The Occurrences of Salt in the Swakopmund Area, South-West Africa.

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By T. W. Gevers, M.A., Dr.Phil., and J. P. van der Westhuyzen, M.Sc.

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Introduction.—The following notes are intended to serve as a brief description not only of the actual deposits of rock-salt and occurences of high-grade brine in the Swakopmund area from an economic point of view, but also of the younger and recent history of that portion of the coast of South-West Africa. In a country where ranching and the production of skins will always play an important rôle in its development, a supply of cheap salt of good quality, both as a lick and for curing skins, is essential and it is to be hoped that in the future the vast supplies of rock-salt provided by South-West Africa itself will be drawn upon to a greater extent than has hitherto been the case.

Apart from their commercial possibilities, the study of the most youthful deposits along the present shore also throws interesting light on the physico-chemical process of salt-precipitation.

Types of Occurrences.—There are two main types of occurrences to be dealt with: (I) Older, stratified rock-salt, interbedded with youthful deposits covering the coastal plain of the Namib, and elevated about 350 M. above sea-level; (II) rock-salt and brine associated with pans. The latter type may be sub-divided into (*a*) pans situated away from the present shore, and (*b*) pans situated along the present shore-line and, to some extent, still in communication with the sea.

(I) *Older, Stratified Rock-salt*.—Before describing these occurrences it is necessary to discuss briefly the morphology of the coastal plain of the Namib and the youthful sediments covering it.

Below the escarpment of the Khomas Highlands the surface of the Namib forms a wide plain, approximately 140 Km. (87 miles) wide south of the Swakop, and gradually sloping towards the sea. Below the escarpment its height is about 1,100 M. above sea-level; 35 miles from the sea it is still 440 M. The 100 M. contour in the coastal strip between Walvis Bay and the mouth of the Omaruru River runs 8-10 Km. from the shore inland. The plain, however, is not an absolute one. Particularly in the area between and around the lower Khan and Swakop Rivers, it is surmounted by numerous ridges, hills and kopjes of the Inselberg type. The most conspicuous of these are formed by the Quartzite and Marble series of the Damara system, and by numerous diabase dykes of probable Karroo age. In the area just south of the Swakop River, the Marble Series forms quite a number of very prominent hills and ridges, and is of remarkable persistence. As already pointed out by Wagner,[1] this would certainly not be the case if the Namib plain had been formed by marine planation, as is maintained in some quarters.

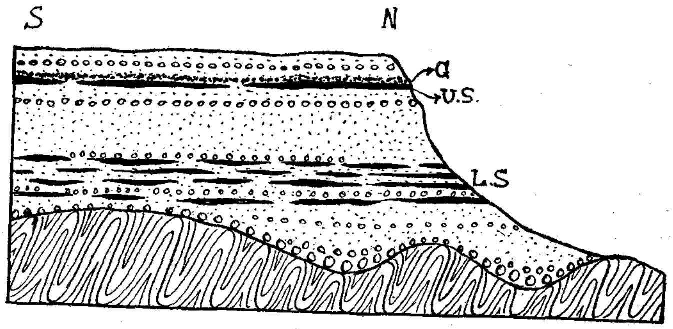
The plain is covered by all manner of surface-deposits typical of weathering under arid conditions. Around the lower Khan and Swakop Rivers, however, definite terraces of fluviatile gravels and grits are met with. Between Haigamchab and Nonidas they form an almost level plateau, cut into by a number of dry rivulets, and overlooking with precipitous cliffs the canyon of the Swakop River, 200 M. deep. The beds consist essentially of lime-cemented felspathic grits with a large number of conglomeratic layers and numerous isolated pebbles. The bulk of the enclosed pebbles are typically riverworn and well rounded. A minority are flat and angular. The thickness of these youthful sediments is very irregular. They were laid down over an uneven surface. They fill depressions and overlap prominences, where they generally contain large rock-fragments and rubble derived from the latter. All this is practically proof against the marine origin of these beds, as maintained by Voigt and Reuning,[2] but contradicted by Wagner (*loc. cit.*, p. 72). The maximum thickness of the beds at a cliff overlooking the Swakop canyon between Birkenfels and Goanikontes is 20-22 M., their average thickness about 15-16 M. No fossils of any kind have so far been found in them.

The Salt occurs interbedded with these sediments in several horizons. There is an upper horizon situated about 2½ M. below the top of the plateau. Here the salt is generally associated with a fair amount of gypsum, the bulk of which overlies the rock-salt in irregular lenses, sometimes 50 cm. in width. The gypsum is fibrous and built up of long, narrow needles arranged with the longest axes at right angles to the stratification. The rock-salt in general immediately underlies the gypsum, though sometimes narrow lenses of grit separate the

[1] Wagner, P. A.: "On Some Mineral Occurrences in the Namib Desert." *Trans. Geol. Soc. S.A.*, Vol. 24, 1921, p. 72.

[2] Reuning, E.: "Gediegen Schwefel in der Küstenzone Südwestafrikas." Centralblatt für Min., etc., 1925. Abt. A., No. 3, p. 83.

two. It presents a columnar structure at right angles to the bedding. The thickness of this upper band of rock-salt varies within wide limits. Thicknesses between 18 and 31 cm. have been measured over several miles. There is little doubt that in the case of all bands of rock-salt, particularly in the case of the lower ones, we are dealing with lens-shaped bodies. The band of the upper horizon is in general not only the thickest, but also the most persistent and uniform.



Pebbly Grits with Conglomerate Layers.

Fundamental Complex.

G U.S. Upper Salt-Horizon with Gypsum-Layer

L.S. Lower Salt-Horizon.

FIG. 1.

Section through salt-bearing sediments of Goanikontes Area.
Vertical scale: 1 cm. = 10 metres.

The lower salt-horizon consists of at least four separate horizons (*vide* section), which begin about half-way down the thickness of the beds, the uppermost being about 7-8 M. below the upper horizon, and are spread over a thickness of 4 to 6 M. The height of the lowest band above the base of the sediments varies with the configuration of the floor. The lens-shaped nature of the layers of salt is far more pronounced in the case of these lower bands, which do not appear to be very consistent individually. The thickness of the individual lenses is very changeable, and varies from 0 to 30 cm. In general, 15-20 cm. would be representative for many lenses. Gypsum appears to be not as marked in these lower horizons as in the upper. The rock-salt is of the same type and quality.

The Quality of the Rock-salt is excellent, and the latter represents a high-grade article. When fresh, it is crystalline, columnar, pure white and brittle, which makes its excavation very easy. The admixed insoluble material is very low, practically negligible. No layers of dark mud-stone were seen associated with any of the layers of rock-salt, as is the case in the present lagoons near the shore. On the contrary, the salt rests immediately on very coarse pebbly grits. The analysis of a representative specimen from near Goanikontes gave the following results:—

	%
NaCl	98·42
$CaSo_4$	0·54
$CaCl_2$	0·24
MgO	Nil
K_2O	Nil
Moisture	0·31
NO_3	Nil
Insoluble matter	0·46
	99·97

The rock-salt is therefore of very pure, high-grade type.

The Economic Possibilities of these occurrences of rock-salt, in spite of the excellent quality of the latter, are meagre. Although the extent of the deposits is considerable (between Haigamchab and Richthofen they outcrop over a distance of 12-15 Km.), nevertheless the very low thicknesses of the individual bands and the fact of their being interbedded in horizontal strata, representing an enormous overburden, make exploitation on a commercial scale impossible. As a source of very cheap salt of good quality to the adjoining farmers in the Swakop river-bed and the natives employed by them, these occurrences have proved useful for a long time, and will continue to do so in the future. On the northern side of the Swakop similar deposits have been reported from a point below Haigamchab, and also from Namib Siding. Further, according to Voigt, rock-salt has been found interbedded with similar deposits away to the south, near Kipneus and Ururas, on the lower Kuiseb River. But everywhere the layers of rock-salt are very narrow.

Mode of Deposition.—A variety of facts has already been adduced to show that the Namib plain was not formed by a marine transgression, and that the pebbly grits and conglomeratic layers making up the youthful plateau sediments are not of marine origin, as held by Voigt and Reuning (*loc. cit.*), in spite of the occurrence of salt and gypsum in them. A further point emphasizing this is the fact that the gravels become coarser, and the pebbles still more abundant in an inland direction towards the Langer Heinrich. There is no doubt, however, that formerly the niveau of the plain in general was much lower, and the area now marked by the occurrence of salt and gypsum lay practically at sea-level. This involves a rise of the coast since that time of over 300 M., approximately 350 M.

From all the evidence available, it appears that at the time of deposition of the salt there existed a low, wide plain below the escarpment possessing arid conditions of climate, and formed mainly by aeolian erosion and sheet-flood action, as already suggested by Wagner (*loc. cit.*, p. 72). The uniform and level fluviatile plateau-gravels around the Khan and Swakop Rivers, and their very wide distribution away from the present river courses, prove that the Khan and Swakop Rivers at that time did not flow in well-established channels, but meandered over a very wide level area, or rather, more probably, changed their shallow channels very frequently with each "coming down" in flood, and in this way spread a thick sheet of grits and river gravels over a wide area.

The region of salt deposition no doubt represents an old lagoon in the shallow river depression near or at its mouth. Reuning, in his paper on the occurrence of native sulphur near Birkenfels (*loc. cit.*, p. 93), considers the sulphur to have been formed from the pyrrhotite, which it accompanies, by reduction under stagnant lagoon conditions. Under the present arid conditions of weathering, sulphur is no longer produced. At various localities along the coast, however, native sulphur is still being formed at the present day, but only in places where the water is stagnant and possesses reducing properties, as at Walvis Bay, Conception Bay, and numerous lagoons along the coast. Since now the occurrences of native sulphur near Birkenfels and Richthofen are overlain by the youthful plateau-sediments with salt and gypsum, there is little doubt that Reuning's conclusion is correct.

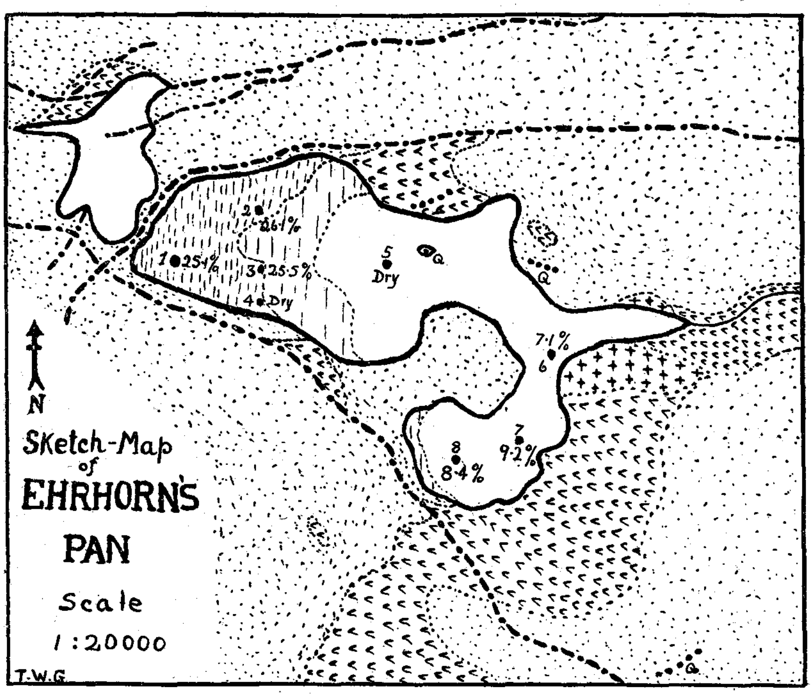
The question now arises whether the lagoon or lagoons were formed by sea-water being cut off from the ocean by a sand-bar, as most of the lagoons along the present shore, or whether the salt was precipitated from an originally fresh-water lagoon fed by the Swakop and Khan Rivers. An important point in this connection is the fact that in the upper salt-horizon, the only one apparently which shows gypsum in any appreciable quantity, the latter overlies the salt and not *vice versa*. The salt lies directly on pebbly grits and is followed by gypsum lenses separated by the same pebbly grits. No remains of the black mud associated with the salt and brine in the lagoons along the shore were seen anywhere. Since in the evaporation of sea-water gypsum is deposited long before the salt begins to be precipitated, and since all fossil salt deposits formed in this way show a bottom layer of gypsum or anhydrite, the latter of the two alternatives was probably the one obtaining. It must be remembered in this connection that the frequent mists along this coast carry large amounts of salt far inland.

During the gradual rise of the coast, the Swakop River slowly cut its bed down through its own deposits and the underlying Fundamental Complex until, now at Goanikontes, the bottom of its bed is situated 200 M. below the plateau on either side. All along the river there are numerous remnants of river-terraces. At the mouth of the Swakop itself, there are outcrops of consolidated river-gravels and boulder beds on its northern bank. These beds were deposited when the basis of erosion of the Swakop lay considerably higher and the gradient of the river-bed was still steeper. The dip of the falsebedding in these sediments indicates that at the time of their deposition the actual river-bed was situated somewhat more to the north, *i.e.*, towards the town.

Rock-salt and Brine Occurring in Pans.—At several localities along the shore between Swakopmund and Cape Cross there are pans and cut-off lagoons, large and small, and greatly differing in their content of salt and brine. While most numerous along the actual shore, there are several, generally small pans, situated some distance away from it. Since the latter present somewhat different features, they will be treated separately. The most important from an economic point of view is Panther-beacon Pan.

(*a*) *Pans situated away from the present shore: Ehrhorn's Pan.*

This pan is situated 10-11 miles by road from Swakopmund, and NNE. of the latter town. Namib railway siding is six miles away. It



Garnetiferous Gneiss and Mixed-Rocks.

Red Granite.

Rock-Débris, Desert-Rubble and Sand.

Main Distribution of Workable, Slab-Rock-Salt.

Main Distribution of Impurer, Thinner Rock-Salt.

Diabase Dykes (probably of Karoo age).

Quartz-Veins.

3•25·5 % Percentage of NaCl of Brine from Pits.

FIG. 2.

is not a large pan, and rather irregular in shape. Its dimensions and form are best gathered from the accompanying map. Its total length is about 1 mile (1·6 Km.), and its maximum width about 600 M. Its situation has been determined by the inter-section of two long diabase-dykes, which form prominent ridges. The country rock is mainly a massive biotite-garnet-gneiss, with some schistose mixed-rocks and subordinate red granite intrusive into the former. The major portion of the surroundings, however, is sand- and débris-covered.

The main value of this pan to-day lies in the rock-salt still covering a portion of the lower pan. The pan as a whole is comparatively shallow, and the sediments filling it are not deep. The pits dug on the lower pan show an average depth some distance from the sides of 0·8 M., when the solid rock floor appears. The sections exposed show a surface crust of rock-salt of varying thickness, attaining an average of 20-25 cm. in that area of the map marking the distribution of payable surface rock-salt. Below the layer of rock-salt there generally follows sand impregnated with salt. In the lowest corner of the pan, however, in the vicinity of Pit No .1, there is a continuous thickness of compact rock-salt of 0·9 M., while the surface salt (25-35 cm.) is slablike and well jointed, and on this account easy to work. The lower salt is exceedingly tough and compact, and excavated only with great difficulty. The brine, since it practically stagnates in rock-salt or sand highly impregnated with salt everywhere in this lower portion of the pan, is highly concentrated (average 25·6 per cent. NaCl). Its depth, however, is low, only 15-20 cm. at present . It must be remembered, of course, that no rain worth speaking of has fallen in this coastal area since 1925. An addition of rain-water would not only raise the level of the brine, but also temporarily dilute it. The solid rock-salt is, however, in too great an excess to allow of any prolonged dilution. Each influx of rain-water is also responsible for a further addition of salt, particularly since the plateau to the east is covered by the salt and gypsum-bearing strata just described.

The reserves of easily workable surface rock-salt in this lower portion of the pan are about 11,000 tons at a moderate estimate. If the present state of affairs be taken as normal, the available brine approximately contains another 10,000 tons of salt. If pumped dry, a strong downpour would soon supply more high-grade brine. Samples of rock-salt and salt produced by natural evaporation of the brine gave the following results on analysis, which show both to be of good quality:—

ANALYSIS—ROCK-SALT.

	%
NaCl	92·43
$CaSo_4$	3·89
$CaCl_2$	2·79
MgO	Nil
K_2O	Nil
No_3	Nil
Moisture	0·92
Insoluble matter	1·26
	101·29

ANALYSIS—SALT PRODUCED FROM BRINE.

	%
NaCl	96·90
$CaSo_4$	2·18
$CaCl_2$	0·21
MgO	Trace
K_2O	Nil
NO_3	Nil
Moisture	1·39
Insoluble matter	0·18
	100·86

(Sample taken from salt deposited in initial stage of precipitation.)

The upper (Gossow's) portion of the pan does not now contain any rock-salt worth speaking of. Its depth is somewhat greater than that of the lower pan, rock-bottom being struck at 0·9-1 M. in its more central parts. The concentration of the brine is rather low (average 8·2 per cent.), as the map shows.

Apart from the recovery of rock-salt from its lower portion, this pan, when compared to that now to be described, cannot be said to be very valuable.

(*b*) *Pans situated along the present shore.*

1. *Panther-beacon Pan.*

General Description (*vide* map).—The lower (southern) end of this pan is situated only 4½ miles by road from Swakopmund station. It forms a long elongate depression, 5 Km. (3 miles) in length, and mostly about 1 mile wide. It is separated from the sea by a narrow bar ±300 M. wide. Nowhere is there normally open water on any portion of the pan.

Needles of gypsum are to be encountered at numerous localities on the pan surface, particularly where the latter is sandy and there is no salt crust. No layers of gypsum, however, were found in any of the pits, no doubt due to the fact that deposition mainly takes place at the surface under the control of capillary action. The pits dug in the

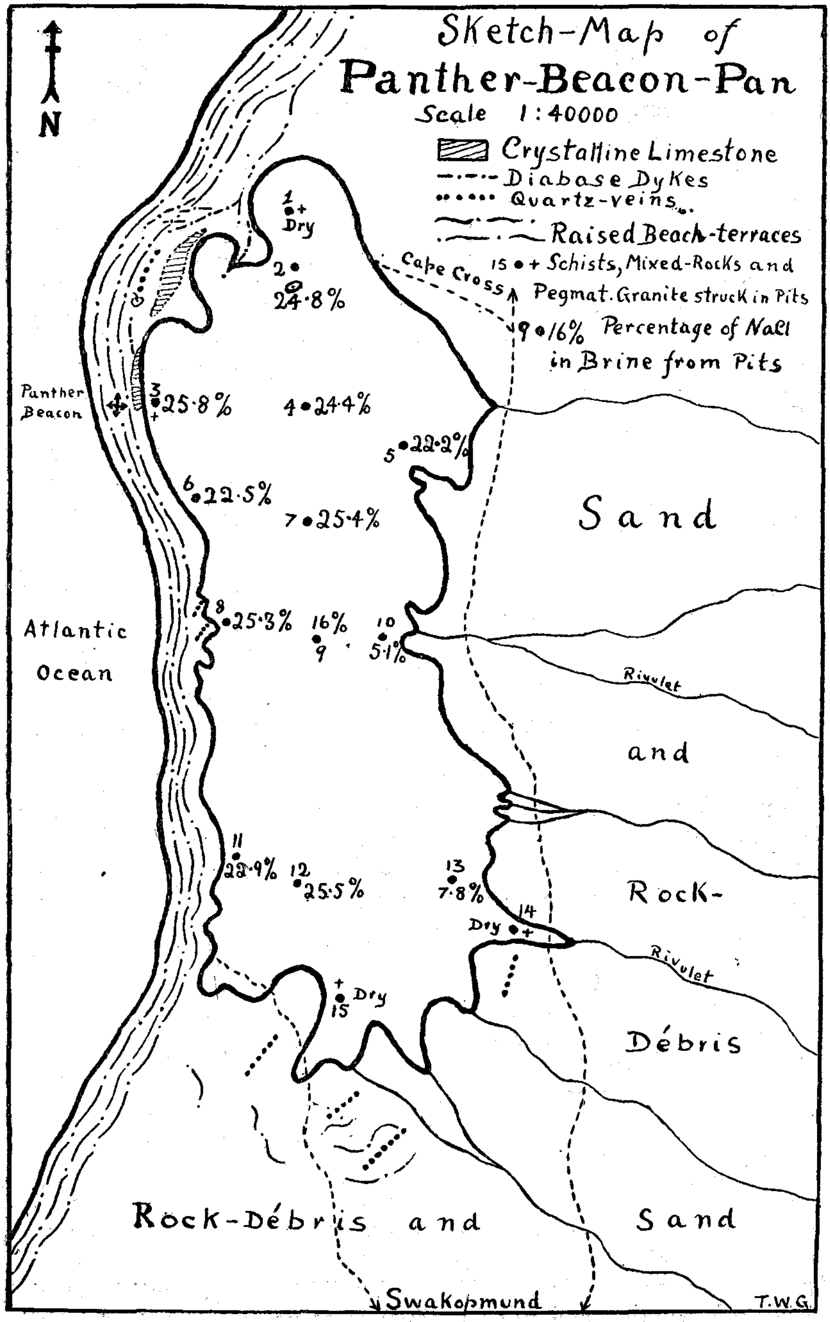

Sketch-Map of
Panther-Beacon-Pan
Scale 1:40000
Crystalline Limestone
Diabase Dykes
Quartz-veins
Raised Beach-terraces
15 • + Schists, Mixed-Rocks and Pegmat. Granite struck in Pits
9 • 16% Percentage of NaCl in Brine from Pits
N
Cape Cross
Panther Beacon
Atlantic Ocean
1 Dry
2 24·8%
3 25·8%
4 24·4%
5 22·2%
6 22·5%
7 25·4%
8 25·3%
16% 9
10 5·1%
11 22·9%
12 25·5%
13 7·8%
14 Dry
Dry 15
Sand
and
Rock-
Débris
Sand
Rivulet
Rivulet
Rock-Débris and
Swakopmund
T.W.G.

FIG. 3.

pan (*vide* map) everywhere show a surface layer of fine yellow sand, usually possessing a salt crust and of a thickness varying from 0·2 to over 1 M. This surface layer is thinnest in the central area of the pan (0·2 to 0·4 cm.), and increases in thickness towards the margins. In the central portion it is followed by a thick, exceedingly tough black mud, generally micaceous and smelling of H_2S. On exposure to the air, the colouring matter, FeS, is oxidized, and the mud turns brown on the surface. The thickness of this mud gradually decreases outwards from the centre of the pan, where 1·5 M. were measured in Pit No. 2, to the sides, and near the northern, eastern, southern and north-western it disappears. It is followed by coarser sand, and, finally, grits, rock débris, and at a number of points along the actual margins rock-bottom was struck at depths varying from 0·35 to 1 M. The depth of sediments in the central portions of the pan is unknown. It is practically certain, however, that rock-floor here is well below sea-level. The surface of the pan can only be a few feet above sea-level at the most.

The Brine.—It has already been stated that no payable rock-salt is to be found anywhere in this pan. As a source of high-grade brine, however, the pan possesses great possibilities. The main supply of brine in the central portion of the pan is found in the grits and coarse sand underlying the mud. The brine in these layers is under pressure, and on penetrating the mud escapes upward with considerable force, generally accompanied by bubbles of H_2S. In the marginal areas, where the mud-layer has disappeared, the brine is also found in coarse sands and grits. Over the whole pan the brine at present rises to 0·7-0·8 M. from the surface. It will be seen from the map of the pan that over its greater portion the brine is very concentrated, average 24·5 per cent. NaCl. It is only the north-eastern marginal portion on the land side which shows low values. This is the opposite of the conditions obtaining in the Cape Cross Pan.

ANALYSIS OF BRINE FROM PIT NO. 4.

	%
NaCl	24·41
$MgCl_2$	2·31
$MgSO_4$	1·36
$CaSO_4$	0·42
Insoluble matter	0·11
Water	71·34
	99·95

Origin of the Brine and History of the Pan.—The Panther-beacon Pan represents a trough-like depression, the rock-floor of which over its largest portion lies well below sea-level. It is not separated from the sea by a simple sand-bar, as, for instance, the Cape Cross Pan. As far south as Pit No. 8 (*vide* map) solid rock (pegmatitic granite, mixed-rock, marble and quartz veins) is actually exposed, the strike being nearly parallel with the separating strip of land. The pan as such is a very youthful one, *i.e.*, its complete separation from the sea took place at a comparatively recent date, more recent than that of the formation of the Cape Cross Pan. Originally it represented, like the latter, an elongate bay separated from the sea by a narrow belt of rocks. The bay was open towards the north, and the separating strip of rocks must, in parts, hardly have projected above high-water mark. The communication with the open sea was therefore complete enough to prevent a concentration of the water in the bay high enough to allow of the precipitation of gypsum and rock-salt on the landside of the bay, as was the case in the Cape Cross Pan.

The coast then further rose in successive steps, now recorded by four more or less well-marked beach-pebble-terraces on the separating land-strip and the shore in general. The highest of these forms the crest of the strip, and is about 3-4 M. (10-12 ft.) above sea-level. Remnants of the same terraces (*vide* map) and of a still higher one, 7-8 M. (20-25 ft.), also occur along the southern end of the pan. The northward drift of the Angola current gradually deposited sand on the strip of rocks, and the surf finally silted up the mouth of the bay to the north. The surface of the pan can at the most be just a few feet, if so much, above sea-level, and is probably below spring-tide and storm-level. Seawater therefore gradually percolates through joints and fissures of the separating rocks mainly into the sand and grits underlying the black mud, where it becomes concentrated by evaporation under the force of capillary action. On the (eastern) land-side of the pan the brine is diluted by brackish ground-water, mainly brought down by the rivulets entering the pan on this side. The latter are nearly always dry, but of considerable length and catchment area (about 30 miles inland). Naturally, these rivers, when flooded, also bring down fresh supplies of salt, partly derived from the older, stratified rock-salt previously described, but that this is subordinate to that derived from the sea is shown by the low concentrations on the land side of the pan.

Economic Possibilities.—Evaporation and salt precipitation has not gone on long enough in this pan to allow of the deposition of workable rock-salt. But as a source of high-grade brine the Panther-beacon Pan is of the utmost importance. A good grade of salt can be prepared from the brine at compartaively low cost by digging trenches and pumping the brine into shallow receptacles. Natural, solar and wind evaporation is quite sufficient in spite of the frequent heavy mists that are a characteristic of this coast during part of the year.

The salt produced is of good quality, as shown by the following analysis of a sample from Mr. Gossow's workings near the northern end of the pan:—

	%
NaCl	95·06
$CaSO_4$	2·04
$CaCl_2$	1·51
MgO	Trace
K_2O	Nil
NO_3	Nil
Moisture	1·35
Insoluble matter	0·32
	100·28

(Sample taken from salt precipitated in initial stages, therefore showing no $MgSO_4$, $MgCl_2$, and Na_2SO_4.)

The estimation of the salt reserves is somewhat difficult. Limiting our attention to the main source of high-grade brine (average 24·5 per cent. NaCl), *i.e.*, that contained in the sand and grits underlying the black mud, utilizing their porous space (0·35-0·38 of their total bulk), and taking an average thickness of 1·5 M. taken for the lens of grits and sand—a very conservative estimate—the figure of 800,000 tons (metric) of salt is arrived at. This figure, however, excludes the brine found in and above the black mud, as well as the salt cementing the upper layers. It must also be remembered that while brine is being pumped out, it is, at the same time, being continually renewed, though at what rate it is impossible to say. It will be seen, however, from this very conservative estimate that this pan alone, situated so near the railway, is capable of supplying South-West Africa with salt for an almost indefinite period. (In 1929, 747 long tons of salt were produced in South-West Africa, and 1,499 long tons were imported, while in 1930, 503 tons were produced.)

2. *Cape Cross Pan.*

General Description.—This pan is by far the largest along this portion of the coast, and contains enormous quantities of rock-salt and high-grade brine. Unfortunately, it is situated at a distance of 82 miles from the nearest rail.

The length of the pan is 15 Km., and its average width nearly 3½ Km. It represents a long, level depression, situated only very little, at the most 2-3 ft., above ordinary sea-level. Its surface is certainly below high- and spring-tide mark. It is separated from the open sea by a narrow strip of loose sand, 300-350 M. wide, and low enough in its southern portion to allow spring tides and heavy seas to sweep sea-water over into the pan. In addition, there are numerous springs on the inner side of the sand-bar in this area, the sea-water percolating through the sand into the open lagoon, which is practically at sea-level. This open lagoon, situated in the southern portion of the pan, behind the sand-bar, is inhabited by thousands of flamingoes and hundreds of thousands of "duikers" (cormorants), which roost on

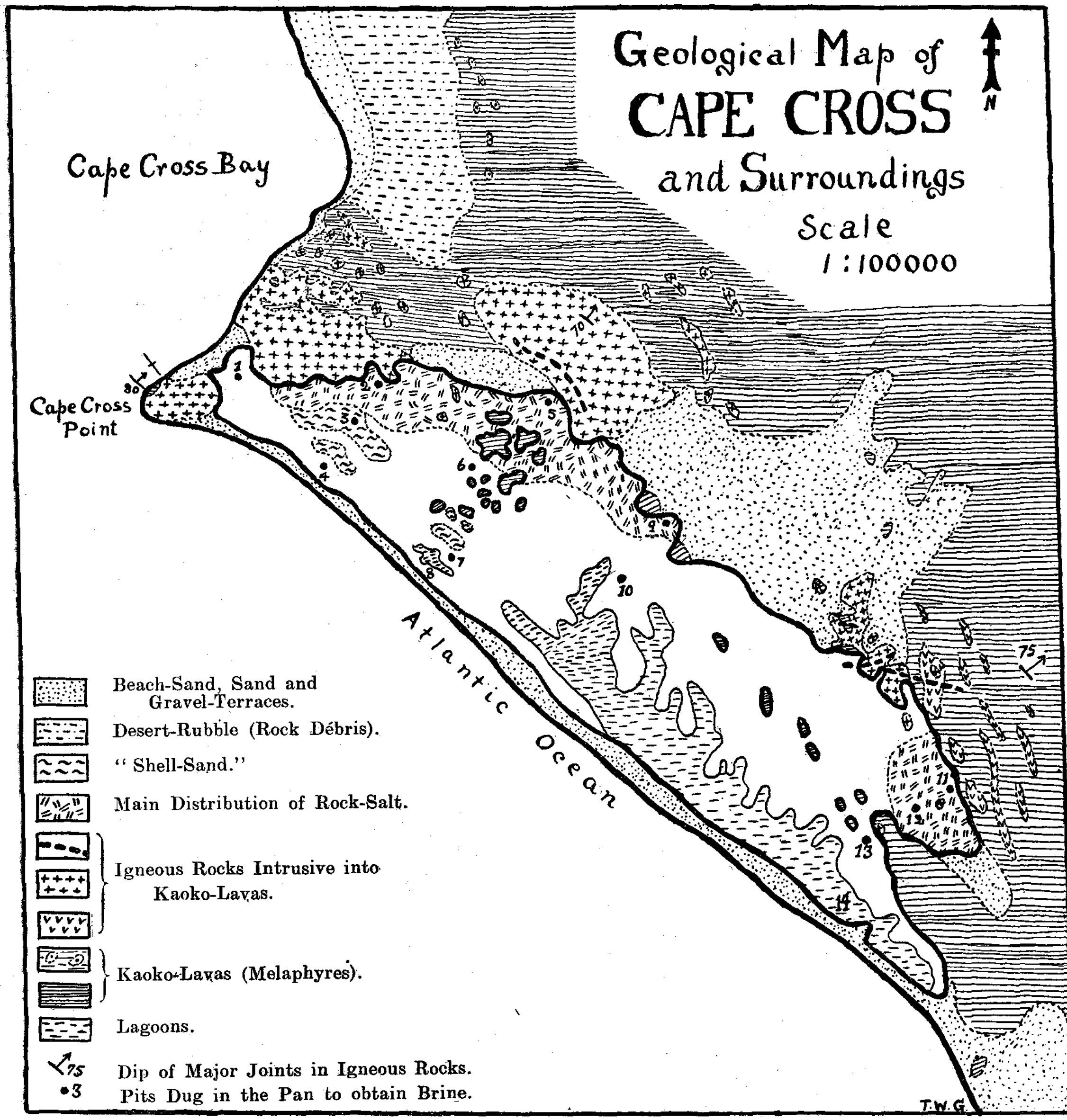


FIG. 4.

Percentage of NaCl in Brines of Cape Cross Pan.

	% NaCl.		% NaCl.
Pit No. 1	5.63	Pit No. 9	25.10
,, ,, 2	25.30	,, ,, 10	25.00
,, ,, 3	22.50	,, ,, 11	25.90
,, ,, 4	4.50	,, ,, 12	25.00
,, ,, 5	24.00	,, ,, 13	25.20
,, ,, 6	25.00	,, ,, 14 (open lagoon-water — main lagoon)	8.90
,, ,, 7	25.10		
,, ,, 8 (open lagoon-water — small lagoon)	17.80		

the low islets in the lagoon, and are the cause of the accumulation of considerable quantities of guano. When a heavy sea is running outside the sand-bar, the water-level in the lagoon rises and slowly overflows its eastern banks with the production of numerous, irregular bays and solution channels. A sample of the water from the lagoon gave an NaCl concentration of 8·9 per cent. NaCl. It is therefore capable of dissolving still further quantities of salt. Even far away from the lagoon the rise of the brine-level very frequently leads to a subsidence of the salt-cemented sand, due to the leaching out of the former, the formation of a depression, and the deposition of a purer salt-crust.

The salt content of the pan gradually increases from west to east, *i.e.*, from the sand-bar towards the land-side of the pan. Rock-salt of considerable thickness and of workable quality is only found along the eastern margin of the pan, particularly in embayments of the pan-shore (*vide* map). Nevertheless, there exist many square-kilometres of the best quality rock-salt. Salt-crusts, of course, exist all over the larger portion of the pan, but they are not everywhere thick and, in the initial stages of crust-formation, very impure. It is easy to distinguish on the surface between thick and shallow crusts. Where the rock-salt attains a considerable thickness, *i.e.*, along the inland shore of the pan, it exhibits a rather smooth and plane surface, and is jointed in the manner of mud-cracks by shrinkage, the joints being again filled up by salt to form slightly elevated ridges. Where these ridges are very high (six inches and more), and the enclosed salt-plates bent very concave, the salt-crust is always very much thinner and, generally, also impure. It is obvious, of course, that these differences merely represent successive stages, the compact rock-salt being formed by leaching and solution of the salt content, the gradual subsidence and settling of the sand, and the subsequent formation of a continually growing crust of purer salt.

A large area of the pan is covered by sand, with or without a salt-crust, but generally containing needles of gypsum. At several localities also fairly thick layers of shell-sand were found, the Lamellibranch-shells (Tellina madagascariensis Gmelin and Dosinia pubescens Phil) very often predominating over the admixed sand. A few types of gastropods (Bullia callosa Wood, Bullia laevissima Gmelin and Thais haemastoma Lenn[3]) were also found.

The sections exposed in the pits dug at different localities over the whole pan vary considerably. Some, along the eastern margin, exhibit nothing but rock-salt. Others show a surface-layer of fine, micaceous sand, generally salt-cemented, followed by coarser sand and grits. Others, again, in the central area of the pan show the presence of a layer of dark micaceous silt and black mud with a strong odour of H_2S, underneath which the brine is always under pressure, and

[3] **Kindly determined by Dr. S. H. Haughton and the British Museum.**

escapes with considerable force and bubbles of H_2S. Needless to say, these layers are the result of stagnant conditions in the former bay or lagoon. In Pit No. 7 a thickness of 0·9 M. of this material was exposed without penetrating it. In several pits a layer of a whitish-yellow powdery gypsum, varying from 0·17-0·3 M. in thickness, was encountered below the surface. The total thickness of sediments in the pan must be very great. Rock-bottom was only struck in one marginal pit (No. 11) at 1·96 M. below the surface.

Rock-salt.—Mention has already been made of the distribution and different types of rock-salt. Up to the present it has been worked near the northern (Offen's workings) and the southern end of the pan (Gossow's workings). At the latter locality it has a thickness of 0·55 M. At the former it appears to be very thick, 8 ft. being stated by the man in charge of the sealing station. According to the same source of information at one locality, it has a total thickness of about 16 ft. Of main immediate interest is a surface layer of very pure and well-jointed, easily workable slab rock-salt 0·30-0·35 M. thick. At Offen's workings it is of very good grade. Below this surface-layer there is still a further thickness (said to be 8 ft.) of very pure, but very compact, rock-salt, considerably more difficult to work. In addition it is saturated with a very high-grade brine, which here rises to 0·45 below the surface *i.e.*, nearly reaching up to the surface layer.

Analyses of the rock-salt gave the following results:—

	1	2
	%	%
NaCl	90·57	81·31
$CaSo_4$	4·70	0·73
$CaCl_2$	3·24	—
MgO	Nil	0·95
K_2O	Nil	—
NO_3	Nil	—
Moisture	1·59	16·20
Insoluble matter ...	0·45	0·17
	100·55	99·36

(Analyst: Dr. Marloth.)

A peculiar feature of the Cape Cross salt is that the rock-salt, where a fresh surface layer has been formed, is coloured a bright pink on the surface, which a few centimetres below changes into a bright sea-green. On drying and continued exposure to the air, both colours gradually disappear. Even the salt produced by the evaporation of the brine, which is of excellent quality and snow-white of colour, is stated to colour skins cured with it pink. It cannot therefore be used for delicate and valuable skins, such as seal.

Attempts were made in the laboratory again to reduce the pink colour to green, but failed, only nascent H_2 being available. Oxidation of the green colouring matter to the pink by means of allowing it to stand for several days with H_2O_2, on the other hand, was successful in producing patches of pink. The colouring matter is an organic one, and there is very little doubt that its origin is to be connected with the animal life in the lagoon, which formerly, of course, was much greater.

Brine.—It has already been stated that at Offen's workings the brine rises to 0·45 M. from the surface, and is stagnant within at least several feet of rock-salt. Its concentration is therefore very high. A reference to the map shows that all over the eastern and central portions of the pan, *i.e.*, east of the open lagoon and some distance away from the sea, the concentration of the brine everywhere is high (average 24·8 per cent. NaCl). The brine rises to within a short distance of the surface (0·3-55 M.), the depth being lowest (0·2-0·25 M.) near the lagoon, the floor of which is below sea-level.

Analysis of Brine from Pit No. 7.

	%
NaCl	25·11
$MgCl_2$	1·49
$CaCl_2$	0·81
$CaSO_4$	0·35
Insoluble matter	0·01
Water	71·69
	99·46

Salt of an excellent quality has been produced from the brine at Offen's workings. Shallow basins are cut into the lower compact rock-salt, which is saturated with brine, and the salt then crystallises out. It is obvious that a very pure, uncontaminated rock-salt can be produced in this way. The tendency to colour skins pink is its only disadvantage. A sample of salt from here on analysis gave the following results:—

(Analyst: J. Muller, Capetown)

	I.	II.	
	%	%	
NaCl	98·77	97·43	
$CaSO_4$	0·64	0·31	
$CaCl_2$	0·31	Nil	
Na_2SO_4	Nil	0·88	
MgO	Trace	0·39	($MgSO_4$)
K_2O	Nil	Nil	
NO_3	Nil	Nil	
Moisture	0·43	0·62	
Insoluble matter	0·07	0·36	
	100·22	99·99	

(Sample I taken from salt removed before complete evaporation of brine.)

Economic Possibilities.—The reserves of rock-salt and brine in this pan are enormous. Taking only the surface rock-salt above the "brine-line," *i.e.*, a thickness of 0·45 M., and only the best grade into consideration, a conservative estimate yields the figure of 7,700,000 tons (metric) of first grade, easily workable, slab rock-salt. If the thinner and less uniform salt-crusts and, above all, the underlying compact rock-salt previously described, which, over a considerable area, is said to have a thickness approaching 8 ft., in places even 16 ft., be added, it is obvious that the available supply of rock-salt alone probably runs into several tens of millions of tons. The compact lower rock-salt, however, is difficult to excavate, and, moreover, saturated with brine.

Turning to the latter and utilizing the same data as for the Panther-beacon Pan, and considering only that portion of the pan having a brine of an average concentration of 24·8 per cent. NaCl and over, and taking the depth of the porous sediments (sands and grits) to be only 4 M., which, no doubt, falls far short of reality, an available supply of salt, amounting to 14,500,000 tons (metric), is arrived at. Taking all the brine of lesser concentration into account—even the open lagoon-water gave results of 10·79 per cent. (big lagoon) and 17·8 per cent. (small lagoon) NaCl—and combining the available rock-salt and brine, it is apparent that the total reserves of salt in this pan no doubt run into many hundreds of millions of tons. This is not to say, of course, that it could all be recovered at a profit.

Unfortunately, the pan is situated 82 odd miles by road from Swakopmund rail, and the road is in part very sandy. Since rock-salt at the present date sells at about £2 10s. a ton f.o.r. Swakopmund or Walvis Bay, it is obvious that transport by road—motor transport only being possible—is practically prohibitive. Shipping the salt by cutter to Walvis Bay also involves considerable expense. These large salt-deposits of Cape Cross are condemned, therefore, to remain practically unexploited under present transport and market conditions.

History of Cape Cross Pan.—Similar to the Panther-beacon Pan, the Cape Cross Pan is another instance of a former bay, formed by the northward drift of the Angola current gradually extending a tongue of sand from a projecting promontory. Its origin is thus entirely similar to that of Sandfish, Walvis and Lobito Bay. The sand-bar was gradually extended, till it finally reached the present promontory of Cape Cross Point, then an island inhabited by guano-producing birds (*vide* map). The narrow outlet between the Point and the Cape Cross bay hills (about 800 M.) was then finally or contemporaneously closed up by the surf. Before that, of course, the silting-up of the practically enclosed bay had already begun. The bed of lamellibranch shells was formed before its complete enclosure and the onset of stagnation. In part, at least it appears to have been accumulated by the surf, since a large proportion of the shells is broken.

Several islands existed in the bay, and formed favourite resting places for guano-producing sea-birds, which now inhabit the low islets in the present lagoon. Between 1895 and 1904 a British company exploited these deposits of guano, and over 100,000 tons are said to have been removed.

When exactly the complete silting-up, partly by the precipitation of salts, took place, it is impossible to say. The event is, no doubt, a comparatively recent one, aided by the rising of the coast previously described. As a lagoon it is probably considerably older than the Panther-beacon Pan, as evidenced by the great thickness of rock-salt.

The separating sand-strip consists entirely of beach-sand, and, as a consequence, in contradistinction to the Panther-beacon Pan, sea-water has practically free access into the pan and lagoon. As a result, therefore, the lowest values of brine-concentration are found behind the sand-bar and near the lagoon.

Salt Precipitation from Evaporating Sea-water.—The Cape Cross lagoon affords a very clear example of the formation of salt-deposits from evaporating sea-water. In the same way, only on a very much bigger scale, one may imagine the Permian salt (potash) deposits of Germany to have originated, but at Cape Cross the scale was not grand enough to allow of the concentration and precipitation in bulk of the most highly soluble, residual salts. (K_2O varies from 0 to 0·05 per cent. in the salt produced from this pan.)

It has already been mentioned that quite a number of the pits dug in the floor of the pan showed a layer of powdery gypsum, containing a little $CaCO_3$ and some salt (NaCl), underlying the salt—cemented sand and salt-crusts. In a little lagoon, somewhat to the north of the main lagoon, and representing a remnant of a former larger extension of the latter, the process of salt-precipitation from evaporating sea-water can be seen going on in a remarkably clear way. This lagoon really consists of a number of isolated shallow depressions, 1-2 ft. deep, separated by ridges consisting mainly of partially crystallized gypsum. On account of their very much smaller size, and, no doubt, also the less easy access of fresh sea-water, these "lagoonlets" are in a more advanced stage of desiccation than the main lagoon. A sample of water taken from one of them gave a 17·8 per cent. concentration of NaCl, while a sample from the latter only reached 8·9 per cent. NaCl.

The ridges of gypsum have been precipitated from the water of an originally continuous lagoon, till they finally rose above the water like a coral reef, in the same way as gypsum is still being deposited in the lagoon-remnants to-day. The precipitated gypsum forms all manner of phantastic shapes: mounds, ridges, mushroom-shaped or dendritic aggregates, etc. Most common are hollow mounds and ridges. The surface of the gypsum is usually reniform, and its bulk consists of fibres pointing to a common centre. On analysis it gave the following results:—

	%
$CaSO_4$	77·98
$CaCO_3$	8·94
NaCl	1·74
Insoluble matter	0·46
Moisture and combined water	10·72
	99·84

The lagoon water is still in communication with the sea, even though on a restricted scale, through the porous sand-bar, and the evaporation maintains a concentration that enables the steady deposition of gypsum over a prolonged period, and the accumulation of considerable thicknesses of this mineral. There is no doubt that the enormous thicknesses of gypsum and salt in many fossil saline deposits have to be explained in a similar way, *i.e.*, by the constant addition of fresh supplies of sea-water. Without this, complete evaporation would be effected within a short period resulting only in limited thicknesses.

It is only when the deposition of gypsum has gone so far as almost to fill up the "lagoonlet," or a small portion of it has become separated from the main portion, *i.e.*, a fresh supply of sea-water or brine is prevented, that salt (NaCl) is precipitated in quantity, filling all the interstices left by the gypsum and, on complete evaporation, leaving a top layer of pure pinkish salt, which a few centimetres below the surface changes into a bright green layer.

There is no doubt that this colouring matter, already previously mentioned, is connected with the animal life in the lagoon. In some portions of the "lagoonlets," particularly in the deeper parts, the gypsum is covered by a slimy gelatinous layer, in places several inches thick, and smelling of H_2S. On top this very often is distinctly reddish or crimson, and below the surface changes into a dirty green, which, in some instances, was followed by another deep-crimson layer. The lower portions are black, and possess a very strong smell of H_2S. Along the margins of some of the bigger "lagoonlets" green algae are growing, beneath which the gelatinous slime is very black, and produces a strong odour of H_2S. They are evidently sulphate (gypsum) reducing plants. In the Panther-beacon Pan, where no lagoon with animal- and plant-life exists, the salt does not contain this colouring matter.

Conclusion.—Comparing the salt produced in South-West Africa with the marketed salt of the Union, it is surprising what degree of purity can be reached under such primitive conditions of evaporation and the absence of any attempts at refining. A factor strongly in favour of the South-West Africa salt is the practical absence of

Na_2SO_4 (Glauber Salt) and $MgSO_4$ (Epsom Salt) in those products obtained before complete evaporation of the brine. The percentages of $CaSO_4$ and $CaCl_2$ are, on the other hand, rather high, but could easily be made negligible by an increased consideration of the factors governing fractional crystallization.

The following analyses of salt produced in the Union are taken from the *Commercial and Industrial Gazette*, Vol. VI, No. 57 (V. Bosmann; " Salt and Saltpans of the Union." The localities are not given).

	Union.			S.W.A. (Unrefined).		
	I. (Fine)	II. (Medium)	III. (Coarse)	IV. (Offen, Cape Cross)	V. (Gossow, Pantherbeacon)	VI. (Ehrhorns Pan)
NaCl	98·6	97·1	95·4	98·77	95·06	96·90
Na_2SO_4	0·65	0·6	1·7	—	—	—
$CaSO_4$	0·15	0·3	0·5	0·64	2·04	2·18
$MgSO_4$	0·4	0·55	0·6	—	—	—
$CaCl_2$	—	—	—	0·31	1·51	0·21
H_2O	0·15	1·35	1·75	0·43	1·35	1·39
Insoluble	0·05	0·1	0·05	0·07	0·32	0·18
	(Salt obtained from inland pans, brine not derived from sea-water.)			(All samples taken from salt precipitated in initial stages of evaporation. Brine mainly derived from sea-water.)		