

carpment. A full account of the geology of the area of Malvernia on the Portuguese side of the border has been given by Ribeiro (1955).

In the eastern part of the area, at the west end of the Clarendon Cliffs, the basal beds are again mainly conglomeratic and are overlain by a thick pink sandstone forming sloping ground at the base of the cliffs. The cliffs themselves are made up of interbedded pale red and white rocks with a rather thicker, bright red, band at the top. Again the division into red and white groups so well seen in the Buffalo Bend area is difficult to apply.

The conglomeratic character of the basal beds is well illustrated in the cliffs south of the Sabi-Lundi confluence.

DISTRIBUTION OF PEBBLES IN THE CONGLOMERATES

A great variety of pebbles and cobbles is encountered in the conglomerates of the Malvernia Beds. Pebbles derived from the Basement Complex are widely distributed, the most common being of quartzite or vein-quartz (these two are often difficult to distinguish). Various types of gneiss and ironstone are also commonly found. Of the Karroo rocks the rhyolite seems to be the most common, closely followed by granophyre. Pebbles of Karroo sediments, such as the Cave Sandstone, are rare, as are basalt pebbles. At Buffalo Bend, boulders of white sandstone and calcareous pebbles derived from the Malvernia Beds themselves are included in the conglomerates. In the southern part of the area most of the conglomerates are made up of cobbles of a tough purplish-red quartzitic sandstone which were probably derived from the Waterberg outcrops of the Zoutpansberg area of the N. Transvaal.

The distribution of the pebbles is of considerable interest in giving an indication of directions of derivation. For example, rhyolite and granophyre pebbles are abundant in the Dumisa, Makonde Pool and Buffalo Bend areas, especially in the outcrops west of the Nuanetsi. They do not occur north of the present outcrop of the rhyolite and granophyre, i.e. in the conglomerates near Chikombedzi Halt, and are replaced there by Basement pebbles. Hence the transport of materials in the whole of the western part of the outcrop shows evidence of a strong southward component.

In the extreme southwest, however, in the area between Pafuri and Dumisa, the quartzitic sandstone pebbles, believed to be derived from the Zoutpansberg, appear in enormous numbers and they are also found in the Malvernia area. Here, therefore, there is evidence of derivation from the west and perhaps an indication of the antiquity of the Limpopo.

ACKNOWLEDGMENTS

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A SUGGESTED THEORY FOR THE ORIGIN AND A BRIEF DESCRIPTION OF SOME GYPSUM DEPOSITS OF SOUTH WEST AFRICA*

by

H. Martin

ABSTRACT

In the vicinity of Swakopmund and Walvis Bay extensive areas of the Namib desert, totalling at least 1,000 square kilometers, are covered by gypsum deposits and gypsum-cemented gravel and sand. The gypsum is an alteration product of Tertiary and Pleistocene calcretes that ranged in composition from pure calcium carbonate rocks to lime-cemented sands and gravels. The alteration proceeded from the surface downwards to depths averaging from one to three feet, with the purity of the gypsum so formed being dependent on the carbonate content of the original calcrete. The enormous quantity of sulphur required for this transformation seems to have been generated as hydrogen sulphide under anaerobic conditions on the Atlantic sea bottom in a deposit of sulphide-bearing, diatomaceous ooze. This azoic zone measures about 15,000 square kilometers and is situated immediately off-shore to the west of the gypsum deposits. The hydrogen sulphide was blown inland and precipitated with mist and dew to react with the calcrete. Several million tons of gypsum having a purity in excess of 90 percent have been proved within a radius of about 30 miles of the towns of Swakopmund and Walvis Bay. The lower grade gypsum deposits of the hinterland of these two towns are of the order of several hundred million tons. These deposits are the largest known in South West Africa.

The gypsum crust is on the average 1-3 feet thick (0.3-1 meter), but may locally attain to a maximum of 12 feet (4m). It grades downwards into calcareous sand and gravel or rests on a basement-surface. Impurities consist of variable quantities of sand and pebbles that were present in the original unreplaced calcrete.

The bulk of the widespread deposits of gypsiferous gravel and calcrete occurring along the coastal part of the Namib desert may be correlated with the upper portion of the Kalahari beds of the interior and are probably of Tertiary age. During the Pleistocene pluvials the bigger rivers, rising in the areas of higher rainfall of the interior, dissected these gravel deposits and even cut deep gorges into the underlying basement-rocks, forming spectacular scarps, one of which can be seen on the south bank of the Swakop gorge. Here the gravels are as much as 100 feet (30m) thick and overlook a maze of barren gorges leading down to the 600 feet (180m) deep canyon of the Swakop River.

The smaller rivers, like the Tubas (Fig. 1), rising within the desert, have in many places not been able to cut down into the basement. They occupy wide depressions in the slightly dissected, undulating gravel plains and are flanked by 12-20 feet (4-6m) terraces of younger calcareous gravels of Pleistocene age. These are also covered with a gypsum crust.

All these gravels, well exposed along innumerable gullies and river banks, are the direct continuation of the crusts of calcareous gravels and calcrete found farther inland. Like these they are practically unsorted and have all the characteristics of gravels and sands deposited by rivers and sheet-floods under semiarid conditions.

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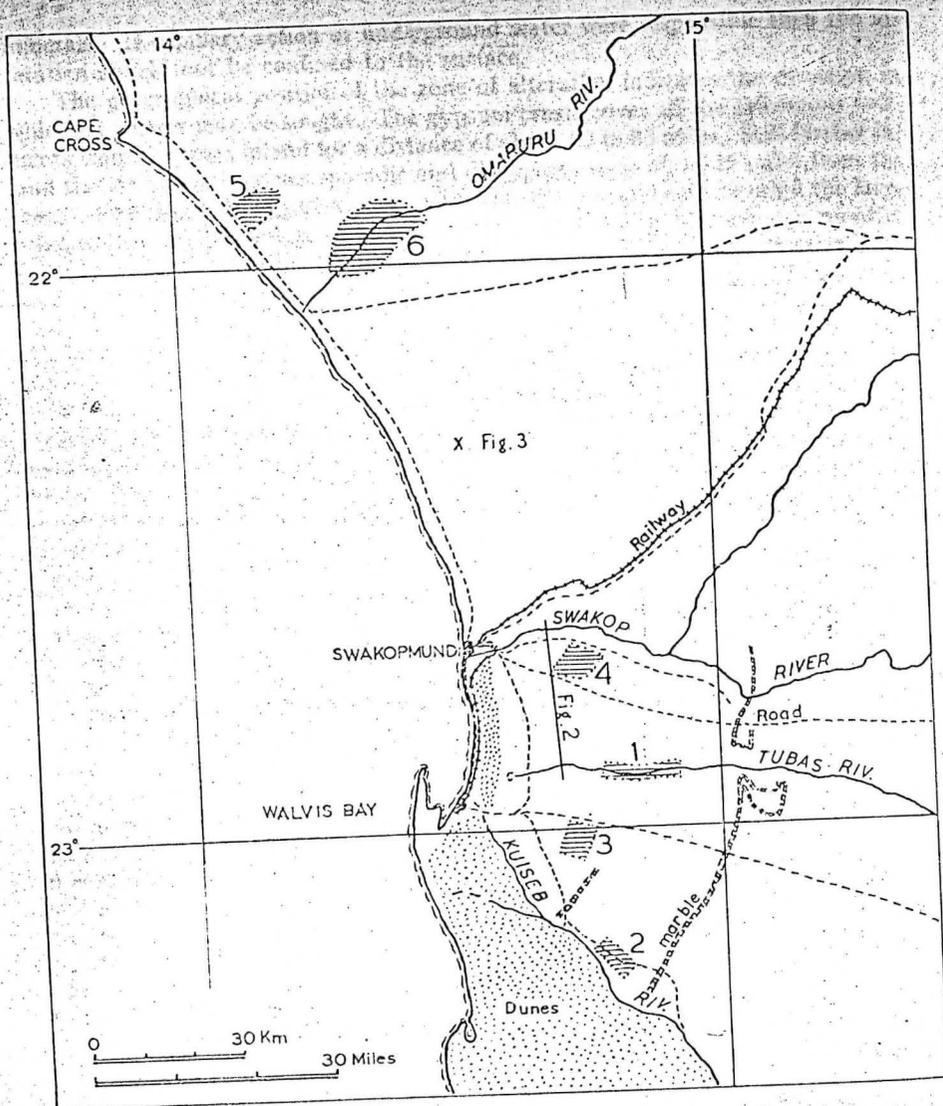


Fig. 1—Approximate position of some major gypsum deposits (hatched) in the vicinity of Walvis Bay and Swakopmund. The high-grade deposit along the Tubas River is situated downstream from some large marble outcrops.

There is not the slightest doubt that these deposits are of terrestrial origin. Gevers (1931) has come to the same conclusion. But can this be true of the gypsum crusts also? Can such widespread gypsum deposits, which are neither confined to pans or depressions (Fig. 2) nor dependent on the lithology of the older basement, be of terrestrial origin also?

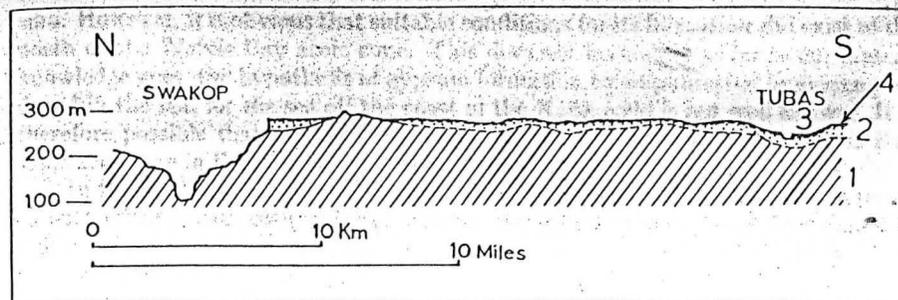


Fig. 2—Schematic section from the Swakop to the Tubas River. 1=basement, 2 = Tertiary retrace-deposits, 3=Pleistocene terrace, 4=gypsum crust.

The relationship of the gypsum deposits to the underlying calcareous sediments must provide the answer to this question. Numerous exposures show that the gypsum mantle grades into the underlying sediments and is only distinguished from the latter by the presence of gypsum in place of calcium carbonate. The whole relationship suggests an alteration of the calcium carbonate to gypsum. The fact that the gypsum crust covers all the calcareous deposits irrespective of age or elevation—even the calcrete-filled fissures on the hillsides have been transformed to gypsum—indicates that the alteration acted from the surface downward. This interpretation is strengthened by a further observation, made on the terrace of a small river, where the alteration to gypsum penetrates along the occasional joints far deeper into the calcareous sediment than it does where no joints are present (Fig. 3). The locality, to the north of Swakopmund, is marked x on Fig. 1).

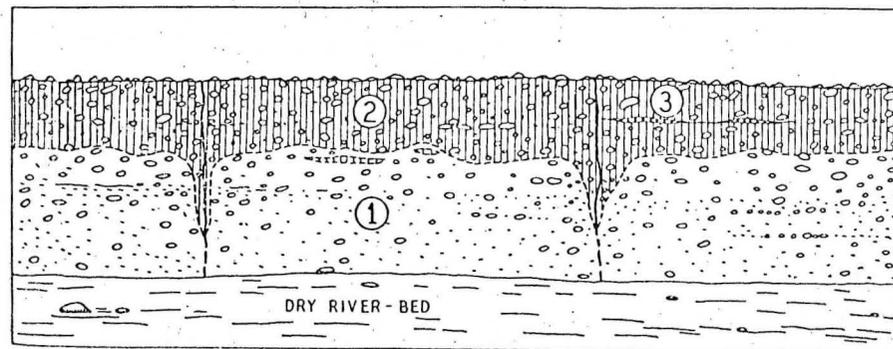


Fig. 3—Pleistocene terrace forming bank of small river. 1=sand and gravel cemented by calcrete, 2=gypsum-cemented sand and gravel, 3=lenses of pure, fibrous gypsum. The gypsum-cemented zone is approximately 3 feet (1m) thick. Along two joints the alteration to gypsum has penetrated deeper into the calcified sediment.

What process or processes can have caused this alteration, and what is the origin of the large volume of sulphur necessary for this transformation? The sulphur could not have been derived from the sediments because the calcareous gravels, sands and calcrete crusts did not contain pyrites or other sulphur-bearing

minerals. If capillary action or underground water were responsible then the alteration should not be confined to the surface.

The geographical position of the zone of alteration indicates the direction in which an answer may be sought. The gypsum crusts cover all the calcareous sediments from the coast inland for a distance of about 30 to 35 miles. Still farther inland the alteration becomes sporadic and disappears some 40 to 45 miles from the coast. This seems to suggest a connection with the sea, and calls to mind the large volume of H_2S released from the sea every year during the summer months. Copenhagen (1953) has described the conditions responsible for this phenomenon: The northward-flowing Benguela current is formed by upwelling cold Antarctic water. This water is rich in nutrient salts which allow the growth of a very rich plankton and fish fauna. During the summer months the normal south and southwesterly winds are occasionally replaced by north or west winds bringing with them invasions of warm, subtropical water of higher salinity. The sudden increase in temperature and salinity destroys the coastal plankton and may lead to the sudden growth of poisonous plankton too, which in turn kills a part of the fish population. The sea bottom thus periodically receives vastly increased quantities of organic matter that, upon decomposition, exhausts the supply of dissolved oxygen in the bottom water. In this anaerobic environment sulphate-reducing micro-organisms flourish to produce large quantities of sulphuretted hydrogen, some of which goes into solution in the bottom water. The periodic supply of organic matter is so great that the anaerobic, azoic conditions exists right throughout the year beneath the area where the invasion of subtropical water occurs most frequently.

The azoic zone lies between Lat. $21^{\circ} 30'$ South and $24^{\circ} 30'$ South and extends approximately from the 150 m to the 50 m bottom contour, the latter being found about three miles off the shore. In this zone the sea bottom is characterised by a deposit of sulphidic, diatomaceous ooze. A broad tongue of this sulphide ooze is also found on the bottom of the Walvis Bay. Under certain meteorological conditions the poisonous bottom water may be forced to the surface, exterminating fish in enormous numbers and emitting large volumes of sulphuretted hydrogen. The contamination of the air may be sufficiently concentrated to turn white lead-base paints and silverware dark grey. The prevailing west wind carries the contaminated air eastward over the desert sufficiently far to be detected 10 to 15 miles from the coast. The author has, on one occasion, distinctly noticed the smell at Arandis Mine some 35 miles inland.

Mist or dew are precipitated practically every night in this part of the desert (Logan, 1960) and there can be little doubt that the sulphuretted hydrogen dissolved in this moisture, is precipitated at the same time.

We can now compare the area of the gypsum deposits with the area of the azoic zone which extends from the neighbourhood of Cape Cross to Meob (Lat. $24^{\circ} 30'$, not on map). The main gypsum deposits occur between Cape Cross and Walvis Bay, whereas the desert between Walvis Bay and Meob is covered by dunes; thus accounting for the lack of deposits there. It would seem that there is a close correspondence between the distribution of the gypsum deposits and the area extent of the gas-producing azoic zone. It should be mentioned that thinner and less extensive gypsum crusts occur also farther north on the Kaokoveld coast. It is possible that the original surface-limestone deposits were less robustly developed in this area than farther south, thus accounting for the inferior development of gypsum.

sum. However, it is obvious that suitable conditions for its formation did exist to the north of the Walvis Bay azoic zone. This does not invalidate as far as our present knowledge goes, the hypothesis of gypsum formation by sulphuretted hydrogen produced in the sea, for the sea off the coast of the Kaokoveld is not well known. It is therefore possible that smaller azoic areas may exist here or that the Walvis Bay azoic zone may in the past have extended farther north.

In the southern Namib, to the south of Lüderitz (Knetsch, 1937) gypsum forms as subsurface crusts over chlorite schists, amphibolites etc., which are probably rich in sulphates. Here conditions seem to be comparable with those under which gypsum is formed in other parts of South Africa too, as described by Wasserstein (1935).

Formations rich in pyrites, impeded drainage and a dry climate seem adequate to explain these last-mentioned occurrences. These factors are, however, totally inadequate to account for the deposits of the hinterland of Walvis Bay and Swakopmund, where enormous volumes of calcareous material that covered slopes, elevated terraces and plateaux have been transformed into gypsum. This alteration, which worked from the surface downward, is thought to have been caused by the periodic precipitation of H_2S derived from the sea and dissolved in mist and dew. Conditions comparable with the present ones have probably existed through most of the Pleistocene. There was thus ample time for the production of sulphur and for the transformation of the calcareous material into gypsum under the influence of ground-moisture or ground-water, rich in sulphate, probably operated at the same time in some of the depressions, for instance along the Tubas river, and has there created gypsum deposits of up to 12 feet thickness.

If this hypothesis is correct then the purity of the gypsum should depend on the purity of the calcareous material from which it has been derived. Such a dependence cannot be proved directly, but indirect arguments indicate that this is probably the case:

1. The impurities found in the gypsum consist exclusively of the silt, sand and pebbles contained in the original calcareous material.
2. It is well known that the purest and thickest calcareous layers occur in the neighbourhood of limestone or marble outcrops. It is therefore probably no accident that the area containing the best gypsum deposits is crossed by several marble ridges (see Fig. 1).

The investigation of the deposits has so far been rather limited. A report by Borchers (1958) on work done by Rand Mines states that the Tubas river area, 35 miles from Walvis Bay (1 on Fig. 1) contains considerably more than 4 million tons of gypsum, with a purity of 90% or better, in the form of a solid surface layer, 1-3 feet thick. In some places gypsum of a grade of more than 80% extends to a depth of 12 feet. In most of the test pits, however, the high-grade crust was underlain by gypsum-cemented conglomerates averaging 33-65% gypsum. The deposit extends far beyond the area investigated by test pits.

The second area investigated by Borchers is situated near the Kuiseb River about 25 miles SE of Walvis Bay. Here pure crystalline gypsum forms irregular dome-shaped or hemispherical shells a few feet in radius and from a fraction of an inch to one foot in thickness. The tonnage of this material, which would be suitable for modelling and medicinal purposes, is not great. The rest of the terraces in this area consist of gypsum-cemented sand and conglomerates.

In 1959 Messrs H. & E. Börgardts K. G. Gypsum Works treated 2 bulk samples from area No. 3, situated along the road to Maltahöhe. If these 2 samples can be

regarded as representative, then the area contains about 15 million tons of gypsum of 95% purity.

Bulk samples from area No. 4, situated about 20 miles from Swakopmund, indicate a deposit of gypsum of 92-93% purity. Here several million tons may be available too.

Area No. 5, to the southeast of Cape Cross contains a large deposit of powdery gypsum mixed with sand. No analyses have been made of samples from this deposit or from area No. 6.

The report by Messrs. Börgardts states that the deposits in the vicinity of Walvis Bay contain several million tons of gypsum averaging 90% purity. This material would be suitable for the manufacture of plaster, plaster-boards, wall-boards, block and tiles, etc., and selected material even for modelling and medicinal purposes.

For agricultural use even the sandy and conglomeratic deposits would probably be suitable if the larger components were removed in the course of the crushing operation.

The relatively uniform thickness of the deposits ranging from 1-3 feet (0, 3-1, 0 m) coupled with the absence of overburden will all tend to facilitate and cheapen exploitation. The main deposits are all situated at distances of 20 to 35 miles from Walvis Bay.

The writer is indebted to Dr. R. Borchers and Mr. A. v. Stryk for their kind permission to quote the unpublished reports listed amongst the references.

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Discussion

Dr. R. A. P. Fockema and G. A. P. Fraser

It gives us great pleasure to congratulate Dr. H. Martin on the very interesting paper he has written. The theory for the origin of the large gypsum deposits in the neighbourhood of Walvis Bay and Swakopmund seems to explain much that has been difficult to account for.

However, we do wish to point out that, although the low grade reserves may be many tens of millions of tons, there are not several million tons of gypsum of 90% or higher purity available, without applying some form of beneficiation.

We did a fair amount of sampling in the areas concerned and found that it is not difficult to take samples of high quality if these are chipped out from channels. However, larger samples do show up that the presence of numerous pebbles of hert, quartzite, quartz and even coarse sand does bring down the purity to 70-80%, even in the best areas.

We do not think that Dr. Martin can be blamed for quoting these better figures since he probably did not do the sampling, but accepted information given to him. Some of these beds certainly appear of better quality than what they are likely to be when mined.

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Author's reply to discussion

Reply to Dr. Fockema and G. A. P. Fraser

I would like to submit the following reply to the discussion by Drs. Fockema and Fraser:

I am grateful to Dr. Fockema and Mr. Fraser for pointing out that their work shows the figures, given in the reports quoted by me, to be too good. No sampling was done by myself. As the bulk of the impurities seems to be coarse, beneficiation should not be difficult or costly.