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SOILS, SOIL EROSION AND VEGETATION IN THE ETOSHA NATIONAL PARK/ NORTHERN NAMIBIA

Field and Laboratory Results of the Investigations of the year 1989 (Part I)

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SOILS, SOIL EROSION AND VEGETATION IN THE ETOSHA NATIONAL PARK/ NORTHERN NAMIBIA (PART I)*

1. Preliminary

Within the scope of the research project "Soils, Soil Erosion and Land Management in the Etosha National Park/Namibia", the author of this paper was staying in the North of Namibia for first field works from July 26 to August 25, 1989. An abridged version of the project description is added as Enclosure No. 1. The mentioned project is conceived as a long-term research co-operation between the Etosha Ecological Institute in Okaukuejo/Namibia, represented by Dr. Malan Lindeque, and the Department of Physical Geographie at the University of Regensburg/Fed. Rep. of Germany (under the chair of Prof. Dr. Klaus Heine), represented by the author, Dr. Manfred W. Buch. The long-term aim of the project is the evaluation and mapping of eco-pedological risks and the geomorphodynamical sensitivity in the Etosha National Park in the light of the proposed climatic and environmental changes within the next 50 years and on the basis of different models of land management policy. The results of the project should lead to land management practices which are well adapted to the semiarid environment. To complete the set task, additional field research in the Etosha National Park will be necessary.

At the given state of the project, the research is fully based on the financial support of the Deutsche Forschungsgemeinschaft. In April 1990 the author has applied for additional research promotion from the "German Ministry for Technical Assistance" as part of the bilateral technical co-operation between the Republic of Namibia and the Federal Republic of Germany.

Starting point and basis of further studies is a full inventory of the pedological and phytogeographical conditions within the Etosha National Park. In the course of the first research period

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in Etosha in the year 1989 extensive soil mapping has already been carried out in interdisciplinary collaboration with Dr. Malan Lindeque (Head of Research, ENP) and Mr. Wynand du Plessis (Plantecologist, ENP). The paper in hand recapitulates the present field results as well as the results of the hitherto accomplished laboratory analysis. With the presumed completion of the laboratory analysis by the end of 1990 the remainig results will be presented.

2. Methods Used for Soil Survey and Laboratory Analysis

In the course of the field works in 1989, 55 soil profiles were being described by pedological-sedimentological field results and interpreted with regard to their phytogeographical and geomorphological-geological background. The vegetation surveys at the locations of the described soil profiles were carried out by Mr. Wynand du Plessis. For more detailed laboratory analysis a total of about 250 soil samples (= 90 kg) was taken from selected soil profiles. Meanwhile, the standard laboratory analyses and some additional special investigations have been completed for half of the soil samples. These results, together with the profile descriptions, have been stored in a EDP-data bank. A compilation of all profile descriptions may be found in Enclosure No. 2. The applied horizon symbols follow the FAO Soil Classification System (FAO-UNESCO 1988) but were partly modified in adaption to local conditions (see Enclosure No. 3). Enclosure No. 4 comprises the definitions of those symbols representing the main soil properties.

The here presented pedological survey is based on the Reconnaissance Soil Map of the Etosha National Park (see Map 1), provided by le ROUX et al. (1988). Therefore, as a first step, the described soil profiles have been related to the there proposed mapping units. The systematic classification of the soil units has been done in accordance to both the Southafrican nomenclature (DEPARTMENT OF AGRICULTURAL TECHNICAL SERVICES 1977) and the internationally largely accepted nomenclature

proposed by the FAO (FAO-UNESCO 1988) (cf. Enclosure No. 5). Yet in this paper the descriptions of the soil profiles exclusively refer to the FAO Soil Classification System; possible modifications or a further subdivision of the mapping units distinguished by le ROUX et al. (1988) are being discussed. The momentary state of knowledge, however, does not allow to present a revised soil map so far.

The pedological field methods applied follow the guidelines of the "Bodenkundliche Kartieranleitung der Bundesrepublik Deutschland" (AG BODENKUNDE 1982) as well as the ones given by the "Booker Tropical Soil Manual" (LANDON 1984). A comparison between the textural classes of the Southafrican and the German classification is given by Fig. 1.

For characterizing the basic physical and chemical soil properites, following laboratory investigation methods have been used:

- **Soil Colour**

Classification after Munsell Soil Color Charts. Colour normally determined of soil sample in moist state; if not so, state is indicated in brackets.

- **Soil Texture**

Combined sieving and pipette sampling particle-size analysis after KÖHN.

- **Concentration of Free Carbonate**

Determination with calcimeter after SCHEIBLER

- **Content of Organic Matter**

Determination after SPRINGER & KLEE. Calculation:

% C x 1,72 = % organic matter

- **Total Nitrogen Content**

Determination after KJIELDAHL

- **Soil pH**

Measurement in a 1n KCl suspension with a soil-to-KCl ratio of 1 : 2.5.

- **Electrical Conductivity**

Measurement in a 1 : 5 soil-water suspension.

Additional special analysis will be mentioned in the corresponding chapters.

3. Field and Laboratory Results of the Soil Survey

According to le ROUX et al. (1988), in large areas of Etosha the distribution of typologically different soils is reflected by the occuring vegetation units (ibid. p. 7, Fig. 5). Le ROUX et al. (1988) distinguish four groups of "Dominant Soil Series" as defined by the Soil Classification of South Africa (cf. Map 1):

- Sandy soils (mapping units S1 to S7)
- Deep soils of the Ovambo Plain (mapping units L1 to L3)
- Soils of the "Karstveld" (mapping units K1 to K2)
- Soils of miscellaneous land classes (mapping units R and P)

3.1 Mapping Units S1 to S7

The occurance of sandy soils of the mapping units S1 to S7 within the Etosha National Park is largely concentrated on the northeastern region ("NE Sandveld"; S1), the western and northern edge of the Etosha Pan, the north-western region (S2 to S5, whereby S5 also is present in the extreme south) and the Kaross region (S7) (Map 1). This group of soils, though, appears to be very inhomogeneous with regard to age and typological properties. On the one hand one can find Ferralsols or, as defined by the FAO classification, Ochric Cambisols respectively, which are probably of tertiary age, and on the other hand there occur Regosols which were formed in the Quaternary or even Late Quaternary Period. The result is the existence of sandy soils with basicly different soil properties.

The decisive difference between the soils of mapping unit S1 and those of unit S6, both classified as Regosols according to the FAO nomenclature (cf. Langebaan-Series after le ROUX et al.

1988), is their different concentration of free calcium carbonate, which is an important phytoecological factor. Numerous soil profiles described by the author illustrate the properties of the soils within mapping unit S1 "NE-Sandveld". Typical soils with an A_h-C_v-C_n or an A_i-C_v-C_n sequence of horizons are represented by profiles Eto 15 and Eto 21. These slightly weathered, slightly clayey medium to fine-sandy soils free of calcium carbonate have formed on non-calcareous fluvial sediments of several metres thickness (Fluvisols), which upper parts obviously have been exposed to aeolian redeposition (Regosols). The content of humus in the topsoil is generally low, ranging between 0.7 % and 0.5 %. Characteristic of their fluvial origin is the high variability in the content of humus. Very low as well is the concentration of total nitrogen in the topsoils of < 0.1 %. The soil pH values < 6 (measured in 1n KCl solution) indicate medium to high acidity, where in extreme cases values of pH 4 do occur (see sample Eto 15-A). In regard of the low pH values, it is more appropriate to speak of soils of the "Fernwood Series" rather than speaking of soils of the "Langebaan Series" (le ROUX et al. 1988), to follow the nomenclature proposed by the Southafrican soil classification.

Several different properties specifying Regosols of the soil unit "NE-Sandveld", which are responsible for the phytogeographical pattern, may be mentioned here.

Geomorphologically speaking, the NE-Sandveld represents a higher lake level, called "Mushara Level" by BUCH (1990), within the area of the Etosha Pan. The Mushara Level is bordered to all sides by dune ridges of a yellowish red colour. The pedogenetic characteristics are shown by soil profile Eto 6, located on the edge of the Mushara Level where it is passing over into the "Andonivlakte" (mapping unit L1). Clayey, fine to medium-grained dune sands of 135 cm thickness lying on top of a calcrete are bearing a soil of the type Xanthic Ferralsol. More than by their yellowish red colour the above mentioned dune sands are different from the Regosols of the actual Mushara Level by a

higher soil pH of about pH 8. This is possibly causing the dominance of *Terminalia prunioides* of more than 10 m height within the tree layer.

The soils of the pans also occupy a special position within the Regosols of the Mushara Level (see profiles Eto 18 and Eto 20). One of the largest pans is the "Beisebvlakte" in the north-east (profile Eto 20). The soils within the pans have formed on weathered calcrete material which before was fluvially redeposited. They have to be classified as calciferous Fluvisols which are enriched with salt within the top half centimetre (Sali-Calcaric Fluvisols). Below 25 cm depth, the beginning dense massive structure of the soil bodies indicates a typological transition from Fluvisol to Planosol.

The area belonging to **mapping unit S6**, located on the western and northern edge of the Etosha Pan, is of great importance due to the land use as pasture, its erodibility and its quaternary landscape history. Sedimentologically speaking, one can find silty and loamy sands rich in calcium carbonate (25 % - 40 %). Those sands were blown out of the Etosha Pan by easterly to south-easterly winds during the Late Quaternary Period, then being redeposited in form of dune ridges. Today, these dune ridges are largely stabilized against erosion through their grass cover, consisting of *Stipagrostis uniplamis, Stipagrostis hochstetterana, Cenchrus ciliaris, Eiagrostis echinochloidea* (perennial species), *Enneapogon cenchroides, Stipagrostis hirtigluma* (annual species), and singular shrubs of the type *Salsola tuberculata*. Damage to the vegetation cover, however, is a immediate trigger to soil erosion. At the moment, the area of Adamax-Nacto-Leeubron is severely subjected to erosion (see Chapter 4).

Horizons with features of slight browning (fC$_v$ horizons) subdivide the dune sands and allow a pedostratigraphic reconstruction of the changing Late Quaternary climatic and environmental conditions (cf. BUCH 1990: 8-18). The surface soils in the area of dune occurance within mapping unit S6 are

classified by le ROUX et al. (1988) as "Langebaan Series" according to the Southafrican Soil Classification System, whereas using the FAO nomenclature they belong to the soil type of the Calcaric Regosols. The latter term especially takes into account the high concentration of calcium carbonate of the sandy virgin soils and makes a clear difference between them and the so-called Eutric Regosols of mapping unit S1 "NE Sandveld". The Calcaric Regosols of the dunes on the western edge of the pan (cf. profiles Eto 44, Fig. 2, and Eto 47) have formed on youngest aeolian sediments, probably accumulated during the last centuries. They generally show higher contents of clay and silt in comparison with the Eutric Regosols of the "NE Sandveld". Worth mentioning is the notably higher content of organic matter, with values ranging between 0.5 % and 0.8 %. The measured concentrations of total nitrogen, though, are of comparably low values < 0.1 %. Negligible are the values found for the electrical conductivity of the solum of < 1 mS/cm. The soil pH varies between pH 8 and pH 8.5. A slightly higher electrical conductivity with values around 0.7 mS/cm is found in profile Eto 47, only few decimetres beneath the youngest aeolian sedimentary cover within a buried horizon of slight browning (fC_v horizon). This weakly developed soil may be classified as a Haplic Calcisol as defined by the revised nomenclature of the FAO (FAO-UNESCO 1988: 43). According to the present state of field results, the sediment bodies of the dunes on the western edge of the pan are subdivided by at least three buried C_v horizons (cf. BUCH 1990: 8-18). Especially in marginal parts of the pan (see profile Eto 44, Fig. 2), the buried C_v horizons present notable salt concentrations (concentration of total salt: 5.4 %) with an electrical conductivity of up to 17 mS/cm.

The pedological conditions in the interdune passage between the first and second dune ridge on the western edge of the pan are characterized by profile Eto 46. Here, too, the stratigraphic succession shows a Calcaric Regosol underlain by a buried Haplic Calcisol. But in this case, the fine-grained sedimentary cover of 90 cm thickness rests upon a calcrete (Petric Calcisol). The

comparably high content of humus throughout the stratigraphic sequence (> 1 % of organic matter), and especially within the topsoil (> 2 % of organic matter), is a result of the profile's position within an accumulation zone of fluvially reworked sediments between the dune ridges. The values of the electrical conductivity ranging between 1 mS/cm and 2 mS/cm have to be interpreted likewise.

So far, the author hasn't done any profile descriptions of the sandy soils within **mapping unit S2** (Roodepoort Series or Rhodic Ferralsols resp.) and **mapping unit S3** (Sunbury Series or Ochric Cambisols/Xanthic Ferralsols resp.). According to own aerial observations and the soil mapping done by le ROUX et al. (1988), mapping unit S2 comprises non-calcareous, eutrophic soils with a clay content of 0 % to 6 % in the fine-sandy, red apedal B horizons. The soils of mapping unit S3 show generally similar properties with the exception of their yellowish brown colour.

Although le ROUX et al. (1988) differentiate the soils of **mapping units S3 and S4** with respect to phytogeographic factors, they classify them jointly as soils of the Sunbury-Series (Ochric Cambisols bzw. Xanthic Ferralsols). In the author's opinion, further differentiation is necessary here. Following own aerial observations and field surveys, **mapping unit S4** comprises a relief-defined soil association of calcrete outcrops, sandy, reddish to reddish yellow (7.5 YR Munsell colour) Rhodic or Xanthic Ferralsols resp. above calcrete in summit positions, and Eutric Vertisols on calcrete located in small closed depressions. A demarcation of the soil association must remain for additional surveys.

The Xanthic Ferralsols above calcrete (cf. profile Eto 30, Fig. 3) are shallow (about 40 cm thick), non-calciferous, slightly loamy to slightly clayey sandy soils (with content of clay ranging between 6 % and 13 %). For the most profiles described, the field results leave the question unanswered, whether we are confronted with erosional remnants of in-situ

soil formation or sediments of reworked Ferralsols. The particle-size analyses show that the slightly humic to humic topsoils (0.3 % to 0.6 % organic matter) are mainly of a considerably lower clay content than the subjacent B_u or B_uM horizons, due to an admixture of youngest aeolian sediments of reworked soil material. In this respect we have clear signs of a stratified profile, at least within the topmost decimetres. The topsoils are characterized by pH values of around pH 7.3. Following the sequence of horizons down to the underlain calcrete, increasing pH values are found. Only soils of the type Ferralsol forming on acid, quartzitic rocks (cf. profile Eto 29) present a reverse vertical trend with values of around pH 7 in the topsoil and pH 6 in the reach of the lower boundary of the solum. The measured electrical conductivity is insignificant for the Xanthic Ferralsols with values below 100 µS/cm.

Totally different phytoecological conditions are given by the dense Eutric Vertisols of dark-grey colour occuring within the small depressions (cf. profile Eto 41 and Eto 42). The non-calciferous vertic PA_h or A_hP horizon resp. is of 35 cm to 60 cm thickness. Below may be situated a massive, non-calciferous pelosol-like horizon which is passing into the underlain calcrete, as it is the case in profile Eto 42. Presenting an altogether strongly sandy, clayey texture, the occurance of desiccation cracks of at least 10 cm in depth is typifying the vertic topsoil. While the dark-grey colour of the vertic topsoil indicates a high content of organic material, the measured values are not exceeding 0.5 %. Yet for thicker PA_h horizons, the absolute amount of humus is comparable to or may be even higher than the content in shallow A_h horizons of Calcret Lithosols (content of organic matter up to 4 %) of the vegetation unit 1 "Sweet Grassveld on Lime" (see below). Besides existing textural differences, the Eutric Vertisols also differ from the Xanthic Ferralsols by notably lower pH values, ranging between pH 5.6 in the topsoil and pH 6.5 at their lower boundary right above the subjacent calcrete. The electrical conductivity values measured are generally below 100 µS/cm but show a

remarkable increase with depth from 45 µS/cm in the topsoil to 100 µS/cm right above the calcrete.

The soils of **mapping unit S5** are classified by le ROUX et al. (1988) as "Zwartfontein-Series", which is equivalent to the Rhodic or Xanthic Ferralsols of the FAO nomenclature. Two soil profiles located within mapping unit S5, Eto 13 and Eto 37, have been described by the author. Profile Eto 37, situated 700 m west of the well Klippan in the western part of the Etosha National Park (see Enclosure No. 2), presents a sequence similar to that of a shallow Xanthic Ferralsol above calcrete but has to be classified as a Rhodic Ferralsol because of the much redder hue in its soil colour (Munsell colour 5 YR). Compared to the two profiles discussed in the last but one paragraph, the Rhodic Ferralsol in question now (Eto 13, Fig. 4), being of medium depth and having formed on dolomite rock, shows a considerably higher clay content of up to 30 % in the relict in-situ B_u horizon. Thus, its character of a stratified profile with a 20 cm to 30 cm thick surface layer of partly aeolian sediments above the in-situ B_u horizon becomes evident, even more than it does in profile Eto 30 (see Fig. 4). The stratification of the profile is of importance to the soil water budget (see Chapter 5.4) as well as to the vertical trend of the pH values, which indicate a moderately to slightly acid soil environment with values ranging between pH 5.7 an 6.7 for the sandy sedimentary cover, while for the B_u horizon the measured soil pH is neutral to slightly alkaline, varying from pH 7 to pH 7.7. The content of humus with 0.4 % in the A_1 horizon is low, as for other Ferralsols, but also shows a high variability (0,4 % to 0,8%) within the vertical sequence.

Like the above described soils of mapping unit S5 - following le ROUX et al. (1988) - the soils of **mapping unit S7** in Kaross, situated in the southwestern corner of the Etosha National Park, belong to the "Zwartfontein Series" (corresponding to medium sandy Rhodic or Xanthic Ferralsols after the FAO nomenclature). But taking into account the results of own field and laboratory

analysis, this classification should be revised, though. From a genetic point of view, the soils found in the trough-shaped valley of Kaross are to be classified as Fluvisols having formed on fluvially redeposited, sandy and gritty sheetwash sediments of the surrounding, sometimes deeply weathered granites (see profile Eto 34). The reddish hue in the colour (Munsell Colour 7.5 YR to 5 YR) of the soils which on the other hand show no clear differentiation into horizons is caused by the granitic component originating from the weathered granite bedrock on the slopes. According to the up to now accomplished laboratory analysis, the soils of mapping unit S5 differ from those of mapping unit S7 mainly by their lower pH values (pH 6 to pH 5.2) and a generally higher content of coarse sand and grus. These grain-size properties are of great importance to the soil water budget (see below).

For further soil mapping great attention has to be directed to following points in question - the delimitation of Rhodic and Xanthic Ferralsols with regard to stratification, the possibly altogether sedimentary character of the soils, the parent rock of soil formation, the association with calcrete outcrops and soils of the type Eutric Vertisol, and the resulting eco-pedological properties.

3.2 Mapping Units L1 to L3

The soils of mapping units L1 to L3 defined as "Deep Soils of Ovambo Plains" by le ROUX et al. (1988) prove to be a very inhomogenous group of soils, comprising soils of the type Ochric Solonetz with albic horizon (L1), Eutric Regosol (L2) and Chromic Cambisol (L3). They mainly occur along the northern border of the Etosha National Park, whereby the Regosols and Cambisols of mapping units L2 and L3 also are present west of Okaukuejo in the central part of Etosha. The few soil profiles described by the author up to now show that, from a geomorphological-sedimentological and ecopedological point of

view, a further differentiation of the "Deep Soils of Ovambo Plains" needs to be discussed in future.

The soils of **mapping unit L1** (Heights Series or Ochric Solonetz with albic horizon resp.) find their description in profiles Eto 5 ("Andonivlakte") and Eto 51 ("Lower Ekuma"). Profile Eto 51 as well as the lower section of Eto 5 consist of calciferous, slightly saline, glauconitic sand of fluvial-limnic or fluvial origin underlain by a glauconitic calciferous sandstone (called "Ekuma Calciferous Sandstone"). The measured pH values of > pH 9 prove a strongly alcaline soil environment. In profile Eto 51, situated on the floodplain of the Ekuma River, features of ground-water influence already appear at 6 cm depth right beneath a salt crust. Characteristic of the soils of the "Andonivlakte" is the hardpan occuring between 10 cm and 25 cm depth (see Enclosure No. 2). Analysed by X-ray diffractometry, the hardpan proves to be a mixture of quartz, calcite, halite, and montmorillonite (known for its swelling capacity). The hardpan acts as a impound-water base. Thus, the percolation of the water precipitated on the "Andonivlakte" during the rainy season is hindered, damming up a shallow lake for a considerable period of time. The hardpan in profile Eto 5 is covered by about 10 centimetres of silty, sandy, very saline aeolian sediments, which are mounting around grass-tufts of *Sporobulus spicatus* and *Odyssea paucinervis* to little tops of 10 cm height. A high salinity, with electrical conductivity values exceeding 14 mS/cm, is to be found within the uppermost 3 cm of sand. With regard to the diagnostic features documenting impound water influence, the saline soils of the Andonivlakte are classified as "Stagnic Solonetz" in this paper.

The soils of **mapping unit L2** are classified by le ROUX et al. (1988) as "Langebaan Series" (corresponding to the Eutric Regosols as defined by the FAO nomenclature) and hence should be closely related with the soils of mapping unit S1. Within mapping unit L2, le ROUX et al. (1988) distinguish two plant associations, i. e. the "Narawandu Shrub Mopaneveld" and the

"Ekuma Woodlands". The phytogeographical facts already let assume pedogeographical differences, an assumption which is supported by the so far described profiles in many respects (see profiles Eto 43, Eto 48, Eto 49 and Eto 50).

The profiles Eto 48, Eto 49 and Eto 50, located within the reach of the "Ekuma Woodlands" (see Map 1) show the diagnostic features of the "Langebaan Series". Regarding sedimentological properties, the profiles describe a sedimentary cover of at least 1.5 m thickness consisting of medium-grained fluvial sands underlain by a sequence of several calcrete strata (profile Eto 49). The sands are slightly calciferous to calciferous (1 % to 7 % of $CaCO_3$) and are interspersed with calcareous fragments, especially at their lower boundary (profile Eto 50). The soil pH of the total sequence is characterized by values around pH 8, pounting out a slightly alcaline to alcaline soil environment. A beginning soil formation with an A_{ch}-C_v horizon sequence is indicated by the vertical gradient in the content of calcium carbonate with 1 % in the A_h horizon and 4 % at the possible lower solum boundary. The assumed decalcification affects the profile down to 60 cm depth. The content of organic matter in the A_h horizon reaches maximum values of 0.7 %, which is typical for sandy soils in Etosha. The concentration of total nitrogen is, according to the at present available laboratory results, below the detection limit.

Profile Eto 53, located on the edaphically dry "Acacia Terrace" at the border of the "Andonivlakte" (see Map 1), presents a slightly further advanced soil formation. The "Acacia Terrace", leading over to the so-called "Mushara Level", occupies a surface merely 1 to 2 m higher than the "Andonivlakte". From a geomorphological point of view, these topographical levels represent different quaternary lake levels in the Etosha Pan (cf. BUCH 1990). Existing sedimentological and pedological differences between the soils of the "Andonivlakte" (see profile Eto 5) and the ones of the "Acacia Terrace" become evident through the abrupt vegetational change from grass-savanna being

composed of halophytic species exclusively to acacia-shrub vegetation at the boundary between both levels (Fig. 5). In contrast to the soils of the Ekuma Woodlands, the ones occuring on the Acacia Terrace (profile Eto 53) have been decalcified down to 60 cm depth. Correspondingly, the measured soil pH values ranging between pH 6.7 and 7.6 are lower. The content of humus of 1.1 % in the A_h horizon, however, is relatively high.

The soils of the central part of mapping unit L2 (profile Eto 43) are basicly different from those of the Ekuma Woodlands by their parent material, texture, and soil association. According to the existing mappings, a relief-defined soil association of Eutric Vertisols ("Rydalvale Series" after the nomenclature of the Southafrican Classification System) - similar to the already described soil profiles Eto 41 and Eto 42 of mapping unit S4 - and (Vertic) Cambisols is found here. Both soil types have formed from calcrete, the (Vertic) Cambisols occuring on surfaces surrounding the small depressions to which the Pellic Vertisols are confined.

The (Vertic) Cambisols described in profile Eto 43 (Fig. 6) may be taken as soils being of a further advanced state of soil formation of the same evolutionary series as either the Calcrete Lithosols (Lithic Leptosols as defined by the revised FAO nomenclature from 1988) present in mapping units K1, K3 and K5 or the Calcic Cambisols of mapping units K2 and K4. After the present state of knowledge, the biogenetic and mechanical desintegration of calcrete to powdery consistency by termites seems to play a dominant role in the progress of soil formation. The mappings show that the "Scrub Mopaneveld" on loamy soils of mapping units L2 and L3 covers the area with the most termite hills per unit area within the Etosha National Park.

Both field results and laboratory analysis point out the stratified nature of profile Eto 43 (Fig. 6). A 45 cm thick dense and massive P horizon rich in calcium carbonate (up to 15.6 %) is underlain by a calcrete at 70 cm depth, which is the

parent material of the horizon in question. The clay content of up to 38 % and the resulting features of damming wetness (Munsell colour 2.5 Y) point out a formation tendency towards soils of either "vertic properties" or "stagnic properties". The topmost 25 cm of the Cambisol (stratigraphically above the mentioned P horizon), which are showing a typical A_h-B_v horizon sequence, are free of calcium carbonate and are characterized by an admixture of aeolian redeposited sand. Due to this admixture, the A_h horizon shows a lower content of clay (26 %) and a higher content of sand, especially of fine sand (about 35 %). Thus, the content of clay is growing with depth, resulting in a difference of 12 % clay between the A_h horizon (texture: strongly sandy clay) and the lower boundary of the P horizon (texture: sandy clay) and a parallel rise of the soil pH values from pH 6.4 to pH 7.8. The vertical trend of the electrical conductivity values confirmes its nature of a stratified profile: The EC values measured in a 1:5 soil-water suspension rise from 0.1 mS/cm in the A_h horizon to 1.0 mS/cm at the boundary to the P horizon, then falling to 0.7 mS/cm. This shows the downward leaching of easily soluble salts through the permeable soil body of the Cambisol and the relative concentration of salts in the top part of the less permeable P horizon, where the absolute concentration of salts with 0.32 % yet proves to be comparably low. The content of organic matter of 0,9 % in the A_h horizon is low to medium but nonetheless higher as for most of the other sandy soils in Etosha. The measured concentration of total nitrogen of 0.04 % is very low.

According to the soil survey completed so far, the relief-defined soil association of (Vertic) Cambisols and Eutric Vertisols of mapping unit L2 is characteristic, too, for the area around the pad between Okaukuejo and Olifantsrus in the northern part of **mapping unit L3**, and may be occuring beyond. Le ROUX et al. classify this soil unit as "Valsriver Series" (corresponding to the Chromic Cambisols of the FAO nomenclature). The "Valsriver Series" is characterized by soils of a predominantly non-red B horizon (with a clay content of

15 % to 35 %) and a calciferous B or C horizon. At present, the author hasn't yet described any soil profiles in the southern part of mapping unit L3. Additional field research in this area must especially be carried out with regard to whether or not the phytogeographical differentiation between mapping units L2 and L3 allows a pedological differentiation as well. Of further importance is a delimitation against the non-calciferous, clayey-loamy to loamy-clayey soils of mapping unit K (profile Eto 27, see below).

3.3 Mapping Units K1 to K7

The so-called "Karstveld Soils" of mapping units K1 to K7 (le ROUX et al. 1988) are mostly found in the south and in some parts in the west of the Etosha National Park. The "Karstveld Soils" in the south of Etosha (comprising the "Kalkbank Series" of K1, the "Lekfontein Series" of K2, the Lithosols of K5, the "Arcadia Series" or Lithosols of K6 and the "Arcadia Series" of K7) all have in common that they have formed on calcrete. The soils of the mapping units K3 (Kalkbank Series or Lithosols resp.) and K4 (Dudfield Series) in the western part of Etosha are associated with sandy soils of the type Rhodic/Xanthic Ferralsols (mapping unit S5).

The occurence of soils of the **Kalkbank Series (K1)** and of the **Lekfontein Series (K2)** is widely identical with the occurence of the vegetational unit "Sweet Grassveld on Lime" as defined by le ROUX et al. (1988). The term is applied to the vast grasslands on the southern edge of the Etosha Pan, which provide the most important pasturelands in the Etosha National Park. But, too, one can find expansive stands of *Colospermum mopane* of the "Mopane Treeveld" west of Okaukuejo on soils of the Lekfontein Series. The mapping in hand was carried out not least with great effort towards finding possible criteria for a pedological differentiation of the vegetational defined units.

The characteristic soil of mapping unit K1 within the area of the "Sweet Grassveld on Lime" is to be seen in profile Eto 1 (Fig. 7). According to the revised FAO nomenclature the soil has to be classified as a Lithic Leptosol (before: Calcrete Lithosol). The Lithic Leptosols show a A_{ch}-C_v A_{ch}-mkC_n horizon sequence and have formed from a calcrete. Typical for them is their shallow soil body of 25 cm to 30 cm thickness, their extremely high content of skeleton material (about 75 % in weight) and a high concentration of free calcium carbonate of up to 43 % throughout the whole profile. Although the solum is just of little thickness, the results of the particle-size analysis point out a clear stratification of the profile. The topmost 6 centimetres within the humic A_h horizon are significantly more sandy, due to an admixture of allochthonic aeolian sand (texture: silty, loamy sand), and present a lower content of skeleton material when compared to the deeper part of the A_h horizon between 6 cm and 25 cm below surface (texture: clayey loam). The soil pH values of pH 7.7 to 7.8 indicate a slightly alcaline soil environment, which is caused by the high content of calcium carbonate. The contents of organic matter of 4 % and total nitrogen of 0.2 % found in the A_h horizon represent the highest values measured so far in soils of the Etosha National Park. For the electrical conductivity values ranging between 0.1 and 0.3 mS/cm have been measured. Consequently, a negligibly low salinity has to be assumed here, contrary to the information given by le ROUX et al. (1988: 8), who assume a high salinity.

In some parts of mapping unit K2 soils with properties described in profile Eto 1 for mapping unit K1 do occur, too, as it is the case in the area of Adamax-Leeubron-Nacto. This should be reason for reconsidering the delimitation of mapping unit K2.

The soils of **mapping unit K2**, according to le ROUX et al. (1988), belong to the "Lekfontein Series" as defined by the Southafrican nomenclature (corresponding with Ochric, Eutric, Calcic Cambisols of the FAO nomenclature). The characteristic soils of mapping unit K2 occuring west of Okaukuejo bear the so-

called "Mopane Treeveld" plant association. With profile Eto 27, located 3.9 k northeast of the well Eindpaal, a shallow to medium deep soil above calcrete of 53 cm thickness is described. In the immediate vicinity outcrops of calcrete have been observed. In contrast to the Lithic Leptosols (Calcret Lithosols) of mapping unit K1, the typical soils of mapping unit K2 are free of calcium carbonate and - apart from sporadic calcrete fragments - free of skeleton material. Due to the missing calcium carbonate, the soil pH proves to be lower than for the Lithic Leptosols. The measured values ranging between pH 6.7 and 6.8 indicate a very slightly acid soil environment. Following the results of the particle-size analysis, a clear stratification is present in the profile under discussion, which is of great importance to root penetration and the physiological conditions for plant life in general. A vertical change in the consistency from sandy loam (clay content of 18 %) within the first 10 centimetres to clayey loam to loamy clay (clay content of 52 %) right above the calcrete is to be observed. Genetically speaking, the profile in question obviously presents a fluvially redeposited sediment of a soil having formed from a calcrete (Fluvisol as defined by the FAO nomenclature above calcrete), which later has been reworked by wind in its topmost 10 centimetres. The aeolian reworked layer (woM horizon) is widely subjected to erosion, except around shrubs and trees of the species *Colosperum mopane*. Because of textural reasons (high contents of silt and fine sand in the topsoil) and the low structural stability the soil of the type described by profile Eto 27 must be considered extremely erodible, as is documented by the current erosional processes, which are set off when the vegetation cover is removed. The content of organic matter is comparably high throughout the profile, reaching 2 % as peak value within the woM horizon and ranging between 0.6 % and 0.9 % in the other parts of the profile. The measured electrical conductivity values are negligibly low.

Recapitulating the present state of results on the pedological conditions which the plant association "Sweet Grassveld on Lime"

on the one hand and the plant association "Mopane Treeveld" on the other hand depend on, it seems that the type of vegetation dominated by *Colospermum mopane* especially grows on relatively heavy and deep soils which are free of calcium carbonate and skeleton material. The resulting consequences for the soil-water budget are discussed in chapter 5.4. A marginal extension of the "Mopane Treeveld" onto soils of the type Lithic Leptosols (see profile Eto 4), which are otherwise covered with grass savanna, yet is possible. The same applies to a variant of the vegetation unit "Sweet Grassveld on Lime" with shrubs of the species *Acacia nebrownii*, which, passing into the "Mopane Treeveld" east of Okaukuejo, also occurs on Lithic Leptosols (see profile Eto 2).

After le ROUX et al. (1988), the prevailing soils of **mapping unit K5**, attaching with its northern edge to mapping unit K2, are of the type (Calcrete) Lithosol. Own mappings, however, resulted in a further differentiation of the soil pattern, while a precise delimitation against **mapping unit K6** was not possible so far. The transition zone between mapping units K6 and K7 south of Dungaries is, for the time being, described by one profile (Eto 14) only. Characteristic of mapping unit K5 is a soil association of calcrete outcrops, Lithic Leptosols (Calcrete Lithosols) and non-calciferous Eutric Vertisols (profiles Eto 7, Eto 8 and Eto 10). Additionally, in the reach of the "Karstveld Turf Pans" west of Gobaub (Sali-)Stagni-Calcaric Vertisols (profile Eto 9) are present.

The Lithic Leptosols (Calcrete Lithosols) of mapping unit K5 are shallow just like the comparable soils of mapping unit K1. In profile Eto 8 the soil body above the underlain calcrete is usually less than 10 cm deep. The textural consistency of the mkC_vA_{ch} horizon is that of a strongly loamy sand. The relatively high content of fine and medium sand and a comparison with the oMA_{ch} horizon of profile Eto 1 suggest an admixture of allochthonic, aeolian sandy sediment for this profile too. On the other hand, the content of calcium carbonate, mostly due to interspersed fine calcareous fragments, is with 4.2 % notably

lower than in profile Eto 1. Correspondingly, the soil pH value of 7.4 is lower too. The contents of organic matter (3.0 %) and total nitrogen (0.2 %) show high values comparable to those of the Lithic Leptosols of mapping unit K1.

While the Lithic Leptosols of mapping unit K5 occur on flat calcrete ridges, the adjacent shallow solution hollows of some tens of meter in diameter, often showing a circular outline, bear soils of the type Eutric Vertisol which have formed from the subjacent calcrete (profile Eto 7, Fig. 8). As it is characteristic of Vertisols in general, extraordinarily high contents of organic matter with values ranging between 1.6 % and 2.4 % and clay exceeding 50 % are prevailing throughout the whole profile in question. The clayey consistency is causing an angular polyhedral structure. Examining the vertical trend of the clay content, a notable increase from the topsoil (52 %) down to the calcrete surface (72 %) is found. According to the consistency (loamy clay) of the topmost 18 centimetres of the profile, an input of aeolian sediments may be assumed here too; this would explain the relatively rare and weakly developed desiccation cracks. The soil pH indicates a slightly acid soil environment within the oMPA$_h$ horizon with values of about pH 6 and shows rising values with increasing depth, reaching pH 7 at the lower boundary of the soil body. Hence, the present acidity is significantly higher here than for the Lithic Leptosols of the immediate vicinity (pH 7.4; see above). The measured electrical conductivity of 0.5 mS/cm at the most is extraordinarily low. Though, a notable rise of values from 0.07 mS/cm to 0.5 mS/cm is to be recognized when examining the vertical downward trend.

The Eutric Vertisol described in profile Eto 10 (Fig. 9) is of 30 cm thickness and hence less deep as the one described in profile Eto 7. Like in profile Eto 7, the soil body is free of calcium carbonate, but its clay content (41 %) is notably lower.

The (Sali-) Stagni-Calcaric Vertisols of the so-called "Karstveld Turf Pans" are described by profile Eto 9. This profile is characterized by a PAch-AchP-Pc horizon sequence. Although the soils of the type in question show a typically developed gilgai relief with desiccation cracks of 25 cm depth at maximum, they all the same present differences in fundamental properties when compared to the above described Eutric Vertisols (cf. especially profile Eto 7). The most important criterion by which to distinguish both types of Vertisols is their content of calcium carbonate, which ranges between 34 % to 37 % in profile Eto 9. Correspondingly, the soil pH shows higher values of around pH 7.9. Due to the extraordinarily high clay content of 70 % and the massive structure below 25 cm depth, impound-water features are strongly developed (cf. Munsell Colour 2.5 Y). The content of organic matter ranges between 0.9 % and 0.7 % within the humus-enriched PAch horizon of 25 cm to 45 cm depth and drops to 0.3 % in deeper parts of the soil body. Intensive swelling and shrinking dynamics following the course of the succeeding yearly rainy and dry seasons together with a relatively high salinity are the limiting factors of plant growth. The measured electrical conductivity values are rising from about 0.2 mS/cm within the topsoil to 2.0 mS/cm at the lower boundary of the AchP horizon at 64 cm depth. This characteristic vertical trend of the electrical conductivity values points out a downward leaching of the easy-to-solve salts from the topsoil into the subsoil.

Within mapping unit K1 soils typologically comparable to the one described in profile Eto 9 are to be found near the southern margin of the Etosha Pan (profile Eto 3). Regarding the altogether high EC values ranging between 1.4 mS/cm and 8.9 mS/cm, a classification as Stagni-Salic-Calcaric Vertisols seems to be appropriate. A striking parallel between the soils of profile Eto 9 and Eto 3 is their maximum salt concentration at a depth of approximately 60 cm.

The above discussed features of the two types of Vertisols suggest that they are of different origin. While the non-calciferous Eutric Vertisols ("Rydalvale Series" according to the Southafrican nomenclature) are to be interpreted in most cases as in-situ soil formations from calcrete, the (Sali-) Stagni-Calcaric Vertisols or Stagni-Sali-Calcaric Vertisols ("Arcadia Series" according to the Southafrican nomenclature) probably are to a considerable extent of sedimentary origin (see also calcrete boulders on the surface!). Thus, a transition to the very clayey, saline Fluvisols of the drainage systems in the south of the Etosha Pan (e. g. profile Eto 25 located in the thalweg of the "Gaseb Drainage System")is given.

As already mentioned, no clear differences between the soils of mapping unit K5 and those of **mapping unit K6** have been found yet. In both units occur soil associations of calcrete outcrops, Lithic Leptosols (Calcrete Lithosols) and non-calciferous Eutric Vertisols. The non-calciferous Eutric Vertisols are described by profile Eto 14, which is located at the contact between mapping units K5 and K6. Presenting a solum of 35 cm thickness, the depth of formation is comparable to the one of profile Eto 10 (mapping unit K5).

For a comprehensive characterization of the soils of **mapping unit K7** ("Arcadia Series" after le ROUX et al. 1988) additional profile descriptions are necessary. According to the present state of research, a relief-defined soil association of calcrete outcrops, shallow and sandy Rhodic or Xanthic Ferralsols above calcrete (profile Eto 11) and non-calciferous Eutric Vertisols (profile Eto 14) is to be found here, similar to the already discussed soil association of mapping unit S4 from the Olifantsrus area.

The **mapping units K3 and K4**, which particularly are to be found in the West of the Etosha National Park, can't be differentiated by the so far accomplished mappings. They shall be hence described collectively.

Le ROUX et al. (1988) are classifying the soils of mapping unit K3 as "Kalkbank/Lithosols" and the ones of mapping unit K4 as "Dudfield Series" according to the Southafrican nomenclature. Characteristic of the "Dudfield Series" (equivalent to Calcic Cambisols or Xanthic Ferralsols resp.) is the calciferous, yellow-brown apedal B horizon of a clay content ranging between 15 % and 35 %. But so far the mappings have brought the result that, for all profiles described (Eto 30, Eto 36, Eto 37, Eto 40), the solum is free of calcium carbonate and of a reddish to reddish yellow colour equivalent to the Munsell hues 2.5 YR, 5 YR, and 7.5 YR.

All soil profiles of mapping units K3 and K4 have in common that their shallow soil bodies of a maximum thickness of 40 cm are not the result of in-situ soil formation but are a product of the redeposition of soils of the type Xanthic or Rhodic Ferralsols of loamy to clayey sandy consistency above calcrete. Outcrops of calcrete have been observed as well. The solum's probable character of a fluvial redeposited sediment especially becomes obvious in profile Eto 36. Here, a 7 cm thick boulder pavement of edge-rounded quartzites delivered from the surrounding heights is interbedded between a slightly loamy sandy to loamy sandy solum of 25 cm depth and the subjacent calcrete. The soil environment of the Xanthic or Rhodic Ferralsol sediments can be characterized as slightly acid (pH 6.5) to slightly alcaline (pH 7.8). Besides the vertical trend of rising pH values with increasing depth as shown by profile Eto 30 (see mapping unit S4), the opposite trend occurs too (see profiles Eto 37 and Eto 40). It must be assumed that the higher soil pH within the very slightly to slightly humic topsoil is caused by an admixture of carboniferous aeolian sediments originating from the outcrops of calcrete (see especially profile Eto 40). The dune east of the well Klippan, largely consisting of fine sand (profile Eto 38), stands for extensive aeolian redeposition processes which must have acted on the soils in the west of Etosha during the Quaternary Period.

The so far analysed soil samples taken in mapping units K3 and K4 showed very low concentrations of total nitrogen with values < 0.04 %. The salinity is insignificant as well.

3.4 The Soils of Miscellaneous Land Classes

The soils having formed on dolomite, marble, calcrete and rhyolithic rock (mapping unit R) as well as the soils of salt pans (mapping unit P) are subsumed by le ROUX et al. (1988) under the category of "Miscellaneous Land Classes".

Mapping unit R, which covers larger areas in the southeast and in the west of the Etosha National Park comprises both areas of solid bedrock without soil cover as well as areas of extremely shallow, largely eroded soils of the type Rudi-Rhodic Ferralsols. With profiles Eto 12 and Eto 31 corresponding soils having formed from dolomite have been described. In some places Rhodic Ferralsols of moderate thickness yet have remained (see profile Eto 13, Fig. 4; cf. mapping unit S4).

As found in profiles Eto 11 and Eto 31, a high content of skeleton material, a slightly loamy sandy texture and an intensive red of the Munsell colour 2.5 YR constitute the characteristic soil properties of the Rudi-Rhodic Ferralsols. The soil pH of these probably tertiary relict soils formed from dolomite is marked by considerably lower values (down to pH 5.7) than those measured of the Ferralsol sediments above calcrete. According to the now acquired state of knowledge it is assumed here that the Ferralsol sediments which typically occur on the pediments of the dolomite and quartzite ridges are a correlate to the fluvial and aeolian erosion of the Rhodic Ferralsols occuring on the corresponding solid rocks. Depending on the degree of degradation of the vegetation cover and the resulting erosional soil damage, the contents of organic matter vary considerably with location, showing values ranging between 0.5 % and 1.0 %.

Among the examined soils of the salt pans within the Etosha National Park (**mapping unit P** after le ROUX et al. 1988) the soils of the Etosha Pan play a crucial role. At the moment, extensive sedimentological and geochemical analysis of the 1989 described profiles Eto 45 (west of Logan's Island) and Eto 52 (eastern section of the Fisher's Pan) are being carried out. The corresponding laboratory results will be presented in the second part of the report together with the already completed interpretation of the geomorphological-sedimentological results (BUCH 1990: 9-10).

3.5 Summary

The soil mapping carried out by the author during the 1989 field-research campaign have largely confirmed the basic classification of the soils of the Etosha National Park into four groups as done by le ROUX et al. (1988). But with view to the soil properties of some of the dominant soil series as well as their delimitation and differentiation the author has come to partly different results. In this connection shall be called in mind that the delimitation of mapping units L2 and L3 is primarily based on phytogeographic criteria and that a further differentiation of mapping unit L2 was found advisable. Hence the results of the accomplished soil mapping make additional field research necessary.

Through the mapping of the "Karstveld Soils" (mapping units K1 bis K7) it has become evident that soil units and vegetation units do not necessarily cover exactly identical areas. Rather do occur transitional zones in many cases. As an essential result of the so far accomplished research must be regarded the fact that the mapping units may best be characterized by soil associations. In Enclosure No. 5 all soil associations of the Etosha National Park are listed which have been differentiated in the here presented soil mapping on the basis of the Reconnaissance Soil Map provided by le ROUX et al. (1988). The term soil association is defined here as a characteristic

spatial pattern of typologically different soils, while in this connection the soils may as well belong to different taxonomic categories (soil type, subtype,..., soil form). In many cases the spacial differences in the formation of soils which belong to one soil association are caused by their relief position. This concept of "soil associations" should be taken into account when large-scale vegetation mappings are carried out in future.

4. Facts about the Problem of Present Soil Erosion

According to RICHTER (1965: 2) "soil erosion comprises all processes of redeposition (denudation, transportation and accumulation) which affect the natural balance of the landscape beyond a natural degree. They are triggered by men and effected in most cases by water, wind and gravity (fluvial, aeolian and gravitational denudation)". Under those conditions prevalent in game reserves, where grazing is directly or indirectly controlled by men, all processes of redeposition triggered by the animal population have to be taken into consideration too.

In his résumé about the scientific results won during the field research period 1989 in Etosha, BUCH (1990: 13) already is pointing out that at least the youngest part of dune generation I, period Ia, is a manifestation of the anthropogenetically enhanced aeolian activity of the last centuries. Features indicating the existence of, at least, very young aeolian surface layers even apart the dune areas in the proper sense can be found throughout the research area in the Etosha National Park. To give more precise information, for the 55 profiles described altogether during the field research period of 1989, 64 per cent of the 47 terrestrial profiles located outside drainage channels and the Etosha Pan present a surface layer of aeolian sediments of 5 cm thickness and more or a surface layer of at least partly aeolian sediments.

Naturally, current aeolian redeposition processes most of all affect dune areas and areas with aeolian sand covers, where even

older aeolian sediments may be remobilized, when the grass vegetation is not forming a continuous cover (as often the case with tussock grasses). Furthermore, sandy Ferralsols are being damaged by aeolian denudation processes. Focus of current aeolian soil denudation problems in the Etosha National Park are the wells, due to the now relatively large numbers of livestock (at present more than 500 elephants, 9 000 zebras and 32 000 Springbocks). Special mention should be made of the well "Gemsbokvlakte" southeast of Okaukuejo, in which vicinity a fierce dust storm was observed on the 29th of July 1989 at 11.30 a.m. Because of a serious degradation of the vegetation cover and entailing soil erosion damages north-west and north of Okaukuejo the wells Nacto and Grunewald had to be closed down already in 1977, the closing of the wells Adamax and Leeubron then followed in 1980.

For analysing the problems caused by the current aeolian redeposition processes a special measuring programme is being initiated (cf. Fig. 9). In the course of annual climatic variation with a rainy season from October to March and a dry season from April to September, an amplification of the aeolian activity through the proceeding desiccation of the soil must be expected especially for the second half of the dry season. According to observations made by the staff of the Etosha Ecological Institute (kindly information), an extinction of vegetation through fire may, too, lead to a considerable redeposition of fine-grained sediments. Following the records in hand, it has to be presumed that every one of the 24 firecamps burns down at least once within ten years. One has to bear in mind, though, that "fire", apart from the fires set deliberately in the National Park for land management reasons, first of all is a natural factor of a savanna ecosystem.

Soil erosion by fluvial processes has let to a serious damage especially of the already shallow Ferralsols which are to be found on the marginal range in the west of Etosha. During the last years attempts have been made to reduce the loss of

sediment through the drainage channels by building gabion weirs. Great fluvial channel systems dissect the calcrete surfaces near the southern border of the Etosha Pan, especially east of Okaukujeo ("Gaseb Drainage System") and around the well "Springbokfontein". All the way along the inner edge of the Etosha Pan short-distance sediment transportation through small systems of channels can be observed. This explains, amongst other things, the wash-out border of the morphological zone IV at the southern and south-western edge of the pan (cf. BUCH 1990: 9-10). Those sediments then are, at least partly, again subjected to a inward aeolian transportation by sudden dust and sand devils, which were observed by the author especially near the border of the pan. Thus, fluvial and aeolian processes are not to be regarded as contradictory but as parts of a normal sequence of processes which is controlled by the present climatic conditions of Etosha with a succession of rainy and dry seasons.

Due to the bounce and splash effect of the rain drops a millimetre to centimetre-thick surface incrustation is formed, a phenomenon which was observed at many of the soil profiles in Etosha. These incrustations, which may be additionally hardenend through a cover of algae, lead to accelerated surface runoff, despite the originally sufficent water storage capacity of the soil. Thus, the amount of water available for plant growth is, of course, lower than the amount supplied by precipitation. Profound knowledge of the relations between surface incrustation, surface runoff, soil water budget and vegetation are of great importance not only from an ecological point of view but also with regard to the management of the National Park. For this reason it is planned to analyse those correlations by means of a special measuring programme.

The area presently experiencing the highest rate of erosional damage (due to fluvial and aeolian denudation) within the Etosha National Park is delineated in Map 2.

5. Preliminary Results of the Pedochemical Laboratory Analysis and their Interpretation with Regard to the Soil Water Budget

The special pedochemical laboratory investigations comprise following analysis: determination of the content of organic carbon (% $C_{org.}$) and total nitrogen (% N), the electrical conductivity (EC), the soil pH (measured in 1n KCl) and the cation exchange capacity (CEC). The techniques of the laboratory analysis named first have already been explained in chapter 2. Further, the cation exchange capacity (CEC) was determined by re-exchanging the exchangeable cations K, Na, Ca and Mg through Ba by percolation at a soil pH of 8.2 after MEHLICH and ensuing measurement by the atomic absorption spectrometer.

The values characterizing the form of water fixation and the pore size distribution have been deduced from field and laboratory results (AG BODENKUNDE 1982: 145-151; cf. RENGER 1971). This evaluation is based on the properties "texture" (according to the results of the particle-size analysis), "effective bedding density" (field determination), "organic matter content" (laboratory analysis after SPRINGER & KLEE) and "content of soil skeleton material" (% by volume of stones determined in the field).

5.1 The C:N Ratio

The C:N ratio is generally used as a measure for the quality of organic matter (humus) and the degree of humification. Even so the significance of the C:N ratio is not undisputed and single values might be strongly influenced by undecomposed residues (LANDON 1984: 140), a larger number of data still supplies sufficient information on the humus quality of soils of selected sites.

The classification of the organic matter content follows the proposal of the BODENKUNDLICHE KARTIERANLEITUNG (AG BODENKUNDE

1982: 98, see Enclosure 4). The ratings of the total nitrogen measurements are adapted from the BOOKER TROPICAL SOIL MANUAL (LANDON 1984: 138).

The majority of the so far analysed soil samples shows C-values of < 1 % and N-values of < 0.1 % (Fig. 11). Hence, the topsoils are "slightly to very slightly humic" according to their content of organic matter (% C x 1.72 = % organic matter) and of a content of total nitrogen classified as "very low". Notably higher C-values of > 1 % and N-values of > 0.1 % have been analysed for the A_h horizons of the Lithic Leptosols (Calcrete Lithosols) described in profiles Eto 1 and Eto 8. Both profiles also present a favourable C:N ratio of < 15. The so far analysed samples of the profiles Eto 7 and Eto 10, both describing soils of the type Eutric Vertisol, show a raised C-value ranging between 0.9 % and 1.4 % too, yet the N-values of < 0.06 % are very low. Correspondingly, the C:N ratio of > 15 is less favourable here.

Despite the considerably higher percentage of organic matter in the soil bodies of the Lithic Leptosols of 3.9 % to 4.1 % in comparison to the Eutric Vertisols of 1.5 % to 2.4 % organic matter, the absolute amounts of humus within the Eutric Vertisols of medium depth may still be larger than for the shallow Lithic Leptosols. The content of humus within the 30 cm thick solum of the Lithic Leptosol described in profile Eto 1, for example, amounts to 17.1 kg/m^2 supposing a soil density of 1.4 g/m^3. For the 70 cm deep soil body of the Eutric Vertisol described in profile Eto 7 an amount of 23.5 kg/m^2 humus is calculated when supposing a soil density of 1.7 to 1.9 g/m^3. Yet for shallow Eutric Vertisols the amount of humus within the solum is generally lower than for shallow Lithic Leptosols (compare profiles Eto 10 and Eto 1), as have shown the results of the laboratory analysis completed so far.

5.2 Cation Exchange Capacity (CEC)

The determination of the cation exchange capacity is part of a general evaluation of the soil fertility. The classification of the CEC-values follows the BOOKER TROPICAL SOIL MANUAL (LANDON 1984: 120).

In Fig. 12 the CEC-values (me/100 g soil) are plotted against the percentage of organic carbon (% $C_{org.}$). The diagram shows that the majority of samples taken from the Rhodic Ferralsols (Eto 13 and Eto 38), the Xanthic Ferralsols (Eto 6) and the Calcaric Regosols (Eto 44 and Eto 47) have a low to extremely low cation exchange capacity coinciding with a low to very low content of humus. Like in the C:N diagram, here, too, the values analysed of the samples taken from the Lithic Leptosols (Eto 1-A) and the Eutric Vertisols (Eto 7-A, B, C) stand out from the cluster of values. A comparison of both soil types results in a higher cation exchange capacity of approximately 25 to 30 me/100 g soil for the Eutric Vertisol.

An evaluation of the data on base saturation and the level of the individual exchangeable cations K, Na, Ca and Mg will follow in the second part of the report.

5.3 Electrical Conductivity (EC) and Soil pH

The electrical conductivity (EC 1:5) has been determined for all samples analysed in the laboratory so far. The investigations have been carried out both in order to determine the present salinity of soils and in order to evaluate the risk of a possible soil salinization. The classification of the measured electrical conductivity values follows the BOOKER TROPICAL SOIL MANUAL (LANDON 1984: 158). The approximate salt concentrations have been calculated from the specific conductivity values of 1:5 soil solution extracts.

The majority of the up to now analysed soil samples, showing electrical conductivity values << 1 mS/cm, are to be classified as "salt free". In Fig. 13 only the electrical conductivity values $\geq$ 1 mS/cm are plotted against the corresponding pH values (1n KCl). The EC/pH diagram differentiates between soil samples taken within the Etosha Pan (including sediments of higher, e. g. older lake levels of the Quaternary Period; see Andonivlakte) and those taken from terrestrial soils. The samples taken within the Etosha Pan altogether show electrical conductivity values > 4 mS/cm ("slightly to moderately saline") and reach peak values of almost 15 mS/cm (limit value towards "strongly saline"). The pH values range between 9.2 and nearly 10.0. Worth mentioning is that the samples of profile Eto 5 ("Andonivlakte") show a similar distribution of values. A slightly raised salinity ("very slightly saline" with values between 1 and 4 mS/cm) has been proved for samples taken from the dune ridges at the western border of the Etosha Pan (profiles Eto 44, Eto 46, Eto 47, 828-833). Noteworthy is the relatively high concentration of salt in a buried horizon of slight browning in profile Eto 44 (samples Eto 44-C and D) situated at the southern point of Logan's Island.

At this point it shall be called in mind that further data on the electrical conductivity and the salt content of the individual profiles may be found in chapter 3.

5.4 Characteristic Values of the Pore-Size Distribution and the Soil Water Budget

The characteristic values of the pore size distribution and the soil water budget for the soils of the Etosha National Park call for a differentiated interpretation. In Fig. 14 therefore was differentiated between a "Total Pore Volume (TPV)"/"Air Capacity (AC)" diagram and a "Field Capacity (FC)"/ "Available Field Capacity (AFC)" diagram.

The total pore volume (TPV) corresponds to the total space of the quickly draining coarse pores > 50 µm, the slowly draining coarse pores between 10 and 50 µm, the medium pores of 0.2 to 10 µm and the fine pores < 0.2 µm. Thus, the total pore volume gives information about the maximum water absorption capacity of the soil in question. Moreover, from the TPV, in connection with the textural properties of the soil, conclusions on the degree of soil compression, which is an important plantphysiological factor, may be drawn. The air capacity (AC), which is corresponding to the storage capacity of ground and impounded water, depends on the space of pores of an equivalent diameter > 50 µm. The field capacity (FC) is defined by the total pore space < 50 µm. In practice, the FC is the percentage of water remaining in a previously saturated soil when a free drainage by the slowly draining pores has ceased two or three days after saturation. The part of the FC available to plants is called available field capacity (AFC), which is determined by pore sizes ranging between < 50 µm to 0.2 µm. The FC absorped by the fine pores < 0.2 µm is not available to plants and hence is called "unavailable water" or UAW.

In the AC/TPV diagram (Fig. 14) four zones (I-IV) of typical soils can be differentiated. Zones I and II comprise soils of a large span of total pore volume, that is between approx. 12 % and > 50 %. At the same time, though, the air capacity doesn't exceed values of 8 % in zone I and of 14 % in zone II. Zone I includes soil samples of Vertisols (Eto 7, Eto 10), of dense and clayey subsoils of (Vertic) Cambisols (Eto 43-B, C, D) as well as of dense and clayey subsoils of Fluvisols (Eto 27-B, C). The relatively high percentages of the TPV of the topsoil samples taken from the Vertisol of profile Eto 7 yet do not surpass the limiting value of 50 %, below which critical conditions for root growth and in favour of soil consolidation exist (cf. LANDON 1984: 83). Samples of partly aeolian influenced A_h horizons of (Vertic) Cambisols (Eto 43-A), of dense Fluvisols rich of clay (Eto 27-A) and of Lithic Leptosols (Calcrete Lithosols) belong to zone II. The samples of zone III and IV are characterized by

TPVs of > 40 % and AC values of > 14 %. In general, the samples are taken from sandy topsoils of Ferralsols and Regosols. Zone IV is presenting the highest AC values and exclusively includes samples of redeposited soils of the types mentioned right before.

The AC/TPV diagram on the whole shows a rather typical distribution of values. The medium value of the total pore volume and the relatively high percentage of coarse pores let assume that the sandy soils are capeable of absorbing the water supplied by longer-lasting excessive precipitation, so that even then surface runoff is prevented. Though, the retarding effect towards water infiltration which is produced by thin surface incrustations must be subject of future scrutiny, especially with regard to the Ferralsols.

From the distribution of values in the FC/AFC diagram fundamental conclusions concerning plant growth may be drawn for the individual soil samples. The central part within the diagram showing AFC values of approx. 15 % and FC values of approx. 25 %, a reach where most of the so far evaluated samples are concentrated, covers a range of values presenting favourable plantphysiological conditions. Here, the mean values of the FC are largely identical to the ones measured for the AFC with a hence small percentage of unavailable water. Again, clear differences between the values delivered by samples of Vertisols (Eto 7-A, B) and those of aeolian sediments (Eto 15-A, Eto 16-A) are noticeable. Although the Vertisols are characterized by far higher values of the FC, the AFC is yet not higher than for aeolian sediments. Reason is the comparably high percentage of unavailable water in the Vertisols of > 30 %. Sample Eto 1-B taken from a Lithic Leptosol rich in skeleton material shows a low FC in connection with a low AFC.

6. Prospects

The report in hand primarily presents a summary of the field results obtained during the research period of the year 1989 in the Etosha National Park. The results of further laboratory analysis shall be subject of the second part of the report.

Although the results of the soil mappings carried out by le ROUX et al. (1988) have been largely confirmed by the here presented soil survey, questions on the occurence, the delimitation and the properties of specific soil units still remain to be answered. Hence, further field and laboratory research will be necessary, especially in the light of possible comprehensive counselling activities to the credit of the National Park management. The so far acquired knowledge on the dependance of plant associations on the diagnosed soil properties shall be discussed with Mr. Wynand du Plessis (Plantecologist, ENP) during the author's stay of research in Etosha from July to September 1990 and then being commented in the second part of the report. On condition that the applied financial research support by the German Ministry for Technical Assistance is being granted, the measuring programme conceived for investigations on the soil water budget and the actual aeolian denudation will be started with the turn of the year 1990/1991. Several wind-erosion traps are being installed by Dr. Malan Lindeque for a pre-experimental phase during the dry season of 1990.

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Dr. Manfred W. Buch

Enclosure 1

SOILS, SOIL EROSION AND LAND MANAGEMENT IN THE ETOSHA NATIONAL PARK /NAMIBIA

UPDATED DESCRIPTION OF THE RESEARCH PROJECT

(1) Objectives and motivation of the project

Soil is one of the most important factors of land-ecosystems. This is especially true for ecosystems of semi-arid environment like the Etosha National Park in the northern part of Namibia. Here, the physical and chemical soil properties determine to a great extent the distribution of the vegetation. The vegetation in turn is the resource for grazing of one of the greatest wild animal populations in the world. In this sence all land management strategies must incooperate practises for soil conservation. In the light of the postulated climatic changes with possible drier climate conditions within the next 50 years it is even more important to get detailed knowledge on the relationship between the vegetation resp. land management and soil properties. Juding from the field and laboratory results of the last year´s investigations, it is likely, that even small climatic and/or human impacts in the sensitive ecosystem of the Etosha National Park may cause great ecological damage (BUCH 1990, in prep.). In the past problems of overgrazing and soil erosion already became evident in the Adamax/Leeubron area.

(2) Previous related research

Reconnaisance surveys of namibian soils were presented by GANSSEN (1963) and SCHOLZ (1968 a - d). The nature and genesis of the soils in the Etosha National Park was discribed by VERSTER (1980), who also presented a soil map. VERSTER´s soils map was updated by LE ROUX et al. (1988). On the basis of a larger number of soil profiles also the relationship of plant communities and soil units were investigated (LE ROUX et al. 1988: 3, Fig. 3; 7, Fig. 5).

The combination of the soil map of the Etosha National Park presented by LE ROUX et al. (1988) and the geomorphological map presented by RUST (1985) reveales a basic information for further more detailed pedo-geomorphodynamic investigations.

(3) Approach to the study and methodology

In the light of the above mentioned problems and on the basis of the current knowledge from the investigations in 1989 (BUCH 1990,

in prep.) the following long-term studies are proposed in the Etosha National Park:

- continuation of detailed description of soil profiles and mapping of soil units on a large scale in relation to plant communities, relief, geology and soil erosion
- mapping of actual soil erosion features in the field and reconstruction of soil erosion history during the last 100 years in order to evaluate future soil erosion risks
- experimentell measurements of eolian soil erosion in the field by wind erosion traps at selected locations within the National Park (Fig. 1)
- continous monitoring of soil water content during the vegetation period at selected locations in combination with field experiments on infiltration
- evaluations on potentiell erodibility of the soils in the Etosha National Park on the basis of field and laboratory data
- laboratory analyses of soil samples with special references of soil moisture conditions, soil fertility and limitating soil properties (compaction, salinity, waterlogging, shallowness, etc.).

The studies on soils and land management practises in the Etosha National Park will be accompanied by elaborations of weather data. Since the beginning of this year, investigations on the problems of temporal variability, spatial variance and erosivity of the rainfall resp. the erosivity caused by wind have been started at the Institute of Geography (University of Regensburg). The long-term aim of the project is the evaluation and mapping of eco-pedological risks and geomorphodynamical sensitivity in the Etosha National Park in the light of the proposed climatic and environmental changes and on the basis of different models of land management policy. The project will be organized and carried out in close interdisciplinary cooperation with the Etosha Ecological Institute in Okaukuejo. The results of the project should lead to land management practises which are well adapted to the semiarid environment.

(4) Working group

Head of the german working group is Dr. Manfred W. Buch (Institute for Geography, University of Regensburg). Dr. M. Buch has experience in tropical soil survey and soil erosion problems from field work in Kenya (JÄTZOLD & SCHMIDT 1983) and Tansania (BUCH 1984). The investigations are supported by Prof. Dr. Klaus Heine (Head of the Department for Physical Geography, University of Regensburg). A small working group of interested students of the University of

Regensburg is involved in the project. All the laboratory analysis can be carried out in the laboratories of the Institute for Geography in Regensburg. The namibian counterpart for the investigations is the Etosha Ecological Institute in Okaukuejo (Dr. Malan Lindeque, Plantecologist Wynand du Plessis). In respect of a long-term success of the project, the **education of a greater number of local scientist and gamekeepers** on the subject of soil and soil erosion is of essential importance.

(5) Sponsership and implications for belateral technical assistance between the Federal Republic of Germany and Namibia

Since the start of the project in August 1989, the investigations in Etosha have been sponsered by the German Research Foundation (Deutsche Forschungsgemeinschaft). Contacts for sponsership - expecially for covering the petrol costs - exist also to the World Wildlife Fund. The outlined project have implications for a belateral technical assistance between the Federal Republic of Germany and Namibia. Therefore, the german part of the project approached the German Government for sponsership. The greatest part of the possibly raised money should be invested for field instruments. In a second step the laboratory of the Etosha Ecological Institute in Okaukuejo should be extended for basic soil analysis. The German Ministry for Technical Assistance has expressed great interest for the cooperative project. There is agreement that the protaction of the natural resources and a land management well adapted to the natural environment will be one of the main tasks for the preservation of the social and economical stability of Namibia in future.

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The

Enclosure No. 2:
Soil Profile Register

Profile No.: Eto 1 (boring) **Date of description:** 89.07.28

Locality: 2 k southwest of the Ondongab Fontein.

Altitude of site: 1085 m a.s.l. **Long.:** 16°06'20" **Lat.:** 19°07'35"

Vegetation: comm. 1 (robust var.; outside of it: ACNE-thicket)
ENDE, ERNJ, LEBA, FZAF, STHJ

Horizon	Depth in cm	
oMAch	0 - 6	7,5 YR 6/2 (dry), h' - h'', *ca, loose, fine-sandy loam, st, big fragments of calcrete on surface; fine-grained sedimentary cover Sample: Eto 1-A (0 - 6 cm)
II mkCvAch	6 - 25/30	7,5 YR 6/2 - 5/2 (dry), h, *ca, loose to moderately dense, fine-sandy loamy limestone debris, merging lower boundary of the humus enrichment zone Sample: Eto 1-B (6 - 25 cm)
II mkCn	25/30+	7,5 YR 7/2 (dry), **ca - ***ca; relatively firm calcrete, occurance of fine roots down to 40 cm depth, in the upper part of the horizon calciferous precipitate along fine roots Sample: Eto 1-C (>30 cm); calcrete

Remark:
profile from top to bottom dry
soil type: Calcrete-Lithosol [Lithic Leptosol]

Profile No.: Eto 2 (profile pit) **Date of description:** 89.07.28

Locality: 400 m south of Eto 1, 1.8 k southwest of the Ondongab Fontein.

Altitude of site: 1116 m a.s.l. **Long.:** 16°06'30" **Lat.:** 19°07'35"

Vegetation: comm. 1 (ACNE shrub)

Horizon	Depth in cm	
oMAch	0 - 5	7,5 YR 6/2 (dry), h'- h'', *ca, loose, loamy fine sand, st'- st''; aeolian fine-grained sedimentary cover with mm-thin "splash sheet"
II mkCvAch	5 - 14	7,5 YR 6/2 - 5/2 (dry), h, *ca, loose to moderately dense, fine-sandy loam, st
II AchmkCv	14 - 30	7,5 YR 5/2 - 6/2 (dry), h - h', *ca, loose to moderately dense, fine-sandy loam, st Sample: Eto 2-A (14 - 30 cm)
II mkCn	30+	calcrete

Remark:
content of skeleton material generally lower than in profile Eto 1!
profile from top to bottom dry
soil type: Calcrete-Lithosol [Lithic Leptosol]

Profile No.: Eto 3 (boring) **Date of description:** 89.07.28

Locality: 500 m SSW of rain-gauge No. 82, colony of aloe plants, "turf pan"

Altitude of site: 1150 m a.s.l. **Long.:** 16°22'50" **Lat.:** 18°59'15"

Vegetation: no vegetation within the area of the small pan, on the edge:

grasses: P: SPSP

shrubs: SUAR

Horizon	Depth in cm	
PA_{zh4}	0 - 5	dark-grey, h, *ca, **sa, loose, silty clayey loam, angular polyhedral microstructure , dry Sample: Eto 3-A (0 - 5 cm)
PA_{zh3}	5 - 42	greyish brown , h - h', *ca, **sa, loose, silty clayey loam, angular polyhedral structure to subangular polyhedral structure, dry Sample: Eto 3-B (5 - 25 cm)
AhP_z	42 - 50	greyish brown to beige-brown, h'- h'', *ca, **sa, loose, silty loam to silty clayey loam, subangular polyhedral structure, dry; transition horizon with clear lower boundary Sample: Eto 3-C (42 - 50 cm)
P_z	50 - 70	beige-brown, *ca, *sa, moderately dense, silty loam, subangular polyhedral structure, slightly moist; merging lower boundary Sample: Eto 3-D (50 - 62 cm)
mkC_vP	70 - 85	beige-grey, **ca - *ca, sa(?), moderately dense, silty loam to silty clayey loam, subangular polyhedral structure to angular polyhedral structure, moist; merging lower boundary Sample: Eto 3-E (70 - 76 cm)
mkC_v	85 - 95+	light-grey, **ca, sa(?), moderately dense to dense, silty loam, massive, moist; superficially weathered calcrete (chalky consistence) Sample: Eto 3-F (85 - 95 cm)

Remark:
soil type: Calcaric Vertisol (salic phase)

Profile No.:	Eto 4 (profile pit)	**Date of description:**	89.07.28
Locality:	2.5 k east of the Rietfontein		
Altitude of site:	1150 m a.s.l.	**Long.:** 16°21'05"	**Lat.:** 19°01'10"
Vegetation:	comm. 8 (Mopane savanna)		
	grasses: TRAM, ENDE, ERNJ, STHJ, RYRE		
	trees: COMO		

Horizon	Depth in cm	
mkCvAch	0 - 20	7,5 YR 5/2 (dry), h, *ca, loose, sandy clayey loam to clayey loam, *st - **st, subangular polyhedral structure, dry, rooting down to 20 cm depth, clear boundary; big fragments of calcrete on surface
mkCn	20+	solid calcrete Sample: Eto 4-A (>20 cm)

Remark:
soil type: Calcrete-Lithosol [Lithic Leptosol]

Profile No.: Eto 5 (0 - 25 cm exposure/ then boring) **Date of description:** 31.07.89 89.08.22

Locality: plain of Andoni , 700 m north of the junction leading to the Andoni Fontein, 10 m west of the track

Altitude of site: 1086 m a.s.l. **Long.:** 16°46'00" **Lat.:** 18°31'25"

Vegetation: halophytic tussock grasses: SPSP, ODPA

Horizon	Depth in cm	
zcoM	+10 - 0	10 YR 6/3, *ca, sa?, silty fine sand, single grain (slightly cemented), dry; aeolian accumulation around tussock grasses Sample: Eto 5-A (+10 - 0 cm)
II zcoM	0 - 0,1	salt crust
II zcoM	0,1 - 3	upper crust 10 YR 6/3 (light-grey), grading downward into 10 YR 5/3 (light-beige), *ca, *sa, silty fine sand, angular polyhedral structure, dry; upward increasing consolidation, upper 1 to 2 mm compressed Sample: Eto 5-B (0 - 3 cm)
II zcoM	3 - 10	lower crust 10 YR 6/2 (beige-grey), *ca, *sa, moderately dense, slightly loamy silty fine sand, consolidated, subangular polyhedral structure, dry; Sample: Eto 5-C (3 - 10 cm)
III fAhmzSd	10 - 25	calcarous(?) gypseous(?) crust ("hardpan") 10 YR 3/1 (dark-grey to black), h, *ca, sa?, hard, slightly moist; black hue due to fire? Sample: Eto 5-D (10 - 20 cm)
IV zcwM	25 - 42	10 YR 4/2, h - h', *ca, moderately dense, slightly loamy medium-sandy fine sand, subangular polyhedral structure, slightly moist to dry, merging boundaries Sample: Eto 5-E (25 - 42 cm)
V zcwM	42 - 68	10 YR 6/3 - 6/4, h''(?), *ca, ab 65 cm *ca - **ca, loose, slightly loamy medium-sandy fine sand, single grain, dry Sample: Eto 5-F (50 - 60 cm)
VI C_{zv}	68 - 75+	5 Y 5/3, **ca, dense, slightly loamy medium sand to loamy medium sand, hard, glauconitic (=greenish), dry Sample: Eto 5-G (68 - 75 cm)

Remark:
below 75 cm no further boring possible
glauconitic calciferous sandstone, Andoni formation, IV mC_{za} horizon)
soil type: Stagnic Solonetz

Profile No.: Eto 6 (exposure) **Date of description:** 89.08.01

Locality: reddish dune, erosional opening 3 m west of the road leading from Namutoni to Andoni, 100 m north of the junction of the "Stinkwater path" and south of the "toilet camp"

Altitude of site: 1087 m a.s.l. **Long.:** 16°48'30" **Lat.:** 18°33'50"

Vegetation: mixed xerophytic forest on the edge of the Andoni gras savanna

trees: TEPR >±10 m

grasses: P: PAMA, STUN

A: SCKA, ENCE, URBR

Horizon	Depth in cm	
AioM	+5 - 0	10 YR 5/4, -ca-, h', loose, silty medium-sandy fine sand, single grain, dry; youngest aeolian accumulation around tussock grasses Sample: Eto 6-A (+5 - 0 cm)
II BuvoMAi	0 - 30	10 YR 4/2 - 4/3, -ca-, h, loose, fine-sandy medium sand, single grain, dry, sharp lower boundary Sample: Eto 6-B (0 - 30 cm)
II AiBuvoM	30 - 75	10 YR 4/3, -ca-, h', loose, fine-sandy medium sand, single grain, dry, merging lower boundary Samples: Eto 6-C (40 - 50 cm) Eto 6-D (60 - 70 cm)
II Buv4oM	75 - 110	10 YR 4/4 - 7,5 YR 4/4, -ca-, -h-, loose to moderately dense, fine-sandy medium sand, ± stable, single grain, dry to slightly moist, merging lower boundary Samples: Eto 6-E (80 - 90 cm) Eto 6-F (100 - 110 cm)
II Buv5oM	110 - 130	7,5 YR 4/6 - 5/6, -ca-, -h-, loose to moderately dense, fine-sandy medium sand, ± stable, single grain, dry to slightly moist, merging lower boundary Sample: Eto 6-G (115 - 125 cm)
II Buv5oMCv	130 - 135	7,5 YR 4/6 - 5/6, ca'- ca, -h-, fine-sandy medium sand, loose to moderately dense, ± stable, single grain, slightly moist, sharp lower boundary Sample: Eto 6-H (130 - 135 cm)
III mkCn	135+	calcrete, upper boundary with dirty-white patina Sample: Eto 6-J (≥135 cm)

Remark:
soil type: Xanthic Arenosol

Profile No.: Eto 7 (boring) **Date of description:** 89.08.04

Locality: at the "Fire Break Road", 1.4 k east of the "Aus" Fontein

Altitude of site: 1112 m a.s.l. **Long.:** 16°13'10" **Lat.:** 19°12'35"

Vegetation: comm. 9 (shallow turf areas)
trees/shrubs: COMO, COAP, COJM
grasses: BORA, ANGA, HECO, PANO, ARRH, URBR

Horizon	Depth in cm	
oMPAh	0 - 18	2,5 Y 3/0 - 7,5 YR 3/0, -ca-, h - *h, moderately dense, loamy clay, angular polyhedral structure, dry, main root zone Sample: Eto 7-A (0 - 18 cm)
II Ah_{P3}	18 - 63	2,5 Y 3/0 - 7,5 YR 3/0, -ca-, h, moderately dense, loamy clay, angular polyhedral structure, down to 50 cm depth, dry, below slightly moist Samples: Eto 7-B (18 - 30 cm) Eto 7-C (50 - 55 cm)
II $Ah_{Sd}P_4$	63 - 70	2,5 Y 3/0 - 3/2, -ca-, h, moderately dense, loamy clay, angular polyhedral structure, slightly moist Sample: Eto 7-D (63 - 70 cm)
II mkC_n	70+	calcrete

Remark:
soil type: Eutric Vertisol
close by: grey termite-hill of calciferous material

Profile No.: Eto 8; **Long.:** 16°13'10" **Lat.:** 19°12'35"

Sample: Eto 8-A (0 - 10 cm): $mkC_{v}A_{ch}$-horizon material of the surrounding Calcrete-Lithosol [Lithic Leptosol]

Profile No.: Eto 9 (boring) **Date of description:** 89.08.04

Locality: "turf pan" west of the "Gobaub" Fontein, 8.1 k southeast of the "Charachas" Fontein, 500 m southeast of the track

Altitude of site: 1146 m a.s.l. **Long.:** 16°21'55" **Lat.:** 19°17'25"

Vegetation: comm. 8
annual herbs: Sesbaria spp.
trees: COMO

Horizon	Depth in cm	
X		calciferous fragments, covering approx. 1 % of the surface, biggest fragments of up to 26 cm lateral length
PAch	0 - 25	2,5 Y 5/0 - 5/2, ca, h, moderately dense to dense, silty clay with small interspersed calciferous fragments, strong angular polyhedral structure to strong prismatic structure, dry, desiccation cracks and fissures down to 25 cm depth, sharp lower boundary Samples: Eto 9-A (0 - 10 cm) Eto 9-B (10 - 25 cm)
AchP	25 - 64	2,5 Y 6/0 - 6/2, ca, below 53 cm *ca, h', very dense, silty clay, with small interspersed calciferous fragments, massive, dry, merging lower boundary Samples: Eto 9-C (25 - 45 cm) Eto 9-D (48 - 53 cm) Eto 9-E (58 - 64 cm)
Pc	64 - 70+	2,5 Y 7/0 - 7/2, *ca, h' - -h-, very dense, silty clay, increasing number of interspersed calciferous fragments, massive, dry Sample: Eto 9-F (64 - 70 cm)

Remark:
soil type: Calcaric Vertisol
content of calcium carbonate increasing with depth

Profile No.: Eto 10 (profile pit) **Date of description:** 89.08.05

Locality: 2.8 k east of the "Gobaub" Fontein

Altitude of site: 1138 m (?) a.s.l. **Long.:** 16°28'20" **Lat.:** 19°18'25"

Vegetation: comm. 9 (le Roux)

Horizon	Depth in cm	
		big fragments of calcrete lying on surface between knee-high grass
$A_h P_3$	0 - 30	7,5 YR 3/0 - 3/2, -ca-, h - *h, moderately dense, loamy clay, angular polyhedral structure to prismatic structure (from 0 to 10 cm angular polyhedral microstructure due to zoogenic influence = PA_{h2}), dry, desiccation cracks (weakly developed) down to 30 cm depth **Sample: Eto 10-A (10 ÷ 25 cm)**
mkC_n	30+	calcrete, superficially weathered Sample: Eto 10-B (30 - 35 cm)

Remark:
soil type: shallow Eutric Vertisol

Profile No.: Eto 11 (profile pit) **Date of description:** 89.08..05

Locality: 4.8 k south of the intersection "Naubes"

Altitude of site: 1179 m a.s.l. **Long.:** 16°40'30" **Lat.:** 19°19'55"

Vegetation: comm. 12 (le Roux)
trees: COM PY
trees/shrubs: COMO/CAAL
grasses: P: CECJ, SCPA, ANPU, ENSC
A: ARAD, STHJ, RYRE

Horizon	Depth in cm	
rBuAh	0 - 15	7,5 YR 3/2 (dark-brown), -ca-, h, sandy clayey loam, loose to moderately dense, subangular polyhedral structure to angular polyhedral structure, dry Sample: Eto 11-A (5 - 15 cm)
rBu	15 - 20	5 YR 3/2 (dark reddish brown), -ca-, h', sandy clayey loam, moderately dense, subangular polyhedral structure to angular polyhedral structure, dry Sample: Eto 11-B (15 - 20 cm)
mkCvn	20+	calcrete with weathering crust, slightly weathered Sample: Eto 11-C (20 - 25 cm)

Remark:
in the vicinity: local outcrops of calcrete
soil type: shallow Ferralsol (erosional remnant)

Profile No.: Eto 12 (profile pit) **Date of description:** 89.08.05

Locality: 9.0 k south of the intersection "Naubes"

Altitude of site: 1209 m a.s.l. **Long.:** 16°40'50'' **Lat.:** 19°22'20''

Vegetation: comm. 19 (le Roux)

trees/shrubs: COMO, COAP, TEPR, CRGR, COMPY

grasses: P: ERNI, ANPU, TRRAM, ENSC

A: ENCE, AREF, ARRH

Horizon	Depth in cm	
		superficial incrustation of 1 mm depth, moderately dense to dense
rBuAi	0 - 6	2,5 YR 3/4, -ca-, h', loamy sand to sandy loam, moderately dense, subangular polyhedral structure Sample: Eto 12-A (0 - 6 cm)
rBuCv	6 - 15	2,5 YR 3/6, -ca-, h'', loamy sandy debris, moderately dense to loose, subangular polyhedral structure to single grain Sample: Eto 12-B (6 - 15 cm)
mkCn	15+	dolomite Sample: Eto 12-C (15 - 20 cm)

Remark:
soil type: shallow Ferralsol, greater part removed by erosion

Profile No.: Eto 13 (boring) **Date of description:** 89.08.05

Locality: 17 k south of the intersection "Naubes"

Altitude of site: 1250 m a.s.l. **Long.:** 16°41'45'' **Lat.:** 19°26'05'

Vegetation: comm. 19 (le Roux)
as against profile Eto 12 following additional species:
trees: LONE
grasses: ARME, ERDJ

Horizon	Depth in cm	
oM	0 - 3	5 YR 3/3 - 3/4, -ca-, h', clayey sand, loose to moderately dense, single grain (partly platy), superficial incrustation of a yellowish reddish colour Sample: Eto 13-A (0 - 3 cm)
BuoMAi	3 - 20	5 YR 3/4, -ca-, h'', clayey sand, loose to moderately dense, subangular polyhedral structure Sample: Eto 13-B (3 - 20 cm)
oMBhu	20 - 32	5 YR 4/4, -ca-, h', clayey sand, loose to moderately dense, subangular polyhedral structure Sample: Eto 13-C (20 - 32 cm)
II rBu	32 - 62	2,5 YR - 5 YR 4/4, -ca-, h', sandy clay, moderately dense, subangular polyhedral structure Samples: Eto 13-D (41 - 46 cm) Eto 13-E (55 - 62 cm)
II rBuCv	62 - 73	2,5 YR 4/6, -ca-, h', st', sandy clayey, moderately dense, subangular polyhedral structure Sample: Eto 13-F (67 - 73 cm)
II mCn	73+	dolomite Sample: Eto 13-G (fragments of dolomite from the bottom of the pit)

Remark:
soil type: Ferralsol of medium thickness, partly eroded

Profile No.: Eto 14 (profile pit) **Date of description:** 89.08.05

Locality: 10.1 k south of the "Dungaries" Fontein

Altitude of site: 1205 m a.s.l. **Long.:** 16°50'00'' **Lat.:** 19°15'15''

Vegetation: comm. 10 (le Roux)

trees: COMO

trees/shrubs: CAAL, TACAM

grasses: P: ANPU, BORA, HECO, ENSC

A: ARAD, ERPOfGL, ARME

Horizon	Depth in cm	
		superficial crust of 5 mm depth, ca' - ca
PAh2	0 - 5	dark-grey, -ca-, h - *h, sandy clayey loam, moderately dense, subangular polyhedral microstructure **Sample:** Eto 14-A (0 - 5 cm)
PAh4	5 - 35	dark-grey, -ca-, h - *h, clayey loam, dense, angular polyhedral structure to prismatic structure **Sample:** Eto 14-B (5 - 35 cm)
mkCvn	35+	calcrete, superficially weathered **Sample:** Eto 14-C (>35 cm)

Remark:
soil type: shallow Eutric Vertisol
close by: Ah-horizon of 5 - 10 cm depth, -ca-, h, sandy loam to sandy clayey loam, below calcrete and/or Calcrete-Lithosol forming into Rendzina

Profile No.: Eto 15 (boring) **Date of description:** 89.08.06

Locality: 5.5 k north of the junction of the "Stinkwater path" from the track leading from Namutoni to Andoni

Altitude of site: 1083 m a.s.l. **Long.:** 16°48'35" **Lat.:** 18°37'20"

Vegetation: variation 4: TEPR, AC veld
grasses: P: STUN, PAMA
A: SCKA, ENCE, SEVE

Horizon	Depth in cm	
owMAi	0 - 23	7,5 YR 5/4 - 4/4, -ca-, h', medium-sandy fine sand, loose, single grain Sample: Eto 15-A (0 - 23 cm)
owMCv	23 - 40	10 YR 5/4, -ca-, h'', medium-sandy fine sand, loose, single grain Sample: Eto 15-B (23 - 30 cm)
owM	40 - 79	10 YR 5/4, -ca-, medium sand to fine sand, loose, single grain Samples: Eto 15-C (40 - 49 cm) Eto 15-D (69 - 79 cm)
II wM	79 - 120+	10 YR 5/4 - 5/6 (i. e. downward tendency to a stronger yellowish pigmentation), -ca-, medium-sandy fine sand, loose, below 88 cm moderately dense (i. e. more stable), single grain, few grey spots and stripes (= bleaching along fissures) Samples: Eto 15-E (79 - 88 cm) Eto 15-F (100 - 120 cm)

Remark:
soil type: Regosol grading into Fluvisol

Profile No.: Eto 16 (boring) **Date of description:** 89.08.06

Locality: 4.2 k south of the northern end of the Mushara fire break road 6 k north of the "Mushara" watermill

Altitude of site: 1104 m a.s.l. **Long.:** 16°53'10" **Lat.:** 18°34'55"

Vegetation: comm. 1 (le Roux), var. 1 ("NE-Sandveld")

trees: AC, CR, LONE, var. BOAL

grasses: P: STUN, ERLE, SCPA

A: ENCE, URBR, SCKA, ARME

Horizon	Depth in cm	
oM	0 - 5	10 YR 4/3, -ca-, h', medium-sandy fine sand, loose, slightly cemented surface, single grain; aeolian accumulation around grass-tufts Sample: Eto 16-A (0 - 5 cm)
II oM	5 - 19	10 YR 4/3, -ca-, h', fine-sandy medium sand, very loose, single grain
III owMAh	19 - 45	10 YR 4/3, -ca-, h' - h, fine-sandy medium sand, loose, single grain Sample: Eto 16-B (19 - 33 cm)
III owMCv	45 - 63	10 YR 4/3, -ca-, h'', fine-sandy medium sand, loose, single grain
III owM	63 - 113	10 YR 4/3 - 4/4, -ca-, fine-sandy medium sand, loose, single grain Sample: Eto 16-C (73 - 87 cm)
III owM/IV wM	113 - 137	10 YR 5/3, -ca-, medium sand to fine sand, loose (with downward growing density), single grain Sample: Eto 16-D (125 - 137 cm)
IV wM	137 - 177	10 YR 5/3, -ca-, silty fine sand, loose to moderately dense, single grain Sample: Eto 16-E (164 - 177 cm)

Remark:
profile more stable than profile Eto 15
soil type: Regosol grading into Fluvisol

Profile No.: Eto 17 (boring) **Date of description:** 89.08.06

Locality: 6.7 k east of the intersection of the Mushara and the Camel Thorn fire break road

Altitude of site: 1124 m a.s.l. **Long.:** 16°58'25" **Lat.:** 18°37'30"

Vegetation: "NE-Sandveld" (comm. 1, le Roux), var. 1

trees: AC/CR/LONE var./BOAL

grasses: P:STUN/ERLE/SCPA/CCCI

A:ENCE/URBR/SCKA/ARME

(grasses generally dominating!)

Horizon	Depth in cm	
		actual aeolian sand accumulation of 2 - 5 mm depth; incrustation
oMAih	0 - 10	grey, -ca-, h - h', fine-sandy medium sand, loose, single grain Sample: Eto 17-A (0 - 10 cm)
oMCv	10 - 34	yellowish grey, -ca-, fine-sandy medium sand, loose, single grain Sample: Eto 17-B (20 - 30 cm)
oM	34 - 49	greyish yellow, -ca-, fine-sandy medium sand, loose, single grain
II wM	49 - 86	greyish yellow, -ca-, silty fine sand, loose to moderately dense, massive to subangular polyhedral structure Sample: Eto 17-C (62 - 72 cm); big roots
II wM III Cv	86 - 109+	yellowish, (c) - ca", silty fine sand, loose to moderately dense, massive to subangular polyhedral structure; calcrete not much further down (!) Sample: Eto 17-D (100 - 109 cm)

Remark:
soil type: Regosol (grading into Fluvisol) on top of calcrete

Profile No.: Eto 18 (0 - 67 cm profile pit, 67 - 123 cm boring) **Date of description:** 89.08.06

Locality: Kameeldoring pan

Altitude of site: 1131 m a.s.l. **Long.:** 16°59'15" **Lat.:** 18°36'55"

Vegetation: shrubs: CAAL/ACKI/CRGR/RHBR

grasses: P: CECJ/STUN/ENSC

A: ARAD/SCKA/RYRE/ENDE

Horizon	Depth in cm	
oM	0 - 4	dark-grey, ca'', h, silty fine sand, platy; youngest aeolian accumulation with superficial incrustation Sample: Eto 18-A (0 - 4 cm)
	at 4 cm	black ash-layer!
II oM	4 - 8	grey, ca', h - h', silty fine sand, single grain to subangular polyhedral structure Sample: Eto 18-B (4 - 8 cm)
III oM	8 - 21	yellowish grey, ca, slightly loamy medium sand, subangular polyhedral structure; lower boundary of the main root zone Sample: Eto 18-C (10 - 20 cm)
IV oM	21 - 45	yellowish grey to slightly reddish grey, ca - *ca, loamy medium sand, subangular polyhedral structure Sample: Eto 18-D (30 - 40 cm)
V Cv	45 - 123	light-yellowish grey, *ca, silty fine sand, with small fragments of calcrete, downward grading into fine-sandy silt plus increasing number of calcrete fragments, massive to subangular polyhedral structure Samples: Eto 18-E (50 - 60 cm) Eto 18-F (87 - 107 cm) Eto 18-G (117 - 123 cm)
	123+	calcrete

Remark:
soil type: Regosol on top of calcrete

Profile No.: Eto 19 (boring) **Date of description:** 89.08.06

Locality: 2.1 k north of "Onguma-Hock"

Altitude of site: 1141 m a.s.l. **Long.:** 17°02'15" **Lat.:** 18°33'45"

Vegetation: "NE-Sandveld" (comm. 1, le Roux)

trees: TESE/LONE/CRGR/BHPE

grasses: P: PAHA/DJPO/TRSC/ERPA

A: DJ ssp.

Horizon	Depth in cm	
oM	0 - 5	beige, -ca-, ± -h-, medium sand, single grain; actual aeolian accumulation
II owMAi	5 - 20	grey to light-grey, -ca-, h', fine-sandy medium sand, single grain
II owM	20 - 80	beige-grey, -ca-, -h-, fine-sandy medium sand, single grain
III owM	80 - 105+	yellowish grey, -ca-, -h-, fine-sandy medium sand; single grain

Remark:
vegetation unit at Eto 19 is the one in Etosha which is most related to the vegetation of the Kalahari;
sand slightly greyer than in preceding profiles;
soil type: Regosol grading into Fluvisol

Profile No.: Eto 21 (boring) **Date of description:** 89.08.07

Locality: 900 m NNE of the southern end of the Makalane tracks

Altitude of site: 1092 m a.s.l. **Long.:** 17°07'00" **Lat.:** 18°34'40"

Vegetation: trees/shrubs: Makalane palm/CRGR/DJCJ/LONE/BHPE

grasses: P: SCPA/ERLE/BRNJ/ERRJ/ERTR

A: ERPO

Horizon	Depth in cm	
		sand accumulation around roots of the grass!
oMAh	0 - 21	10 YR 4/2, -ca-, h - h', medium-sandy fine sand, single grain, very loose Sample: Eto 21-A (0 - 21 cm)
oMCv	21 - 49	10 YR 3/3, -ca-, h", slightly clayey medium-sandy fine sand, loose, single grain to weak subangular polyhedral structure; horizon perhaps only reaching down to 37 cm depth Sample: Eto 21-B (37 - 49 cm)
II wM	49 - 103	10 YR 4/3, -ca-, h', slightly clayey medium-sandy fine sand, moderately dense, single grain to weak subangular polyhedral structure, few charcoal fragments Samples: Eto 21-C (63 - 76 cm) Eto 21-D (88 - 93 cm)
II/III wM	103 - 130	10 YR 4/3 - 5/3, few lighter spots (2,5 YR 5/4), -ca-, h", slightly clayey medium-sandy fine sand, moderately dense, single grain to weak subangular polyhedral structure Sample: Eto 21-E (113 -122 cm)
III wM	130 - 163+	10 YR 5/4 - 2,5 YR 5/4, -ca-, h", slightly clayey medium-sandy fine sand (with clearly visible quartzes of the coarse sand fraction), single grain, moderately dense Sample: Eto 21-F (149 - 163 cm)

Remark:
soil type: Regosol (on top of Fluvisol)

Profile No.: Eto 22 (profile pit) **Date of description:** 89.08.09

Locality: catena "Gaseb fluvial channel system", east of Okaukuejo, planation of the western slope

Altitude of site: 1104 m a.s.l. **Long.:** 15°55' **Lat.:** 19°10'

Vegetation: comm. 1 (le Roux)
acacia shrubs

Horizon	Depth in cm	
coM	+10 - 0	beige-grey, *ca, h, st' - st, sandy silty loam, single grain, loose to moderately dense; aeolian accumulation around acacia shrub Sample: Eto 22-A (+10 - 0 cm) down to 0.5 cm incrustation of the surface
coMAch	0 - 14	beige-grey, *ca, h, st' - st, sandy silty loam, weak subangular polyhedral structure, moderately dense to loose Sample: Eto 22-B (0 - 14 cm)
coMAchCv	14 - 21	greyish brown, *ca, h', st' - st, sandy silty loam, single grain to subangular polyhedral structure, moderately dense to loose Sample: Eto 22-C (14 - 21 cm)
II wMX	21 - 25	desert pavement (out of calcrete fragments) Sample: Eto 22-D (21 - 25 cm)
III cwMfBv	25 - 31	strongly brown, slightly reddish, *ca - **ca, limestone fine gravel in ground mass of silty loam Sample: Eto 22-E (25 - 31 cm)
III cwMfBvCcc	31 - 37	strongly brown, slightly reddish, *ca - **ca, limestone fine gravel in ground mass of silty loam with dirty-white coating of secondary calciferous precipitation
IV mkCnv	37 - 50+	dirty whitish, friable calcrete

Remark:
soil type: "Calcaric Cambisol" on top of "buried Cambisol" developed on a fluvial sediment of calcrete fine gravel on top of "calcrete"

Profile No.: Eto 23 (boring) **Date of description:** 89.08.09

Locality: catena "Gaseb fluvial channel system", east of Okaukuejo, nearest depression to the main drainage channel

Altitude of site: 1103 m a.s.l. **Long.:** 15°55' **Lat.:** 19°10'

Vegetation: comm. 1 (le Roux)
acacia shrubs, "silver shrubs", ground covered by grass

Horizon	Depth in cm	
X		few fragments of calcrete of up to 20 cm lateral length lying on surface, mollusks (sample Eto 23-I)
(cwM?)PAch	0 - 40	dark-grey, *ca - **ca, h, small rounded calciferous fragments of the fine gravel fraction in ground mass of silty clayey loam; from 0 - 10 cm desiccation cracks, angular polyhedral microstructure, moderately dense; from 10 - 40 cm massive to angular polyhedral structure, moderately dense to dense
(cwM?)AhPc	40 - 50	greyish brown to beige, *ca - **ca, h', silty clayey loam, with interspersed calciferous fragments like above, massive, dense
mkCnv	50 - 55	dirty-white, ***ca, silty clayey loam (massive, dense) with few hard calcrete fragments
mkCn	55+	calcrete, unweathered

Remark:
"Calcaric Vertisol" ("Arcadia Series") developed on calcarous fluvial/colluvial sediment

Profile No.: Eto 24 (profile pit) **Date of description:** 89.08.09

Locality: catena "Gaseb fluvial channel system", east of Okaukuejo, ramp-like planation on the western edge of the main drainage channel **Long:** 15°55' **Lat:** 19°10'

Vegetation: comm. 1 (le Roux)
no more acacia shrubs, only "silver shrubs", low-grown grass cover on the ground and creeping succulents

Horizon	Depth in cm	
coM	+10 - 0	actual aeolian accumulation around shrubs
X		numerous calcrete stones on surface
mkCv Ac i	0 - 10	10 YR 5/3, **ca, h', fine-sandy silty loam, calcrete debris
mkCv	10 - 20	7,5 YR 5/4 - 5/6, **ca - ***ca, calcrete debris in ground mass of fine-sandy silty loam
mkCn	20+	7,5 YR 6/4, cellular to platy structure of calcrete

Remark:
soil type: "Calcrete-Lithosol" [Lithic Leptosol]

Profile No.: Eto 25 (boring) **Date of description:** 89.08.10

Locality: catena "Gaseb system of channels", east of Okaukuejo, thalweg of the main channel system, 20 m south of the track

Altitude of site: 1098 m a.s.l. **Long.:** 15°55' **Lat.:** 19°10'

Vegetation: comm. 1 (le Roux)
typical halophytic variety of vegetation within comm. 1

Horizon	Depth in cm	
wMX		few fragments of calcrete of up to 30 cm lateral length lying on surface
cwMP$_4$Ach	0 - 15	dark-grey, *ca - **ca, h, calciferous fragments in ground mass of silty clayey loam, desiccation cracks, angular polyhedral microstructure, loose, dry Sample: Eto 25-A (0 - 15 cm)
cwMP$_2$Ach	15 - 20	dark-grey, *ca - **ca, h, calciferous fragments in ground mass of silty clayey loam, weakly developed desiccation cracks, blocky to polyhedral structure, moderately dense to dense, dry
cwMAhSdPc	20 - 40	dark-grey to brown, *ca - **ca, h - h', calciferous fragments in ground mass of silty clayey loam, massive, moderately dense to dense, dry to slightly moist Sample: Eto 25-B (20 - 30 cm)
cwMPcSd	40 - 52	beige-grey, *ca - **ca, h' - h'', calciferous fragments in ground mass of silty clayey loam, massive, dense, dry to slightly moist Sample: Eto 25-C (45 - 50 cm)
mkCv	52 - 66	dirty beige-white, **ca - ***ca, silty loam to silty clayey loam (partly fine-sandy by decomposed calcrete), few small fragments of calcrete, massive, dense, dry to slightly moist Sample: Eto 25-D (55 - 60 cm)
mkCnv	66 - 70+	dirty-white, **ca - ***ca, silty loam, decomposed firm calcrete with strongly increasing content of calcrete fragments, dense to moderately dense, dry to slightly moist Sample: Eto 25-E (66 - 70 cm)

Remark:
soil type: "Calcaric Vertisol" ("Arcadia Series") developed on fluvial sediments

Profile No.: Eto 26 (profile pit) **Date of description:** 89.08.10

Locality: catena "Gaseb system of channels", east of Okaukuejo, planation of the eastern slope (at the junction to the Gaseb Fontein, 20 m north of the track)

Altitude of site: 1101 m a.s.l. **Long.:** 15°55' **Lat.:** 19°10'

Vegetation: comm. 1 (le Roux)
beginning vegetation of acacia shrubs extending towards the Gemsbokvlakte

Horizon	Depth in cm	
coM	+10 - 0	10 YR 4/2 - 7,5 YR 4/2, *ca, h, fine-sandy silty loam, few small fragments of calcrete; aeolian accumulation of fine-grained sediment around acacia shrubs
		moderate coverage of surface by calcrete stones
		0.5 cm surface incrustation
coMAch	0 - 10	10 YR 4/3, *ca, h - h', st, fine-sandy silty loam, single grain to weak subangular polyhedral structure, loose
mkCv	10 - 20	7,5 YR 5/4 - 4/4, *ca - **ca, h'', fine-sandy silty loam, calcrete debris, loose
mkCn	20+	calcrete

Remark:
soil type: Calcrete-Lithosol [Lithic Leptosol]

Profile No.: Eto 27 (boring) **Date of description:** 89.08.11

Locality: track runnig between the Grünewald Fontein and the Eindpaal Fontein, 3.9 k northeast of the Eindpaal Fontein

Altitude of site: 1136 m a.s.l. **Long.:** 15°55' **Lat.:** 19°10'

Vegetation: comm. 8 (le Roux)

Horizon	Depth in cm	
		very few calcrete stones on surface; in the vicinity of described profile: flat calcrete tops on surface; mollusks on the lee-side of acacia shrubs (Sample: Eto 27-I)
		surface incrustation of up to 5 mm thickness
woM	0 - 10	10 YR 4/2 - 4/3, -ca-, h, very fine-sandy silty loam, loose, single grain (powdery, slightly cemented); horizon largely eroded, except around acacia shrubs Sample: Eto 27-A (0 - 10 cm)
wM	10 - 35	10 YR 4/3, -ca-, h', very fine-sandy silty loam, loose, single grain (powdery), very weak subangular polyhedral structure Sample: Eto 27-B (10 - 35 cm)
wM	35 - 53	10 YR 4/3 - 5/3, -ca-, h'' - -h-, very fine-sandy silty loam, single grain (powdery), very weak subangular polyhedral structure, loose, within the last 4 cm above calcrete interspersed fragments of calcrete, sharp lower boundary Sample: Eto 27-C (35 - 53 cm)
mkCn	53+	calcrete

Remark:
soil type: Fluvisol on top of calcrete; high erodibility due to low structural stability, and, as clearly visible, erosion already has acted on the soil;
profile free of coarse fragments, except within the last 4 cm above calcrete

Profile No.: Eto 28 (0 to 70 cm profile pit, 70 to 108 cm boring) **Date of description:** 89.08.12

Locality: horse camp "Marais dam", southern entrance ("Sweetveld"-level)

Altitude of site: 1113 m a.s.l. **Long.:** 15°30' **Lat.:** 18°55'

Vegetation: comm. 1 (le Roux); "Sweetveld" with beginning occurance of the Shrub-Mopane

Horizon	Depth in cm	
coM	0 - 20	aeolian accumulation of up to 20 cm thickness around shrubs and tussock grasses (by absence of aeolian sediment: 1 - 2 mm deep incrustation of surface); upper 5 cm: 10 YR 5/3, ca'- ca, h' (moderate root penetration), slightly loamy silty fine sand, ± platy structure, loose; 5 - 20 cm: 10 YR 4/3 - 5/3, ca - *ca, h (high root penetration), slightly loamy silty fine sand to loamy silty fine sand, single grain to subangular polyhedral structure Samples: Eto 28-A (0 - 5 cm) Eto 28-B (5 - 20 cm)
II coMAi	20 - 40	10 YR 5/3, *ca, h', slightly loamy fine-sandy medium sand (with light spots); subangular polyhedral structure, moderately dense, root penetration (big roots) down to 40 cm depth Sample: Eto 28-C (25 - 35 cm)
II coM	40 - 70	10 YR 5/3 - 5/4 (with light spots), **ca, loamy fine-sandy medium sand, subangular polyhedral structure to massive, moderately dense to dense, sporadic fragments of mollusk shells Sample: Eto 28-D (50 - 60 cm)
III w?M	70 - 108	10 YR 6/4, **ca, loamy fine-sandy medium sand to loamy silty medium sand, moderately dense to dense, single grain to subangular polyhedral structure Sample: Eto 28-E (70 -87 cm) Eto 28-F (98 - 108 cm)

Remark:
high aeolian activity within this area
soil type: Regosol on top of Fluvisol (?) (natural levee?)

Profile No.: Eto 29 (profile pit) **Date of description:** 89.08.12

Locality: 2.3 k west of the Teëspoed Fontein

Altitude of site: 1150 m a.s.l. **Long.:** 15°00' **Lat.:** 18°55'

Vegetation: comm. 21 (le Roux): "Shrub-Mopane on loamy soils"

Horizon	Depth in cm	
oM	+10 - 0	aeolian accumulation around acacia or mopane shrubs respectively; on top of the little hill sequence of mm-thick layers with a total depth of 2 cm: 10 YR 4/3, -ca-, h, slightly loamy fine sand to slightly loamy medium sand, platy to subangular polyhedral structure, loose to moderately dense Sample: Eto 29-A (+10 - 0 cm)
	0	3 mm thick surface incrustation, accumulation of fine sand on surface
Ah	0 - 10	10 YR 4/4, -ca-, h - h', slightly loamy fine sand to slightly loamy medium sand, subangular polyhedral structure, moderately dense, sharp lower boundary Sample: Eto 29-B (0 - 10 cm)
AhBu	10 - 20	7,5 YR 5/6, -ca-, -h-, slightly loamy fine sand to slightly loamy medium sand, subangular polyhedral structure, moderately dense, clear lower boundary Sample: Eto 29-C (10 - 20 cm)
Bu	20 - 30	7,5 YR 4/6, -ca-, -h-, loamy fine sand to loamy medium sand, dense, subangular polyhedral structure to angular polyhedral structure (cementation with ferric iron and illuvial clay?), merging lower boundary Sample: Eto 29-D (20 - 30 cm)
BuCv	30 - 40	7,5 YR 4/6 - 5/6, -ca-, -h-, stony loamy sand , dense, subangular polyhedral structure to angular polyhedral structure; grading downward into dolomite decomposition zone Sample: Eto 29-E (30 - 40 cm)
mCv	40 - 45+	7,5 YR 7/6 - 6/6; decomposed dolomite Sample: Eto 29-F (40 - 45 cm)

Remark:
profile situated on top of a flat dolomite ridge;
soil type: Ferralsol (in situ) developed on quarzite

Profile No.: Eto 30 (profile pit) **Date of description:** 89.08.12.

Locality: 300 m NNE of the Okawao Fontein

Altitude of site: 1189 m a.s.l. **Long.:** 14°40' **Lat.:** 19°05'

Vegetation: comm. 16 (le Roux): "Sandy Shrub Mopaneveld"

Horizon	Depth in cm	
		mm-thin fine-sand layer between grass-tufts
BuMAh	0 - 10	10 YR 4/3, -ca-, h, slightly loamy fine sand, few quartz grains of the coarse-sand fraction, loose, single grain to subangular polyhedral structure Sample: Eto 30-A (0 - 10 cm)
AhBuM	10 - 25	10 YR 5/3 - 7,5 YR 5/8, -ca-, h', slightly loamy medium-sandy fine sand, few quartz grains of the coarse-sand fraction, loose, single grain to subangular polyhedral structure Sample: Eto 30-B (10 - 25 cm)
CvBuM	25 - 30	7,5 YR 4/4, -ca-, -h-, st (calcrete fragments, few quartz grains), loamy fine sand to loamy medium sand, subangular polyhedral structure, moderately dense Sample: Eto 30-C (25 - 30 cm)
II BuMCv	30 - 40	7,5 YR 4/4 - 4/6, -ca-, -h-, *st (calcrete fragments, few quartz grains), loamy fine sand to loamy medium sand, moderately dense, subangular polyhedral structure Sample: Eto 30-D (30 - 40 cm)
II mkCn	40+	calcrete

Remark:
soil type: Ferralsol sediment

Profile No.: Eto 31 (profile pit) **Date of description:** 89.08.12

Locality: pass on the dolomite ridge east of Renostervlei

Altitude of site: 1284 m a.s.l. (acc. map) **Long.:** 14°30' **Lat.:** 19°10'

Vegetation: comm. 25 (le Roux): "Shrub-Mopane"

Horizon	Depth in cm	
X		quartz stones and dolomite stones of fist size on surface
CvBuAi	0 - 6	2,5 YR 3/4, -ca-, h', st - *st, gritty (due to quartz grains) slightly loamy sand, loose to moderately dense, single grain to subangular polyhedral structure Sample: Eto 31-A (0 - 6 cm)
BuCv	6 - 20	2,5 YR 4/6, -ca-, h" - -h-, **st, gritty (due to quartz grains) slightly loamy sand, moderately dense, single grain (due to high content of skeleton material) Sample: Eto 31-B (6 - 20 cm)
mCv	20+	dolomite blocks Sample: Eto 31-C (20+ cm); fist-sized fragments of dolomite from the bottom of the pit: decomposed and unweathered dolomite

Remark:
soil type: largely eroded Ferralsol, at present intensive erosional soil damage; the surface around Mopane shrubs is up to 20 cm higher

Profile No.: Eto 32 (profile pit) **Date of description:** 89.08.13

Locality: northern fence of the Etosha National Park in Kaross, 2.5 k west of the junction of the track leading to the Karosshoek Fontein

Altitude of site: 1280 m a.s.l. **Long.:** 14°30' **Lat.:** 19°20'

Vegetation: western edge of comm. 8 (le Roux)

Horizon	Depth in cm	
X		flat granite ridges; few granite blocks lying on surface
		beginning surface incrustation, 0.5 cm deep at maximum
owM	0 - 5	loose cover of sand and quartz grains of the fine-gravel fraction Sample: Eto 32-A (0 - 5 cm)
Ai	5 - 15	2,5 YR 3/6, -ca-, h', slightly loamy gritty sand, single grain to weak subangular polyhedral structure, moderately dense to dense, penetrated by fine roots (of the grass) Sample: Eto 32-B (5 - 15 cm)
CvBv	15 - 20	2,5 YR 4/6, -ca-, h'' - -h-, loamy gritty sand, subangular polyhedral structure to single grain, dense to moderately dense Sample: Eto 32-C (15 - 20 cm)
BvCv	20 - 27	10 R 3/6, -ca-, *st (quartz grains and decomposed granite), loamy gritty sand, single grain to subangular polyhedral structure, dense Sample: Eto 32-D (20 - 27 cm)
Cv	27+	decomposed granite Sample: Eto 32-E (27+ cm)

Remark:
soil type: largely eroded Ferralsol developed on granite (phenotype: Ranker)

Profile No.: Eto 33 (boring) **Date of description:** 89.08.13

Locality: northern fence of the Etosha National Park in Kaross, junction of the track leading to the Karosshoek Fontein

Altitude of site: 1279 m a.s.l. **Long.:** 14°35' **Lat.:** 19°20'

Vegetation: comm. 8 (le Roux)

Horizon	Depth in cm	
oM		Mopane shrubs, partly situated on top of up to 20 cm high aeolian accumulation: 7,5 YR 4/4, -ca-, h - h', slightly sandy silty loam, subangular polyhedral structure Sample: Eto 33-B (+20 - 0 cm)
wM		2 cm thick incrustation of surface : 7,5 YR 4/4 - 4/6, -ca-, h'- h, sandy silty loam, platy structure; denudation horizon Sample: Eto 33-A (0 - 2 cm)
II wMAh	0 - 20	7,5 YR 4/4, -ca-, h, slightly sandy silty loam, subangular polyhedral structure, moderately dense Sample: Eto 33-C (0 - 20 cm)
II wMAhCv	20 - 29	7,5 YR 4/4 - 5 YR 4/4, -ca-, h', silty loam, subangular polyhedral structure, moderately dense to dense
II wMCv4	29 - 37	5 YR 4/4, -ca-, clayey loam, angular polyhedral structure to subangular polyhedral structure, dense Sample: Eto 33-D (29 - 37 cm)
II wMCv3	37 - 44	5 YR 4/4, -ca-, clayey loam, subangular polyhedral structure to angular polyhedral structure, moderately dense to dense Sample: Eto 33-E (37 - 44 cm)
III wM	44 - 48	5 YR 3/3, -ca-, gritty sandy clayey loam to stony sandy clayey loam (quartz grains, fragments of granite), subangular polyhedral structure, moderately dense to dense Sample: Eto 33-F (44 - 48 cm)
IV mkCv	48+	calcrete grit (moderate resistance to penetration with auger), 7,5 YR 4/4 - 4/6, ca, sandy silty loam, moderately dense to dense

Remark:
soil type: multiphasial Fluvisol ("Colluvisol") on top of superficially weathered calcrete

Profile No.: Eto 34 (boring) **Date of description:** 89.08.13

Locality: 2.4 k northwest of the Karossfontein, bifurcation of the track leading to the wells Zeprapomp and Karosspomp, thalweg of a trough-shaped valley between granite hills

Altitude of site: 1120 m a.s.l. **Long.:** 14°30' **Lat.:** 19°20'

Vegetation: comm. 28 (le Roux)

Horizon	Depth in cm	
wMAh	0 - 25	7,5 YR 3/4, -ca-, h, loamy gritty sand, single grain to weak subangular polyhedral structure, loose (below 5 cm depth stable, though) Sample: Eto 34-A (0 - 25 cm)
AhwM	25 - 40	7,5 YR 3/4 - 5 YR 3/4, -ca-, h', slightly loamy gritty sand, single grain to weak subangular polyhedral structure, loose (yet stable) Sample: Eto 34-B (25 - 40 cm)
CvwM	40 - 60	5 YR 4/6 - 2,5 YR 3/6, -ca-, strongly sandy gritty loam, subangular polyhedral structure, loose to moderately dense, higher content of reddish, loamy decomposed granite Sample: Eto 34-C (50 - 60 cm)

Remark:
soil type: Fluvisol (developed on more or less unweathered granite or decomposed granite respectively)

Profile No.: Eto 35 (profile pit) **Date of description:** 89.08.14

Locality: 1.2 k northeast of the Dinteri Fontein, cut road off the main track; summit position right before junction to Dinteri

Altitude of site: 1280 m a.s.l. **Long.:** 14°25' **Lat.:** 19°10'

Vegetation: comm. 25 (le Roux)

Horizon	Depth in cm	
X		surface largely covered with calcrete and granite debris, few head-sized quartz stones
C_vA_i	0 - 11	10 YR 4/3 - 5/3, ca - *ca, h', sandy silty loam, st - *st (calcrete debris), loose
mkC_nC_v	11 - 20	10 YR 5/3 - 4/3, *ca - **ca, h'', sandy silty loam, *st - **st (calcrete debris), loose
	20+	calcrete

Remark:
soil type: Calcrete-Lithosol [Lithic Leptosol]

Profile No.: Eto 36 (profile pit) **Date of description:** 89.08.14

Locality: 1.4 k south of the Assvoelbad Fontein

Altitude of site: 1284 m a.s.l. **Long.:** 14°25' **Lat.:** 19°10'

Vegetation: comm. 26 (le Roux)

Horizon	Depth in cm	
		singular flat calcrete ridges in the vicinity
BuMAh	0 - 10	2,5 YR 3/6, -ca-, h - h', st'- st (calcrete fragments), slightly loamy sand, loose to moderately dense, weak subangular polyhedral structure to single grain Sample: Eto 36-A (0 - 10 cm)
BuM	10 - 25	5 YR 3/4 - 2,5 YR 3/4, -ca-, h'- -h-, st - *st (calcrete fragments), slightly loamy sand to loamy sand, moderately dense, subangular polyhedral structure to single grain Sample: Eto 36-B (10 - 25 cm)
II MX	25 - 32	boulder pavement, granite boulders with weathering crust and subangular quartz stones Sample: Eto 36-C (25 - 32 cm); boulder pavement
III mkCv	32 - 40+	platy calcrete pebbles or superficially weathered calcrete respectively Sample: Eto 36-D; calcrete

Remark:
soil type: Ferralsol sediment

Profile No.: Eto 37 (boring) **Date of description:** 89.08.14

Locality: 700 m west of the Klippan Fontein, south of the track

Altitude of site: 1267 m a.s.l. **Long.:** 14°20' **Lat.:** 19°05'

Vegetation: at the edge of comm. 26 (le Roux)

Horizon	Depth in cm	
oM		acacia and mopane shrubs situated on elevation of up to 15 cm height -> high aeolian activity, at present strong southwesterly winds 1 cm deep surface incrustation
Bu(M?)Ah	0 - 9	5 YR 3/4, -ca-, h - h', sandy loam, moderately dense, subangular polyhedral structure Sample: Eto 37-A (0 - 9 cm)
Bu(M?)	9 - 25	5 YR 4/4 - 4/6, -ca-, h'', sandy clayey loam, moderately dense to dense, subangular polyhedral structure to angular polyhedral structure, root penetration down to 25 cm depth. Sample: Eto 37-B (9 - 25 cm)
II mkCv	25+	superficially weathered calcrete Sample: Eto 37-C (25+ cm)

Remark:
in the vicinity: flat calcrete ridges of 2 - 3 cm height
soil type: strongly eroded Ferralsol or Ferralsol sediment respectively

Profile No.: Eto 38 (boring) **Date of description:** 89.08.14

Locality: 3.3 k east of Klippan, crest of dune (reddish dune) near the ascent to the dolomite chain

Altitude of site: 1274 m a.s.l. **Long.:** 14°25' **Lat.:** 19°00'

Vegetation: comm. 1 (subcomm. "sandy deposits") + camel thorn

Horizon	Depth in cm	
BuoMAi	0 - 29	7,5 - 5 YR 4/4, -ca-, h' - h", slightly loamy fine sand (very well sorted), loose, single grain, dry Sample: Eto 38-A (0 - 29 cm)
BuoM	29 - 85	5 YR 4/4 - 4/6, -ca-, -h-, slightly loamy fine sand (very well sorted), loose, single grain, dry Samples: Eto 38-B (29 - 44 cm) Eto 38-C (51 - 70 cm) Eto 38-D (80 - 85 cm)

Remark:
soil type: Chromic Arenosol

Profile No.: Eto 39 (boring) **Date of description:** 89.08.14

Locality: "Dolomitpoint" Fontein

Altitude of site: 1268 m a.s.l. **Long.:** 14°25' **Lat.:** 19°00'

Vegetation: comm. 1 ("sweetveld on lime", le Roux), strong damage by grassing

Horizon	Depth in cm	
oMAi	0 - 30	7,5 YR 5/4, -ca-, h'', slightly loamy silty fine sand, loose, single grain, sporadic occurance of shells, dry Sample: Eto 39-A (0 - 30 cm)
II oM	30 - 50	7,5 YR 5/4 - 6/4, -ca-, -h-, slightly loamy silty fine sand, loose (yet stable), single grain, few small subangular calcrete fragments, dry Sample: Eto 39-B (40 - 50 cm)
III oMfAi	50 - 60	7,5 YR 5/4 - 5/6, -ca-, -h-, slightly loamy silty fine sand, loose (yet stable), single grain, few small calcrete fragments, dry Sample: Eto 39-C (50 - 60 cm)

Remark:
"aeolian sand cover" of grey, reworked, very well sorted, non-calcarous sand
soil type: Regosol on top of calcrete

Profile No.: Eto 40 (profile pit) **Date of description:** 89.08.15

Locality: 1 k southwest of the Renostervlei Fontein, pediment between granite chains and main dolomite range northwest of the track

Altitude of site: 1274 m (acc. map) **Long.:** 14°30' **Lat.:** 19°10'

Vegetation: comm. 30 (le Roux)

Horizon	Depth in cm	
oM	+10 - 0	actual aeolian accumulation around acacia and mopane shrubs
wM	0 - 0,3	surface incrustation 2,5 YR 3/6, ca (!), h', loamy sand, moderately dense, platy structure; result of current fluvial sheetwash Sample: Eto 40-A (0 - 0,3 cm)
BuMAh	0,3 - 10	2,5 YR 3/4 - 3/6, -ca- (?), h - h', sandy loam to sandy clayey loam, subangular polyhedral structure to angular polyhedral structure Sample: Eto 40-B (0,3 - 10 cm)
BuM	10 - 20	2,5 YR 3/6, -ca- - (c), sandy loam to sandy clayey loam, moderately dense, subangular polyhedral structure to angular polyhedral structure; horizon sometimes absent, then outcrop of calcrete at 10 cm depth Sample: Eto 40-C (10 - 20 cm)
II mkCv	10/20+	superficially weathered calcrete Sample: Eto 40-D (20+ cm)

Remark:
highly fluctuating depth of soil profile within little distance, in places outcrop of calcrete at surface
soil type: Ferralsol sediment on top of sheetwash pediment

Profile No.: Eto 41 (boring) **Date of description:** 89.08.15

Locality: "small black pan" 6.9 k southwest of the "Olifantsrus" Fontein

Altitude of site: 1183 m a.s.l. **Long.:** 14°50' **Lat.:** 18°55'

Vegetation: comm. 16 (le Roux)

Horizon	Depth in cm	
PAh	0 - 20	10 YR 4/1, -ca-, h, sandy clayey loam, moderately dense, angular polyhedral structure to subangular polyhedral structure, desiccation cracks (hardly visible on surface) down to 10 cm below surface
AhP	20 - 30	10 YR 4/1, -ca-, h', sandy clayey loam, moderately dense to dense, subangular polyhedral structure to massive Sample: Eto 41-B (20 - 30 cm)
CvAhP	30 - 35	10 YR 5/1, -ca-, h', sandy clayey loam, st'- st (fragments of calcrete), moderately dense to dense, subangular polyhedral structure to massive Sample: Eto 41-C (30 - 35 cm)
mkCn	**35+**	**calcrete** **Sample: Eto 41-D (35+ cm)**

Remark:
soil type: shallow Eutric Vertisol (within the "small black pan")

Profile No.: Eto 42 (boring) **Date of description:** 89.08.15

Locality: 200 m east of the Tobieroen Fontein, approx. 10 m north of the track (setting in of the typical relief of the "small black pan")

Altitude of site: 1154 m (acc. map) **Long.:** 14°55' **Lat.:** 18°55'

Vegetation: setting in of comm. 21 (le Roux): "19th Latitude Shrub-Mopane on loamy soils"

Horizon	Depth in cm	
PAh	0 - 23	10 YR 4/1, -ca-, h, sandy clayey loam, loose, subangular polyhedral structure, despite high content of clay, of zoogenic origin, penetrated with fine roots, hardly visible desiccation cracks on surface Sample: Eto 42-A (0 - 23 cm)
AhP	23 - 63	10 YR 5/2 - 5/3 bis 10 YR 5/3, -ca-, h' - h'', clayey loam to silty clayey loam, below 45 cm few calcrete fragments, moderately dense to dense, massive Samples: Eto 42-B (23 - 39 cm); 10 YR 5/2 - 5/3 Eto 42-C (45 - 63 cm); 10 YR 5/3
P	63 - 89	10 YR 5/3 - 6/3, -ca-, -h-, silty clayey loam, few calcrete fragments, moderately dense to dense, massive Sample: Eto 42-D (79 - 89 cm)
PcCv	89 - 90	10 YR 6/2 - 6/3, ca - *ca, -h-, silty loam to silty clayey loam, calcrete fragments, moderately dense to dense, massive, sharp lower boundary Sample: Eto 42-E (89 - 90 cm)
mkCn	90+	calcrete

Remark:
soil type: Vertisol of medium to great depth

Profile No.: Eto 43 (0 - 40 cm profile pit, 40 - 70 cm boring) **Date of description:** 89.08.15

Locality: fire break road "Sonderkop", 5.8 k north of the "Sonderkop" Fontein

Altitude of site: 1138 m (acc. map) **Long.:** 15°15' **Lat.:** 18°55'

Vegetation: comm. 21 (le Roux)
mopane shrubs in knee-high grass

Horizon	Depth in cm	
		1 cm surface incrustation
oM(?)Ah	0 - 10	10 YR 3/1, -ca-, h, sandy clayey loam to clayey loam, loose to moderately dense, subangular polyhedral structure with tendency to vertical fissures Sample: Eto 43-A (0 - 10 cm)
oM(?)AhBv	10 - 25	10 YR 4/1, -ca-, h - h', sandy clayey loam to clayey loam, few calcrete fragments, moderately dense, subangular polyhedral structure Sample: Eto 43-B (10 - 25 cm)
II Pc	25 - 60	2,5 Y 5/2, *ca - **ca, st (calcrete fragments), silty clayey loam, moderately dense to dense, massive Sample: Eto 43-C (25 - 40 cm)
II PcmkCn	60 - 70	10 YR 6/2 - 2,5 Y 6/2, *ca - **ca, *st - **st (calcrete fragments), silty clayey loam, moderately dense to dense, massive Sample: Eto 43-D (60 - 70 cm)
II mkCn	70+	calcrete

Remark:
soil type: Vertic Cambisol

Profile No.: Eto 44 (exposure) **Date of description:** 89.08.18

Locality: south point of Logan's Island

Altitude of site: 1086 m a.s.l. **Long.:** 18°45' **Lat.:** 15°50'

Vegetation: SPSP

Horizon	Depth in cm	
coMAi	0 - 15	10 YR 6/3, h'' - h', **ca, *sa, loose, slightly loamy silty fine sand, subangular polyhedral structure to single grain, surface slightly indurated, hardly visible rooting Sample: Eto 44-A (0 - 10 cm)
II cwM	15 - 35	10 YR 6/3, h'- h'', **ca, *sa, loose to moderately dense, slightly loamy silty fine sand, subangular polyhedral structure to single grain, ± horizontal rooting Sample: Eto 44-B (20 - 30 cm)
III cwMfC$_{z}$vAh	35 - 80	10 YR 7/4, h' - h, **ca, sa?, moderately dense to dense, slightly loamy silty fine sand, strongly angular structure, horizontal and vertical rooting Samples: Eto 44-C (40 - 50 cm), Eto 44-D (60 - 70 cm)
IV fAhC$_{z}$vcoM	80 - 100	**10 YR 7/3, h' - h''(?), **ca, sa?, moderately dense, loamy silty fine sand to strongly loamy silty fine sand, subangular polyhedral structure to single grain Sample: Eto 44-E (80 - 90 cm)**
V coMfC$_{(z)}$v	100 - 115	**10 YR 7/3, h' - h''(?), **ca, sa?, loose, loamy silty fine sand to strongly loamy silty fine sand, subangular polyhedral structure to single grain Sample: Eto 44-F (100 -110 cm)**

Profile No.: Eto 45 (boring) Date of description: 89.08.18

Locality: pan surface 400 m W of Logan's Island and 800 m E of the western border of the pan

Altitude of site: **Long.:** 18°45' **Lat.:** 15°50'

Vegetation: free of vegetation, desiccation cracks on ground surface

Horizon	Depth in cm	
MAiBtn	0 - 5	2,5 Y 7/2, **ca - *ca, **sa, silty clayey loam to clayey loam, moderately dense to dense, columnar structure
MAiBtn	5 - 25	5 Y 6/4, **ca - *ca, **sa, silty clayey loam to clayey loam, moderately dense to dense, massive, dry Sample: Eto 45-A (0 - 25 cm)
MAiBtn	25 - 40	5 Y 6/2 - 5/2, **ca, **sa, silty clayey loam to clayey loam, moderately dense to dense, massive, dry Sample: Eto 45-B (25 - 40 cm)
II MBtn2	40 - 57	5 Y 5/2, **ca - *ca, **sa, silty clayey loam to clayey loam, moderately dense to dense, massive, dry Sample: Eto 45-C (40 - 52 cm)
III MGoBt	57 - 102	5 Y 5/2 - 6/2, **ca - *ca, **sa - *sa, sandy silty loam with small clay nodules, moderately dense, massive to subangular polyhedral structure, dry Samples: Eto 45-D (63 - 81 cm), Eto 45-E (93 - 102 cm)
IV MGo	102 - 125	5 Y 5/2, **ca, **sa - *sa, loamy sand grading downward into sandy loam , moderately dense, subangular polyhedral structure to single grain, dry Samples: Eto 45-F (110 - 121 cm) Eto 45-G (121 - 125 cm)
IV mCzn	>125	glauconitic calciferous sandstone

Remark:
at 125 cm no further boring possible!

Profile No.: Eto 46 (boring) Date of description: 89.08.18

Locality: interdune zone between 1st and 2nd dune crest of the western dune ridges of the Etosha Pan

Altitude of site: approx. 1108 m a.s.l. **Long.:** 18°45' **Lat.:** 15°50'

Vegetation: grasses: P: CECI, EREC, STUN, STHO
A: ENCE, STHI, ZYGSI
shrubs: SALTU, LEBA

Horizon	Depth in cm	
coMAch	0 - 27	10 YR 4/3, h - h', **ca - *ca, moderately dense to loose, silty loam, massive to powdery structure, dry Sample: Eto 46-A (0 - 27 cm)
II coMfAchCv	27 - 38	10 YR 5/4 - 4/3, h' - h'', **ca, moderately dense, silty loam, massive to powdery structure, dry Sample: Eto 46-B (27 - 38 cm)
II coM	38 - 64	10 YR 5/4, **ca, moderately dense, silty loam, massive to powdery structure, dry Sample: Eto 46-C (50 - 64 cm)
II coMmkCv	64 - 86	10 YR 6/4 - 5/4, **ca, moderately dense, silty loam, with interspersed fragments of calcrete, massive to powdery structure, dry Sample: Eto 46-D (80 -86 cm)
III mkCn	86+	calcrete

Profile No.: Eto 47 (boring) Date of description: 89.08.18

Locality: dune crest of the 2nd dune to the west of the western border of the Etosha Pan

Altitude of site: approx. 1112 m a.s.l. Long.: 18°45' Lat.: 15°50'

Vegetation: grasses: P: STUN, STHO, CECI, EREC
A: ENCE, STHI
shrubs: SATU

Horizon	Depth in cm	
		Superficial incrustation of 3 mm depth, mollusks on ground surface Sample: Eto 47-I
coMAch	0 - 28	10 YR 5/4, h, **ca - *ca, loose, subangular polyhedral structure to massive, loamy fine sand, dry Sample: Eto 47-A (0 - 28 cm)
II coMfAchCv	28 - 62	10 YR 5/4, h', **ca - *ca, loose to moderately dense, subangular polyhedral structure to massive, silty sandy loam, with few interspersed calciferous concretions, dry Samples: Eto 47-B (39 - 50 cm) Eto 47-C (50 - 62 cm)
II coMfCvCkc	62 - 107	10 YR 5/4 - 6/4, **ca, moderately dense, massive, loamy silty fine sand, with many interspersed calciferous concretions (?), dry Samples: Eto 47-D (79 - 93 cm) Eto 47-E (96 - 107 cm)
III coMfCv	107 - 145+	10 YR 6/6 - 5/4, *ca - **ca, moderately dense, massive, loamy fine sand, low to moderate abundance of calciferous concretions (?), dry Samples: Eto 47-F (107 - 117 cm) Eto 47-G (135 - 145 cm)

Profile No.: Eto 48 (boring) **Date of description:** 89.08.18

Locality: catena "Ekuma River Road", 500 m northeast of the junction of the main track

Altitude of site: approx. 1091 m a.s.l. **Long.:** 18°35' **Lat.:** 15°55'

Vegetation: grasses: P: ANPU, CECI, HECO, STUN, SCPA
A: ENCE, TRPU, ERAN

Horizon	Depth in cm	
	+10 - 0	actual aeolian accumulation around tussock grasses, 0.5 mm platy surface incrustation
wMAh	0 - 28	10 YR 4/2, h, ca, loose, loamy medium sand, single grain, dry Sample: Eto 48-A (0 - 28 cm)
wMAhCv	28 - 45	10 YR 5/3 - 4/2, h - h', ca, loose, loamy medium sand, single grain, dry
wMCv	45 - 61	10 YR 5/3, h'- h'', *ca - **ca, loose, loamy medium sand to slightly loamy medium sand, single grain, dry Sample: Eto 48-B (45 - 61 cm)
cwM	61 - 80+	10 YR 6/4, h''(?), **ca, loose, slightly loamy sand, single grain, dry Sample: Eto 48-C (70 - 80 cm)

Remark:
cf. profile/samples Eto 50
soil type: Eutric Cambisol

Profile No.: Eto 49 (exposure) Date of description:

Locality: outer bank of the Ekuma river, south of the "Ekuma Horsecamp"

Altitude of site: 1088 m a.s.l. **Long.:** 18°35' **Lat.:** 15°55'

Vegetation:

Horizon	Depth in cm	
--	0 - 40	bright yellowish brown to brown sand, high content of calcium carbonate; cf. profiles Eto 48 and Eto 50
--	40 - 80	morphological highly resistant calcrete ("calcrete gravel"; concretionary, nodular), cemented by calcium carbonate, partly open pores
--	80 - 100	morphological resistant calcrete ("calcrete gravel"; concretionary, nodular), slightly cemented by calcium carbonate (cellular, porous)
--	100 - 130	pale brown to yellowish, high content of calcium carbonate, with calcium carbonate cemented sand; cover of debris?
--	130 - 150	morphological very resistant calcrete ("calcrete gravel"; concretionary, nodular), strongly cemented by calcium carbonate, partly open pores; cover of debris?
--	150 - 500	cover of debris(?); basis at 1083 m. a.s.l.: high-water bed of the Ekuma river

Profile No.: Eto 50 (boring) **Date of description:** 89.08.19

Locality: catena "Ekuma River Road", 5.2 k NE of the main track's junction

Altitude of site: 1091 m a.s.l. **Long.:** 18°35' **Lat.:** 16°00'

Vegetation: grasses: P: STUN, CECI
A: SCKA, URBR, STHI

Horizon	Depth in cm	
$A_{ch}coM$	0 - 30	10 YR 4/3, h' - h, ca, slightly loamy sand, loose, single grain, dry Sample: Eto 50-A (0 - 30 cm)
II $cwMA_{ch}$	30 - 43	10 YR 4/2, h, ca, slightly loamy sand, loose, single grain, dry
II $cwMA_{ch}C_v$	43 - 56	10 YR 4/3, h' - h, ca, slightly loamy sand to loamy sand, loose, single grain, dry
II cwM	56 - 93	10 YR 5/2 - 4/3, ca - *ca, loamy sand, loose, single grain, dry
II/III cwM	93 - 108	10 YR 5/3 - 4/3, *ca - **ca, loamy sand, loose, single grain, dry
III cwM	108 - 140+	10 YR 5/3, **ca, loamy sand, loose, single grain, with few interspersed small fragments of calcrete, dry Samples: Eto 50-B (108 - 116 cm), Eto 50-C (134 - 140 cm)

Remark:
from 0 - 30 cm = youngest aeolian sediment;
cf. profile/samples Eto 48

Probile No.: Eto 51 (boring) **Date of description:** 89.08.19

Locality: Ekuma River Floodplain, approx. 100 m SW of the current river bed (completely fallen dry at date of description)

Altitude of site: 1089 m a.s.l. **Long.:** 18°35' **Lat.:** 16°00'

Vegetation: grasses: P: v. a. SPSP, ODPA
SPTE, SPPA, GRSA
A: ERPO
shrubs: SUAR

Horizon	Depth in cm	
--	0 - 1	10 YR 7/2, salt crust
--	1 - 6	10 YR 5/1 - 4/2 (brownish grey), h', ca, **sa, slightly loamy sand, moderately dense, weak platy structure, dry Sample: Eto 51-A (0 - 6 cm)
--	6 - 25	2,5 Y 6/4, -h-, *ca - **ca, sa?, loamy medium to coarse sand, few fragments of lime sandstone, loose, single grain, dry Sample: Eto 51-B (15 - 25 cm)
--	25 - 50	2,5 Y 6/4, -h-, **ca, sa?, loamy medium sand, subangular polyhedral structure to single grain, loose, dry Sample: Eto 51-C (25 - 39 cm)
--	50 - 74	5 Y 5/2, -h-, **ca, sa?, silty loam (glauconitic), (in nodes sandy loam to sandy silty loam), few glauconitic lime sandstones, moderately dense to dense, subangular polyhedral structure, dry Sample: Eto 51-D (56 - 74 cm)
--	74 - 85+	5 Y 5/2, **ca, sandy loam to silty loam ("Ekuma Calciferous Sandstone", glauconitic, superficially weathered), hard, dry Sample: Eto 51-E (74 - 85 cm)

Profile No.: Eto 52 (boring) **Date of description:** 89.08.21

Locality: Fisher's Pan; 2.4 k NNW of the Twee Palms Fontein, 2.3 k SSE of the northern shore of Fisher's Pan, 10 m W of the pan track

Altitude of site: 1082 m a.s.l. **Long.:** 17°01'25" **Lat.:** 18°44'40"

Vegetation: free of vegetation, desiccation cracks on ground surface

Horizon	Depth in cm	
--	0 - 10	2,5 Y 6/2, h'(?), **ca, sa?, silty clayey loam, strong angular polyhedral structure to prismatic structure (*Scherbengefüge*), dessication cracks, dry
--	10 - 35	2,5 Y 7/2 - 6/2, h'(?), **ca, sa?, silty clayey loam, moderately dense, massive, slightly moist to moist Sample: Eto 52-A (10 - 35 cm)
	35 - 45	2,5 Y 7/2 (= lighter than above), **ca, sa?, silty clayey loam, moderately dense, massive, slightly moist to moist Sample: Eto 52-B (35 - 45 cm)
--	45 - 154	5 Y 7/3 (bright "bottle green"), **ca - *ca, sa?, medium-sandy fine sand, loose, single grain, from 45 cm to 110 cm moist, beneath 110 cm wet (waterlevel from 08.21.89) Samples: Eto 52-C (63 - 77 cm) Eto 52-D (136 - 144 cm)
--	154 - 194	5 Y 7/3 (shining dark "bottle green"), **ca - *ca, sa, clayey silt, with brownish inclusions (due to illuvation processes?), dense, massive, moist to very moist Sample: Eto 52-E (164 - 194 cm)
--	194 - 220	5 Y 7/3 (bright "bottle green"), **ca - *ca, sa, medium-sandy fine sand, loose, single grain, wet Sample: Eto 52-F (200 - 210 cm)
--	220 - 230	5 Y 7/3 (shining dark "bottle green"), **ca - *ca, sa, fine-sandy silty loam, moderately dense to dense, massive, moist to very moist Sample: Eto 52-G (220 - 230 cm)
--	230 - 260	5 Y 7/3 (bright "bottle green") + 5 Y 7/3 (paler than before, often with light-coloured inclusions), **ca - *ca, sa, fine-sandy medium sand, loose, single grain, wet Sample: Eto 52-H (248 - 260 cm)

Profile No.: Eto 53 (boring) **Date of description:** 89.08.22

Locality: 2.6 k ESE of the Andoni River. ("Acaciae Terrace")

Altitude of site: 1096 m a.s.l. **Long.:** 16°47'55" **Lat.:** 18°31'05"

Vegetation: Andoni-Grasveld + acaciae

Horizon	Depth in cm	
oMAh	0 - 25	10 YR 3/2 - 7,5 YR 3/2, h - *h, -ca-, slightly loamy fine sand, loose, single grain to subangular polyhedral structure Sample: Eto 53-A (0 - 25 cm)
AhoM	25 - 44	10 YR 4/2 - 3/2, h - h', -ca-, loamy fine sand, loose, single grain to subangular polyhedral structure
II oMmkCv	44 - 58	10 YR 4/2 - 4/3, h''(?), -ca-, fine-sandy loam, loose to moderately dense, subangular polyhedral structure to single grain Sample: Eto 53-B (44 - 58 cm)
II mkCv	58 - 67	10 YR 4/3, *ca, sandy loam to sandy clayey loam, sf (calcrete fragments), moderately dense, subangular polyhedral structure **Sample: Eto 53-C (58 - 67 cm)**
II mkCn	67+	calcrete

Remark:
0 - 44 cm: reworked aeolian sand (?)
44 - 58 cm: reworked aeolian sand (?), mixed with superficially weathered fragments of calcrete

Profile No.: Eto 54 (boring) **Date of description:** 89.08.22

Locality: 3.6 k SE of the Stinkwater Fontein, 10 m SW of the Stinkwater track towards the pan (Bay of Stinkwater), pediment leading towards the pan

Altitude of site: 1094 m a.s.l. **Long.:** 16°51'05" **Lat.:** 18°38'05"

Vegetation: salt-tolerating grasses

Horizon	Depth in cm	
--	0 - 0,5	Surface crust + algae
oM	0,5 - 10	10 YR 5/2 - 5/3, h' - h'', -ca-, slightly loamy fine sand, loose, platy structure Sample: Eto 54-A (0 - 10 cm)
II wMAh/Ai	10 - 20	10 YR 4/3 - 5/3, h - h', -ca-, slightly loamy fine sand, loose to moderately dense, weak subangular polyhedral structure Sample: Eto 54-B (10 - 20 cm)
II wM	20 - 30	10 YR 5/3 - 5/4, ca', slightly loamy fine sand, loose to moderately dense, weak subangular polyhedral structure
III cwM	30 - 64	10 YR 6/3 - 6/4, **ca, fine-sandy silty loam, sf. (fragments of lime or lime sandstone), moderately dense, subangular polyhedral structure Sample: Eto-C (40 - 55 cm)
IV cwM(fCv?)	64 - 87	2,5 Y 6/4 - 7/4, *ca - **ca, silty fine-sandy loam, moderately dense, subangular polyhedral structure Samples: Eto 54-D (72 - 79 cm) Eto 54-E (79 - 87 cm)
V mCn	87+	calciferous sandstone or calcrete?

Remark:
from 0,5 - 10 cm youngest reworked aeolian sediment

Profile No.: Eto 55 (exposure) **Date of description:** 89.08.22

Locality: 100 m panward from profile Eto 54 (Stinkwater Bay), dune-like ridge

Altitude of site: 1094 m a.s.l. **Long.:** 16°51'00" **Lat.:** 18°38'10"

Vegetation: halophytic grasses

Horizon	Depth in cm	
oM	0 - 6	2,5 Y 4/4, h"(?), -ca-, sa(?), slightly loamy fine sand, loose, platy structure
II wMAh/Ai	6 - 15	10 YR 4/3 - 5/3, h' - h, -ca-, sa(?), slightly loamy fine sand, moderately dense, weak angular polyhedral structure
II AiwM	15 - 27	10 YR 5/3 - 5/4, h' - h", -ca-, slightly loamy fine sand, moderately dense, subangular polyhedral structure
III(cwM?)fmkCv	27 - 31	10 YR 5/4 - 2,5 Y 5/4, -ca-, slightly loamy fine sand, moderately dense, subangular polyhedral structure, sharp boundary
III Cv	31 - 60+	2,5 Y 5/4, *ca - **ca, slightly loamy sand to loamy sand, moderately dense to dense, subangular polyhedral structure (superficially weathered lime sandstone?)

Remark:
from 0 - 6 cm youngest aeolian sediment
profile comparable to Eto 54

Enclosure 3

HORIZON SYMBOLS

X Residual Boulder Pavement

A Topsoil: epipedon; topsoil horizon which is characterized by the presence of organic material

A_i topsoil with little accumulation of organic material showing signs of initial soil formation; content of organic material < 0.6 % for sand or < 1.2 % for clay respectively

A_h topsoil rich of humus with 0.6 % (or 1.2 % resp.) to 15 % organic material

A_{ch} calcareous topsoil rich of humus; in comparison with parent material only little decalcification (partly secondary infiltration of calcium carbonate)

A_{cch} topsoil rich of humus, secondarily infiltrated with calcium carbonate (diagnostic feature may be calciferous precipitation lines of net-like character along pores)

A_w structurized topsoil, where structure is mostly due to desiccation cracks

Transitional Horizons and Additional Features of the Topsoil

$coMA_i$ topsoil developing on a calcareous aeolian sediment with little accumulation of organic material and signs of initial soil formation

oMA_i topsoil developing on a non-calcareous aeolian sediment with little accumulation of organic material and signs of initial soil formation

$B_{uo}MA_i$ topsoil developing on a ferralitic/rubefied aeolian sediment (hue 5 YR) with little accumulation of organic material and signs of initial soil formation

oMPAh humous topsoil on clayey material (clay content > 45 %) mixed with aeolian sediment: swelling and shrinking dynamics as well as prismatic and/or angular polyhedral structure less strongly developed as for a typical PA_h-horizon

coMAch calcareous topsoil rich of humus developed on a calcareous aeolian sediment

oMAch calcareous topsoil rich of humus developed on a young aeolian fine-grained sedimentary cover of a stratified profile (content of calcium carbonate less than in subjacent A_h-horizon developed on calciferous rock)

$A_{ch}C_v$ initial B-horizon, calcareous, enriched with humus

$C_{zv}A_h$ humous topsoil slightly brown by chemical weathering (corresponding to parent material usually calcareous) and relatively enriched with salts

$A_hC_{zv}coM$ calcareous aeolian sediment, slightly brown by oxidation and enriched with salts and humus (transitional horizon at the lower boundary of corresponding A_hC_{zv}- or $C_{zv}A_h$-horizons respectively < 9

PAh **humous topsoil of clayey consistence (clay content > 45 %) with strong swelling and shrinking dynamics, dense prismatic and/or angular polyhedral structure (frequently serving as slickenside) and, at times, desiccation cracks**

B Subsoil

in which colour, composition and structure of the parent material has been changed by pedogenetic processes (i. e. weathering, translocation, accumulation)

Bv B-horizon developed in situ by weathering which, compared to the corresponding parent material, has undergone a change in colour, content of clay and structure (hue 10 YR)

Bu ferralitic/rubefied B-horizon (hue 5 YR)

Bhu ferralitic/rubefied B-horizon (hue 5 YR) enriched with humus

rBu relict ferralitic/rubefied B-horizon (hue 5 YR)

Buv slightly ferralitic/rubefied B-horizon (hue 7.5 YR)

Bt **clay illuvation horizon (luvic) with clay cutans and/or clay lumps**

Bn strongly alcaline (pH > 8.5) B-horizon with/without high Na-concentration

Bsn **diagnostic B-horizon of a solonetz**

C Mineral Parent Material:

solid or loose parent material which overlying soil has originated from and which does not show any features of the other main horizons

Cv **slightly weathered C-horizon (initial browning)**

Cco **C-horizon secondarily enriched with illuviated calcium carbonate**

Cko **C-horizon secondarily enriched with concretions of illuviated calcium carbonate**

C(s) **C-horizon secondarily enriched with salts, EC1 or EC5 resp. > 1 and < 4 mS/cm**

Cz **C-horizon secondarily enriched with salts, EC1 or EC5 resp. > 4 mS/cm**

Csn **C-horizon, unweathered and enriched with salts**

mC **solid parent material**

mkC — solid, calcareous parent material

mkC$_n$ — solid, calcareous and unweathered parent material

P Mineral Subsoil
of clayey material (clay content > 45 %) and with strong swelling and shrinking dynamics, dense prismatic and/or angular polyhedral structure (frequently serving as slickenside) and, at times, desiccation cracks

Ah$_S$$_d$P — mineral subsoil of clayey material, dense, water-impounding and enriched with humus

M Topsoil:
mineral soil horizon of alluvial, colluvial or aeolian deposits, largely without pedogenetic alterations

wM — fluvial or colluvial sediment

cwM — calcareous fluvial or colluvial sediment

oM — aeolian sediment

coM — calcareous aeolian sediment

B$_u$oM — aeolian sediment of ferralitic/rubefied B$_u$-horizon material (hue 5 YR)

B$_{uv}$oM — aeolian sediment of slightly ferralitic/rubefied B$_u$-horizon material (hue 7.5 YR)

S Mineral Soil Horizon
altered by impound water and showing hydromorphic features

Sd — dense impound-water horizon, mottled (base of impound water)

G Mineral Soil Horizon
altered by ground water

Go — ground-water horizon with oxidation features (mottling)

Gr — ground-water horizon with reduction features (bleaching)

G$_{kcr}$ — ground-water horizon with reduction features and secondary enrichment with calciferous concretions

G$_{or}$ — transitional ground-water horizon with both oxidation and reduction features

f	buried horizon, symbol normally used for horizons beneath bioturbation zone
r	relict horizon
II, III, ...	(prefix) additional symbols corresponding to geological stratification: 2nd, 3rd layer
1, 2, 3, ...	(suffix) state of development of a horizon: 1 = very weak, to 5 = very strong
(z), ...	brackets are indicating that symbol stands for non-diagnostic horizon

Enclosure 4

LIST OF SYMBOLS DEFINING SOIL PROPERTIES

1) Soil-Colour

classification after Munsell Soil Color Charts [1]; colour normally determined of soil sample in moist state; if not so, state is indicated in brackets.

2) Humosity

classification after Bodenkundliche Kartieranleitung [2], p.98 (symbols partly modified)

% organic matter	definition	symbol
	free of humus	-h-
	sporadically humic	(h)
< 1	very slightly humic	h'
1 - 2	slightly humic	h''
2 - 5	(moderately) humic	h
5 - 10	strongly humic	*h
10 - 15	very strongly humic	**h
15 - 30	extremely humic	***h

3) Content of Free Calcium Carbonate

classification after Bodenkundliche Kartieranleitung [2], p.94 (symbols partly modified)

% by weight of $CaCO_3$	definition	symbol
0	free of calcium carbonate	-c-
< 0,5	very slightly calciferous	c''
0,5 - 2	slightly calciferous	c'
2 - 10	calciferous	c
10 - 25	strongly calciferous	*c
25 - 50	very strongly calciferous	**c
> 50	extremely calciferous	***c

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[1] for purchase contact: Munsell Color Company Inc., Baltimore, Maryland 21218, USA

[2] AG Bodenkunde, Bodenkundliche Kartieranleitung, 3. edition, Hannover 1982; on commission: E. Schweizerbartsche Verlagsbuchhandlung (Nägele und Obermiller), Johannesstraße 3A, D 7000 Stuttgart 1

4) Salinity

classification after Tropical Soil Manual [3] (own symbols conceived), based on the electrical conductivity (EC 1:5)

mS/cm	definition	symbol
< 1	salt free	-sa-
> 1 - 4	very slightly saline	sa''
> 4 - 8	slightly saline	sa'
> 8 - 15	moderately saline	sa
> 15	strongly saline	*sa

5) Content of Stones

classification after Bodenkundliche Kartieranleitung [2], p.89 (own symbols conceived)

% by weight	definition	symbol
< 2	very slightly stony	st''
2 - 15	slightly stony	st'
15 - 45	moderately stony	st
45 - 60	strongly stony	*st
60 - 85	very strongly stony	**st
> 85	skeleton soil	St

[3]Landon, J. R. (ed.): Booker Tropical Soil Manual. Bath 1984, Pitman Press.

Enclosure 5

ATTACHING OF THE SOIL PROFILES (BUCH, field campaign 1989) TO THE SOIL UNITS OF THE SOIL MAP OF THE ETOSHA NATIONAL PARK (le ROUX et al. 1988)

South African Soil Classification (Form/Soil Series):
S 1: Fernwood Form (FW) / Langebaan Series (sand of normal topography lacking marked wetness, medium sandy in upper regic horizon, neutral to alkaline
approximate FAO Correlation:
Dystric / Eutric Regosols
Soil Classification (FAO-Nomenclature) (BUCH):
Eutric Regosols (above non-calcareous Fluvisols)
Soil Profile No. (BUCH):
Eto 6, 15, 16, 17, 19, 21, 54, 55

South African Soil Classification (Form/Soil Series):
S 2: Hutton Form (HU) / Roodepoort Series (Non-calcareous, eutrophic B horizon, 0-6% clay content in fine sandy, red apedal B horizon
approximate FAO Correlation:
Rhodic Ferralsols
Soil Classification (FAO-Nomenclature) (BUCH):
no soil profile descriptions yet in NW-Etosha
Soil Profile No. (BUCH):
no soil profile descriptions yet in NW-Etosha

South African Soil Classification (Form/Soil Series):
S 3: Clovelly Form (CV) / Sunbury Series (Non-calcareous, eutrophic in B horizon, 0-6% clay content in fine sandy, yellow-brown apedal B horizon
approximate FAO Correlation:
Ochric Cambisols / Xanthic Ferralsols
Soil Classification (FAO-Nomenclature) (BUCH):
no soil profile descriptions yet in NW-Etosha
Soil Profile No. (BUCH):
no soil profile descriptions yet in NW-Etosha

South African Soil Classification (Form/Soil Series):
S 4: Clovelly Form (CV) / Sunbury Series (Non-calcareous, eutrophic in B horizon, 0-6% clay content in fine sandy, yellow-brown apedal B horizon)
approximate FAO Correlation:
Ochric Cambisols / Xanthic Ferralsols
Soil Classification (FAO-Nomenclature) (BUCH):
calcrete outcrops / (medium sandy) Rhodic/Xanthic Ferralsols
Soil Profile No. (BUCH):
Eto 30, 41, 42

South African Soil Classification (Form/Soil Series):
S 5: Hutton Form (HU) / Zwartfontein Series (Non-calcareous, eutrophic in B horizon, 6-15% clay content in medium sandy, red apedal B horizon)
approximate FAO Correlation:
(medium sandy) Rhodic/(Xanthic) Ferralsols
Soil Classification (FAO-Nomenclature) (BUCH):
(medium sandy) Rhodic Ferralsols
Soil Profile No. (BUCH):
Eto 13, 36, 37

South African Soil Classification (Form/Soil Series):
S 6: Fernwood Form (FW) / Langebaan Series (sand of normal topography lacking marked wetness, medium sandy in upper regic horizon, neutral to alkaline
approximate FAO Correlation:
Dystric / Eutric Regosols
Soil Classification (FAO-Nomenclature) (BUCH):
Calcaric Regosols (with palaeosoils of the type Haplic Calcisols and Petric Calcisols)
Soil Profile No. (BUCH):
Eto 28, 46, 47

South African Soil Classification (Form/Soil Series):
S 7: Hutton Form (HU) / Zwartfontein Series (Non-calcareous, eutrophic in B horizon, 6-15% clay content in medium sandy, red apedal B horizon)
approximate FAO Correlation:
(medium sandy) Rhodic/(Xanthic) Ferralsols
Soil Classification (FAO-Nomenclature) (BUCH):
(medium to coarse sandy, red coloured) Fluvisols

Soil Profile No. (BUCH):
Eto 34

South African Soil Classification (Form/Soil Series):
L 1: Estcourt Form (ES) / Heights Series (B horizon lacks continuous black cutans; clay content of B horizon above 25%; medium sandy albic horizon with clay content 0-6%)
approximate FAO Correlation:
Ochric Solonetz (with albic horizon)
Soil Classification (FAO-Nomenclature) (BUCH):
Gleyic Solonetz, Stagnic Solonetz, (Eutric Regosols)
Soil Profile No. (BUCH):
Eto 5, 51, 53

South African Soil Classification (Form/Soil Series):
L 2: Fernwood Form (FW) / Langebaan Series (sand of normal topography lacking marked wetness, medium sandy in upper regic horizon, neutral to alkaline
approximate FAO Correlation:
Dystric / Eutric Regosols
Soil Classification (FAO-Nomenclature) (BUCH):
Eutric Regosols and Eutric Vertisols/(Vertic) Cambisols
Soil Profile No. (BUCH):
Eto 43, 48, 49, 50

South African Soil Classification (Form/Soil Series):
L 3: Valsriver Form (VA) / Valsriver Series (B horizon colour predominantly non-red; calcareous in B or C horizon; clay content in B horizon 15-35%)
approximate FAO Correlation:
Chromic Cambisols
Soil Classification (FAO-Nomenclature) (BUCH):
Eutric Vertisols/(Vertic) Cambisols
Soil Profile No. (BUCH):
Eto 29, 42, 43

South African Soil Classification (Form/Soil Series):
K 1: Mispah Form (MS) / Kalkbank Series (calcareous in A horizon, hardpan calcrete underlying A horizon)
approximate FAO Correlation:
Calcrete Lithosols <Lithic Leptosols>

Soil Classification (FAO-Nomenclature) (BUCH):
Calcrete Lithosols <Lithic Leptosols>
Soil Profile No. (BUCH):
Eto 1, 3

South African Soil Classification (Form/Soil Series):
K 2: Glenrosa Form (GS) / Lekfontein Series (calcareous in or immediately below B horizon; A horizon fine sandy with clay content 15-35%
approximate FAO Correlation:
Ochric / Eutric / Calcic Cambisols, lithic phase
Soil Classification (FAO-Nomenclature) (BUCH):
Calcrete Lithosols <Lithic Leptosols)/Non-calcareous Fluvisols
Soil Profile No. (BUCH):
27

South African Soil Classification (Form/Soil Series):
K 3: Mispah Form (MS) / Kalkbank Series/Lithosol (calcareous in A horizon, hardpan calcrete underlying A horizon)
approximate FAO Correlation:
Calcrete Lithosols <Lithic Leptosols>
Soil Classification (FAO-Nomenclature) (BUCH):
Calcrete Lithosols <Lithic Leptosols> / Sediments of Xanthic/ Rhodic Ferralsols
Soil Profile No. (BUCH):
Eto 30, 36, 37

South African Soil Classification (Form/Soil Series):
K 4: Clovelly Form (GV) / Dudfield Series (calcareous in B horizon, undifferentiated in grade of sand; clay content of B horizon 15-35%)
approximate FAO Correlation:
Ochric / Eutric / Calcic Cambisols; Xanthic / Ochric Ferralsols
Soil Classification (FAO-Nomenclature) (BUCH):
Calcrete Lithosols <Lithic Leptosols> / Sediments of Xanthic/ Rhodic Ferralsols
Soil Profile No. (BUCH):
Eto 38, 39, 40

South African Soil Classification (Form/Soil Series):
K 5: Lithosols (hardpan calcrete)

approximate FAO Correlation:
Calcrete Lithosols <Lithic Leptosols>
Soil Classification (FAO-Nomenclature) (BUCH):
calcrete outcrops/Calcrete Lithosols <Lithic Leptosols>/Eutric Vertisols/((Sali-) Stagni-Calcaric Vertisols)
Soil Profile No. (BUCH):
Eto 2, 4, 7, 8, 9, 10, 32, 33

South African Soil Classification (Form/Soil Series):
K 6: Arcadia Form (AR) / Arcadia Series/Lithosol (Self-mulching or weakly crusting surface; calcareous in or immediately below dark coloured vertic A horizon)
approximate FAO Correlation:
Pellic Vertisols/Vertic Cambisols / Calcrete Lithosols <Lithic Leptosols>
Soil Classification (FAO-Nomenclature) (BUCH):
calcrete outcrops/Calcrete Lithosols <Lithic Leptosols>/Eutric Vertisols
Soil Profile No. (BUCH):
no soil profile descriptions yet in SE-Etosha

South African Soil Classification (Form/Soil Series):
K 7: Arcadia Form (AR) / Arcadia Series/ (Self-mulching or weakly crusting surface; calcareous in or immediately below dark coloured vertic A horizon)
approximate FAO Correlation:
Pellic Vertisols/Vertic Cambisols
Soil Classification (FAO-Nomenclature) (BUCH):
calcrete outcrops / (medium sandy) Rhodic/Xanthic Ferralsols / Eutric Vertisols
Soil Profile No. (BUCH):
Eto 14

South African Soil Classification (Form/Soil Series):
R: Dolomite, Marble, Calcrete & Rhyolithic Rock
approximate FAO Correlation:
./.
Soil Classification (FAO-Nomenclature) (BUCH):
Lithosols, Rudi-Rhodic Ferralsols, Rhodic Ferralsols
Soil Profile No. (BUCH):
Eto 11, 12, 31, 35

South African Soil Classification (Form/Soil Series):

P: Saline Pan

approximate FAO Correlation:

Haplic / Gleyic Solonetz

Soil Classification (FAO-Nomenclature) (BUCH):

Haplic / Gleyic Solonetz

Soil Profile No. (BUCH):

Eto 18, 20, 44, 45, 52, 55

Fig. 2

Analytical Standard Values, Profile Eto 44

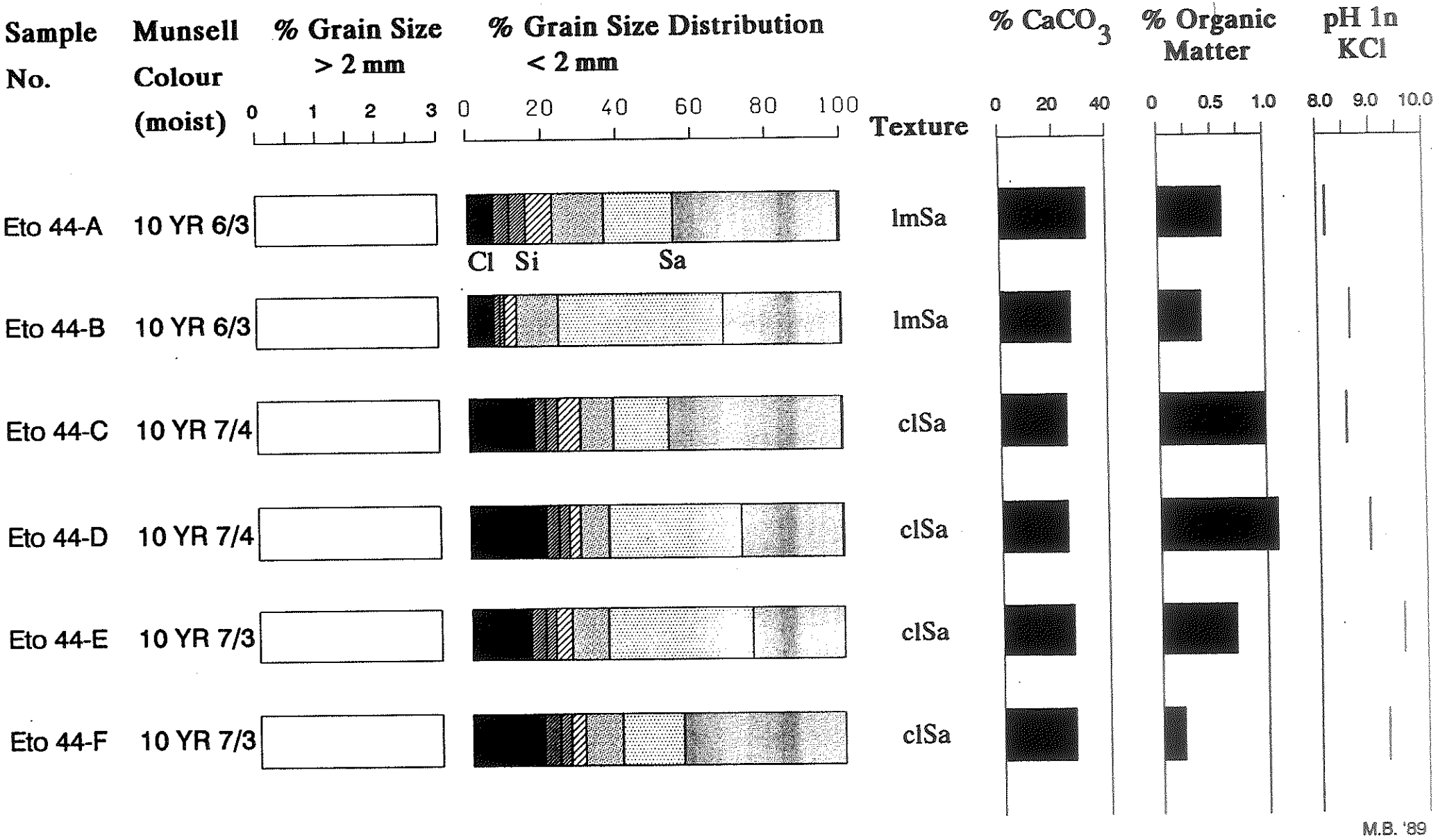


Fig. 3

Analytical Standard Values, Profile Eto 30

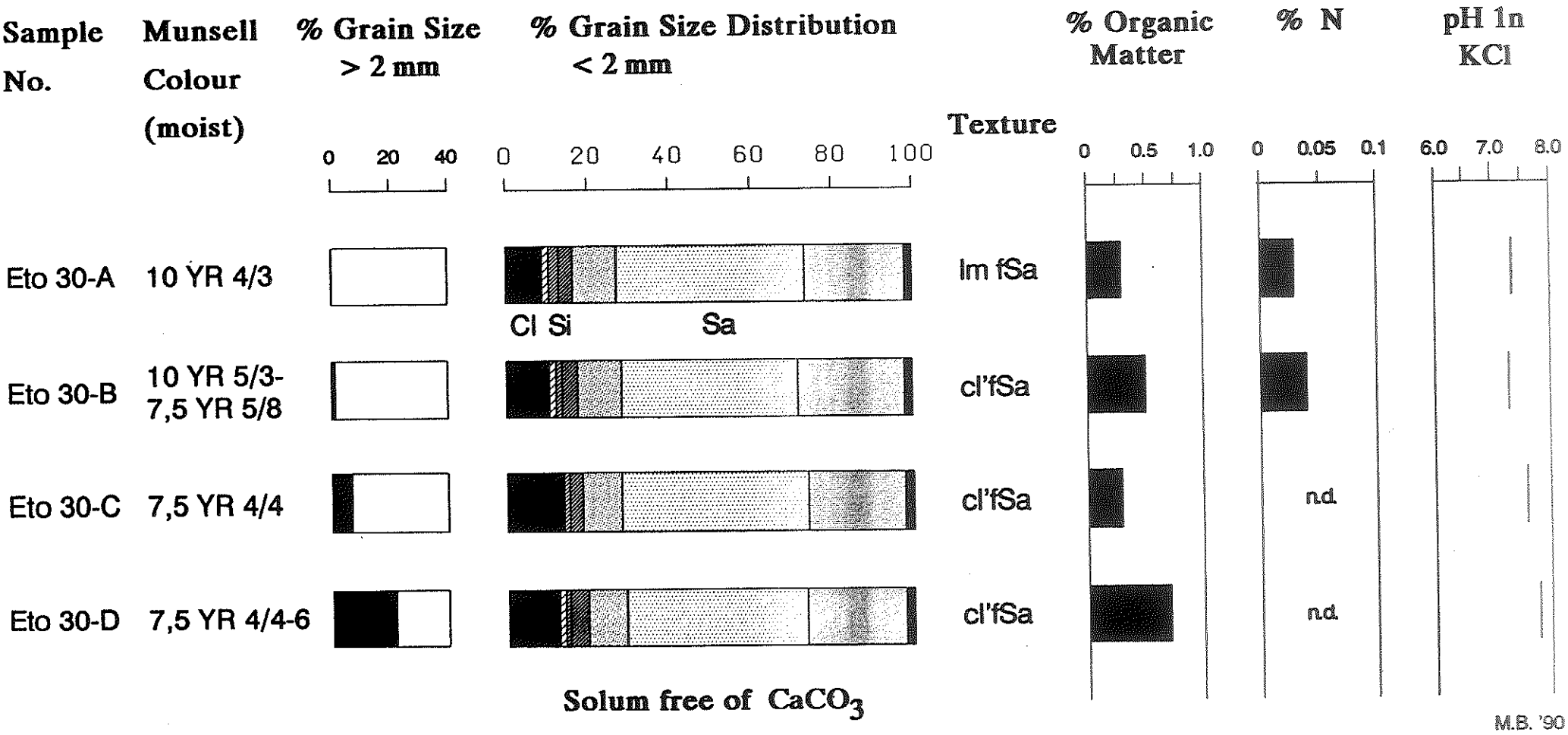
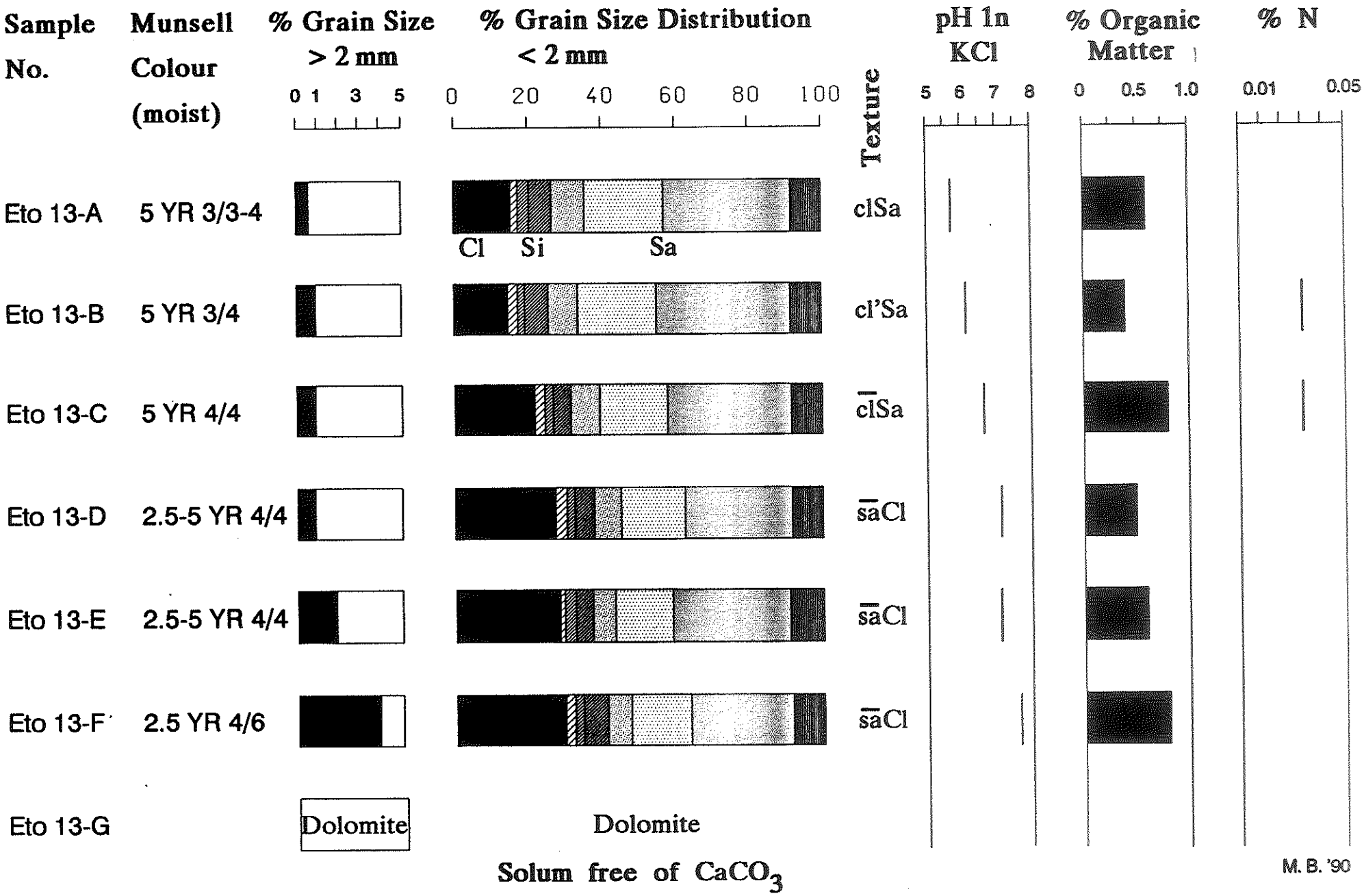


Fig. 4

Analytical Standard Values, Profile Eto 13



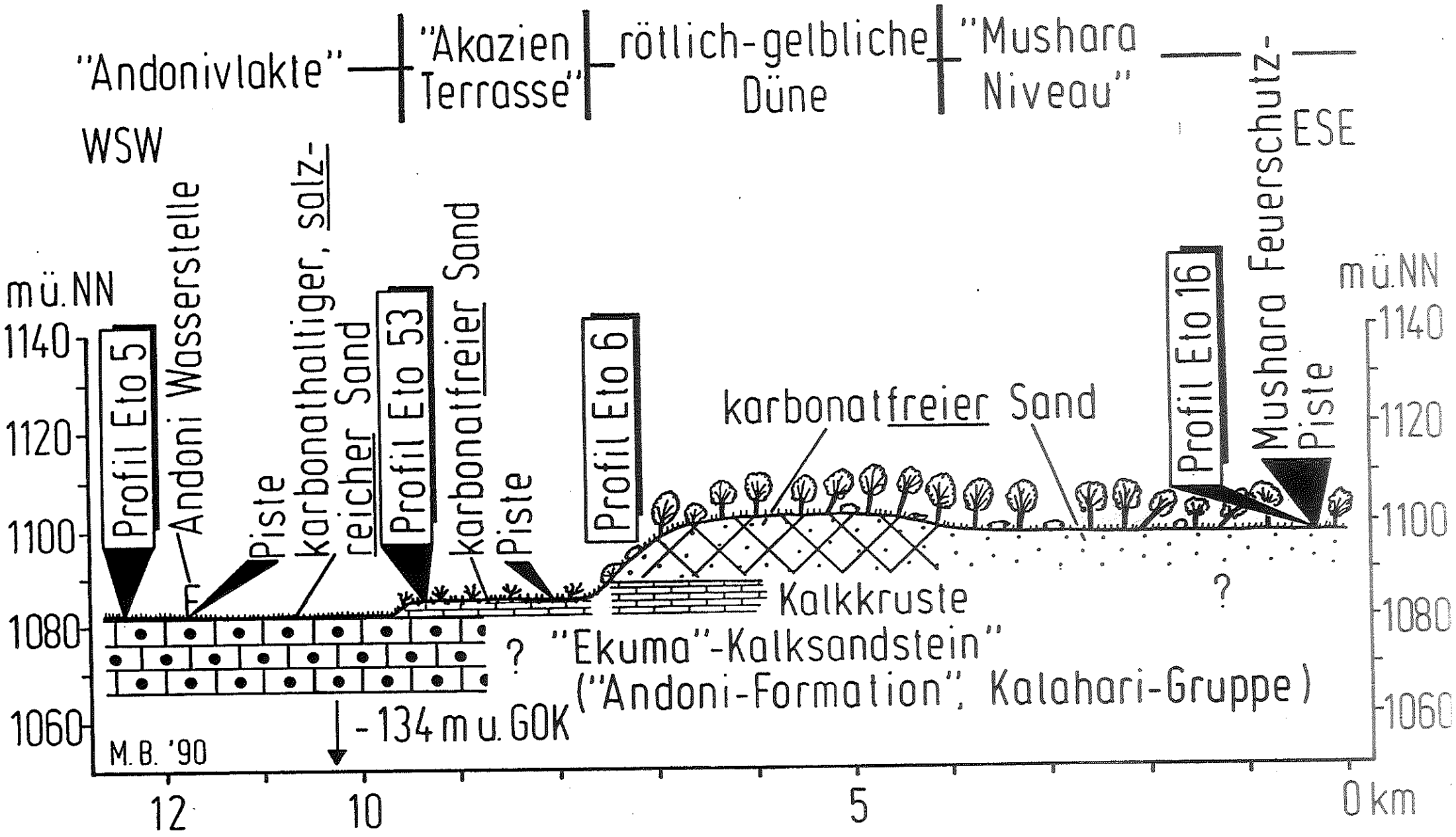


Fig. 5 Geländeprofil "Andonivlakte - Mushara Niveau" ("NE Sandveld"; zur Lage, vgl. Abb. 5)

Fig. 6

Analytical Standard Values, Profile Eto 43

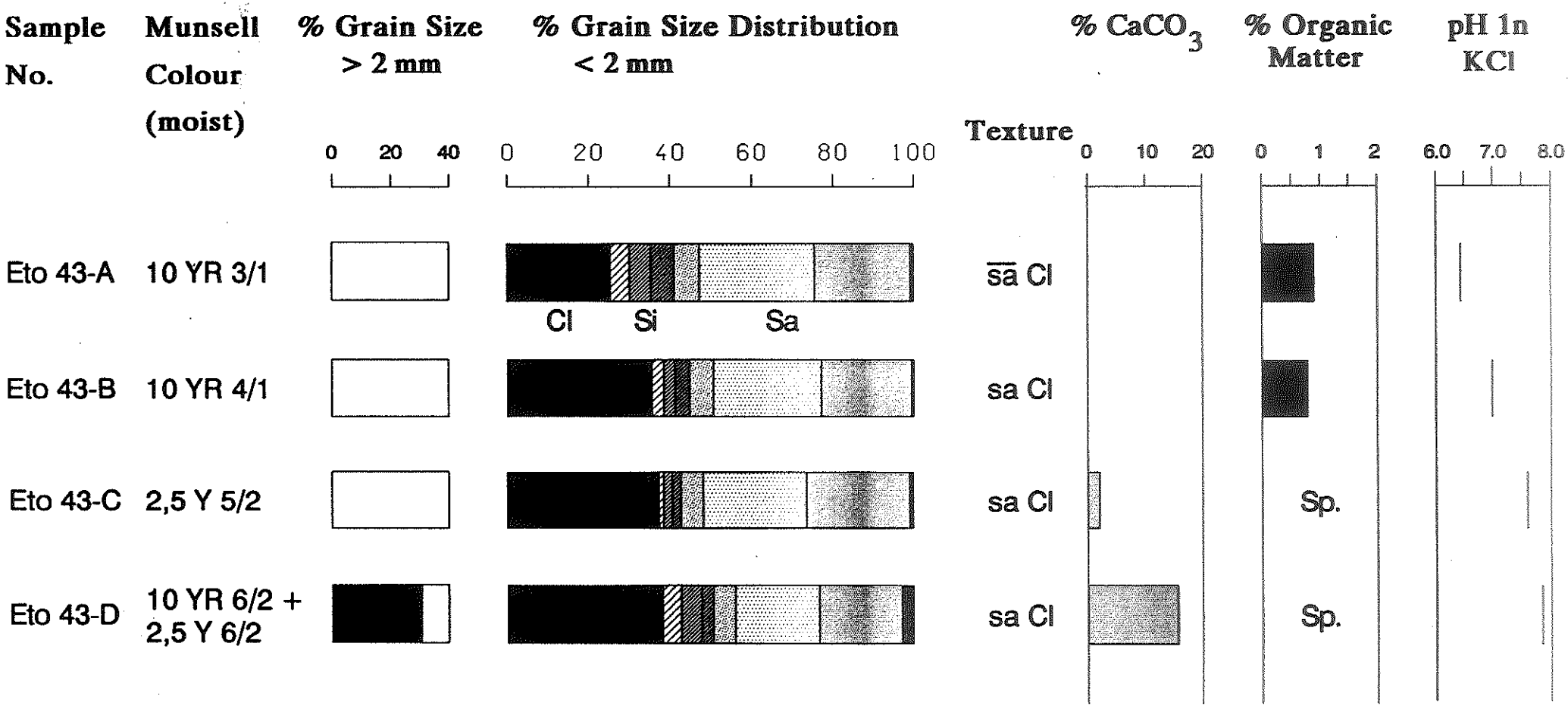
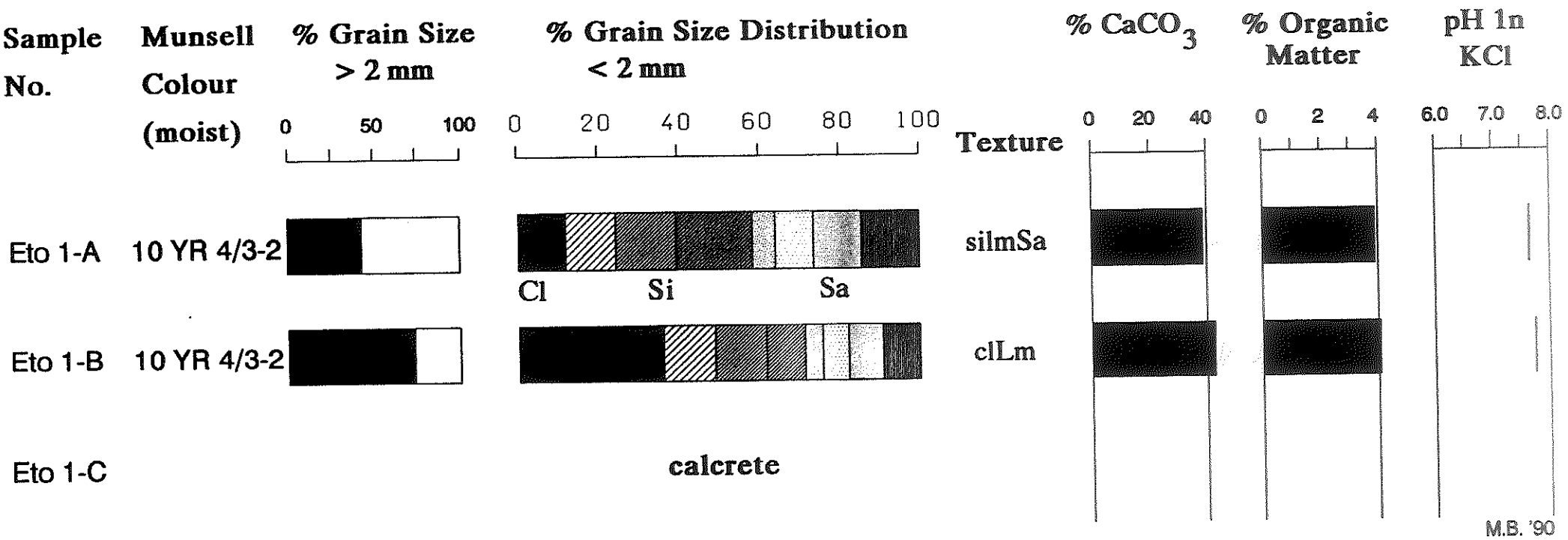


Fig. 7

Analytical Standard Values, Profile Eto 1



LEGEND: % Grain Size Distribution
< 2 mm

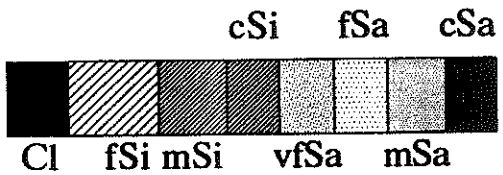


Fig. 8

Analytical Standard Values, Profile Eto 7

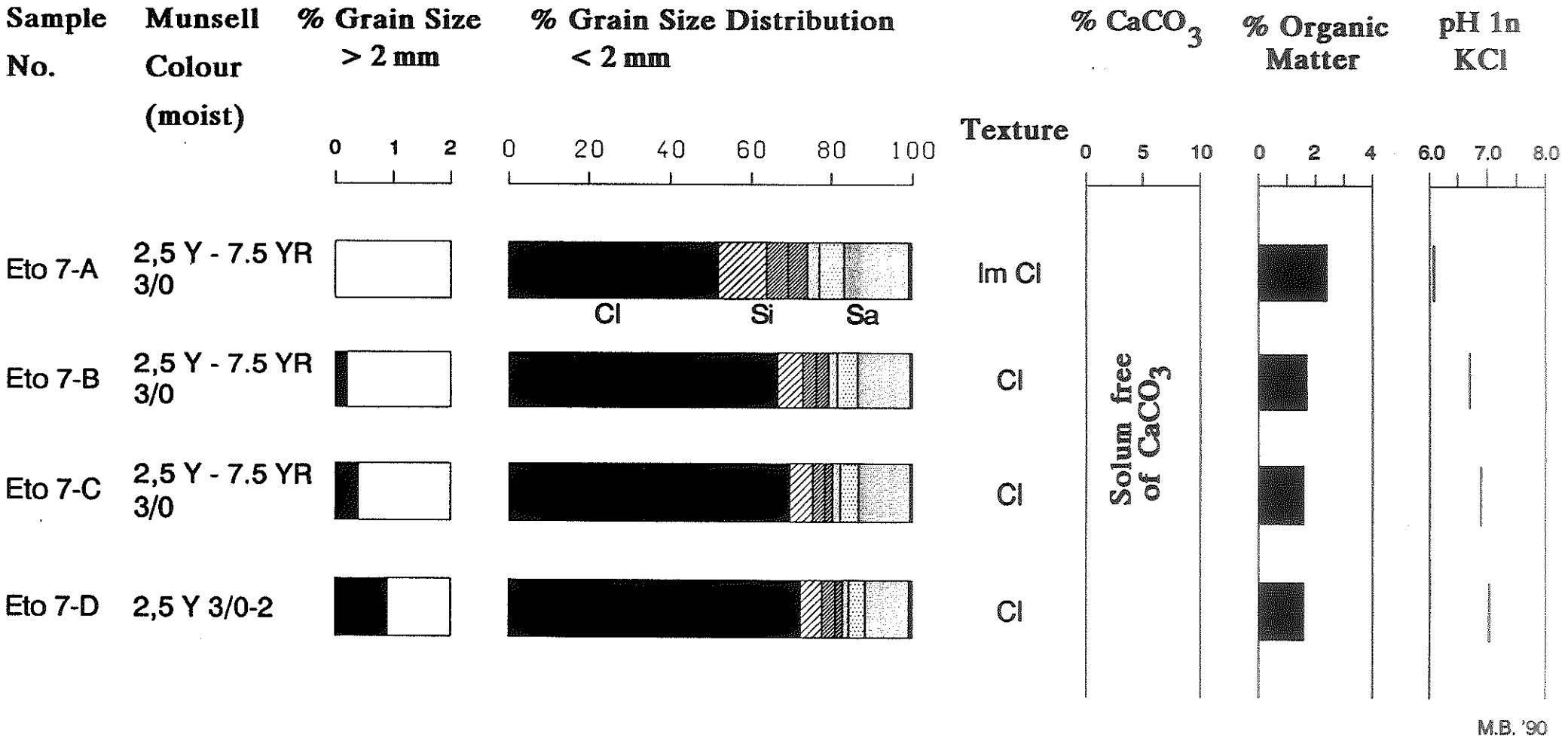


Fig. 9

Analytical Standard Values, Profile Eto 10

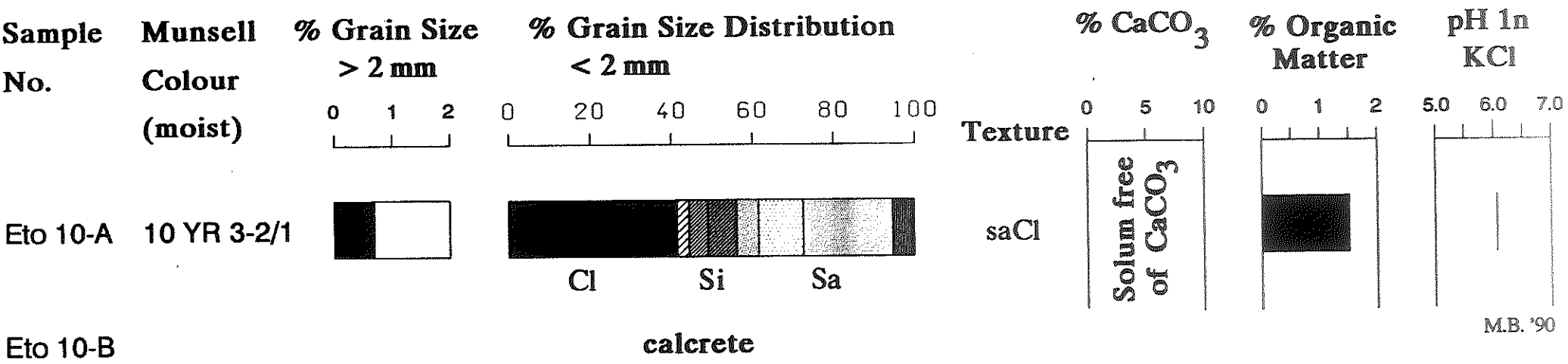
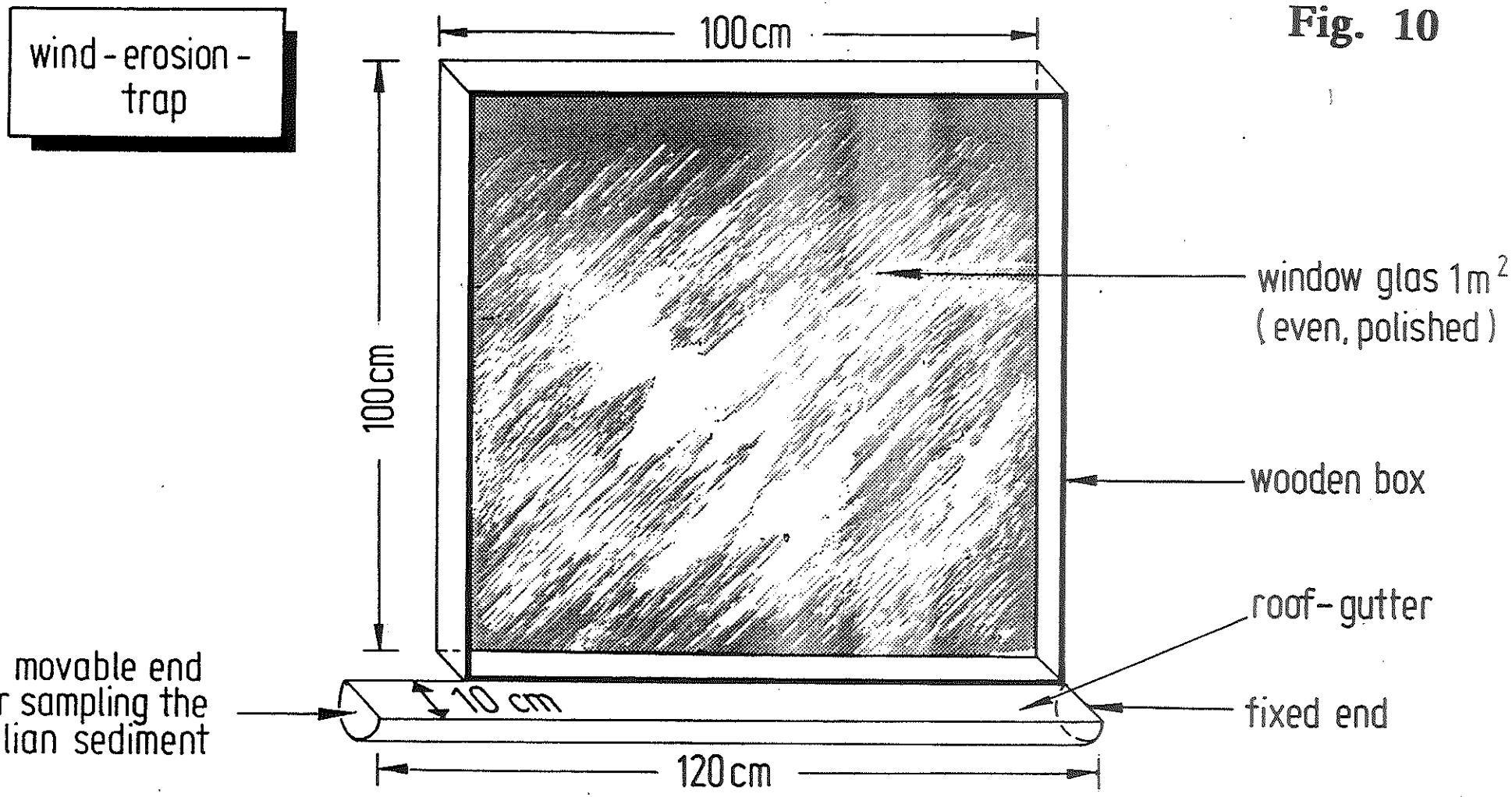
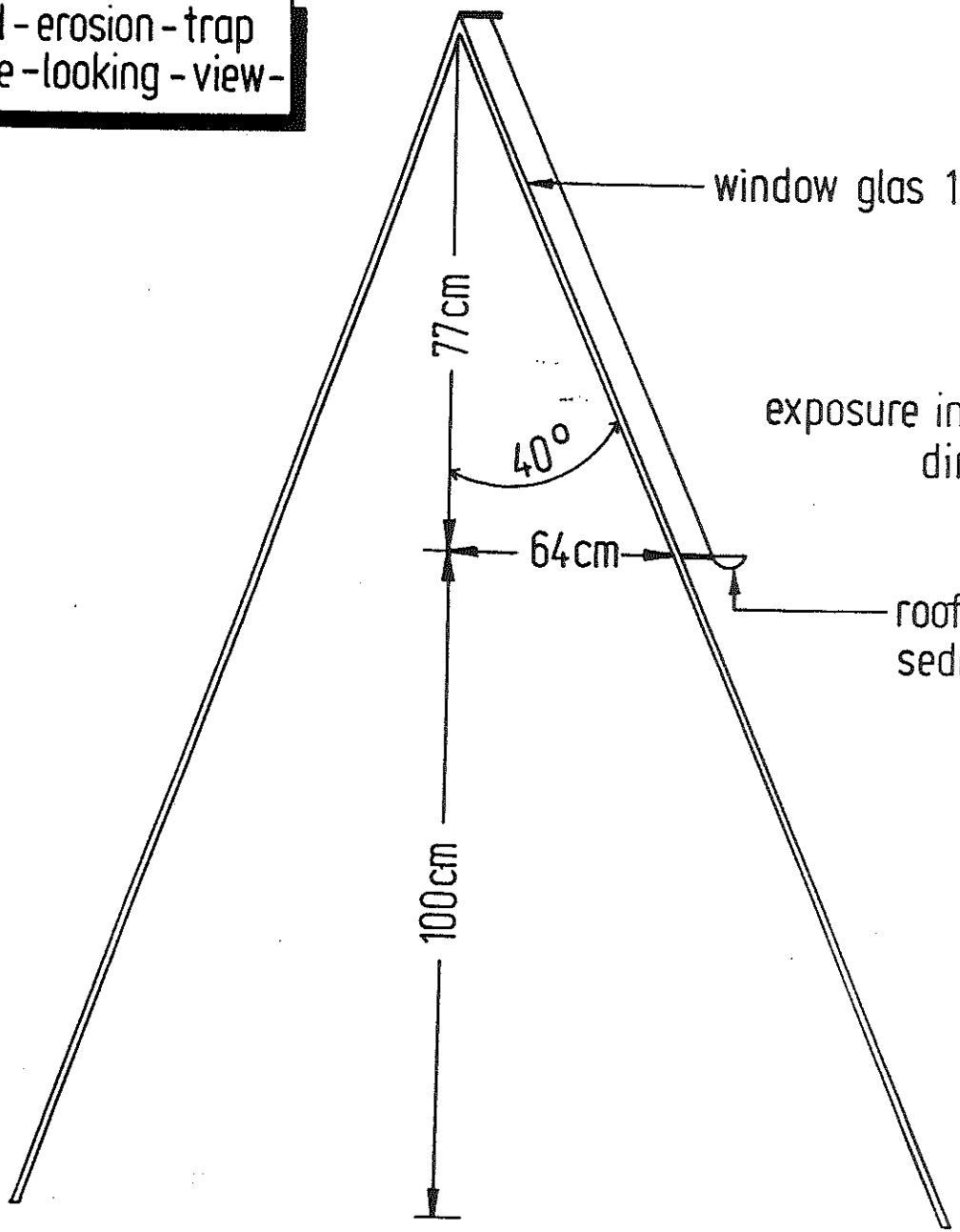
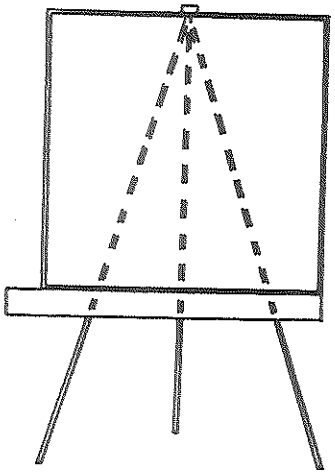


Fig. 10

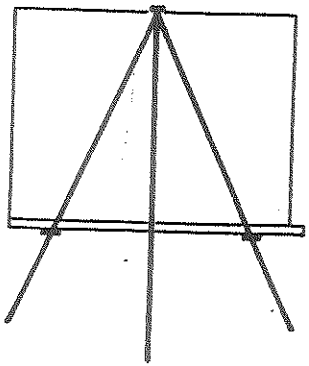

wind - erosion - trap
100 cm
100 cm
window glas 1 m²
(even, polished)
wooden box
roof - gutter
movable end
for sampling the
eolian sediment
10 cm
fixed end
120 cm

wind - erosion - trap
- side - looking - view -





front - looking view



back - looking view

Fig. 11

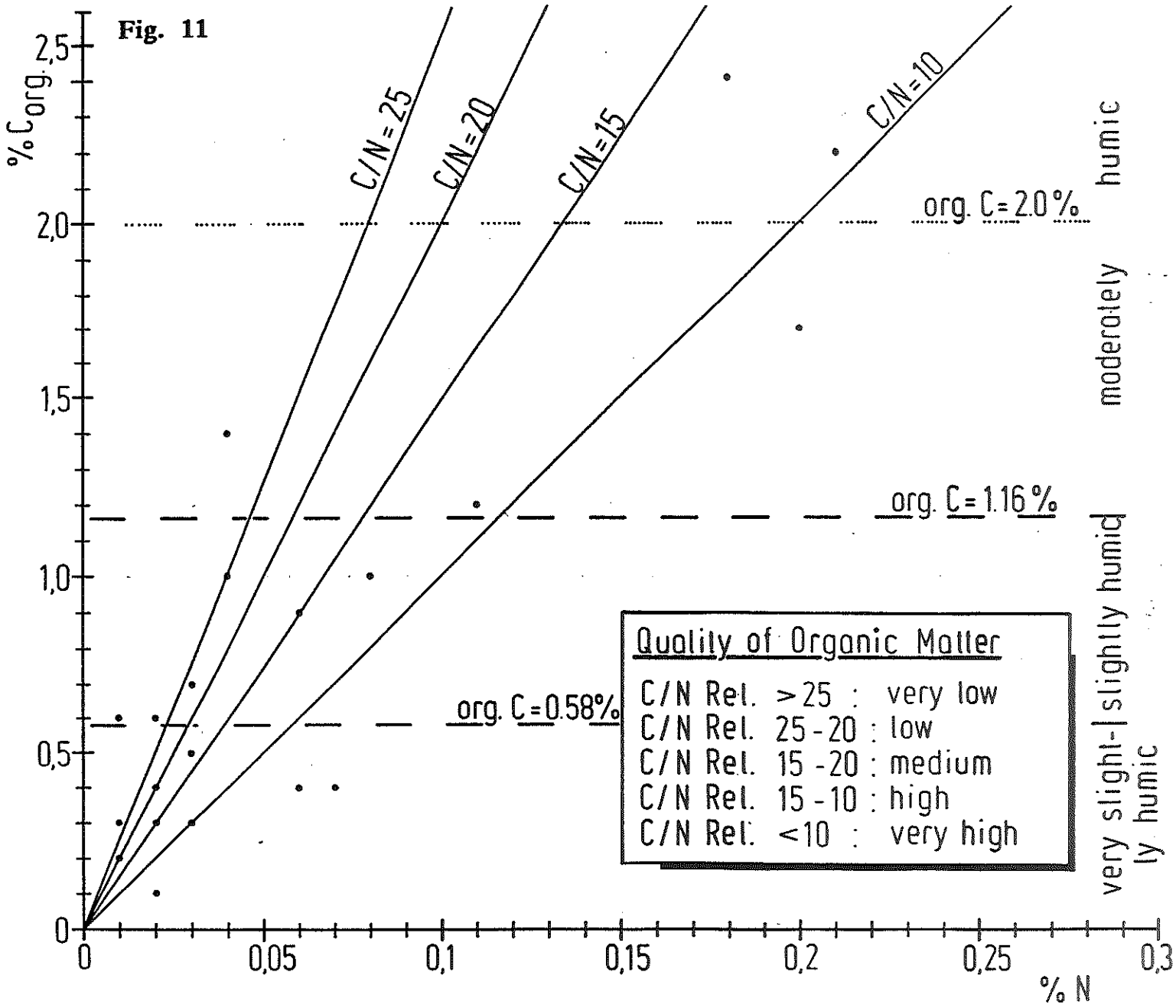

% C org.
2,5
2,0
1,5
1,0
0,5
0
C/N = 25
C/N = 20
C/N = 15
C/N = 10
org. C = 2.0 %
org. C = 1.16 %
org. C = 0.58%
humic
moderately
slightly humic
very slightly humic
Quality of Organic Matter
C/N Rel. > 25 : very low
C/N Rel. 25 - 20 : low
C/N Rel. 15 - 20 : medium
C/N Rel. 15 - 10 : high
C/N Rel. < 10 : very high
0
0,05
0,1
0,15
0,2
0,25
0,3
% N

Fig. 12

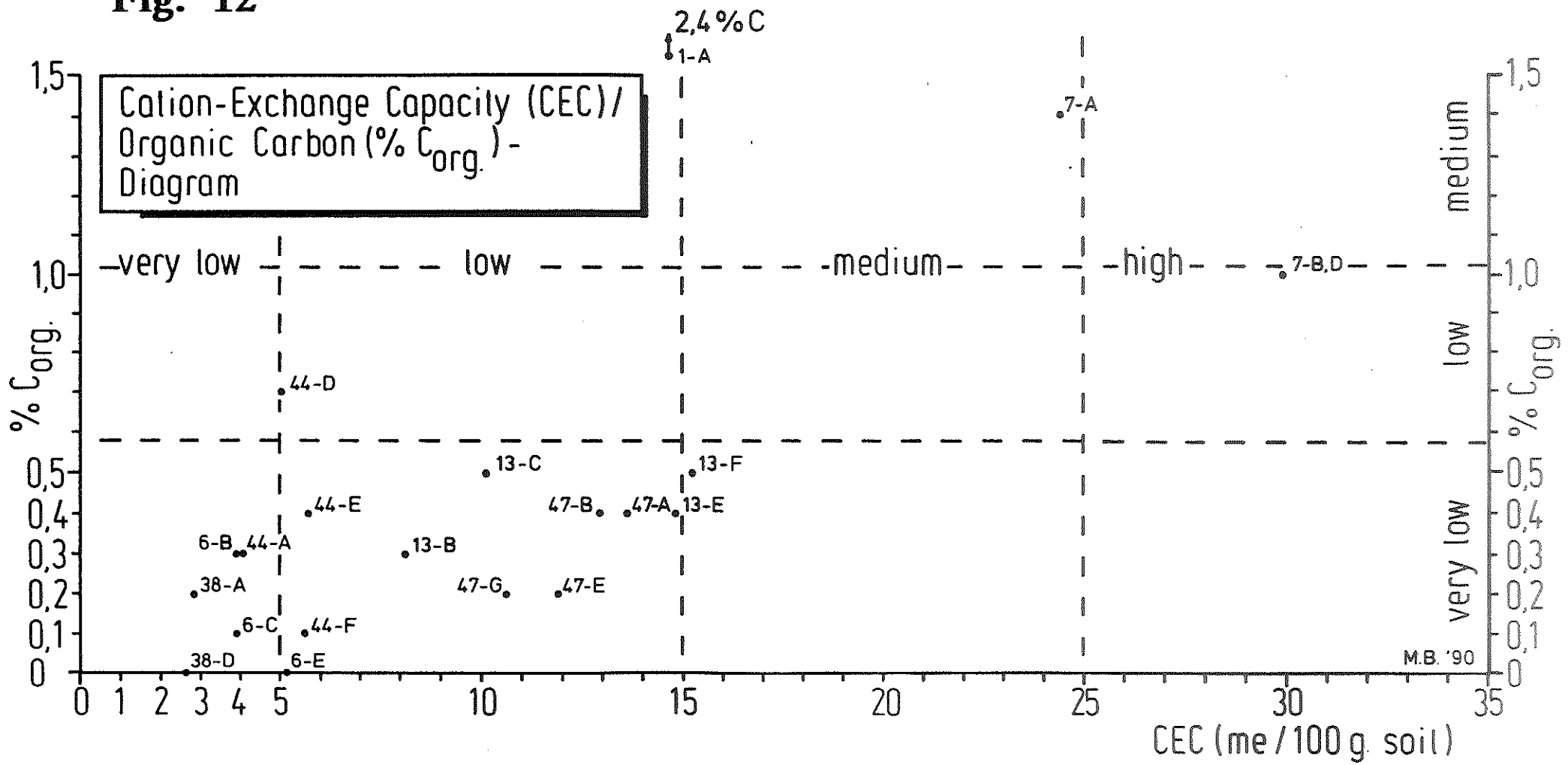

Cation-Exchange Capacity (CEC)/ Organic Carbon (% $C_{org.}$) - Diagram
2,4 % C
1-A
7-A
7-B,D
very low
low
medium
high
44-D
13-C
13-F
44-E
47-B
47-A
13-E
6-B
44-A
13-B
38-A
47-G
47-E
6-C
44-F
38-D
6-E
% $C_{org.}$
CEC (me / 100 g soil)
M.B. '90

Fig. 13

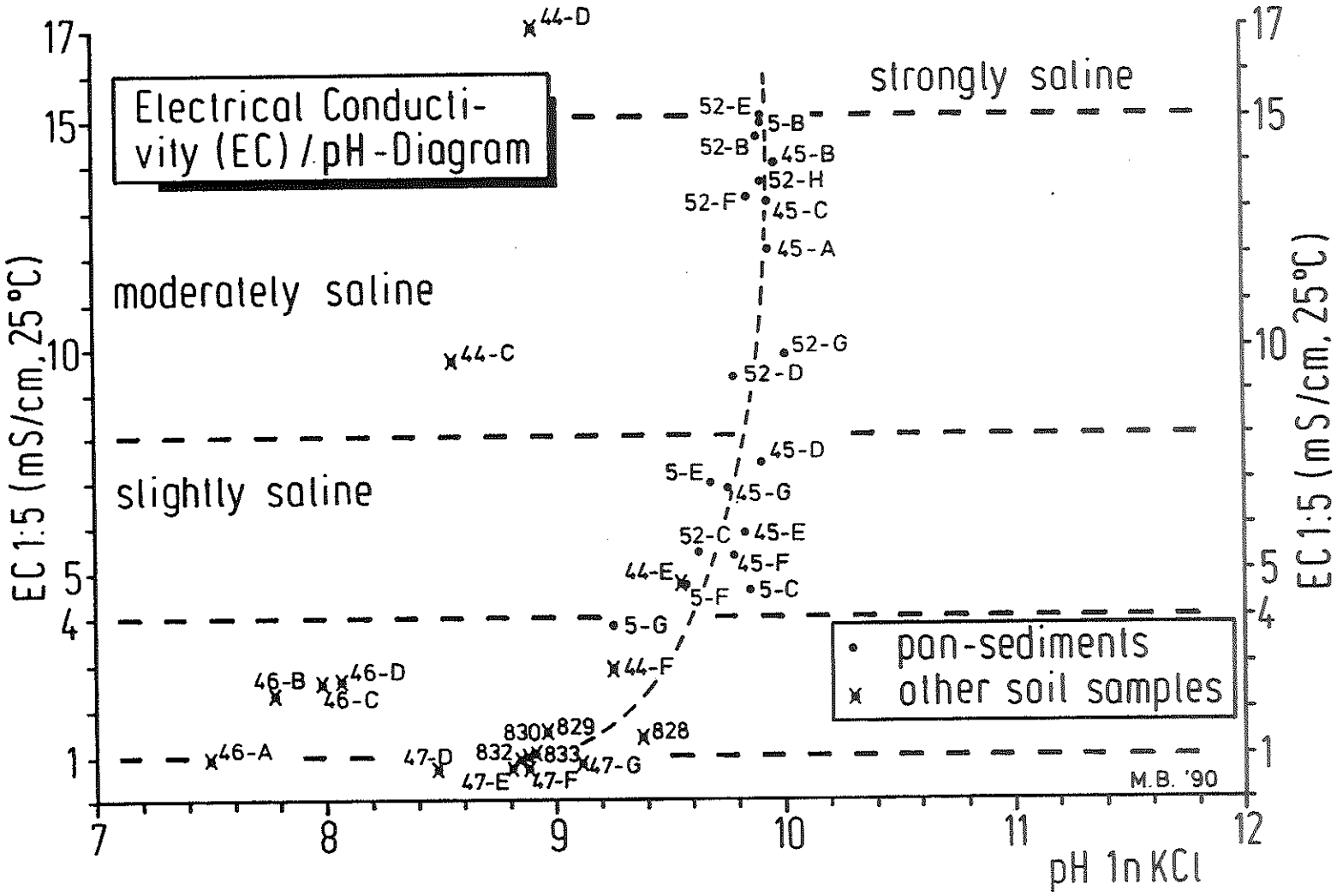
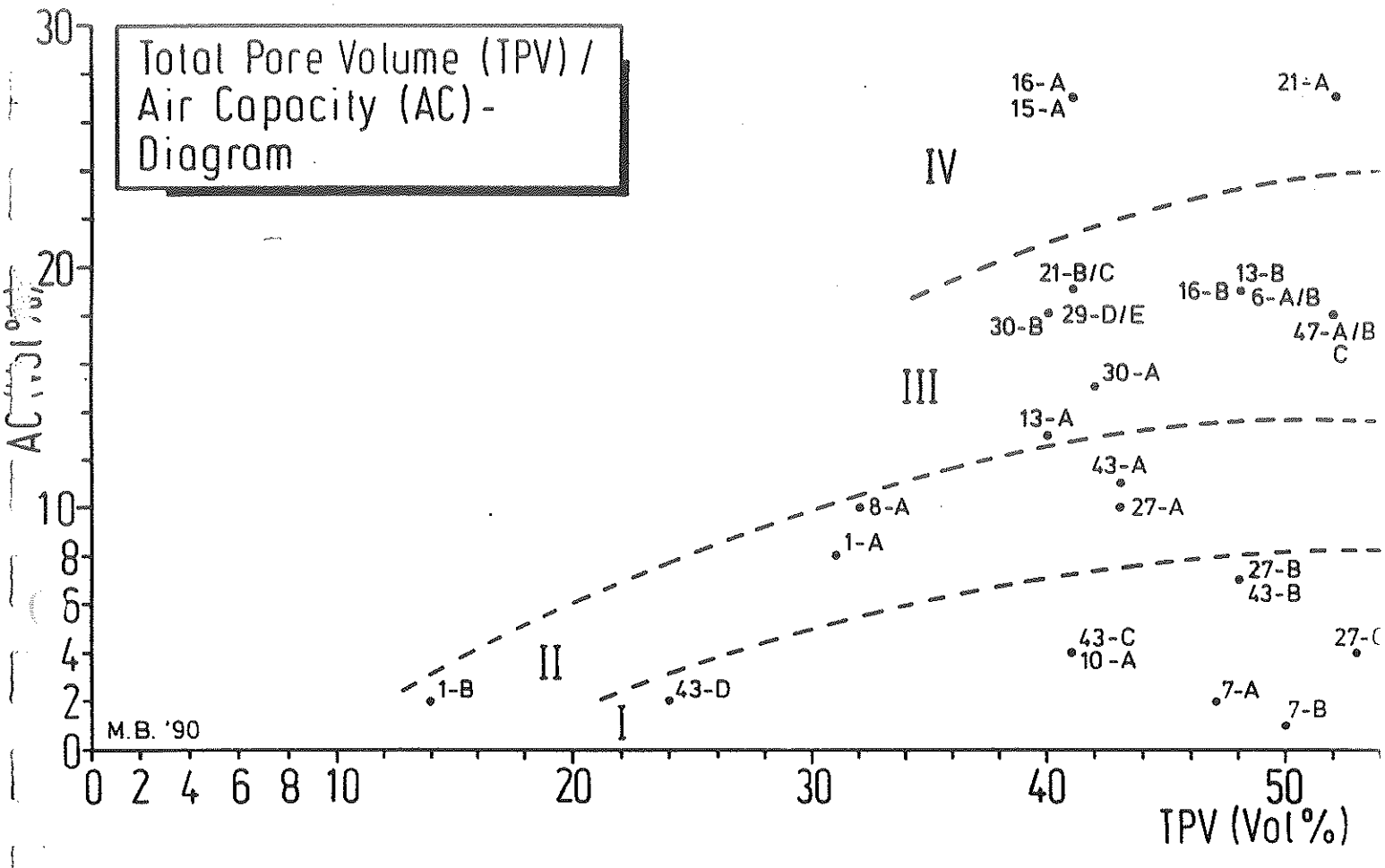
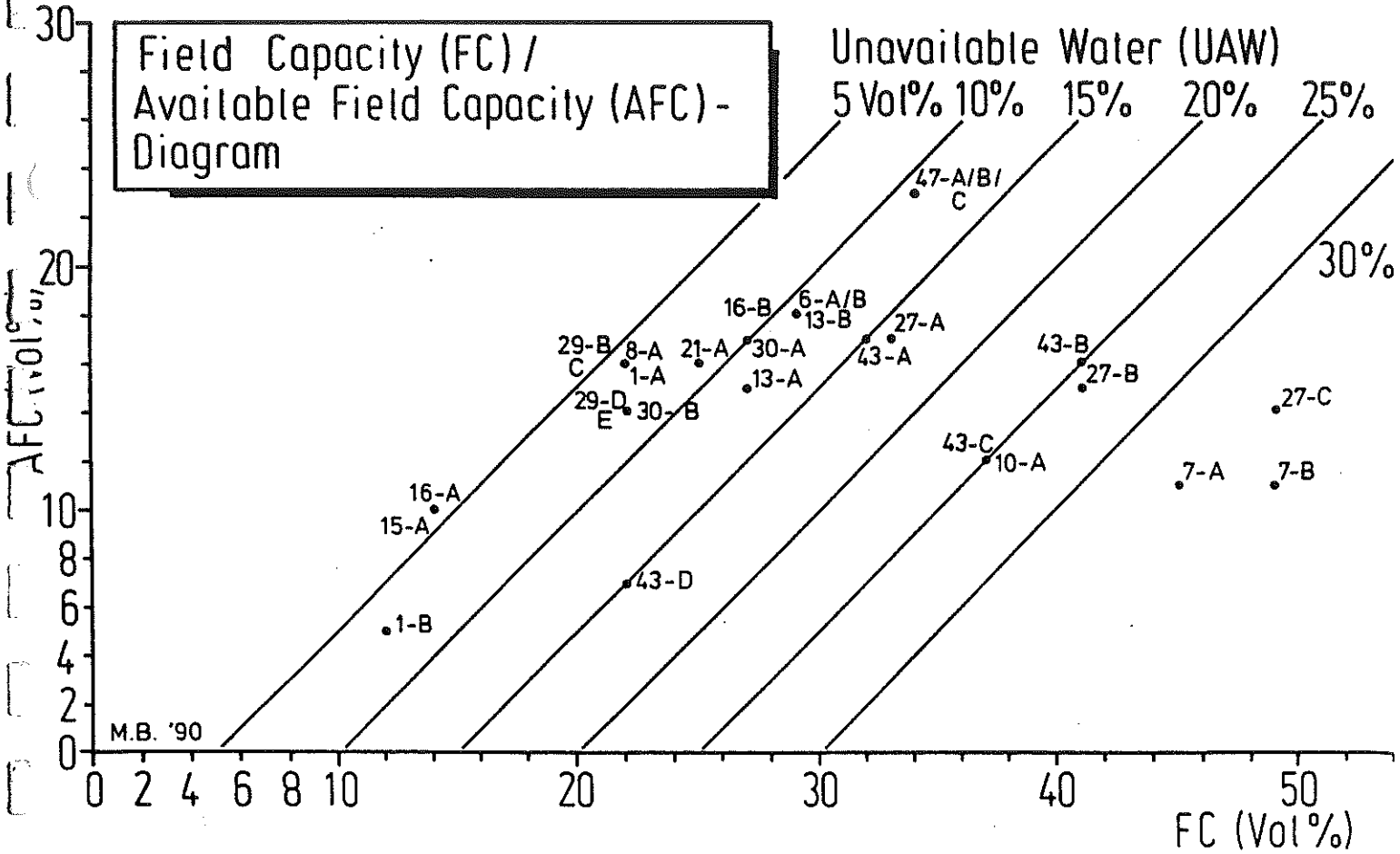
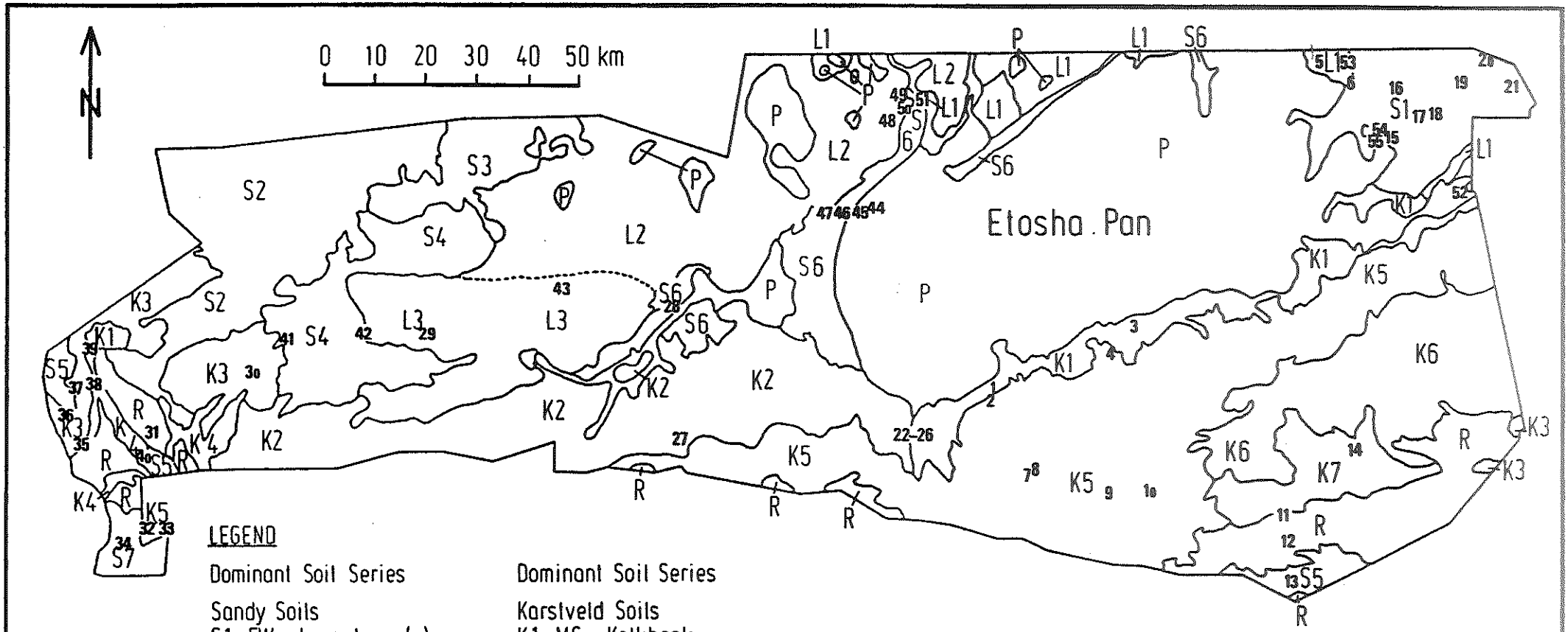

Electrical Conductivity (EC) / pH-Diagram
strongly saline
moderately saline
slightly saline
pan-sediments
other soil samples
EC 1:5 (mS/cm, 25°C)
pH 1n KCl
M.B. '90
17
15
10
5
4
1
7
8
9
10
11
12
44-D
52-E
5-B
52-B
45-B
52-H
52-F
45-C
45-A
44-C
52-G
52-D
45-D
5-E
45-G
52-C
45-E
45-F
44-E
5-F
5-C
5-G
44-F
46-B
46-D
46-C
830
829
828
832
833
47-G
46-A
47-D
47-E
47-F

Fig. 14


Total Pore Volume (TPV) / Air Capacity (AC) - Diagram
AC (Vol%)
TPV (Vol%)
I
II
III
IV
16-A
15-A
21-A
21-B/C
13-B
16-B
6-A/B
30-B
29-D/E
47-A/B C
30-A
13-A
43-A
8-A
27-A
1-A
27-B
43-B
43-C
10-A
27-C
1-B
43-D
7-A
7-B
M.B. '90


Field Capacity (FC) / Available Field Capacity (AFC) - Diagram
Unavailable Water (UAW)
5 Vol%
10%
15%
20%
25%
30%
AFC (Vol%)
FC (Vol%)
47-A/B/C
16-B
6-A/B
13-B
27-A
29-B C
8-A
21-A
30-A
43-A
1-A
13-A
29-D E
30-B
43-B
27-B
27-C
43-C
10-A
16-A
15-A
7-A
7-B
43-D
1-B
M.B. '90

Map 1 SOIL MAP OF THE ETOSHA NATIONAL PARK (le ROUX et al. 1988) WITH NEW SOIL PROFILE DESCRIPTIONS (BUCH field campaign 1989)



LEGEND

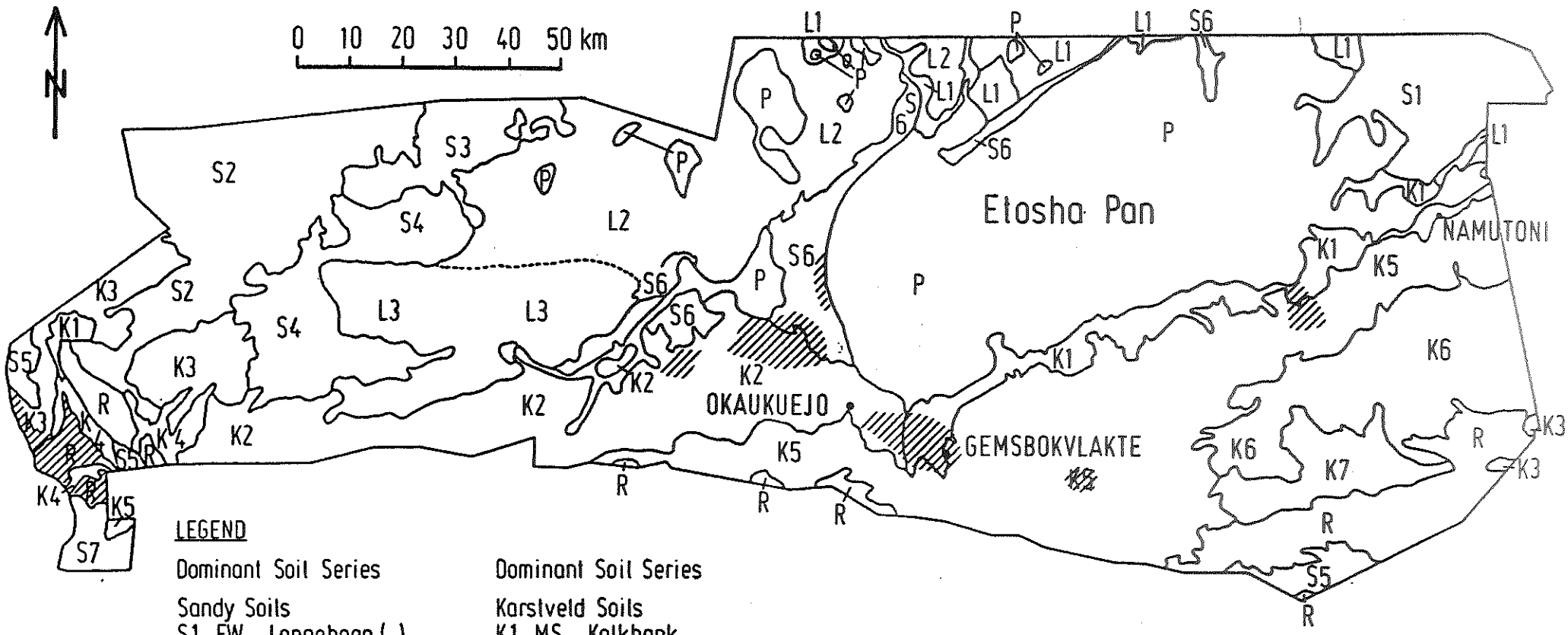
Dominant Soil Series			Dominant Soil Series		
Sandy Soils			Karstveld Soils		
S1	FW	Langebaan (-)	K1	MS	Kalkbank
S2	HU	Roodepoort	K2	GS	Lekfontein
S3	CV	Sunbury	K3	MS	Kalkbank/Lithosol
S4	CV	Sunbury	K4	CV	Dudfield
S5	HU	Zwartfontein	K5		Lithosol
S6	FW	Langebaan (-)	K6	AR	Arcadia/Lithosol
S7	HU	Zwartfontein	K7	AR	Arcadia
Deep Soils of Ovambo Plains			Miscellaneous Land Classes		
L1	ES	Heights	R		Dolomite, Marble, Calcrete & Rhyolitic Rock
L2	FW	Langebaan (+)	P		Saline Pan
L3	VA	Valsriver			

1 soil profile descriptions, BUCH field campaign 1989

le Roux et al. 1988

SOIL EROSION IN THE ETOSHA NATIONAL PARK (basis: Soil Map of the ENP; le ROUX et al. 1988)

Map 2

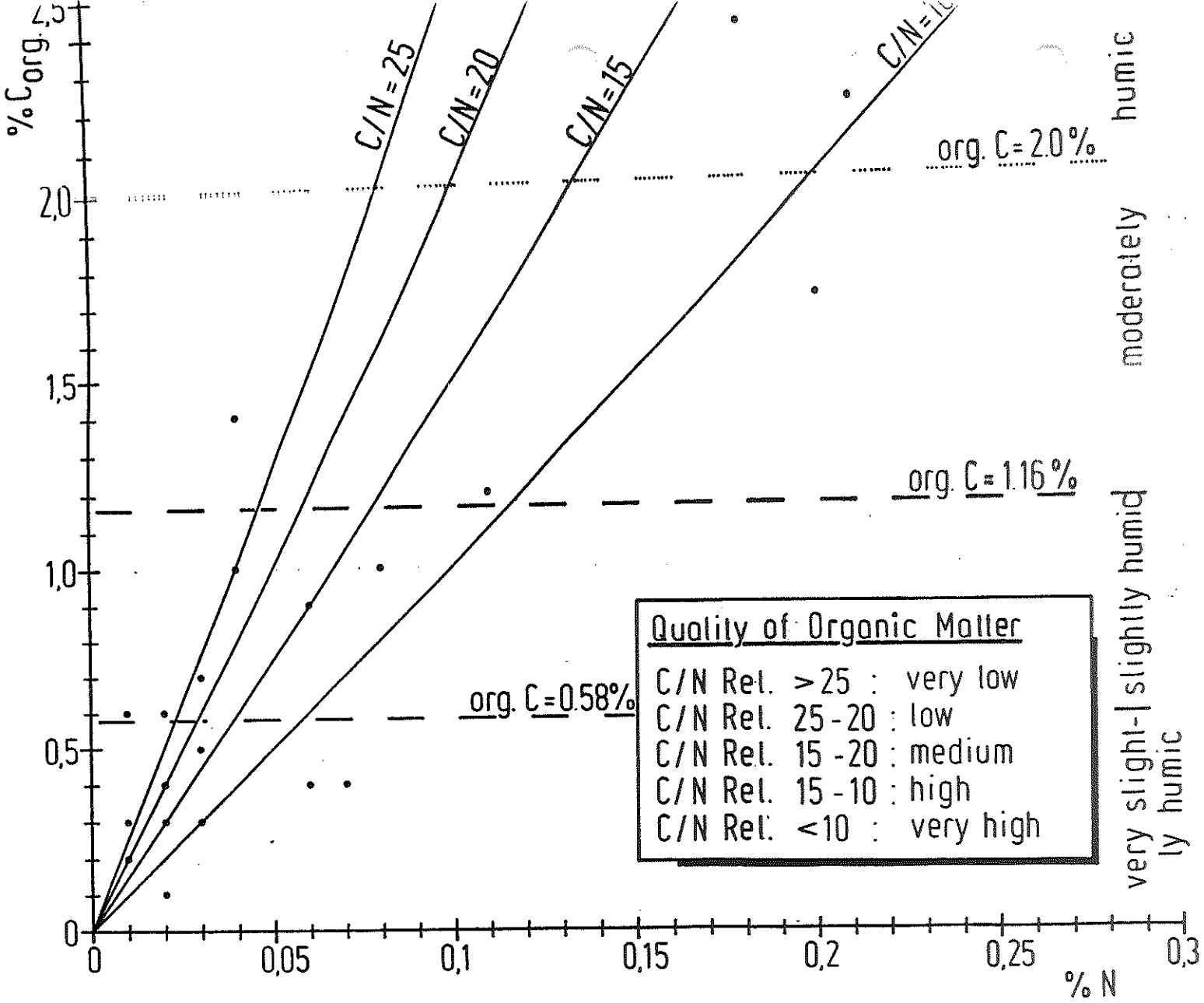


LEGEND

areas affected by severe soil erosion

Dominant Soil Series			Dominant Soil Series		
Sandy Soils			**Karstveld Soils**		
S1	FW	Langebaan (-)	K1	MS	Kalkbank
S2	HU	Roodepoort	K2	GS	Lekfontein
S3	CV	Sunbury	K3	MS	Kalkbank/Lithosol
S4	CV	Sunbury	K4	CV	Dudfield
S5	HU	Zwartfontein	K5		Lithosol
S6	FW	Langebaan (-)	K6	AR	Arcadia/Lithosol
S7	HU	Zwartfontein	K7	AR	Arcadia
Deep Soils of Ovambo Plains			**Miscellaneous Land Classes**		
L1	ES	Heights	R		Dolomite, Marble, Calcrete & Rhyolitic Rock
L2	FW	Langebaan (+)	P		Saline Pan
L3	VA	Valsriver			

M.W. Buch '90


% C org.
2,5
2,0
1,5
1,0
0,5
0
0
0,05
0,1
0,15
0,2
0,25
0,3
% N
C/N = 25
C/N = 20
C/N = 15
org. C = 2.0 %
org. C = 1.16 %
org. C = 0.58 %
humic
moderately
slightly humid
very slight-
ly humic
Quality of Organic Matter
C/N Rel. > 25 : very low
C/N Rel. 25 - 20 : low
C/N Rel. 15 - 20 : medium
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C/N Rel. < 10 : very high