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CALCRETES AND THEIR FORMATION
A SURVEY BASED ON OBSERVATIONS IN SOUTH-WEST-AFRICA (*)

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Introduction

The problem of calcretes is becoming more and more of primary importance in the attempts to make use of arid areas for agricultural purposes. Opinions still differ considerably as to the formation of calcretes. Originally it was assumed that calcretes formed in the soil only (FRANZ, 1967; RUELLAN, 1967 and 1968, MACHATSCHEK, 1959). Later on calcretes were supposed to be formed in the ground only (FRANZ, 1967; RUELLAN, 1967 and 1968, WILBERT *et al.*, 1962). Furthermore there are reports of calcretes being formed on lacustrine sediments (DURAND, 1963; GOUDIE, 1968).

The disagreement in opinion refers not only to the formation of calcretes, but also to the use of the appropriate terms. In the USA alone the following expressions are used: « caliche », « caprock », « duricrust » and « hardpan ». In Europe calcretes are called: « calcareous crusts », « croûtes calcaires » and « Kalkkrusten », in South-Africa: « calcretes »(**), in East-Africa, India and Australia: « kankar » or « kunkar ». These are only a few examples of the different terms to be found in the literature.

It seems only to be unanimously accepted that calcretes cannot be formed in a completely arid climate. They need a climate with periodical dry seasons and an annual precipitation of 250 to 750 millimeters.

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(**) In this paper the term « calcrete » is used.

Observations in South-West-Africa carried out over years seem to indicate that there are several different types of calcrete formation. In this paper a preliminary review is given, which by no means claims to be complete. For reasons of clarity and perspicuity the chemical processes involved in the formation of calcretes are neglected.

1. Surface calcretes

The formation of surface calcretes cannot be denied, it is of universal validity. For this type of formation the following conditions are necessary :

a) a shallow, coarse-grained soil lying on rocks that are impermeable by water;
b) the existence of $CaCO_3$, either in the soil itself or in the seepage water.

In South-West-Africa these conditions are fulfilled on slopes with rocks containing Ca, either in the form of carbonates or in the form of silicates. These rocks may consist of alkaline magmatites, dolomites, marble or old calcretes.

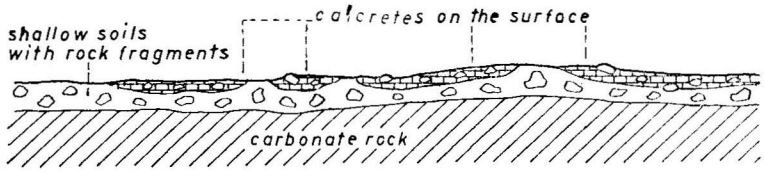
During heavy downpours water runs over the Ca-containing rocks, which frequently are still warm. As a result there is always some calcium dissolved in the form of hydrocarbonate. The shallow soils of the slopes, for the most part consisting of coarse-grained detritus, are moistened. Shortly after the rains they are again exposed to intense sunshine. Due to the heating and the resulting high gradient between the humidity of the air and that of the soil, the water on the soil surface evaporates before it can be used by the plants. The hydrocarbonate that has been dissolved in the water precipitates as $CaCO_3$, thus gradually encrusting the soil from the surface. Out of these crusts $CaCO_3$ may again be dissolved and precipitate on the soil further down the slope. By this process certain slopes of mountains may be covered completely by calcretes.

2. Calcretes within the soil

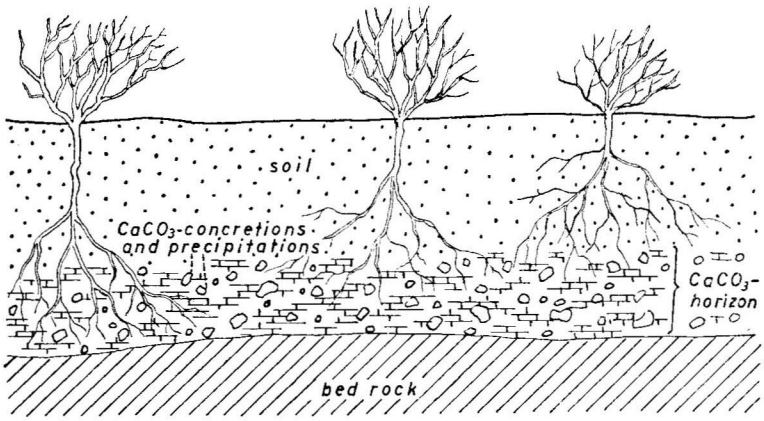
This type of calcrete formation occurs mainly in deep soils, if calcium is available, available either from plagioclase, pyroxenes and amphiboles or from the groundwater itself. Once such a soil is moistened, it does not dry out as quickly as a shallow soil. A rising of the groundwater by means of capillary action is of hardly any importance in South-West-Africa with its mostly slightly loamy to sandy soils. In the topsoil that is intensely heated by the sun most of the water evaporates below the surface.

In the soil itself the minerals containing calcium are hydrolysed. The Ca that becomes disengaged is now dissolved again as hydrocarbonate. As the soil is gradually drying out, this process being promoted by the plants, the concentration of the groundwater with its dissolved substances increases so that finally $CaCO_3$ precipitates.

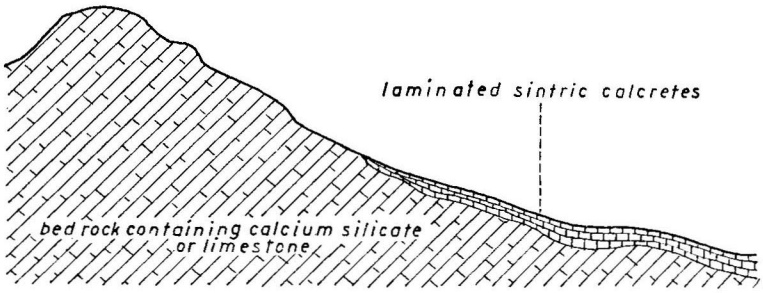
1. Calcrete formation by evaporation on the soil surface



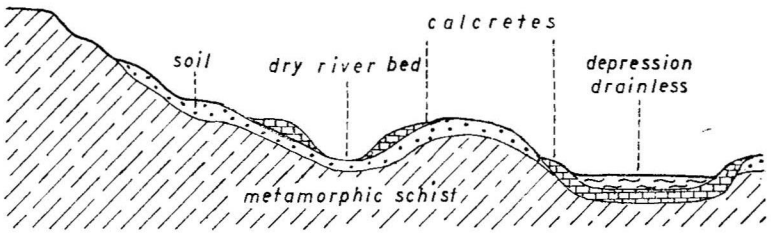
2. Formation of calcretes in deep soils by precipitation of $CaCO_3$ sometimes with formation of concretions



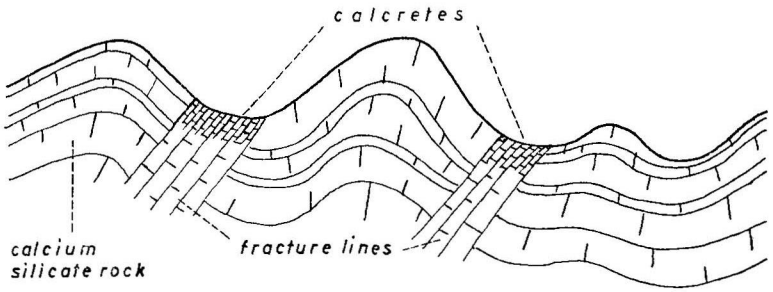
3. Formation of sintric calcrete by evaporation of run-off water



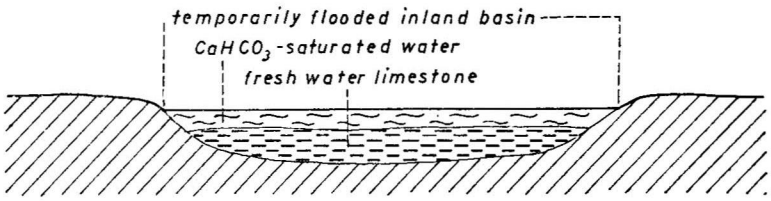
4. Formation of calcretes in the periphery of depressions and dry river beds



5. Formation of calcretes on fracture zones of calcium silicate rock



6. Formation of calcretes on lacustrine limestone



7. Formation of calcretes on eolian sands and gravels

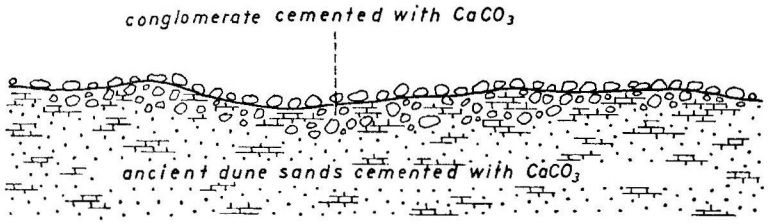


Fig. 1
Schematic view of the different ways of formation of calcretes.

On the one hand it may be a diffuse precipitation of $CaCO_3$, especially in slightly loamy soils. First it occurs in the fine cracks formed by shrinkage of the soil mass when drying out, and is then proceedingly developing from the outside to the inside of the aggregates, until finally a more or less solid crust may be formed, which, however, remains permeable by water. On the other hand the precipitation of $CaCO_3$ may occur in form of nodules, which grow by concentric precipitation of calciumcarbonate. This form is mainly found in soils with a single grain structure (fossil dune sands). The concretions thus formed become larger and larger until at last they grow together, forming a crust.

All these calcretes formed within the soil may be uncovered by erosion, mainly in periods of climatic alterations that frequently occur in arid climate zones. These denudated crusts are the reason for the contradictory theories about the development of calcretes.

3. **Calcretes as sintric deposits**

From the calcretes lying on the surface the rain water runs off evenly. In this way $CaCO_3$ is dissolved, which later, after the water has been distributed and — at least partially — evaporated, precipitate anew, forming thin layers and crusts. Thus crusts of a laminated structure with a thickness of up to several centimeters are formed on older crusts, which themselves could have developed within the soil as well. These crusts contain up to 80 % $CaCO_3$ and are free from coarse inclusions of sand or stones. They are formed not only at the surface, but in all places where calcareous water can flow and evaporate. Possibly existing cavities or crotovines can thus be outlayed with concentric crusts of $CaCO_3$.

In South-West-Africa the different structure of surface crusts can be observed in all climate zones. There is always a less homogeneous stratum below, which may be several meters thick containing many inclusions of the original sediment; this stratum is then covered by a more homogeneous laminated layer of only a few centimeters. Regarding the formation of these crusts, two different processes have therefore to be distinguished :

a) the crust formation within the soil itself and

b) the crust formation at the surface.

While the first is of pedogenetic origin, the latter is formed by a geological process, the depositing of sinter material. Sintric deposits such as these can be observed in all calciumcarbonate-containing rocks lying on the surface, as for example in dolomite and marble. These sintric calcretes cover the rock itself, as no soil is necessary for their development.

4. Calcretes on banks of rivers and depressions

In arid zones calcretes are formed to a large degree especially in those parts, where much water evaporates in a relatively short time, for example in the drainless depressions of the peneplains. These depressions sometimes have a diameter of only a few meters, but sizes of many square kilometers occur as well. In Southern Africa they are called « pans » or « vleys ». During the rainy seasons the water from the surrounding lands is collected in these basins or « vleys », resulting in temporarily floods. The water seeps partly into the underground, and partly into the marginal parts, which are thus intensively wetted. So these parts get much more water than the surrounding plains do from the precipitation. The amount of water that evaporates from the peripheral parts is accordingly larger. It is here that $CaCO_3$ precipitates. This $CaCO_3$ stems either primarily from the weathering of Ca-containing material, or secondarily from the water enriched with hydrocarbonate.

In consequence of this process $CaCO_3$ precipitations are found at the edges of all pans. In smaller pans they consist of loose, friable calcretes. In larger and older depressions the crusts can be several meters thick and very compact. The original soil material was blended with the crust material while it was formed, as can be seen from the enclosed material.

Fundamentally the same kind of calcrete formation takes place on water permeable banks of rivers. During the annual rains, when the rivers run, a great deal of water seeps into the banks at the sides. In the following process of drying out the same happens as in the peripheral parts of the pans. In South-West-Africa calcrete formations along the rivers is a typical appearance wherever the necessary amounts of $CaCO_3$ are available.

5. Calcretes on geological faults of Ca-containing rocks

In referring to Ca-containing rocks, carbonate rocks such as marble and dolomite are included, as well as alkaline magmatites or calcium silicate schists. If there are clefts, fissures or faults in these rocks, water can penetrate alongside these fracture zones. The water moves very slowly in this system of mostly tiny fissures, remaining there for a relatively long time. As a result of this the minerals are hydrolysed or dissolved. Thus the seepage water may contain larger amounts of hydrocarbonate. With the fissures drying out the $CaCO_3$ precipitates in form of thin layers

and crusts along the cracks and fissures of the rock. These calcretes on geological faults may reach depths of some meters or more: in fact as deep as the water is subjected to evaporation from the surface or to drainage through plant roots.

In South-West-Africa this type of calcretes can be found even in semi-deserts, and is of recent origin.

6. Calcretes on lacustrine sediments

In the northern and eastern parts of South-West-Africa calcretes of a thickness of more than 50 meters were detected by boring. Such enormous calcretes can not be explained pedogenetically. They can only be the result of sediments from large inland basins (pans), comparable to the calcareous sediments of the sea (BRINKMANN, 1964). In Botswana, Kenya, Tanzania and Australia calcretes are said to exist that definitely have been formed on lacustrine sediments (GOUDIE, 1968).

In South-West-Africa the Etosha-Pan is a proof that even in arid climates there are calcareous sediments similar to those of the sea. The Etosha-Pan is surrounded by calcretes that are somehow connected with the tertiary weathering of the dolomite. During rainfalls the crust material is brought to the Pan either through the mud or through the river water, in which it has been dissolved.

GEVERS (1930) found 40 % of dolomite in the sediments, which leaves no doubt as to the origin of the material. Both the sedimentation as well as the precipitation may extend over a long period of time, which might explain the enormous thickness of some calcareous deposits.

Out of these sediments calcretes are formed partly by diagenetical consolidation, and partly in the course of the gradual drying out of the pans during the dry seasons. Due to evaporation, the pH values and the concentration of the mineral salts dissolved in the water increase. With alkalinity rising the solubility of the silica increases (ALEXANDER, 1954). It finally precipitates on the surface and in the vertical fissures of the muddy calcareous sediment, forming coatings of up to several centimeters. Depending on the porosity the sediment itself may also be silicified to some extent. Thus the silicification of the lacustrine limestone is an important process contributing to the formation and induration of this particular type of calcrete.

As a result of the silicification the upper parts of the calcretes are much more compact than the lower ones. The lower parts are soft and chalky, the silicified parts on the other hand can be used

as building material. It is quite easy to remove these layers as long as they are fresh, but with growing age they become gradually harder.

Frequently lacustrine calcretes contain fossils of diatoms and snails. They are to be found in the limestone of the Etosha-Pan as well as in that of the Kalahari Desert (PASSARGE, 1904). They have, however, not yet been found in all the calcretes that are of lacustrine origin according to their petrographic structure.

7. Calcretes on dune sands

Calcretes may be formed in dune sands, too (see 2). In the following reference is made to calcretes that are not the products of a specific soil forming process. In South-West-Africa these calcretes are found mainly where the bigger rivers cross the bordering zone of the shifting sands of the Namib Desert. In order to explain the formation of these crusts, a short review of the geological history of the country is necessary.

Since the cretaceous period there has been a repeated change of dry and humid climates in Southern Africa (MARTIN, 1961). During a desert climate following a more humid period, large parts of the country were therefore covered by eolian sands. In this process the river beds were filled with sand, as there was no longer enough running water in the rivers to remove it. With a following increase of precipitation during another more humid climate, running water was found in the rivers again, at least occasionally; it levelled the sand and transported large amounts of rock fragments, which in part were deposited as gravel on the top of the remaining sand in the river beds. Several times the gravel and sand were saturated by the apparently calcareous river waters. The $CaCO_3$ precipitated and gradually cemented sand and gravel, this probably occurred as a result of dryer climatic conditions. After cementation of the sands, the gravel, in addition, was partly silicified. The crusts on the gravel are therefore much more compact than those on the cemented sands lying underneath.

If canyons are cut into these calcified dune sands, which can have a thickness of more than 50 meters, the softer sands being calciumcarbonate cemented and often flecked red-brown are much more affected by the weathering than the very strongly cemented gravels above. As a result of this they are decayed, and overhangs and caves are formed. PETTIJOHN (1965) called such cemented dune sands « eolanites ». For these calcified deposits the term « calcretes » can be used only with reservation.

DISCUSSION

Regarding the formation of calcretes there are some different types to be distinguished. The important factors contributing to their formation are, however, the same for all of them. The most important factors are as follows :

1. a climate with a periodical change of dry and rainy seasons and amount of evaporation being larger than that of precipitation;
2. the availability of a certain minimum of water for the dissolution of $CaCO_3$;
3. the availability of calcium.

It is not important whether the water as well as the Ca is of primary or secondary origin. The water may be derived directly from the precipitation, or else from its accumulation in fissures, valleys or basins; the Ca may be available from calcium silicates, carbonate rocks or from secondary limestone.

Therefore calcretes may be formed even in a desert climate, if sufficient rain water is collected, as it is the case, for example, in mountains of alkaline rocks with slopes free of any vegetation.

Calcretes of recent origin are known to exist also in semi-humid areas (FUECHTBAUER, 1970), but these are travertines or sinters(*). The formation of these crusts is based on different principles than the formation of calcareous crusts or calcretes in arid and semi-arid climates.

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Summary

Calcretes and the different types of their formation in arid climates were described, using the calcretes of South-West-Africa as examples. The following types were dealt with :

1. Surface calcretes
2. Calcretes within the soil
3. Calcretes as sintric deposits
4. Calcretes on banks of rivers and depressions
5. Calcretes on geological faults
6. Calcretes on lacustrine sediments
7. Calcretes on dune sands.

(*) E. g. in the case of the « Münchener Schotterebene », West-Germany, (personal communication).

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Kalkkrusten und ihre Bildung — Eine Beschreibung an Hand von Beobachtungen in Südwestafrika

Zusammenfassung

Die verschiedenen Entstehungsarten von Kalkkrusten im ariden Klima wurden am Beispiel Südwestafrikas beschrieben. Im einzelnen wurden behandelt:

1. Die Kalkkrustenbildung an der Oberflache
2. Die Kalkkrustenbildung im Boden
3. Die Kalkkrustenbildung durch Aufsinterung
4. Die Kalkkrustenbildung an den Randzonen von Niederungen
5. Die Kalkkrustenbildung auf Störungen Ca-haltigen Gesteins
6. Die Kalkkrustenbildung auf lakustrinen Kalken
7. Die Kalkkrustenbildung auf äolischen Sanden.

Croûtes calcaires et leur formation — Une description basée sur des observations en Afrique du Sud-Ouest

Résumé

Diverses formes de croûtes calcaires ont été décrites sous climat aride en prenant comme exemple ceux de l'Afrique du Sud-Ouest. Les types suivants ont été étudiés.

1. Croûtes de surface
2. Croûtes dans le sol
3. Croûtes scoriacées
4. Croûtes sur les levées des rivières et dans les dépressions
5. Croûtes associées à des failles géologiques
6. Croûtes sur sédiments lacustres
7. Croûtes sur sables dunaires.

Calcreten en hun vorming — Een beschrijving aan de hand van waarnemingen in Zuidwest-Afrika

Samenvatting

Verschillende vormen van calcreten en hun vormingswijze werden beschreven aan de hand van voorbeelden uit Zuidwest-Afrika. Volgende typen werden bestudeerd.

1. Oppervlaktekorsten
2. Calcreten in de bodem
3. Sintel calcreten
4. Calcreten op oeverwallen en in kommen
5. Calcreten geassocieerd met geologische breuken
6. Calcreten op meerafzettingen
7. Calcreten op duinzanden.
