

Pools 3 and 4 were the first of the numbered pools to thaw out in the two summers during which observations were made, and it seems probable that these two pools are always the first to thaw; because of their relatively exposed positions, they have a thinner snow layer over them at the end of the winter than the other pools. In an average summer, pools 3 and 4 are probably open for about 150 days, pools 1, 2 and 2B for about 120 days and pool 2A for about 100 days. However, these conclusions are based on evidence obtained during only two summers, and must be treated with reserve.

It can be seen from the graphs of ionic concentration and conductivity (Figs. 4–9) that the pools can be grouped according to their ranges of concentration. For example, pools 1, 2, 2A, 2B and 3 had similar concentration levels, although pools 1 and 3 showed the effects of gross inundations of sea-water towards the end of the summer. Pool 4 had a very much higher average ionic content with large day-to-day fluctuations.

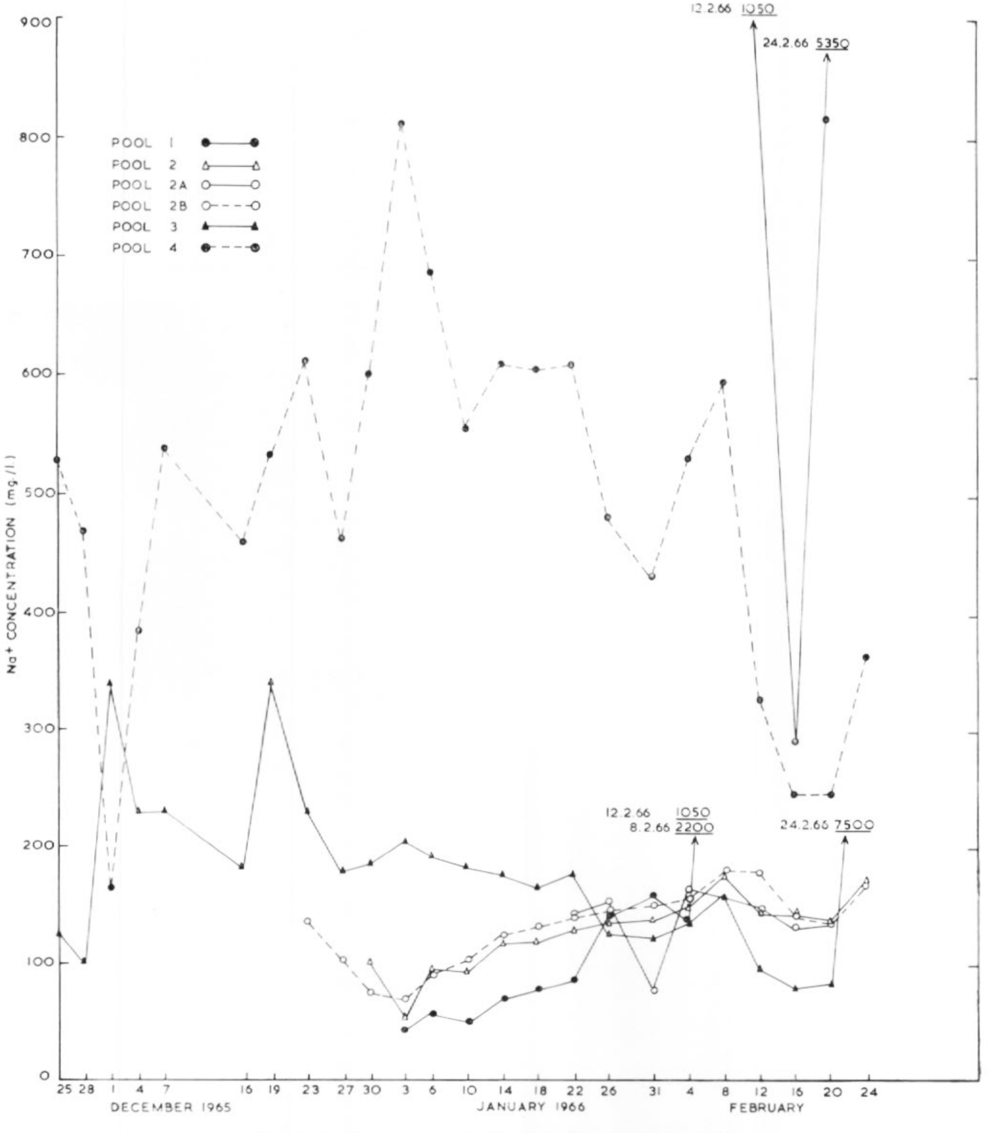

Fig. 4. Sodium concentrations in the pools (mg./l.).

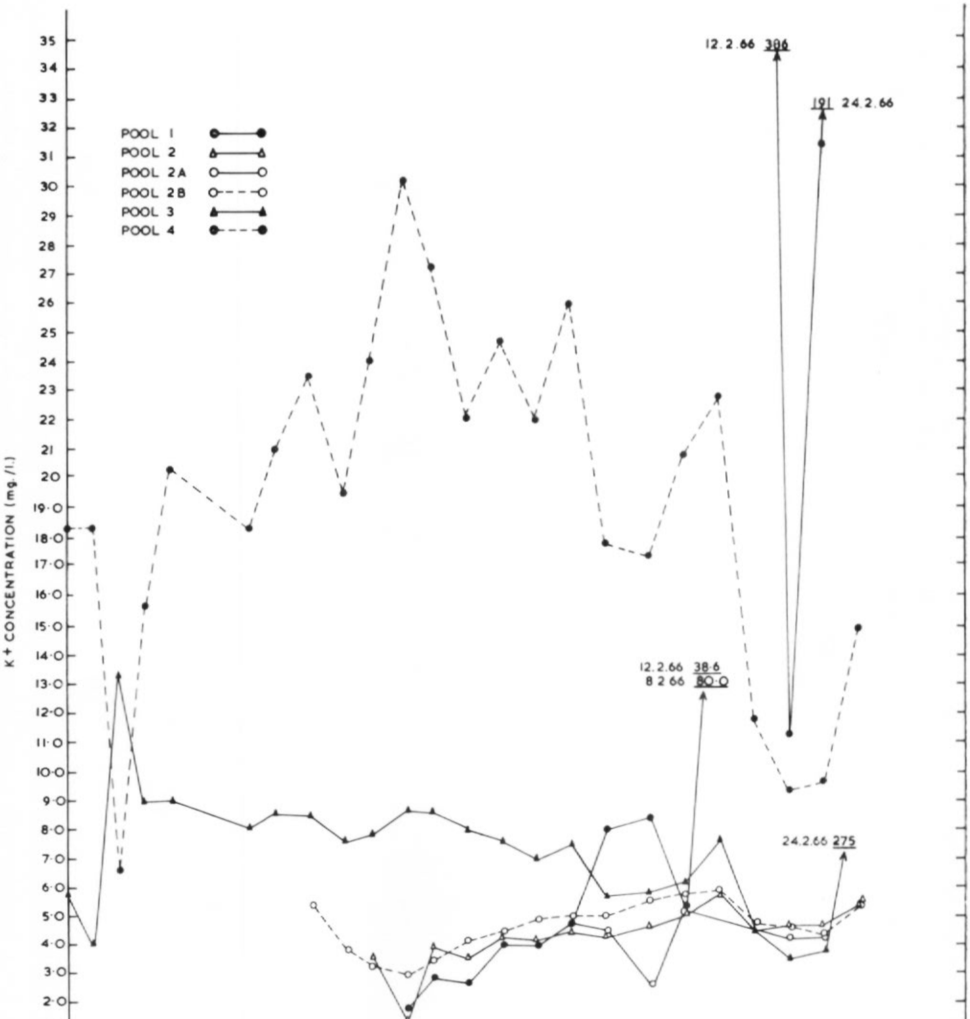

Fig. 5. Potassium concentrations in the pools (mg./l.).

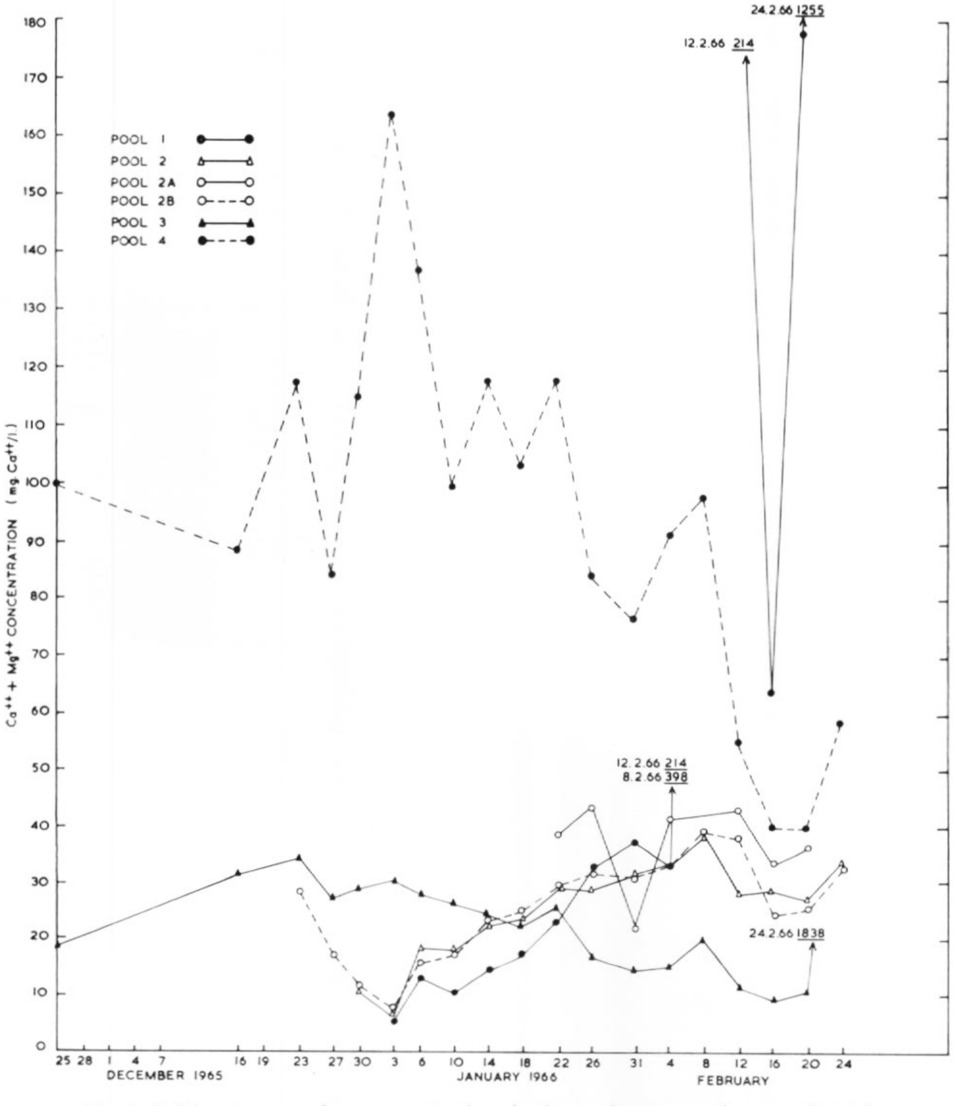

Fig. 6. Calcium + magnesium concentrations in the pools, expressed as mg. $Ca^{++}$/l.

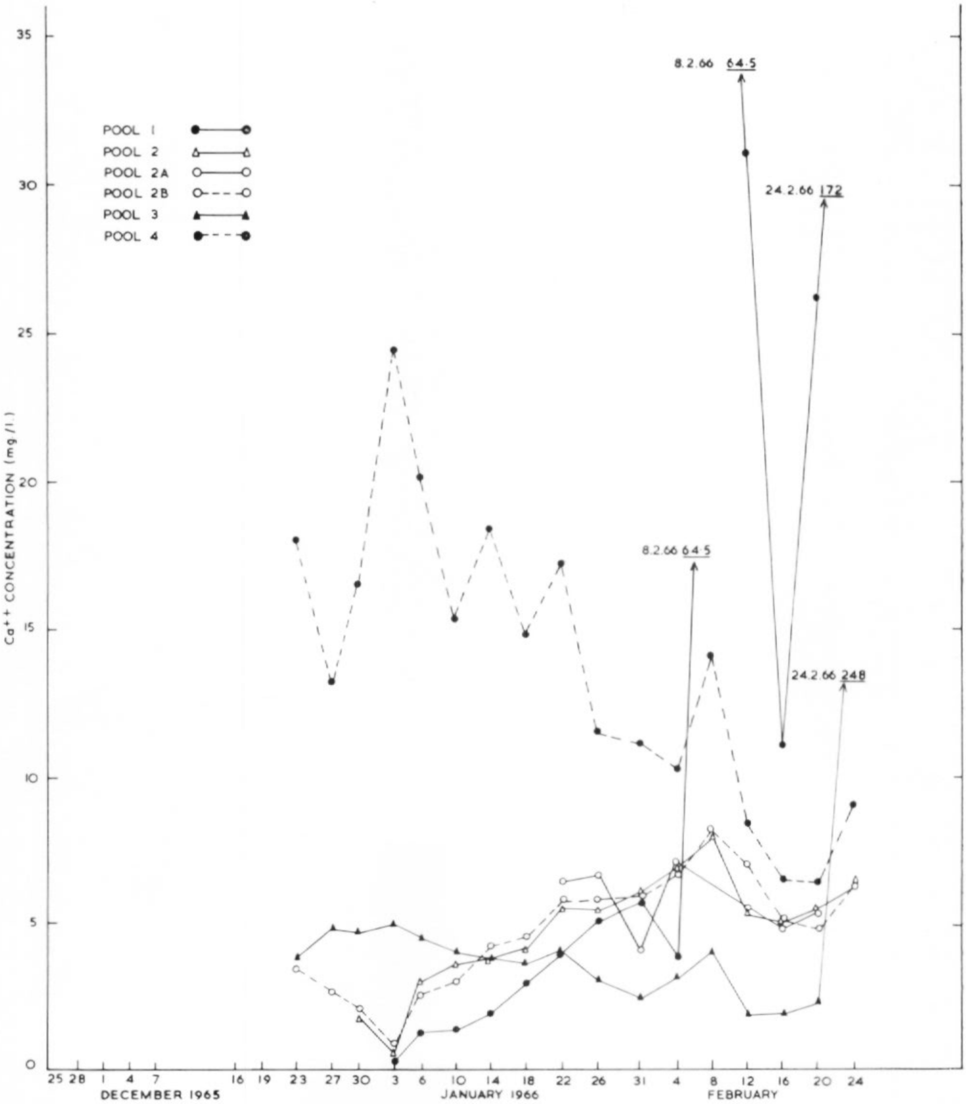

Fig. 7. Calcium concentrations in the pools (mg./l.).

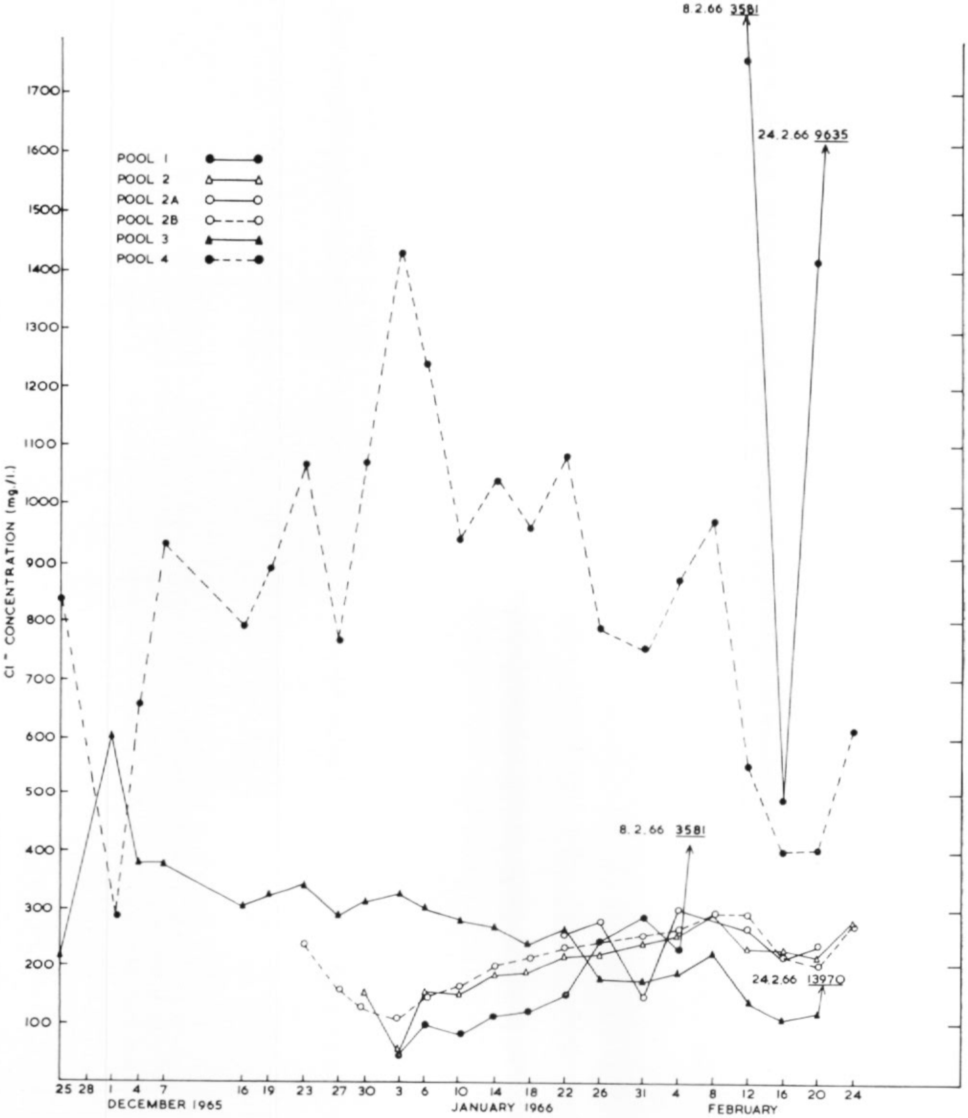

Fig. 8. Chloride concentrations in the pools (mg./l.).

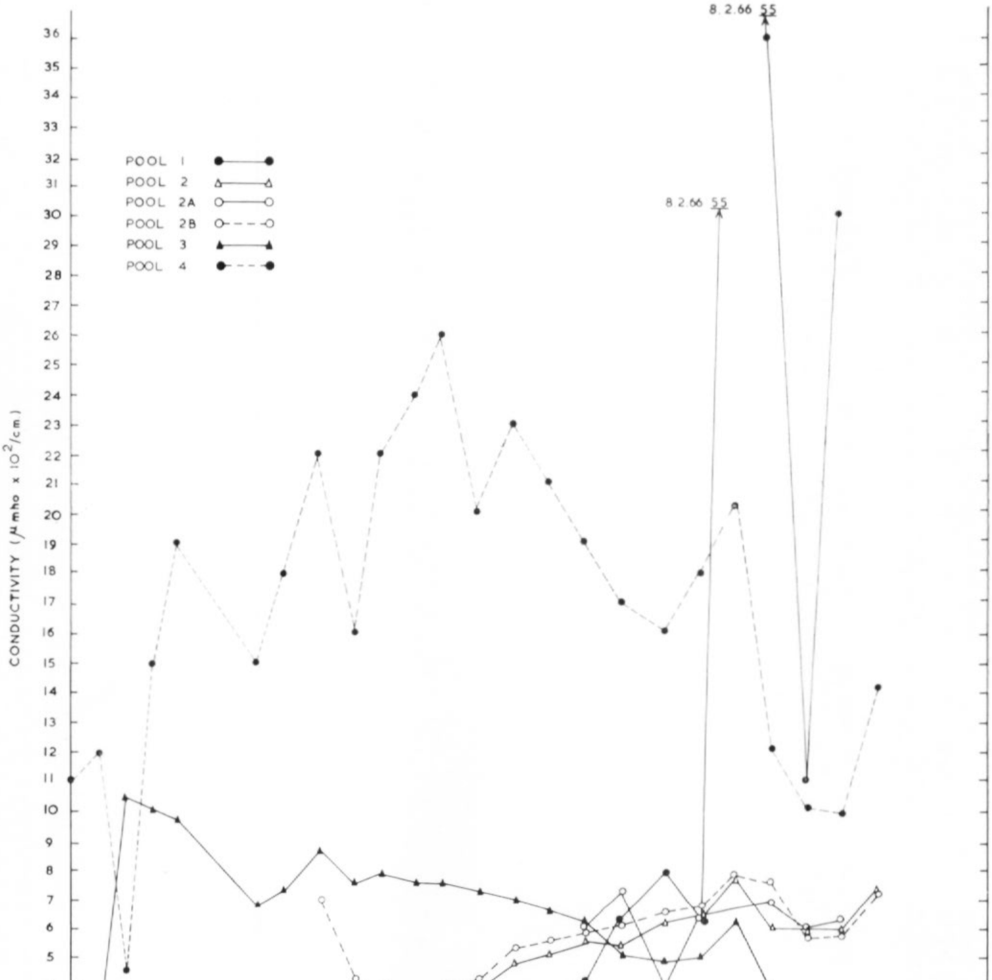

Fig. 9. Conductivity of the pools measured at 22·5° C (μmho × 10²/cm.).

Table VI shows that pools 3 and 4 had a generally higher pH than pools 2, 2A and 2B, while, at the beginning of the summer pool 1 was in the same range as pool 2 but it increased in pH throughout the season until it was in the same range as pools 3 and 4. The low pH of the pool 2 group can be attributed to the surrounding moss mats, which were saturated with water from the pools. The area surrounding pools 3 and 4 is mainly rock and this is reflected in the higher pH values for these two pools. Although pool 1 is in a rock basin, it is considered that its pH was low at the beginning of the season because of the melt water which the pool received from the moss-covered slopes of the cirque.

TABLE VI. pH AT POOL TEMPERATURE

| *Date* | *Pool number* | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 2A | 2B | 3 | 4 |
| *1965* | | | | | | |
| 25 November | — | — | — | — | 6·6 | 7·2 |
| 28 | — | — | — | — | 7·9 | 6·9 |
| 1 December | — | — | — | — | 7·4 | 7·1 |
| 4 | — | — | — | — | 7·2 | 7·4 |
| 7 | — | — | — | — | 6·1 | 6·6 |
| 16 | — | — | — | — | 8·0 | 7·8 |
| 19 | — | — | — | — | 7·5 | 7·6 |
| 23 | — | — | — | 5·2 | 8·3 | 8·0 |
| 27 | — | — | — | 5·1 | 6·6 | 6·3 |
| 30 | — | 5·7 | — | 5·4 | — | 6·2 |
| *1966* | | | | | | |
| 3 January | 4·5 | 5·4 | — | 5·5 | 8·2 | 6·8 |
| 6 | 4·2 | 5·4 | — | 5·3 | 8·2 | 6·4 |
| 10 | 5·2 | 5·0 | — | 5·1 | 7·4 | 6·1 |
| 14 | 5·2 | 5·4 | — | 5·5 | 8·2 | 7·0 |
| 18 | 5·1 | 5·0 | — | 5·6 | 7·8 | 6·0 |
| 22 | 5·1 | 5·0 | 5·1 | 5·6 | 7·6 | 5·8 |
| 26 | 6·5 | 5·2 | 4·6 | 5·5 | 7·7 | 6·2 |
| 31 | 6·5 | 5·3 | 4·7 | 6·4 | 7·4 | 6·1 |
| 4 February | 6·0 | 5·3 | 4·9 | 6·2 | 8·4 | 6·6 |
| 8 | 6·6 | 5·2 | — | 6·4 | 7·6 | 6·3 |
| 12 | 6·6 | 5·4 | 4·8 | 5·1 | 7·8 | 6·9 |
| 16 | 6·0 | 4·8 | 4·6 | 5·0 | 6·7 | 6·3 |
| 20 | 6·4 | 5·2 | 4·8 | 5·1 | 7·8 | 6·8 |
| 24 | 6·5 | 5·4 | — | 5·8 | 6·5 | 6·4 |

A classification may also be considered based on the trends in concentrations of the measured ions. Again, pools 2 and 2B showed similar behaviour, with pool 1 also increasing in concentrations, although rather more rapidly and erratically. Pool 3 showed a decline in concentrations shortly after it thawed out, which continued throughout the summer, while pool 4 showed a peak in concentrations of the measured ions at the beginning of January, but then concentrations decreased in an erratic manner throughout the rest of the summer. Pool 2A has not been considered in this classification, as there is not enough information available to establish the trends in concentrations. However, it is considered likely that it would have exhibited similar characteristics to pools 2 and 2B.

*Fluctuations in concentrations*

The preceding section described the sources of ions available to the pools and the causes of ionic depletion. These factors can be used to explain some of the fluctuations of concentrations in the pools.

Qualitative explanations can be given for most of the main features in the graphs of ionic concentrations if weather factors are considered in conjunction with the dates of spring tides. For example, the general rise in concentrations in pools 3 and 4 between 30 December 1965 and 3 January 1966 appears to be due to spray from the high winds of 2 January. The decrease in concentrations in pools 2 and 2B over the same period were the result of ice melting in the pools. Influxes of sea-water also caused the very high concentrations in pools 1 and 3 on 24 February and in pool 1 on 8 February. Spring tides occurred on 5 and 20 February and, although wind speeds were not high, there was moderate swell on 21 February which was seen occasionally to splash water into pools 1 and 3. The drop in concentrations observed in all the pools from 8 to 16 February had two causes; first, the concentrations for 8 February were slightly increased due to a 2 cm. layer of ice on all the pools which melted between 8 and 12 February, and secondly, 5·5 mm. of rain was recorded at the meteorological station between 12 and 16 February.

A quantitative explanation of the ionic budget is difficult, but the calculations in the Appendix (p. 30) are an attempt to estimate the amounts of precipitation required to produce the measured changes in the concentration of $Na^+$ in pools 2, 2B, 3 and 4 from 3 January to 26 January 1966. Owing to lack of accuracy in the measurements of changes of volume in the pools, these calculations are only approximate. However, they indicate that the drop in concentration in pools 3 and 4 and the increase in pool 2B could have been caused by precipitation, but that the increase in concentration in pool 2 appears to be too large to be entirely the result of the addition of ions by precipitation and subsequent concentration by evaporation.

*Anomalies in the ionic composition of the pools*

As the ionic content of the pools is largely derived from marine sources, such ratios as $Cl^-/K^+$ were expected to be substantially the same as in sea-water. However, Figs. 10–16 show that the pools exhibited marked differences from this dilute sea-water constitution. As these differences could have been due to experimental error, the standard deviations for the methods of analysis for $Na^+$, $K^+$ and $Cl^-$ were found using duplicates of the apparatus in the laboratory at Signy Island. Results obtained show that determinations of $Na^+$ and $Cl^-$ were reproducible to within ±1·5 per cent and $K^+$ to ±2 per cent. This indicates that the deviation from a dilute sea-water constitution is greater than could be expected from experimental error. Both biological activity and leaching of ions from the substrate seem to be precluded as possible causes by the magnitude of the deviations (up to several mEq./l. in some cases). F. J. H. Mackereth (personal communication) has suggested that this could be explained by assuming that precipitation and melt water did not have the composition of dilute sea-water. Results of analyses of precipitation (Table V) give ratios of the constituents differing from those found in sea-water. However, the surface of the snow receives considerable quantities of spray from the sea during the winter which could be expected to result in melt water of a dilute sea-water composition in the spring. Mackereth has suggested that during periods of thawing in the winter, the various species of ions pass through the snow at different rates according to the

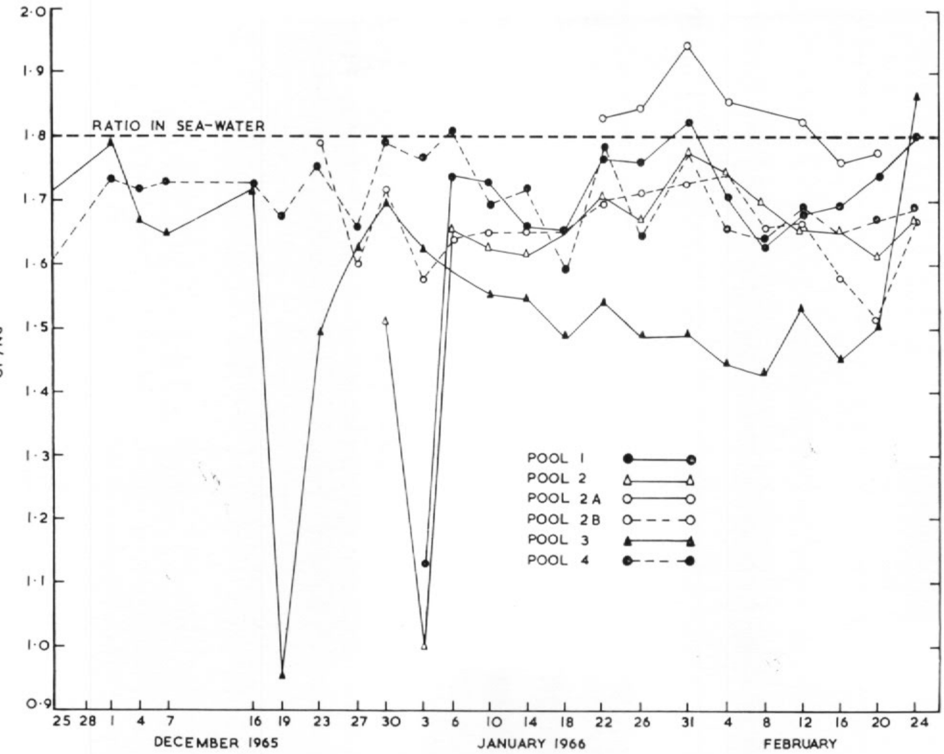

Fig. 10. The ratio of the concentrations of Cl⁻ to Na⁺ in the pools.

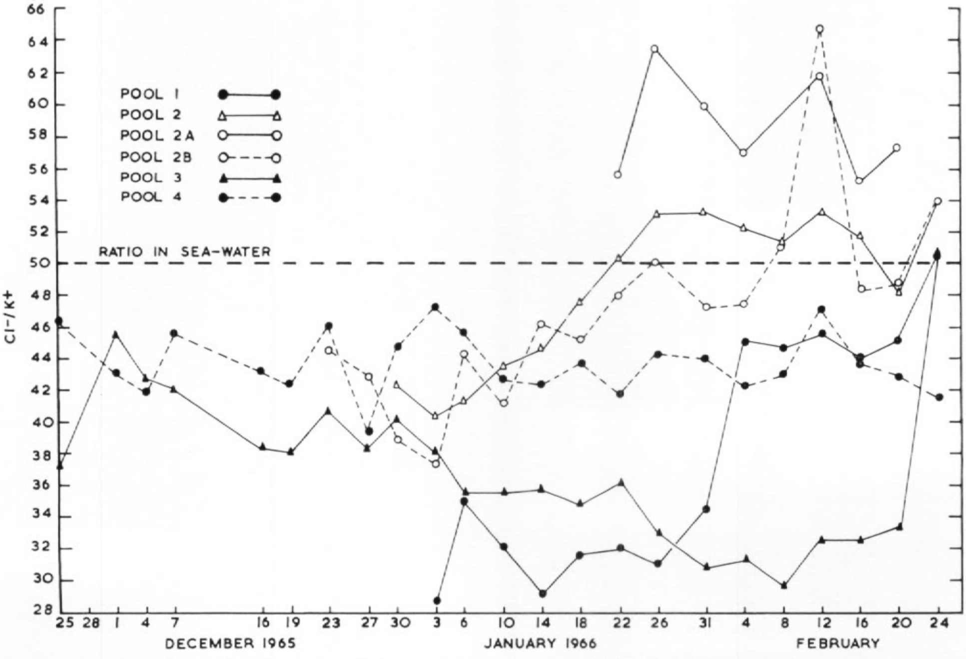

Fig. 11. The ratio of the concentrations of Cl⁻ to K⁺ in the pools.

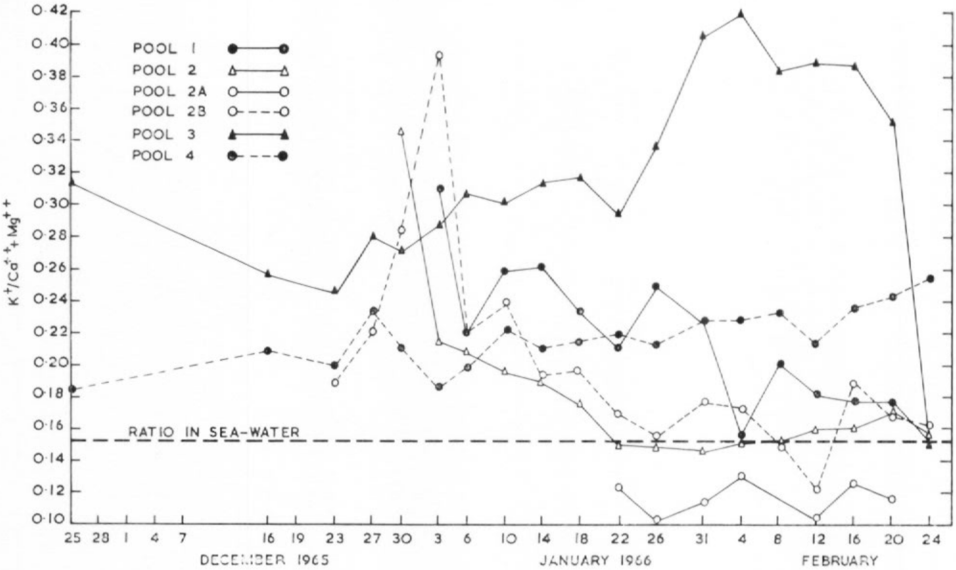

Fig. 12. The ratio of the concentrations of $K^+$ to ($Ca^{++}+Mg^{++}$) in the pools.

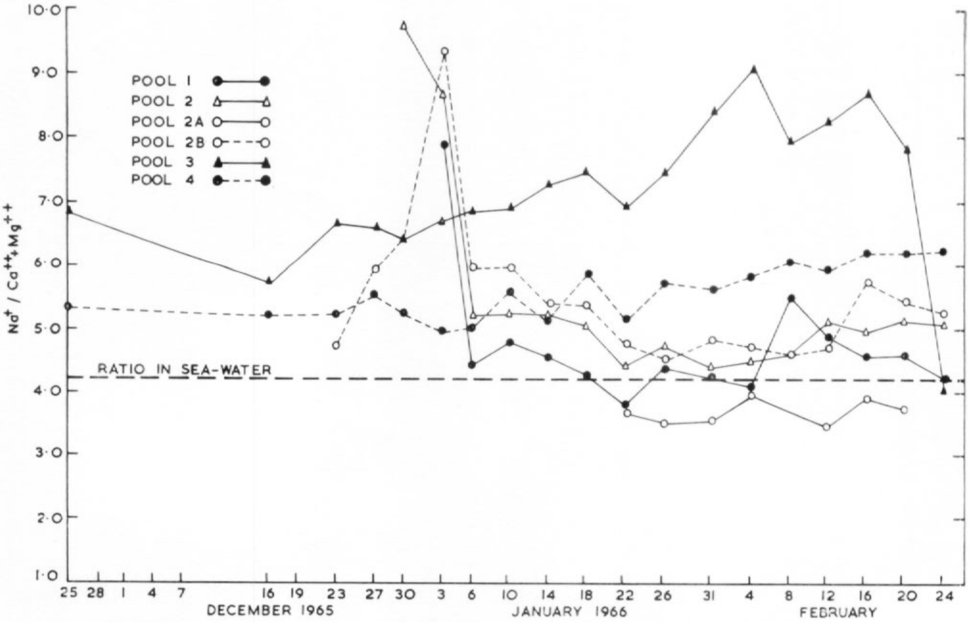

Fig. 13. The ratio of the concentrations of $Na^+$ to ($Ca^{++}+Mg^{++}$) in the pools.

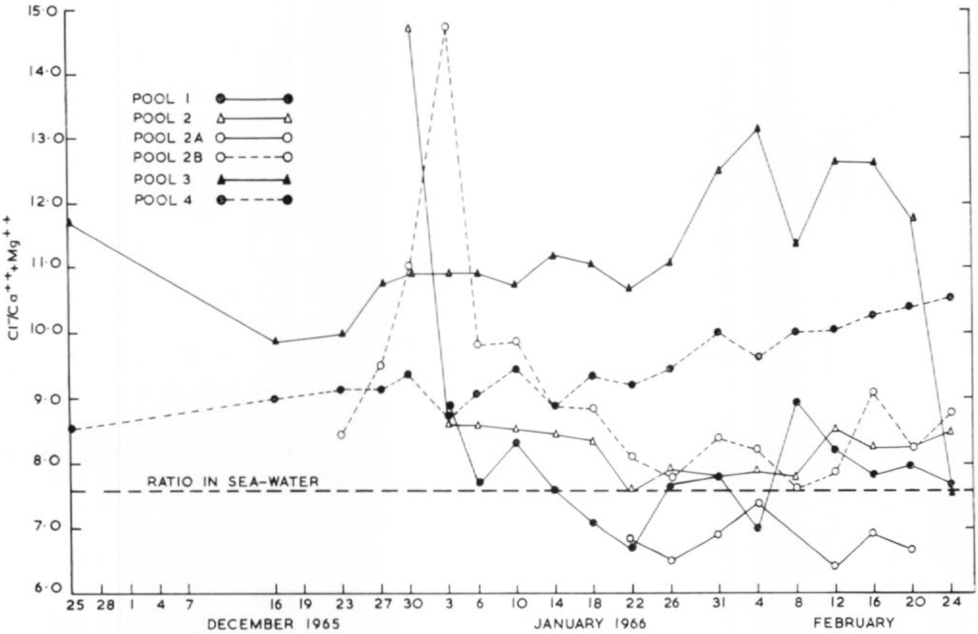

Fig. 14. The ratio of the concentrations of $Cl^-$ to $(Ca^{++}+Mg^{++})$ in the pools.

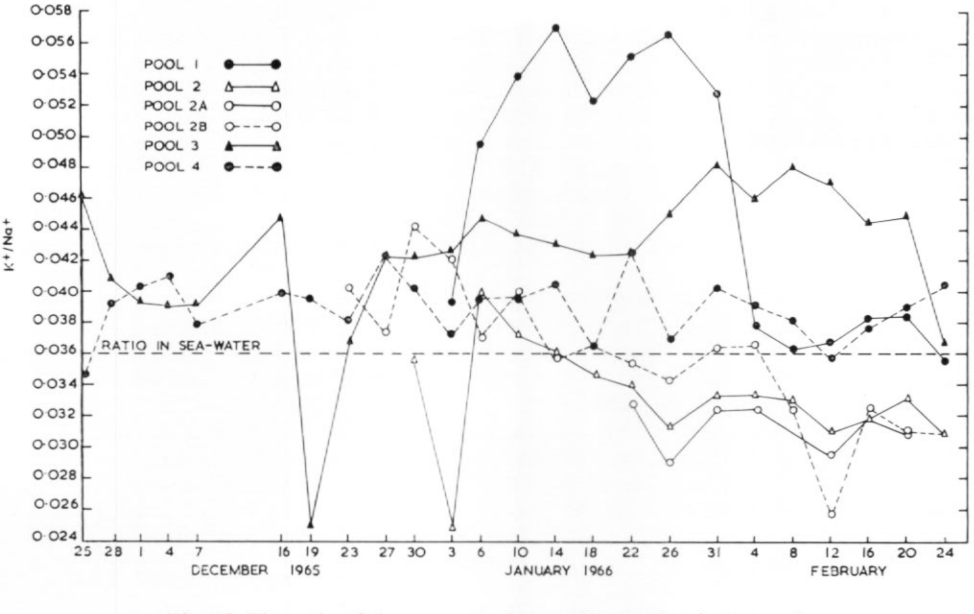

Fig. 15. The ratio of the concentrations of $K^+$ to $Na^+$ in the pools.

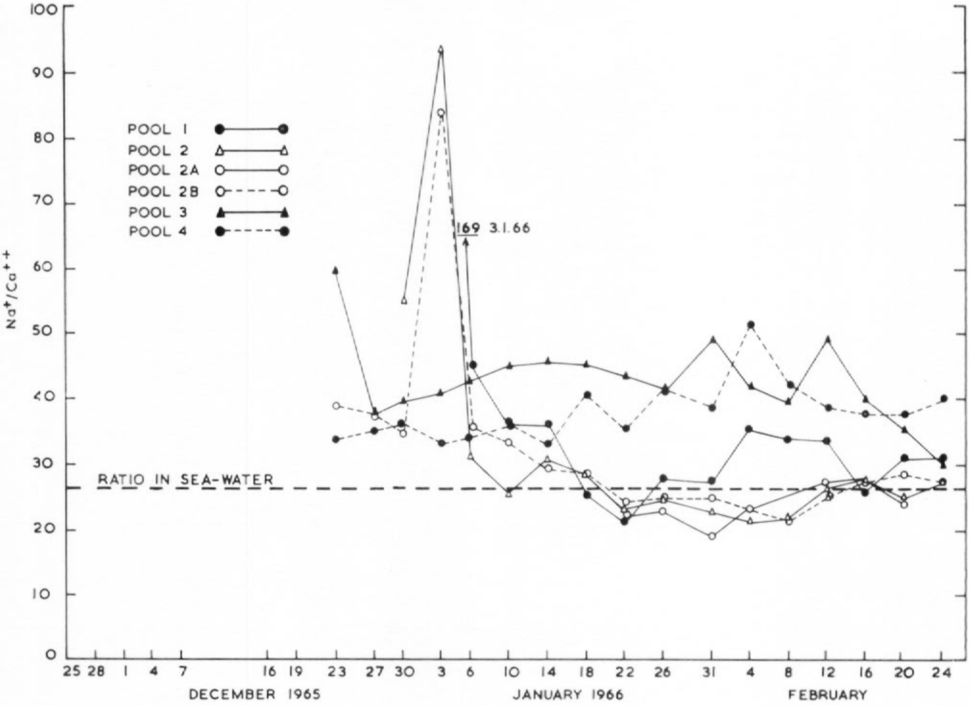

Fig. 16. The ratio of the concentrations of $Na^+$ to $Ca^{++}$ in the pools.

relative strengths of bonding to ice crystals. Wind ablation of the snow surface may then effect a permanent separation of different species of ions.

Experiments were carried out to see if this phenomenon could be reproduced in the laboratory. The experimental procedure was as follows: 1 ml. of a synthetic brine was introduced at the top of a column of finely crushed ice. The column was kept at $-10°$ C but periodically partly thawed with infra-red light to advance the brine front through the substrate. Samples for analysis were obtained by applying the infra-red source to the bottom few centimetres and collecting melted effluent in 2 ml. portions. Two brines were used, one of $K_2SO_4$ and $Li_2SO_4$, and the other NaCl and KCl. The concentrations of their constituents were selected so that the portions could be analysed directly by flame photometry. The results obtained, which are shown in Figs. 17 and 18, indicate that some separation of ions occurred in both brines.

*Relative proportions of some of the constituent ions*

As micro-climate and chance wave splashes played a large part in altering the ratios of the amounts of ions in the pools, interpretation of the ionic ratios is difficult but some general trends may be discerned. If the ratios of ions in pool water are compared with the ratios of ions in sea-water as in Figs. 12, 13 and 14, it can be seen that $Ca^{++}+Mg^{++}$ was generally deficient in comparison with $Cl^-$, $Na^+$ and $K^+$. In pools 1, 2 and 2B this relative deficiency of $Ca^{++}+Mg^{++}$ was less marked than in pools 3 and 4 where it increased during the summer. In pools 1, 2 and 2B the relative deficiency of $Ca^{++}+Mg^{++}$ decreased until the end of January, at which point it started to increase again. These observations in conjunction with the graphs of concentrations seem to indicate that when the general level of concentrations in a pool were falling the concentration of $Ca^{++}+Mg^{++}$ fell more rapidly than the concentrations of $Cl^-$, $Na^+$ and $K^+$, and caused the ratios of these ions to $Ca^{++}+Mg^{++}$ to increase. Conversely, when concentrations were rising generally, the relative deficiency of $Ca^{++}+Mg^{++}$ tended to decrease.

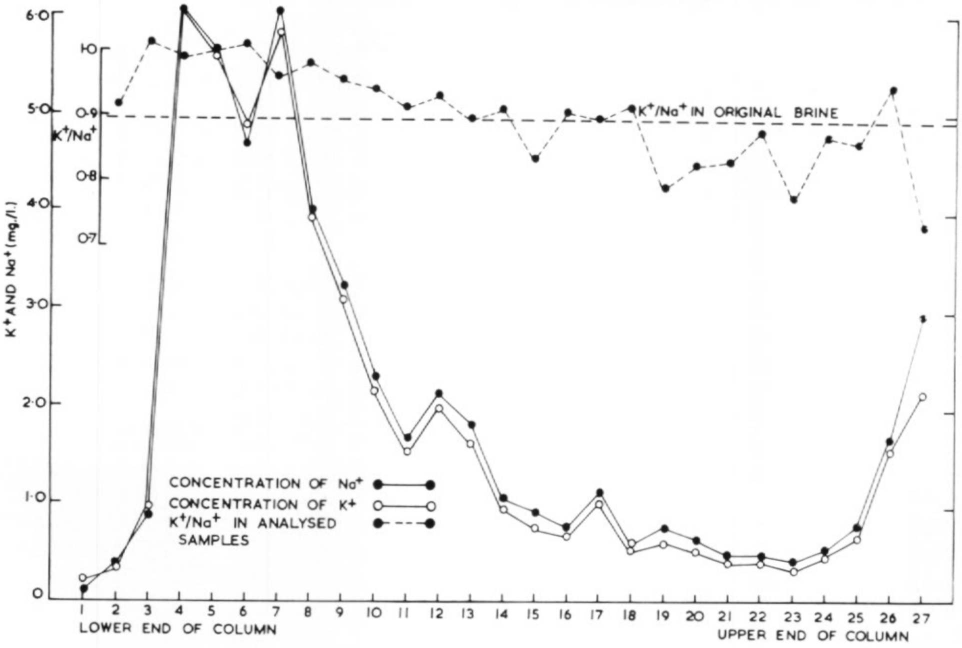

Fig. 17. A comparison of the different rates of diffusion of $Na^+$ and $K^+$ through a column of crushed ice.

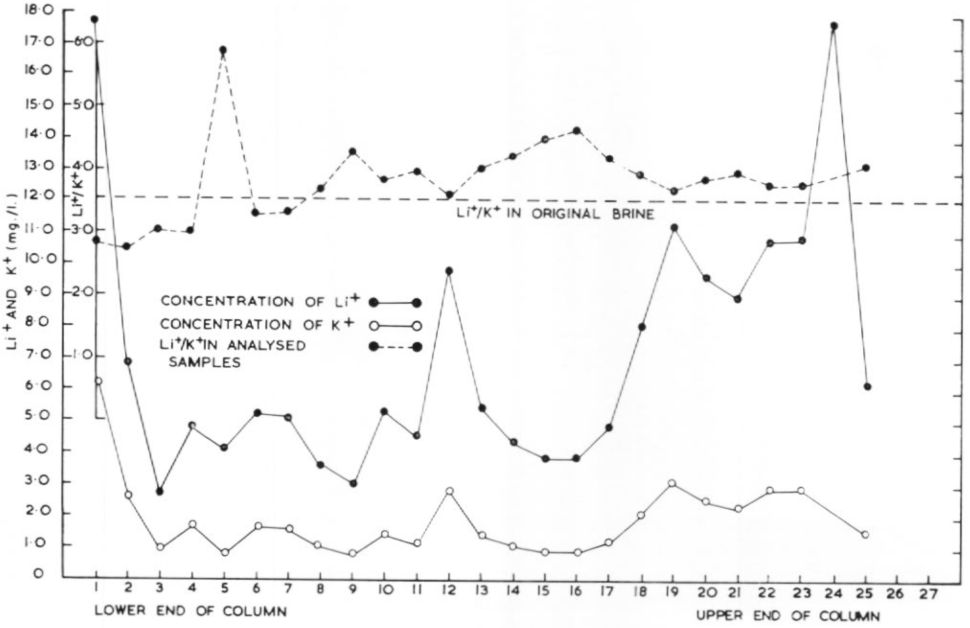

Fig. 18. A comparison of the different rates of diffusion of $Li^+$ and $K^+$ through a column of crushed ice.

Pool 3, from 1 December 1965 to 8 February 1966, provides an example of falling concentrations. Although there are some anomalous fluctuations, the general trend is a decrease in concentrations and increasingly divergent values of the ratios of $Cl^-$, $Na^+$ and $K^+$ to $Ca^{++}+Mg^{++}$. Convergent values of these ratios may be seen in pool 2 from 3 to 22 January, and in pool 2B from 23 December 1965 to 3 January 1966.

If precipitation was causing the fall in concentrations in pools 3 and 4, it would seem to be a reasonable inference that at this time the precipitation contained relatively less $Ca^{++}+Mg^{++}$ than would be found in dilute sea-water of the same overall ionic concentration.

*Calcium results*

When the pools are subjected to a large influx of sea-water, as in pools 1 and 3 on 24 February 1966, the relative proportions of the ions in the pools approach the proportions commonly found in sea-water (Figs. 10–15). But Fig. 16 shows that in this instance the values of $Na^+/Ca^{++}$ are in excess of the sea-water value, indicating that the measured $Ca^{++}$ concentration is probably too small. From the concentration of the $Na^+$ the concentration of $Ca^{++}$ could be expected to be 16 per cent higher than the measured value. Table VII shows results for $Ca^{++}$ obtained titrimetrically and it can be seen that for pool 1 on 24 February these results are too high by approximately 10 per cent. There does not appear to be any constant or predictably variable relationship between the two sets of $Ca^{++}$ results, but comparison of the flame photometer results for $Ca^{++}$ with results for other ions shows marked similarities in the general trends. Thus it would appear that the $Ca^{++}$ results shown in Fig. 7 are representative only of the trends in $Ca^{++}$ concentrations in the pools and not of the absolute concentrations.

TABLE VII. CONCENTRATION OF $Ca^{++}$ (mg./l.) FOUND BY TITRATION

| *Date* | *Pool number* | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 2A | 2B | 3 | 4 |
| *1965* | | | | | | |
| 25 November | — | — | — | — | 3·42 | 17·12 |
| 16 December | — | — | — | — | 5·24 | 14·98 |
| 30 | — | 2·14 | — | 2·03 | 4·82 | 14·98 |
| *1966* | | | | | | |
| 14 January | 3·75 | 5·56 | — | 4·82 | 5·35 | 19·3 |
| 31 | 9·20 | 7·12 | 6·90 | 6·96 | 5·56 | 14·02 |
| 12 February | 37·0 | 6·21 | 10·49 | 8·13 | 2·68 | 9·10 |
| 24 | 220 | 8·45 | — | 8·56 | 315 | 9·95 |

It is not known if a correction factor of 16 per cent can be applied to all the values for $Ca^{++}$ obtained by flame photometer. In some cases, for example pool 2 on 22 January 1966, the concentration of $Ca^{++}$ is already higher than the concentration that could be predicted from the ratio of $Na^+/Ca^{++}$. But, as no influx of sea-water occurred, it does not necessarily follow that this ratio should be the same as in sea-water even though the other ratios are close to the theoretical sea-water values. Thus the best estimate of the concentrations of $Ca^{++}$ is the flame photometer result plus 16 per cent, but it should be emphasized that this may be an erroneous correction. The section on methods of analysis explains the problems involved in the flame photometric method of determining $Ca^{++}$, and it is possible that this discrepancy is due to the presence of $SO_4^{--}$ in the analysed solutions.

### *Dissolved oxygen*

Some measurements were made of dissolved oxygen in the pools, using the probe designed by Mackereth (1964) and the results obtained are shown in Table VIII. As the pools are small, levels of saturation were generally at or near 100 per cent. In those cases in which the levels of saturation were abnormally low, e.g. pools 2A and 3 on 17 February 1965 and pools 3 and 4 on 25 November 1965, the pools had layers of ice on the surface. The high degree of supersaturation on 13 March 1965 can be explained because the pools had warmed appreciably during the day with radiation and high air temperatures, and these are favourable conditions for supersaturation. When the pools were not covered with ice, the percentage saturation of oxygen was generally higher than 95 per cent. As the pools were not ice-covered for prolonged periods during the summer, further measurements of oxygen concentration were not made.

TABLE VIII. DISSOLVED OXYGEN (mg./l.) AND SATURATION (per cent)

| *Pool number* | *17 February 1965* | | *13 March 1965* | | *25 November 1965* | |
|---|---|---|---|---|---|---|
| | (per cent saturation) | (mg./l.) | (per cent saturation) | (mg./l.) | (per cent saturation) | (mg./l.) |
| 1 | 107 | 13·7 | 104 | 12·2 | — | — |
| 2 | 101 | 12·5 | 119 | 14·2 | — | — |
| 2A | 94·7 | 13·0 | — | — | — | — |
| 2B | 99·0 | 12·4 | — | — | — | — |
| 3 | 70·2 | 8·91 | 128 | 15·0 | 91·4 | 11·7 |
| 4 | 102·5 | 12·9 | 120 | 14·4 | 88·1 | 11·1 |

### *Conductivity*

The results obtained for conductivity are not entirely satisfactory. Bright platinum electrodes were used instead of platinized electrodes and conductivity was measured at 22·5° C instead of 25° C, so that the results are only comparative.

### *Results of the 1964–65 programme*

The concentrations of strong acid salts, phosphorus, nitrate and sulphate, and the total alkalinity during the period 25 November to 24 February are shown in Tables IX–XIII.

TABLE IX. CONCENTRATION OF STRONG ACID SALTS (mEq./l.)

| *Date* | *Pool number* | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 2A | 2B | 3 | 4 |
| *1965*<br>25 November | — | — | — | — | 6·67 | 25·8 |
| 16 December | — | — | — | — | 9·56 | 23·8 |
| 30 | — | 4·76 | — | 3·83 | 9·85 | 32·4 |
| *1966*<br>14 January | 3·77 | 5·76 | — | 6·41 | 8·57 | 32·5 |
| 31 | 9·09 | 7·54 | 4·41 | 8·00 | 5·57 | 22·5 |
| 12 February | 55·0 | 7·42 | 8·69 | 9·32 | 4·57 | 16·7 |
| 24 | —* | 8·75 | — | 9·03 | —* | 19·2 |

* Analysis was unsuccessful in these cases because of the high concentrations involved.

TABLE X. TOTAL ALKALINITY (mEq./l.)

| *Date* | *Pool number* | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 2A | 2B | 3 | 4 |
| *1965* | | | | | | |
| 25 November | — | — | — | — | 0·20 | 0·31 |
| 16 December | — | — | — | — | 0·13 | 0·08 |
| 30 | — | 0·04 | — | 0·02 | 0·08 | 0·02 |
| *1966* | | | | | | |
| 14 January | 0·03 | 0·03 | — | 0·04 | 0·13 | 0·06 |
| 31 | 0·21 | 0·01 | 0·01 | 0·02 | 0·16 | 0·05 |
| 12 February | 0·28 | 0·02 | 0·01 | 0·02 | 0·14 | 0·06 |
| 24 | 0·71 | 0·01 | — | 0·09 | 0·66 | 0·12 |

TABLE XI. CONCENTRATION OF PHOSPHORUS (mg./l.) IN THE FORM OF ORTHOPHOSPHATE

| *Date* | *Pool number* | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 2A | 2B | 3 | 4 |
| *1965* | | | | | | |
| 25 November | — | — | — | — | 0·016 | 0·244 |
| 16 December | — | — | — | — | 0·000 | 0·012 |
| 30 | — | 0·230 | — | 0·148 | 0·000 | 0·042 |
| *1966* | | | | | | |
| 14 January | 0·160 | 0·072 | — | 0·112 | 0·010 | 0·024 |
| 31 | 0·965 | 0·088 | 0·148 | 0·061 | 0·006 | 0·035 |
| 12 February | 0·340 | 0·048 | 0·132 | 0·056 | 0·000 | 0·014 |
| 24 | 0·000 | 0·074 | — | 0·091 | 0·084 | 0·254 |

TABLE XII. CONCENTRATION OF NITRATE NITROGEN (mg./l.)

| *Date* | *Pool number* | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 2A | 2B | 3 | 4 |
| *1965* | | | | | | |
| 25 November | — | — | — | — | 0·18 | — |
| 16 December | — | — | — | — | 0·19 | 0·60 |
| 30 | — | 0·52 | — | 0·22 | 0·33 | 0·18 |
| *1966* | | | | | | |
| 14 January | 2·2 | 0·45 | — | 0·42 | 0·06 | 0·14 |
| 31 | 3·4 | 0·30 | 0·71 | 0·42 | 0·06 | 0·09 |
| 12 February | 5·8 | 0·39 | 1·8 | 0·73 | 0·10 | 0·14 |
| 24 | 3·3 | 1·4 | — | 0·82 | 0·44 | 0·17 |

TABLE XIII. CONCENTRATION OF SULPHATE (mg./l.)

| *Date* | *Pool number*<br>1 | 2 | 2A | 2B | 3 | 4 |
|---|---|---|---|---|---|---|
| *1965* | | | | | | |
| 25 November | — | — | — | — | 28·3 | 87·4 |
| 16 December | — | — | — | — | 42·2 | 73·0 |
| 30 | — | 22·1 | — | 13·4 | 41·3 | 102 |
| *1966* | | | | | | |
| 14 January | 17·2 | 22·1 | — | 32·2 | 45·6 | 139 |
| 31 | 36·0 | 33·1 | 9·12 | 34·6 | 27·4 | 33·6 |
| 12 February | 233 | 37·9 | 43·7 | 44·2 | 24·5 | 59·0 |
| 24 | —* | 31·2 | — | 46·6 | —* | 86·9 |

* The concentration of strong acid salts was not measured.

Results in this table were obtained by subtracting the concentrations of chloride and nitrate from the corresponding concentration of strong acid salts.

A selection of results from the sampling on 13 March 1965 is shown in Table XIV, and $Ca^{++}+Mg^{++}$ and $Cl^-$ results for other samplings are shown in Tables XV and XVI. It should be pointed out that the $Cl^-$ results have been obtained by the Volhard titration, and $PO_4^{---}$ was measured with an EEL filter photometer. Other procedures were similar to those employed in 1965–66. The results obtained in this series of analyses were of secondary importance as this was intended to be a trial of methods for the following summer.

TABLE XIV. RESULTS OF SAMPLING, 13 MARCH 1965

| *Pool number* | pH | *Conductivity* ($\mu$mho $\times 10^2$/cm.) | $PO_4$–P (mg./l.) | $K^+$ (mg./l.) | *Alkalinity* (mEq./l.) |
|---|---|---|---|---|---|
| 1 | 5·0 | 7·4 | 0·74 | 8·1 | 0·03 |
| 2 | 4·8 | 2·7 | 0·082 | 2·7 | 0·05 |
| 3 | 7·9 | 20 | 0·016 | 17 | 0·15 |
| 4 | 8·6 | 2·2 | 0·12 | 1·8 | 0·05 |

TABLE XV. CONCENTRATION OF CALCIUM PLUS MAGNESIUM IN TERMS OF CALCIUM (mg./l.), SUMMER 1964–65

| *Pool number* | *21 January 1965* | *17 February 1965* | *13 March 1965* |
|---|---|---|---|
| 1 | 8·54 | 69·8 | 48·5 |
| 2 | 6·98 | 22·1 | 15·7 |
| 2A | — | 16·2 | — |
| 2B | 8·39 | 13·4 | — |
| 3 | 18·1 | 68·9 | 132 |
| 4 | 19·4 | 13·3 | 11·1 |

TABLE XVI. CONCENTRATION OF CHLORIDE (mg./l.), SUMMER 1964–65

| *Pool number* | *17 February 1965* | *13 March 1965* |
|---|---|---|
| 1 | 357 | 264 |
| 2 | 33·5 | 61·7 |
| 2A | 31·6 | — |
| 2B | 40·9 | — |
| 3 | 303 | 681 |
| 4 | 20·4 | 62·1 |

Results obtained for the sampling on 21 January 1965 were not reliable.

On 13 March 1965 only four pools were sampled as, due to the relatively warm and dry summer, pools 2A and 2B had dried out entirely. The relatively low concentrations of ions in pools 2 and 4 are of interest. Figures for pool 2 are also increased by a factor of two because of the reduction in volume of the pool, and it is plain that neither pool had received significant quantities of ions from any source. Pool 3 appears to have received an influx of sea-water at some stage during the summer and pool 1 also shows a relatively high concentration of ions.

It can be seen that the classifications of pools do not remain the same from year to year. Table XV shows concentrations of $Ca^{++}+Mg^{++}$ and, although pool 4 showed a decrease during the course of the summer, the general level is only about 20 per cent of the concentrations found during the 1965–66 summer, while pool 3 had a very much higher concentration than in 1965–66 which increases during the summer.

### BIOLOGY

Representatives of the Protozoa, Rotifera, Nematoda, Tardigrada and Arthropoda were found in the pools. The following arthropods have been identified: *Branchinecta gaini* Daday (Anostraca), *Pseudoboeckella silvestri* Daday (Copepoda), *Alaskozetes antarcticus* Michael, *Halozetes belgicae* Michael and *Cyrtolaelaps racovitzai* Trouessart (Acarina). The mites are terrestrial species, but in addition specimens of a fresh-water mite of the family Acaridae were found in the pools.

The flora consisted mainly of blue-green algae (*Phormidium* sp.) and green filamentous algae.

The distribution of fauna is given in Table XVII. An exhaustive search of specimen material was not made and negative inferences cannot be drawn from this table except in cases of the anostracan and copepod. It is probable that the terrestrial mites had been washed in from the surrounds of the pools and that marine plankton had been brought into the pools by spray.

TABLE XVII. DISTRIBUTION OF FAUNA AMONG THE POOLS, SUMMER 1965–66

| | *Pool number* | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 2A | 2B | 3 | 4 |
| Anostraca | — | + | — | + | — | — |
| Copepoda | — | — | — | — | + | — |
| Tardigrada | + | + | + | + | + | + |
| Rotifera | — | + | + | + | — | + |
| Nematoda | + | + | + | + | + | — |
| Acarina* | + | + | — | — | + | — |

* The fresh-water mite only.

From the available information no estimate can be made of the productivities of the pools but it is interesting to compare the relative amounts of algal growth during the summer of 1965–66. By the end of February 1966, pool 2B was completely full of green filamentous algae, while the other pools could be arranged in the following descending order of amounts of algal growth: pools 2, 3, 4, 2A and lastly 1, which had no green filamentous algae and only small quantities of blue-green algae.

Temperatures recorded under a snow cover have been discussed in the section concerning the effects of weather. From the available information it is not possible to estimate the minimum temperatures occurring at the bottom of the pools, as these were mainly dependent on the depth of snow over the pools at the start of cold weather.

Animals in the pools probably overwinter in the egg stage, or perhaps, as in the case of mites, in a dormant form. However, they may have to withstand high salinities while the pools freeze, due to the reduction in volume of free water and consequent concentration of the dissolved salts in the pools.

## CONCLUSIONS

Signy Island is a favourable area for the establishment of small fresh-water pools; snow melts from the lowland areas every summer providing considerable supplies of melt water, and precipitation during the summer is frequent although the quantities involved are small. Furthermore, owing to the low average air temperature during the summer, together with the relatively small amounts of sunshine received, the pools under observation did not normally dry out but froze solid at the start of the winter.

The pools at Paal Harbour apparently support a flora and fauna which show considerable similarities to those of the lakes on the island (Heywood, 1967). The fresh-water mite has not yet been found in the lakes but all other species found in the pools were also present in the lakes. However, the lakes contained some fauna not found in the pools.

As could be expected, the physical and chemical characteristics of the pools were far more changeable than those reported for the lakes (Heywood, 1968). For example, temperatures in the lakes ranged from 0° to 6° C, and the rate of change of water temperature was small, whereas in the pools the temperature could rise from 0° to 17° C in 24 hr.

Weather conditions can vary considerably from one summer to another, resulting in different life spans of the pools. Thus in the summer of 1964–65, pools 3 and 4 were probably in existence for about 7 months, whereas in the summers of 1948–49 and 1957–58 it is doubtful whether the pools could have been open for more than 1 month.

The concentrations of $Ca^{++}+Mg^{++}$ in pools 2 and 2B during the summer of 1964–65 were similar to the concentrations in these pools in the following summer. Although only the results of the analyses for $Ca^{++}+Mg^{++}$ have been recorded for all three samplings in the 1964–65 summer (Table XV), it is considered that they are indicative of the levels and trends in concentrations of the other ions. Thus on the evidence of these two summers it is probable that pools 2 and 2B are the least likely to receive large influxes of sea-water and this is perhaps why they were the only numbered pools to support the anostracan. However, these pools did not apparently contain the copepod and no reasonable explanation can be suggested as to why it should have been absent from pools 2 and 2B but present in pool 3.

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## APPENDIX

### CONCENTRATION OF $Na^+$ IN POOLS

The concentration of $Na^+$ in precipitation was assumed to be 30 mg./l. as this was the approximate figure obtained from the analysis of rain water (Table V). It is considered that this figure is more representative of the concentration of $Na^+$ than the value of 6 mg./l. found from the analysis of snow (Table V). The calculation was based on the concentration of $Na^+$, as this was one of the most reliable and accurate determinations made on the samples of pool water.

From Tables XVIII and XIX, the quantity of $Na^+$ in pool 2 on 3 January = 52 g. and the quantity of $Na^+$ in pool 2 on 26 January = 121 g. Thus between these dates, approximately 69 g. $Na^+$ must have been added to the pool system, which would have required $69 \times 10^3/30 = 2{,}300$ l. precipitation.

TABLE XVIII. APPROXIMATE VOLUMES (l.) OF WATER IN THE POOLS

| *Date 1966* | *Pool number* 2 | 2B | 3 | 4 |
|---|---|---|---|---|
| 3 January | 1,000 | 280 | 300 | 390 |
| 26 | 900 | 210 | 380 | 470 |

TABLE XIX. CONCENTRATIONS OF $Na^+$ (mg./l.) IN THE POOLS

| *Date 1966* | *Pool number* 2 | 2B | 3 | 4 |
|---|---|---|---|---|
| 3 January | 52 | 68 | 203 | 812 |
| 26 | 134 | 144 | 124 | 480 |

Similarly, for pool 2B, the quantity of $Na^+$ in the pool on 3 January = 19 g. and the quantity of $Na^+$ in the pool on 26 January = 30 g. Thus, 11 g. $Na^+$ had been added, requiring $11 \times 10^3/30 = 367$ l. precipitation.

To calculate the amount of precipitation required for the dilution in pools 3 and 4, the following formula (which was kindly supplied by Dr. P. M. Cohn of the Mathematics Department, Queen Mary College, University of London) was used:

$$V = S \ln \frac{c_1 - p}{c_2 - p},$$

where $V$ is the volume of precipitation, $S$ is the volume of the pool, $c_1$ is the concentration of a specific ion in the pool before dilution, $c_2$ is the concentration of that ion after dilution, and $p$ is the concentration of that ion in precipitation.

Pool 3 contains approximately 380 l. when full, and 80 l. precipitation must be added to the pool before overflow can occur. The concentration of $Na^+$ in the pool is then

$$\{(203 \times 300) + (80 \times 30)\}/380 = 167 \text{ mg. } Na^+/\text{l.}$$

Thus the total volume of precipitation required to cause the observed change in concentration

$$= 80 + 380 \ln \frac{0{\cdot}167 - 0{\cdot}030}{0{\cdot}124 - 0{\cdot}030} \text{ l.}$$

$$= 80 + 143 = 223 \text{ l.}$$

Pool 4 contains approximately 480 l. when full, so that 90 l. of precipitation must be added to bring the pool to overflow level. The concentration of $Na^+$ in the pool is then

$$\{(812 \times 390) + (90 \times 30)\}/480 = 665 \text{ mg. } Na^+/\text{l.}$$

Immediately after overflow had ended the $Na^+$ concentration in the pool was

$$470 \times 480/480 = 470 \text{ mg. } Na^+/\text{l.}$$

Thus the volume of precipitation required to cause the observed change in concentration

$$= 90 + 480 \ln \frac{0{\cdot}665 - 0{\cdot}030}{0{\cdot}470 - 0{\cdot}030} \text{ l.}$$

$$= 90 + 176 = 266 \text{ l.}$$

The amounts of precipitation required by pools 1 and 2A have not been determined as these pools still contained ice.