KASTANOZEMS IN THE OTJIWARONGO REGION (NAMIBIA): PEDOGENESIS, ASSOCIATED SOILS, EVIDENCE FOR LANDSCAPE DEGRADATION

With 8 figures and 1 photo

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Zusammenfassung: Kastanozems im Raum Otjiwarongo (Namibia): Pedogenese, Bodenvergesellschaftung, Hinweise auf Landschaftsdegradation

Der vorliegende Beitrag befaßt sich mit der Entstehung der Kastanozems in Namibia und mit aktuellen Degradationsvorgängen sowie ihrer Vergesellschaftung mit anderen dunkel gefärbten Böden. Dies sind besonders Calcisols, die im Untersuchungsgebiet mehrere Dezimeter mächtige humose Oberböden besitzen, und um Vertisols. Die Böden unterliegen (sub-) rezenten Erosionsprozessen.

Die Kastanozem-Gesellschaften treten fleckenartig, in Form mehrere 100 ha großer Flächen auf. Die humosen Böden sind an Feinsedimente gebunden, die beiderseits der subkontinentalen Wasserscheide zwischen Ugab (zum Atlantik) und Omatoako Omuramba (ins Kalahari Becken) abgelagert wurden. Die wichtigsten pedogenetischen Faktoren sind darüber hinaus das besondere semiaride Klima, eine dichte Grasdecke (offene Dornstrauchsavanne) und eine Phase geomorphodynamischer Stabilität. Die Kastanozems gehen an den Hängen und zu den Toplagen bei zurückgehendem Humusgehalt und steigendem Carbonatgehalt in Calcisols über. In den Mulden werden sie bei steigendem Smectitanteil in der Tonfraktion von Vertisols abgelöst. Die Kastanozems bilden eine bedeutende natürliche Ressource der Region, da sie sehr fruchtbar sind und eine große Wasserspeicherfähigkeit besitzen. Rezent werden sie von Erosionsprozessen betroffen. In einer ersten Phase sind die Kastanozems und Vertisols durch Hangabspülung von kolluvialen Sedimenten bis mehrere Dezimeter mächtig bedeckt worden. Derzeit werden die Bodengesellschaften durch Rillen- und Grabenerosion abgetragen, was auf einen erhöhten Oberflächenabfluß zurückgeht.

Summary: The paper deals with Kastanozem formation, with associated dark soils like Vertisols and Calcisols which have thick humic epipedons and with actual erosional processes in the Otjiwarongo region

The Kastanozem soil associations occur as patches of several hundreds of hectares. Important pedogenetic factors were fine-grained host sediments, the semi-arid climate, a dense savanna grass cover and geomorphic stability. The Kastanozems show gradual transitions to Calcisols on slopes and on tops due to a decreasing amount of soil-organic matter and increasing carbonate content, and to Vertisols in the lowest positions of the relief due to an increasing amount of smectites in the clay fraction. The dark savanna soils are an important natural resource of the region because they are very fertile and have high water retention capacity. At present soil degradation is the most remarkable process affecting the pedosphere in the study area. In a first phase most of the Kastanozems and Vertisols are buried by slope wash sediments up to several decimeters. Actually this soil association is affected by rill and gully erosion indicating an increased run-off.

1 Introduction

Only a small number of papers dealing with soil geography and/or pedogenetic processes have been published in south-western Africa. The FAO-UNESCO Soil Map of Africa (1977) shows Luvic Arenosols associated with Chromic Luvisols for the study area around Otjiwarongo. Included are Eutric Fluvisols, Pellic Vertisols and Lithosols. But of course, it is not possible to consider the real soil associations at a scale of 1:5 000 000.

With their synthetic reports on soil development and soil geography in Namibia GANSSEN (1960; 1963), GANSSEN a. MOLL (1961) and SCHOLZ (1968a; 1968b) prepared the path for detailed studies. Most work has been done subsequently on the formation of Calcisols and of pedogenic calcretes by NETTERBERG (1969), BLÜMEL (1982) and EITEL (1993; 1994). In the same period clay-mineralogical and palaeoecological investigations of calcretizised soils have been carried out (WATTS 1980, SINGER et al. 1995, EITEL 1995; 1999). WATSON (1985; 1988) and HEINE a. WALTER (1996) studied Gypsisols in the central Namib Desert for soil-genetic and palaeoclimatic purposes. Until now detailed work on soil geography has remained rare: Erongo soils have been investigated by BLÜMEL (1979), and from the Etosha National Park BEUGLER a. BUCH (1993) and TRIPPNER (1993) have supplied detailed soil analysis.

As a striking pedological element in the Otjiwarongo region, patches of dark, more or less humic soils occur. GANSSEN (1960) mentioned "greyish, earthy soils" from this region for the first time without further characterization. It is not clear whether he meant Calcisols with thick Ah-horizons, Vertisols or Kastanozems (all

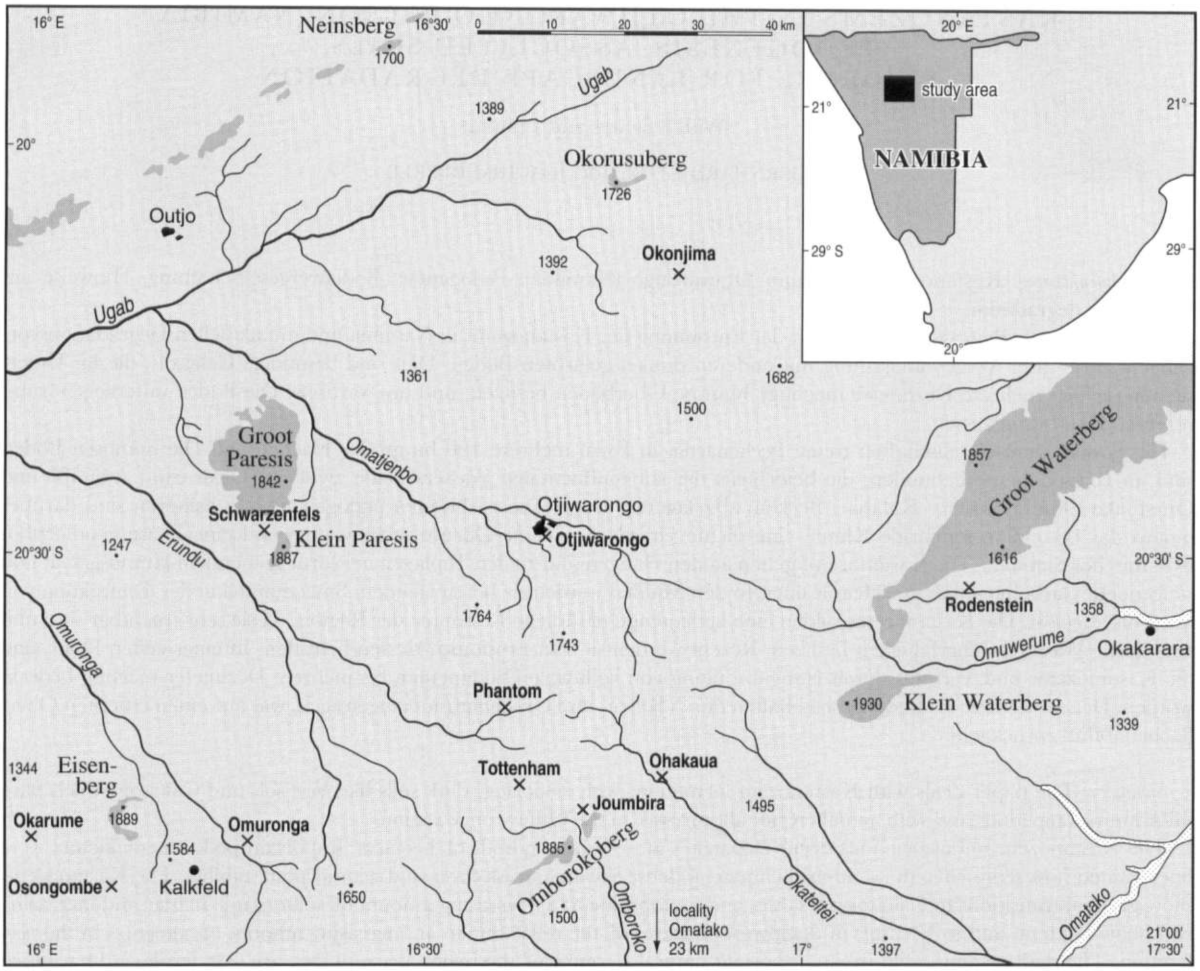

Fig. 1: Map of the study area of the Otjiwarongo region. The crosses indicate localities of typical soil profiles which were analyzed

Karte des Untersuchungsgebiets um Otjiwarongo. Die Kreuze zeigen die Lokalitäten der Leitprofile

soil units according to the FAO-UNESCO / World Reference Base [WRB] 1998 soil classification system). Until now Kastanozem associations have been unknown in Namibia because in the Otjiwarongo region detailed soil-geographical and soil-analytical studies are missing. It is possible that this is due to the fact that the region is south of the dry farming zone and agriculture is restricted to very small irrigated areas. Most of the previous scientific work focussed on geomorphology, climate, vegetation or socio-economy.

The purpose of this paper is to present soil- analytical data and to discuss the environmental conditions which led to Kastanozems and related soils in northern central Namibia. The knowledge of detailed soil geographic relations can contribute to the identification of initial or progressive landscape degradation, and this knowledge can be the starting point for strategies for a sustainable land use.

2 *The Otjiwarongo region – a short characterization*

About 250 km north of Windhoek, the capital of Namibia, the study area lies above of the flexural bulge which forms the western rim of the innercontinental Kalahari Basin (Fig. 1). The flexure replaces the Great Escarpment further south (Khomas Highlands). East of Otjiwarongo at about 1600 m a.s.l. there is the watershed between the Ugab River, which discharges into the Atlantic Ocean (when crossing the coastal Namib Desert), and the Omatako Omuramba, which ends in flat valleys (omurambo) endoreically in the Kalahari Desert. Both are ephemeral rivers. In general, the tributaries around Otjiwarongo have no deep valleys, due to the watershed position. The Damara schists (Precambrian to Lowest Palaeozoic basement) are predominant north and west of Otjiwarongo. Large planation surfaces are due to Tertiary denudation processes

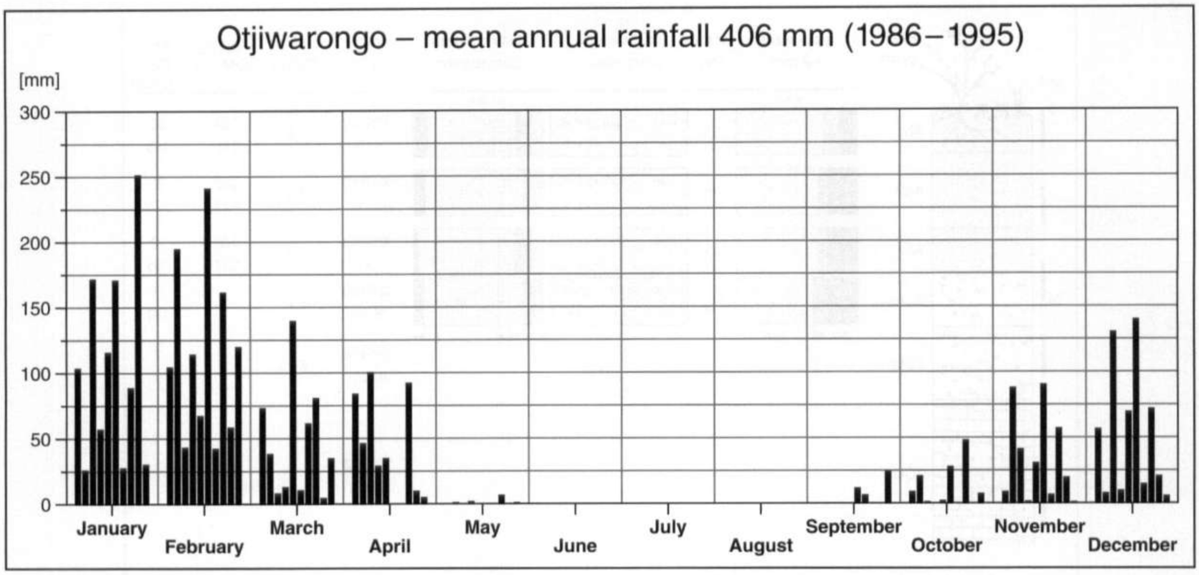

Fig. 2: The figure shows the amount of monthly precipitation between 1986 and 1995 at Otjiwarongo (*source:* German School / Otjiwarongo). The seasonality is evident. For 10 years it never rained in the winter months June, July and August. But the high variability is obvious as well. Even in January the rainfall quantities can vary between 26 mm and more than 250 mm

Monatliche Niederschläge zwischen 1986 und 1995 in Otjiwarongo (*Quelle:* Deutsche Schule / Otjiwarongo). Deutlich ist die jahreszeitliche Gliederung erkennbar: Im betrachteten Zehnjahreszeitraum fiel in keinem der Wintermonate Juni bis August Regen. Offensichtlich auch die starke Niederschlagsvariabilität: selbst die Januarniederschläge können zwischen 26 mm und über 250 mm schwanken

(African Surface, KING 1967). The granite complex of the Paresis Mountains (a Cretaceous intrusion) form a prominent landmark (Fig. 1). In contrast to the land surfaces north and west of Otjiwarongo, widespread Palaeozoic Damara granite outcrops form an inselberg relief south of Otjiwarongo. As the third petrographic element, Mesozoic sedimentary rocks (above all sand-, silt- and mudstones of the Karoo Sequence) cross the study area from northeast to southwest, forming more or less isolated cuestas. They are due to the Waterberg-Omboroko-Etjo lineament (STOLLHOFEN 1999).

The Otjiwarongo region is part of the western margin of the Kalahari Desert. During the summer months (Sept.–April) it gets 350–450 mm of mean annual rainfall characterized by high variability in space and time (Fig. 2). The potential natural vegetation is an open thornbush savanna with transitions to the more humid, but seasonal dry, savanna with growth of bigger trees.

3 *Particular features of Kastanozems and associated soils*

In the Otjiwarongo region dark soils which have thick, more or less humic epipedons could be classified as Calcisols, Kastanozems and Vertisols (after WRB 1998). They form typical soil associations with gradual transitions between the soil groups.

Calcisols are defined by their calcic or petrocalcic horizon. The calcic horizon is at least as thick as 15 cm and shows secondary carbonate accumulation. It must have a calcium-carbonate equivalent content in the fine earth fraction of 15% or more (hypercalcic horizons more than 50%). A petrocalcic horizon is an indurated calcic horizon (> 50% $CaCO_3$) with a thickness of at least 10 cm or 2.5 cm if it is laminar and rests directly on bedrock. The epipedon of Calcisols is an ochric horizon, that means a surface horizon lacking fine stratification and which is either light coloured, or thin, or has low organic content (< 1% organic matter), or is hard when dry. In most parts of the Otjiwarongo region carbonate is available. It occurs as an intercalated component in the Damara schists, as secondary carbonate in Tertiary and Quaternary calcretes (EITEL 1994) as well as aeolian dust blown from Kalahari calcrete surfaces and pans to the study area soils. As shown by NETTERBERG (1969) and BLÜMEL (1982), descendent solutions move the lime to lower horizons where it re-crystallizes, forming diffuse secondary carbonate, nodules or petrocalcic horizons (calcretes). As a peculiarity in the Otjiwarongo thornbush savanna, Haplic

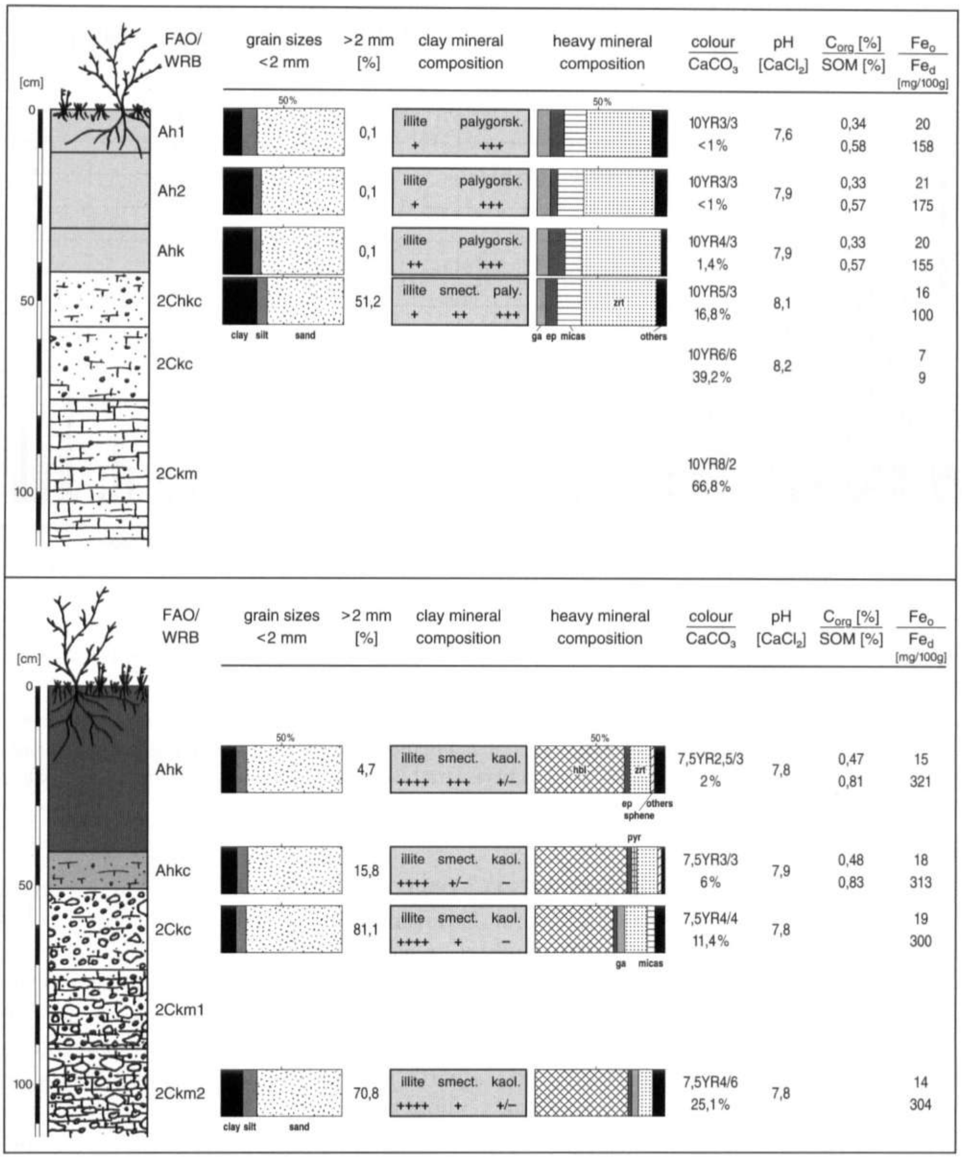

Fig. 3: Typical Calcisols with remarkable thick (ochric) Ah-horizons: above Omatako locality (23 km south of the study area), below locality Otjiwarongo locality (cf. Fig. 1)

Typische Calcisols mit mächtigen Ah-Horizonten: Oben vom Standort Omatako (23 km südlich des Arbeitsgebietes), unten vom Standort Otjiwarongo (s. Fig. 1)

and Petric Calcisols occur with dark brown to very dark brown Ah-horizons (Fig. 3) of up to 50 cm thickness but having less than 0.6% organic carbon (ochric horizon). The thick Ah-horizons can lead to confusion with Kastanozems if no analytical data exist.

Kastanozems are soils with a mollic horizon which is a well-structured dark coloured surface horizon of more than 10 cm thickness if resting directly on hard rock or a duripan, of at least 25 cm and more than one-third of the thickness of the solum where the solum is less than 75 cm thick, or of more than 25 cm where the solum is more than 75 cm thick. The mollic Ah has a high base saturation (> 50%) and a moderate to high content in organic matter (> 1%). Its moist chroma is of more than 2 to a depth of at least 20 cm. Kastanozems have concentrations of secondary carbonates within 100 cm of the soil surface. Until now Kastanozems have not been described in the thornbush savanna of Namibia. The Kastanozems of the Otjiwarongo region (Fig. 4, Fig. 7) are characterized either by a more or less

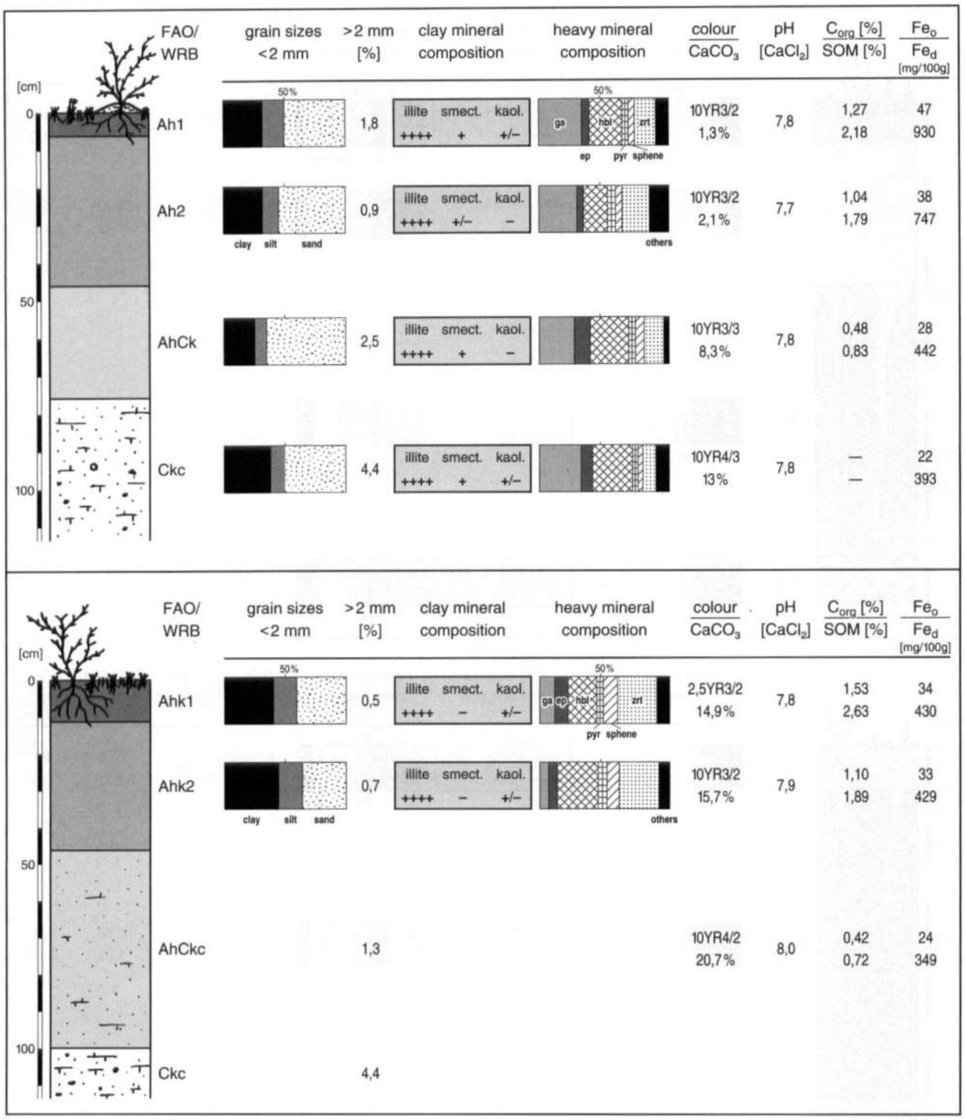

Fig. 4: Typical Kastanozems: above Vertic Kastanozem (locality Omuronga), below Calci-Vertic Kastanozem (locality Okarumue; localities s. Fig. 1)

Typische Kastanozems aus der Otjiwarongo-Region: Oben ein Vertic Kastanozem (Standort Omuronga), darunter ein Calci-Vertic Kastanozem (Standort Okarumue; s. Fig. 1)

high amount of secondary carbonate (Calcic Kastanozems), or by a high amount of clay (Vertic Kastanozems), or both (Calci-Vertic Kastanozems). Most of the diagnostic Ah-horizons are 40–60 cm thick and have a content of organic matter between 1 and 3% (Fig. 4). The high amount of clays in the Kastanozems can render it very difficult to differentiate them from Vertisols. X-ray diffraction analysis of the clay fractions can help: The Kastanozems – even with more than 40% clay – show no or only very small amounts of smectites whereas they are predominant in Vertisols. In Kastanozems the illite is the predominant clay mineral which derived above all from the Damara schists. The occurrence of metamorphic rocks explains the high amount of mica-derived illites. This additionally explains why Vertic Kastanozems do not show deep cracks or slickensides on aggregates because the illites – especially in alkaline soil milieus – do not swell and shrink as smectites in Vertisols do.

Vertisols are defined by their vertic horizon which has 30% or more clay throughout, wedge-shaped or parallelepiped structural aggregates, intersecting slickensides and cracks which open and close periodically as a result of shrinking and swelling clay minerals.

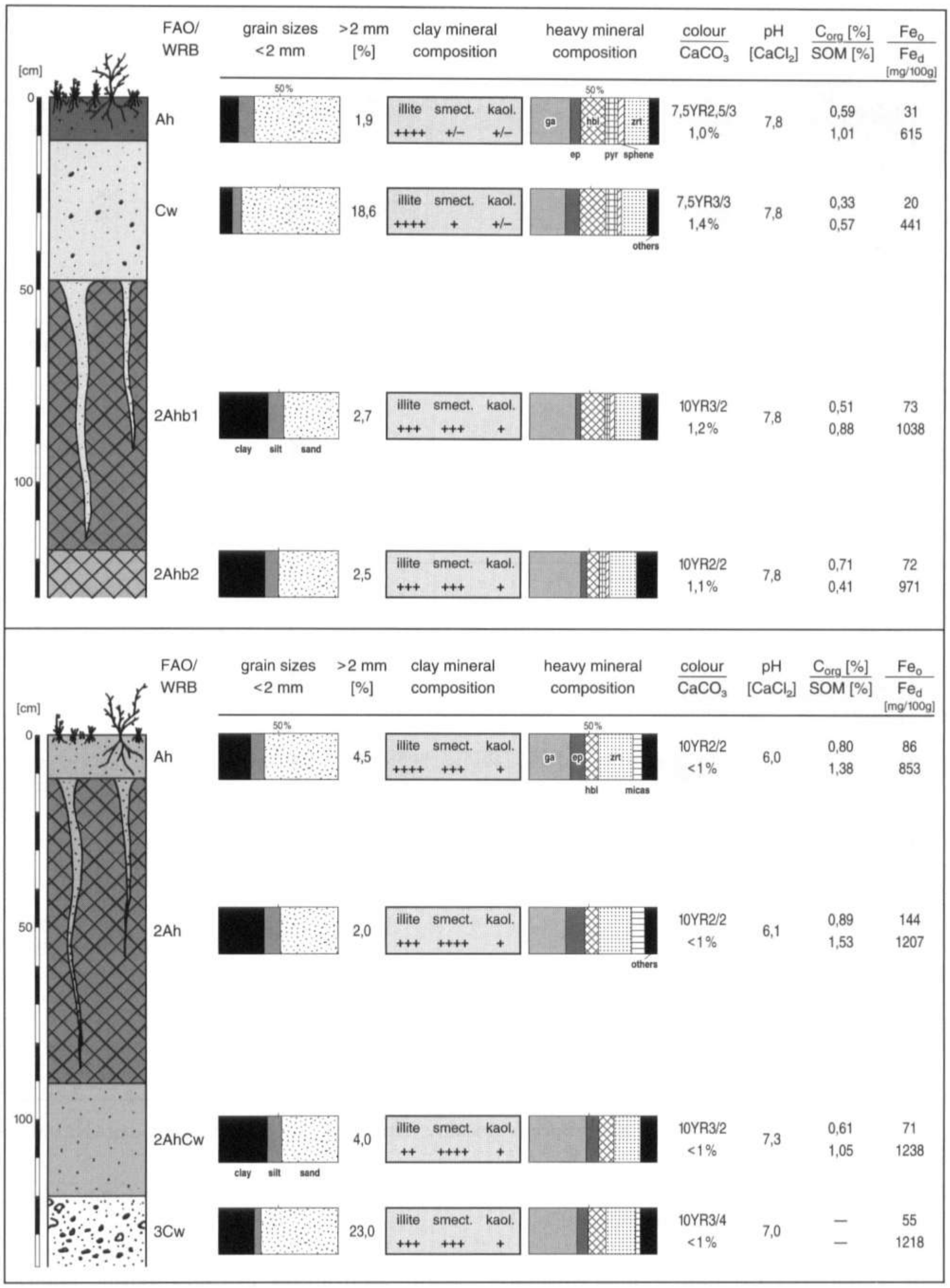

Fig. 5: Typical Vertisols: Arenosol above Haplic Vertisol at the Osongombo locality (above), Regosol above Haplic Vertisol at the Tottenham locality (below) (cf. Fig. 1)

Typische Vertisols: Oben ein Arenosol über einem Haplic Vertisol (Standort Osongombo), unten ein Regosol über einem Haplic Vertisol (Standort Tottenham, s. Fig. 1)

The vertic horizon has a thickness of 25 cm or more. The dark colour of most of the Vertisols is due to clay-humus-complexes (melanization) which can simulate a very high amount of organic carbon. The Vertisols in the study area have 0.5 to 1.2% Corg (Fig. 5). Smectites are predominant in the clay fraction. They can be authigenic due to cation supply during the rainy season (Milne 1935). The Mg-availability is the most important factor. Mg derives by solution of Damara high-Mg calcite or dolomites which are intercalated in the mica schists (Porada 1973, Schneider 1983, Eitel 1993). Smectites can be allochthoneous as well and can accumulate in valleys and basins of semiarid to semihumid regions (ESWARAN et al. 1988, AHMAD 1996). In the Otjiwarongo region allochthoneous palygorskites are a third possible smectite source, due to aeolian input and subsequent mineral-transformation (s. Fig. 3). The fibrous silicate is related to smectites by its similar chemism and structural elements (VELDE 1995). Palygorskite is predominant in the clay mineral fraction of Tertiary calcretes and calcareous sediments (EITEL 1994) some ten kilometers north and east of the study area in the western Kalahari.

4 Conditions for good humification

The most striking feature of the soils are the dark, more or less black soil colours. Generally the accumulation of organic matter in thornbush savanna soils is slight, due to low biomass production rates. The bushes – most of them acaciae – produce only very small leaves. Termites assimilate the wood from dead bushes and small trees so that re-mineralization is predominant. The most efficient humus supplier are grasses and their rhizosphere. For that reason high amounts of soil organic matter hint at favourable locations for grasses. In the study area with 350–450 mm mean annual rainfall these conditions are given. In more arid regions the vegetation cover is more or less diffuse, and in more humid savannas further north the re-mineralization of soil organic matter is intensified. In the northern thornbush savanna near Otjiwarongo humification of the dead organic substance is favoured because the long dry period (4–5 months) and the high variability of the rainfalls, even during the humid summer, restrict the humus re-mineralization. But there is enough rain to produce a more or less complete grass cover every year.

Thick Ah-horizons are due to fine-grained substrata and intensive bioturbation. This is given in the study area as well. The weathering of the Paleozoic schists produces a lot of fine-grained materials. Together with older, Quaternary or Tertiary sediments from the western margin of the Kalahari Basin, large parts of the weakly undulated land surface are covered by sediments. This is ideal for ubiquitous termite activity and burrows of mammals which mix the organic matter with the inorganic soil material. The widespread coverbeds on Damara metamorphites explain the fact that not all but most of the Kastanozems are developed outside the granitic outcrops south of Otjiwarongo with its tops and downs and incised rivers transporting sand and pebbles. The Damara schists have another important influence on pedogenesis because they bear carbonate. Due to calcareous dust input, most of the soils therefore show neutral or weak alkaline milieus (pH 7–8). During the rainy season Ca-ions due to solution of calcareous particles stabilize the clay-humus-complexes. In general the precipitation is not able to leach the soils. This fact, together with the intensive bioturbation and the rainfall variability, prevents a progressive horizontation through mineral transformation and translocation. The lowest pH-level (pH 5.7) was found in a Ah-horizon of a Vertisol from Farm Phantom (see Fig. 1). Leaching here seems to be due to lateral and alluvial water supply in a granitic environment.

In this way Calcisols with thick epipedons and Kastanozems occur patch-like in the Otjiwarongo region, forming soil associations with Vertisols, Regosols and Leptosols. Especially on the Damara schist planation surface they are arranged in typical soil-toposequences.

5 Toposequential relations

Only flat ephemeral rivers and omuramba drain the land surface in the watershed region between the Ugab and the Omatako catchment. Therefore soil-toposequences reflect larger soil areas than they do in more eroded geomorphic units. A transect through such a flat valley can reach several kilometers. Nevertheless the soil distribution is adapted to certain positions. This explains the patch-like occurrence of the different soil types in the two major soil regions where the Damara schists occur and where the granitic inselbergs dominate the surfaces.

In the northern and western parts of the study area the low watersheds are mostly due to resistent quartz veins, which are intercalated into the schists. Beneath the quartz outcrops more or less rounded quartz pebbles and boulders are widespread. Sometimes they are buried by fine-grained, silty to sandy sediments which must be of aeolian origin because they cover the tops. Here as well as on the weak slopes Calcisols, Regosols or Arenosols formed due to changing amounts of sand or secondary carbonate. The sands are often reddish. Above all the Kalahari sand fields (Neogene) and the weathering products of the Etjo sandstone (Lower Jurassic) serve as sources for red sand. But it must be noted that most of these soils are marked by up to 0.5 m-thick, dark coloured surface horizons which have mostly an amount of only 0.3–0.5% Corg. On the flattest and lowermost parts of the slopes the soils show a finer texture and become more humic. Calcic and Calci-Vertic Kastanozems are predominant on such deposits. Below the mollic Ah-horizons in 0.5 to 1.5 m

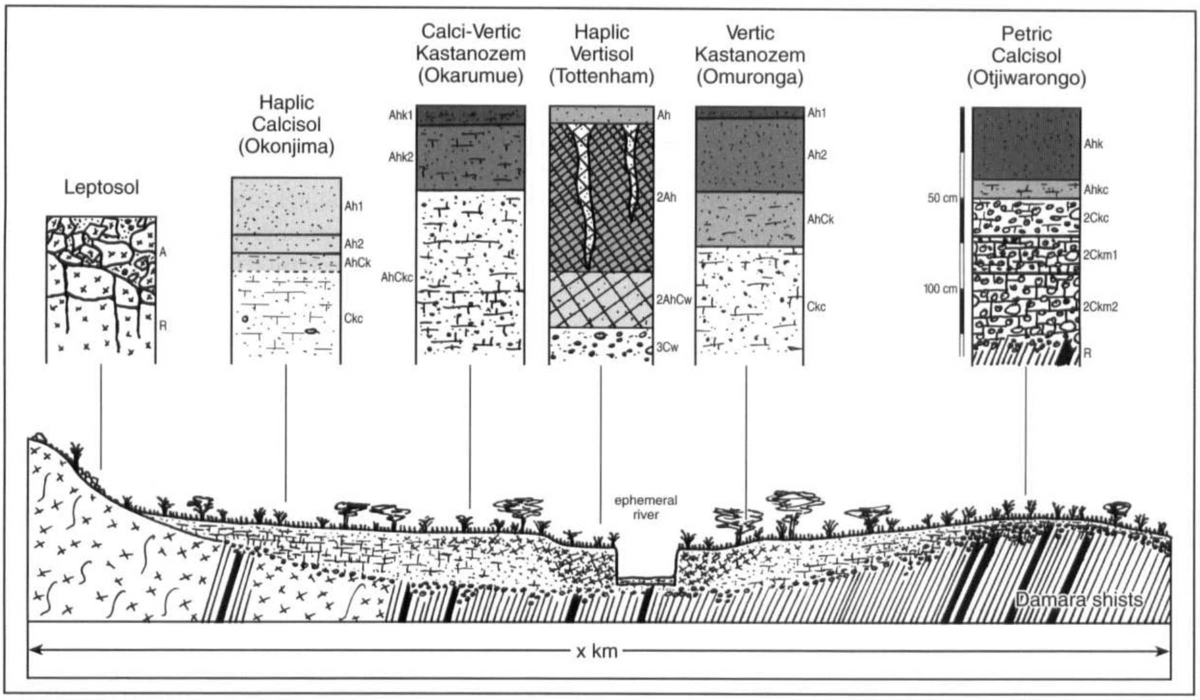

Fig. 6: Idealized soil-toposequence in the Otjiwarongo area. The underlying rocks influence the geomorphology of the region and modify the typical soil associations. Above all on the Damara schist planation surface Calcisols with thick Ah-horizons change to Calcic Kastanozems, then to Vertic Kastanozems and to Vertisols according to the positions in the top, on slopes and in the lowest parts of the relief. In granitoid rocks the change is more local and the soil texture often affected by the coarser granite weathering detritus. For typical soil profiles and analytical data see Figs. 3, 4, 5. At Okonjima (see Fig. 1) the Haplic Calcisol humification is like at Otjiwarongo (see Fig.3): The Ah-horizons have an amount of 0.4–0.5% Corg

Idealisierte Bodentoposequenz im Raum Otjiwarongo. Die Gesteine im Liegenden beeinflussen das Relief und damit auch die typischen Bodengesellschaften. Auf der Rumpffläche (dominant Damara-Schiefer) wechseln von den flachen Hängen bis in die tiefsten Positionen Calcisols über Calcic Kastanozems und Vertic Kastanozems zu Vertisols. Auf granitoiden Gesteinen sind die Übergänge kleinräumiger und die Bodenarten sind durch den Granitdetritus oft gröber (Repräsentative Bodenprofile und Analyseergebnisse s. Figs. 3, 4, 5). Am Standort Okonjima tritt der Haplic Calcisol wie bei Otjiwarongo auf (s. Fig. 3): Die Ah-Horizonte haben einen Corg-Gehalt von 0,4–0,5%

depth they often have calcified layers. It is not clear whether the calcification is due to in situ pedogenic calcretization, to Ca-rich lateral interflow during the rainy season or whether the calcretes are part of the underlying sediment complex (Pleistocene or older). Perhaps all three possibilities occur. In the lowest positions of the local relief, small basins or flat valleys, and mostly in the vicinity of the ephemeral rivers, the soils change to Vertisols because its illites are substituted by smectites. The Kastanozem-Vertisol associations form isolated areas of up to several hundreds of hectares.

South of Otjiwarongo the granitic inselbergs modify this typical soil toposequence. Leptosols are dominant on granite surfaces more or less covered by blocky weathering detritus. Regosol areas are smaller. The sediments on etchplaines, in valleys and in intercalated small basins consist of more coarse sand and gravel than in the region further north where the schists dominate. This is due to physical granite weathering and denudation. The valleys have a steeper gradient which affects smaller areas of Calcisols and Kastanozems beween Leptosols around the inselbergs and the Vertisols beneath the rivers.

A schematic cross-section (Fig. 6) through an idealized flat valley in the Otjiwarongo thornbush savanna shows granite outcrops with Leptosols on the left side whereas on the right side the flat landscape on Damara schists with intercalated quartz veins is generalized. Here Calcisols on tops and slopes are associated with Kastanozems and Vertisols in lower positions. From Kastanozems to Vertisols gradual transitions are common. Calcisol epipedons become more and more humic, changing to Calcic Kastanozems. They pass over to Calci-Vertic and Vertic Kastanozems with respect to

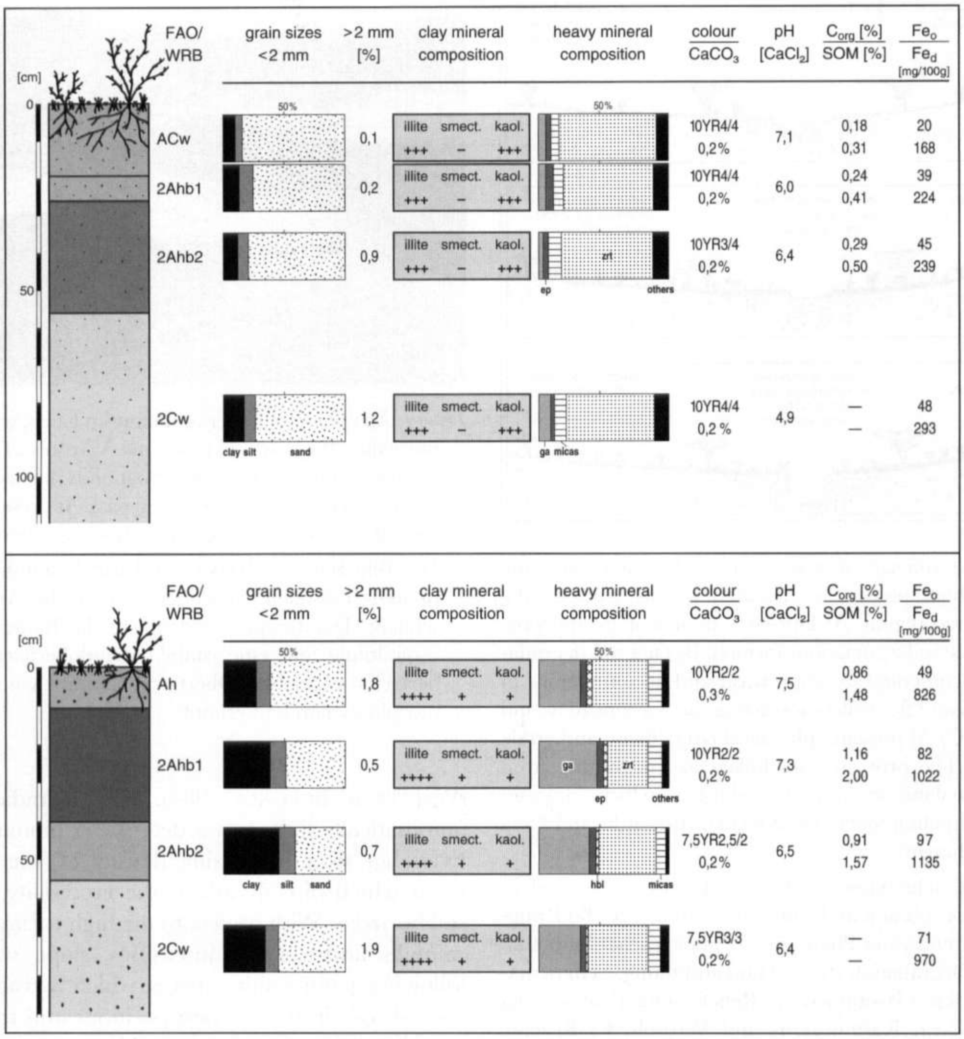

Fig. 7: Buried soils in lower positions: A Haplic Arenosol from Rodenstein Farm and a Vertic Kastanozem from Joumbira Farm (localities in Fig. 1). For buried Vertisols see Fig. 5

Beispiele für überdeckte Böden in tieferen Reliefpositionen: Haplic Arenosol (Farm Rodenstein) und Vertic Kastanozem (Farm Joumbira, s. Fig. 1). Vertisols betrifft das ebenso (s. Fig. 5)

the increasing amount of clay. At last increasing smectite content leads to Vertisols.

6 Evidence of soil degradation

The soils formed during a period of reduced geomorphodynamics when weak run-off dominated and fine-grained weathering products accumulated in the lowlands of the study area. The sediments are characterized by enrichment of organic matter and by neoformation of clay minerals in the lowermost relief positions. At present, most of the soils show features of degradation. The ephemeral rivers dissect the pedosphere and the fine-grained deposits which accumulated before (Photo 1). In the catchments initial and proceeding badland surfaces develop by gully erosion. The channels drain the pedosphere, reduce the infiltration of water, concentrate the run-off and intensify the erosion anew. Especially when wet the Vertisols are very dense and advance their own erosion. The Vertisol formation is actually reduced because the soils become drier, the interflow passes beyond the vertic horizon to the channels and the ion supply decreases. As shown by Vertisol exposures, this obvious actual soil destruction is already the final process of degradation. A lot of soils, Arenosols or Regosols as well as Kastanozems and Vertisols are covered by a less weathered sandy layer due to

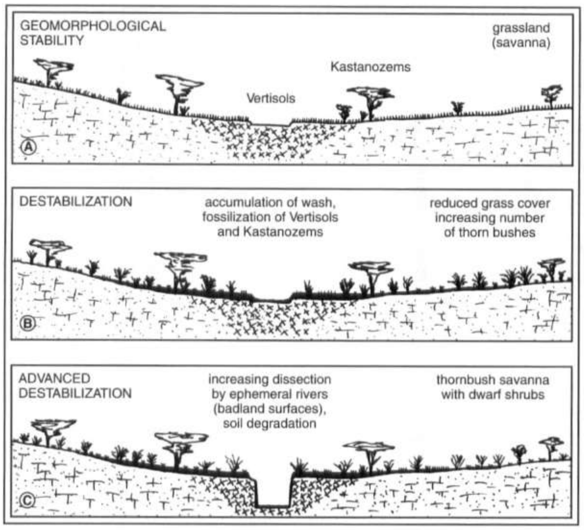

Fig. 8: The sequence of schematic profiles illustrates the degradational phases as indicated by the soils of the Otjiwarongo region. A) During a period of geomorphic stability the soil associations formed. B) First soil degradation is documented by slope wash and accumulations in the basins and flat valleys fossilizing the Kastanozems and Vertisols. C) At present ephemeral rivers incise and erode the soils. The processes are linked to a transition from dense grassland to more thornbushes, which indicates either a human impact (overstocking with cattle) and /or a climatic change

Die Folge schematischer Profile illustriert die Bodendegradationsphasen im Raum Otjiwarongo. A): Bodenbildung während einer Phase geomorphologischer Stabilität. B) Erste Degradation durch Hangabspülung, Sedimentation in tieferen Positionen des Reliefs unter Fossilisierung besonders von Kastanozems und Vertisols. C) Rezente Einschneidung und Bodenerosion. Dies ist gebunden an die Verbuschung ehemaligen Graslandes, was eine Folge anthropogen ausgelöster Überweidung und/oder klimatischen Wandels sein kann

Photo 1: An ephemeral river on Phantom Farm, which dissects the valley floor and exposes the Vertisols. The example illustrates that the Vertisol formation is due to more stable environmental conditions in the past. At present increased run-off and intensified geomorphodynamics occur

Das Bild zeigt ein Rivier auf Farm Phantom, das einen breiten Talboden zerschneidet und die Vertisols aufschließt. Das Beispiel verdeutlicht die Bindung der Vertisolbildung an eine stabile Landoberfläche. Derzeit herrscht vermehrt Oberflächenabfluß vor. Die Geomorphodynamik ist erhöht

slope wash and other denudational processes. The heavy mineral compositions of the soils show that the cover beds as well and the buried soils derive from local sources (Figs. 3, 4, 5, 7). The burial preceded the actual river incision and increased soil erosion. Therefore the soil associations show two degradational phases (Fig. 8).

It is very difficult to decide whether the soil burial and the soil erosion is due to climatic change, to human impact, or both. But all observations give hints that the effects of human activities are involved. In the Otjiwarongo region the potential of the natural vegetation for grazing purposes is 8-10 ha per large animal unit (Van der Merwe 1983). It is a well known fact that especially after overstocking, annual grasses are predominant and at last a reduced grass cover favours the bushes (Walter a. Breckle 1984). This degradation is not automatically linked to a decreasing biomass productivity but to a decreasing density of the vegetation cover which directly affects the erodibility of surface soil horizons. With respect to the high variability of the rainfalls and varying intensities, slope wash is the following geomorphic process, which is visible through eroded soils in the steepest positions and more or less buried soils on lower slopes. The erosional processes affect the seeds as well so that the plant cover – especially the grasses – becomes more and more diffuse even after intensive rains. These connections led to the observed soil burial in lower positions. Run-off increased due to the reduced plant cover and subsequently provided river incision and at last the actual gully erosion of the clay-rich Vertisols and Kastanozems.

7 Outlook

This study focuses on Calcisol-Kastanozem-Vertisol associations in Namibia. Soil analysis shows that the fine-grained sediments and the related soils which are rich in organic matter are an important natural resource in the Otjiwarongo region. The fertile soils have a high potential for water retention and can therefore provide good grasslands for cattle and game. The study shows the importance of soil scientific investigations in Namibia as a basis for further work dealing with a) sustainable land use, b) landscape degradation and c) palaeoenvironments. The work on this topics is ongoing.

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