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WESTERN PROVINCE

BUNGOMA DISTRICT

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N'ZOIA SUGAR PROJECT

MORPHO-PEDOLOGICAL SURVEY

NUCLEUS ESTATE

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TECHNISUCRE
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M. BACH
J.-M. GRÉGOIRE
M. RAUNET

NORMAN BENGTSON SEMINARS

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I - INTRODUCTION

1 - ORIGIN OF THE SURVEY

A prefeasability study realized in 1974 by "Dookers Agricultural and Technical Services" brought a favorable response to the establishment of a sugar cane estate in the region of BUNGOMA - WEBUYE.

Following this study, a zone of 5,000 hectares consisting of the best soils had been demarcated and proposed for the "Nucleus Estate" of the "N'Zoia Sugar Project". Around this Nucleus Estate, approximately 30,000 hectares have been set aside for the "Out Growers".

This report renders an account of the detailed survey realized by "Technisucre", of the 5,000 hectares proposed by "Bookers".

2 - LOCALIZATION OF THE ESTATE

The area studied is located in the Western Province (District of Bungoma), along the river Kuywa, tributary of the river N'Zoia (principal river of the western part of Kenya), which flows into Lake Victoria. The zone extends between 0°30' and 0°40' latitude North, and between 34°40' and 34°45' longitude East.

The Nucleus Estate is situated at approximateley 15 km as the crow flies to the East of the town of Bungoma (see sketch). It is bounded (topographical map 1:50,000 Bungoma) to the North by the railroad Nairobi-Kampala, to the West by the road joining the villages of Sudi-Station and Kongoli-Market, to the East by the road Khalumuli-Mangana ; the southern boundary passes by Mangana school and Khaweli-Market.

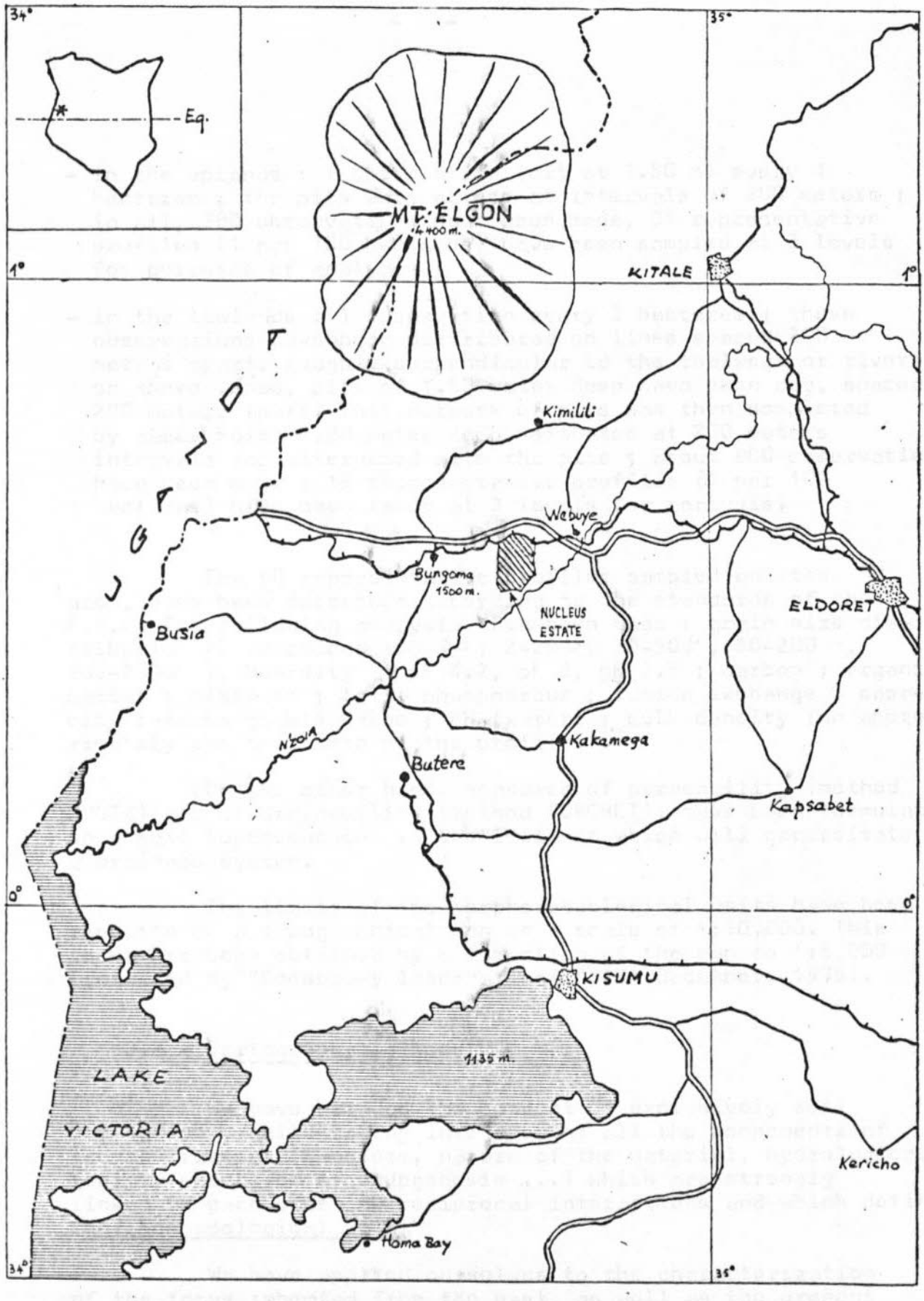
3 - METHOD OF WORK - CARTOGRAPHY

3.1 - Work standards

The area mapped out has a surface of 5,000 hectares composed of approximately 3,200 hectares of well drained uplands and 1,800 hectares of lowlands which are naturally deficient in drainage.

The surface was developed between March and June, 1976.

The accuracy of the study was based on the following standards :



SITUATION MAP

1 : 1,000,000

- in the uplands : 1 observation (pit at 1.50 m) every 4 hectares ; the pits were alined at intervals of 200 meters ; in all, 780 observations have been made, 31 representative profiles (1 per 100 hectares) have been sampled at 3 levels for purposes of analysis ;

- in the lowlands : 1 observation every 2 hectares ; these observations have been distributed on lines spaced 200 meters apart, roughly perpendicular to the thalwegs or rivers ; on these lines, pits of 1.50 meter deep have been dug, spaced 200 meters apart. This network of pits was then completed by auger holes 1.20 meter deep, situated at 200 meters intervals and alternated with the pits ; about 800 observations have been made ; 19 representative profiles (1 per 100 hectares) have been taken at 3 levels for analysis.

The 50 representative profiles sampled on the area, have been described according to the standards of the F.A.O. The following analysis have been made : grain size distribution (5 fractions : 0-2 µ, 2-20 µ, 20-50 µ, 50-200 µ, 200-2000 µ), humidity at pF 4.2, pF 3, pF 2.5 ; carbon ; organic matter ; nitrogen ; total phosphorous ; cation exchange capacity ; exchangeable bases ; pH (water) ; bulk density (on approximately one thirtieth of the profiles).

On the other hand, measures of permeability (method MUNTZ) and of drainability (method PORCHET), have been formulated on a soil toposequence in the lowlands which will necessitate a drainage system.

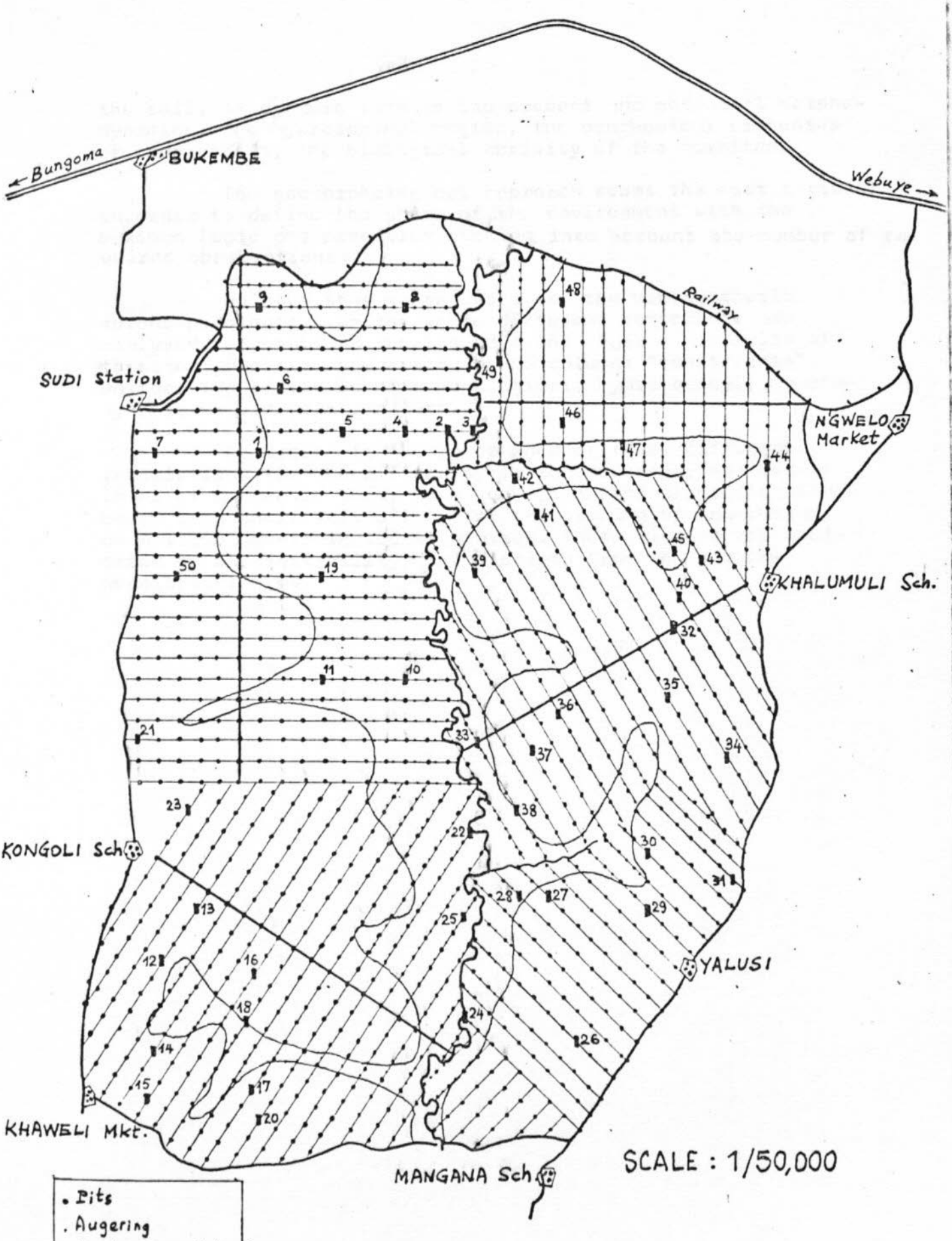
The limits of the morpho-pédological units have been reported on a topographical map on a scale of 1:10,000. This sheet has been obtained by a reduction of the map to 1:5,000 (realized by "Geosurvey International", in December, 1975).

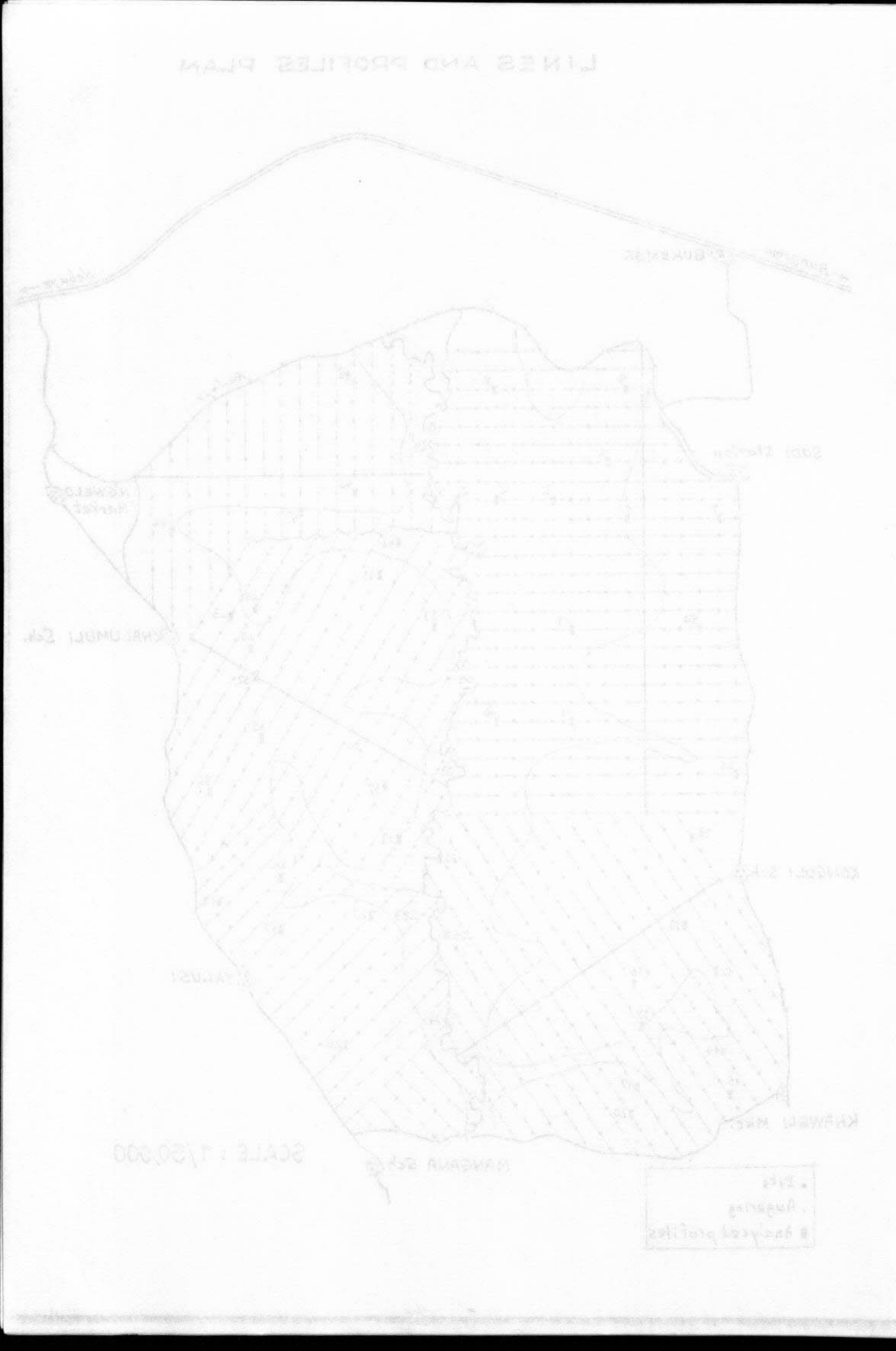
3.2 - Cartography methods

We have broaded the concept of exclusively soil cartography, while taking into account all the components of the environment (landform, nature of the material, hydrological regime, processes of pedogenesis ...) which are strongly linked to each other by reciprocal interactions and which define "morpho-pedological units"

We have applied ourselves to the characterization of the forms inherited from the past, as well as the present forms and processes ; this approach has thus permitted us to logically map the limitations of the environment whether they be static such as the depth of a cuirasse and the texture of

LINES AND PROFILES PLAN





the soil, or dynamic such as the present and potential morpho-dynamics, the hydrological regime, the geochemical processes of pedogenesis, the biological activity of the termites.

The geomorphological approach seems the most rational in order to define the units of the environment with the maximum logic and precision (taking into account the number of required observations).

We have thus represented on the map synthetic morpho-pedological units, whose different components are analyzed in detail in the legend ; the "use results of this analysis are summarized in the columns "constraints", whether the latter be of a pedological, hydrological, morpho-dynamic or biological nature.

According to the importance of these different restrictions and the difficulty of the necessary management in order to reduce them, we have made a land classification based upon their suitability for the growing of sugar cane on a large non-irrigated plantation. These classes are indicated on the suitability map, separate from the morpho-pedological map.

II - GENERAL PRESENTATION OF THE REGION

The landscape of the region of Bungoma-Webuye is composed of highly cultivated interfluves running roughly from North to South, with wide convex summits ; these interfluves are linked to the hydrographic system by "glacis" whose rectilinear or slightly concave inclines are on the order of 3 %. The summits of interfluves are at an altitude varying between 1,450 and 1,500 meters. Inselbergs and piles of large granite blocks appear sparsely and form the essential features of the local relief.

The whole is dominated to the North by Mount Elgon, an enormous volcano of the tertiary age, approximately 4,500 meters high. To the East, the "Nandi Escarpment" a fault line running NW-SE, on which is situated the town of Webuye, dominates the region from 100 to 300 meters ; this escarpment diminishes progressively towards the North.

The substratum is composed of very old rocks (precambrian) basically granite, granodiorite, sandstone and schists more or less metamorphized.

The climate of Bungoma is tropical of altitude : the average annual rainfall is from 1300 to 1400 mm, with a maximum in April and May. A large dry season extends from December to March (monthly averages above 40 mm). A short unstable and comparatively dry season takes place in June and July. The average of the maxima temperatures is about 29°7 C from February to April ; the average of the minima is about 25° 4 C. in July. Insolation is high (2789 hours per year) with a maximum in December (8.8 hours a day) and a minimum in July (6.5 hours). Evapotranspiration is also high (1689 mm per year) with a minimum in June (100 mm) and July (108 mm), and a maximum in March (193 mm).

These altitude climatic conditions involve a growth cycle for sugar cane from 20 to 24 months ; without irrigations the cane may suffer from dryness, on some sandy soils, between December and March.

As in all the Western Kenya, the use of the land is important ; the population is dense but scattered. All the slopes are cultivated as well as the alluvial terraces. The base crop is maize but one can also find millet, finger millet, beans, cassava and small banana plantations. The zones with indurated plinthite or where gravel is near the surface, are less cultivated and are generally left under fallow and covered with bushes. The poorly drained zones ("glacis" linking the slopes to the talwegs) are seldom cultivated ; they are covered by grasslands serving as pasture for herds of cattle (oxes, sheep).

III - GEOLOGY

The basement of the region is composed of precambrian rocks. A.B. GIBSON (1954) classified four large groups, which in chronoligical order were the followings :

- the "basement system" composed of rocks formerly considered to be the oldest ; it was attributed to the lower precambrian (Archean). However, it was proved later that these formations were in fact more recent than those of the "Nyanzian and Kavirondian Systems". The term "Basement System" although having lost its original significance, has been conserved out of habit.

This system is composed of metamorphic rocks : metamorphic schists, gneiss, migmatites ... These formations have been crossed by intrusive rocks (granites and pegmatites).

They are localized to the North of the "Nandi Escarpment" ; they do not exist in the region of Bungoma.

- the "Nyanzian System" : volcanic formations (rhyolites, tuffs) more or less metamorphized, that are observed in outcrops reduced and discontinued only along the "Nandi Escarpment", to the East of the site studied.

- the "Kavirondian System" : Sedimentary formations lightly metamorphic (rather fine feldspathic sandstones, shales). These rocks can be seen on the surface, essentially along the river N'Zoia. In the region which interests us, the geological map indicates their presence, mainly on the left bank of the river Kuywa, but we have never seen outcrops.

- the intrusive posterior formations : the intrusive "post Kavirondian" granites form the largest part of the bedrock of the region of Bungoma. These intrusive rocks belong to the "Kitosh batholith" and form the Northen limit of it. The main facies are the following : biotite and hornblende granite, granodiorite, granitogneiss, basic rocks (hornblendite).

All these rocks are generally rich in black ferromagnesian and basic minerals ; this richness is due to phenomens of chemical exchange within Kavirondian sediments.

- Some fine and localized intrusions cross the preceding formations : porphyroid granites, pegmatites, aplites, microgranites, peridotites, dolerites. Veins of quartz are small in size but extremely numerous.

The limits between the intrusive granite rocks and the sandy schist rocks of the "Kavirondian System", the two formations which interest us in the region of Bungoma, is very indistinct considering the profound "ferrallitic" alteration of all these materials. The outcrops are only seen in the river beds where they form little rocky bars. On the interfluves there are only outcrops of granite cores which have resisted alterations : boulders without root, domes, boulder fields, inselbergs.

The grain size distribution of the rocks, in particular the size and the proportion of the grains of quartz, seem to have an importance on the texture of the soils found at the surface, and this is true in spite of the profound and intense "ferrallitic" alteration of the basement on the one hand, and the biological reworking (termites) on the other.

A certain number of volcanic and tectonic events as well as periods of peneplanation occurred after the end of the precambrian, and these affected or covered the earlier formations described above (A.D. GIBSON) :

- the larger fault escarpment close to Webuye (Nandi Escarpment) could have been formed between the end of the Precambrian and the cretaceous, with a slight upbuilding at the beginning of the Pleïstocene.

- Four phases of peneplanation would have successively worn down the precambrian basement. These surfaces are schematically the following :

  - the "cretaceous surface" of which a few traces remain at about 2,300 meters altitude in the Nandi Escarpment
  - the surface formed at the beginning of the tertiary, or "surface of Kitale," which is located at a neighbouring altitude of 2,000 meters.
  - the "Sub-miocene" surface, at about 1,750 meters altitude.
  - the surface formed at the end of tertiary and found at an altitude of about 1,500-1,600 meters. The pebbles of quartz that are frequently seen in the gravel sheet, at the base of the red loamy cover, on the interfluves in the region of Bungoma seem to be characteristic of this surface. This one is tangential to the largely convex interfluves.

- Mount Elgon, which dominates the entire region at an altitude of 4,500 meters, was built at the end of the Tertiary. It is an enormous [illegible] volcano about 50 km in diameter at the base. The essentially explosive eruptions have given birth to hydrovolcanic products (blocks of all size and cinders, consolidated in conglomerates and breccia) ; these ejecta have the composition of nephelinites.

IV - PAST AND PRESENT GEOMORPHOLOGICAL EVOLUTION

The landforms of the region is characterized by a succession of hills, widely convex at the summit, roughly elongated North-South. These interfluves are joined to the talwegs by means of a "linking glacis", rectilinear to concave, with inclines 2 to 3 %.

The study of these two principal units of the landscape is going to permit us to consider the major past and present morpho-pedological processes. The inheritances of the past are essentially seen on the well drained interfluves, while the present phenomena are visible on the hydromorphic "linking glacis". As we shall see, the role of the hydrological regime plays a preponderant part in this morpho-pedological evolution.

1 - THE MATERIAL OF THE SLOPES

A section in the material of the interfluve, such as one observes at Sudi-Station (railway cutting), shows us the following succession, from top to bottom :

- on a variable thickness, between 0,50 and 4 meters : reddish-yellow to red material, without mottles, very homogeneous, of a sandy-clayey-loamy texture, with a friable consistence, and without coarse fragments. This material rests directly (discontinuity) on the underlying gravel sheet.

- a "gravel sheet" of a variable thickness (20 to 100 cm), festooned, and composed of ferruginous elements (rather friable nodules, blocks of cuirasse) angular pieces of quartz, some pebbles of quartz of fluviatile origin. The proportion of quartz and of ferruginous elements is very variable : in certain places, there is praticelly nothing but fragments of quartz, while elsewhere one see very few of them. Sometimes, the gravel sheet is cemented into cuirasse.

- a mottled clayey material, often hardened or indurated, with an alveolar structure. The alveoles which are often oblong are either empty or filled with friable loamy material, while the anastomosed divisions are hardened by iron oxides. This material is crossed by numerous quartz veins, unworked ; it is thus autochtone ; it represents a clayey alteration zone of the granito-gneissic basement. This mottled level has retained former hydromorphic traces; it was formerly saturated by ground water, assuring the progression of the alteration. Then the water level having descended, it evolved by induration.

The thickness of this "plinthite" is of the order of 1 to 5 meters.

- a sandier alteration material, of a rosy color, where one still recognizes the structure of the rock and the minerals : powdered kaolinised feldspars, flakes of mica ; the consistence is loose. The depth can reach 20 meters. Ground water saturates a part of this material.
The passage between the more or less indurated plinthite and the micaceous alteration zone is gradual.

This succession is very characteristic of the interfluves ; the only things which vary in depth are the upper covering layer, which is very interesting from the agronomic point of view, and the undulating gravel sheet.

In this section one can wonder especially about the following facts :

- the perfect homogeneity of the coloured covering layer devoid of the slightest coarse element.

- the very abrupt passage of this material to the lower gravel sheet

- the presence of some pebbles of quartz of fluviatile origin in the gravel sheet, mixed with fragments of indurated plinthite and with angular quartz coming from dislocated veins. These quartz pebbles are not found in large numbers, but are present at any level of the interfluves (at the summit as well as on the slopes).

2 - THE MORPHO-PEDOLOGICAL EVOLUTION OF THE INTERFLUVES DURING THE QUATERNARY - HYPOTHESES

These pebbles, and their areal distribution are evidence of a climatic phase with much more contrasted rainfall regime than presently, permitting an important solid discharge from the streams. Their presence confirms the existence of an original surface, with large fluviatile over-spreading, reminding piedmont cones (perhaps originating from the Nandi Escarpment). This surface could then be the fourth surface (end tertiary) proposed by A.B. GIBSON, by relation to which the summits of present interfluves would be tangent, as a result of a later evolution. This evolution can be imagined in the following way :

after the intense morpho-climatic conditions, which have presided in the formations of the surface, new conditions of a more uniformly humid environment and with good forest covering, began to develop ; during this period, the intense ferrallitic pedogenesis and the stability of the environment permitted a profound alteration of the granito-gneissic basement.

Then, new changes in the conditions of stability of the environment (more contrasted climate, or sinking of the base-level, or both at the same time), have led to the degradation of the original surface : cutting by the hydrographical system, formation of slopes ; the correlative reduction of the ground water brought about the progressive induration of the alteration products (plinthite) which was no longer saturated by this water. This evolution produced a surface reworking of the soil with a tendancy to the "inversion of the materials" by headward erosion : the coarser elements, blocks of cuirasse, gravels and nodules of plinthite quartz fragments and pebbles, are not carried far or even concentrated without moving, while the alteration zone still friable underneath, undergoes a minor colluvial transportation and thus comes to recover the gravel sheet.

Such a dynamics is not, however, to be envisaged as being perfect, and a few coarse elements should necessary remain in the "covering layer" ; the gravel sheet ought to be embodied in a rather important earthy matrix. This is not the case however ; moreover these two materials are perfectly separated by a clear discontinuity.

In order to explain these facts, we think that the role of the termites is undeniable. These animals presently have a considerable activity, above the surface as well as below ; they build hillocks from 2 to 4 meters high (1 per hectare on the average) capable of being as large as 30 meters at the base ; but between these large "mature" termite hills there remain traces of former constructions in different degrees of degradation, or embryonic termite hills. This as result in the complete reworking of the interfluve.

It is very difficult to be precise as to how long this biological activity has been going on. The termites are most active in a soft material, with balanced grain size distribution, permanently moist, but not subject to water-logging. The ferrallitic soils, with deep ground water, in a sufficiently humid climate (without a too define dry season), constitute the most favorable environment ; it is this type of environment which is prevalent in the Western part of Kenya.

Even without knowing how old this biological activity is (which must be figured in thousands of years), it is presently occuring in such a spectacular way that one is obliged to consider the termites in order to explain the elaboration of the "covering layer".

The termites have completed the morphogenetic action resulting in the inversion of the coarse materials. These animals have brought to the surface the fine particles constituting the matrix of the gravel sheet ; the coarser elements which could remain in the covering layer have descended little by little in order to become a part of the gravel sheet ; there was thus a progressive concentration of the latter in coarser elements, and a homogenization of the covering layer : the limit between the two materials was thus able to become clearly defined.

As a result of the preponderant but very irregular activity of the termites, the distribution of the materials on the interfluves, in particular their thickness, doesn't obey any predictable laws. The depth of the gravel sheet (recimented or not in cuirasse), or of more or less indurated plinthite is difficult to represent on a map with precision. Its seems however that the indurations are generally closer to the surface at the summits of the interfluve ; at the time of the degradation of the initial surface (end Tertiary ?) the processes of regressive erosion ending in an "inversion" of the coarser materials was undoubtedly less intense and less well defined upon ascending toward the water partings. The covering, of morphogenetic origin, was then less thick, moreover the hardening of the plinthite was preferentially produced at the summit of the interfluve, there where the ground water was reduced the fastest. Consequently, the termites thus had less soft material to rework and their activity was less.

3 - ROLE OF THE PRESENT GEOCHEMICAL PROCESSES IN THE EVOLUTION OF THE LANDFORM

The interfluves with well drained slopes and highly cultivated red soils, pass, usually abruptly, to a "linking glacis" with rectilinear to concave slopes (1 to 4 %), joining them to the properly so called lowlands which are more or less wide and floodable, or directly to the stream.

This "glacis" is generally not well cultivated ; one find there a grassland without trees, used as pasture. The large termite mounds have practically disappeared ; in contrast, they are extremely numerous and close together at the beginning of the "linking glacis" ; this line of termite hills underlines very clearly the boundary with the slopes of the well drained interfluves.

We are now in the presence of a type of environment which is very different from that of the interfluves. The current geochemical and hydrological processes play fundamental roles in it.

3.1 - Toposequence on the "linking glacis" and the lowland (or the plain)

The study of the materials and the pedogenesis which affects them (that we shall describe in greater detail in the following pages) shows us the following section :

- in the upper part of the "linking glacis" : the soils, of a light color, are leached at a thickness of approximately 60-120 cm, they are rich in coarse sands ; in depth one

passes progressively (without discontinuity) to a mottled clay, very hydromorphic ; this material is being impoverished under the effect of a leaching by the ground water, which leads to a progressive degradation of the clays and to their elimination to the base of the glacis.
The ground water which, on the interfluves is located in the deep sandy alteration zone outcrops on the "linking glacis" particulary at the top. Here a line of springs is located, many of which are permanent. This spring line corresponds to the "inflection point" marking the passage between the convexity (more or less clear) of the base of the well drained slopes of the interfluves, and the concavity of the "linking glacis". The zones of permanent seepage forming overspreading cones, show soils having a top organic horizon of the "hydromor" type.

- in the lower part of the "linking glacis" : the incline lessens (1 to 2 %) ; the soils show a distinct differenciation: the upper part, still sandy, from 40 to 70 cm thick, rests on a clayey floor by the intermediary of a discontinuity which becomes more distinct as one progresses towards the base of the glacis ; the clayey level presents vertic characters which become equally strongly accentuated downstream. There is a very clear enrichment in swelling clays of the montmorillonite type.

- in the lowland or the floodable plain, pratically flat (incline less than 1 %), situated (when they exist), in an prolongation down from the "linking glacis", the swelling clays are in even greater proportion and invade almost the totality of the material. There remains only a top horizon from 20 to 40 cm, of silty texture, and which seems to be a relic of the leached horizon that one presently observes on the "linking glacis".

3.2 - The present morphopedological evolution

The ground water, which is near the surface or in outcropping below the line of termite hills, degrades the kaolinic clays of the covering layer ; the products of degradation are drained off towards the bottom ; the only thing left remaining is the sandy skeleton of the material. The degradation progresses from top to bottom. The upper part of the glacis is then a geochemical environment of draw off of material. This draw off procedes towards the head ; the slopes progressively "melt" under the action of a true geochemical planation.

As the slopes recede, and thus enlarge the glacis, the termite hills which were present there are abandoned ; the termites which don't suffer long waterlogging, retreat and rebuild their hills higher up ; there is in some manner, a

"sweeping up" of the termite hills at the top of the "linking glacis". This is what explains their impressive concentration in the form of a string of beads at this point.

The base of the linking glacis, as well as the plain or lowlands, which are flat, constitute a geochemical environment of accumulation ; the degradation products of the kaolinic clays from the linking glacis, recombine in a confined medium favorable to the formation of montmorillonite, since it is a question of a sandy alteration zone which issue from rocks generally rich in ferro-magnesian basic minerals (granodiorites).

These neoformed swelling clays, after having invaded the low areas which become compacted and saturated, proceed progressively headwards ; the middle of the "linking glacis" is thus a mixed medium, where the vertic characters are not yet very clear, but which is nevertheless invaded little by little due to blockage in the lowlands. When the clayey floor is sufficiently compact, there is produced in the sandy upper part of the soil, a hypodermic flow and an abrupt discontinuity at the contact of the two materials. This discontinuity marks the convergent meeting point of two processes : on one hand the degradation of the kaolinic clays progressing from top to bottom, on the other hand, the neosynthesis and ascending accumulation (oblique and vertical) of montmorillonite. It is a geochemical limit ; the latter is nearer the surface at the base of the toposequence, where the rate of accumulation surpasses the rate of degradation, and finally invades the whole profile ; inversely, at the top of the glacis where only progressive degradation and draw off are produced, the discontinuity does not yet exist.

In conclusion the present shaping of the landform is essentially manifested by a progressive regression of interfluve slopes, under the action of a draw off by ground water ; the slope recedes for the benefit of the enlargement of the "linking glacis", a true geochemical laboratory. This glacis becomes larger little by little and actually is quite large in some place ; its slope thus becomes weaker downstream (less than 1 %) and it evolves towards a veritable plain with completely impermeable material, very clayey, with strong vertic characters, very waterlogged and often floodable in rainy season.

This is the case with plain bordering the right bank of the Kuywa River, in the perimeter of the "Nucleus Estate".

4 - THE ALLUVIAL FORMATIONS

Only the main
by alluvial deposits. The
linking glacis ; the small
outcrops.

The KUYWA Riv
the "Nucleus Estate", is a
River. Its catchment upstre
Mount Elgon.

The present b
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meandering ; numerous bends

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water-worn quartz pebbles
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directly on the alteration
fills the little pot-holes
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(strong competency) in a cl
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Below, a fine
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of the terrace. The freshne
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to this upbuilding.

5 - THE PRESENT MORPHODYNAM

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responsible for the present
we have seen, is rather of

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the main stream which crosses
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is located on the slopes of

f the KUYWA is encased in an
bank escarpment from 2 to 4
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t back on themselves

bars (granodiorite) cross the
tle rapids. The alluvial
ble plain of vertic clays, or
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vegetation, and their slopes are steep ; they are thus sensitive to stripping on their periphery, but they are regenerated progressively by the adding of particles set apart in the subsoil ; one ends up thus with these large domes.

The domes which are in a process of degradation, and which cover in reality almost the totality of the surface, release a clayey-loamy material very sensitive to the action of the rain as soon as the cohesion of the particles by the secretions of the termites has disappeared.

These morphodynamics result nevertheless more in a local redistribution of the materials of the termite mounds than in a general movement toward the lower slopes. The water run-off has the affect of spreading by wash erosion the particules constituting the hillocks as far as the center of the interpolated spaces.

The richness in silts and in pseudo-sands of the material, and its weak structuration are responsible for a "glazing" of the soils.

On the low slopes of the interfluve, upstream from the termite hills line marking the passage to the linking glacis, the slopes are generally steeper (3-4 %) and the soils sometimes in the beginning stages of leaching ; their sandier texture makes them especially sensitive to sheet erosion ; stripping is consequently more frequent there.

- on the "linking glacis" the present morphodynamics are of little importance. The environment is generally "penestable" that is to say that the balance is maintained by the presence of a grassland which covers the soil well, the glacis being not well cultivated. The material is however very fragile in its upper part, due to its sandy texture, and the cultivation (especially annual crops), rapidly sets in action the stripping.

Very localized landslides sometimes affect the upper part of the linking glacis at approximately the spring line. These shearings or gullying are provoked by the chemical drawoff of the material, waterlogged by sub-outcropping ground water ; this is intensified by the cattle.

Finally, we should mention frequent manifestation of concentrate morphodynamics on the small escarpment situated at the base of the linking glacis or of the floodable plain, cut in the swelling clays, and which overhang the alluvial terrace. It is a preferential zone of convergence of the running waters from the floodable plain or the glacis. The gullies which are formed there recede by headward erosion ; landslides are produced, which are carried away by the stream.

V - THE DIFFERENT TYPES OF ENVIRONMENT AND THEIR LIMITATIONS

A certain number of types of environment naturally emerge in the landscape. These morpho-pedological units are defined by a group of characteristics and specific processes which have strong reciprocal interactions, in particular :

- the landform, the topography, the morphodynamics
- the nature of the material
- the hydrological regime
- the pedogenesis processes.

It is not question then of pure soil units, which would offer little of interest, but of very strongly individualized natural synthetic units. The different components which characterize these units, can be sources of limitations for the growing of sugar cane.

Upon leaving the high points toward the River Kuywa, five major morpho-pedological units emerge :

- the well drained interfluve slopes
- the lower part of lightly hydromorphic interfluve slopes
- the linking glacis
- the floodable plain
- the alluvial terrace.

These units have already been defined in the preceding chapter concerning the general geomorphological description of the area.

We are now going to examine each one in detail. That will allow us to differentiate the various types of contraints and to draw out of each the consequences for the industrial cultivation of non-irrigated sugar cane.

1 - THE WELL DRAINED INTERFLUVES SLOPES

1.1 - Landform - Topographic position

The elongated interfluves consist of a slightly elevated landform with roughly convex summits : their width is approximately 2.5 kilometers. The difference in level between the rocky bed of the stream and the summit of the interfluve is from fifty to sixty meters. The interfluves are separated by wide hydromorphic zones ("linking glacis" and

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ALLUVIAL TERRACE | TEMPORARILY FLOODED LOWLANDS | LINKING GLACIS | INTERFLUVE

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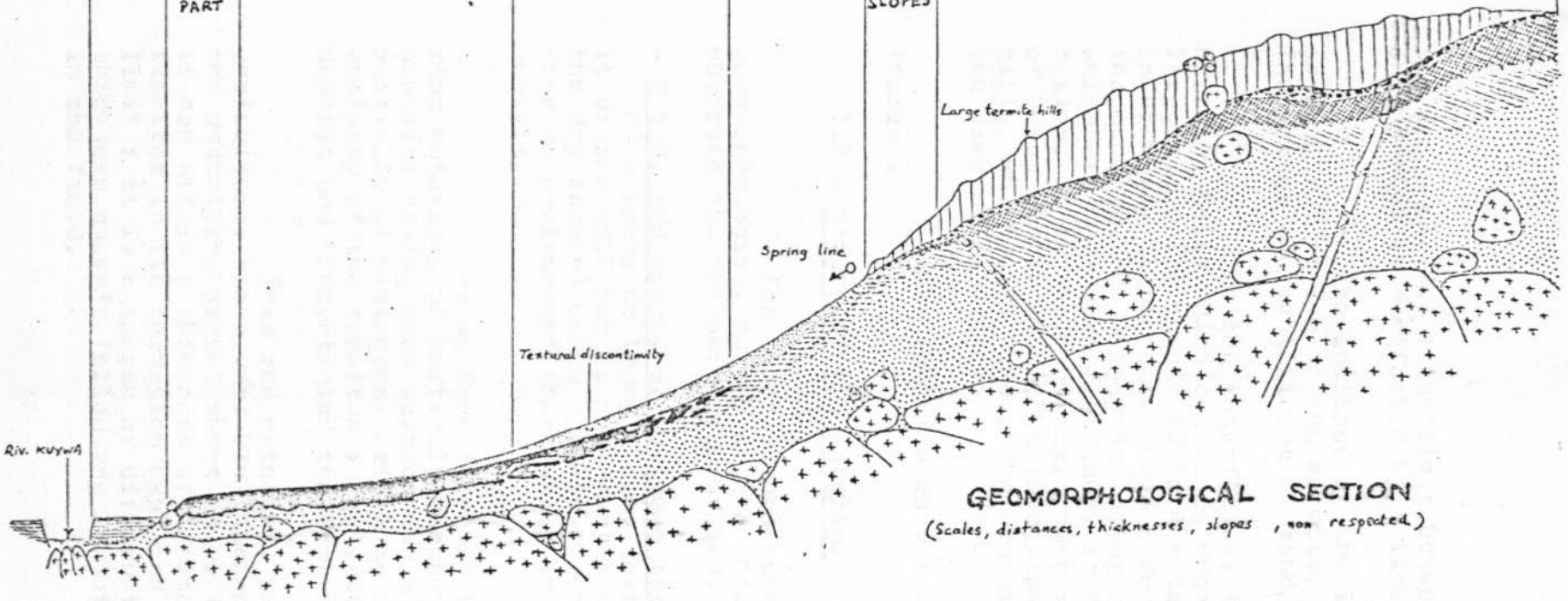
BETTER DRAINED PART | LOWER PART | UPPER PART | HYDROMORPHIC SLOPES | WELL DRAINED SLOPES



GEOMORPHOLOGICAL SECTION

(Scales, distances, thicknesses, slopes, non respected)

- Reddish homogeneous loamy COVERING MATERIAL (termite activity). 0 to 4 meters depth.
- Wavy irregular, more or less consolidated GRAVEL SHEET (ferruginous nodules, quartz gravels, some quartz pebbles)
- INDURATED PLINTHITE (autochtone). Alveolar structure.
- NON INDURATED CLAYEY PLINTHITE (Mottled clay) Waterlogged by ground-water during rainy season.
- COARSE TEXTURED LAYER : clay degradation and leaching, drawoff, due to fluctuation of watertable and hypodermic runoff.
- HYDROMORPHIC MOTTLED CLAY Waterlogged by water during rainy season
- MONTMORILLONITIC CLAY : neosynthesis, headward accumulation. Strong vertic characters.
- Friable, silty, MICACEOUS ALTERATION PRODUCTS. Presence of permanent ground water.
- ALLUVIAL DEPOSIT. 1 to 4 meters depth Brown-reddish color. Loamy-clayey texture.
- Discontinuous "BASEL GRAVELS"
- UNALTERED GRANITO-GNEISS Substratum or residual isolated blocks.
- QUARTZ VEIN

floodable plains) ; the limit between these two types of environment is manifested by a line of large termite hills.

The inclines of the interfluves are generally gradual : 0 to 2 % on the summits, 2 to 4 % on the slopes. The latter are rectilinear or tend to be convex.

On the interfluves, the termites are highly active, building hills which can be as much as four meters high. The largest termite mounds (2 to 4 meters high, 20 to 30 meters in diameter at the base) have a density of one per hectare on the average. But among the latter are found somme hillocks which are much more flattened, in different stages of degradation, or on the contrary, young termite hills in the course of being constructed. The topography in detail is thus very hilly, which will hinder the preparation of the terrain at the time of planting.

The interfluves are currently well cultivated (maize).

1.2 - Nature of the material

The material has been described above in the geomorphological survey of the whole. Let's recall that one observes the following succession, from top to bottom :

- A red, red ochre, or yellow material, homogenous, friable, of a loamy or loamy clayey texture without coarse elements ; it drains well but is permanently moist (even at the end of the dry season) below a depth of one meter ; the termites find an environment there which is very favorable to their activity.

As we have formerly stated, it is probably covering material, of partially morphodynamic origin (colluvial deposits having been washed down a short distance) and, partially of biological origin as a result of the intense activity of the termites : the latter have homogenized the deposit and concentrated the coarser particles at the base.

This red material, extremely interesting for agriculture, has a variable thickness : it can be lacking when the underlying gravel sheet comes to the surface but elsewhere it can attain a thickness of 4 meters. The probable role of termites in its formation explains the undulations of its lower limit ; it is a source of difficulty for mapping since its thickness doesn't follow any law of perceptible distribution in the field.

- A gravel sheet composed of a more or less consolidated agglomerate of :

  . ferruginous nodules (particles of hardened plinthite, but still rich in clay) from 0.5 to 5 cm. wide, red, ochre or blackish in color, very irregular in form, but generally not smooth.

  . fragments of all sizes of alveolar carapace (plinthite)

  . pieces of angular quartz of all siezs ; the quartz is often rotten ready to disaggregation ; it results directly from the dismantlement and from the reaping of the very numerous veins of quartz

  . some residual pebbles of quartz, of alluvial origin.

This gravel sheep is present everywhere under the covering material, but it is extremely irregular in composition (proportions and sizes of the various components), in thickness and in consistency. It seems that in general, the fragments of rugged quartz are more abundant at the base of the gravel sheet ; sometimes one find ferruginous nodules only, while elsewhere the gravel sheet may be composed solely of fragments of quartz. The frequency of the latter depends upon the local density of the veins. The fragments are more or less cemented together by iron ; they can be independent (absence of earthy matrix in general) and then they do not greatly impede the growth of the roots ; but in certain cases they are firmly welded together in a veritable conglomeratic cuirasse and then the gravel sheet constitutes a floor which is impenetrable to roots. The degree of consolidation, very important from the agronomic point of view, is not however capable of being mapped out when one takes into account its extreme variability. Finally, the thickness also varies greatly because the gravel sheet is very uneven.

The gravel sheet probably originated with the dismantlement of an original surface (end tertiary surface) more or less indurated in the zone of alteration, and of which the upper part has been reworked ; this has mixed the fragments of plinthite, broken veins of quartz and the existing superficial formations, un particular the alluvial formations of which the pebbles of quartz are all that currently remain.

The coarser fragments are currently found concentrated at the base of a covering material due to the action of erosive and biological processes that we have mentioned above.

- Mottled clayey-ferruginous alteration zone more or less firmly indurated (plinthite) : one passes now into the authoctonal unworked material ; the veins of quartz have not been disturbed here. The material, of a generally dark red

color, is of alveolar structure ; the alveoles more or less horizontally elongated, are empty or filled with a kaolinic clay which is pale and friable ; they are separated by anastomosed divisions hardened by iron. The whole can have a relatively friable consistency (especially in the lower part of the material), but it is generally firm, due to the effect of hardening processes (more or less pronounced). In general, the consistency is that of a hardpan, that is to say, that the material is breakable by hand, but locally one can find a real cuirasse which is very hard.

These alteration products are generally thick (several meters) ; one often observes oblique fissures which cut across one another, and which can be the evidence of settling, originating from the chemical draw off which occurs at lower depths in the sandier alteration products saturated with ground water.

The indurated material evolves very little from the bio-geochemical point of view ; it is inherited from ancient pedo-climatic conditions and represents a former hydromorphic "ferrallitic" alteration zone where ground water used to circulate ; the latter, as a consequence of a change in the base level or of a drying up of the climate, was lowered (it is presently situated at a depth of about 15 m), which created the irreversible induration of the alteration products.

- A loamy-sandy alteration zone situated underneath the preceding level (progressive passage), less clayey and less ferruginous than the latter. The minerals are easily recognizable (kaolinised feldspars, flakes of mica), as well as the structure of the rock. It represents the presently active alteration zone of the basement (hydrolisis, chemical draw off), of which a large part is saturated with the ground water.

The material is friable, loamy to loamy-sandy, of a pale color (light red). These alteration products can be quite thick, about 10 meters ; they progress in depth along the fissures of granite which widen ; subsisting residual boulders deteriorate into concentric shales.

- Unweathered rock, granite, granodiorite and schists, are found in river beds. One finds them also in the shapes of partially visible domes, large isolated blocks, and field-blocks on the summits of interfluves. It is a question then of residual granite cores having resisted "ferrallitic" alteration because of a progressive lowering of the landform (mechanical or geochemical leveling). Large blocks of residual granite can subsist at the interior of any one of the materials that we have just described. Their alteration can really only

proceed at the base of the succession ; it is only at the interior of the loamy-sandy alteration zone that the hydrolosis of minerals (ground water) is capable of being maintained : above, the blocks are "fixed" and practically no longer alter. On the surface then these blocks often form outcrops without roots in the immediate neighborhood of which the soils can be very deep.

1.3 - Hydrological regime

- Ground water impregnates a part of the present loamy sandy zone of alteration. This water is often deep ; wells are rare on the interfluves the inhabitants prefer to look for water at the place where the spring emerges, at the head of the linking glacis.

- the surface waters (rain) seep rapidly down, the material is in effect highly filtering. At no moment does the rainwater stagnate on the surface or at any level under the soil ; the red upper material never shows signs of hydromorphy. There is thus no problem of drainage.

1.4 - Environment and processes of pedogenesis

It is now necessary to distinguih what happens in depth at the level of the initial and present alteration of the basement, and where chemical processes predominate, from what takes place in the upper part of the section where the biological and physico-chemical processes prevail.

It is necessary to give equal consideration to the present processes and to those of the past. The latter may be fixed, but are also capable of being the center of current superimposed processes.

We can distinguish from bottom to top :

- the current deep geochemical processes, which take place in the loamy-sandy micaceous alteration zone. The ground water which impregnates this material assures the hydrolisis of minerals and the elimination of soluble products ; it is a "ferrallitic" alteration on which we shall not insist since it doesn't present any direct interest for agricultural development. This initial alteration zone evolves little by little towards the upper part, by clayification and a certain iron segregation, in order to produce a hydromorphic mottled clay.

- The material of inherited pedogenesis, without present notable evolution

  . The mottled hydromorphic clay, passes progressively to a firmer and firmer material which ends up by hardenning into alveolar indurated plinthite. This induration is the result of a rather rapid reduction of the ground water at a moment of the Quaternary (lowering of the base level), which accelerated the segregation of the iron impregnating the material. This "indurated plinthite", paleoclimatic inheritance, is "fixed" and no longer evolves when the clayey alveoles, delimited by the ferruginous rigid divisions, have been degraded or leached.

  . The gravel sheet situated above the plinthite arrived at a senile stage of maximum concentration by the termite, when there practically no longer exists any clayey matrix between the coarse fragments.

- Current processes in the red covering material

It is not easy to distinguish the present and the past in what concerns the physical chemical characteristics such as rubefaction ; it is probable that the permanent mixing and reworking by the termites has been assuring excellent drainage for a very long time, which is an essential condition for rubefaction.

The present processes are of essentially biological origin : the termites have an intense activity under the surface as well as above, in the termite mounds. There is a permanent process comprising : the raising of soil particles from down deep towards the surface (numerous hypogeum galeries), the elaboration of the termite hill, and finally its degradation by erosion ; the rounded dome-like shape at the summit is the result of the concurrence between the biological deposits and the reworkings by rain erosion on the sides (wash erosion, landslides).

The material of the termite hill is clayey-sandy-loamy ; the cavities are demarcated by rigid partitions (secretions of the animals). At the base of the termite hill is often found an accumulation of coarse calcareous segregations, with angular edges and capable of being 20 cm large. These large nodules are never found again in the soils ; they dissolve rapidly at the time of the degradation of the termite hill.

Between 20 and 60 cm deep, the soils systematically show a firm and relatively well structured level which contrasts with the friableness and absence of structure of the horizon

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- Horizon " B " located below 60 cm depth, is limited to a variable depth (up to several meters) by a gravel sheet which is more or less consolidated. The color is very bright : ochre or red (5 YR 5/6 - 4/6 ; 10 R 5/6 ; 2,5 YR 5/6) and never observes coarse elements ; the texture is sandy-clayey-loamy. The granulometric analysis indicate on the average : 27 % clay - 20 % silt - 53 % sand. But it is necessary to point out that the manual estimation of the size distribution on the field indicates a clay content less than the analytic results, this giving the impression of a coarser texture. This is due probably to the abundance of "pseudo-particles" representing a particular link between the amorphous iron and the clay surfaces.
The consistence is very friable when moist, sticky and slightly plastic when wet ; the horizon is structureless (absence of cracks and differentiated aggregates). The prosity (tubular) is excellent ; the material drains well ; one sees no trace of hydromorphy. The content of non negligeable organic matter (1 %) could have originated with the mixing by the termites. The supply of total phosphorous is on an average of 205 ppm. The base exchange complex has an exchange capacity of 6,1 me/100 g ; the sum of the exchangeable bases is about 2,65 me/100g (saturation 40 %) ; the pH is 5,5.
The available water (AW) reserve is 7,2 % in volume, that is to say, taking into account a bulk density of 1,14, about 82 mm per meter of soil.

- The more or less consolidated gravel level underlies the preceding level (clear discontinuity) and has an extremely variable depth. This level was described above ("nature of the material") ; it consists of about 80 % coarse elements : ferruginous nodules, pieces of indurated plinthite, quartz fragments in relative proportions which are highly variable. This level may be non consolidated, the fine roots then being able to pass through it, or else consolidated, and then totally impenetrable.

Classification

. French classification : these soils belong to the "class" of "ferrallitic" soils. The "subclass" is determined by the base exchange complex in the "B" horizon : the total of the exchangeable bases is 2,65 me/100 g, the saturation is 40 %, the pH is 5,5. These characteristics permit us to arrange the soils in the subclass : "ferrallitic soils of a poorly average desaturation in B". At the level of the "group" the biological reworking of the horizon (B) obliges us to arrange these soils in the "groupe remanié". In terms of the depth of the gravel sheet we will place it in the "subgroup " : indurated" "reworked" or "medal".

. F.A.O. classification : the red soils of the region of Bungoma are placed in the category of the "ferralsols". When the indurated plinthite is at more than 125 cm depth, it is put in the classes of "orthic" or "rodic" ferralsols. When this plinthite is less than 125 cm deep, the soil is classified as a "plinthic" ferralsol : "petroferric" phase when the plinthite is a true cuirasse and it is located between 50 and 100 cm depth, "lithic" phase if this cuirasse is less than 50 cm deep, "petric" phase when the non cemented gravel sheet is located at less than 100 cm deep.

1.6 - Constraints for the growing of sugar cane

The principal limitations on agricultural development and more especially on the growing of sugar cane are due to the important density of termite hills on one hand and the available depth of the soil on the other.

- the presence of large termite hills is general. The hillocks from two to four meters high, 25 to 35 meters at the base, occupy 10 % of the total surface at the rate of 1 per hectare. The mesorelief is then important, and leads to a limitation which cannot be overlooked in the work of setting of soil to sugar cane. The leveling of the termite hills by bulldozer is indispensable and costly ; however, once leveled they begin to be rebuilt little by little.
We should point out also the role of the termites themselves as possible parasites of the cane.

The termite hills constitute a common constraint to the whole of the interfluves. They seem nevertheless a little less frequent when the gravel sheet or the cuirasse are sub-outcropping.

- the depth of the soil. The principal soil constraint procedes from the presence at a certain depth, of a level of hardpan or gravels capable of stopping or impeding the rooting of the cane. We have distinguished 4 classes of depth according to which the gravel sheet could be located :

  . between 0 and 50 cm depth
  . between 50 and 100 cm depth
  . between 100 and 150 cm depth
  . more than 150 cm depth.

. Indurated plinthite or gravel sheet between 0 and 50 cm depth. This unit is characterised by a great heterogeneity ; the level forming an obstacle can have a consistence and a composition varying greatly within a very short distance. It is a question either of a hardpan (carapace) or a cuirasse (harder) which cannot be penetrated by roots

(in this case it is an absolute obstacle), or of a level of non cemented gravels (ferruginous nodules, quartz fragments) ; we have then a constraint to rooting, but which is not redhibitory in itself.
The cementation and the induration, which vary according to places and are not predictable, have necessitated the regrouping in a single unit. Considering this heterogeneity, the frequency of a discontinuous cuirasse outcropping, the minor thickness usable by the roots, this unit is the least favorable of the interfluves ; the soils there are especially sensitive to dryness, the sugar cane yields will be very irregular and will reflect the heterogeneity of the land.
A deep sub-soiling, breaking the upper part of the hardpan is not likely to be effective, since this indurated plinthite, when present, tends to be quite deep.
This unit of sub-outcropping cuirasse or gravels is especially located on the summits of the interfluves, particularly on the left bank of River Kuywa.

- Indurated plinthite or gravel sheet between 50 and 100 cm depth : like the preceding unit, the latter is marked by heterogeneity due to the variability of the state of cementation and induration of the gravel sheet (distribution in "mosaïc") ; it is however a unit already more favorable in spite of the weak water supply. It the upper friable material, the available water content is between 45 and 85 mm ; however, it is the most unfavorable case since we don't take into account the non-negligeable, but unknown, water reserve of the gravel level when this one is not consolidated.
On this unit, sugar cane risks suffuring in the dry season ; the reaction to dryness will not be the same everywhere, but on the whole, there will be a depressing effect. We classify this unit as having a mediocre aptitude for industrial growing of sugar cane.
This class of depth of the gravel sheet is located in rings around the sub-outcropping unit, that is to say, essentially on the interfluves of the left bank of the River Kuywa.

- Indurated plinthite or gravel sheet between 100 and 150 cm depth : the spatial variability of the state of cementation, so the importance of the obstacle, is always very great, but the seriousness of this constraint of heterogeneity of the environment tends to diminish with the depth of the gravel sheet. Here the roots have a vital space which is sufficient, although not optimal ; the available water supply in the red friable material, above the impenetrable or simply bothersome obstacle, is between 85 and 125 mm, but the gravel sheet, when it is not cemented, then in a very uncertain way, can equally furnish water.
The suitability for sugar cane is medium to good.

. Indurated plinthite or gravel sheet at more than 150 cm depth : this unit contains the best soils of the region. They have a great depth and excellent physical properties. Their available water supply is superior to 125 mm. In spite of the presence of large termite hills, which are present everywhere, and which it will be necessary to put up with, these zones with deep soils, well drained, have a good suitability for sugar cane.

- The risks of stripping

As the first works in preparing the soil has shown, at the time of the installation of the nursery, the soils of the interfluves are rather sensitive to sheet erosion. This sensitivity which is due to the richness of the material in silt and in pseudo-sands (weak structural stability), is accentuated by the meserelief created by the termite hills ; the morphodynamics are manifested on the flanks of the domes devoid of vegetation and which steep slopes ; under the present agricultural conditions, the material of the termite hill is spread out in rings around it ; it doesn't seem to have any generalized transportation downstream, but simply local redistribution ; the environment is on the whole then stable ; but when the soil is laid bare in large plots a general sheet erosion is possible, until minima covering by the cane plants is assured. The general incline of the terrain can attain 4 % on the slopes of the interfluves, which taking into account the fragility of the soil is an strong value. In order to limit these effects, it would be preferable to carry out all the works by roughly following the contour lines.

2 - THE HYDROMORPHIC LOW SLOPES OF THE INTERFLUVES

This distinction is based on a change of hydric regime in the material, which is manifested by a environment of pedogenesis marked by a more or less pronounced hydromorphy thus by different soils from those of the well drained interfluves.

This type of environment is characteristic of certain positions of low slopes, above the termite hills line ; although still forming part of the interfluve, these units make the transition with the really hydromorphic "linking glacis" ; they announce the "chemical drawoff of the slopes, which begins at the summit of the linking glacis, beyond the line of termite hills. The passage from the well drained slopes with red soils to the slightly hydromorphic low slopes, is made progressively This unit is not generalized ; it forms a discontinuous fringe , the inclines, with a convex tendancy, are from 2 to 4 %.

The original material is the same as that of the well drained slopes, it is modified by the hydromorphic

processes in the covering layer.

We have distinguished two sub-units in terms of the morphology of the soils and the intensity of the hydromorphy.

2.1 - The soils having a fine texture

These soils are affected by a hydromorphy which is not very pronounced, and which is manifested by small red mottles beyond the depth of 1 meter. Their color on the whole tends more towards yellow than towards red. Except these characteristics of color, the soils of this unit are completely similar to the well drained red soils described above. We refer then to the description of these soils.

The hydrological regime is characterized by a fluctuation of the water table below the depth of 1 meter. It is probably the same ground water which, on the summit of interfluves, is much deeper, and which approachs the surface little by little at the base of the slope. The minor hydromorphic characters indicate however that the saturation of the soil by the ground water, when the latter swells during the rainy season, is not prolonged, and that the soil reoxydizes rapidly.

According to the French classification, these soils are located among the "ferrallitic" soils weakly to moderatly desaturated, hydromorphic.

The F.A.O. classification places them among the "gleyic ferralsols".

The constraints for the growing of sugar cane are minor. The rooting will not suffer from this hydromorphy in depth, considering its weak intensity and its weak duration.

Naturally the constraints of the termite hills is a constraint as it was for the preceding soils, as well as sensitivity to sheet erosion in case of denudation on a large surface in rainy season. The slopes are relatively steep (up to 4 %).

2.2 - The coarse textured soils

These soils of the low slopes have arrived at a more advanced stage of degradation than the preceding soils ; their morphology tends to approximate the soils of the hydromorphic "linking glacis" which begins more downstream.

- the hydrological regime is characterised by a strong fluctuation of the water-table, affecting the whole of the material up to the surface ; the waterlogging seems to be produced at the end of the rainy season, when the ground water is swollen at the maximum ; at that moment, a hypodermic flow is produced. The interconnected actions of the fluctuation of the water table and of the hypodermic runoff result in a progressive impoverishment of the soil, in clays ; the latter are degraded and their products are evacuated toward the low zones of the landform.

- the morphology of the soil

  - the humic top horizon is about 20 cm thick. The color is dark gray (10 YR 3/1), without mottles. The texture is loamy-sandy to sandy-loamy (about 12 % clay - 17 % silt - 71 % sand). The structure is generally very fragile ; there are no coarse elements ; the consistence is very friable when moist, non plastic and not sticky when wet ; the horizon is very porous, and filtering. There is from 4 to 5 % organic matter (C/N = 11), the available water supply (difference between humidity at pF 2,5 and humidity at pF 4,2), is about 10 %. The bulk density being on the order of 1,20 this supply is about 24 mm per 20 cm of soil. The total phosphorous is about 200 ppm. The exchange capacity is 8 me/100 g ; the sum of the exchangeable bases is about 6 me/100 g ; the pH (water) is about 5,50.

  - The intermediate horizon, located between 20 and 40 cm deep, is of a dark grayish-brown color (10 YR 4/2) ; no mottles ; the texture is sandy-loamy (10 % clay - 10 % silt - 80 % sand) ; there are no coarse elements ; structureless ; good porosity ; consistence very friable when moist, non plastic and slightly sticky when wet. The proportion of organic matter is on the order of 2 to 3 % (C/N = 11). The available water supply is about 10 %, that is to say about 24 mm for a slab of 20 cm. The exchange capacity is from 4 to 6 me/100 g, the sum of the bases on the order of 3 me/100 g ; the pH is 6.

  - the leached mineral horizon, located between approximately 40 and 80 cm deep, is of a rather light color (10 YR 4/2), one frequently observes numerous brown faint mottles ; the texture is sandy-loamy (6 % clay - 10 % silt - 84 % sand) ; there are no large elements ; structureless ; excellent porosity ; the consistence is very friable when moist, non plastic, neither sticky when wet. The available water supply is on the order of 7 % that is to say about 35 mm for a slab of soil of 40 cm. The exchange capacity is about 5 me/100 g and the total bases from 1 to 3 me/100 g ; the pH is from 5 to 6.

- the loamy clayey sandy horizon in process of degradation is a mottled clay, very hydromorphic : red or yellow mottles on a light gray background. The texture passes progressively from sandy-loam to clayey-sandy-loam, then to sandy clay in depth. The structure is medium angular blocky ; the consistence is friable to firm when moist, sticky and plastic when wet.
  The available water supply is on the order of 10 % (in volume) that is to say 135 mm per slab of soil of 1 meter of thickness (bulk density = 1,35). The exchange capacity is on the order of 13 me/100 g, and the sum of exchangeable bases is 2,5 me/100 g ; the pH is 6.

Classification :

In the French system these soils are placed in the category of "hydromorphic mineral leached gleysoils".

In the F.A.O. classification, they are classified as "gleyic luvisols".

- Constraints for sugar cane

Besides the mesorelief created by the termite hills, two unfavorable characteristics devalue these soils : the temporary waterlogging and the susceptibility to sheet erosion :

- waterlogging : the swelling, at a certain period of the rainy season, of the ground water, saturates the soils. This waterlogging, without being redhibitory, can be prejudicial to the sugar cane roots, thus to the crop yields. In these zones, drainage is desirable.

- stripping : The sandy soils, with weak structural stability, are predisposed to sheet erosion. The latter is presently evident in numerous places, more frequently than on the red soils located more upstream. It is to be feared that at the time of preparing the soil for planting, the morpho-dynamics will start in a more generalized way.
  Considering these reservation, we will consider this unit to have an average suitability for sugar cane, completely acceptable if one combines it with a drainage plan.

3 - THE "LINKING GLACIS"

3.1 - Landform - Topographic position

The linking glacis is well demarcated upstream by a clear line of large termite hills which separate it from the properly so called interfluve slopes. In the aerial photographs, the distinction between these two large units is very clear : the linking glacis is characterized by a darker gray due to the hydromorphy of the material, to the numerous water seepages, the minor importance of cultivation and of termite hills ; these zones are generally used to pastures.

The glacis is concave ; in the upper part the incline is from 2,5 to 4,5 % ; it diminishes downstream (1 to 2,5 %), where the glacis joins either directly the stream, or progressively the plain with temporary flooding.

On the Nucleus Estate, when the linking glacis is oriented towards the River KUYWA, this one is quite wide in place. IT reaches 950 meters on the right bank ; the upper slope is then about 3 %. In other places, in particular to the south of the site, it is very narrow, its upper incline is then stronger (5 %) and it is cut directly by the river or by the alluvial terrace which is inset in it.

3.2 - Nature of the material

We have never observed any profound section in the material of the linking glacis, as we had been able to do in the material of the interfluve, so that we do not know what takes place below 160 cm of depth. As we have shown ; the linking glacis derives from the slopes by regressive geochemical drawoff ; it is then likely that the succession of materials there is the same as on the slopes situated upstream from the line of termite hills ; that is to say that from bottom to top, there must be : unweathered rock, rather sandy autochtonal alteration products, clayey and hydromorphic autochtonal alteration products, a ferruginous and quartz gravel sheet, and finally a covering layer.

The present geochemical processes (degradation of clay, drawoff) are produced in this covering layer and in the upper part of the clayey hydromorphic alteration products. These two material present then different aspects from those observed on the well drained interfluves. The profiles will show us an upper sandy part (impoverished in clay) then, in depth, a mottled kaolinic clay, in the upper part of the glacis, while in the lower part, this clayey level becomes richer and richer in montmorillonite in order to form a very compact floor.

3.3 - Hydrological regime

The linking glacis is a place of discontinuous emergence of the ground water. The latter, which was deep on the slopes of the interfluves, comes to recut the surface immediately downstream from the "termite hill line". A line→ of springs located roughly at the head of the glacis, in a more or less permanent way, in order to spread out in large cones ; certain springs serve to provide water for animals ; the zones of permanent seepage are swampy ; one sees there "semi-peaty" soils.

At the height of the rainy season, when the ground water is sufficiently swollen, the water is outcropping or sub-outcropping on almost the whole of the glacis, which then becomes nearly impractical. Except the permanent springs, the ground water seems to fluctuate between the surface and two meters deep ; when the sandy top soil is saturated by water, a hypodermic flow is produced .

3.4 - Environment and processes of pedogenesis

- in the upper part of the linking glacis

The hydrological regime of water table fluctuation up to the surface, and of hypodermic flow, vertical and oblique at the same time, leads to a progressive degradation of the kaolinic clays of the covering material" of the interfluves ; the products of degradation are evacuated downstream where a part will be able to recombine in order to produce neosynthetised, swelling clays.

The upper part of the linking glacis is a departure zone of materials in solution ; the front of impoverishment of the soil in not abrupt ; it is not underlined by a textural discontinuity as will be the case further dowstream. The mottled very hydromorphic kaolinic zone where one frequently sees large canals in which the groundwater flows, goes through a slow process of degradation which only leaves a sandy skeleton. The draweff is accompanied by a settling of the material ; this process of chemical draweff progressively attacks the slope of the interfluve which recedes to result in the enlarging of the linking glacis ("geochemical leveling"). The termites, which cannot endure prolonged waterlogging take refuge above the glacis, at the level of "draweff front" and there rebuild their edifices. Certain termite hills can last on the glacis but it is rather rare.

- In the lower part of the linking glacis

In proportion as the slope of the glacis diminishes the environment becomes more and more confined ; there is a competition between the neoformations of montmorillonitic clay in depth and the processes of degradation by hypodermic flow. The elements in solution (bases, silica), which originate from the leaching of the head of the glacis, permeate the kaolinic clay of the part downstream and recombine in order to produce swelling clays. The vertic characters are more and more pronounced from the head towards downstream.

Above the clayey flour, the hypodermic runoff tends to become more intense by a reduction of the permeability of the material, and there is created then at this level, an abrupt textural discontinuity between a surface material of coarse texture (40 to 70 cm thick) and a very clayey, vertic material below.

3.5 - Characters of the soils - Classification

3.5.1 - In the upper part of the linking glacis

When they are not permanently waterlogged, the soils present the following average characters :

- The humic top horizon (A_1) : 20 cm thick, very dark gray (10 YR 3/1) ; without coarse fragments, loamy to sandy-loamy texture (19 % clay - 35 % silt - 46 % sand) ; weak medium subangular blocky structure ; consistence very friable when moist, non plastic and slightly sticky when wet ; the organic matter content is 4,3 % (C/N = 11) ; total phosphorous content is 140 ppm ; available water supply is 13 %. The base exchange capacity is on the order of 9 me/100 g ; the sum of exchangeable bases is about 6 me/100 g ; the pH (water) is 5,55.

- The intermediate horizon (A_{12}) : situated between 20 and 40 cm depth, is dark grayish brown (10 YR 4/2) ; there are no coarse fragments ; the texture is loamy-sandy (11 % clay - 30 % silt - 59 % sand) ; structureless ; the porosity is good ; the consistence is friable when moist, non plastic and slightly sticky when wet. The organic matter content is about 2,2 % (C/N = 11) ; the total phosphorous content is 100 ppm. The available water supply is about 12 % of the total volume. The base exchange capacity is on the order of 4 me/100 g, the sum of bases of 2,3 me/100 g. The pH is about 6.

- The mineral leached horizon (A_2), between 40 and 100 cm depth (on the average), is light (10 YR 6/2), without coarse elements ; the texture is still loamy-sandy (4,5 % clay - 41 % silt - 54,5 % sand) ; structureless ; tubular porosity is well developed ; the consistence is friable when moist, non plastic, non sticky when wet. The available water supply is about 8 % (of the volume). The exchange capacity is 5 me/100 g and the total exchangeable bases are 1 me/100 g. The pH is 6.

- The mottled kaolinic clayey horizon (Bg), begins at about 100 cm depth ; the texture passes progressively from loamy-sand to sandy-clay-loam then to sandy-clay. The average texture is sandy-clay-loam (30 % clay - 21 % silt - 41 % sand), no coarse elements ; the structure is medium to coarse angular blocky, rather well developed. Porosity is good. The consistence is firm to friable when moist, plastic and sticky when wet. The available water supply is on the order of 11 %, that is to say 143 mm per meter of soil (bulk density = 1,30).

The soils which are permanently and entirely waterlogged by the ground water, present a topsoil of about 20 cm thick, of the "hydromor" type, of a black color, with fibrous structure (undecomposed organic debris) and with weak bulk density .

Classification :

- French classification : "hydromorphic mineral leached gleysoils", when these soils are not permanently waterlogged, or "hydromorphic semi-organic humic leached gley soils"with "hydromor-horizon", when they are permanently waterlogged.

- F.A.O. classification : "gleyic luvisols" and "humic luvisols" (or "humic gleysols").

3.5.2 - In the lower part of the linking glacis

- Humic horizon (A_1) : 20 cm thick ; dark gray (10 YR 4/1) ; no coarse fragments ; loamy to loamy-sandy texture (16 % clay - 40 % silt - 44 % sand) ; weak medium subangular blocky structure ; very friable when moist ; non plastic and slightly sticky when wet ; about 6 % organic matter (C/N = 12) ; 200 ppm total phosphorous ; available water supply : 18 % ; bulk density on the order of 1 (then 36 mm water supply for 20 cm of soil). Exchangeable capacity about 13 me/100 g ; exchangeable bases : 7 me/100 g ; pH on the order of 5,4.

- Intermediate horizon (A_{12}) : 10 to 20 cm thick ; color grayish brown (10 YR 4/2) ; no coarse elements ; loamy-sandy texture (14 % clay - 34 % silt - 52 % sand) ; structureless ; good tubular porosity ; friable when moist , non plastic and slightly sticky when wet. About 3 % organic matter (C/N = 11) ; available phosphorous content = 100 ppm.

- leached mineral horizon (A_2) : 20 to 50 cm thick, light (10 YR 6/2) ; some faint brownish mottles ; no coarse elements. Loamy-sandy texture (11 % clay - 34 % silt - 55 % sand) ; structureless ; very friable when moist ; non plastic, non sticky when wet ; very good tubular porosity ; about 13 % available water ; organic matter = 1,5 %. Base exchang capacity = 6 me/100 g ; exchangeable bases = 2 me/100 g ; pH = 5,5.

The passage to the next horizon is marked by a wavy abrupt discontinuity.

- Upper part of the clayey material (B_{1g}) : situated about 50/70 and 90 cm depth. Dark grayish-brown color (10 YR 4/2) ; many yellowish mottles ; clayey texture (65 % clay - 11 % silt - 24 % sand) ; well developed coarse to medium angular blocky structure ; fine sub-structure ; many small rounded iron-manganese concretions (2-4 mm) ; the consistence is firm when moist, sticky and plastic when wet ; no clear slicken-sides yet. The available water supply is about 10 %. Exchange capacity = 36 me/100 g ; exchangeable bases = 23 me/100 g (saturation = 65 %) ; pH = 5,6.

The upper part of this horizon is frequently underlined by a line of small rounded iron-manganese concretions (2-5 mm diameter). This line has a variable thickness (1 to 10 cm) and it is wavy.

- the clayey vertic material (B_{2gv}), of a grayish-brownish to dark grayish color (10 YR 4/1) begins at about 90 cm depth, with the presence of very large slicken-sides and a large prismatic structure (when dry) ; the vertical prisms are 20 cm wide and are separated by cracks 1 to 2 cm width ; they have a coarse angular blocky sub-structure. The texture is very clayey (68 % clay - 12 % silt - 20 % sand) ; there are no coarse elements, but one observes some small rounded iron-manganese concretions. The consistence is firm when moist, sticky and plastic when wet, very hard when dry ; the aggregates have a very weak porosity ; in depth (150 cm) one sometimes observes large calcareous concretions. The available water supply is about 15 %. Exchange capacity = 50 me/100 g ; exchangeable bases = 30 me/100 g ; pH = 6,3

Classification

The present processes of pedogenesis are :

- hydromorphy, during the rain season
- leaching and degradation of clays in the upper part with the apparition of a planic character (discontinuity)
- the confinement and neo formation of swelling clays in depth, showing up through vertic characters.

These soils will therefore be called "hydromorphic mineral, vertic, leached and planic gleysoils" (French classification).

In the F.A.O. classification, they are called "gleyic luvisols" with a planic character and vertic properties.

3.6 - Constraints for sugar cane

- Soil waterlogging

The main constraint is due to unfavorable water regime.

A part of the glacis is the site of permanent flow down-stream from the springs ; in this zone, soils are permanently water-logged by the outcropping water-table. Other zones of the glacis are water-logged during the rain season only and the soils in these zones depend on the ground-water table fluctuation. Both zones are demarcated on the map, but it will be difficult to distinguish them in the drainage network, which is necessary to them both. The zones have already been drained in the past, but the drain-ditches have not been maintained so that the whole network shoud be re-organized. The network could be composed of drain-ditches roughly perpendicular to the slope, draining the surface waters and depressing the ground-water table during the rain season ; other drain-ditches could be built perpendicular to the drain-ditches mentionned above to discharge the waters into the river.

- The coarse texture of the upper part of the soils

This texture may have three unfavorable results :

. The material, because of its weak structural stability, is potentially unstable. The existing grassland is an efficient protection to the soil against rain aggressivity. The cultivation works which will abruptly lay the soil bare, will expose it to stripping ; if precautions are not taken, this stripping may take great proportions ; this is the reason why we advise the building

of benches perpendicular to the slope and inserted between the drain-ditches. The plots will be of extended shape following the contour lines.

. The coarse texture of the soils is the cause of their fairly low water-supply ; during the dry season, and without any irrigation, the canes may suffer from lack of water.

. The considerable lateral drainability of the upper sandy layer is prejudicial to a good retention of the fertilizing elements which are leached during the rain season.

- Specific constraints for the lower part of the linking glacis

. The presence of an abrupt discontinuity in the texture : during the dry season, this discontinuity can result in a real "detachment" of the sand layer and a horizontal crack 5 to 10 mm wide. This can be a considerable constraint for the rooting of the cane and can reduce the available soil depth. This discontinuity also interferes with a good water-supply to the canes (capillarity failure).

This discontinuity can generally be found at a depth of approximately 50 to 60 cm ; a deep sub-soiling could eliminate it ; this would result in an intermediate horizon. Taking into account the compact nature of the clayey floor, this sub-soiling should preferably be carried out at the beginning of the rain season, after a sufficient moistering.

. High content in clay and vertic characters in depth : the high proportion of swelling clay (montmorillonite) results in swelling phenomena during the rain season and a considerable shrinkage during the dry season which harms the perennial root-system.

The swelling of the material results in important frictions among the clays, the origin of very large "sliken-sides". These frictions may cause the shearing of the roots. The shrinkage of the clays is on the contrary accompanied by an important vertical crack which may damage some roots.

When in their maximum swelling, these clays are practically impervious. Therefore somme difficulties in drainage must be expected. Moreover, if the drain-ditches are deep, frequent maintenance will be required, since they may collapse because of this swelling-shrinkage alternation of the clays.

4 - THE TEMPORARILY FLOODED PLAIN

4.1 - Landform - Topographic position

This plain is essentially situated along the right bank of the KUYWA river. It is situated in the prolongation of the linking glacis because of a progressive reduction of the slope. The slope of the "plain" is inferior to 1 % ; its width reaches 800 metres. The potentially flooded plain which is hydromorphic to a high degree is not cultivated ; it constitutes a huge transit area for the cattle during the dry season. On the aerial photographs it is quite distinct from the linking glacis since a network can be clearly seen in this area ; this network more or less oriented at places, is composed of light and dark strips in juxtaposition. The light strips correspond to zones which are not flooded, being slightly higher than the dark ones which are flooded during the rain season. This could be the result of very wide undulations of the ground, slightly similar to the "Gilgaï" ; its origin would be the underground movements of the differential swellings of the highly montmorillonitic clays which constitute the material of the plain. The flooded zones which represent the main part of the plain, present a network of small anastomosed mounds (30 to 40 cm high) with steep sides. These mounds, very likely of biological origin (worms ?), are composed of a tangle of vertical stems and roots graminaceae agglomerated by a silty cement, raised up by animals. These mounds make progression in the plain very difficult.

4.2 - Nature of the material

The zone of sandy alteration, rich in minerals can be found in depth, above the granito-gneissic basement. A material extremely clayey, rich in montmorillonite, 2 to 4 metres thick, can be found above. On the surface a silty layer, 20 to 60 cm thick can be found resulting essentially in the anastomosed mounds.

This material is therefore quite different from the material of the interfluves, although it derives from it through geochemical processes (degradation of clays, leaching, neoformations, settlements of materials ...).

4.3 - Hydrological regime

The definition of the hydrological regime is slightly problematic. Apparently there is a water-table fluctuation regime and a flood regime due to the surface waters running from the linking glacis and the slopes.

(degradation, leaching) ; the lower part of the glacis is a mixed area (degradation, leaching as well as neo-formation of clay) ; the plain is an area of accumulation of clay, all the more saturated as one goes downstream. This is why the innermost part of the flooded plain still possesses a clear top soil with a coarse texture (sandy silt), which is underlined at its basis by an abrupt textural discontinuity (planic character). This discontinuity is due to the progressive spreading of clay from the lower parts of the profile towards the upper parts as well as to the hypodermic surface water which owes its importance to the fact that the material lower down becomes practically impervious.

On the contrary the top soil of the downstream part of the plain is thin, more silty than sandy and it essentially constitutes the biological mounds ; in this part of the plain, the original sandy residues from the degradation of the materials of the slopes, has practically disappeared, being completely invaded by the neosynthetized clays.

These montmorillonitic clays, present strong vertic properties ; this means they swell during the rain season being subject to important internal movements which result in "sliken sides" quite visible in the profiles ; during the dry season these clays shrink enormous prisms which are very hard and separated by large cracks.

The confinement of the environment results in the formation of calcareous nodules in depth (more than 1.40 m).

As a conclusion, the consequences of this pedogenesis environment which will be the origin of constraints to cane cultivation, are as follows :

endohydromorphy (water logging by means of saturation of the cristalline network of the clays), during the rain season, together with the flood due to the surface water from upstream, the internal movements of the clays, and the hypodermic surface water above the textural discontinuity line.

4.5 - Characters of the soils - Classification

In the upstream part of the floodable plain, the soils present the following average characters :

. from 0 to 30 cm : mound, very probably formed by biological raising, silty particles along the stems of graminaceae. The color is blackish to dark grayish (10 YR 4/1). Rust red coating along the roots. The texture is very fibrous (vertical tangle of roots and stems). Loamy texture (26 % clay - 48 % silt - 26 % sand, most of the sand being fine). The consistency is friable when moist, non plastic or sticky when wet ; low bulk density (0.6). The organic matter content is about 6 % (C/N = 12). The

available water supply is 23 %. The total phosphorous content is 230 ppm. The exchange capacity is about 19 me/100 g and the sum of exchangeable bases is 23 me/100 g ; the pH is about 5.5

. from 30 to 60 cm : leached horizon (A2). The color is grayish brown (10 YR 5/2) ; red rust coating along the numerous fine roots. Structureless ; loamy texture (25 % clay - 48 % silt - 27 % sand) ; no coarse elements ; important tubular porosity ; the consistence is friable when moist, non plastic and slightly sticky when wet. The organic matter content is about 2.8 % (C/N = 11) ; the available water supply is 10 % ; the total phosphorous content is 160 ppm ; the exchange capacity is about 14 me/100 g ; the sum of exchangeable bases is 7 me/100 g. pH = 5.6.

Abrupt and wavy <u>textural discontinuity</u> at the basis of the horizon.

. from 60 to 70 cm : the horizon is composed of 80 % of round iron-manganese concretions of a grayish color and a diametre of 2 to 5 mm. The width of this horizon varies extremely and presents numerous undulations. The passage to the lower horizon is very clear.

. from 70 to 90 cm : clayey horizon (65 % clay - 15 % silt - 20 % sand), dark grayish brown color (10 YR 4/2) ; <u>numerous yellowish</u> or constrasted red rust mottles ; no coarse elements but presence of round iron-manganese concretions. Well developed coarse to medium angular blocky structure ; <u>fine sub-structure</u> ; very porous aggregates ; firm to friable when moist, plastic and sticky when wet, hard when dry. The organic matter content is 1.5 %. The available water supply is about 11 %. The exchange capacity is about 36 me/100 g and the sum of exchangeable bases is 23 me/100 g ; pH = 5.6. The passage to the lower horizon is progressive.

. from 90 to 150 cm : very clayey level (68 % clay - 12 % silt - 20 % sand) grayish brown color (10 YR 5/2) which brightens up in depth (10 YR 6/2). Numerous yellowish mottles with very little contrast ; no coarse elements ; some small iron-manganese concretions. Coarse prismatic structure with prisms 20 cm wide separated by cracks 2 cm wide ; coarse angular blocky sub-structure. Numerous sliken-sides ; non porous aggregates ; firm consistence when moist, plastic and sticky when wet, very hard when dry. At places, presence of some calcareous nodules in depth ; the available water supply is 15 %. The exchange capacity is 50 me/100 g ; the sum of exchangeable bases is 30 me/100g pH = 6.3.

As we go further away from the basis of the linking glacis and nearer the KUYWA river, the superior loamy-sandy horizon gets thinner and its texture becomes progressively finer

until it becomes silty. This horizon frequently constitutes nothing but the biological mounds, the clayey floor is immediately underneath.

On the map we have demarcated two units in the plain :

. the presence of a superior horizon with a coarse texture and of a rather considerable thickness. The textural discontinuity can be found around 50 to 60 cm deep.

. no superior horizon with a sandy texture (or very thin). The textural discontinuity, when it exists, is near the surface of the channels running between the mounds.

Classification

The strong vertic characters lead us to classify these soils among the "vertisols with a reduced external drainage, hydromorphic, degraded, planic" (French classification).

The F.A.O. classification calls them "vertic, planic gleysols".

4.6 - Constraints for sugar cane

The main constraints are due to the hydrological regime and the highly vertic nature of the material. The overspreading of the water from the linking glacis, the raising up of the water table as well as the swelling properties of the clays are the causes of the water-logging of the soils which therefore become impervious and the flood is generalised, 30 to 40 cm high.

Drainage is absolutely necessary but the weak lateral permeability of the clays make its carrying out quite difficult. If drainage is based on open ditches, maintenance will be required, otherwise, due to the internal movements of the clays (swelling-shrinkage), they may collapse.

The vertic clays are a disadvantage as for the tilling ; when dry they are hard and when moist they are heavy and sticky. Moreover they can be a damaging element to the perennial root system ; when the clays swell (slicken-sides) and then shrink (important cracks), the roots are subject to shearing and damaging.

Finally, the presence of a textural discontinuity is also a disadvantage. The abrupt changes in the physical properties are very hard on the roots. During the dry season, the

discontinuity between the sandy top level and the clayey floor is underlined by a horizontal crack which can be as wide as 1 cm.

This heavy constraint is lessened in the eastern part of the plain, where the discontinuity corresponds to the surface of the channels situated between the mounds ; a tilling will be sufficient to suppress this discontinuity. But, in the western part, in prolongation with the basis of the linking glacis, the discontinuity is lower down (50 to 60 cm) and will require deep sub-soiling.

5 - THE BETTER DRAINED PART OF THE LOWLANDS OVERHANGING THE ALLUVIAL TERRACE

As one gets nearer the KUYWA river, the hydrological conditions of the vertic plain get better since the plain is dissected by an alluvial terrace which is inset in the vertic material. A more or less degraded slope 2 to 3 metres steep, overlooks the recent alluvial terrace of the KUYWA river. The result of this difference in level is the improvement of the drainage of the edge of the plain situated along the alluvial terrace and with à width varying from 40 to 400 metres.

This unit is therefore in a perfect prolongation with the flooded plain, the only difference being the hydrological regime and the top part of the soil which is better drained. There is practically no flood : this is testified to by the presence of some huts as well as cultivated fields. The slope is practically non-existant. There are no biological mounds or if so with a very small difference of level.

- The material there, is the same as the one described in the preceding paragraph concerning the flooded plain.

- The hydrological regime : its characteristic is a total water-logging during the rain season ; however, the top part of the soil is quite rapidly drained by the water table lowering due to the nearness of the slope.

- The pedogenesis environment is similar to the one of the flooded plain : the material is the result of neoformations of montmorillonitic clay in an area previously leached ; this material is at the present time completely saturated with clay ; it is the privileged area to a vertic pedogenesis (swelling during the rain season, shrinkage during the dry season).

- The soil presents a top part (an average of 0-70 cm) which is better drained and has a well developed blocky structure from medium to fine getting crumbly in the humic horizon , numerous mottles can be observed coloring the soil in yellow-red rust. The texture is still clayey. No sandy top soil has been observed, therefore there is no textural discontinuity.

Lower down and progressively, a material with heavy vertic characters, similar to the material described in the soils of the flooded plain, can be found.

6.4 - The soils

The present pedogenesis processes are characterized by hydromorphic phenomena. This hydromorphy is due to the raising up of the ground water table. We are in presence of a hydromorphy due to water saturating the numerous interstices of the material, and not an endohydromorphy due to the saturation of the montmorillonitic clays as it was the case in the plain : this means that this water flows freely and therefore the environment can easily be drained. The reoxydation is fast : this explains the fact that no traces of high hydromorphy can be seen.

These alluvial soils present excellent physical properties : porosity, structure, balanced texture (loamy clay, silt, clayey silt) ; from an average of 70 cm black iron-manganese mottles can be seen on the faces of the aggregates. No coarse elements can ever be found ; rooting is always very good. These soils are classified in the French classification "weak developed hydromorphic alluvial soils" or "mineral hydromorphic gleysoils", in the ox-bows. The F.A.O. classification puts them among the "eutric fluvisols" and the "gleyic fluvisols".

6.5 - Constraints for sugar cane

Subject to a drainage meant to avoid the rising up of the water table over 1 metre in depth, which would interfere with a good rooting of the cane, the soils of the terrace are of an excellent quality. Furthermore, the farmers account them to be the best in the area. There is still a doubt, though, regarding the risks and the frequency of the floods which may overflow the terrace. Apparently this potential flood does not seem likely to cause important damage to the plantation (low speed of the flow, quick drying up).

The presence of ox-bows could interfere with development. To make their utilisation possible, drainage ditches, linking them to the river should be built, but these basins will still be the preferential zones of water-logging and it would be better not to use them.

Finally the fluviatile dynamics may damage the concave banks of the river which are undercut. The presence of cribs can be justified on the banks which are most likely to be sapped.

VI - HYDRODYNAMIC CHARACTERISTICS OF THE SOILS

1 - CALCULATION OF THE WATER SUPPLIES

The calculation of the water supply poses three problems :

- the choice of the depth of soil on which the calculation is carried out
- the choice of the pF of the field capacity
- the choice of the percentage permitting the calculation of the "easily available water supply" from the available water (A W).

1.1 - The choice of the depth of soil

The choice must depend upon the depth of soil penetrated by the roots : those of sugar cane can go down as far as 4 meters deep. But the observations and samplings have only been made up to a depth of 1,50 meters ; thus, in the absence of obstacles to roots penetration, before the bottom of the profile, the calculation of the water supply was made on a thickness of soil of 1,50 meters. In this case the figure obtained is a minimum and the plant is able to draw water form a greater depth. In the case of the presence of an obstacle, indurated plinthite or cuirasse above 1,50 meters, the depth selected is between the obstacle and the surface.

1.2 - The choice of the pF of the field capacity

The latter varies according to the water retention energy of the soil, thus of the texture. The pF of the field capacity is all the higher as the texture is fine. Two measures have been made on each sample: humidity at pF 3,0 and humidity at pF 2,5. The choice between the two was determined according to the curve of correlation between the moisture content at pF 3,0 and the pF of the field capacity established by Gras (1962, in Ducheufour).

- moisture content at pF 2,5 for the horizons whose moisture content at pF 3,0 is inferior to 26,3 %
- moisture content at pF 3,0 for horizons whose humidity at pF 3,0 is superior to 26,3 %.

1.3 - Calculation of the "easily available water supply"

A ratio of 2/3 was chosen to give an approximate idea of the "easily available water supply" in comparison to the total "available water supply". Therefore it must be diminished in unfavorable cases of very strong evapotranspiration, when the demand for water is very important.

2 - MEASURES OF PERMEABILITY AND DRAINABILITY

The measures have been carried out on a section of analyzed profiles characteristic of hydromorphic soils of the linking glacis and of the floodable plain on the right bank of the KUYWA River.

2.1 - Permeability

The measures have been made at 40 cm depth. No measure has been made on the surface ; it would have had no significance since the first 40 cm must be completely disturbed at the time of bush clearing and tilling.

The double ring Muntz method, with a diminishing charge has been used. The central ring where the measures were carried out had a diameter of 50 cm and was sunk 3-4 cm in the soil : The level of the water in the internal cylinder was maintained permanently at the same level as in the internal cylinder.

On each profile the measures made at regular intervals between 10 and 30 min.) were repeated for 3 days. At each hour when a reading was made, a coefficient K was calculated which corresponded to the beginning of the stabilization of the flow.

2.2 - Drainability

The measures have been taken in depth by the Porchet method (auger hole in non saturated soils). The auger hole was between 8 and 10 cm in diameter, and about 20 cm deep. The horizontal flow is calculated by a formula voiding the vertical flow from the depth of the hole. The coefficient K which is retained is the one which corresponds to the beginning of the stabilisation of the flow.

2.3 - The results

The results of the measures of permeability and of drainability allow the distinction of two types of soil : those of the linking glacis and of the floodable plain on one hand, those of the terrace on the other.

PERMEABILITY AND DRAINAGE RATINGS OF TYPICAL PROFILES

N° PROFILE	MOISTURE	PERMEABILITY			DRAINAGE		
		Depth m cm	k (10^{-5} m/s)	Rating	Depth cm	k (10^{-5} m/s)	Rating
1	moist	40	0,3	good	140	0,2	moderate
2	moist	40	0,3	good	140	0,02	poor
3	moist	40	0,5	good	140	0,2	moderate
4	moist	40	0,2	good	180	0,02	poor
5	moist	40	0,4	good	130	0,03	poor
6	moist	40	0,2	good	120	0,02	poor
8	wet	40	0,2	good	170	0,0008	very poor

The first are characterized by a good permeability in the average horizons (0,2 - 0,3 10^{-5} m/s) whatever their texture is.

The deep very clayey horizons, generally montmorillonitic clays, have a drainability which varies with the state of moisture content of these soils. When the latter are very wet, the drainability there is extremely weak. When they are moist, drainability is improved by shrinkage of the clays ; it remains weak however (0,02 - 0,03 10^{-5} m/s).

The better drained terrace soils with better biological activity have a slightly better permeability, but especially good drainability of the deep horizons.

VII - SUMMARY AND GENERAL CONCLUSIONS

The morpho-pedological study of the site of 5,000 hectares of the "Nucleus Estate" has permitted us to put in evidence a certain number of very characteristic types of environment resulting from interactions between the nature of the material, the topographical position, the landform, the hydrological regime and the processes of pedogenesis to which it is appropriate to add the biological activity of termites whose role is condiderable. Beyond these basic components, we have strived to distinguish on one hand the earlier forms and materials, resulting from past processes, and on the other hand the current processes, such as the features of pedogenesis, the movements of water or the morphodynamics, which interest us particularly from the stand-point of the reclamation of the land. The study of the heritages of the past permits us to describe the environment in is "static" aspect ; it is indispensable in order to understand the distribution of the "fixed" limitations which are attached to it (depth of a cuirasse, texture of the material ...) ; on the order hand, the inherited materials and forms serve as support and orient the present dynamic processes from which issue "dynamic" or "evolving" restrictions (present or potential erosion, leaching of the soils). Following this method of study whose purpose is the characterization of all the restrictions of the environment, we have listed and described the following principal morpho-pedological units :

- <u>the well drained slopes of interfluves</u>, where the inherited materials are the site of relatively non intense present processes except for the activity of termites. The reddish clayey-loamy material ("sols ferrallitiques faiblement desaturés remaniés" - "ferralsols") which cover these slopes lies on a "sheet of gravel" more or less cemented into cuirasse. This material possesses physical properties very favorable to cultivation. The essential limitations result then from the depth of the gravel sheet. We have defined 4 classes of depth : less than 50 cm (unfavorable suitability) ; 50-100 cm (mediocre suitability) ; 100-150 cm (medium suitability) ; more than 150 cm (favorable suitability). A common restriction to all these slopes is the mesorelief created by the important density of large termite hills

- <u>the hydromorphic lowslopes of the interfluves</u>, caracterized by the appearence of waterlogging in the soil during the rainy season. With respect to the intensity of the hydromorphy we have distinguished :

  . fine textured soils without pronounced or prolonged waterlogging at a depth of more than one meter. These soils are suitable for sugar cane.

• soils of a coarse texture having a longer period of waterlogging which affects the whole profile at certain periods of the year, resulting in a leaching of the clays. These soils are sensitive to sheet erosion and drainage is necessary.

- the "linking glacis" joining the preceding slopes to the lower parts of the landform. This unit where the present geochemical processes are important in land formation, is essentially characterized by its special hydrological regime.

Ground water may be present permanently or for temporary periods during the year. This hydrological dynamic results in a degradation of the clays in the upper part of the glacis, and in the elimination of their products toward the low parts where they recombine in part in order to produce neoformative clays of the montmorillonite type. We thus have the following section : leached sandy hydromorphic soils - soils with an accumulation of vertic clay in depth, topped off by a sandy horizon (residue of an earlier leaching) separated by a strong discontinuity - soils almost entirely vertic in the whole profile completely saturated by neoformative clays, thus poorly drained.

This last part of the section occupies the lower extension of the linking glacis, where the rate of incline is less than 1 % and may thus be classified as a plain where temporary flooding occurs.

To each of these units there correspond certain restrictions on cultivation :

• in the upper part of the linking glacis : waterlogging of the soil, risk of sheet erosion, susceptibility to dryness and to leaching of the fertilizers.

• in the lower part of the glacis : waterlogging, presence of an abrupt textural discontinuity at about 70 cm ; vertic clays in depth.

• in the floodable plain : waterlogging, flooding, excessively vertic characteristics.

All of these units obviously necessitate being drained.

- The alluvial terrace which borders the KUYWA River is "embedded" in the vertic plain or the linking glacis. The material there drains well, the possible constraint is the risk of exceptional overflowing, tempered by a rapid natural draining. The hydromorphic soils equally require drainage ; in spite of that, the soils of the terrace are favorably suitable to sugar cane.

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