THE INTERPRETATION OF SOME BASIC CALCRETE TYPES

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Introduction

Calcretes are associated with many sites of archaeological or palaeontological interest in southern Africa and have long interested Quaternary workers, probably mainly on account of their possible palaeoclimatic implications. These materials are still not fully understood however, and it is the purpose of this paper to illustrate some of the basic types and to attempt to deduce something about the conditions under which they formed. There are many different types of calcretes, and as they have not previously been fully described or defined and as a comprehensive work on their detailed classification is being prepared for publication elsewhere, only the most useful types from the interpretation point of view will be selected for discussion here. The types dealt with are nodular calcretes, calcified gravels and sands, hardpan calcretes and boulder calcretes, and have been briefly described by Netterberg (1967).

It should be noted that rainfall figures given are approximate, since although climate (of which rainfall is only a part) is the most important calcrete-forming factor, like all soils, calcretes are subject to all the usual soil-forming factors, as well as to changes of these factors with time. It is also not yet possible to recognize all cases of polyphase calcification, another reason for restricting this discussion in the first instance to some simple basic types. The effect of all the other pedogenic factors except perhaps the subfactors annual rainfall and temperature distribution are however probably seldom equivalent to more than about ± 50 mm of mean annual (mainly summer) rainfall. Calcretes can occur under slightly higher rainfall conditions if temperatures are also higher, Crowther's leaching factor (see Robinson, 1949) probably roughly holding. The effect of the annual distribution of rainfall has not been studied, but is probably quite important. Absence of a source of carbonate (for example the Waterberg and Table Mountain sandstone and Namib active dune areas) and insufficient time (also a factor in the Namib dune area for example) can also occasionally cause quite large deviations from the figures given.

Nodular Calcretes

Plate I shows a typical nodular calcrete profile, consisting of about 18 in. of non-calcareous brown silty sand overlying at least 8 ft of loose nodular calcrete. The fines of the upper 6 in. or so of the nodular calcrete are in this case not typical, in that they are non-calcareous. Only in the lower parts of the profile are the fines strongly calcareous.

Interpretation

Nodular calcrete normally represents an early and probably active stage of calcrete development, but in the profile illustrated the upper 6 in. of calcrete is not forming, but is being leached out and the carbonate deposited lower down in the profile. The upper calcrete is thus fossil and the lower calcrete active. This phenomenon could be brought about by an increase in rainfall or permeability of the topsoil or a decrease in temperature (causing a decrease in evaporation), topsoil thickness, run-off or evapotranspiration from the profile. It may be difficult to decide whether any change in the vegetation, run-off or overburden thickness has taken place, but a microscopic study of the sand grains and heavy minerals present would show whether there has been any change in overburden type. While clay eluviation would also have caused an increase in permeability, the carbonate horizon would have migrated downwards to keep pace with this, so that this cause can be ruled out.

A thick deposit of nodular calcrete of this sort indicates rainfall conditions at the time of its formation of less than about 550 mm (22 in.), but depending on drainage and parent material, much thinner deposits (usually also with not such strongly calcareous fines) could form under a rainfall of up to 800 mm (32 in.) or more. The present-day rainfall received by this profile is difficult to assess. It lies midway between Pienaarsrivier (535 mm) and Rust-Der-Winter (590 mm), but Kalkheuvel, halfway between Pienaarsrivier and the profile, receives 815 mm. The surrounding country is generally flat and the altitudes of the three stations are within 13 m of each other. The nearest temperature station is Kalkfontein, 5 miles north of Pienaarsrivier (18·6°C annual average). Several calcrete profiles in this general area exhibit this feature of possessing non-calcareous fines in their upper part, supporting the possibility that the rainfall has increased since the nodular calcrete was formed. The time that the change in leaching depth occurred could be assessed by C14 dating the fine carbonate lower in the profile. Some work could usefully be carried out on this aspect as it is not yet possible to state exactly what fraction to use or from which depth it should come. The initial C14 content to assume is another difficulty, but this aspect will be dealt with elsewhere (Netterberg, in preparation).

It is of interest to note that on the basis of stream rejuvenation, the dying out of trees typical of more arid areas such as the Kalahari and the establishment of moisture-loving species, in 1927 Wagner had postulated that the Springbok Flats receives a higher rainfall now than it did in the past. Calcrete nodules may be of pedogenic or non-pedogenic origin.

Calcified Gravels and Sands

The calcified gravels and sands of the Vaal and other rivers must be familiar to most Quaternarists

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PLATE I.

(plate II). These are among the thickest of calcretes and attain unbroken thicknesses of 30 ft or more. The deposits are normally massive and well-cemented, the only structure being due to bedding inherited from the original deposit.

Interpretation

If the deposits were calcified as they were deposited, one would expect to find that layers of non-calcified material are common. The reverse is however the case, though occasional layers of non-calcified material as well as possibly pedogenic hardpans are found in some profiles. Such great thicknesses of calcification cannot be ascribed to pedogenesis and for other reasons as well (Netterberg, in preparation), the deposits must be regarded as largely having been calcified after they were formed as the water table slowly dropped in the alluvium. A fluctuating but steadily dropping water table under semi-arid conditions (rainfall less than about 550 mm) would be required. As some of the youngest alluviums in the Windsorton area are not calcareous, it is uncertain whether the above conditions are met at the present time. Recent non-calcareous alluviums are also common in South West Africa under much more arid conditions than prevail at present in the Windsorton area (386 mm and about 18°C). The source of the carbonate was probably the river water, though the underlying bedrock (mainly Ventersdorp diabase or Dwyka shale at Windsorton) may also have contributed. C14, C13 and O18 measurements should yield data on which materials are being calcified at the present time and the source of the carbonate.

It is interesting to note that the cement of the 'calcified' sands in at least one profile through the Younger Gravels II at Riverview Estates is dolomite and not calcite as is the case of the 100 ft gravels at Proksch Koppie, the 200 ft Basal Older Gravels at Ions' Claim and the pedogenic bouldery and hardpan calcrete overlying the 'calcified' sands. While the origin of the dolomite is by no means yet solved, the necessity for hypersaline conditions is one factor which is accepted by the adherents of all hypotheses for the origin of dolomite. The nature of the carbonate cement of the gravels underlying the 'calcified' sands is unfortunately not known, but it would seem that conditions of very much more intense evaporation prevailed at the time of 'calcification' of the 'calcified' sands (First Intermediate) than at the time of calcification of the other deposits. At the time of formation of the bouldery (probably Recent) and hardpan calcrete (probably Second Intermediate) overlying the 'calcified' sands, magnesium was largely (but not completely) eliminated. This would indicate wetter conditions than those which prevailed during the time of dolomite formation.

The lack of nodule development is normal in clean sands and gravels and the stage of development of the calcified gravel in plate II lies just below the hardpan stage. Note also the makondo or pothole development and the two hardpan-like layers.

Hardpan Calcretes

A typical tufaceous hardpan calcrete (the Pfannenkalktuff, Schneckenkalk, vlei limestone and diatomaceous pan limestone of other authors) is shown in plate III. The typical profile consists of 12 to 18 in. of grey silty sand overlying up to 18 in. of grey, lightweight, porous hardpan containing gasteropod shells and diatoms which in turn overlies several feet of calcrete at an earlier stage of development—in this case a leached (?) nodular calcrete. The soil cover is often absent and these hardpans commonly outcrop around pans and along watercourses. Stone artefacts are often associated with this type of hardpan and in this particular case the artefacts (provisionally Later Middle Stone Age/Second Intermediate—Miss H. R. MacCalman, 1965; personal comm.) are exposed underlying the calcrete in another pit about 50 ft away.

Interpretation

The hardpan is interpreted as the final stage of calcrete development wherein all the nodules (in this case) have become cemented together. This particular example is undergoing solutional wastage and starting to weather to boulder calcrete. This probably indicates an increased depth of leaching at present over that which prevailed during hardpan formation and may indicate increased rainfall since hardpan formation. This is of course subject once again to the other possibilities already mentioned, although in this case while a change in overburden texture is possible, much change in thickness is unlikely, since the hardpan is already near the maximum depth at which hardpans probably form. The present rainfall at Runtu is 626 mm, higher than the normal conditions under which hardpans occur (about 550 mm), though the annual average temperature at Runtu is also higher (22·4°C, Weather Bureau; personal comm.). The carbonate appears to have been leached from many calcretes (whether outcropping or not) in the Runtu area, including many of the nodules underlying the hardpan in plate III, supporting the hypothesis of increased rainfall. It is also of interest to note that two radiocarbon dates on this hardpan yielded apparent ages of 11,390 and 12,550 years B.C. (Netterberg, in preparation), indicating that it formed during the Second Intermediate, generally held to have experienced a climate drier than the present.

Hardpan is difficult to explain merely as the logical end product of pedogenic calcrete formation. If this is merely the case, why does a solid layer several feet thick not form instead of the more usual thin crust, as in plate III? Two possibilities exist. The first is that the growing together of the upper nodules decreased the permeability so that hardpan could not form lower down in the profile and the second is that a decrease in leaching depth (probably occasioned by a decrease in rainfall) took place and the bottom of the hardpan marked the level of the new depth of leaching. Carbonate would then be leached from the nodular calcrete above this point to cement the nodular calcrete lower down into honeycomb and finally into hardpan calcrete. The transition between the bottom of the hardpan and the underlying looser calcrete is usually remarkably sharp. No hardpan calcrete assessed in the field as possibly active has been observed with a lower surface at greater than about 3 ft.

Hardpans are extremely widespread in that part of southern Africa receiving less than about 550 mm of rainfall at present, but most of them are outcropping or are undergoing boulder formation. They are therefore fossil, but the interesting point is that there does not seem to be any well-defined transition zone, i.e. in many places hardpans or boulders crop out up to say the 550 mm isohyet, but do not occur at all on the wet side of it. If widespread hardpan formation is taking place in southern Africa at present, one would expect a calcrete map of southern Africa to show a transition between nodular calcrete via honeycomb calcrete to hardpan calcrete (which would not outcrop) on a regional basis across the 550 mm isohyet. To the author's knowledge this transition zone of honeycomb calcrete does not exist. Where then are the actively forming hardpans? There does not seem to be any entirely satisfactory answer to this at the moment. Honeycomb calcretes with calcareous fines can be taken to be actively forming hardpans, but they are rare. It is thus tempting to suggest that there are none, or at least that very little *hardpan* formation is taking place in southern Africa at the present time. This would at first seem unlikely, since surely the range of aerial climate and other pedogenic factors in southern Africa must be sufficient to ensure hardpan formation somewhere. A special *change* in climate may however perhaps be necessary, such as the waning of a pluvial. This should decrease the depth of leaching and in a nodular calcrete profile should theoretically form the typical mature calcrete profile, i.e. about 18 in. of soil overlying up to 18 in. of hardpan calcrete overlying several feet of looser calcrete. An alternative explanation for the vast areas of outcropping hardpan and boulders (mostly Second Intermediate?) even outside the Kalahari Limestone area (Pliocene?) may be that the calcretes brought this situation on themselves (killing themselves off so to speak) by creating an horizon impermeable to water very near the surface conducive to the erosion and devegetation of the overlying soil.

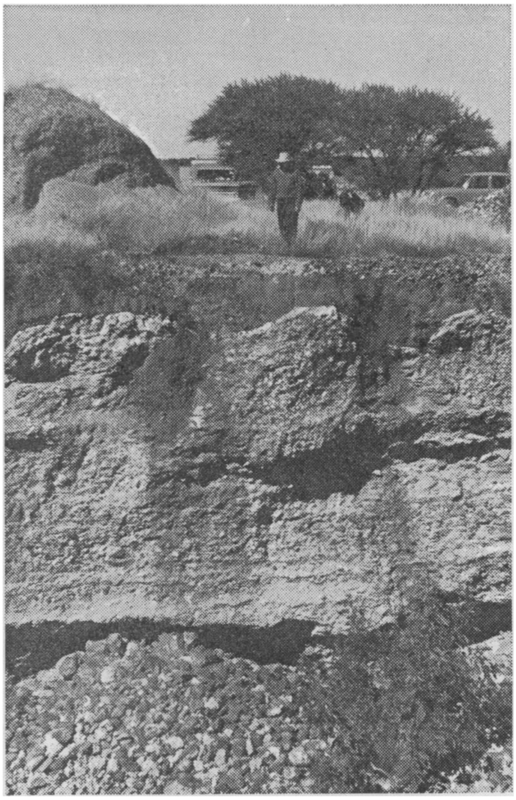


PLATE II.

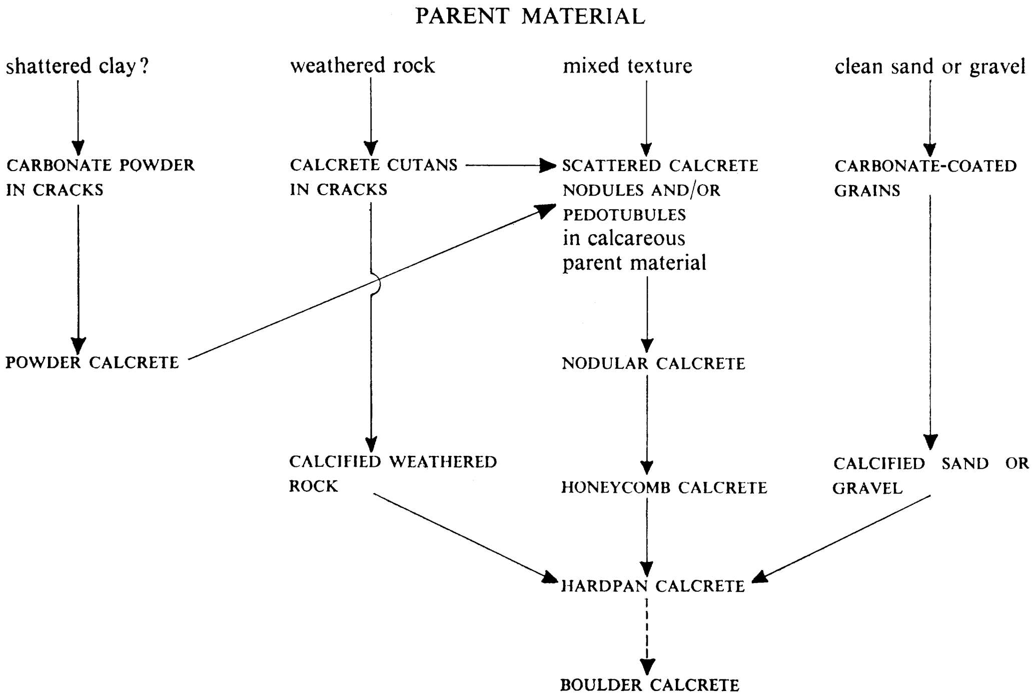
It should be noted that an increase in rainfall would tend to leach a hardpan horizon downwards, but that a decrease in rainfall could fossilize it, as it would not tend to migrate upwards but would remain

PLATE III.

PLATE IV.

TABLE I

Suggested sequence of calcrete development



fixed in position. An aggrading profile would cause a similar effect and this is thought to be the explanation for multiple hardpan layers. This basic principle probably first appeared in the work of Breazeale & Smith (1930)—still one of the best works on calcrete yet published.

Boulder Calcrete

A typical deposit of boulder calcrete is shown in plate IV. When covered by soil the boulders are always rounded on their upper surfaces. The soil in which they occur is almost invariably non-calcareous and the boulders themselves are among the hardest of calcretes.

Interpretation

Boulder calcrete is considered to be a weathered hardpan calcrete and is therefore a fossil calcrete. Hardpan weathering to boulders can actually be seen in some profiles and the deposit in plate IV is such an occurrence. Outcropping calcretes weather also to boulders, but with the typical limestone solution faceting.

Boulder calcretes occurring under a rainfall of more than about 550 mm may indicate increased rainfall (but see also the other possibilities already mentioned), the boulders being leached and the carbonate deposited as laminae on their lower surfaces and also lower down in the profile. The example shown is at Grootfontein in South West Africa (543 mm and about 22°C).

Probable Relations between the Basic Types

The relative degree of development of the particular calcrete studied may be interpreted from the suggested sequence (see table 1):

The above sequence probably caters for all single phase calcrete types. The sequence of Gile *et al.* (1966). does not cater for several important basic types, while that of Netterberg (1967) is both also incomplete and misleading at one point, as only a calcified sand with some silt or clay content could probably develop into a nodular calcrete, and not a calcified clean sand as implied by him. Netterberg also suggested that Du Toit (1956 or earlier) may have been the first to propose the coalescing nodule hypothesis of calcrete formation, but it would appear that credit should rather go to Hawker (1927) or Fox (1905)—see Price (1933).

A calcrete profile owing its origin to several phases of calcification will exhibit more than one of the basic types if each phase of calcification has proceeded far enough to be recognizable by simple visual inspection.

They may or may not be separated by more or less non-calcareous material.

Conclusions and Summary

1. While a reasonable explanation can be given for most calcrete profiles, possible variation of a number of factors does limit their usefulness as indicators of the palaeo-environment. Some of these factors can probably be accounted for by detailed study of the whole profile.

2. Palaeo-climatic significance can only at present be assigned within broad limits. On the basis of present-day occurrence, *scattered* calcrete nodules, pedotubules, cutans and powder-filled cracks and *thin* (less than 1 or 2 ft thick) nodular calcretes only indicate a rainfall of less than about 800 mm (32 in.) under present South African climatic conditions. The more advanced calcrete types only indicate conditions drier than about 550 mm (22 in.), although a special change in climate (such as the waning of a pluvial?) may possibly be required to bring about hardpan formation.

3. The amount of information that can be gleaned from the visual observation and description of calcretes has possibly reached its limit and further advances will probably only be made by the application of modern geochemical, geochronological, sedimentological and pedological techniques. Much scope exists for work along these lines, both in southern Africa and elsewhere.

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