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THE GREAT BAHAMA BANK. I. GENERAL HYDROGRAPHICAL AND CHEMICAL FEATURES

By

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I. INTRODUCTION

The Bahama Islands are characterized by the presence of thousands of square miles of shallow sea (<5 fathoms) lying between the various islands. The most extensive of these are the Great Bahama, Little Bahama and Exuma Banks (cf. Fig. 44). A certain amount of discussion has arisen concerning these areas, both in relation to their geological formation and to chemical changes taking place in the water. The author has no knowledge, however, of any previous attempt to make systematic hydrographical and chemical observations in these shallow seas. In view of this the opportunity was taken to make such observations as were possible, with the time and equipment available, while engaged on conservation work in connection with the local sponge fishery. For this purpose a small section of the northern Great Bahama Bank was selected for special study (Fig. 44). All the sea going work was carried out from a 54 foot motor patrol vessel, the 'Basil Blackett,' which has been fitted out for making simple hydrographic observations. Owing to the inadequate laboratory facilities on board ship the analytical work has been carried out at the shore laboratory in Nassau, whenever the nature of the work permitted.

II. THE GREAT BAHAMA BANK

The position of the Bahama Islands and the main ocean channels in relation to Florida and Cuba is shown in Fig. 44. The largest group of islands and banks is that known as the Great Bahama Bank, including Andros Island and several smaller outlying islands and cays. This bank is so irregular in shape that its general outline is best appreciated by reference to Fig. 44 where the 100 fathom line marks the edge.

On three sides it is bounded by deep ocean channels and on the fourth by Andros Island and shallow flats. To the North is the North West Providence Channel varying from 300–600 fathoms in depth, to
the West is the Florida Channel approximately 500 fathoms deep, and to the South the Old Bahama Channel with a depth of from 300 to 500 fathoms. Between the southern end of Andros Island and the Old Bahama Channel the bank is continuous with the Exuma Bank lying on the eastern side of the deep ocean pocket known as the Tongue of Ocean (800 fathoms). The ocean edge of the bank is marked in many places by small cays and a few habitable islands such as the Biminis and the Berry Islands. The transition from the shallow bank to deep ocean is everywhere very abrupt, the five and hundred fathoms lines often being less than a mile apart.

Andros Island, the largest of the Bahama group, is about 95 miles long and varies in width from 18 miles at the southern end to 40 miles in the centre and only 10 miles at the northern end. The formation of the island is oolitic limestone (Vaughan 1914). This rock supports a low vegetation of palmetto scrub with ridges of pine forest, though soil is practically non-existent except in rock holes. Continuous erosion of the calcareous rock is taking place, and in many places it is honeycombed by solution. The topography of the island has been
well described by Drew (1914). Along the eastern side there is a low range of hills about 100 feet high and offshore there is a very well developed barrier reef of coral. The west coast of the island is composed of soft slimy mud and is so low that in northwesterly gales it is overflowed to a considerable distance inland. Offshore the water is so shallow that it is impossible to approach within several miles of the coast in anything but a dinghy boat. The west coast is broken up by numerous creeks which may run inland for considerable distances, giving off branches in all directions, and forming a veritable maze of inland waterways. Some of these creeks are comparatively deep (1 fathom) and they all lead eventually to shallow inland lakes, locally called 'swashes,' which very often contain only a few inches of water and several feet of very soft mud. These lakes are many square miles in area and from the air the west side of the island appears to be largely composed of water. The tidal streams in the creeks are swift and carry down large quantities of mud which forms shallow bars across their mouths and renders access to them difficult.

Andros Island is divided into two main parts by three bights which lead from the Tongue of Ocean on the East to the shallow bank on the West side. These are known as North, Middle and South Bights, although North and Middle Bights are only divided by an archipelago of small cays and communicate freely. At the northern end of the Island an extensive mud flat, dry in many places at low water runs some 12 miles northward. To the north of this flat the contour of the bank forms a deep V-shaped indentation of deep water, at the head of which is a narrow 10 foot channel leading onto the bank (North-west channel).

The low swampy West coast of the island slopes very gradually and is continuous with the shallow submarine flats forming the Great Bahama Bank which extend some 60 miles out to sea. The course of the one, two and three fathom lines is shown in Figs. 46 to 49 and it can be seen that the greater part of the northern bank is less than 3 fathoms in depth, while the one fathom line may lie as far as 5 miles from the shore. The bottom consists of fine calcareous marl composed almost entirely of minute unorganized particles of calcium carbonate. Near the shore this marl is very soft and a 12 foot pole may be pushed down into it in places without striking hard bottom. The greater part of the bottom is very clean there being little living matter with the exception of small rootlets of Zostera. Scattered over the bank, however, there occur patches of rocky bottom and here an abundant fauna is found consisting mainly of gorgonid corals, sponges, Zostera and schools of fish. This bank is one of the richest grounds in the
colony for commercial sponges, most of them being taken from these rocky patches or 'bars,' although many sponges break off from their original attachment and become 'rollers,' when they occur wherever the currents drift them.

Vaughan (1918) gives a very complete description of mechanical and chemical analyses of samples of the bottom deposits in the waters near Andros Island. He found that these deposits could be separated into four main categories:

(a) Sands forming behind the coral reef on the Eastern side of the island. These contained only 1.7% of clay and silt size particles (0.05–0.0 mms.), and were composed largely of remains of organisms. They were characterized by a high magnesium carbonate content (5.24%).

(b) Lagoon deposits forming on the extensive flats protected by land on the windward side. This type was a fine grained oolitic mud (60% clay and silt sizes), light gray in color, with an alkaline reaction. It contained a few shell fragments, fragmental CaCO₃ and a few foraminifera. The chemical analysis showed 96.84% CaCO₃, 2.72% MgCO₃, 0.29% SiO₂ and 0.15% (Al, Fe)₂O₃. The depth of this deposit varied from 2–7 feet the underlying material being hard rock.

(c) Oolitic sand formed by the breaking up of indurated oolite by wave action. This type contained only 2–3% of clay and silt sizes and was practically pure CaCO₃ (99.5%). In all respects it was identical with the oolite now elevated above sea-level.

(d) Globigerina ooze, covering the bottom of the Tongue of Ocean. Vaughan found the deposits of type (b) & (c) on the Great Bahama Bank, type (b) being universal close to the western end of South Bight and type (c) at the northern end of the bank (the samples were taken on a W. N. W. course from the North end of Andros to Gun Cay on the edge of the Florida Channel).

Unfortunately Vaughan did not collect any samples from the central part of the bank, nor did he ascertain the total areas covered by each type of deposit.

Thorp (1936) also carried out mechanical analyses of samples of the bottom deposit from the West end of South Bight. His results were essentially the same as Vaughan's. Both observers found many oolite grains in these deposits and also countless minute particles of aragonite. They both reached the same conclusion that this type of deposit is forming by chemical precipitation of calcium carbonate from sea-water.

The author has collected several bottom samples from various parts of the Bank and though no attempt at mechanical or complete chemi-
cal analysis has been made it is apparent that the conditions described by Vaughan and Thorp still obtain in this area. The lagoon deposits of Vaughan are not confined to the entrance of South Bight but extend right along the shore of North Andros and in many cases for a considerable distance offshore. The percentage of clay and silt sizes is probably higher inshore owing to the small amount of water movement. As one proceeds towards the edge of the Florida Channel a mixture of the fine lagoon deposit and oolitic sand is encountered, the oolitic sand proportion increasing as the edge of the bank is approached.

The results of partial analyses of four bottom samples are listed in Table I.

**TABLE I**

**Analyses of Bottom Samples from Great Bahama Bank. For Station Positions of Fig. 47. Samples Washed and Dried in Air**

<table>
<thead>
<tr>
<th>Station No.</th>
<th>Description</th>
<th>CaCO₃</th>
<th>Total CO₃%</th>
<th>MgCO₃</th>
<th>Total CaCO₃+MgCO₃ grs. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>53</td>
<td>Oolitic Sand</td>
<td>98.2</td>
<td>44.4</td>
<td>2.30</td>
<td>100.5</td>
</tr>
<tr>
<td>60</td>
<td>Fine Mud</td>
<td>97.7</td>
<td>44.7</td>
<td>3.26</td>
<td>100.96</td>
</tr>
<tr>
<td>49</td>
<td>Fine Mud</td>
<td>95.5</td>
<td>44.7</td>
<td>5.17</td>
<td>100.67</td>
</tr>
<tr>
<td>75</td>
<td>Oolitic Sand</td>
<td>98.9</td>
<td>44.4</td>
<td>1.72</td>
<td>100.62</td>
</tr>
</tbody>
</table>

The calcium content of each sample was estimated by standard gravimetric procedure and total carbonate content by heating strongly till constant weight was attained. The latter method is subject to variable errors due to loss of other volatile matter in addition to carbon dioxide, so that the carbonate content observed will be too high. The carbonate remaining after subtracting that present as CaCO₃ was calculated as MgCO₃. The total CaCO₃ + MgCO₃ is slightly in excess of 100% owing to the positive errors mentioned. Estimations of the total organic nitrogen content of bottom samples have been made and were found to vary between 0.12 and 0.04%, the higher values being found in samples taken near patches of Zostera. The four samples shown in Table I can be divided into oolitic sand and fine mud categories by the naked eye. Microscopical examination shows that they all contain oolite grains, though these are fewer and smaller in Nos. 49 and 60. Minute undifferentiated particles and needles (aragonite) are found in abundance in these two samples, though of the two No. 49 is definitely the finer deposit. Nos. 53 and 75 contain many large oolite grains with but a small proportion of undifferentiated fragments and needles (very few of the latter in No. 75). Foraminifera of the *Orbiculina* type are found in all the samples. Of
these samples, then No. 49 from close inshore is the finest with No. 60 from about 25 miles offshore only slightly coarser. No. 53 from near the western edge of the bank is an oolitic sand with a slight but definite admixture of a finer deposit, while No. 75 from the more northern part of the bank is an almost pure oolitic sand.

Bottom samples have also been taken in the shallow lakes inland and they were of essentially the same type as No. 49.

III. WATER MOVEMENTS

The general ocean current system around the Bahama Islands is bound up with the currents forming the sources of the Gulf Stream. The main current is a general westerly drift representing the continuation of the Northern Equatorial Current. The low surface salinities (36.2–36.4‰), however, indicate that water of a southern origin is also being carried up into these latitudes. The Antilles current is the most probable agency in effecting this transportation, although its strength is rather uncertain. The ‘Atlantis’ observations off Abaco Island (Iselin 1936) showed only a relatively weak current close inshore while the surface water down to 400 metres appeared to be moving southward. The northward flow at mid-depths was presumably stronger, though the resulting movement was relatively small. Iselin, however, points out that the velocity of this current may be greater in the summer months when the trade winds follow the sun northwards.

The currents in the Old Bahama Channel are described in the West Indies Pilot as setting to the North West, but they are weak and readily influenced by the wind. The same authority describes the currents in N.E. Providence Channel as being variable, while in N.W. Providence Channel there is generally but little current except after northerly winds when it may set eastward with a velocity of 1 knot. It must be remembered, however, that the West Indies Pilot refers only to observed currents in the surface layer and it is most probable that at mid-depths in all the above channels there is a steady westerly drift, the varying wind currents being super-imposed on this movement. The Florida Channel, of course, contains the main axis of the northbound Gulf Stream. The width of the Gulf Stream is variable and at times it strikes full on the Great Bahama Bank about latitude 25° 30’, though generally it lies farther offshore. The ‘Atlantis’ observations North of Cape Hatteras have sometimes shown the presence of strong counter currents along the southern edge of the Gulf Stream (communication from Dr. H. B. Bigelow) and it is probable that similar currents may develop along the outer edge of the current.
in the Florida Channel as the result of short period changes in its
strength. In view of this it may be that the deep water immediately
offshore from the Great Bahama Bank has a southerly movement at
times.

Due to the peculiar relation of the Great Bahama Bank to neigh-
boring land masses and deep ocean channels the tidal streams run-
ning on and off the bank tend to be complex. Near the edge of the
bank the tidal direction is roughly at right angles to the 100 fathom
line and the strength varies from 1 to 2 knots, but in the central region
the opposing streams tend to meet and produce a resultant tidal flow.
Thus, on the Northern part of the bank, the tide from the Florida
Channel has an East-West, while that from the Providence N. W.
Channel has roughly a North-South direction. Where these two
streams meet the tide may be observed as flooding towards the South
East and ebbing towards the North West. With increasing distance
from the Providence N.W. Channel the influence of the North-South
components becomes less and less and in about latitude 24° 20' N. the
tide floods toward E. by S. On the Southern edge of the bank the
tide floods to the North from the Old Bahama Channel and the central
part of the Southern bank has a tidal set towards N.E. owing to an
interaction similar to that described above. The tidal rise and fall
over the whole area is small being about 3 feet at ordinary spring tides
on the edge of the bank and decreasing on the central and inshore areas.

When considering the chemical changes taking place in the water
on the bank it is more important to know the direction and extent of
the daily water drift (residual current) rather than the tidal move-
ments. For this purpose several observations have been made on the
Bank with a Carruthers' Drift Indicator (Min. Agri. Fish. Notice No.
17). This instrument shows the daily residual current after the op-
posing tidal influences have been cancelled out. Table II shows the
records obtained with the instrument and the average wind conditions
during the period of the observations.

The most extensive series of observations was made in December
1939, during a period of very light winds. Under such conditions the
residual current over the central part of the area is approximately 1
mile per lunar day towards S.E. Inshore the current tends to be
weaker (0.5 miles/day at St. 125) and more easterly. Although the
wind was very light throughout the cruise, the resultant wind force
over the period Dec. 1st–14th was computed as a 3 m.p.h. wind from
N.N.W. A single current meter observation was made on Jan. 17th
1940 at approximately the position of station 125 (St. 137), when the
resultant wind force was 2.5 m.p.h. from N.E. x N. On this occasion
TABLE II

Carruthers' Drift Indicator Observations. Records from Great Bahama Bank are Shown Graphically on Figs. 46 and 49

<table>
<thead>
<tr>
<th>Position &amp; Date</th>
<th>Total daily water movement nautical miles</th>
<th>Duration of observations lunar days</th>
<th>Residual Current Miles per lunar day</th>
<th>Wind Average Force</th>
<th>Wind Average Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Bahama Bank</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17: 9: 38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stat. 28 . . . .</td>
<td>7.2</td>
<td>1</td>
<td>2.0</td>
<td>W. x S.</td>
<td>6 m.p.h. S.E.</td>
</tr>
<tr>
<td>4: 12: 39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stat. 113</td>
<td>8.6</td>
<td>2</td>
<td>1.0</td>
<td>S.E.</td>
<td>Light Airs Variable</td>
</tr>
<tr>
<td>6: 12: 39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stat. 116</td>
<td>5.0</td>
<td>1</td>
<td>0.3</td>
<td>S.E. x S.</td>
<td>Calm</td>
</tr>
<tr>
<td>7: 12: 39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stat. 119</td>
<td>3.0</td>
<td>1</td>
<td>0.9</td>
<td>S.E.</td>
<td>Light Airs N.W.–N.E.</td>
</tr>
<tr>
<td>9: 12: 39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stat. 121</td>
<td>3.0</td>
<td>1</td>
<td>0.8</td>
<td>S.E. x E.</td>
<td>Light N.–N.E.</td>
</tr>
<tr>
<td>10: 12: 39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stat. 125</td>
<td>1.3</td>
<td>1</td>
<td>0.5</td>
<td>E.S.E.</td>
<td>Light Airs N.W.–N.E.</td>
</tr>
<tr>
<td>12: 12: 39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stat. 127</td>
<td>3.5</td>
<td>2</td>
<td>0.9</td>
<td>E.</td>
<td>4.5 m.p.h. N. x E.</td>
</tr>
<tr>
<td>17: 1: 40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stat. 137</td>
<td>1.7</td>
<td>1</td>
<td>0.6</td>
<td>S.W.</td>
<td>2.5 m.p.h. N.E. x N.</td>
</tr>
</tbody>
</table>

Andros Middle Bight

<table>
<thead>
<tr>
<th></th>
<th>Total daily water movement nautical miles</th>
<th>Duration of observations lunar days</th>
<th>Residual Current Miles per lunar day</th>
<th>Wind Average Force</th>
<th>Wind Average Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>28: 2: 37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5: 3: 37</td>
<td>12.8</td>
<td>2</td>
<td>2.5</td>
<td>S.E.</td>
<td>Fresh S.W. to N.</td>
</tr>
<tr>
<td>28: 4: 37</td>
<td>7.5</td>
<td>3</td>
<td>2.1</td>
<td>W. x N.</td>
<td>Light to S.E. moderate</td>
</tr>
<tr>
<td>1: 5: 37</td>
<td>13.5</td>
<td>3</td>
<td>1.9</td>
<td>W. x N.</td>
<td>Fresh E.N.E.–E.S.E.</td>
</tr>
</tbody>
</table>

and similarly the four observations in the Andros Bight shown in Table II, indicate a similar reversal of the current due to wind action. With a westerly wind the water flows from the bank to the Tongue of Ocean and in the opposite direction with an easterly wind.
This dependence of the residual current on wind action enables one to follow the main seasonal changes by studying the yearly wind records from the Bahamas. In Table III, the number of days per month on which the wind blew from various directions is shown for the year 1939.

### TABLE III

**SHOWING WIND DIRECTION IN NUMBER OF DAYS PER MONTH DURING 1939 FROM NASSAU METEOROLOGICAL STATION RECORDS**

<table>
<thead>
<tr>
<th>Month</th>
<th>N.</th>
<th>N.E.</th>
<th>E.</th>
<th>S.E.</th>
<th>S.</th>
<th>S.W.</th>
<th>W.</th>
<th>N.W.</th>
<th>Calm</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>February</td>
<td>1</td>
<td>7</td>
<td>4</td>
<td>12</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>March</td>
<td>1</td>
<td>9</td>
<td>7</td>
<td>10</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>April</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>11</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>May</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>10</td>
<td>3</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>June</td>
<td>0</td>
<td>4</td>
<td>8</td>
<td>10</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>July</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>14</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>August</td>
<td>0</td>
<td>3</td>
<td>7</td>
<td>12</td>
<td>3</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>2</td>
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<tr>
<td>September</td>
<td>1</td>
<td>7</td>
<td>2</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>October</td>
<td>0</td>
<td>21</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>November</td>
<td>6</td>
<td>12</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>December</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

These records show that a rough distinction between summer and winter phases can be drawn. In the summer the wind blows largely from the S.E. and E., owing to the effect of the trade wind belt moving northward. In the winter, however, the influence of the trades is less and the winds become more variable with an increasing northerly component, the end of the summer phase being usually characterized by a series of fresh N. westerly winds which cause a sharp fall in air temperature. To illustrate this seasonal change in wind direction the resultant force and direction of the wind for the months of July and December 1939 has been computed from the daily records kept by the Nassau Meteorological Station. In July the resultant wind action was equivalent to a 3 m.p.h. wind from the S.E., while in December the direction was N. by E. and the velocity 2.4 m.p.h., showing a shift of 125° to the North.

In the summer the predominating south easterly winds will result in a steady westerly current across the central part of the bank. The variable and more northerly winds of the winter months will cause a southerly drift, and during the periods of north-westerly gales water will be transported in an easterly direction from the Florida Channel towards the Andros coast. The nature of the current system deduced from these direct observations and wind records is clearly confirmed.
by the patterns of the isohaline charts which will be discussed in the next section (Figs. 46 to 49).

The column in Table II, showing the total daily water movement at each station is of interest, as it shows the very quiescent nature of the Bank. Thus at Station 113 towards the northern edge of the bank the daily movement is only 8.6 nautical miles while at Station 125 in the wide bay formed by the shore of Andros Island it falls as low as 1.3 miles. This, of course, represents the minimum movement during a period of light winds, and with a fresh wind it will probably increase. For example, at Station 28 with a fresh S.E. wind, 7.2 miles of daily movement was recorded, while at Station 119, in approximately the same position, only 3.0 miles was recorded in calm weather. The semi-static state of the water which is a product of the opposing tidal influences discussed above and the sheltering effect of the land masses to the East, favors the development and maintenance of hydrographical properties very different from those shown by the surface water of the open ocean. With the prevailing drift observed in December, 1939 water coming onto the bank from the Florida Channel would take at least two months to reach the shore of Andros Island, although such conditions would never obtain for so long a period. Even with the 2 miles per day westerly drift observed with a fresh S.E. wind it would require one month of such drifting to move a body of water from close inshore out into the Florida Channel. As the winds are regularly shifting it is therefore apparent that once a body of water drifts on to the bank it may be shifted to and fro by conflicting wind influences for a long period without making much mileage in any one direction.

**IV. DISTRIBUTION OF TEMPERATURE AND SALINITY**

(a) *Temperature:* Unfortunately it has not been possible to record the daily temperature of the water on the Bahama Bank so no information is available as to the seasonal variation of the average temperature beyond that yielded by the temperatures recorded when water samples were being taken. Daily records of water temperature have, however, been kept at a field station in the Middle Bight of Andros. The water in this area is in closer communication with the ocean and the tidal movement is greater than on the central part of the bank and hence the records are not strictly applicable to the bank water, but they are sufficiently so to show the nature and extent of the seasonal temperature changes.

In Fig. 45 the average water temperature at 8 a.m. for each month during 1939 based on daily observations, is compared with the average
monthly maximum and minimum air temperatures for the same year recorded at the Nassau Meteorological Station. It is apparent that the water temperature follows the air temperature very closely. Both air and water heat up rapidly between May and June and there is an equally sharp fall in temperature between October and November. The maximum average water temperature (29.7° C.) is reached in August (individual maximum 30.5° C.) and the minimal value (21.6° C.) in December (individual minimum 19.5° C.). The average temperatures recorded for the bank water over short intervals during the same year agree fairly well with the average values for the Bight water with the exception of a temperature of 30.0° C. recorded over a 10 day period in early October. This observation is 1° higher than the average September value in the Bight and 2° C. higher than that for October. It may well be, therefore, that the maximum temperature was maintained till later in the year on the bank. Temperature observations of the surface water in the ocean have not been observed frequently enough to permit the tabulation of monthly values. The

![Temperature Graph](image-url)
observations show, however, that the ocean attains its maximum surface temperature in October (28–29° C.) and reaches minimal values about February (23° C.). This lag of the ocean temperature behind that of the bank water was shown very clearly in December 1939 when the ocean surface temperature was 25.0° C. and the average bank temperature had already fallen to 21.4° C.

The distribution of temperature at any one time over the bank is very uniform both horizontally and vertically. The water is too shallow and mixing by wind action too thorough for any vertical stratification to be set up. Significant variations in horizontal distribution have only been observed close to the edge of the bank when the ocean temperature differs appreciably from that of the shallow water. At such times, with a flood tide, the influence of the warmer or cooler ocean water can be detected up to a distance of 5 miles from the edge of the bank. Observations of the diurnal temperature range on the bank show that it is of the order of 1° C. throughout the year, and subject to very little seasonal variation.

(b) Salinity: The distribution of salinity over the northern part of the Great Bahama Bank during Sept. 1938, and April, October and December 1939 is shown in Figures 46, 47, 48, and 49 respectively. It is readily apparent that the charts for September, April and October present a roughly similar pattern, while that for December is of a very different type.

The first pattern is characterized by the occurrence of very high salinity water lying close to the shore of North Andros Island, the maximum value being >43‰ in September 1938 and April 1939. From the position of the salinity maximum the isohalines push out like a wedge, between the lower salinity water to the North and South, towards the Florida Channel. The apex of this wedge lies constantly fairly close to the 25th parallel of latitude. In Fig. 46 there is distinct evidence that the apex of this wedge of high salinity water is being pinched off by an invasion of less saline water from both sides, while a similar process is probably beginning in Fig. 47. In September and April there is a zone of very rapid salinity change close to the edge of the bank. This is shown clearly in Fig. 46 but not in Fig. 47 as the high salinity water extended beyond the edge of the bank (where the salinity was >39‰) and outside the range of the samples. In the latter case the transition zone was probably sharper than in Fig. 46 as dilution by surface ocean water would be very rapid. Another zone of extremely sharp salinity change occurred in Sept. 1938 (Fig. 46) at the northern end of Andros Island, where the salinity fell 3‰ in a distance of five miles. The salinity change in this area was
more gradual in April 1939, though there is a secondary transition zone farther South, lying between stations No. 47 & 71. In October 1939 the transition zone between the bank water and the ocean in the Florida Channel was broader though still quite clearly defined,

and again there is a sharp transition zone near the northern end of the island. On the southern side of the high salinity wedge the salinity changes tend to be more gradual on all three cruises. There is again a narrow belt of high salinity water close inshore but the salinity falls regularly with increasing distance offshore and in September and October at least there was no sharp transition zone on the edge
of the bank in latitude 24° 30'. Conditions in April were somewhat different as water >39% occurred over all the southern part of the area and a sharp zone of salinity change probably did occur in this latitude just beyond the edge of the bank. This marked westerly extension of high salinity water in April is due to strong easterly winds,

The resultant wind for the period April 10th-22nd, being 8 m.p.h. from East.

In December, 1939 (Fig. 49) the pattern of salinity distribution is very different from the above. With the exception of Station 127 (38.24%) the salinity over the whole area is <38%. At Stations 130 & 129 there is also evidence of dilution by fresh water. This is probably caused by land drainage from the North and Middle Bights where salinities <23% were recorded in early November after a
period of heavy rain. The 37% isoline on this cruise showed a somewhat irregular distribution, moving westerly towards the Florida Channel at Station 122, but there is no evidence of the high salinity wedge so characteristic of the other cruises.

Figure 48. Showing distribution of isohalines over part of the Great Bahama Bank during period of Sept. 29—Oct. 8, 1939. See legend Figure 46. Resultant wind during period = 5 m.p.h. from N.E.

The broad outlines of the current system on this bank have already been described and evidence presented showing that seasonal changes are to be expected. Such a concept makes the salinity charts readily intelligible. Thus in September, April & October (Figs. 46, 47 & 48) the main current is towards the West or North-West and it is obviously carrying high salinity water from the inshore area out towards the ocean. As this water is transported westward there would be a tendency for the lighter water ahead and on both sides to flow over
it, but this is prevented by the frictional force of the wind, so that mixed water does not appear in any quantity.

In December the observed drift at several stations (shown on Fig. 49) had a definite easterly component, so that low salinity water from the ocean is being carried across the bank towards the land. The slight increases in salinity observed are due to a combination of two factors. In the first place even in the winter months some evaporation of the water in its slow progress across the bank takes place. Secondly high salinity water is continually spreading on to the bank from the shallow lakes on the west coast of Andros by tidal action. This latter effect may be considered in greater detail with the aid of salinity observations made in one of the creeks. Figure 50 shows the salinity changes over a complete tidal period at an anchor station in Deep Creek in January 1940.
At low water high salinity water from the lakes inland appears in
the creek, while on the flood tide the lower salinity bank water flows
in, until at high water the salinity is the same on the bank and in the
creek. Considerable admixture of these two bodies of water must
take place on every tide and there will be a tendency for the salinity
of the bank water outside the creek to be raised. This tendency must
be more pronounced in the summer when the general current is west-
erly. In addition there will then be a high rate of evaporation from

![Graph showing salinity changes over a tidal period](image)

Figure 50. Salinity at an anchor station in Deep Creek, N.W. Andros over a tidal period.
Jan. 17–18, 1940.

the surface of the bank water itself. If the sluggish nature of the
currents on the inshore part of the bank is borne in mind, it is not
difficult to realize why such high salinities are found in this area.
The direction of the coastline of North Andros assists the develop-
ment of extreme salinity values offshore by affording shelter from
the prevailing winds. Farther South where the shore runs from N.W.
to S.E. the maximum salinity recorded is less than 41 %.

If, as shown above the high salinity water on the northern part of
the bank is slowly moving westward in summer there must be a slow
drift into the area to replace this water. It is suggested that this
water flows in from the northern end of Andros Island, and to a cer-
tain extent from the inshore area farther south. The extreme sharp-
ness of the salinity transition zone at the northern end of the island
would indicate that the mixed water is being carried away by a weak current running parallel to the isolines. Between stations No. 16 and 18 (Fig. 46) the density \((\sigma_r)\) decreased from 26.8 to 24.2 over a distance of five miles. The internal dynamic forces in this zone would be great enough to establish a current in opposition to the wind force. Such currents are known to occur in coastal regions where two bodies of water of contrasting density are in juxtaposition. The sharp density transition zones at the apex of the wedge of high salinity water may also be characterized by eddy currents of a similar nature.

V. HYDROGRAPHIC DATA

During 1938 a series of deep sea hydrographic observations were made at a station in the Providence Channel (77° 21' W., 25° 16' N.). These observations were unfortunately interrupted by a mishap to the research vessel which disabled her for a long period. A typical hydrographic record for this station is shown in Fig. 51, where temperature, salinity, pH, oxygen content and phosphate content are plotted against depth of the sample. The depth was recorded by means of a metre wheel and when the wire angle was \(>10^\circ\) a correction has been applied. Owing to the limitations of a small vessel and slow hauling gear the greatest depth sampled was 1250 metres. This depth is sufficient to reach below the main thermocline and penetrate the more homogeneous deep water.

The section shown in Fig. 51, is fairly representative of all the records apart from seasonal variations in the upper 200 metres. The temperature observations show a surface layer down to 100 metres where vertical mixing is sufficient to maintain a homogeneous condition. In the summer, when calmer weather obtains this homogeneous layer shows considerable contraction. Below the surface layer, the thermocline layer extends down to 1,000 metres (taking the 5° isotherm as the lower limit of the thermocline), and the deepest sample enters the upper limit of the deep water layer. Observations during the summer show the presence of a secondary thermocline immediately below the surface layer. The salinity section corresponds fairly closely to the same pattern, the lower limit of the halocline also lying close to 1,000 metres and a maximum salinity of 36.60 \(\%\) occurring at 150 metres.

The curve for percentage saturation with oxygen shows an oxygen ‘poor’ layer \((<60\%\) saturation) lying between 600 and 830 metres, below which depth it increases continuously to 1,200 metres. This may be regarded as typical for the ocean water in this latitude (Sei-
well, 1934), as the oxygen minimum lies close to the 10° isotherm and well within the main thermocline.

Considerable variation in the thickness of the oxygen poor layer has been observed at this station (460–900 metres in April 1938) but

the mean position and relation to the thermocline are fairly constant. Fluctuations in oxygen content appear in the surface layer, due to photosynthesis and respiration. The oxygen saturation in this layer is approximately 90% in the winter months, but supersaturation was found at 10 metres in April and such values are probably characteristic of the summer period. $\text{pH}_w$ increases from 8.24 to 8.27 in the
surface layer, then falls steadily to 8.15 at 700 metres, and rises again to 8.20 at 1,200 metres.

In the surface layer phosphate is practically undetectable, but below this it increases steadily to a maximum of 70 mgs. P₂O₅ per cubic metre at 700 metres.

Owing to possible inaccuracies in the recorded depth of the samples it is difficult to compare the several observations at this station directly. For this purpose use has been made of the temperature-salinity correlation method. The standard curve adopted for comparison is that given by Iselin (1936) for the 'Atlantis' stations in the deep water off Elbow Cay, Abaco (Nos. 1476–1478). Table IV, shows the salinity departures from the standard curve for three observations in the Providence Channel and one station off Elbow Cay, Abaco. The salinity anomalies were read off horizontally, a positive sign being given to points to the right of the standard curve and vice versa. The depths given are those recorded for these observations and do not correspond with the depth scale on Iselin's curve.

<table>
<thead>
<tr>
<th>Depth (Metres)</th>
<th>Station 12 miles North from Nassau, N.P. in Providence Channel. Depth 2,800 m.</th>
<th>Station 10 miles East from Elbow Cay, Abaco. Depth 1,000 m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0</td>
<td>+3</td>
</tr>
<tr>
<td>300</td>
<td>-6</td>
<td>-6</td>
</tr>
<tr>
<td>500</td>
<td>-4</td>
<td>-5</td>
</tr>
<tr>
<td>750</td>
<td>-3</td>
<td>-5</td>
</tr>
<tr>
<td>1,000</td>
<td>-3</td>
<td>-2</td>
</tr>
<tr>
<td>1,250</td>
<td>0</td>
<td>-6</td>
</tr>
</tbody>
</table>

The observations off Elbow Cay on 30th November, 1937 correspond fairly closely with the standard T–S curve, showing negative anomalies at mid-depths. The Providence Channel station, however, shows considerable variation, both in the different observations and in comparison with the Elbow Cay T–S curve. The mid-depths in December and January 1938 show negative anomalies (more marked in December), while high positive anomalies occurred in April at from 750 metres to 1,250 metres depth. It is possible that these changes are due to variation in the influence of the high salinity.
Mediterranean water and low salinity sub-Antarctic intermediate water (cf. Iselin 1936).

The depth scale for the T-S curve in the Providence Channel departed considerably from that off Elbow Cay. The Elbow Cay observations agreed fairly closely with the depth scale for the 'Atlantis' stations, the only discrepancy being a slightly higher level of the isolines between 300 and 750 metres. The Providence Channel observations, however, all show considerable elevation of the isolines, especially between 300 and 750 metres where in several cases they are 200 metres nearer the surface than off Elbow Cay. Iselin (1936) observed that at the two most eastern stations in a section across the Gulf Stream off Cape Canaveral water characteristic of the Antilles Current at 500 metres appeared at 300 metres. In view of the elevation of the isolines found at this Providence Channel station it may be that the water found by Iselin at these Gulf Stream stations represented Antilles Current water which had joined the main Gulf Stream after passing through the Old Bahama or Providence Channels.

Hydrographic stations have also been occupied in the remarkable ocean pocket, known as the Tongue of Ocean, lying between New Providence and Andros Islands. The temperature and salinity sections for this area show no significant departure from those in the nearby Providence Channel.

The relation between the temperature and salinity of the shallow water on the Great Bahama Bank and the surface water in the ocean has already been mentioned, and other chemical differences will be described in a subsequent paper. It may, however, be noted that the phosphate content of the shallow water, like that at the ocean surface is practically undetectable, although a few observations in winter showed about 2–3 mgs. P_2O_5 per m^3. Silicate content is also low (100–150 mgs. SiO_2/m^3 in winter) with a tendency to be lower on the bank than in the ocean. Silicate content of the bank water must be largely controlled by the presence of a large sponge fauna on the bottom, several species having a skeleton composed of siliceous spicules. A slight seasonal change in the oxygen content of the shallow water has been observed on the bank, due to the increased temperature and photosynthetic activity in the summer months. In general the water is 96–100% saturated with oxygen in December, while in April 107–118% saturation occurs. No observations are available to show the maximum degree of supersaturation attained in mid-summer.
VI. METHODS

1. Sampling. The water samples for the deep sea hydrographic stations were taken in a Nansen-Petersen water bottle with paired reversing thermometers attached so that they reversed when the bottle closed. The bottle was suspended on 3 mm., steel wire rope and was hauled up by means of a hydraulic capstan on the deck of the vessel. The amount of wire run out was recorded on a metre wheel, and corrections made for wire angles >10°. Owing to the shallow draught of the boat and her relatively large wind area, it was only practicable to work stations in light weather, as otherwise the drift while working a station was found to be too great.

Water samples on the Great Bahama Bank are spot samples taken about 1 foot below the surface. Previous observations have shown that there is no difference between surface and bottom samples in such shallow water. All water sample bottles were of standard Marine Biological Association pattern.

2. Temperature. Deep sea temperatures were all recorded by reversing thermometers. These were used in pairs to guard against errors developing in one of the instruments. The temperature of shallow water samples was taken by direct observations on the sample when taken. These readings were usually checked by using reversing thermometers from the side of the vessel.

3. Salinity. Salinity was estimated by titration with silver nitrate. The silver nitrate was frequently standardized against International Sea Water and titrations were made in duplicate. The salinity results are considered to be accurate within ±0.02‰ Cl.

4. Oxygen. has been determined by the standard Winkler method. In deep sea work the samples were drawn off directly from the Nansen-Petersen bottle, while in shallow water a special sampling bottle was used to ensure that the sample did not come in contact with the atmosphere. The Winkler reagents were added on board ship when the sample was taken. Fox's table (1907) has been used for calculating the percentage saturation at the temperature and salinity observed at each station.

5. Phosphate. was estimated by Atkins' modification of Denigès method (Atkins 1923 (1)). The comparison with standard solutions was made in Hehner tubes and a blank correction applied for the blue color of sea water and for impurities in the reagent (Cooper 1933). The results have not been corrected for salt error.

6. Silicate. was estimated by Diénert and Wandenbulckes' method. (Atkins 1923 (2)).
VII. SUMMARY

1. A general description of the topography and bottom deposits of the Great Bahama Bank is given.

2. It is shown that the water movement over the bank is primarily controlled by the direction and velocity of the wind. The seasonal changes in the wind system in the Bahamas are discussed and the consequent effect of such changes on the current system. Drift Indicator observations show the quiescent nature of the water mass and its suitability as a region where the chemical changes taking place in the water of shallow tropical seas may be investigated.

3. Charts are given showing the seasonal distribution of salinity over part of the Bank. In the summer very high salinities occur inshore (>43 %o), and owing to the westerly drift a wedge of high salinity water extends almost to the edge of the Florida Channel. In the winter, weather conditions are not favorable to the development of this system. The origin of this highly concentrated water is discussed in relation to the system of creeks and extensive shallow lakes which is found on the West coast of Andros Island.

4. Observations made at a deep sea hydrographic station in the Providence Channel are briefly discussed. The character of the water at mid-depths suggests a Northern Equatorial Current origin, while the low surface salinities indicate that this layer has originated farther South.

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