# CALCRETES IN NAMIBIA AND SE-SPAIN RELATIONS TO SUBSTRATUM, SOIL FORMATION AND GEOMORPHIC FACTORS

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## **SUMMARY**

Genetic relations of calcretes to substratum, soil formation and geomorphic factors were studied in Namibia (eastern Namib and Erongo mountains). The results have been confirmed by investigations in SE-Spain. Methods used included observations on the macro- and microstructure, and petrological examinations of the residues after treatment with 3-4% HCl.

Calcretes are not restricted to any particular type of substratum: host sediment can be nearly pure quartzose dune sand, granitic or basaltic debris, limestone gravels, marls, fossil soils and others. To generate calcrete, only loose sufficiently permeable material is necessary to absorb CaCO<sub>3</sub> by descending solution transport or clastic infiltration.

The causative factor is allothic eolian material ('loess'), bound to special climatic phases: The eolian components, which are found within the calcretes covering the wide-

phases: The eolian components, which are found within the calcretes covering the wide-spread peneplain around the Erongo mountains, prove the allothic origin of the carbonate in the duricrusts. The residues consist mainly of physically weathered detritus, and of eolian sand and dust. Loessic sediments are found NW of Erongo (near Khorixas) in rather fresh condition because of the arid climate. The light brown loess contains the same red sand as the calcretes mentioned. Brown soils on loessic material with thick calcic and petrocalcic hori-zons of nodular structure are found around Erongo, near Waterberg. This region recieves 400-600 mm rainfall, which causes descending infiltration of the CaCO<sub>3</sub>. Eolian components

have been found in Spanish calcretes, too, even in those developed on silty marls.

Calcretes pass through several stages: 1. A subterraneous stage with a descending calcic or petrocalcic horizon, syngenetic or postgenetic with dust sedimentation. 2. A subaerial stage of macro-structural diagenesis, including exhumation and surficial weathering, leading to a hard upper and a lower nodular crust. 3. A late diagenetic stage of surficial transformation; solution by run-off water, void filling, formation of lamellar (and algal) structure on

top of the calcrete.

C-14 dates of upper crust samples from different calcretes of the youngest generation have produced ages of 30000 to 15000 years B.P. Because of contamination, the dates apply only to the subaerial diagenetic stages, while the actual time of carbonate accumulation (stage 1) may be much older and separated from the subsequent stages by a long time interval and different elimete. and different climate.

Observations in and around Erongo, eastern Namib and SE-Spain indicate that in siliceous substrates calcretes can be formed only by allothic (eolian) increment and that relief factors are subordinate. On slopes and footplains (glacis), run-off water from the mountains enhances calcrete development in the proximate parts, by washing down the aerosolic dust.

This review paper cannot consider all arguments and discussions to be found in the extensive literature treating the calcrete phenomena in the last few decades. We attempt merely to show and identify the significant factors causing calcretes and seek to comprehend the corresponding, complicated genetic process (arguments and local examples have been spliced out of a larger manuscript; see extend documentation and details in BLUMEL, 1981). In spite of the wide regional and global spatial distribution of calcretes there has never been either a consensus concerning the relevant climatical and ecological conditions, or about their basic petrographical and/or pedological status. The following analysis thus relates calcrete genesis to (1.) type of host sediment/base rock, (2.) to eventual soil-forming processes, and (3.) to geomorphic factors.

# 1. RELATIONS BETWEEN CALCRETES AND HOST SEDIMENT

The definition and genesis of calcrete is often based on the character of the host sediment (f.e. ARISTARAIN 1971, BLAKE 1901, GOUDIE 1972, RATHJENS 1957 a.o.). A CaCO<sub>3</sub>-rich substratum is believed to be most favourable to form calcretes. Representing many authors, VAN ZUINDAM (1975, 93) states:

"Calcrete can be found in, and on many base rocks. According to CHOUBERT (1948, p.1613) the most favourable rocks are calcium-rich types such as marls, marly lime stone and calcareous sandstones; silicate-rich rocks and clay-types would not be favourable. GILE et al. (1966, p. 347-348) found that calcrete can also be found on coarse alluvial fan material as well as on finer sediments which may or may not be carbonate bearing. BROWN (1956, p. 2) reports that in Texas, U.S.A., calcrete commonly rests upon uncemented gravels, sands, and silts, and where this unconsolidated rock is missing, it rests directly upon limestone and sandstone."

It is necessary to supplement the contents of this fundamental quotation by some explanatory and corrective remarks:

Calcretes are not restricted to any particular type of substratum. In the regions mentioned in the title calcretes (showing the same macro-structure) are to be found on a wide variety of loose sediments. The spectrum consists for example of quartzose sand (border of the Namib desert/SWA), coarse granitic sands, basaltic debris (Erongo mountains/SWA), CaCO<sub>3</sub>-rich marls and marine deposits (SE-Spain).



Photo 1: Peneplain (1000 m NN; cutting different – mostly siliceous – paleocoic rocks) and Spitz-koppen-inselbergs (granite) WSW of the Erongo-Mts./Namibia. The erosional surface is completely covered by polygenic calcrete. Only the recent episodic rivers destroy the duricrust by incising up to several metres.

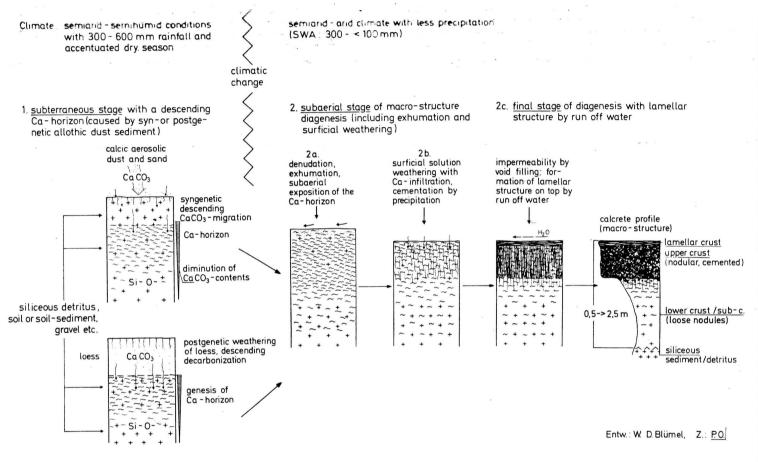


Fig. 1: Multistage process of calcrete genesis on/in siliceous host sediments (Namibia, SE-Spain)

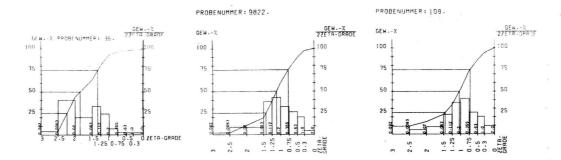


Fig. 2: Calcrete-residues ( < 2 mm grain-size; after treatment with 4% – HCl) showing the influence of flying sand and dust on the origin of calcrete.

95 calcrete-residue (SE-front of the Erongo-Mts., Onguati-station; calcrete with enclosed gravels

of an elder crust; see tab. 2)
9822 calcrete-residue (upper/lower crust, -30 cm/foot of the Erongo-Mts., SE-front, Farm Onguati; see photo 2d)

108 calcrete-residue near Spitzkoppen-inselbergs (peneplain; SW of the Erongo-Mts., see photo 1)

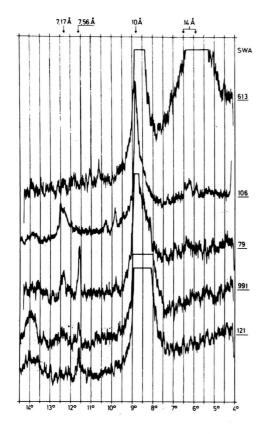


Fig. 3: Clay minerals in calcretes and soils from the Erongo-Mts. and surrounding peneplain (Namibia)

613 recent soil on granodiorite (Cv-horizon, 60 cm deep/Erongo)

106 recent soil on basaltic rocks (dyke near Spitzkoppen-inselbergs/peneplain)

79 calcrete on granite (Farm Etemba/Erongo) 991 weathering calcrete on siliceous sediments (Groot Rooiberg, Farm Ameib; Erongo)

121 calcrete on diff. sedimentary rocks of the Damara-system (road from Usakos to Karibib/peneplain)

14 Å = smectite-group; 10 Å = micagroup; 7,17 Å = caolinite; 7,56 Å = gypsum

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To generate calcrete, only loose and sufficiently permeable material is necessary to absorb CaCO₃ by solution transport and subsequent precipitation or soaking of clastic carbonate particles. We even found strongly cemented calcretes in clay-rich soil-sediments (dislocated terra rossa?) in Spain. Loose substrata constitute a skeleton of the initial ca-horizon, i.e. the first stage of calcrete genesis ( ⊆ subterraneous stage; see fig. 1).

Calcretes have been analysed by us in different petrographical environments, as well as under various geomorphic situations. This analysis was necessary to identify the origin of the cement (matrix) – the most decisive factor in calcrete genesis.

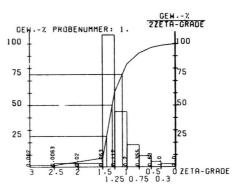
Under purely siliceous conditions with only low level chemical decomposition of the host substratum (e.g. intramontaneous basins of the Erongo mountains/SWA) it is to be expected that the calcretes would be generated by allothic eolian ca-carbonates. The imported  $CaCO_3$  is post- or syngenetically transformed and dislocated by a 'pedogenic' process (see fig. 1).

It is impossible to regard the calcrete-forming substrata for example as viei (pan) deposits because the basins of the Erongo extend in different altitudes (HÜSER 1977, 119 ff.) without any river coming from reas outside the siliceous mountains to import carbonate sediments.

The eolian origin of calcrete covering the wide-spread peneplain around the Erongo mountains (photo 1) is also undoubtedly proven, too. The erosion surface is cutting different, primarily non-calcic, sediments/metamorphic rocks of the Damara system. Some characteristics of the calcretes are:

- 1. The calcrete-residues (after treatment with 3-4% HCl) of samples from the inner Erongo, as well as from the surrounding peneplain, contain considerable quantities of allothic rounded quartz-grains (wind-borne sand with pellicles of Fe<sub>2</sub>O<sub>3</sub>; dominant fine-grained; see fig. 2). Their character corresponds to the red sand of the Namib desert.
- 2. About 170 km NNW of the Erongo, sediments similar to loess have been found in flat depressions (photo 2a). They contain the same red sands which could be proved as cemented in the calcretes further south. The sediment is composed as following:

location	CaCO <sub>3</sub>	sand	silt and clay	
Twyfelfontein Khorixas	26% 14%	24% 33%	50% 53%	



- 3. In all calcretes analysed from Namibia and Spain, gypsum is to be identified by use of X-rays. It is, however, absent in all recent soils or noncarbonatic soil sediments. Gypsum seems to have been part of the CaCO<sub>3</sub>-dust accumulation and has been fixed in the originating ca-horizon and subsequently in the cemented calcrete-profile (see fig. 3).
- The degree of chemical decomposition of the host sediment is rather low. Unweathered feldspar and mica (fig. 3) are to be found in high quantities. Newsynthesis of CaCO<sub>3</sub>,

by in situ weathering can be ignored: neither in Namibia nor in Spain was any hint at a corresponding, massive upper soil (= origin horizon for new-built CaCO<sub>3</sub>) to be observed.

On the contrary: the petrographical analysis of the calcrete residues suggest definite divergences in comparison with the grain spectrum of recent soils. Sample 62 and 67 (fig. 4) illustrate the characteristic higher proportion of coarse components, whereas in all calcrete residues sand of fine and middle size are dominant (samples 781/85 and 8821/632 in fig. 4). This is evidently caused by eolian transport of sand together with silt and CaCO<sub>3</sub>.

Even in statistical experiments by means of different petrographic parameters (BLÜ-MEL 1981), the genetic relation between calcretes and eolian sand becomes clear (see fig. 5): Samples from the eastern Namib possess high proportions of sand already initially, whereas host sediments of the Erongo are enriched by allothic sand – to be demonstrated in the near statistical correlation of both. The composition of loess (Khorixas and Fransfontein) corresponds very well with Namib samples, too. However, there are also statistically widespread recent soil samples out of and around the Erongo with (only very low) correlations to the calcrete residues.

This kind of air-borne sands mentioned above as well as the carbonate material don't belong to the normal petrographical inventory of the concerning regions. Obviously, the wind-borne sand and the calcic dust belong together and mark paleo-climatic phases when

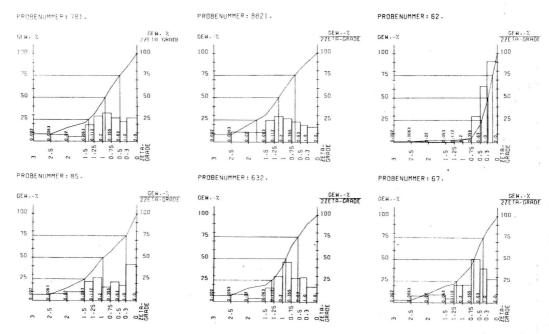


Fig. 4: Grain-spectrum (< 2 mm Ø) in calcretes, calcrete-residues and recent soils from intramontainous basins of the Erongo (Namibia). 781/85 residues of high indurated calcretes

8821/632 unsoluble skeleton of weathering calcretes following recent soils on granite and basaltic rocks

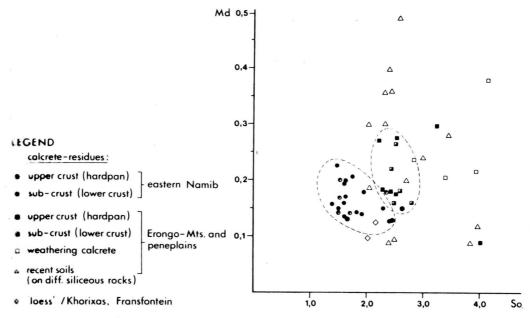


Fig. 5: Statistical relations of calcrete-residues, soils and loess (Namibia). - Md : So (TRASK) -

they have been transported in rather high quantities. Nowadays observations in Israel concerning partly recent airborne dust and sand with the same grain-size and composition confirm this correlation (see YAALON & DAN 1974, YAALON & GANOR 1973). The term 'loess' for those sediments may be uncorrect and is not used in sensu stricto because of the grain-size (Md over  $100~\mu m$ ; fig. 5). The properties of the Fe-coated sand are similar to those of the Namib. The desert, however, can scarcely be regarded as the region of origin of the calcic dust, too, because of its primarily non-calcic components. This question cannot be answered. Maybe that the sinking sea-level during glaciation periods in the Pleistocene caused deflation of calcic silt and clay along the coastal border. Annother possibility could be changing wind-systems mixing sand from the Namib and calcic dust from the Etosha pan or surrounding.

### 2. RELATIONS BETWEEN CALCRETE AND SOIL FORMATION

This section is concerned with the relationship between calcretes and soil formation. The pedogenetic explanation of calcrete formation is gaining wider acceptance and evidence (ROHDENBURG & SABELBERG 1969, 1973, SABELBERG & ROHDENBURG 1975, WERNER 1971). It would be, however, more prudent to disassociate from the term 'pedogenetic' and rather to use more common formulations such as 'per descensum' (DURAND 1963), 'by descending water movement', or others. This is because the term 'pedogenetic' usually suggests in situ processes – in this case the carbonisation (= CaCO<sub>3</sub>-dislocation of Ca(HCO<sub>3</sub>)<sub>2</sub> within a calcic soil.

This is not the case, however, with the numerous calcretes in or over siliceous host

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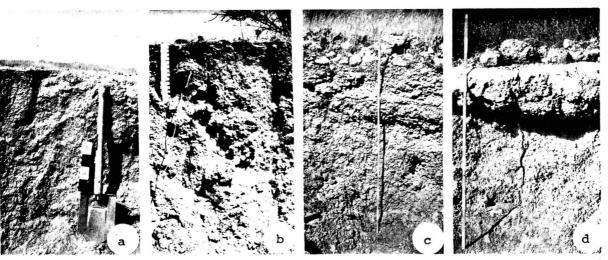


Photo 2 a-d: Illustrations concerning stages of calcrete genesis in Namibia:

 (a) Loess (intersperced by ca-concretions) near Khorixas and Fransfontein – conserved under rather dry climatic conditions: ~ 200 mm rainfall.

(b) Ca-horizon (weathering loess?); descending water produces a nodular accumulation of CaCO₃ near the surface (scale: 30 cm). Nowadays rainfall: ~ 600 mm. (Waterberg region; E Otjiwarongo)

(c) Exposed stage of diagenesis: the exhumation of the ca-horizon, subaerial weathering and syngenetical induration under rather arid conditions lead to the formation of an upper crust (eastern Namib: N Solitaire).

(d) Final stage (= complete profile of a calcrete): Thin laminated crust on top formed by runoff water; strongly cemented upper crust; lower crust with the former structure of the nodular ca-horizon (Farm Onguati; SE-front of the Erongo-Mts.).

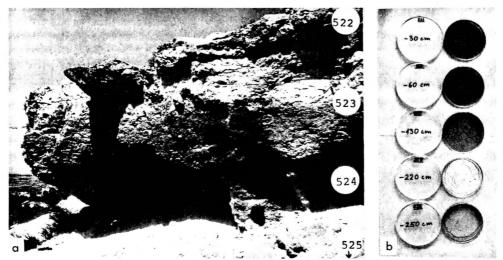


Photo 3a, b:

(a) Calcrete profile forming the top of a table mountain on/in tertiary marls (near Sucina, SW of Murcia/Spain).

(b) Calcrete residues (after treatment with 4% HCl) show organic matter and colours of a paleo-soil completely incorporated by proceeding induration/ca-accumulation.

Fig. 6: LA I. partly p clastic | II. UPI 65-95% in easy debris laminat accentu indurat voids b of volu III. LO host m nodules strata ( dusty diminis tance IV. HO calcic o sand, m detritus

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Fig. 6: Structure and common features of calcrete I. LAMINATED CALCRETE

partly pellicles of calcite; algal structures; oxide-films; few clastic particles; > 95% soluble in HCl
II. UPPER CRUST (hardpan calcrete; caprock)

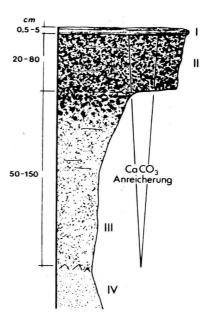
65-95% CaCO<sub>3</sub> (medium: 80%); mostly nodular structure in easy permeable host sediments (sand, gravel, rock debris etc.); in loamy host material often horizontal lamination; in clay-rich substrata seldom regular or accentuated structures; usually high degree of induration; in nodular calcretes sometimes non-filled voids between cemented concretions; enormous growth of volume

III. LOWER CRUST (sub-crust)

host material/skeleton identical to upper crust; loose nodules or weak cementation; in clay- and silt-rich substrata cloddish-irregular aggregations, between them dusty components; CaCO<sub>3</sub>-enrichment 25-65%, diminishing by growing depth; low geomorphic resistance

IV. HOST MATERIAL ('base rock')

calcic or siliceous permeable sediments: eolian or fluvial sand, marls, soils and soil-sediments, rock debris, gravel, detritus a.s.o.



sediments. In such cases, allothic CaCO<sub>3</sub> subsequently develops into a duricrust-material which had not earlier been a part of the ecosystem concerned (fig. 7). This observation conceals a direct causal relationship between climate and calcrete formation:

Any CaCO<sub>3</sub>-rich base rock/sediment is necessary for the origin of such duricrusts, but only certain climatic conditions lead to the import of calcic dust-deposits ('loess'). Loess, or parts of it, can be transported by syn- or postsedimentary means into the underneath substratum (photo 2b). This process generates a ca-horizon (= calcic accumulation by descending water) without the prerequisite of a high leaching-horizon. Micro-structure observations further demonstrate sedimentary and cristalline matrix (calcite), produced by solution and precipitation (BLÜMEL & T. VOGT 1979). Change of climate to more arid conditions causes diagenetic processes within the former nodular ca-horizon and the resulting proper macro-structure (fig. 6). These processes are demonstrated schematically in fig. 1.

The origin of calcrete, therefore, is evidently a climatic-ecological succession (photo 2): the initial stage (i.e. proper 'genesis' in an ecological significance) may be seen in the ca-horizon because of its allothic character. The contemporary profile (indurated upper crust and loose nodular lower crust; see fig. 6) is the result of different stages of diagenesis (fig. 1), altering the fossil ca-horizon by partial surface-weathering, ca-infiltration and precipitation. Those processes are climatically independent of the earlier subterraneous ca-accumulation. They take place under more arid conditions as mentioned above. In this context, we should distinguish carefully between initial (climatic) origin and resulting macro-structure of the duricrust. More details can be gathered from fig. 1, 7 and its annotations.

The term 'pedogenic' as used in connection with the origin of calcrete should not be too narrowly interpreted. 'Pedogenic' in this context means – as mentioned above – descending infiltration and accumulation of CaCO<sub>3</sub>. Further examples confirm this conception: regions possessing calcic material as 'base rock', real pedogenic in situ formation of a ca-horizon is no problem. The mechanism is solution weathering by rainfall, descending decarbonisation and precipitation during the arid season. Any allothic influence on principle is necessary to

Tab. 1 'EL ALTEA': CALCRETE IN/ABOVE TERTIARY MARLS (road from Sta. Pola to Alicante/Spain)

stratum	description	sample	CaCO <sub>3</sub>	residue*	residue-		MUNSELL- colour	
(cm)		(nr)				silt + clay		
			%	%	%	<u> </u>		
CALCRE	CTE							
40-50	upper crust: strongly indurated calcrete; with encluded flying	4111	96	4	19	81	5YR4/3	reddish brown
	sand and organic matter	4112	92	8	29	71	5YR4/4	reddish brown
	lower crust:							
60	cloddish or friable cemented marls, partly nodular	412	88	12		100	5YR6/3	light reddish brown
90	crumbly or friable							
	aggreted marls	413	90	10		100	5YR6/3	light reddish brown
		414	52	48	•	100	5YR6/3	light reddish brown
MARLS								
70	marls; prismatic structure; black dendritic stains (Mn ?)	415	44	56		100	5YR5/6	yellowish red
80	cloddish or prismatic	i .						*
	aggregates; dendritic stains	416	60	40	-,-	100	5YR5/6	yellowish red
30-40	weathered horizon							
	(paleosoil?); structure — sample 416	417	39	61	•••	100	5YR4/4	reddish brown
140	marls; features -	418	79	21		100	5YR5/6	yellowish red
	sample 416	419	42	58		100	5YR5/6	yellowish red
	* 1	4 20	42	58		100	5YR5/6	yellowish red

after treatment with 4% HCl

produce a subsequent duricrust in case of local carbonates. Nevertheless, we also found allothic elements in such environments: one such example is calcrete completely covering flat hills of tertiary silty marls near El Altea (S Alicante/Spain). The brownish-grey marls contain 40-60% CaCO<sub>3</sub>, the duricrust on top up to 96% (tab. 1).

The allothic influence may only be seen within the strongly indurated upper crust (about 50 cm thick). Here we found reddish fine-grained sand (flying sand; tab. 1, Pr. 4111/4112). It should also be noted that the residue of the upper calcrete layer is coloured dark-brown to black by organic matter. Brown soil colours in the residue of the lower crust (Pr. 412) are different to the colour of the underlying marls.

The fact that flying sand (= allothic components) is only to be found in the present upper crust suggests an original near-surface CaCO<sub>3</sub>-accumulation taking place on and in a preexisting or syngenetic soil. The occurrence of air-borne sand within a calcrete (covering the total hill in the same thickness!), suggests that allothic calcic material has been deposited at

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present and in a ring the sited at the same time. Result: even in parts of the northern hemisphere, periods when intensified mobilisation of eolian calcic dust and sand have taken place seem to be connected with the occurrence of calcretes.

A further example – calcrete SW Murcia/Spain – leads to suggest a process which can be described as 'secondary carbonisation' (recharging of CaCO<sub>3</sub>). Calcrete is a strongly cemented layer forming a small table-mountain in tertiary marls (photo 3a). The residue of the upper and lower crust suggests a complete former soil with about 1 m thickness on top of the marls (photo 3b). This paleosoil must have been later indurated by an allothic descending (secondary carbonatisation) which caused its present (over 90%) CaCO<sub>3</sub> content.

No matter, if host material/base rock is of siliceous or calcic composition – calcretes in Namibia and Spain have been originated or completed by allothic carbonates, silt and sand. Carbonates have been infiltrated by descending water into the host sediments, forming a cahorizon. Climatic change caused exhumation; subaerial weathering under more arid conditions gradually produced several stages of diagenesis resulting in a differenciated calcrete-profile (scheme see fig. 6).

#### 3. CALCRETE AND GEOMORPHIC FACTORS

The widespread, subaerial exposed calcretes in Namibia and Spain possess many common features. Some of them are as following:

- 1. There is a striking but not exclusive concurrence of calcretes with glacis (footplains) or slopes. Middle and upper parts of the mountain slopes do not show any calcrete (fig. 9, 7).
- 2. The origin of calcrete is not directly connected (= syngenetically) with the forming of glacis and slopes. The structure of the crusts indicates morphodynamic inactivity during the time of definite induration (diagenetic stage; see fig. 1). It is significant that calcretes could only develop their typical profile (fig. 6; BLÜMEL 1979, 1981) where rock debris or other loose substrata occured in landscape. Therefore the beginning of indurated surfaces usually coincides with the footplain sedimentation. Greatest thickness of profiles is to be found in nearby sites, evidently influenced by the high permeability of the coarse material. Run-off water from the mountains enhanced calcrete development in the nearby areas by washing down calcic dust and/or dissolved CaCO<sub>3</sub> derived from local limestones. This is the true significance of the geomorphic environment (see fig. 7). The same process and intensity of secondary carbonate accumulation forced by runoff-water can be watched in recent soils in Israel (Sede Boqer Experiment site, about 90 mm rainfall; see YAIR 1981, 239 f., WIEDER 1977).

With the increasing distance from mountain areas, this 'interzonal' influence gradually disappears – the duricrust shows its normal ('zonal') thickness. These relations can be demonstrated in basin-range-structures in Namibia (especially along the eastern border of the Namib desert) and several parts of Spain (especially in sierras and basins of the E- and SE-cordillere).

3. Calcretes also occur independent of plains or slopes and in this way document zonal conditions of origin: they cover peneplains (e.g. around the Erongo/SWA; photo 1; Mancha/Spain) or hills (e.g. El Altea/Spain) no matter what kind of host sediment exists. The causing allothic factors have frequently been mentioned.

The independence of calcrete origin (in spite of apparent relations) from relief and substratum may be shown by photo 4: this concave slope is superficially indurated by a thick cal-

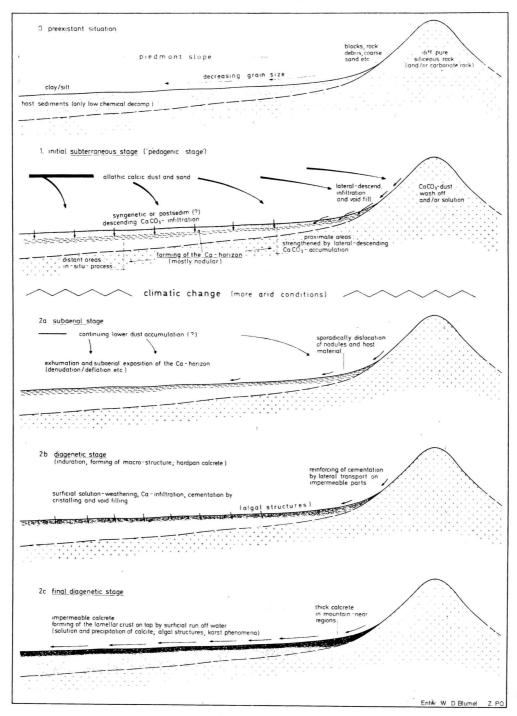


Fig. 7: Multistage process of calcrete genesis, allothic and geomorphic factors



Photo 4 eroded b allothic e be source



Photo 5: fig. 8). All tem belo:



Photo 4: Calcrete covering siliceous red sands of the ancient Namib desert, partly destroyed and eroded by present climate conditions (less than 100 mm rainfall). The origin of calcrete was related to allothic eolian  $CaCO_3$ -accumulation. The small range belonging to the indurated slope surface cannot be source of the carbonate matrix in the calcrete.

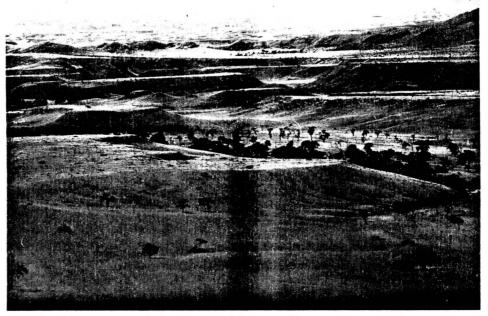


Photo 5: Two more generations of flat glacis/slopes seen from an elder rest (table mountain; see fig. 8). All niveaux are covered by an individual calcrete, except the river beds of the recent drainage-system belonging to the Kuiseb-river (Farm Cha-Ré; eastern border of the Namib/SWA).

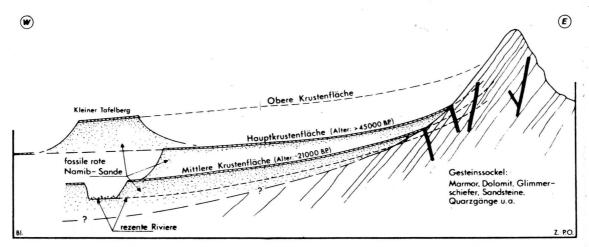


Fig. 8: Generations of glacis-terraces, each covered by an individuel calcrete. The bed of the recent creeks (riviere) is free of ca-accumulation or cementation. Erosion is influenced by the activity of the Kuiseb-system. (Farm Cha-Ré; eastern Namib; only few Kilometers distant from the situation shown on fig. 9).

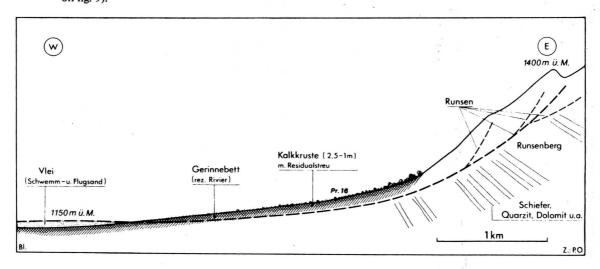


Fig. 9: Polygenetic calcrete covering a glacis. The recent drainage (episodical runoff; belonging to the Tsondab-system) is cutting the proximate parts by few meters. (Farm Spaarwater; eastern Namib, N Solitaire).

crete. Host sediments consist of red quartzose sands of the ancient Namib covering parts of a lower range. The CaCO<sub>3</sub> within the calcrete cannot derive from the sand. Lateral transport from the range in such quantities is not a realistic possibility. Eolian calcic deposits are responsible for the occurence of calcrete in this area; relief and substratum are only spuriously correlated with the covering duricrusts.

We have emphasized that calcretes do not occur in accordance with special relief configurations of substrata. They represent, rather, peculiar morphodynamic phases within

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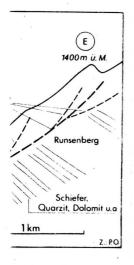
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Tab. 2: <sup>14</sup>C-DATATIONS OF CALCRETES (HIGH INDURATED UPPER CRUSTS) FROM NAMIBIA (1-5) AND SPAIN (6-8)

la	Beginning of glacis-sedimentation (Saagberg; Farm Samara; eastern Namib)	8385 ± 140 B.P.
lb	-"- (2,5 km distant from 1a)	15690 + 650 B.P.
2	Main calcrete-generation (Farm Cha-Ré; eastern Namib; see photo 5 and fig. 8)	> 45000 B.P.
3	Middle calcrete-generation (see 2)	$21280 \pm 560 \text{ B.P.}$
4	SE-front of the Erongo; Farm Onguati (photo 2d)	$19635 \pm 465 \text{ B.P.}$
5	-"- (Onguati railway-station)	$30480 \pm 650 \text{ B.P.}$
6	Table-mountain (Garrucha/Spain)	21775 + 300 B.P.
7a	Slope (a) to basin-centre (c); (Cancarix; between Cieza	
	and Hellin/Spain)	$19880 \pm 330 \text{ B.P.}$
7b	-"- (middle part)	$23580 \pm 340 \text{ B.P.}$
7c	-"- (basin centre)	$23570 \pm 990 \text{ B.P.}$
8	Ca-horizon (Los Escullos; Sierra de Gata/Spain)	16100 ± 165 B.P.

climatic cycles. This is to be seen in Namibia as well as in Spain by the existence of calcrete-covered sequences (generations) of footplain terraces (fig. 8; photo 5). Additionally, the very complex origin of calcrete can be simplified: elder glacis, partly only rudimentarily preserved, possess a polygenetic (polycyclic) calcrete in comparison with younger but also completely structured ones. Old duricrusts survive phases of reinforced erosion and denudation. They are attacked by karst processes, acquire new CaCO<sub>3</sub> by allothic influences and also alter their macro- and micro-structure but only to a very small extend.

Climatic variability within essentially semiarid conditions (altering humidity/aridity) preserve most of the rather mobile CaCO<sub>3</sub> in the landscape concerned. Drainage systems without erosional tendencies under the same climatic and geological conditions possess only one single calcrete of polygenetic origin (fig. 9). Both examples (fig. 8 and 9) belong to the eastern Namib. The distance between them is only a few kilometers. Fig. 8 belongs to the active system of the Kuiseb rivier; fig. 9 to the 'inactive' Tsondab.

Temporal correlation of those calcrete generations is difficult. Tab. 2 contains some C-14-Dates. The uncertainties resulting from contamination are well-known. Nevertheless, it is suggested that the youngest calcrete generation belongs to the time of last (Würm) glaciation. The next generations (example Cha-Ré; fig. 8) can be dated only as originating > 45000 B.P.

All samples dated were taken out of high indurated upper crusts. The resulting C-14-dates only identify the time and stage of subaerial diagenesis (fig. 1), rather than the time of the true **initiation** (subterraneous stage).

It can be supposed that the cyclic genesis of calcretes corresponds to the glaciations and subarctic climates in the middle latitudes. At the same time we find climatic variations especially with respect to humidity. More humid conditions (up to  $\sim 600$  mm rainfall?) cause the origin of the ca-horizon by descending infiltration; more arid phases (up to < 100 mm) cause diagenesis and macro-structure (e.g. in the time between 25000 and 15000 B.P. in the case of the youngest widespread calcrete). Forming of micro- and macro-structure has continued until recent times: the laminated crust (sample 1a in tab. 2) was dated as 8385 B.P. and is the result of repeated solution and precipitation under subaerial conditions (fig. 1, 6).

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ARIDIC SOILS AND

GEOMOR PLICEPROCESSES

CĂTENA SUPPLEMENT I

This Volume is the PROCEEDINGS of the INTERNATIONAL CONFERENCE of the INTERNATIONAL SOCIETY OF SOIL SCIENCE, Jerusalem, Israel, March 29 - April 4, 1981

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Printed in West Germany: Graphische Kunstanstalt W. Herr, 6300 Giessen

ISSN 0722-0723 / ISBN 3-923381-00-X

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DAN, J.,