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WAGENINGEN

ENKELE GRONDEN VAN NOORDELIJK BOTSWANA

Onderzoek in het kader van een globale verkenning  
van de droogtegevoeligheid

(A DROUGHT SUSCEPTIBILITY PILOT SURVEY IN NORTHERN BOTSWANA)



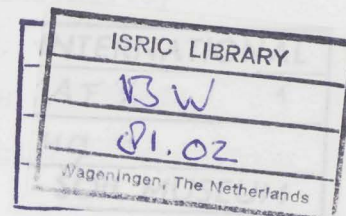
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Onderzoek in het kader van een globale  
verkenning van de droogtegevoeligheid

(A DROUGHT SUSCEPTIBILITY PILOT SURVEY IN NORTHERN BOTSWANA)

A.F. van Holst

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Wageningen, december 1981.



## Voorwoord

Op verzoek van het International Institute for Aerial Survey and Earth Sciences (ITC) te Enschede heeft Ir. A.F. van Holst als lid van een interdisciplinair team in juli 1978 een bodemkundige bijdrage geleverd gedurende een geomorfologische terreinverkenning van Noordelijk Botswana.

Het onderzoek is verricht in het kader van een samenwerkingsproject tussen de Universiteit van Botswana (UCB) en het ITC. De uitvoering van het project is mogelijk gemaakt door een financiële bijdrage van het Netherlands Universities Foundation For International Cooperation (NUFFIC).

Het doel van het project was tweeledig: a. het in het veld toetsen van een luchtfoto-interpretatiekaart ter compilatie van een definitieve geomorfologische kaart; b. het verzamelen van gegevens omtrent klimaat, bodem, hydrologie, bodemgebruik en vegetatie waaruit in combinatie met de geomorfologie een droogtegevoeligheidsclassificatie zou kunnen worden opgemaakt.

Het voorliggende deelrapport "The Soils" omvat naast de voorlopige legenda en de beschrijving van de kaarteenheden profielbeschrijvingen van 14 karakteristieke bodemprofielen. Ter complettering zijn in dit rapport fotokopiën opgenomen van de titelpagina, inhoudsopgave, enz. van het definitieve rapport, ten einde daarmee de samenhang tussen deelrapport en eindrapport duidelijk vast te leggen.

De Directeur,

Ir. R.P.H.P. van der Schans.

# A DROUGHT SUSCEPTIBILITY PILOT SURVEY IN NORTHERN BOTSWANA

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H.J. Cooke and

sponsored by the Netherlands University Foundation for International Co-operation (NUFFIC)

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ENSCHDEDE, THE NETHERLANDS

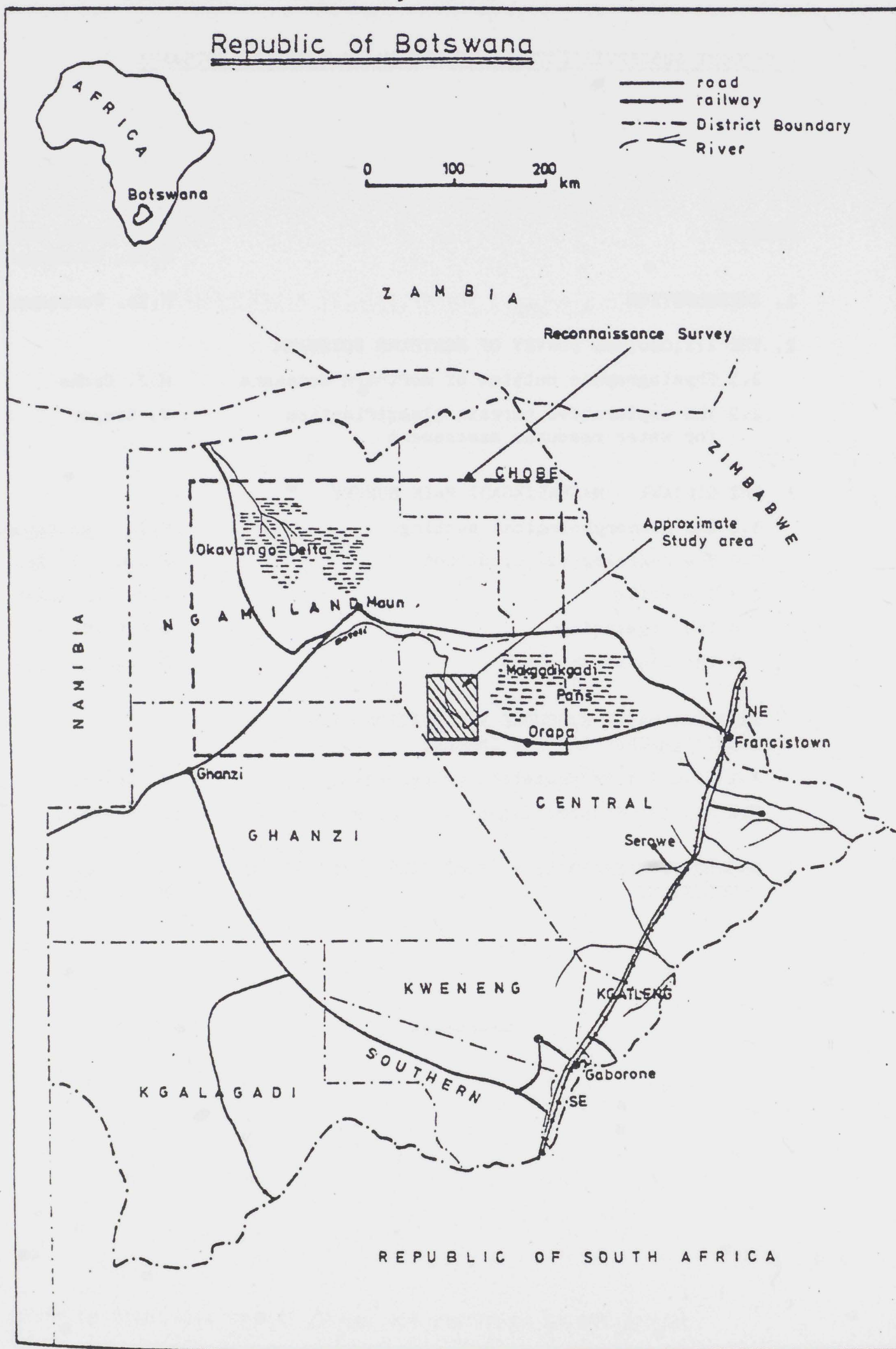


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## P R E F A C E

A drought susceptibility pilot survey was carried out in northern Botswana by the Department of Geography, University College of Botswana, (UCB) and the Department of Geomorphology of the International Institute for Aerial Survey and Earth Sciences (ITC), Enschede, the Netherlands, in July and August of 1978, in the framework of a project of cooperation between UCB and ITC sponsored by the Netherlands Universities Foundation For International Cooperation (NUFFIC).

The philosophy of the project was that when the rains fail, one area will be more severely affected by drought than another and that a terrain classification geared to this matter should be of lasting value and could be used time and time again when drought occurs.

Since very little work has been done in this field to date, the criteria for the classification still had to be properly defined and therefore the term 'pilot survey' has been applied. Although it cannot be claimed that the concept of drought susceptibility survey has now taken final shape, it is hoped that the methods and results of the survey, embodied in this report, will prove to be a useful approach also for other semi-arid areas with similar problems.

Thanks is expressed to Prof. Sethidisho, Rector of UCB and to Prof. Ir. A.J. van der Weele, then Rector of ITC for their support and to NUFFIC for financing the project.

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The Soils

by A.F.van Holst



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## T H E S O I L S

### 1. INTRODUCTION

The soil information presented here mainly originates from the Rakops - Mopipi Area. According to the reconnaissance geomorphological terrain classification as given by Breyer (1979) the various soil units are described. Out of 25 geomorphological units only 14 mapping units are compiled. This partial coverage is due to lack of time and inaccessibility of the terrain during the fieldwork.

By making use of the legend of the geomorphological terrain classification map a limited number of units have been translated into soil mapping units. Based on this relation a tentatively legend for a preliminary soil map is given (chapter 2). However, a soil map is not drafted. In the legend the soils are primarily grouped according to the kind of parent material, namely fluvial, aeolian or lacustrine deposits. The subdivision is based on differences resulting from soil forming processes. The soils are described briefly in the legend and are classified according to the FAO - Unesco soil map of the world system.

A description of a representative profile of each soil mapping unit can be found in Appendix I.

Appendix III comprises a location map of the observation points.

A review of the soil and land qualities is presented in Table 1.

With some explanatory notes on Table 1 the report will be concluded.

It should be kept in mind that the classification of the soils and the compilation of the legend is not more than an approximation. Because of the very short period that could be spent on fieldwork proper, only a limited amount of observations could be carried out.

Moreover, a preparation of the fieldwork in terms of

- the aim of the soil survey,
- an aerial photo interpretation for the soil survey, and
- the study of existing literature

was performed insufficiently, due to lack of time.



## 2. PRELIMINARY LEGEND OF THE SOILS

### Soils developed in alluvial deposits

AL1 Geomorphological\_unit:Active floodplain (notation Breyer: F 1)

Soils: poorly drained,deep and moderately deep,grayish brown,friable sandy loam to silt loam, with a 20 to 50 cm thick topsoil of black,friable silt loam;in places non calcareous.

Soil\_classification: (mollic GLEYSOLS)

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AL2 Geomorphological\_unit:Semi-active floodplain (notation Breyer: F 2)

Soils: moderately well to well drained,deep,grayish brown to dark brown, friable sandy loam, with a 35 to 60 cm thick topsoil of very dark grayish brown,loose,calcareous sandy loam.

Soil\_classification: (calcaric PHAEOZEMS)

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AL3 Geomorphological\_unit:Inactive floodplain (notation Breyer: F 3).

Soils: well drained,deep,grayish brown,calcareous,soft to firm silt loam with a 60 to 110 cm thick topsoil of black,slightly hard to hard siltloam; locally slightly calcareous.

Soil\_classification: (calcic CHERNOZEMS)

---

AL4 Geomorphological\_unit:Inactive floodplain;large fossil valleys (notation Breyer:F 3a)

Soils: moderately well to well drained,deep,dark grayish brown to brown, non-calcareous,loose,fine to coarse sand with a 50 to 75 cm thick topsoil of dark grayish <sup>brown</sup> to black,non-to slightly calcareous sandy loam to loam.

Soil\_classification: (haplic PHAEOZEMS)

---

### Soils developed in aeolean deposits

AE1 Geomorphological\_unit:Fossil floodplain modified by aeolean processes (notation Bryer: F 4).

Soils: well drained,deep,light brownish gray,calcareous,saline,very friable sandy loam to loam with a 15 to 40 cm thick topsoil of dark grayish brown,calcareous,loose sandy loam.

Soil\_classification: (albic ARENOSOLS,saline phase)



AE2 Geomorphological\_unit:Lineated sandplain associated to 945 m Lake Level  
(notation Breyer: L5).  
Soils: excessivily drained,very deep,dark grayish brown,calcareous,soft  
loamy sand with a 10 cm thick topsoil of dark brown,non calcareous,  
loose sand.

Soil\_classification: (cambic ARENOSOLS)

-----

AE3 Geomorphological\_unit:Dune complex in old lake bottom (notation Breyer: E 1).  
Soils: well drained,very deep,grayish brown,calcareous,soft loamy sand with  
a 15 cm thick topsoil of dark grayish brown,calcareous,loose loamy  
sand.

Soil\_classification: (cambic ARENOSOLS)

-----

Soils developed in lacustrine deposits

LA1 Geomorphological\_unit:Prominent strandline,945 m lake level (notation Breyer:  
L 1).  
Soils: moderately well drained,moderately deep,dark grayish brown (matrix) and  
light gray (concretions),calcareous, soft to very hard sandy loam  
to loam with a 15 cm thick topsoil of dark brown,  
calcareous,loose loamy sand over calcrete.

Soil\_classification: ( cambic ARENOSOLS )

-----

LA2 Geomorphological\_unit;Less prominent strandline,920 m lake level (notation  
Breyer: L 2).  
Soils: well drained,deep,brown,calcareous,soft sandy loam to loam with a 10  
cm thick topsoil of dark brown,calcareous,loose loamy sand.

Soil\_classification: ( cambic ARENOSOLS )

-----

LA3 Geomorphological\_unit:Old Lake Bottom,shallowly dissected (notation Breyer: L6a  
Soils: moderately well to well drained,deep,brown,calcareous,saline,very  
firm sandy loam with a 15 cm thick topsoil of very dark grayish brown,  
calcareous,loose loamy sand.

Soil\_classification: (calcic CAMBISOLS,saline phase)

-----



LA4 Geomorphological\_unit: Old Lake Bottom, shallowly intensively dissected  
(notation Breyer: L6b).  
Soils: well drained, deep to very deep, brown to dark grayish brown, slightly  
calcareous, soft to friable silt loam with a 20 cm thick topsoil of  
black, slightly to non calcareous, loose to hard siltloam.

Soil\_classification: ( haplic CHERNOZEMS )

---

LA5 Geomorphological\_unit: Pans, structurally controled (notation Breyer:  
L7a and L7b).  
Soils: poorly drained, moderately deep to deep, light brownish gray to gray-  
ish brown, calcareous, saline and alkali, friable to firm siltloam  
with a 10 to 15 cm thick topsoil (with salterust) of very dark  
grayish brown, calcareous, saline and alkali, friable to firm loam to  
silt loam.

Soil\_classification: (gleyic SOLONCHAKS)

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LA6 Geomorphological\_unit: Pans, aeolean origin (notation Breyer: L8a and L8b).  
Soils: poorly to imperfectly drained, deep to very deep, light to dark  
grayish brown, calcareous, saline and alkali, friable to firm sandy  
to silt loam with a 5 to 20 cm thick topsoil (with salterust) of  
grayish brown to very dark grayish brown, calcareous, saline and  
alkali, friable to very firm silt loam.

Soil\_classification: (gleyic SOLONCHAKS)

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LA7 Geomorphological\_unit: Lacustrine-aeolean sands covering sandstone with  
intrusions (notation Breyer: C 1).  
Soils: 20 to 35 cm moderately well to well drained, very dark grayish  
brown, calcareous, loose loam with calcrete concretions over very  
hard calcrete.

Soil\_classification: (calcaric REGOSOLS)

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3. DESCRIPTION OF THE SOIL MAPPING UNITS





Fig. 1 Soils of mapping unit AL 1 have a black topsoil (left in the photo).  
To the right the outflow of the Boteti river.



Fig. 2 Molapo farming on the soils of mapping unit AL 3.



Soil mapping unit: AL 1

Representative profile no. 1

Geomorphological unit: Active floodplain (F 1)

Parent material: fluvial deposits of Boteti river (Fig.1)

Topography: flat to almost flat

Vegetation: dense reet along channel only, otherwise barren with halophytes  
but in places sparse grasses

Landuse: grazing, molapo farming (Fig.2)

Drainage conditions: poorly drained; periodically flooded; groundwater level  
near the surface

Soils: have a 20 to 50 cm thick, black topsoil of humic loam to silt loam.  
On the surface a thin saltcrust or saltcrystals are found. A transis-  
tional horizon to a depth of 75 or 85 cm consists of grayish brown,  
unripened silt loam with dark coloured stains of organic matter.  
The subsoil is pale brown silt loam, locally sandy loam, with firm  
elements.

Physical aspects: infiltration rate of the topsoil is slow to moderate;  
available water capacity is high ( $>15$  mm/dm).

Chemical aspects: the carbonate content varies from place to place:  
non calcareous to calcareous profiles. Soil reaction of the topsoil  
is moderately alkaline ( $\text{pH} > 8$ ), locally strongly alkaline ( $\text{pH} > 9$ ); in  
general the pH decreases with depth.

The topsoil is slightly affected by free salts (saline phase).

Soil mapping unit: AL 2

Representative profile no. 2

Geomorphological unit: Semi-active floodplain (F 2)

Parent material: fluvial deposits of Boteti river

Topography: flat

Vegetation: sparse to dense grass, locally barren

Landuse: grazing

Drainage conditions: moderately well to well drained; rarely flooded; the  
soils in the transistional zone to mapping unit AL 1 are poorly  
drained (seepage) with a rather shallow groundwater level at 80 cm

Soils: have a 10 to 15 cm thick light brownish gray topsoil of sandy loam.  
The surface is sealed with a thin layer of algae and organic matter.  
In places, especially near the present floodplain, a 15 cm thick,  
black, mucky topsoil is present, not seldom with salt efflorescence.



The subsoil consists of brown sandy loam with a considerable amount of hard calcrete concretions. With depth the profiles contain more sandy material.

Physical aspects: infiltration rate of the topsoil is moderate to slow; available water capacity varies from low (5-10) to high (>15 mm/dm). The sealing of the topsoil promotes runoff.

Chemical aspects: the soils are calcareous throughout. Soil reaction of the topsoil is mildly alkaline (pH=7.5) and decreases with depth. The subsoil is neutral (pH=7). The soils in the lower parts of this unit have groundwater influence. They have a slightly calcareous, slightly saline topsoil.

Soil mapping unit: AL 3 (related to AL 4)      Representative profile no. 3

Geomorphological unit: Inactive floodplain (F 3)

Parent material: fluvial deposits (basin) of Boteti river

Topography: flat

Vegetation: barren to sparse trees, shrubs and moderate dense grass

Landuse: molapo farming, grazing

Drainage conditions: well drained; periodically flooded; groundwater level more than 2 m below surface

Soils: the topsoil varies in thickness from 60 to 110 cm and consists of black, humic silt loam with a subangular blocky structure in the upper 40 cm. In places white lime mottles are present.

The subsoil is a grayish brown silt loam.

Throughout the profile hard fragments and some calcrete concretions occur. In places the upper part of the subsoil is moderately cementated.

Physical aspects: infiltration rate of the topsoil is slow to moderate; available water capacity is high (>15 mm/dm).

Chemical aspects: the calcareous soils have locally a non-calcareous toplayer of 20 cm.

Soil reaction is mildly to moderately alkaline (pH: 7-8). Free salts are absent.

Soil mapping unit: AL 4 (related to AL 3)      Representative profile no 4

Geomorphological unit: Semi-active floodplain; large fossil valleys (F 3a)

Parent material: fluvial deposits in old stream courses of Boteti river

Topography: flat with calcrete ridges at valley sides



Fig. 3 Gently undulating dunes of soil mapping unit AE 1, bordering a pan covered with a saltcrust (soil mapping unit LA 6).



Vegetation: predominantly grasses and herbs, some shrubs

Landuse: grazing and molapo farming

Drainage conditions: moderately well to well drained; periodically flooded; groundwater level about 2 m below surface, in places deeper

Soils: have a 50-75 cm thick (dark) grayish brown topsoil of loam to sandy loam. The subsoil, starting at 75 cm, has a light brownish gray colour and ranges in texture from medium fine sand to rather coarse sand.

Physical aspects: infiltration rate of the topsoil is moderate; available water capacity is low (5-10 mm/dm).

Chemical aspects: the soils don't have free carbonates. The soil reaction of the topsoil is neutral (pH=7) and remains constant with depth. In places, especially near the valley sides, acid profiles are found (pH=5). This is probably due to leaching by an excess of surface water.

Soil mapping unit: AE 1

Representative profile no. 5

Geomorphological unit: Fossil floodplain modified by aeolian processes (F 4)

Parent material: aeolian deposits over fluvial deposits of old floodplain

Topography: gently undulating dunes around aeolian pans; undulating lenticular dunes (Fig.3)

Vegetation: dense grasses

Landuse: extensive grazing

Drainage conditions: except for the bisecting profiles which are moderately well drained, the other soils are well drained; never flooded; groundwater level more than 2 m below surface. The sealed topsoil may contribute to runoff and severe gully erosion towards the bordering aeolian pan (Fig.4).

Soils: have a 15 to 40 cm thick topsoil of light brownish gray sandy loam. The surface is coated with a 3 mm thick seal of algae and organic matter. Underneath the topsoil a layer of brown sandy loam to loam is present, not seldom continuing till a depth of 120 cm. In places a buried profile at a depth of 60 to 70 cm is encountered. The topsoil of this old profile consists of a 25 cm thick, very dark gray silt loam overlying black to dark brown silt loam to loam with some calcrete concretions.

Physical aspects: infiltration rate of the topsoil is Slow to moderate available water capacity is low (5-10 mm/dm).

Chemical aspects: exclusive of the part of the buried profile, the



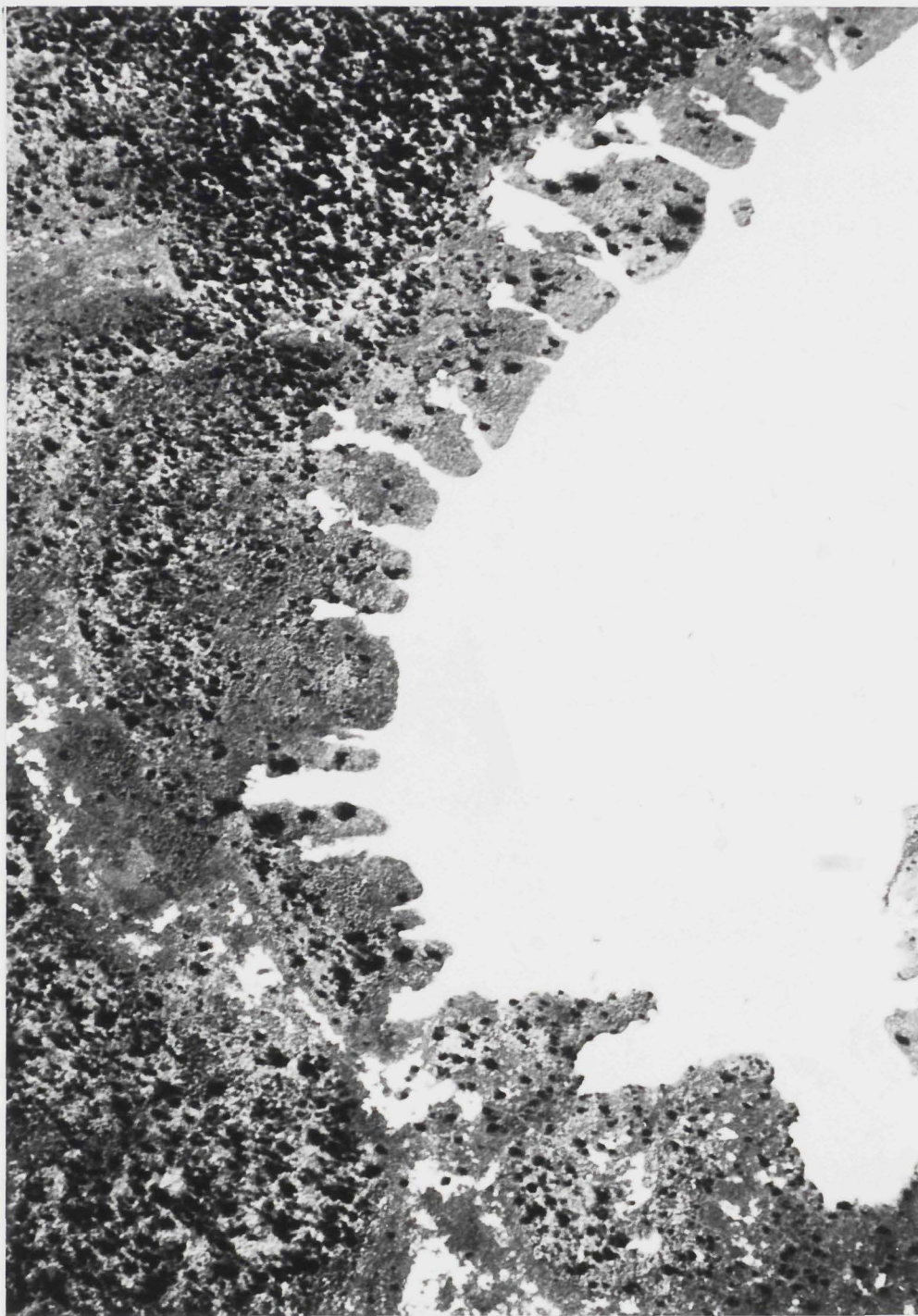


Fig. 4 The erosion of soils of mapping unit AE 1, bordering unit LA 6, is caused by surface runoff due to surface sealing (aerial photograph).



soils are calcareous.

Soil reaction of the topsoil is moderately alkaline (pH=8). Starting at a depth of 40-50 cm the soil reaction becomes strongly alkaline (pH>9). The soils close to the aeolian pans are partly very slightly salt affected.

Soil mapping unit: AE 2

Representative profile no. 8

Geomorphological unit: lineated sandplain associated to 945 m lake level (L 5)

Parent material: aeolian sand

Topography: flat to slightly undulating

Vegetation: predominantly grasses, some herbs and trees

Landuse: wildlife, grazing ?

Drainage conditions: excessively drained; groundwater level deeper than 3 m below surface; never flooded

Soils: have a 10 cm thick grayish brown topsoil of fine sand overlying pale brown to light gray fine sand to loamy fine sand. The topsoil is sealed with algae and organic matter.

Physical aspects: infiltration rate of the topsoil is rapid; available water capacity is very low (< 5mm/dm).

Chemical aspects: the top- 40 cm is free of carbonates; the rest of the profile shows effervescence with diluted hydrochloric acid.

The soil reaction of the topsoil is medium acid (pH=6); with depth the pH rises gradually to 7.5 in the subsoil (mildly alkaline).

Non saline.

Soil mapping unit: AE 3 (related to LA 6)

Representative profile no. 13

Geomorphological unit: Dune complex in old lake bottom (E 1)

Parent material: aeolian deposit

Topography: undulating (dunes)

Vegetation: predominantly grasses with some herbs

Landuse: wildlife

Drainage conditions: well drained; never flooded; groundwater level deeper than 2 m below surface

Soils: have a 15 cm thick topsoil of light brownish gray sandy loam. Underneath the topsoil a thick layer of light gray sandy loam occurs, which gradually changes in colour to light brownish gray and in texture to loamy sand. At a depth of 190 cm a silt loam layer is pre-



sent with some manganese mottles.

This mapping unit also comprises soils with a 50 cm thick topsoil of very dark grayish brown, humic, fine sand. On the surface bleached sand grains can be observed.

Physical aspects: infiltration rate of the topsoil is slow to moderate; available water capacity is low (5-10 mm/dm).

Chemical aspects: these soils are calcareous, except for the top-15 cm which is slightly calcareous.

Soil reaction of the topsoil is about neutral (pH=6.5). To a depth of 140 cm the subsoil is mildly alkaline (pH=7.5); over 140 cm strongly alkaline (pH>9).

Soil mapping unit: LA 1

Representative profile no. 6

Geomorphological unit: Prominent strandline associated with 945 m lake level (L 1)

Parent material: lacustrine deposit (terrace)

Topography: undulating with flat parts

Vegetation: dense grasses, scattered shrubs and barren patches

Landuse: extensive grazing

Drainage conditions: moderately well drained; never flooded; groundwater level deeper than 2 m below surface

Soils: have a 15 cm thick pale brown topsoil of loamy sand overlying a 30 cm thick layer of pale brown loam. The surface is sealed with algae and organic matter. The transitional horizon is weakly cementated by calcium carbonate and holds a considerable amount of white calcrete concretions.

The subsoil to a depth of 100 cm consists of light brownish gray sandy loam to loam. The last 30 cm are cementated; many very pale brown concretions are present. At 100 cm depth starts light gray indurated calcrete.

Physical aspects: infiltration rate of the topsoil is moderate to rapid; available water capacity is very low (<5 mm/dm).

Chemical aspects: the soil reaction of these calcareous soils varies from neutral to mildly alkaline (pH=7 to 7.5). Non saline.



Soil mapping unit: LA 2

Representative profile no. 7

Geomorphological unit: Less prominent strandline, associated to the 920 m lake level (L 2)

Parent material: lacustrine deposits (terrace)

Topography: flat

Vegetation: moderate dense grass, shrubs, trees and barren patches

Landuse: intensive grazing

Drainage conditions: well drained; never flooded; groundwater level deeper than 2 m below surface

Soils: have a 10 cm thick topsoil of light brownish gray loamy sand. Underneath this topsoil a 40 cm thick layer of light brownish gray sandy loam is present.

The subsoil, starting at 50 cm, is (very) pale brown loam. Below 70 cm light gray to white lime mottles can be observed.

Physical aspects: infiltration rate of the topsoil is moderate to rapid; available water capacity is very low ( $\leq 5$  mm/dm).

Chemical aspects: calcareous soils. The soil reaction of the whole profile is neutral (pH=7). Non saline.

Soil mapping unit: LA 3

Representative profile no. 9

Geomorphological unit: Old lake bottom, shallowly dissected (L 6a)

Parent material: lacustrine deposit

Topography: slightly undulating ridges

Vegetation: dense grass, barren patches

Landuse: grazing

Drainage conditions: moderately well to well drained; never flooded; groundwater level deeper than 2 m below surface, capillary rise reaches till less than 2 m below surface.

Soils: have a 15 cm thick topsoil of brown sandy loam overlying a light yellowish brown loam layer of 55 cm thickness.

The subsoil till 120 cm consists of pale brown sandy loam to loam; from 70 cm weakly cementated.

Physical aspects: infiltration rate of the topsoil is moderate to rapid; available water capacity is low (approx. 5-10 mm/dm).

Chemical aspects: calcareous soils with a neutral topsoil (pH=7). From 15 cm below surface the soil reaction is strongly alkaline (pH=9). At the same time a slightly saline to saline influence can be noticed.

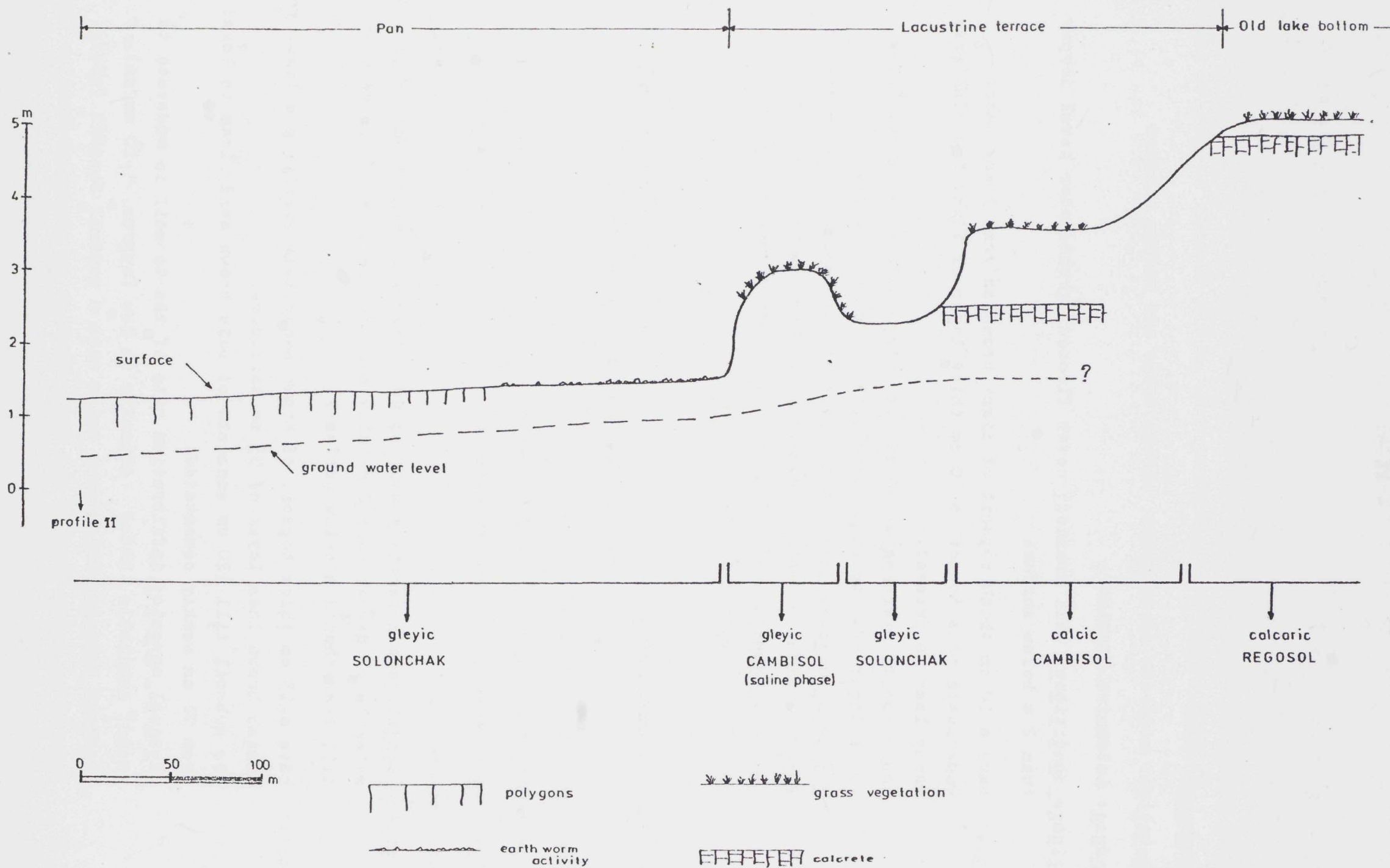


Fig. 5 Cross section indicating the transition from the old lake bottom to a pan.  
(for location see profile No. 11: Appendix III)



Soil mapping unit: LA 4

Representative profile no. 10

Geomorphological unit: Old lake bottom, intensively, shallowly dissected (L 6b)

Parent material: lacustrine/fluviail deposits

Topography: flat

Vegetation: dense grass, shrubs and barren patches

Landuse: grazing, locally overgrazed; some scattered small cornfields (Fig.8)

Drainage conditions: well drained; occasionally flooded; groundwater approximately 2 m below surface

Soils: have a 20 cm thick topsoil of dark grayish brown silt loam. The transitional layer with a thickness of 25 cm consists of dark gray silt loam with pale brown lime mottles. The underlying horizon is a very pale brown silt loam to a depth of 70 cm. The above described profile overlies a buried profile with a 20 cm thick topsoil of black silt loam which gradually becomes less dark coloured with depth. The texture is silt loam with white lime patches. At 180 cm depth pale brown silt loam occurs with calcrete concretions.

Within this mapping unit also soils are found without a buried profile. Besides this difference they distinguish from the described profile in the occurrence of a subangular blocky structure of the silt loam topsoil and the weak cementation of some subsurface horizons ( see also chemical aspects).

Physical aspects: infiltration rate of the topsoil is slow to moderate; available water capacity is moderate (10-15 mm/dm).

Chemical aspects: the soils are slightly to non calcareous. Calcareous material is not found within 160 cm . The soil reaction of the topsoil is slightly acid (pH=6), both of the present topsoil and of the buried profile. The other horizons are neutral to mildly alkaline (pH: 7.0-7.5).

The soils without a buried profile are not only non calcareous, but also strongly alkaline (pH=9) starting at a depth of 20 cm below the surface; the subsoil tends to be saline.

Soil mapping unit: LA 5

Representative profile no. 11

Geomorphological unit: Structurally controlled pans (L 7a and 7b)

Parent material: lacustrine sediment

Topography: flat pan bottom, small terraces and calcrete outcrops at the margins (Figures 5 and 6)



Vegetation: barren pans alternate with grass covered pans

Landuse: none

Drainage conditions: poorly drained; barren pans are periodically inundated; groundwater level in the pan centre about 80 cm and at the rim due to seepage more shallow ( 50 cm below surface). In the undisturbed situation the groundwater level is somewhat deeper because of the impermeable, heavy-textured overlying layer (perched watertable).

Soils: have a 2-3 mm thick, white, hard saltcrust which is segmented in small polygons with a diameter of 3-8 cm. Underneath the crust a white, soft, fluffy salt layer is present. At 1 to 4 or 5 cm below the surface a platy-structured silt loam horizon occurs: thin olive gray (matrix) layers alternate with black ones. Earthworm activities and salt efflorescence along the peds can be observed.

The upper part of the subsoil to a depth of 60 cm is olive silt loam merging into a 5 cm thick, strongly cementated, impermeable layer of grayish brown silt loam with concretions. This layer can be found on variable depth, apparently related to the height of the groundwater level.

The subsoil consists of unripened, grayish brown silt loam.

The compound polygon structure of the topsoil vanishes gradually in the direction of the rim of the pan; at the same time the intensity of worm activities - as seen by small heaps on the surface - increases.

Physical aspects: infiltration rate of the topsoil is slow; available water capacity is moderate (10-15 mm/dm).

Chemical aspects: except for the saltcrust and the subsoil which are slightly calcareous, the soils are calcareous.

The soil reaction is very strongly alkaline (pH<sub>7</sub>9).

The soils are moderately to strongly salt affected.

Soil mapping unit: LA 6

Representative profile no. 12

Geomorphological unit: Pans of aeolian origin ( L 8a and L 8b )

Parent material: lacustrine deposits; where found amidst dunes lacustrine deposits over either lake bottom sediments or fluvial deposits

Topography: flat; usually dunes along the rims and small terraces

Vegetation: barren pans alternate with pans covered by grasses and halophytes; also partly barren, partly grassed pans are found (Fig.7)

Landuse: none

Drainage conditions: poorly to imperfectly drained; periodically inundated; groundwater levels vary from 90 to 170 cm below surface





Fig. 6 Calcrete outcrop (part of soil mapping unit LA 7) along the transition to a pan (soil mapping unit LA 5). The photo illustrates the calcrete outcrop at the right in fig. 5.



Soils: have a 5 mm thick, white, hard, stratified saltcrust with curling edges overlying a light gray, loose, fluffy salt layer of about 5 mm thickness. Here below to a depth of 4 to 7 cm a stratified layer ranging in colour from grayish brown to very dark grayish brown silt loam is present. Polygons (diameter 3-8 cm) and biological activities can be observed.

The transitional zone to the subsoil consists of light brownish gray sandy loam to loam which is underlain by a buried profile at a depth of 160 cm. Remarkable in the 10 cm thick sandy loam topsoil of this profile is the presence of coarse, sandy-like grains, concretions and dark brown litter.

The subsoil is a pale brown (silt) loam layer.

In places where the buried profile is absent, more stratification can be observed: impermeable silt loam layers of variable thickness (20-30 cm) alternate with loam layers and calcrete concretions.

Physical aspects: infiltration rate of the topsoil is slow to moderate; available water capacity is moderate (10-15 mm/dm).

Chemical aspects: these soils are calcareous throughout, although the stratified profiles have sometimes intercalations of slightly calcareous material. The soil reaction from top- to subsoil is very strongly alkaline (pH > 9). The soils are slightly to strongly salt affected.

Soil mapping unit: LA 7

Representative profile no. 14

Geomorphological unit: Lacustrine-aeolian sands covering sandstone with in-

Parent material: thin lacustrine deposit over calcrete intrusions (C 1)  
(Figures 5 and 6)

Topography: flat to slightly undulating

Vegetation: dense grass, shrubs and trees

Land use: grazing, wildlife

Drainage conditions: moderately well to well drained; never flooded; groundwater level ?

Soils: have a 20-35 cm thick, light brownish gray topsoil of loam texture overlying indurated calcrete. In general the surface is sealed with a thin (1-2 mm) layer of algae and organic matter.

The topsoil contains many small and coarse calcrete concretions/fragments.

Physical aspects: infiltration rate of the topsoil is moderate; available water capacity is low (5-10 mm/dm).

Chemical aspects: calcareous soils; mildly alkaline topsoil (pH: 7.5-8.0)



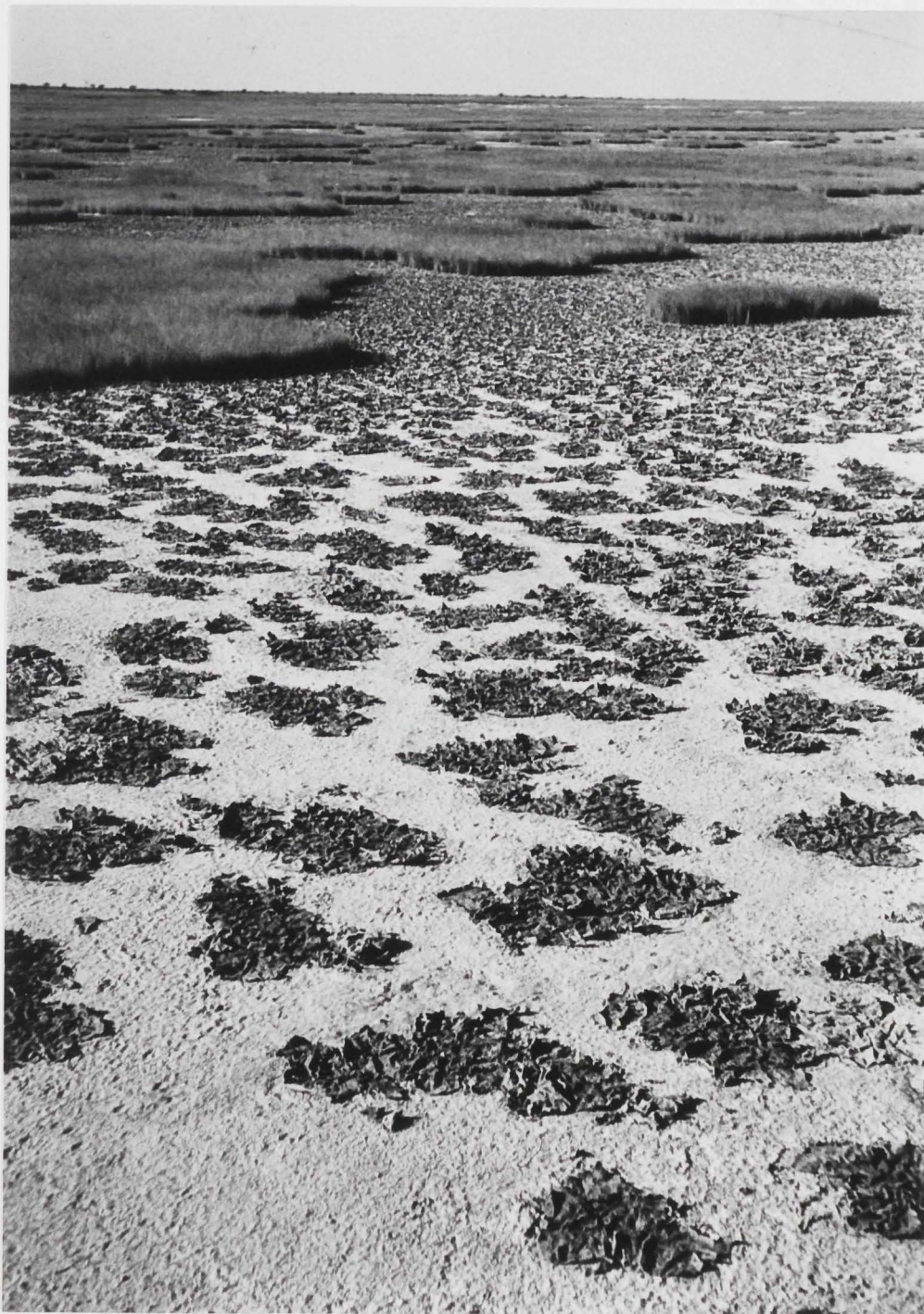


Fig. 7 The soils of mapping unit LA 6 are partly covered with grasses and are partly barren. Note the saltcrust which in parts has curling edges.



| SOIL MAPPING UNIT | PHYSICAL ASPECTS      |                            |                     |                              |                        |                          |   | CHEMICAL ASPECTS          |         |                      |             |                        |          | LIMITATIONS  |                 | RANK ORDER |
|-------------------|-----------------------|----------------------------|---------------------|------------------------------|------------------------|--------------------------|---|---------------------------|---------|----------------------|-------------|------------------------|----------|--|-----------------|------------|
|                   | frequency of flooding | depth to ground-water (cm) | drainage conditions | infiltration rate of topsoil | depth of rootzone (cm) | available water capacity | moisture supply from watertable to rootzone | soil reaction (pH) of the |         | affected by salinity |             | affected by alkalinity |          | susceptibility for moisture shortage (approximation) | chemical        |            |
|                   |                       |                            |                     |                              |                        |                          |   | topsoil                   | subsoil | topsoil              | subsoil     | topsoil                | subsoil  |  |                 |            |
| 1                 | periodically          | <20                        | poorly              | slow/moder.                  | 50                     | high                     | yes   | ≥8                        | 7       | slightly             | no          | slightly               | no       | none to slight                                       | saline + alkali | 2          |
| 2                 | rarely                | <80                        | mod./well           | mod./slow                    | 40                     | low/high                 | yes   | 7,5                       | 7       | no                   | no          | no                     | no       | slight   | none            | 1          |
| 3                 | periodically          | >200                       | well                | moderate                     | 50                     | high                     | no  | 7                         | 8       | no                   | no          | no                     | no       | slight   | none            | 1          |
| 4                 | periodically          | +200                       | mod./well           | moderate                     | 30                     | low                      | some  | 7                         | 7       | no                   | no          | no                     | no       | slight to mod.                                       | none            | 2          |
| 1                 | never                 | >200                       | well                | slow/moder.                  | 40                     | low                      | no  | 8                         | 9       | slightly             | no          | no                     | slightly | mod. to severe                                       | saline + alkali | 3          |
| 2                 | never                 | >300                       | excessively         | rapid                        | 10                     | very low                 | no  | 6                         | 7,5     | no                   | no          | no                     | no       | severe   | none            | 3          |
| 3                 | never                 | ≥200                       | well                | slow/moder.                  | 50                     | low                      | some  | 6,5                       | 7,5     | no/slightly          | no          | no                     | slightly | moderate   | saline + alkali | 3          |
| 1                 | never                 | >200                       | moderately          | mod./rapid                   | 15                     | very low                 | no  | 7                         | 7       | no                   | no          | no                     | no       | severe   | none            | 3          |
| 2                 | never                 | >200                       | well                | mod./rapid                   | 20                     | very low                 | no  | 7                         | 7       | no                   | no          | no                     | no       | severe   | none            | 3          |
| 3                 | never                 | >200                       | mod./well           | mod./rapid                   | 25                     | low                      | no  | 7                         | ≥9      | no/slightly          | no          | no                     | slightly | severe   | saline + alkali | 3          |
| 4                 | occasionally          | +200                       | well                | slow/moder.                  | 30                     | moderate                 | some  | 6                         | 7       | no                   | slightly    | no                     | no       | slight to mod.                                       | none            | 2          |
| 5                 | periodically          | <80                        | poorly              | slow                         | ?                      | moderate                 | yes   | ≥9                        | ≥9      | mod./strong.         | moderate    | mod./strong.           | moderate | none to slight                                       | saline + alkali | 3          |
| 6                 | periodically          | <170                       | poorly/imperf.      | slow/moder.                  | ?                      | moderate                 | yes   | ≥9                        | ≥9      | mod./strong.         | slight/mod. | mod./strong.           | moderate | slight   | saline + alkali | 3          |
| 7                 | never                 | >200?                      | well                | moderate                     | 25                     | low                      | no  | 7,5                       | 8       | no                   | no          | no                     | no       | severe   | none            | 3          |

Table 1. Soil- and land qualities of soil mapping units.



#### 4. SOME NOTES ON SOIL-AND LAND QUALITIES OF SOIL MAPPING UNITS

In Table 1 the various soil-and land qualities per soil mapping unit are summarized. They have been derived from the relevant descriptions of the soil mapping units. The qualities are differentiated into physical aspects and chemical aspects. The conclusive result of each set of aspects is given in the column 'limitations', viz the physical aspects lead to the final conclusion concerning susceptibility for moisture shortage and the chemical aspects can result in the presence of chemical limitations. Based on the combination of these limitations a rank order of the soil mapping units can be achieved, as given in the last column of Table 1.

The origin and/or the classification of the given factors can be briefly explained as follows:

##### 4.1 Physical aspects.

- The frequency of flooding is conform the legend of the geomorphological terrain classification, as presented by Breyer (1979).
- The depth to the groundwater level is taken from the descriptions of the soil profiles within the relevant mapping unit. It should be noted that these figures are given for July 1978, but they may differ considerably from groundwater levels in other periods, both months and years.
- Drainage conditions correspond with the definitions as given in the USDA Soil Survey Manual.
- The infiltration rate of the topsoil is presented in a descriptive scale and based on measurements by Breyer during the fieldwork on soils after removing a few cm's of the topsoil. The infiltration rate under natural conditions is probably considerably slower than indicated, because of the presence of a distinctly sealed surface crust occurring over vast areas.
- The depth of the rootzone has been derived from the various profile descriptions. Impeded horizons or layers in the profile, which form a hindrance for rooting, are taken into account. However, the number of observations is far too limited to give a more justified indication.
- Available water capacity is defined as the total amount of water which a soil can retain between field capacity and wilking point.



The amount of water is mainly dictated by the texture and the structure of the soil and the amount of organic matter.

The given qualifications range from very low ( $< 5$  mm water/dm) to high ( $> 15$  mm water/dm). These rates are given tentatively and are corresponding with data in literature. The available water capacity is restricted to the soil material in the rootzone.

Although the total available moisture capacity could be easily calculated as the product of available water capacity and effective rooting depth, these results are omitted. The lack of adequate field and analytical data on both parameters prevents the presentation of those results. Nevertheless, in the column 'limitations' an effort is made to produce a complementary statement in terms of moisture shortage.

The available water capacity for plants of salt - affected soils is probably less than in non - saline soils.

- Moisture supply from the watertable to the rootzone. In this column the contribution of groundwater to the moisture supply of the profile is stated in very qualitative terms. This is done regardless the hazard of salinization and/or the quality of the groundwater. The hydraulic conductivity of some fine sandy loam and silt loam textured subsoils is such that a contribution of capillary water to the rootzone takes place.

#### 4.2 Chemical aspects.

- The soil reaction (pH) of the top- and subsoil has been determined during the fieldwork by the Hellige-Truog test.
- Affected by salinity. Based on the conductivity data as collected by Breyer in the field and also on circumstantial evidence the salinity classes of the top- and subsoil are given. The mentioned indications of the salinity classes conform the definitions in ' USDA Saline and Alkali Soils, 1969 '.
- Affected by alkalinity. This column merely gives an indication of alkalinity as can be deduced from the pH-measurements and from the presence of salts. The USDA - alkalinity classes are applied tentatively.

#### 4.3 Limitations and rank order.

From the preceding physical aspects a rough approximation of the susceptibility for moisture shortage is given. The terminology is a purely qualitative one, as quantitative information on soil



moisture supply, potential evaporation etc is lacking.

It will be evident that the soils of the present floodplain of the Botletle river (mapping unit AL 1), the older floodplains (mapping units AL 2 and AL 3) and the pans (mapping units LA 6 and LA 7) are hardly susceptible for moisture shortage. If also the chemical limitations are considered, expressed in the presence of salinity/alkalinity hazards, the soil mapping units AL 1, LA 6 and LA 7 have severe drawbacks and are therefor ranked low. Consequently only the soil mapping units AL 2 (semi-active floodplain) and AL 3 (inactive floodplain) offer the best prospects, because they combine a slight susceptibility for moisture shortage and no chemical restrictions.

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Appendix I : Description of representative soil profiles

( for location see map, Appendix III )

| Soil profile no. | Soil mapping unit | Geomorphological<br>Terrain Class.Unit<br>(acc.to Breyer 1979) |
|------------------|-------------------|--|
| 1                | AL 1              | F 1  |
| 2                | AL 2              | F 2  |
| 3                | AL 3              | F 3  |
| 4                | AL 4              | F 3a   |
| 5                | AE 1              | F 4  |
| 6                | LA 1              | L 1  |
| 7                | LA 2              | L 2  |
| 8                | AE 2              | L 5  |
| 9                | LA 3              | L 6a   |
| 10               | LA 4              | L 6b   |
| 11               | LA 5              | L 7a and L 7b  |
| 12               | LA 6              | L 8a and L 8b  |
| 13               | AE 3              | E 1  |
| 14               | LA 7              | C 1  |

Profile no. 1Soil mapping unit: AL 1Soil classification FAO-system: mollic GLEYSOL (Gm)Parent material: fluvial depositPhysiography: floodplainTopography: flatVegetation/landuse: barren with some halophytes; noneDrainage conditions: poorly drained; groundwater at date 18 cm; periodically flooded

|      |             |  |
|------|-------------|--|
| Az   | 0 - 0,1 cm  | salt crust   |
| Ahg1 | 0 - 20 cm   | black (10YR2/0 moist), silt loam; friable when moist; non calcareous; pH=8; EC=6,9 mmhos   |
| Ahg2 | 20 - 50 cm  | black (10YR2/0 moist), silt loam; sticky when wet; ripened; non calcareous; pH=8; with firm elements   |
| AChg | 50 - 85 cm  | grayish brown (10YR5/2 moist), loam; sticky when wet; unripened; non calcareous; pH=7  |
| Cg   | 85 - 120+cm | pale brown (10YR6/3 moist), silt loam; sticky when wet; almost ripened; calcareous, at 110 cm slightly calcareous; pH=8; with firm elements. |



Profile no. 2Soil\_mapping\_unit: AL 2Soil\_classification FAO-system: calcaric PHAEOZEM (Hc)Parent\_material: fluvial depositPhysiography: levee in floodplainTopography: flatVegetation/landuse: predominantly grasses; extensive grazingDrainage\_conditions: well drained; groundwater level at date > 200 cm;  
rarely flooded

|      |              |  |
|------|--------------|--|
| Al   | 0 - 10 cm    | light brownish gray (10YR6/2 dry, 10YR3/2 moist),<br>fine sandy loam; loose when dry; calcareous; pH=7,5;<br>top- 2mm sealed; EC= 0,09 mmhos |
| Ack  | 10 - 60 cm   | brown (10YR5/3 dry, 10YR3/2 moist), fine sandy loam;<br>loose when dry; calcareous; pH=7,5; hard calcrete con-<br>cretions; roots to 40 cm   |
| Clck | 60 -100 cm   | brown (10YR5/3 dry, 10YR3/3 moist), fine sandy loam;<br>loose when dry; calcareous; pH=7; many very hard cal-<br>crete concretions           |
| C2ck | 100 -120+ cm | yellowish brown (10YR5/4 dry, 10YR3/3 moist), loamy<br>sand; loose when dry; calcareous; pH=7; many very hard<br>calcrete concretions.       |

For mechanical and chemical data see Appendix II.

Profile no. 3Soil mapping unit: AL 3Soil classification FAO-system: calcic CHERNOZEM (Ck)Parent material: fluvial deposit (basin)Physiography: old floodplain (backswamp)Topography: flatVegetation/landuse: bare with scattered trees and shrubs; overgrazedDrainage conditions: well drained; groundwater level at date >200 cm;  
periodically flooded

|      |               |   |
|------|---------------|---|
| * A1 | 0 - 30 cm     | dark gray (10YR4/1 dry, 10YR2/0 moist), silt loam; subangular blocky structure; hard fragments; calcareous; pH=7,5; abundant roots; EC= 0,11 mmhos  |
| AC   | 30 - 60 cm    | dark gray (10YR4/1 dry, 10YR2/1 moist), silt loam; slightly hard when dry; light gray (10YR7/1 dry), lime mottles; hard fragments; calcareous; pH=8 |
| C1   | 60 - 100 cm   | grayish brown (10YR5/2 dry, 10YR3/1 moist), silt loam; soft when dry; patches with powdery lime; some hard fragments; calcareous; pH=8              |
| C2   | 100 - 120+ cm | light gray (10YR7/2 dry, 10YR5/2 moist), silt loam; soft when dry; some lime concretions; some hard fragments; calcareous; pH=7,5.                  |

\* For mechanical and chemical data see Appendix II.



Soil mapping unit: AL 4

) saline phase

e

3

e

| Horizon | Depth (cm) | Color                                       | Texture  | Notes |
|---------|------------|---|--|-------|
| A       | 0 - 30     | dark grayish brown (10YR4/2 moist)          | sandy loam; soft when dry; non calcareous; pH=7; EC= 0,03 mmhos              |       |
| AC      | 30 - 50    | grayish brown (10YR5/2 moist)               | sandy loam; soft when dry; non calcareous; pH=6,5;                           |       |
| C1      | 50 - 75    | brown (10YR5/3 moist)                       | fine sand; loose when dry; non calcareous; pH=7                              |       |
| C2      | 75 - 140+  | white (10YR8/2 moist)                       | fine sand; loose when moist; non calcareous; pH=7.                           |       |
|         | 140 - 155  | very dark gray (10YR3/1 dry, 10YR3/3 moist) | silt loam; friable when moist; slightly calcareous; pH=9                     |       |
| ACb     | 155 - 133  | black (10YR2/1 dry, 10YR2/0 moist)          | silt loam; firm when moist; slightly calcareous; pH=9                        |       |
| Cb      | 133 - 160+ | dark brown (10YR4/3 dry, 10YR3/2 moist)     | loam; very friable when moist; carbonate concretions; non calcareous; pH=8,5 |       |

Profile no.5Soil mapping unit: AE 1Soil classification FAO-system: albic ARENOSOL (Qa), saline phaseParent material: 65 cm aeolian deposit over fluvial depositsPhysiography: dune along aeolian panTopography: gently undulating; gully erosion due to runoffVegetation/landuse: grasses; very extensive grazingDrainage conditions: well drained; groundwater level at date > 200 cm;  
never flooded

|     |            |    |  |
|-----|------------|----|--|
| A   | 0 - 15     | cm | light brownish gray (10YR6/2 dry, 10YR3/2 moist), sandy loam; loose when dry; calcareous; pH=8; top-3 mm sealed with algae and organic matter; snail shell fragments on the surface; rooted till 50 cm; EC= 1,60 mmhos |
| C1  | 15 - 40    | cm | pale brown (10YR6/3 dry, 10YR4/2 moist), fine sandy loam; soft when dry; calcareous; pH=8,5  |
| C2  | 40 - 65    | cm | brown (10YR5/3 dry, 10YR4/2 moist), sandy loam; very friable when moist; calcareous; pH=9  |
| Ab  | 65 - 90    | cm | very dark gray (10YR3/1 dry, 10YR3/3 moist), silt loam; friable when moist; slightly calcareous; pH=9  |
| ACb | 90 - 135   | cm | black (10YR2/1 dry, 10YR2/0 moist), silt loam; firm when moist; slightly calcareous; pH=9  |
| Cb  | 135 - 160+ | cm | dark brown (10YR4/3 dry, 10YR3/2 moist), loam; very friable when moist; calcrete concretions; non calcareous; pH=8,5.  |



Profile no. 6Soil\_mapping\_unit: LA 1Soil\_classification FAO-system: cambic ARENOSOL (Qc)Parent\_material: lacustrine depositsPhysiography: lacustrine terrace (intermediate lake level 945-920 m)Topography: flatVegetation/landuse: predominantly barren, some grasses; very extensive grazingDrainage\_conditions: moderately well drained; groundwater level at date > 200 cm; never flooded

|      |          |    |  |
|------|----------|----|--|
| x A1 | 0 - 15   | cm | pale brown (10YR6/3 dry, 10YR3/3 moist), loamy sand; loose when dry; calcareous; pH=7; top 2 mm sealed with algae and organic matter; EC=0,05 mmhos            |
| Clck | 15 - 45  | cm | light brownish gray (10YR6/2 dry, 10YR3/3 moist), sandy loam; hard when dry; calcareous; pH=7,5; many white (10YR8/2 dry, 10YR7/3 moist), calcrete concretions |
| C2   | 45 - 70  | cm | light brownish gray (10YR6/2 dry, 10YR4/2 moist), sandy loam; soft when dry; calcareous; pH=7; calcrete concretions  |
| C3ck | 70 - 100 | cm | pale brown (10YR6/3 dry, 10YR4/2 moist), sandy loam; very hard when dry; pH=7,5; abundant very pale brown (10YR8/3 dry, 10YR7/2 moist), calcrete concretions   |
| R    | 100+     | cm | light gray (10YR7/2 moist), extra hard calcrete.   |

\* For mechanical and chemical data see Appendix II.

Profile no. 7Soil\_mapping\_unit: LA 2Soil\_classification FAO-system: cambic ARENOSOL (Qc)Parent\_material: lacustrine depositPhysiography: lacustrine terrace (intermediate lake level 920-912 m )Topography: flatVegetation/landuse: grasses; intensive grazingDrainage\_conditions: well drained; groundwater level at date > 200 cm;  
never flooded

|      |           |    |   |
|------|-----------|----|---|
| * A1 | 0 - 10    | cm | light brownish gray (10YR6/2 dry, 10YR3/3 moist),<br>loamy sand; loose when dry; calcareous; pH=7;<br>top - 2 mm sealed with algae and organic matter;<br>EC = 0,08 mmhos |
| Bw   | 10 - 50   | cm | light brownish gray (10YR6/2 dry, 10YR4/2 moist),<br>loamy sand; loose when dry; calcareous; pH=7   |
| C1   | 50 - 70   | cm | pale brown (10YR6/3 dry, 10YR5/3 moist), sandy<br>loam; soft when dry; calcareous; pH=7   |
| C2k  | 70 - 120+ | cm | very pale brown (10YR7/3 dry, 10YR 5/3 moist),<br>sandy loam to loam; soft when dry; calcareous;<br>pH=7; patches of powdery lime; few calcrete con-<br>cretions.         |

\* For mechanical and chemical data see Appendix II.



Profile no. 8Soil mapping unit: AE 2Soil classification FAO-system: cambic ARENOSOL (Qc)Parent material: aeolian depositPhysiography: dune; sandplain associated with 945 m lake levelTopography: flat to slightly undulatingVegetation/landuse: predominantly grasses, some herbs and trees; wildlifeDrainage conditions: excessively drained; groundwater level at date > 200 cm;  
never flooded

|      |          |    |   |
|------|----------|----|---|
| * AE | 0 - 10   | cm | grayish brown (10YR5/2 dry, 10YR3/3 moist), fine sand; loose when dry; non calcareous; pH=6; top - 2 mm sealed with algae and organic matter; EC = 0,06 mmhos |
| BW1  | 10 - 40  | cm | pale brown (10YR6/3 dry, 10YR3/3 moist), fine sand; soft when dry, very friable when moist; non calcareous; pH=6,5  |
| BW2  | 40 - 80  | cm | pale brown (10YR6/3 dry, 10YR4/2 moist), fine sand; soft when dry, very friable when moist; slightly calcareous, at 60 cm calcareous; pH=7                    |
| C1   | 80 - 110 | cm | light gray (10YR7/2 dry, 10YR4/2 moist), loamy fine sand; soft when dry, very friable when moist; calcareous; pH=7,5  |
| C2   | 110+     | cm | very pale brown (10YR7/3 dry, 10YR5/3 moist), fine sand; soft when dry, very friable when moist; calcareous; pH=7,5.  |

\* For mechanical and chemical data see Appendix II.

Profile no. 9Soil mapping unit: LA 3Soil classification FAO-system: calcic CAMBISOL (Bk), saline phaseParent material: lacustrine depositPhysiography: ridge between Lake Xau and Makgadigadi pan (old lake bottom)Topography: slightly undulating; observation point on concave slope to  
Lake XauVegetation/landuse: grasses; grazingDrainage conditions: well drained; groundwater level at date > 200 cm; never  
flooded

|      |           |    |  |
|------|-----------|----|--|
| A    | 0 - 15    | cm | brown to dark brown (10YR4/3 dry, 10YR3/2 moist),<br>loamy sand; loose when dry; calcareous; pH=7; roo-<br>ting depth 25 cm; EC = 0,30 mmhos |
| Bw   | 15 - 70   | cm | light yellowish brown (10YR6/4 dry, 10YR4/2 moist),<br>sandy loam; soft when dry; calcareous; pH=9;<br>EC = 1,82 mmhos                       |
| Cmkn | 70 - 120+ | cm | pale brown (10YR6/3 dry, 10YR5/3 moist), sandy loam;<br>very firm when moist; calcareous; pH=9.  |





Fig. 8 Overgrazing on soils of mapping unit LA 4. Between the scattered shrubs and trees all vegetation has vanished.

Profile no. 10Soil mapping unit: LA 4Soil classification FAO-system: haplic CHERNOZEM (Ck)Parent material: lacustrine depositPhysiography: drainage channel in old lake bottomTopography: flatVegetation/landuse: grasses; locally bare due to severe overgrazing, some scattered corn fields (Fig.8)Drainage conditions: moderately well drained; groundwater level at date >200 cm; occasionally flooded

|      |           |    |   |
|------|-----------|----|---|
| A    | 0 - 20    | cm | dark grayish brown (10YR4/2 dry, 10YR2/1 moist), silt loam; loose when dry; slightly calcareous; pH=6; rooting depth 30 cm; EC = 0,09 mmhos                         |
| AC   | 20 - 45   | cm | dark gray (10YR4/1 dry, 10YR3/1 moist), silt loam; very friable when moist; slightly calcareous; pH=7,5; some very pale brown (10YR7/3 dry) patches of powdery lime |
| C    | 45 - 70   | cm | very pale brown (10YR7/3 dry, 10YR5/3 moist), silt loam; very friable when moist; non calcareous; pH=6,5  |
| Ab   | 70 - 90   | cm | black (10YR2/0 dry, 10YR2/1 moist), silty clay loam; very firm when moist; slightly calcareous; pH=6,0  |
| ACb  | 90 - 160  | cm | black (10YR2/1 dry, 10YR3/1 moist), silt loam; firm when moist; slightly calcareous; pH=7,5 ; patches of powdery lime, increasing with depth                        |
| Cb   | 160 - 180 | cm | very dark gray (10YR3/1 dry, 10YR4/2 moist), silt loam; friable when moist; calcareous; pH=7 ; patches of powdery lime  |
| Cckb | 160- 200+ | cm | pale brown (10YR6/3 moist), silt loam; very friable when moist; calcareous; pH=7 ; lime patches; some calcrete concretions.   |



Profile no. 11Soil mapping unit: LA 5Soil classification FAO-system: gleyic SOLONCHAK (Zg)Parent material: lacustrine depositPhysiography: centre of structurally controlled panTopography: flatVegetation/landuse: barren; noneDrainage conditions: poorly drained; groundwater level at date 82 cm; seasonally inundated; pH - groundwater = 11

|     |            |    |  |
|-----|------------|----|--|
| Az1 | 0 - 0,3    | cm | white (5Y8/1 dry, 2.5Y3/2 moist), 2-5 mm thick salty crust; hard; slightly calcareous; pH $\geq$ 9; segmented in polygons of 3-8 cm diameter   |
| Az2 | 0,3- 1     | cm | white (5Y8/1 dry, 2.5Y3/2 moist), loose, fluffy salt layer; calcareous; pH $\geq$ 9  |
| Ah  | 1 - 4      | cm | olive gray (5Y5/2 dry, 5Y5/3 moist), silt loam; platy structure; firm when moist; slightly calcareous; pH $\geq$ 9; alternated by 1-2 mm thick black (5Y2/1 moist) layers of organic matter; earthworm activities; EC = 14,9 mmhos |
| C1  | 4 - 60     | cm | olive (5Y5/3 moist), silt loam; friable to firm when moist; calcareous; pH $\geq$ 9  |
| Cmk | 60 - 65    | cm | grayish brown (2.5Y5/2 moist), silt loam; indurated; calcareous; pH $\geq$ 9; small calcrete concretions   |
| Cr  | 65 - 110+  | cm | grayish brown (2.5Y5/2 moist), siltloam; sticky to very sticky when wet; unripened; calcareous; pH $\geq$ 9.   |
| Cg  | 110 - 200+ | cm | pale brown (10Y5/3 moist), loam; slightly sticky when wet; calcareous; pH $\geq$ 9.  |

For chemical and physical data see Appendix II.

Profile no. 12Soil\_mapping\_unit: LA 6Soil\_classification FAO-system: gleyic SOLONCHAK (Zg)Parent material: lacustrine depositPhysiography: pan of aeolian originTopography: flatVegetation/landuse: 50% grasses, 50% barren; barren at sample spot; noneDrainage conditions: imperfectly drained; groundwater level at date 168 cm; occasionally inundated; pH groundwater = 10

|     |            |    |   |
|-----|------------|----|---|
| Az1 | 0 - 0,5    | cm | white (10YR8/1 dry, 2.5Y5/2 moist), salty crust; hard; stratified; curled; segmented in polygons of 10-15 cm diameter; calcareous; pH > 9   |
| Az2 | 0,5- 1     | cm | light gray (2.5Y7/2 dry, 10YR3/2 moist), salt layer; loose; fluffy; calcareous; pH > 9  |
| Ah  | 1 - 5      | cm | grayish brown (2.5Y5/2 dry, 2.5Y3/2 moist), silt loam; friable to firm when moist; slightly calcareous; pH > 9; alternated by 1-2 mm thick very dark grayish brown (2.5Y3/2 moist) layers of organic matter; earthworm activities; segmented in polygons of 3-8 cm diameter; EC = 4 mmhos |
| x C | 5 - 165    | cm | light brownish gray (2.5Y6/2 moist), loam to sandy loam; friable to firm when moist; calcareous; pH > 9   |
| Ahb | 165 - 175  | cm | dark yellowish brown (10YR3/4 moist), loam; very friable when moist; calcareous; pH > 9; light brownish gray (2.5Y6/2 moist), coarse sand-like grains and concretions; dark brown (10YR3/3 moist) litter and twigs  |
| Cgb | 175 - 200+ | cm | pale brown (10YR6/3 moist), loam; slightly sticky when wet; calcareous; pH > 9.   |

x For mechanical and chemical data see Appendix II.



Profile no. 13Soil mapping unit: AE 3Soil classification FAO-system: cambic ARENOSOL (Qc)Parent material: aeolian depositPhysiography: dune around aeolian pan on old lake bottomTopography: undulatingVegetation/landuse: grasses; wildlifeDrainage conditions: well drained; groundwater level at date  $\pm$  200 cm;  
never flooded

|    |            |    |  |
|----|------------|----|--|
| A1 | 0 - 15     | cm | light brownish gray (10YR6/2 dry, 10YR4/2 moist),<br>sandy loam; loose when dry; calcareous; pH=6,5 ;<br>many roots            |
| Bw | 15 -110    | cm | light gray (10YR7/2 dry, 10YR5/2 moist), sandy loam;<br>loose to soft when dry; calcareous; pH=7 ; some roots<br>up till 80 cm |
| C1 | 110 -140   | cm | light brownish gray (10YR6/2 dry, 10YR4/2 moist),<br>loamy sand; very friable when moist; calcareous; pH=7,5                   |
| C2 | 140 - 170  | cm | grayish brown (10YR5/2 moist), sandy loam; friable<br>when moist; calcareous; pH=9   |
| C3 | 170 - 190  | cm | grayish brown (10YR5/2 moist), sandy loam; friable<br>when moist; calcareous; pH> 9  |
| C4 | 190 - 220+ | cm | light brownish gray (10YR6/2 moist), silt loam;<br>slightly sticky when wet; calcareous; pH> 9.                                |

Profile no. 14Soil mapping unit: LA 7Soil classification FAO-system: calcaric REGOSOL (Rc)Parent material: 35 cm lacustrine deposit over calcretePhysiography: lake bottomTopography: flatVegetation/landuse: predominantly grasses, some shrubs; wildlifeDrainage conditions: moderately well drained; groundwater level at date ? ;  
never flooded

|     |         |    |  |
|-----|---------|----|--|
| A   | 0 - 20  | cm | light brownish gray (10YR6/2 dry, 10YR3/2 moist),<br>loam; loose when dry; calcareous; pH=7,5 ; many<br>roots; surface sealed; EC = 0,04 mmhos |
| Ack | 20 - 35 | cm | light brownish gray (10YR6/2 dry, 10YR3/2 moist),<br>loam; loose when dry; calcareous; pH=8 ; many<br>fine and coarse calcrete concretions     |
| R   | 35+     | cm | indurated calcrete.  |



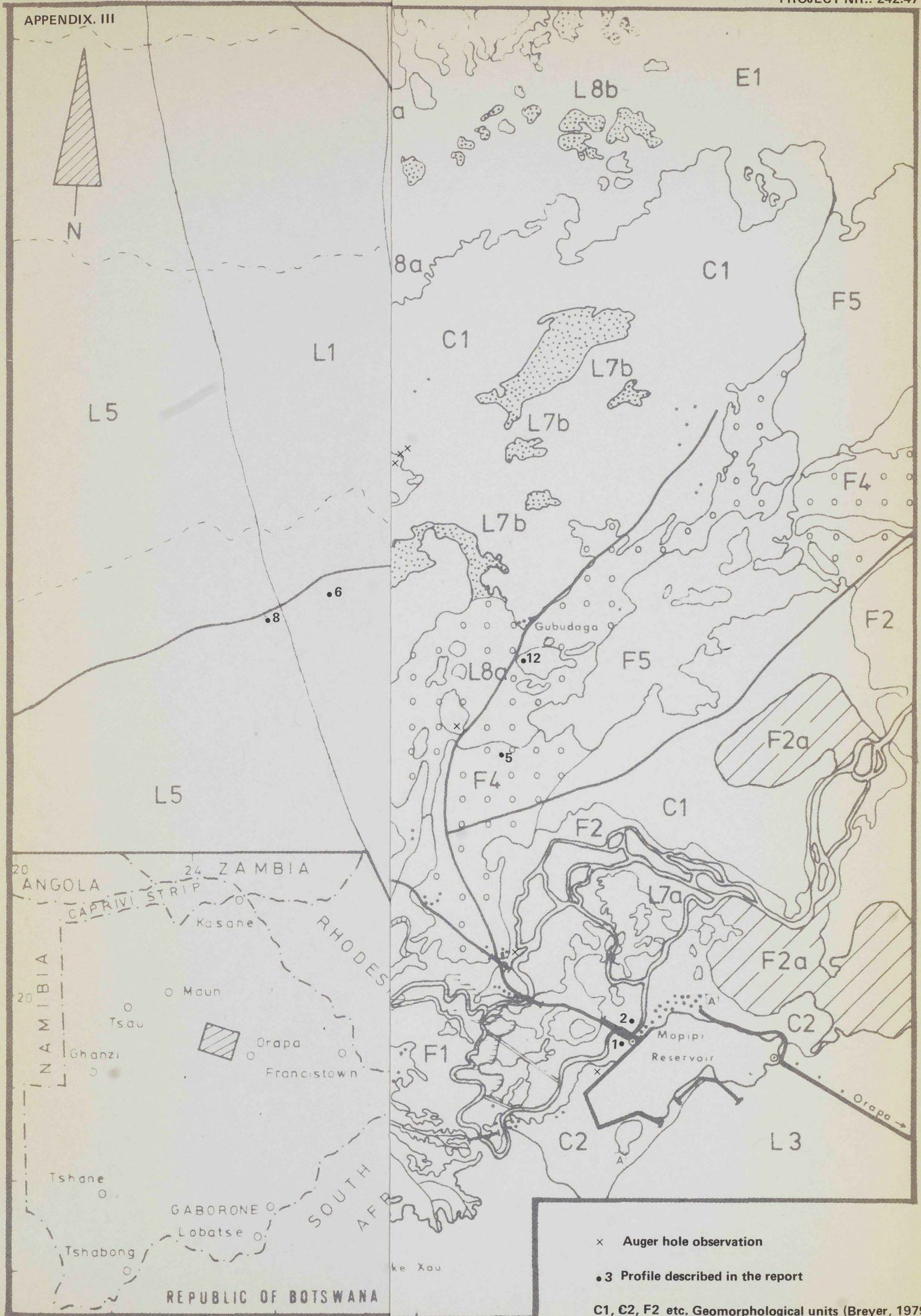
Appendix II : Analytical data of some soil horizons

( the analyses are carried out by the Laboratory  
for Soil and Crop Testing at Oosterbeek, Holland )

| Profile no.                      | 3              | 6              | 7              | 8      | 12            |
|----------------------------------|----------------|----------------|----------------|--------|---------------|
| Depth in cm                      | 0 - 10         | 0 - 10         | 0 - 10         | 0 - 10 | 80 - 120      |
| Horizon                          | A <sub>1</sub> | A <sub>1</sub> | A <sub>1</sub> | AE     | C             |
| <u>Texture %</u>                 |                |                |                |        |               |
| Sand 2,0 - 0,21 mm               | 6              | 6              | 11             | 6      | 14            |
| 0,21 - 0,15 mm                   | 4              | 11             | 17             | 17     | 12            |
| 0,15 - 0,05 mm                   | 24             | 60             | 55             | 70     | 34            |
| Total sand                       | 34             | 77             | 83             | 93     | 60            |
| Silt 0,05 - 0,002 mm             | 51             | 15             | 10             | 4      | 31            |
| Clay < 0,002 mm                  | 15             | 8              | 7              | 3      | 9             |
| Textural class                   | silt<br>loam   | loamy<br>sand  | loamy<br>sand  | sand   | sandy<br>loam |
| <u>Chemical data</u>             |                |                |                |        |               |
| Organic matter %                 | 7,3            | 3,7            | 2,7            | 0,8    | 7,3           |
| Carbonate as CaCO <sub>3</sub> % | 1,4            | 13,8           | 17,7           | 0,6    | 30,4          |
| pH-KCl                           | 7,6            | 7,6            | 7,6            | 7,5    | 9,4           |



## APPENDIX. III





# LOCATION OF SOIL OBSERVATIONS

RAPPORT NR.: 1664  
PROJECT NR.: 242.47

