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VARIATIONS IN COMPOSITION OF SUB-SURFACE WATER IN THE SWAKOP RIVER, SOUTH-WEST AFRICA

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With 1 Map.

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Introduction.

While geologically mapping portions of Damaraland and the adjoining Namib desert, the senior author collected a number of water samples along the Swakop River from source to mouth. The samples were mainly obtained from shallow pits and wells sunk in the sand-filling of the dry river-bed.

The purpose of these investigations was to determine by analysis the nature of the gradual increase in salinity of the sub-surface water in the Swakop River on its way to the sea.

All samples were analysed by Mr. J. P. van der Westhuyzen in the laboratory of the Mines Department of the South-West African Administration at Windhoek.

The analyses are herewith presented in table form, together with a discussion of the results. A description of the drainage basin of the Swakop River, and a discussion of the general climatic conditions of the region traversed by it on its way to the sea, is also appended.

Drainage Basin of the Swakop River.

With the exception of the rivers forming its boundaries in the south, north and north-east (Orange, Kunene and Okavango), South-West Africa possesses no perennial streams. There exist, however, a number of dry river-beds of considerable size that flow intermittently during the rainy season, generally for not more than a few days at a time.

The bulk of these rivers is situated in the central portion of the territory, draining the region of higher rainfall between Windhoek and Otavi.

The Swakop River (Nama=Tsoachob) is one of the most important of these.

The head streams of the Swakop River rise in the Windhoek Highlands, the Ovitoto and Otjozonjati Mountains, representing the eastern extension of the Khomas Highlands, the most highly elevated tract of the whole territory (6,000—8,000 feet).

The total length of the Swakop River from source to mouth is approximately 230 miles. (See attached map.)

As far west as Ukuib, the river flows in a more or less open valley, through mountainous and hilly country. From its junction with the Gamikaub River westwards, i.e., in the arid tracts of the Namib desert, it enters a rocky gorge, incised to a depth of approximately 800 feet into the surrounding Namib plain.

The Swakop canyon opens out again between Birkenfels and Richthofen, some 15 miles from the sea.

Nature of Infilling.

Everywhere from Okatjemisse onwards the bed of the river is filled to a considerable depth with grit and sand, interspersed with gravel layers. These porous sediments hold considerable quantities of sub-surface water at shallow depths.

The actual channel is generally more than a hundred yards, in places even several hundred yards wide. On either side of it there generally occur strips of alluvial silt of varying width.

Rainfall.

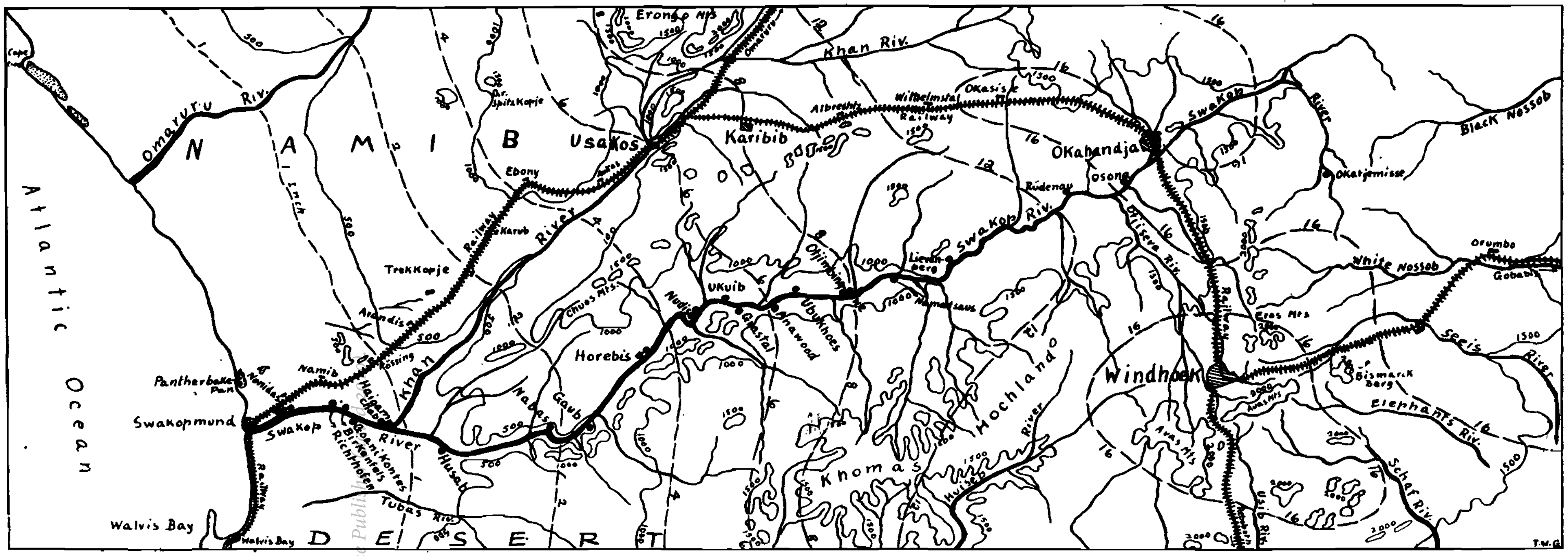
The rainfall over the interior uplands is considerable, that over the Windhoek Highlands, Ovitoto and Otjozonjati Mountains, the source region of the Swakop River, being 15-16 inches per annum. The bulk of the precipitation takes place during the months of January—March.

The rainfall rapidly drops in a westerly direction, and in the area of Otjimbingwe, some 100 miles to the west, it is only 7-8 inches. (See attached map.) Here begins the transitional zone gradually merging into the Namib desert. The rainfall in the transitional belt is low and erratic.

Still farther west the rainfall rapidly recedes to practically nothing, the Namib desert here being 80-90 miles wide.

The actual coastal belt is practically without any rain at all. Records over 20 years give the average annual rainfall at Swakopmund as 0·64 inches. This moisture, however, is almost entirely derived from mists, which enshroud this portion of the coast, swept by the cold Benguella current, for the greater part of the year. These mists carry considerable quantities of salt far into the Namib.

Depending on the amount of precipitation in the interior, the run-off water travels for varying distances down the dry river-bed. Extensive and prolonged rains in the interior uplands are necessary before the water penetrates right through the Namib desert as far as the mouth. Normally the latter is closed from the sea by a sand-bar.



Map showing Drainage Area of Swakop River. Scale 1 : 1000000.

Contours in metres. _ _12_ _ Normal rainfall curves in inches.

● Pits, wells and open water in bed of Swakop River from which water for analysis was obtained.

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When sufficient water has accumulated behind the sand-bar, it breaks through into the sea, the accumulated débris being carried northward by the Benguella current. Normally this happens only a few times a year. When, however, during the abnormal rainy season of 1933-34, following on five years of drought, the river flowed almost uninterruptedly for close on five months, such was the scale of soil erosion in the parched interior uplands, that the shore north of the mouth at Swakopmund was built out to sea by sand and débris for a distance of approximately 1½ miles.

Sub-surface Water.

In spite of the comparative rarity of flowing water in the Swakop River, there is a considerable sub-surface flow in the porous sediments filling the bed all the way down to the coast. Where a ledge of harder rock, such as a dyke, etc., forms a sub-surface barrier, or where the river-bed suddenly becomes markedly attenuated, either in width or depth, the pore-space in the sand-filling may no longer be sufficient to hold all percolating water. It then rises to the surface to form a natural waterhole or even a flowing stream of water, which after varying distances again disappears in the sand.

All along the Swakop River, from Okatjemisse to the sea, water can be obtained at shallow depths, varying from just below the surface to a depth of 10-12 feet.

This ready supply of abundant sub-surface water has been utilised by a number of farmers, mainly between Richthofen and Haigamchab, water for irrigation being pumped from shallow, wide-diameter wells sunk in the bed of the river. Most of these farms were swept away by the floods of 1933-34.

The salinity of the water on the farms mentioned varies from 136 to 282 parts per 100,000, and yet rendered the cultivation of most types of vegetables possible.

Vegetation.

Large trees are found all along the Swakop River from beyond Okatjemisse as far west as Husab, some 30 miles from the sea. In the upper reaches of the river, as far down as Gross Barmen, i.e., on the colder highlands, *Acacia giraffae* and *Acacia horrida* are the most abundant. From Gross Barmen (altitude 4,000 feet) westwards their place is taken more and more by the Ana tree *(Acacia albida)*. From Gaub westwards large trees become more sparing, but are still found at Husab. They then become more isolated and smaller, and gradually disappear, with only occasional stragglers as far west as Birkenfels, some 16 miles from the sea. In this region the Tamarisk *(Tamarix austro-africana)* is quite abundant along the river banks.

The main factor in determining the gradual reduction of the larger trees does not appear to be a decrease in sub-surface water or its increase in depth, water being quite abundant at shallow depth, but a marked increase in the salinity of the water, the latter now having risen to over 100 parts, and at Richthofen to over 200 parts per 100,000. In addition, the cooler temperatures of the immediate coastal belt begin to make themselves felt in this region.

Gradual Increase of Salinity from Source to Mouth.

The sub-surface water on its way down to the sea traverses regions of progressively increasing aridity. From Otjimbingwe westwards very little water is contributed to the main channel by tributary streams, though an important addition is made by the Khan River at Haigamchab.

With the exception of the immediate coastal belt, a few miles wide, and enshrouded in mist for long periods, the humidity of the air is excessively low over the desert tract throughout the whole year. In the interior uplands the humidity of the air is also negligible during the dry winter months from April to November. Conditions for evaporation are therefore at an optimum.

As evaporation on the surface by capillarity proceeds, the salinity of the sub-surface water should progressively increase. Added to concentration by evaporation is the solution by the ground water of soluble materials in the sediments and rock floor within, and over which it percolates.

In addition, considerable quantities of salt are being carried far into the Namib, but particularly into the immediate coastal belt, by salt-laden mists that enshroud the coast for the greater part of the year, and often travel far inland.

Finally, tertiary lagoon-sediments, dissected by the Swakop River in its lower course between Goanikontes and Nonidas, and now outcropping high up on the edges of the canyon, contain layers of salt and gypsum. The immediate coastal tract still farther west was evidently submerged beneath the sea in late tertiary times, there being remnants of quite recently elevated marine shingle terraces at elevations up to 20 feet along the coast to the north of Swakopmund. Within this tract there exist a number of salt pans, mostly along the shore; a few are also situated several miles inland.

All these factors combine in yielding the higher salinity of the sub-surface water in the Swakop River actually observed in the coastal belt.

In the following table 36 analyses are arranged in order of sequence from source to mouth. A list of localities is also appended. For comparison an analysis of concentrated natural brine from the Panther-Beacon pan, four miles north of Swakopmund, is also given.

The samples were taken in the winter months, several months after the river had last come down in flood. From each area the bulk were collected over as short a period as possible. The conditions at the various localities were therefore comparable.

TABLE OF ANALYSES OF SUB-SURFACE WATERS IN THE SWAKOP RIVER—BY J. P. v. d. WESTHUYZEN.

	Very Low Salinity: 8—25					Low Salinity: 25—100 parts per 100,000												
Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Total Solids per 100,000 ...	11·6	8·8	18·0	24·0	10·4	32·8	71·2	32·4	42·0	48·4	71·2	70·8	40·8	72·4	74·8	164·0	60·4	72·4
Organic and Volatile Matter ...	0·2	0·3	1·9	0·3	0·3	2·3	0·7	0·9	1·0	2·0	2·1	9·0	2·3	11·1	5·8	3·8	0·1	2·0
Suspended Matter	0·5	—	—	—	trace	trace	6·3	0·2	trace	trace	—	—	—	—	—	—	—	—
Silica (SiO_2)	1·2	1·0	0·8	1·5	0·8	1·4	2·7	1·4	1·8	1·7	1·1	6·4	0·5	8·2	0·6	0·8	1·9	2·0
Iron Oxide (Fe_2O_3) and Aluminium Oxide (Al_2O_3)	0·6	0·5	0·4	0·5	0·5	0·4	0·8	0·9	0·3	0·6	0·3	3·0	0·2	4·1	0·5	0·7	0·2	0·3
Calcium Oxide (CaO)	0·8	1·4	3·3	5·8	2·4	8·6	13·5	8·7	8·8	10·5	12·6	15·4	12·6	11·2	12·6	16·1	11·5	12·3
Magnesium Oxide (MgO) ...	2·1	1·5	1·3	2·2	1·2	2·0	4·4	2·7	4·0	4·6	3·3	5·3	2·9	5·0	5·0	9·1	3·8	4·8
Sodium Oxide (Na_2O)	2·3	0·7	3·4	3·4	1·0	4·1	17·7	4·6	8·1	8·2	20·4	8·4	4·4	9·6	17·2	54·2	15·3	19·0
Combined Carbon Dioxide (CO_2)	2·9	2·4	5·7	7·9	3·4	9·4	15·4	10·3	12·7	13·2	17·6	15·0	14·0	6·3	14·7	18·6	13·1	9·8
Sulphur Trioxide (SO_3)	0·8	0.5	0·8	1·9	0·7	3·4	5·9	1·3	2·6	3·5	2·8	trace	3·4	6·9	7·5	25·0	4·6	7·4
Chlorine (Cl_2)	0·9	0·7	0·5	0·7	0·5	1·9	13·0	2·1	3·5	5·3	14·2	10·9	0·9	13·3	14·2	46·1	12·3	19·3
PROBABLE SALTS																		
Sodium Silicate (Na_2SiO_3) ...	1·8	—	—	—	—	—	3·5	1·6	2·0	1·8	—	10·3	—	13·2	—	—	2·0	2·4
Sodium Chloride (NaCl) ...	1·5	1·2	0·8	1·2	0·8	3·1	21·4	3·5	5·8	8·7	23·4	6·0	1·5	5·5	23·4	76·0	20·3	31·8
Sodium Sulphate (Na_2SO_4) ...	1·4	—	1·4	3·4	1·2	6·0	10·5	2·3	4·6	6·2	5·0	—	6·0	—	11·0	31·8	8·2	2·0
Sodium Carbonate (Na_2CO_3) ...	—	—	4·1	2·1	—	—	—	1·5	3·4	—	9·9	—	1·7	—	—	—	—	-
Magnesium Chloride ($MgCl_2$) ...	—	—	—	—	—	—	—	—	—	—	—	9·8	—	11·8	—	—	—	—
Magnesium Sulphate ($MgSO_4$)	—	0·8	—	—	—	—	—	—	—	—	—	trace	—	—	2·0	10·7	—	11·1
Magnesium Carbonate ($MgCO_3$)	4·4	2·5	2·7	4·6	2·5	4·2	9·2	5·6	8·4	9·6	6·9	2·5	6·1	-	9·0	11·5	7·9	—
Calcium Chloride ($CaCl_2$) ...	—	—	—	—	—	—	—	—	—	—	—	—	—	1·9	—	—	—	—
Calcium Sulphate ($CaSO_4$) ...	—	—	—	—	—	—	—	—	—	—	—	—	—	11·7	—	—	—	—
Calcium Carbonate ($CaCO_3$) ...	1·4	2·5	5.9	10·4	4·3	15·4	24·1	15·5	15·7	18·7	22·5	27·5	22·5	9·6	22·5	28·7	20·5	22·0

Medium Salinity: 100—200							Saline: 200—500						Medium		Saline		Highly Saline: over 500	Brine	
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	Number
144·4	308·0	77·2	118·0	167·2	148·0	136·0	282·0	413·6	326·4	329·6	340·0	385·6	167·4	185·6	230·0	357·2	673·5	34,293·0	Total Solids per 100,000
7·6	5·4	4·3	3·2	6·8	5·0	8·1	3·8	5·1	3·1	6·0	8·6	5·1	19·7	6·6	6·0	20·0	6·2	66·0	Organic and Volatile Matter
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	trace	—	133·0	Suspended Matter
2·6	3·9	2·7	2·4	0·9	2·9	2·2	3·5	3.6	trace	3·0	trace	trace	2·7	2.4	trace	3·0	2·9	—	Silica (SiO_2)
trace	0·5	0·3	trace	0·6	trace	trace	trace	trace	trace	trace	2·1	2·3	0·7	9·3	6·0	0·6	trace	—	Iron Oxide (Fe_2O_3) and Aluminium Oxide (Al_2O_3)
21·0	19·6	12·6	18·2	28·0	12·6	15·4	29·4	58·9	15·4	32·2	29·4	30·8	22·4	16·8	23·8	33·6	82·7	206·9	Calcium Oxide (CaO)
5·4	11·6	3·9	5·1	7·5	6·4	6·2	10·5	15·2	11·3	11·1	12·4	14·1	8·3	8·3	10·0	15·0	38·4	1,714·6	Magnesium Oxide (MgO)
41·2	121·9	19·8	34·4	44·7	52·7	40·6	109·5	129·8	137·6	120·9	122·7	145·8	41·4	57·9	75·3	123·1	216·9	15,476·0	Sodium Oxide (Na_2O)
13·0	17·0	7·8	13·1	15·5	12·8	3·8	16·7	17·3	14·1	18·1	9·1	17·9	5·9	14·7	17·6	27·2	40·6	trace	Combined Carbon Dioxide (CO_2)
20·9	29·2	7·5	14·2	23·2	18·3	18·5	27·0	43·6	32·7	27·1	29·7	38·1	17·3	14 8	20·0	26·0	40·4	1,377·5	Sulphur Trioxide (SO_3)
42·6	127·6	23·9	35·5	51·4	47·9	53·2	117·0	180·8	145·0	143·6	154·0	170·2	63·3	71·9	93·0	140·4	317·0	19,783·0	Chlorine (Cl_2)
																			PROBABLE SALTS
2·0	6·3	4·3	3·9	0·4	4·3	2·2	4·7	4·3	—	3·4	—	—	3·9	2·7	—	4·3	3·7	—	Sodium Silicate (Na_2SiO_3)
70·3	210·4	33·2	58·5	83·8	79·0	74·5	185·0	240·7	239·1	224·6	231·4	275·1	74·3	106·5	142·0	228·0	405·5	29,200·0	Sodium Chloride (NaCl)
6·4	16·3	—	3·2	—	19·7	—	—	—	24·5	—	—	—		—	—	—	—	—	Sodium Sulphate (Na_2SO_4)
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Sodium Carbonate (Na_2CO_3)
—	—	5·1	—	0·7	—	10·7	6·4	35·9	—	9·9	18·3	4.3	19·6	9·8	9·3	2·8	90·7	2,764·0	Magnesium Chloride ($MgCl_2$)
16·0	30·0	5·1	15·1	22·5	10·8	5·1	23·3	—	28·4	20·9	13·7	36·7	—	12·5	17·9	39·1	—	1,627·0	Magnesium Sulphate ($MgSO_4$)
—	3·3	—	—	—	5·9	—	—	—	3·8	—	—	—	—	—	—	1·5	—	—	Magnesium Carbonate ($MgCO_3$)
—	—	—	—	—	—	—	—	12·7	—	—	—	—	5·6	—	—	—	5·5	—	Calcium Chloride ($CaCl_2$)
11·4	—	7·0	4·1	13·9	—	25·7	19·6	74·1	—	22·4	46·6	23·3	29·4	11·1	13·8	—	68·7	502·0	Calcium Sulphate ($CaSO_4$)
29·1	35·0	17·3	29·5	37·8	22·5	8·6	38·0	39·3	27·5	41·1	18·2	37·8	13·4	21·8	32·3	60·0	92·1	—	Calcium Carbonate ($CaCO_3$)

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List of Localities.

No.			
1.	Okatjemisse	...	Well.
2.	Okahandja	...	Municipal Water Supply.
3.	Okahandja	...	Open water.
4.	Okahandja	...	Borehole.
5.	Osona	...	Well.
6.	Rüdenau	...	Well.
7.	Namatsaus	...	Open water.
8.	Otjimbingwe	...	Well on edge of river.
9.	Otjimbingwe	...	Well in Garden No. 1.
10.	Otjimbingwe	...	Well in Garden No. 2.
11.	Ubukhoes	...	Well in riverbed.
12.	Anawood	...	Well in riverbed.
13.	Grastal	...	Well in riverbed.
14.	Ukuib	...	Well in riverbed.
15.	Nudis	...	Well in garden.
16.	Nudis	...	Well near house.
17.	Horebis	...	Well No. 1.
18.	Horebis	...	Well No. 2.
19.	Gaub	...	Well.
20.	Nabas	...	Well in riverbed.
21.	Husab	...	Open water
22.	Haigamchab	...	Well in garden.
23.	Haigamchab	...	Well near house.
24.	Goanikontes	...	Well.
25.	Birkenfels	...	Well.
26.	Richthofen	...	Well.
27.	Nonidas	...	Well near dam.
28.	Nonidas	...	Well No. 1, north bank of river.
29.	Nonidas	...	Well No. 2, north bank of river.
30.	Nonidas	...	Well No. 3, south bank of river.
31.	Nonidas	...	Open water.
32.	Swakopmund	...	Municipal Water Supply.
33.	Swakopmund	...	Municipal Water Supply—Old well.
34.	Swakopmund	...	Municipal Water Supply—Tap in hotel.
35.	Swakopmund	...	Municipal Water Supply—New well.
36.	Swakopmund	...	Well near former railway bridge.
37.	Panther-Beacon Pan		Brine.

Discussion of Results.

(a) Progressive Increase in Salinity.—There is a progressive increase in salinity from the source region to the sea, with slight local variations. The relative proportion of the various salts, however, changes. The amount of soluble matter dissolved varies from 8·8 (Okahandja River, tributary of Swakop River) to 673·5 parts per 100,000 at Swakopmund, a few hundred yards in from the sea. The concentrated brine, however, from the Panther-Beacon pan, four miles north of Swakopmund, by comparison contains 34,293 parts per 100,000, or 34 per cent.

The waters in the source region, i.e., in the area of highest rainfall, are extremely soft and pure, the dissolved materials varying from 8·8 to 24 parts per 100,000. These soft waters extend downstream for some 50 miles away from Okatjemisse in the Otjozonjati Mountains, where the first sample was taken. The rocks, over which the water flows, are mostly biotite schists, to a lesser extent granite. The waters of this zone may be designated as being of very low salinity.

Then follows a stretch, some 120 miles long, characterised by waters of greater, yet still comparatively low salinity, dissolved salts being present from 32·8 to 74·8 parts per 100,000. No. 16, a well on Nudis, situated a few hundred yards away from the river bank, falls outside this category, and will be discussed later. These waters extend from west of Osona, with an average yearly rainfall of 13-14 inches, for some 120 miles downstream to beyond Horebis, in the interior portion of the Namib desert, where the rainfall is scanty and highly erratic. The average yearly rainfall given for this part of the country is 3-4 inches, but these figures are without much significance, since the rain falls episodically at long irregular intervals.

Then follows a section characterised by waters of medium salinity, varying from 118 to 148 parts per 100,000. This section is some 55-60 miles long, and extends throughout the entire length of the Swakop canyon as far west as Birkenfels, where the canyon opens out again. Two analyses in this group appear to be incongruous:- the narrow stream of flowing water at Husab, which is too low (77·2 p.p. 100,000), and falls into the preceding group, and the water from a shallow pit at Nabas, at the entrance to the Swakop canyon. The salinity of the latter is abnormally high (308 parts per 100,000), and falls entirely outside this zone into that of the succeding belt of saline waters. The reason for this high value is obscure.

Westwards then follows a stretch of saline waters from Richthofen to west of Nonidas, a distance of 11-12 miles. In this area the values of total dissolved solids show a marked increase, varying from 282 to 413 parts per 100,000, and in general more than double those of the preceding zone. This sudden increase in salinity is probably in part due to external influences. In this area there occur salt- and gypsum-bearing beds on both sides of the river, e.g., around Namib siding and on the southern bank of the river between Goanikontes and Richthofen. Furthermore, this is the coastal tract just outside the canyon, which, prior to the elevation of the sub-continent in late tertiary times, was submerged beneath the sea. A small saltpan occurs in this belt a few miles to the north.

In spite of the very restricted rainfall, the sub-surface water of the Swakop River in this zone, therefore, is most likely contaminated with salts from the outside, the increase in salinity over a short distance being too sudden to be accounted for by progressive evaporation. This deduction appears to be all the more plausible, since farther west, towards the mouth of the river (old wells and municipal water supply), there again intervene waters of medium salinity, varying from 167·4 to 185·6 parts per 100,000. These values are somewhat higher than most of those in the stretch preceding the saline zone, but yet considerably lower than the values characteristic of the latter.

Near the mouth, however, conditions appear to vary rather rapidly, for samples from the new well at Swakopmund (1930) and from a tap of the town water supply again proved to be rather saline. The water from the outermost well, situated a few hundred yards from the beach near the lagoon, is highly saline. The high salinity in this case appears to be due, partly at least, to contamination with sea-water seeping through the porous beach sand, particularly since Na_2O and Cl_2 show an abnormally sharp rise in this water. The latter, therefore, no longer represents pure river-water.

A further point brought out by the values for total dissolved solids is that in wells sunk in the river bed, or close to its edge, the salinity is generally lower than in closely neighbouring wells situated farther away from the actual stream-bed. Nos. 3 and 4, 15 and 16, and again 22 and 23, bring this out very clearly. The greater rate of percolation and greater quantity of solvent in the stream-bed no doubt is responsible for this feature.

(b) Organic and Volatile Matter.—This in general is least in the soft waters of the source region, where, moreover, the wells are invariably properly cased, and animals do not drink at the well itself. Organic matter is distinctly higher in the open pits and shallow wells owned by natives along the river bank, where small stock drink from troughs in the immediate neighbourhood of the well, the water being bailed out in buckets. Also in stagnant open waters the values are higher, primarily due to the vegetation growing around such pools.

In general, with widely fluctuating local variations, the values for organic and volatile matter increase towards the coast. While in its upper course the river is generally filled with dry clean sand and grit, in its lower course open pools, surrounded by vegetation, and even flowing water become more frequent, and various types of vegetation thriving in brackish water are often quite abundant, e.g., at Nonidas. Near the mouth the underlying lagoon sediments contain organic matter, and also gases, mainly H_2S. All the cut-off lagoons along this coast show the presence in pits of more or less thick layers of black mud underneath the surface sands and grit. Invariably the mud emits a strong odour of H_2S, this gas being produced by sulphate reducing organisms in stagnant lagoons and partially enclosed bays.

(c) Silica.—This in general is lowest in the pure soft waters of the source region. Towards the sea there is a slight increase, modified by local variations and erratic values. This increase is, no doubt, due to the fact that silica is appreciably soluble in alkaline solutions, sodium silicate being formed.

A remarkable feature is the fact that two samples (12 and 14) from Anawood and Ukuib, both shallow wells in the river bed below large Ana trees [with considerable numbers of small stock coming to drink every day], and showing abnormally high values for organic matter (9 and 11·1 parts per 100,000), also exhibit abnormally high values for silica (6·4 and 8·2 parts per 100,000).

It has been ascertained by Gruner that river and swamp waters, rich in organic matter, may carry considerable quantities of iron and silica. Humic acids, derived from vegetable matter, are said to decompose silicates. By a reaction between humic acids, ammonia and rockforming silicates, as well as quartz, a series of silico-azo-humic acids is formed, the alkaline salts of which are easily soluble. Azo-humic acids in the presence of alkaline carbonates are capable of dissolving silica. Even quartz may be corroded by this class of solvent. (Cited by F. W. Clarke: "The Data of Geochemistry," p. 83.)

(d) Al_2O_3 has been determined in small quantities in the very soft waters and those of low salinity. It was not found in the more saline waters. This seems to indicate that the small quantities are mainly present in collodial solution. A more appreciable concentration of electrolytes evidently leads to its coagulation and removal from the sub-surface water.

(e) Fe_2O_3.—This is present in small quantities again mainly in the soft waters and those of low salinity. The reason for its more sparing presence in the saline waters is probably the same as for Al_2O_3.

The two wells from Anawood and Ukuib (12 and 14), containing abnormally high values for organic matter, and already mentioned in connection with silica, also show abnormally high values for Fe_2O_3. It has already been stated that river and swamp waters rich in organic matter may carry large quantities of iron and silica. It has been shown by experiment, that as much as 3·6 parts per 100,000 of ferric oxide can be held in colloidal solution by 1·6 parts per 100,000 of organic matter. (Moore and Maynard: "Solution, Transportation and Precipitation of Iron and Silica." Econ. Geol., Vol. 24, 1929, p. 299.) In addition various humic acids form soluble salts with iron.

The comparatively high iron values of certain waters from the Swakopmund municipal water supply (6-9·3 parts per 100,000) may again be due to admixed organic matter, though the samples showing highest values for the latter do not also exhibit the highest values for iron, or to the rusting of water pipes, saline water being more corrosive than soft water.

(f) CaO shows a progressive increase, with local variations, towards the coast. The exceptionally high value for Nonidas (27) may be due to contamination from gypsum layers occurring in this neighbourhood, or the presence of marble bands in the rock-floor of the river. Since the values for CO_2, however, are not abnormal, the high CaO values are probably due to the former cause. The comparatively high values near the mouth of the river (35 and 36) are probably due to both causes, since CO_2 here shows an increase. A number of outcrops of limestone occur in the river bed near the mouth. Gypsum is abundant in all lagoon sediments along the coast.

The somewhat higher value of CaO of the well at Nudis, some distance away from the river bank (16), is probably to be explained by the increased total salinity generally observed in wells situated in the river sediments some distance away from the actual stream-bed. Incidentally this well is situated at the foot of a marble ridge. The other salts, chlorides and sulphates, however, also show higher values, indicating increased evaporation, reduced volume of solvent and lower rate of percolation to be the main factors involved.

In the waters of the source region of very low salinity, and generally also in most waters of somewhat higher salinity as far west as Ukuib, i.e., for more than half its course down to the sea, CaO is generally the most abundant base present, exceeding MgO and Na_2O. West of Ukuib it becomes rapidly subordinate to Na_2O. This feature, of course, is due to the relative insolubility of calcium salts compared with those of sodium. Considerable quantities of the former are precipitated along the upper course of the river to form thin crusts of surface limestone or of lime-cemented sand. The highly soluble sodium salts, on the other hand, remain in solution and become progressively enriched in the sub-surface water. In addition, considerable quantities of NaCl are carried far into the Namib by the mists already referred to, and in the coastal tract there occur layers of rock salt, and, near the sea, lagoon sediments.

(g) MgO shows a progressive increase towards the sea, with local variations. Its highest values are found at the mouth, where contamination probably takes place with sea-water seeping through the sandbar. The magnesium salts may partly also be derived from lagoon sediments and the salt-laden mists that enshroud the coast for the greater part of the year. Except in the very pure waters of the source region, where it occasionally equals, or is in excess of CaO, MgO is generally present in considerably lesser amounts than CaO. In the brine, however, from the Panther-Beacon pan (57), MgO is more than eight times as abundant as CaO, due to the great solubility of its salts, which remain in solution long after all $CaCO_3$ and $CaSO_4$, and even after most NaCl has been precipitated on evaporation.

(h) Na_2O exhibits a steady increase, with local variations, towards the coast. In the source region as far west as Ukuib, it generally occurs in lesser quantities than CaO, but for the last hundred miles of the river's course it is in considerable, gradually increasing excess over CaO.

The reason for this has already been discussed in connection with CaO. The sudden increase in salinity from Richthofen to beyond Nonidas has also been explained as probably being due to contamination from various sources of salt occurring in this area. The sudden jump in the farthest well at the very mouth of the river (36), is no doubt to be explained by contamination with sea-water percolating through the sand-bar or from salt-bearing lagoon sediments.

In the brine Na_2O is, of course, the predominating base.

(i) Combined CO_2 in the pure waters of the source region is greatly in excess of both SO_3 and Cl_2, showing that the bases mostly occur as carbonates. This condition is maintained, with local variations, as far west as the beginning of the Namib desert

(Ukuib-Nudis, 14-15), when Cl_2, and somewhat later also SO_3, begin to predominate.

(j) SO_3 is subordinate to CO_2 in the pure waters of the source region, and also in those of somewhat higher salinity as far west as the beginning of the Namib (Ukuib, 14). For a further distance, as far west as Horebis (18), it fluctuates, sometimes being still lower than combined CO_2. From Gaub (19) onwards, however, it is generally present in considerable excess over CO_2. It is highest in the region between Richthofen (26) and Nonidas (31), where, as already explained, beds of gypsum ($CaSO_4$ $2H_2O$) occur in the neighbourhood. It then falls again, and near the actual mouth combined CO_2 and SO_3 appear to be present in almost equal proportion (34-36).

(k) Cl_2, as already explained, is subordinate to CO_2, and generally also to SO_3, in the pure waters of the source region. It then begins to increase until from west of Rüdenau onwards it invariably exceeds SO_3 (with one exception: 13). From Nudis—Horebis (15-17), westwards, it begins to exceed combined CO_2, and from Gaub (19) onwards completely overshadows the latter. The reasons for this progressive increase in chlorides, mainly of sodium, have already been discussed; also the cause of the sudden rise from Richthofen to Nonidas, where salt-bearing sediments occur in the surroundings traversed by the Swakop River.

Comparison with Waters from Boreholes in the Interior.

The sub-surface waters of the Swakop River may be classed as good and useful for domestic and agricultural purposes as far down as the end of the canyon at Birkenfels, i.e., as far as the formerly submerged salt-bearing coastal tract. With one exception (Nabas, 20), all samples up to this point have dissolved materials less than 150 per 100,000. Also the water of the Swakopmund municipal water supply, mostly containing less than 230 parts per 100,000, is quite potable and suitable for consumption. When compared with many inland boreholes it is by no means particularly saline.

In the artesian area of the Auob-Nossob rivers, near the Bechuanaland border, many waters contain as much as 400 parts of dissolved substances per 100,000, 164 parts being Na_2SO_4. In the Maltahöhe district a borehole yielded water containing 346 parts per 100,000, and certain wells near Kanus 674 parts per 100,000. Another borehole in the same district even gave 907 parts of dissolved substances per 100,000. A content of 225 parts per 100,000 is by no means uncommon in the southern interior portion of South-West Africa. (J. Cock: "The Composition of some Water Supplies in S.W.A." *Jour. S.W.A. Scientif. Soc.*, 1926-7, Vol. II., p. 67.)

On the other hand, water from certain boreholes south-east of the Waterberg, in the northern part of the territory, only contained 40-57 parts of dissolved substances per 100,000, as determined by J. P. van der Westhuyzen.

COMPARISON WITH SURFACE WATERS OF FLOWING RIVERS.

	Parts per 100,000.
St. Lawrence River, Montreal, Canada ...	16
Mississippi River, Minneapolis	20
Amazon River, Obidos	3·7
Thames (average)	27
Danube, Regensburg	20·4
Rhine, Cologne	17·8
White Nile, Khartoum	17·4
Nile, Cairo	11·9
Vaal River	20-40
Klip River	17-29
Mooi River, Transvaal	27-57
Crocodile River	10-23
Pienaars River	137·6
Great Oliphants River	14-20
Buffels River	154·3

ABSTRACT.

The Swakop River is an intermittently flowing stream draining the interior uplands of Central South-West Africa, where the average annual rainfall reaches a maximum of 16 inches. On its 230 mile course down to the Atlantic Ocean it traverses progressively more arid tracts, the last 100 miles of its course being through the Namib desert, where rainfall is very scanty, or even absent in the immediate coastal tract.

The Swakop River only contains flowing water after extensive rains in the interior uplands. Throughout the greater part of the year the river bed, filled with sand, gravel and grit, is dry. Sub-surface water, however, is abundant, and can be obtained at shallow depth.

Thirty-six analyses of sub-surface water of the Swakop River, from source to mouth, are provided and discussed.

There is a gradual progressive increase in salinity of the sub-surface water, the water in the source region being very pure and soft, that in the lowermost course saline. In the coastal tract the sub-surface water is probably contaminated by salt from salt-bearing lagoon sediments occurring in this area.

As far as the edge of the Namib desert CaO is the most abundant base, and CO_2 the most common acid radicle, the preponderating salt being calcium bicarbonate. Na_2O and MgO, as well as SO_3 and Cl_2 gradually increase, until in the interior portion of the Namib desert they predominate, and finally completely overshadow calcium bicarbonate. In the last 100 miles of the river's course NaCl is greatly in excess of any other salt.

The quantity of total solids in solution varies from as low as 8·8 parts per 100,000 in the source region to 673·5 parts per 100,000 near the mouth.

Certain waters showing an unusually high content of organic matter also exhibit abnormally high values for combined silica and iron. The reasons for this feature are discussed.

The sub-surface waters of the Swakop River are compared with those obtained from boreholes in the interior, and with flowing waters of various rivers, both in and outside South Africa.