PHYSIOGRAPHY AND SOILS OF THE LLANOS ORIENTALES, COLOMBIA

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door

DOEKO GOOSEN
geboren te Wildervank

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SUMMARY

This study deals with the relationships between physiography and soils in the Llanos Orientales, the eastern tropical savanna plains of Colombia. Extensive use has been made of the results of the soil survey, carried out in 1960-1964 (FAO report, 1965).
Chapter 1 describes the background of this study, and its relations to the soil survey. Chapter 2 describes the general features of the area, including the geology of the Eastern Andes Mountains. The physiography of the Llanos is discussed in chapter 3. Chapter 4 deals with the principal soil associations and soil series of three landscapes: the Alluvial Overflow Plain, the Aeolian Plain and the High Plains. Chapter 5 treats degradational processes occurring in these three landscapes, and certain correlations between soil properties and degradational processes. Chapter 6 describes the significance of the results discussed in chapters 4 and 5, for the physical soil management in future agricultural development schemes.

The most important conclusions can be summarized as follows. The majority of the surface sediments in the Llanos date from Late Pleistocene to Early Holocene. The alluvial sediments extend from the Eastern Andes Mountains far to the East. Near the mountains large Alluvial Fans were built up, which at about 50 km East of the mountains gradually change into a vast Alluvial Overflow Plain, characterized by numerous natural levees, with many splays branching out from the levees. The intermediate areas in the Alluvial Overflow Plain are slackwater areas, at present heavily inundated by rain water during the wet season. Towards the East this Alluvial Overflow Plain is covered by an aeolian sediment, called Llanos loess. This area has been called Aeolian Plain. Apart from the level, poorly drained Llanos loess several strips of longitudinal rivers dunes are found within the Aeolian Plain.

Farther East, starting at the right-hand bank of the river Meta, the so-called High Plains occur. The geogenesis of the High Plains is similar to that of the Aeolian Plain, viz. the substratum consists of Pleistocene alluvial sediments, which has been covered by the deposit of Llanos loess to a depth of several meters. The reason to separate the High Plains from the Aeolian Plain lies in the fact that the bound-

ary between them is a fault line, along which the river Meta runs. The High Plains are now situated several tens of meters higher than the Aeolian Plain and are therefore much better drained, except for the most level parts which occur principally in the northeastern part of the High Plains. It is possible that the alluvial substratum and the aeolian cover of the High Plains are somewhat older than the surface sediments of resp. the Alluvial Overflow Plain and of the Aeolian Plain. The relative position of the described landscapes is sketched in fig. 5. From it can be seen, that the zone between the Andes and the river Meta is a zone of tectonic subsidence. This subsidence is still going on, as evidenced by the occurrence of faults across recent alluvial sediments near the mountains. The mineralogical analysis of the soils show that kaolinite and quartz are dominant in all soils.

The pattern of soil associations conforms to physiographic subdivisions of the three landscapes. In the Alluvial Overflow Plain the natural levees and splays have been combined in one soil association. In the Aeolian Plain the principal soil associations are those of resp. the dunes and the level, poorly drained Llanos loess. Traversing these units are shallow and broad drainageways, called 'esteros', which are permanently wet. This unit forms the third important soil association. The level High Plains are separated in a well drained, and in a poorly drained part. The poorly drained part is very similar to the poorly drained area of Llanos loess in the Aeolian Plain. The well drained part is very gently undulating. The broad savanna divides between drainageways are several hundreds of meters wide and have a smooth surface. The drainageways of the High Plains also are called 'esteros'.

The soil formation in most of the well drained soils in these three landscapes is thought to be polygenetic. There are several indications that in the past the savanna areas were covered by a forest vegetation. Under the influence of alternating wet and dry seasons it appears likely that both lessivage and ferrallitization occurred, leading to the formation of deep Ultisols with a number of Oxic characteristics. The change from forest into grass resulted in a higher biological activity, especially of ants, and a higher degree of dispersion of organic matter. The laboratory data on the dispersion of clay and silt in the soils of the High Plains make it seem plausible that lessivage of silt and clay particles is an active process. However, cutans were not recognized in most of the soils, and it is thought that they are continuously being destroyed by the biological activity. It is for these reasons that most of the well drained soils have been classified as Oxic and Ultic intergrades of Dystropepts.

The poorly drained soils have a similar polygenetic history, with some differences. The formation of an Argillic horizon occurred at depths of one to two meters, in combination with the formation of plinthite. The upper horizons, especially of the soils in the level, poorly drained areas of Llanos loess, lost a considerable amount of iron oxides, as evidenced by the extreme low contents of iron oxides in these soil horizons. The increased biological activity in the poorly drained soils under the savanna vegetation is due mainly to termites, instead of to ants. The destruction of cutans is thought to be rapid, and the soils have been classified as Ultic intergrades of Plinthaquepts, while some have Oxic characteristics.

The degradational processes active or having been active in the three discussed landscapes, were recognized as follows. In the well drained soil associations toposequences were found, in which the textural sequence from top to bottom of the slopes is from clay or silty clay loam to sandy loam or loamy sand. The process of sheet erosion is responsible for this textural sequence. This process is discussed using the level, well drained High Plains as a case-study. In the poorly drained soils of the slackwater areas in the Alluvial Overflow Plain usually a network of gullies is found, called 'zurales' in the Llanos. The gullies are the result of reticular gully erosion, and this process is thought to be active because the soil properties are indicative of values for cohesion and friction, which under the present conditions of vegetation, drainage and relief, induce this kind of erosion.
The soils of the poorly drained loess areas, both in the Aeolian Plain and in the High Plains, show a characteristic micro-relief, called 'escarceos'. The escarceos are elongated curving ridges approximately along contours, not higher than 50 cm, usually several meters wide, and are asymmetrical in cross section, with the steepest slope facing in the downslope direction. The general slope of the land where the escarceos occur, is below 1%. Based on the soil properties it is demonstrated that cohesion and friction are likely to attain extremely low values when the soil is saturated with water. It is postulated that in some period in the past liquefaction and soil flow occurred, as triggered by earthquakes, and that the escarceos formed during this process as transverse undulations. Through a comparison between the escarceos and similar micro-relief in tropical and subtropical savannas, it is suggested, that the described kind of mass movement may play an important role in the formation of micro-relief in several level savanna areas of the world.

The importance for physical soil management in the Llanos of the three types of degradational processes lies in the fact, that degradation can be a very active process in these level savannas. It can therefore be expected that under more intensified systems of agriculture the degradation accelerates or is reactivated. Accelerated sheet, gully and wind erosion does occur already in certain areas where the land is cultivated. For the poorly drained loess area an additional hazard is that the soil mass will easily flow, thereby closing drainage and irrigation channels if such are constructed.

RESUMEN

Este estudio trata de las relaciones entre la fisiografía y los suelos en los Llanos Orientales, las sabanas tropicales en el Oriente de Colombia. Se han utilizado extensamente los resultados del levantamiento edafológico, ejecutado durante los años 1960-1964 (FAO report, 1965). En el capítulo 1 se describe el origen de este estudio, y su relación con el levantamiento edafológico. En el capítulo 2 se describen las características generales del área, incluyendo la geología de la Cordillera Oriental de los Andes. La fisiografía de los Llanos comprende el contenido del capítulo 3.
El capítulo 4 trata de las asociaciones y las series de suelos principales de tres paisajes: Llanura Aluvial de Desborde, Llanura Eólica y Altillanuras. El capítulo 5 trata de los procesos de degradación que ocurren en estos tres paisajes, y de ciertas correlaciones entre las propiedades del suelo y los procesos de degradación. En el capítulo 6 se trata de la importancia de los resultados discutidos en los capítulos 4 y 5 para el manejo físico del suelo en futuros proyectos de desarrollo agrícola.

Las conclusiones de mayor importancia pueden ser resumidas así:
La mayoría de los sedimentos superficiales en los Llanos datan del Pleistoceno Reciente al Holoceno Antiguo. Los sedimentos aluviales se extienden desde la Cordillera Oriental de los Andes muy lejos al Oriente. Cerca de la Cordillera se formaron grandes abanicos aluviales, los cuales a una distancia de aproximadamente 50 km de la Cordillera cambian gradualmente en una vasta Llanura Aluvial de Desborde, caracterizada por un sinnúmero de diques naturales o 'bancos' con muchos esplayamientos o 'salidas de madre' desprendiéndose de los diques. Las áreas intermedias en la Llanura Aluvial de Desborde son formadas por los basines, o 'bajos', que son inundados por el agua de lluvia en la época húmeda.
Hacia el Oriente esta Llanura Aluvial de Desborde está cubierta por un sedimento eólico, llamado Llanos loess. Esta zona ha sido llamada Llanura Eólica. Aparte del Llanos loess, que tiene un relieve plano y que es mal drenado, se encuentran dentro de la Llanura Eólica varias fajas de dunas longitudinales de río, los médanos.

Más al Este, empezando en la ribera derecha del río Meta, se encuentran las llamadas Altillanuras. La géogenesis de las Altillanuras es similar a la de la Llanura Eólica, es decir el substrato también consiste de sedimentos aluviales del Pleistoceno, que ha sido cubierto por un depósito de Llanos loess a una profundidad de varios metros. La razón por la cual se separan las Altillanuras de la Llanura Eólica estriba en el hecho de que el límite entre las dos es una línea de falla geológica, a lo largo de la cual corre el río Meta. Hoy día las Altillanuras están situadas a una elevación de algunas docenas de metros superior al nivel de la Llanura Eólica, y por lo tanto tienen un mejor drenaje con excepción de las partes más planas que ocurren predominantemente en la parte noreste de las Altillanuras.

Es posible que la edad del substrato aluvial y de la cubierta eólica de las Altillanuras sea algo mayor que la de los sedimentos superficiales de la Llanura Aluvial de Desborde y la Llanura Eólica respectivamente. La posición relativa de los paisajes descritos ha sido bosquejada en la fig. 5. En ésta puede observarse que la zona entre la Cordillera y el río Meta es una zona de subsidencia tectónica. Esta subsidencia aún continua en la presente época, como es demonstrado por la occurrencia de fallas a través de los sedimentos aluviales recientes cerca de la Cordillera.
Los análises mineralógicos de los suelos demuestran predominancia de kaolinita y cuarzo.

El pátron de las asociaciones de suelos es conforme a las subdivisiones fisiográficas de los tres paisajes. En la Llanura Aluvial de Desborde se han combinado los diques naturales y los esplayamientos en una sola asociación de suelos, mientras que los bajos forman otra asociación. En la Llanura Eólica las principales asociaciones de suelos son respectivamente la de los médanos y la de Llanos loess plano y mal drenado. Atravesando estas unidades ocurren vías de drenaje may amplias y poco profundas, llamadas 'esteros'. Los esteros son permanentemente húmedos, y forman la tercera asociación importante de suelos. Las Altillanuras planas han sido separadas en una parte bien drenada, y en otra probremente drenada. La parte pobremente drenada es muy semejante al área pobremente drenada del Llanos loess en la Llanura Eólica. La parte bien drenada es muy suavemente ondulada. Los amplios divorcios de agua entre los caños tienen una anchura de varios centenares de metros, y su superficie es bien suave sin irregularidades con excepción de las hormigueras. Las vías de drenaje en las Altillanuras planas tambien han sido llamadas 'esteros'.

La formación del suelo en la mayoría de los suelos bien drenados en estos tres paisajes es supuestamente poligenética. Existen varias indicaciones que en el pasado las sabanas estaban cubiertas por vegetación boscosa. Bajo la influencia de las épocas húmedas y secas alternantes parece probable que ocurrío tanto 'lessivage' como 'ferrilitización', lo que resultó en la formación de Ultisuelos profundos con un número de características Oxicas. El cambio de bosque hacia sabana fomentó una mayor actividad biológica, especialmente de las hormigas, y un mayor grado de dispersión de la materia orgánica. Los datos del laboratorio sobre la dispersión de la arcilla y del limo en los suelos de Las Altillanuras parecen confirmar que 'lessivage' de las partículas de limo y arcilla es un proceso todavía activo. Sinembargo, no se observaron películas de arcilla en la mayoría de los suelos, y se supone que esas sean continuamento destruídas por la actividad biológica. Es por éstas razones que la mayoría de los suelos ha sido clasificada como intergrados Oxicos y Ulticos de los Dystropepts. Los suelos pobremente drenados tienen una historia poligenética similar, con algunas diferencias. La formación de un horizonte Argflico ocurrió a profundidades de uno a dos metros, en combinación con la formación de plintita. Los horizontes superiores, especialmente en los suelos de las áreas planas y pobremente drenadas como el Llanos loess, perdieron una cantidad considerable de hierro, como es demostrado por los contenidos extremadamente bajos en estos horizontes. El aumento de la actividad biológica en los suelos pobremente drenados bajo la vegetación de sabana, se debe principalmente a los comejenes (nombre local de las termitas) en lugar de las hormigas. Se piensa que la destrucción de las películas de arcilla y de limo es rápida, y los suelos han sido clasificados como intergrados Ulticos de Plinthaquepts, mientras que algunos tienen características Oxicas.

Los procesos de degradación activos o activos en el pasado fueron reconocidos como sigue.
En las asociaciones de suelos bien drenados se encontraron toposecuencias, en las cuales la secuencia textural desde la cima hasta el pie de las pendientes es de arcilla o franco limoso arcilloso a franco arenoso o arena franco. El proceso de erosión laminar es responsable de esta secuencia textural. Se discute este proceso utilizando las Altillanuras planas y bien drenadas como ejemplo. En los suelos pobremente drenados de los bajos en la Llanura Aluvial de Desborde se encuentra por lo general una red de cárcavas, que se llama 'zurales' en los Llanos. Las cárcavas son el resultado de erosión reticular por cárcavas, y se opina que este proceso es activo porque las propiedades del suelo son indicativas de valores para la cohesión y la fricción, que, bajo las condiciones actuales de la vegetación, drenaje y relieve, fomentan este tipo de erosión. Los suelos de las áreas de loess pobremente drenadas, tanto en la Llanura Eólica como en las Altillanuras, muestran un microrrelieve típico, llamado 'escarceos'. Los escarceos son camellones alargados y suavemente curvados, en una dirección aproximadamente perpendicular a la dirección de la pendiente. Su altitud no es mayor a los 50 cm, y su anchura por lo general es de varios metros. En corte transversal los escarceos tienen una forma asimétrica, con la pendiente mayor hacia la dirección inferior de la pendiente. La pendiente general del terreno donde ocurren los escarceos es menor al 1%. Basándose en las propiedades de los suelos se demuestra que es muy probable que la cohesión y la friction puedan alcanzar valores extremadamente bajos cuando el suelo está saturado de agua. Por lo tanto se opina, que en algún período del pasado ocurrió licuefacción y flujo del suelo, ocasionado por terremotos, y que los escarceos se formaron durante este proceso como ondulaciones transversales. A través de una comparación entre los escarceos y microrelieves similares en un número de sabanas tropicales y subtropicales, se sugiere que el tipo descrito de movimiento en masa podría jugar un papel importante en la formación del microrrelieve en varias áreas planas de sabana del mundo.

La importancia de los tres tipos de procesos de degradación para el manejo físico de los suelos en los Llanos radica en el hecho de que la degradación puede ser un proceso muy activo en estas sabanas planas. Por lo tanto, se pueden esperar que bajo ciertos sistemas de agricultura más intensos la degradación se acelerará o se reactivará. La erosión acelerada, sea laminar, por cárcavas o por el viento ya ocurre en ciertas zonas de los Llanos donde se cultiva la tierra. En las áreas de loess pobremente drenadas existe el peligro adicional de que la masa del suelo fácilmente fluya, lo que efectuaría la destrucción de zanjas de drenaje y de riego, una vez construídas.

SAMENVATTING

Deze studie behandelt de relatie tussen fysiografie en bodem in de Llanos Orientales, de oostelijke tropische savanna vlakten van Colombia. Hierbij is uitgebreid gebruik gemaakt van de resultaten van de bodemkartering, verricht in de jaren 1960-1964 (FAO report, 1965). In hoofdstuk 1 wordt de achtergrond van deze studie en zijn verhouding tot de bodemkartering besproken. Hoofdstuk 2 bespreekt het gebied in het algemeen, inclusief de geologie van het Oostelijk Andes Gebergte. De fysiografie van de Llanos wordt in hoofdstuk 3 besproken. In hoofdstuk 4 worden de voornaamste bodemassociaties en bodemreeksen besproken van drie landschappen: de Alluviale Vlakte, de Aeolische Vlakte en de Hoogvlakte. In hoofdstuk 5 worden de degradatie processen, die in deze drie landschappen voorkomen, behandeld samen met bepaalde correlaties tussen de bodemeigenschappen en de degradatieprocessen. De betekenis van de resultaten, besproken in hoofdstukken 4 en 5, wordt behandeld in hoofdstuk 6, voorzover betrekking hebbend op de fysische aspecten van bodembeheer in toekomstige projecten voor landbouwkundige ontwikkeling.

De belangrijkste conclusies kunnen als volgt worden samengevat. De meerderheid van de oppervlakte sedimenten in de Llanos dateren van Laat Pleistoceen tot Vroeg Holoceen. De alluviale sedimenten breiden zich ver oostwaarts uit vanaf het Oostelijk Andes Gebergte. In de nabijheid van dit gebergte zijn grote alluviale waaiers gevormd, die op ongeveer 50 km ten Oosten van het gebergte langzamerhand overgaan in een uitgestrekte Alluviale Vlakte, gekarakteriseerd door talrijke natuurlijke oeverwallen van waaruit zich vele overstromingsruggen, de 'splays', vertakken. De tussenliggende gebieden zijn kommen, die in het natte seizoen door regenwater geïnundeerd zijn. Naar het Oosten toe is deze Alluviale Vlakte bedekt met een aeolisch sediment, Llanos loess genaamd. Dit gebied wordt de Aeolische Vlakte genoemd. Naast de vlakgelegen en slecht gedraineerde Llanos loess komen verscheidene stroken van longitudinale rivierduinen voor in de Aeolische Vlakte.
Verder naar het Oosten, vanaf de rechteroever van de Meta rivier, wordt de zogenaamde Hoogvlakte aangetroffen. De geogenese van de Hoogvlakte is vergelijkbaar met die van de Aeolische Vlakte, nl. de ondergrond bestaat uit Pleistocene alluviale sedimenten, later afgedekt met een aantal meters dikke laag Llanos loess. De reden om de Hoog-

vlakte van de Aeolische Vlakte te onderscheiden ligt in het feit, dat de grens tussen beide een breuklijn is, waarlangs de Meta rivier stroomt. De Hoogvlakte ligt nu enkele tientallen meters hoger dan de Aeolische Vlakte en is daardoor veel beter ontwaterd, met uitzondering van de meest vlakke delen die hoofdzakelijk in het noordoostelijk deel van de Hoogvlakte voorkomen. Het is mogelijk dat de alluviale ondergrond en het aeolische dek van de Hoogvlakte iets ouder zijn dan de oppervlakte sedimenten van resp. de Alluviale Vlakte en de Aeolische Vlakte.
De relatieve positie van de beschreven landschappen is geschetst in fig. 5. Hieruit kan afgelezen worden, dat de zone tussen de Andes en de Meta rivier een zone van tectonische daling is. Deze daling gaat nog steeds door, zoals blijkt uit het voorkomen van breuken dwars door recente alluviale afzettingen aan de voet van de Andes. Mineralogisch gezien bestaan de sedimenten in de Llanos hoofdzakelijk uit kaoliniet en kwarts.

Het patroon van de bodemassociaties komt strikt overeen met de fysiografische onderverdeling van de drie landschappen. In de Alluviale Vlakte zijn de oeverwallen en overstromingsruggen verenigd in één bodemassociatie, terwijl de kommen een andere bodemassociatie vormen. De belangrijkste bodemassociaties in de Aeolische Vlakte zijn overeenkomstig resp. de duinen en de vlakke, slecht ontwaterde Llanos loess. Deze eenheden worden doorsneden door ondiepe en brede natuurlijke ontwateringskanalen, die 'esteros' genoemd worden en permanent nat zijn. Deze vormen de derde belangrijke bodemassociatie. De vlakke Hoogvlakte is onderverdeeld in een goed ontwaterd deel en een slecht ontwaterd deel. Het slecht ontwaterde deel is in vele opzichten gelijk aan het slecht ontwaterde gebied met Llanos loess in de Aeolische Vlakte. Een van de belangrijkste bodemreeksen komt in beiden voor. Het goed ontwaterde deel van de Hoogvlakte is zwak golvend. De brede savanna stroken tussen de natuurlijke waterlopen zijn honderden meters breed en hebben een zeer gelijkmatig vlak oppervlak op zacht glooiende hellingen. De waterlopen in de Hoogvlakte worden evenals in de Aeolische Vlakte, 'esteros' genoemd.

De bodemvorming in de meeste van de goed gedraineerde bodem in deze drie landschappen wordt verondersteld polygenetisch te zijn. Er zijn verschillende aanwijzingen dat in het verleden de savanna gebieden bedekt waren met bos. Onder de invloed van afwisselend natte en droge seizoenen lijkt het aannemelijk dat zowel 'lessivage' als ferrallitizatie voorkwam, leidende tot de vorming van diepe Ultisols met een aantal 'Oxic' eigenschappen. De overgang van bos naar gras resulteerde in een hogere biologische activiteit, speciaal van mieren en een hogere mate van dispersie van organische stof. De laboratorium gegevens over de dispersie van de lutum- en siltfractie in de gronden van de Hoogvlakte lijken er op te wijzen, dat lessivage van lutum en silt een aktief proces is. In de meeste gronden werden echter geen 'cutans' gevonden en er wordt verondersteld dat deze continu afgebroken worden door de biologische activiteit. Om deze redenen zijn de meeste goed gedraineerde gronden geklassificeerd als Oxic en Ultic intergrades van Dystropepts.

De slecht gedraineerde gronden hebben eveneens een polygenetische geschiedenis, op enkele punten verschillend van de goed gedraineerde gronden. De vorming van een 'Argillic horizon' vond plaats op een diepte van slechts één à twee meter, in combinatie met de vorming van plinthiet. De bovenste horizonten, speciaal van de gronden in de vlakke, slecht gedraineerde gebieden met Llanos loess, werden voor een belangrijk deel ontijzerd, zoals blijkt uit de bijzonder lage gehalten aan ijzeroxide in deze bodemhorizonten. De toegenomen biologische activiteit onder de savanna vegetatie in de slecht gedraineerde gronden is hoofdzakelijk afkomstig van termieten, inplaats van mieren. De afbraak van de 'cutans' is waarschijnlijk snel, en de gronden zijn geklassificeerd als Ultic intergrades van Plinthaquepts, terwijl sommigen eigenschappen van Oxic intergrades vertonen.

De degradatie processen, die actief zijn of actief zijn geweest, werden als volgt onderscheiden. In de goed gedraineerde bodemassociaties komen toposekwenties voor, waarin het textuurverloop van hoog naar laag langs de helling gaat van klei of 'silty clay loam' naar 'sandy loam' en 'loamy sand'. Het proces van laminaire erosie is verantwoordelijk voor dit textuurverloop. Dit proces wordt besproken aan de hand van de vlakke, goed gedraineerde Hoogvlakte. In de slecht gedraineerde gronden van de kommen in de Alluviale Vlakte komt veelal een net van geulen voor, dat in de Llanos 'zurales' wordt genoemd. De geulen zijn het resultaat van reticulaire geulen erosie en dit proces wordt verondersteld aktief te zijn omdat de bodemeigenschappen overeenkomen met waarden voor cohesie en wrijving, die, onder de huidige omstandigheden van vegetatie, drainage en relief, dit type erosie bevorderen. De gronden van de slecht gedraineerde loess gebieden, zowel in de Aeolische Vlakte als in de Hoogvlakte, vertonen een karakteristiek micro-relief, 'escarceos' genaamd. De escarceos zijn langgerekte, zwak gebogen ruggetjes ongeveer in de richting van hoogtelijnen. Zij zijn niet hoger dan 50 cm, en meestal verscheidene meters breed, terwijl ze in doorsnede asymmetrisch zijn met de steilste helling naar beneden gericht. De gemiddelde helling van het land waar de escarceos voorkomen, is minder dan 1%. Gebaseerd op de bodemeigenschappen wordt aangetoond, dat cohesie en wrijving extreem lage waarden zouden kunnen bereiken wanneer de grond met water verzadigd is. Daarom wordt in deze studie verondersteld, dat in een bepaalde periode in het verleden liquificatie en bodemvloeiing heeft plaats gevonden onder de invloed van aardbevingen en dat de escarceos tijdens dit proces werden gevormd als transversale terreingolvingen.
Aan de hand van een vergelijking tussen de escarceos en soortgelijk micro-relief in tropische en subtropische savannas, wordt verondersteld dat het beschreven type van massabeweging een belangrijke rol zou kunnen spelen in de vorming van micro-relief in diverse vlakke savanna gebieden van de wereld.

Het belang van de drie typen van degradatie processen voor het fysische bodembeheer in de Llanos is gelegen in het feit, dat degradatie een zeer actief proces kan zijn in vlakke savannas. Daarom kan worden verwacht dat onder intensievere landbouwsystemen de degradatie versneld of gereaktiveerd wordt. In bepaalde gebieden, waar het land in cultuur gebracht is, treedt reeds versnelde laminaire, geulen en wind erosie op. Een additioneel gevaar voor de slecht gedraineerde loess gebieden is dat de bodemmassa gemakkelijk zal vloeien, waardoor eventueel geconstrueerde drainage en irrigatie kanalen dicht zullen vloeien.

Chapter 1

INTRODUCTION

The present study deals with the relationships between soils and some aspects of physiography in the Llanos Orientales of Colombia. The underlying principle has been the following: firstly to demonstrate and explain some typical soil/physiography relationships and secondly to indicate the consequences of these relationships for land and soil management.

The author participated as soil surveyor in an integrated survey of agricultural resources of an area of 130,000 sq. km in the Llanos Orientales (see Fig. 1). This survey was a joint project of the United Nations Special Fund and the Government of Colombia, executed under the auspices of the Food and Agriculture Organization of the United Nations in the years 1961-1964. The detailed results of this survey have been edited and published by the FAO in Rome (1965) under the title 'Reconocimiento Edafológico de los Llanos Orientales, Colombia'. References to this publication will be given in the following as 'FAO report, 1965'.

During the soil survey six major landscapes were recognized:

Piedmont
Alluvial Terraces
Alluvial Overflow Plain
Aeolian Plain
Alluvium
High Plains

Some of the landscapes have been subdivided according to age differences, sedimentation differences, drainage differences or degree of erosion, and this resulted in a total of ten sub-landscapes or physiographic units (see Fig. 7), each one with a distinct set of soil associations.

Within the physiographic units a total number of 35 soil associations have been distinguished and mapped (FAO report, 1965). Each soil association is composed of two or more soil series. A total of 184 soil series have been recognized and described. The mapping of individual soil series has only been done in selected areas, to show their relative location within the soil associations. The maps of these sample areas have not been published, but they have been used to draw the block diagrams included in the following chapters.

The FAO report, published in 1965, describes the inventory of agricultural resources and presents a land classification in terms of capability and recommendations for future agricultural use. As such the report has a technical character. Several aspects of the relation between physiography and soil formation are not discussed; they are the subject of the present study.

The criteria for the division into landscapes and sub-landscapes are based on various aspects of physiography. They will be discussed in Chapters 2 and 3. A detailed description of the units is given in Chapter 3.

Within this frame of reference a selection has been made of those aspects which were not fully known when the survey started. They are in particular certain processes of erosion and mass movement, acting upon alluvial and aeolian landscapes. An attempt is made to relate these degradational processes to certain properties of the soils, to slope and to drainage conditions, and to show the interaction between the soil formation and these processes.

To illustrate these relationships a selection of typical soils of the following landscapes or sub-landscapes (see Fig. 7) will be discussed.

Alluvial Overflow Plain
Aeolian Plain
High Plains

Although the Piedmont, the Alluvium and the Alluvial Terraces landscapes are very important for agriculture, they are not discussed here in detail. The physiographic aspects of these landscapes conform to universal patterns of sedimentation, which are well known from the literature. See e.g. Allen (1965), Coleman (1969) and Thornbury (1954).

Furthermore, a limitation has been made with regard to relief. Only those landscapes and sub-landscapes which have level to gently undulating relief are discussed. Therefore, only the level High Plains will be discussed; the dissected High Plains are excluded, even though they comprise almost one-third of the total area.

One of the results of the foregoing limitations is that most of the present forest area is excluded. Tropical rain forest occurs in the Llanos mainly in the Piedmont, Alluvium and the southern part of the dissected High Plains landscapes. There are several indications that large parts of the other landscapes were also covered with forest at one time. But the burning practices of the Indians native to the area, and later of the settlers, are believed to be responsible for the destruction of the forest. Nowadays, natural grasses cover most of the area.

As a consequence of the limitations set forth above, the study covers only the tropical savanna areas in the Llanos with level and gently undulating relief, where no active sedimentation is going on, nor severe dissection of the terrain occurs. The total area of these savannas is approximately 70,000 sq.km, or 55% of the survey area. The other landscapes are described to show the general relationships between them and the tropical savannas mentioned above.

Twelve soil series, representing typical soils of the principal soil associations occurring within the three selected landscapes, are discussed in Chapter 4. These series do not cover the whole range of soils, but are representative of the soil associations and therefore typical of the soil mapping units. In some cases other soil series are mentioned briefly to indicate the variations occurring within the mapping units.

Preceding the description of the soil series some specific aspects of soil formation and physiography are treated.

The dictum " Soils, then, are landscapes as well as profiles" (Soil Survey Staff, 1951) has been taken as a guideline. The profiles form the 'internal' aspects, and the landscapes provide the 'external' aspects of the soils.

During the soil survey certain physiographic phenomena were found, in general related to degradational processes (specifically sheet erosion, gully erosion and solifluction) occurring under conditions of subdued relief. In Chapter 5 a comparison is made between similar phenomena in other tropical savannas and those of the Llanos, and an attempt to explain the features in the Llanos is presented.

Chapter 6 deals with the significance of physiographic features and related soil patterns for agricultural evaluation. This is not a duplication of the land classification already presented in the FAO report (1965), but rather a series of basic considerations on the role which some of the more important physiographic and soil features play in soil and land management in the Llanos. As has been stated, these features are related to sheet erosion, gully erosion and solifluction. The activity of these processes has been larger in the past than it is at present. However, if agriculture would be intensified, the processes may be accelerated.

Chapter 2

DESCRIPTION OF THE AREA

2.1 GENERAL

The area studied covers 130,000 sq. km of the Llanos Orientales (Eastern Plains), the eastern tropical savanna plains of Colombia. The term 'Llanos Orientales' is understood by some to refer to the entire eastern 3/5 of Colombia, including the Amazonian forest to the South and the savannas to the North. However, most people, when they speak of the Llanos Orientales, refer to the savannas, even though they may include certain forest areas.

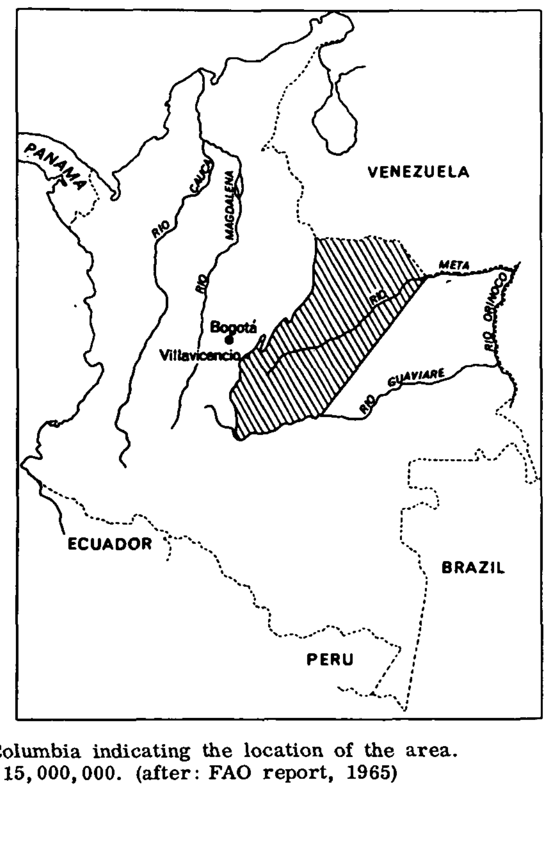


Fig. 1 Map of Columbia indicating the location of the area. Scale 1 : 15,000,000. (after: FAO report, 1965)

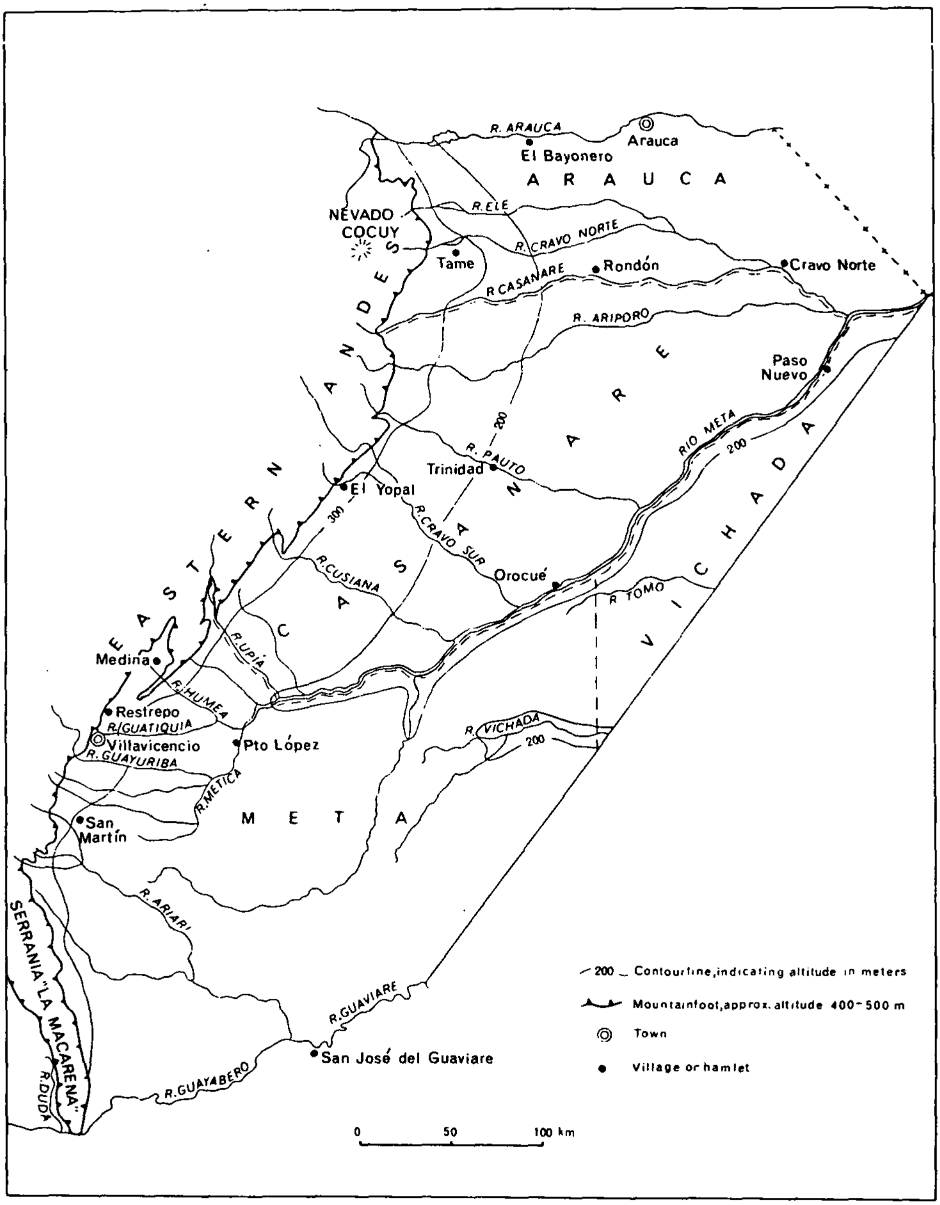


Fig. 2 Topographic sketchmap, showing rivers, towns, villages, areas, etc., mentioned in the text. (after: FAO report, 1965)

The sketch map of Figure 1 gives the location of the area. It lies immediately east of the Eastern Andes Mountains (the 'Cordillera Oriental de los Andes'), between Venezuela to the North and the river Guaviare to the South. The eastern boundary is a straight line, because of the coverage of aerial photographs available at the time the survey started.

The map of Figure 2 shows the area in more detail, and is referred to for locating all sites and regions mentioned in the text.

Near the Andes the land is approximately 500 m above sea level. Towards the East it drops gradually to an altitude of about 200 to 150 m above sea level.

The total population is estimated at 400,000 (1964 census) of which half is not native to the Llanos, but migrated from the western regions of Colombia. The population density is 3 inhabitants per sq. km. The accelerated migration of the last decades accounts for the increased interest in the economic development of the region.

Villavicencio is the principal town of the area studied; it has about 60,000 inhabitants. It is situated, as are most villages along the mountain foot of the Andes, at the apex of an alluvial fan. There, favourable conditions for settlement are found, such as, gravelly subsoils for firm building foundations, and fresh and cool water from the mountain rivers. Stagnant water, where mosquitoes might breed, is mostly absent at such sites. Away from the mountain foot, villages are mostly situated on river banks.

2.2 CLIMATE

The trade winds blowing from the northern sub-tropical belt of maximum pressure to the equatorial belt of minimum pressure have a major influence on the climate of the Llanos. They blow from North-East to the South-West, and are strongest in the period December - April. This period is also the period of minimum rainfall. When the equatorial belt shifts to the North, the winds abate and the wet season starts. It is this rhythm of winds and rains which determines the climatic pattern of the Llanos.

Figure 3 shows lines of equal rainfall (isohyets) and the number of dry months. The precipitation varies from less than 1,800 mm in the North-East to nearly 5,000 mm in the South-West. Around the upper Ariari river rainfall may exceed 5,000 mm per year. The isohyets curve parallel to the mountain foot. This indicates that where the air is forced upwards at the mountains, precipitation increases. The map also shows that the dry period is longer in the North-East. There it starts earlier and ends later than in the South-West.

In Figure 4 two typical rainfall patterns, showing the mean monthly rainfall of Villavicencio and Orocué respectively, are drawn. Both show a similar rain distribution throughout the year. The differences are found in the total annual rainfall and the length of the dry season. Months with less than 50 mm rainfall are considered dry months. The slight abatement of rains in August/September is known as the 'veranillo de San Juan' (little summer of Saint John).

The relative humidity of the air is high in the whole Llanos. It is 80 % in the wet season, but falls in the dry season to values of 50 % to 60 %.

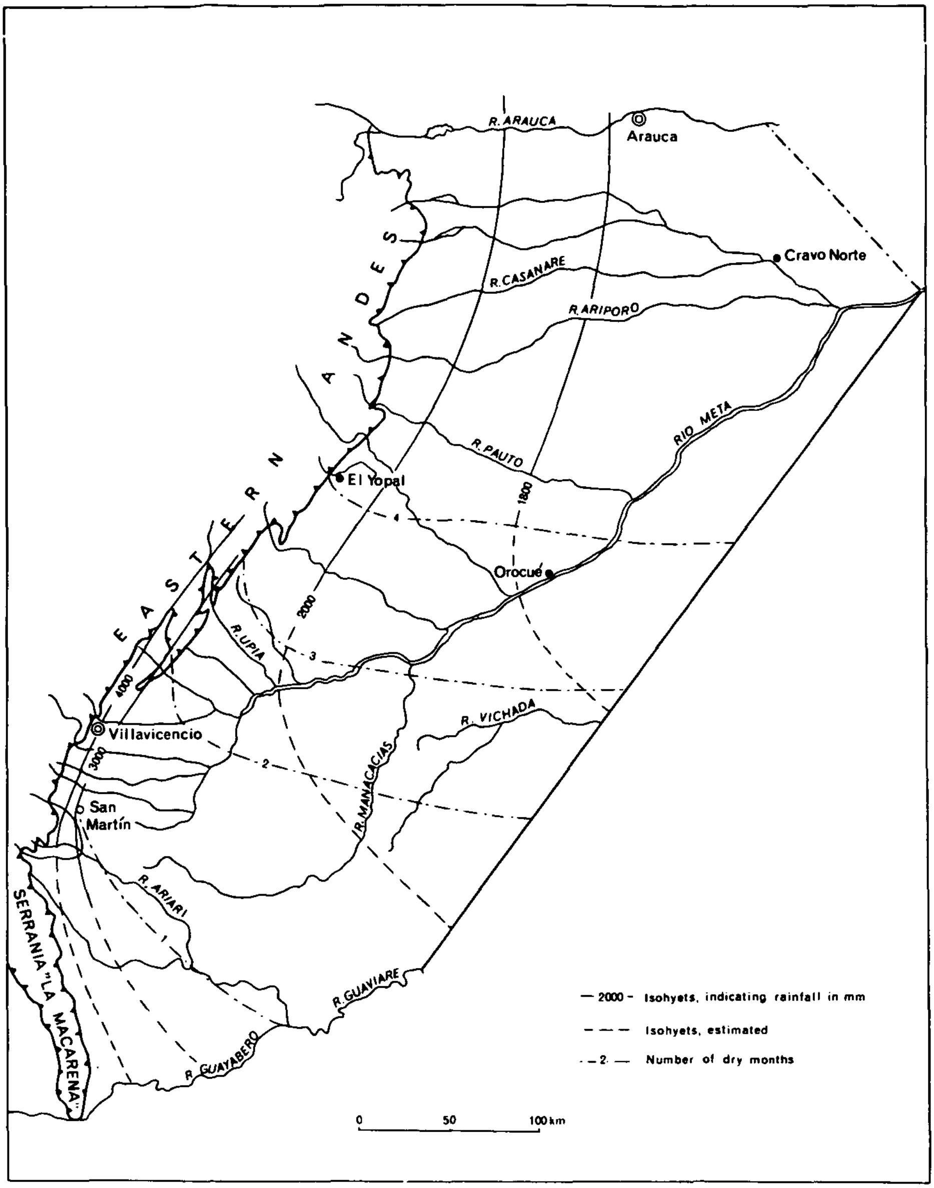


Fig. 3 Map showing lines of equal rainfall (isohyets) and number of dry months. (after: FAO report, 1965)

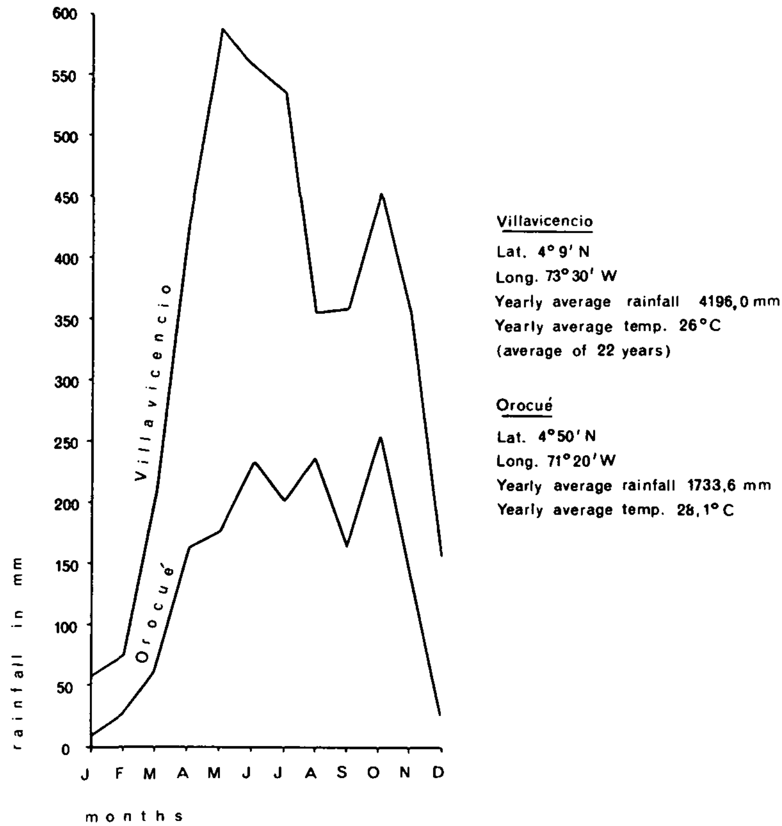


Fig. 4 Average monthly rainfall in Villavicencio and Orocué. (after: FAO report, 1965)

The annual mean air temperature is 25° C to 28° C. It shows little variation. Fluctuations of the monthly mean air temperature range between 1.1° C and 2.3° C. The daily variation between maximum and minimum air temperature is larger, as the following data demonstrate. The annual average maximum of the daily air temperatures, compounded from the data of the three stations Villavicencio, Orocué and Arauca, recorded over more than seven years (Mejía, 1959), fluctuates between 31.2° C and 33.4° C, while the annual minimum fluctuates between 20.9° C and 22.8° C. The highest temperatures occur in March or April, at the end of the dry season, and the lowest at the end of the wet season, when the trade winds start again and evaporation is at its maximum.

The climate of the Llanos can be classified, according to Köppen-Geiger (1954) as Aw, savanna climate; according to Koeppe and De Long (1958) it ranges between tropical wet and dry; and according to Papadakis (1961) it is semi-hot equatorial wet-dry monsoon in the North and semi-hot equatorial in the South. This last classification mentions the word 'monsoon'. It must be pointed out that the winds in the Lanos do not have a true monsoon character. If that were the case, their direction would have to change with the seasons. But the south-eastern trade winds of the southern hemisphere do not penetrate sufficiently far into the Llanos to cause the variation in wind direction typical of monsoon areas. It is rather the fluctuation in intensity of the north-eastern trade winds which cause the alteration of dry and wet seasons. The somewhat misleading term 'monsoon' however, is often applied in similar connections with trade winds (Moore, 1952).

2.3 GEOLOGY

2.3.1 Geology of the Eastern Andes Cordillera

The geology of the Llanos Orientales is closely related to the geology of the Eastern Andes Cordillera. This section starts therefore, with a discussion of the latter. The general outline is according to Bürgl (1961), and information from several other authors, as cited in the text, has been used to illustrate certain points.

The geological map of Colombia (Serv. Geol. Nac., 1962) shows that the bulk of the Eastern Andes Cordillera consists principally of Cretaceous formations. In various places these formations have been eroded, whereby older formations of the Mesozoic and Palaeozoic Eras are exposed. Intrusive granitic rocks are found in the southern part. Formations of Tertiary Age are found on the flanks of the Cordillera. Most of the lower mountain foot is composed of these Tertiary formations. The approximate lithological composition of the principal formations is given in Table 1.

Tertiary		sandstone and conglomerates (the latter especially in the upper tertiary)
Cretaceous		
Upper	(form. Guadalupe)	sandstones
Middle	(form. Villeta)	shales with layers of limestone
Lower	(form. Cáqueza)	shales
Palaeozoic	(Carboniferous)	pelitic schists alternating with metamorphic limestone
Intrusive rocks of Cundinamarca		granodiorite

Table 1 Geological formations of the Cordillera Oriental de los Andes

The formations older than the Upper Cretaceous have a marine character. From then onwards sedimentation occurred under terrestrial conditions. The rivers responsible for this sedimentation came from the South, and from the Central Cordillera. In the Tertiary Era the Central Cordillera was very much higher than the Eastern Cordillera.

Throughout its geological history, the Eastern Cordillera has been subject to uplift in various phases. As regards the geology of the Llanos, the last big uplifts of the Tertiary Era are the most interesting. They have given rise to huge erosion in the Cordillera, and this has resulted in very extensive sedimentation in the Llanos.

In the middle of the Tertiary (Oligocene-Miocene) the first stage of a large uplift started on two main fronts: a long one to the South in the area between the rivers Duda and Upía, and a shorter but equally important one, to the North in the region of Cocuy. The uplift caused strong folding, and was accompanied by faulting, parallel

and transverse to the folds. The general effect was an enormous erosion of the previously deposited Tertiary sediments. The erosion products were re-deposited at lower levels, at the mountain foot far into the Llanos. There Upper Tertiary formations are still present at the surface on the flanks of the Cordillera, mainly to the East of the two principal fronts of the uplift; in the Llanos they have been buried by later sediments. The first stage of the uplift probably reached altitudes no higher than 2,000 m above sea level.
Only later, in the Miocene-Pliocene Epochs, did the largest uplift occur. According to Bürgl (1961), the Eastern Andes Mountains reached approximately their present height at the beginning of the Quaternary era. Hubach (1954) deduces from the present outcrop of the Lower Tertiary that the following maximum heights were attained:

in the area near Villavicencio (south) more than 6,000 meters;
in the area of the river Upía (center) about 4,000 meters;
in the Nevado de Cocuy (north) more than 7,000 meters;
and in the depression of the upper Arauca River (extreme north) between 2,000 and 3,000 meters. The differences clearly indicate the undulating longitudinal axis of the Cordillera.

Erosion followed the uplift. Huge quantities of material were carried away by the rivers and were deposited in the Llanos (Oppenheim, 1942). In a very simplified manner we may state that the deposits in the Llanos correspond to the strata of the Cordillera, but in reverse order. The upper strata of the Cordillera were eroded first, and consequently their material was deposited first in the Llanos. A lower stratum of the Cordillera was later attacked by erosion, and therefore was deposited on top of the first sediment in the Llanos.

The intensity of the erosion varied from place to place. Where the Cordillera was higher, erosion was more intense, especially in the zones of major uplift where length and inclination of slopes was greater. In these zones, particularly, the upper strata were eroded completely, and older strata were exposed, which has caused different strata to outcrop in different parts of the Cordillera. To a certain extent the sediments in the Llanos reflect these differences, as will be indicated in the following paragraphs.

In general, it can be said that the Tertiary strata were almost completely eroded from the higher parts of the Cordillera. The Upper Cretaceous sandstone (Guadalupe formation) was completely removed in the South and Central part, but still predominates North of the Cocuy, that is in the lower area of the upper Arauca River. The alluvial sediments in the Llanos in Arauca are very sandy; they are derived from this Cretaceous sandstone.

To the South outcrops of the Middle and Lower Cretaceous shales are more extensive. The corresponding sedimentary zones in the Llanos contain more clay than in the North. Still, admixture with sand is common, because in the southern region of the Cordillera also Pre-Mesozoic conglomerates together with intrusive granodiorite occur.

This general outline is necessarily very schematic. For additional information see De Mier Restrepo (1937 a and b), and Bürgl (1961).

One example, to illustrate the complexity, may be given from the area North of Villavicencio. During the soil survey it was noted that, to the North-East of Villavicencio, the soils are redder than most other soils in the Llanos, while chemical fertility of these soils is somewhat higher that that of soils of comparable age. The parent material of these soils is derived from erosion products of the Cordillera west of Medina. Wokittel and Lôpez (1953) mention 'thick red layers' of clayey sandstone in the Cordillera west of Medina; the layers probably belong to the Permian or Upper Carboniferous. The same authors describe limestones of the Upper Carboniferous located in the same area of the Cordillera. Hubach (1955) describes the Gachalâ group belonging to the Carboniferous, which is outcropping west of Medina. This group consists of pelitic schists alternating with metamorphic limestone, and in his opinion can produce productive soils.

There are two other interesting factors in connection with the soils of the Llanos. The first concerns previous weathering cycles of the sedimentary material, and the second the glaciations of the Pleistocene epoch.

As mentioned before, all Tertiary strata and part of the Upper Cretaceous strata in the Cordillera were sedimented under terrestrial conditions. The material come from the Central Cordillera, which was higher in elevation at those periods. Because of these facts it can be assumed that the material of the sediments had already undergone at least one weathering cycle in the Central Cordillera. It underwent another weathering cycle in the Eastern Cordillera, and after sedimentation in the Llanos the third weathering cycle started. The more recent sediments of the Llanos, derived from the Middle and Lower Cretaceous, and now found in some alluvial fans and many flood plains, did not undergo the second weathering cycle. They are derived from marine sediments.

During the Pleistocene Epoch the most severe erosion of the Cordillera took place, because this followed the period of greatest uplift. Also during this Epoch a number of glaciations occurred in the South American Andes (Raasveldt, 1957; Schuchert, 1935). Glacial phenomena, such as moraines and U-shaped valleys, can be found in most parts of the Andes in Colombia from 3,000 m upwards. The glaciers used to cover from 1/5 to 1/6 of the area of the Eastern Cordillera, althought at present they occur only above 4,800 m and are limited to the Nevado de Cocuy. The glaciers of the past have been very active in the erosion of the Cordillera. They loosened large quantities of material, which were carried into the Llanos. The end of the last glaciation most likely corresponds with the last period of heavy sedimentation in the Llanos. In this connection it is interesting to quote the results of Van der Hammen's (1961) pollen-analytical studies. He summarizes them as follows:

1. "In the Colombian equatorial Andes, a glacial is at the same time a pluvial; and interglacial, an interpluvial".
2. "The glacials and interglacials, and also certain interstadials and stadials of the Colombian equatorial Andes, correspond eactly in time, in so far as the evidence goes, with those from other parts of the world. ..."
3. "Even the minor climatic fluctuations of the Holocene of the Colombian equatorial Andes correspond in time with the European".

The upgrowth of vegetation during the Holocene over the glacially loosened materials effectively reduced erosion. The decline in precipitation during this same period, as mentioned by Van der Hammen, had a similar effect. These drastic changes are reflected in the physiography of the Llanos, as will be explained in the following section and in the next chapter.

2.3.2 Geology of the Llanos Orientales

This section discusses, in general terms, the geological history of the Llanos, starting from the end of the Tertiary Era, and is especially concerned with the origin and mode of deposition of the actual surface sediments in the Llanos. The present landscapes will be discussed in more detail in Chapter 3. The data of this section were mainly gathered during the soil survey (FAO report, 1965). Few references of other investigations exist. Oppenheim (1942) and Hubach (1954) deal briefly with the Llanos, and their information is incorporated in this section. Various oil companies have investigated the Llanos, but their results have not been published. The author had opportunity to discuss some points with a few geologists of Shell de Colombia Ltda., and it appeared that the assumptions on the tectonic movements made during the soil survey, were in accordance with their investigations.

Generally speaking, the Llanos area was gradually filled with sediments derived from the Eastern Cordillera. The pattern of sedimentation conforms to normal features of alluvial sedimentation where young mountains border low-lying plains. First of all, near the mountain foot, the coarsest particles are deposited in the form of alluvial fans. The rivers have there a braiding form. Lower down, the rivers change into meandering forms, and huge alluvial floodplains are formed with numerous shifts in the channels. The slope of lands thus formed is gradually decreasing downstream, and has therefore a very gentle concave form. Downstream, the textures of the sediments become gradually finer and the drainage becomes poorer. This general pattern of alluvial sedimentation is also applicable to the alluvial sediments of the Llanos.

Firstly, the oldest surface formation, dating from the Early or Middle Pleistocene, is distinguished. This was originally a vast alluvial cover extending from the Cordillera to the Orinoco River. Near the Cordillera, and especially in Arauca and Casanare, the material is sandy and gravelly; towards the east it gradually becomes more clayey. Possibly during and certainly after its formation these Pleistocene alluvial deposits were affected by tectonic movement; the zone nearest the Cordillera was uplifted and somewhat folded, and a large number of faults occur parallel to the Cordillera in this zone. Some kilometers to the East the formation has subsided. The subsidence affected the Arauca and Casanare regions and continued to a lesser extent in Meta. The eastern boundary of the zone of subsidence is the present valley of the river Meta, which, from its confluence with the river Manacacías to the Venezuelan border, runs in an almost straight line, while the escarpment on the right bank is from 10 to 50 meters higher than on the left. From these characteristics the existence of a fault is deduced. See also Fig. 7.

The depression thus formed between the Cordillera and the river Meta was filled later on with younger alluvial deposits, dating from the Middle and Late Pleistocene. At the foot of the raised zone of the earlier Pleistocene sediments new alluvial fans were formed. Downstream these fans gradually merged and the terrain became one extensive Alluvial Overflow Plain. With the climatic change at the end of the Pleistocene, erosion in the Cordillera was very much reduced, and therefore, sedimentation in the Llanos was correspondingly reduced.

As no material is being added at present to the Alluvial Overflow Plain, its surface sediment dates from Late Pleistocene to Early Holocene. Recent sedimentation occurs only on some alluvial fans in the Piedmont area, and in narrow strips bordering the main rivers.

The subsidence in Arauca and Casanare is apparently still continuing. In about the last fifteen years the river Arauca has split into two at a point called 'El Bayonero'. The water streaming to the southeast inundates large areas, locally known as 'raudales', see Figure 7. Evidently there is a depression in central Arauca at a level lower than that of the river. It could be said that this is simply because the river Arauca has elevated itself by sedimentation in its bed and on its banks, in which case the breakthrough at El Bayonero would be a normal breach in the natural levee. But this is not the case. All the rivers, including the Arauca, have slightly cut down into the sediments of the alluvial overflow plain, establishing narrow river valleys with alluvial floodplains. They no longer inundate the Alluvial Overflow Plain, So it is more logical to postulate the continuation of geological subsidence, especially as the zone of 'raudales' coincides with the centre of the Tertiary and Pleistocene subsidence. Another indication of recent tectonic movement is found in the Piedmont area. In Casanare and in Meta many faults are visible running parallel to the mountains, and several are cutting across recent deposits along the rivers. During the soil survey they were noted near the rivers Casanare, Pauto and Upía.

Another process influencing the physiography of large parts of the Llanos has been aeolian activity.

The vast Alluvial Overflow Plain covering Casanare and Arauca, and continuing far into Venezuela north of the river Meta towards the river Orinoco, has been subject to strong wind action. This occurred especially in the eastern and north-eastern parts, because there the dry season is longest and the winds are strongest. The combination of freshly deposited alluvial sediments over vast areas, and strong wind in a pronounced dry season, was very favourable for aeolian activity. Enormous quantities of fine material were picked up by the wind before the vegetation of forest and grasses had been established to fix them, and redeposited in areas to the South-West of the place of origin. This aeolian sediment will be referred to as 'Llanos loess'. It covers the eastern part of the Alluvial Overflow Plain and the older Pleistocene alluvial deposits east of the river Meta. Along the rivers traversing the Alluvial Overflow Plain, longitudinal dunes were formed, aligned parallel to the wind direction.

The cross-section (Figure 5) presents the geomorphological units discussed so far. It also shows that the Early to Middle Pleistocene deposits at the mountain foot were partly eroded after their uplift. As a result of this erosion locally some underlying Young Tertiary strata were exposed. The whole sketch is typical for Casanare, Arauca and Vichada. The situation in Meta is somewhat different, and will be dealt with in the following paragraphs.

The fault along which the river Meta flows has been traced, in the preceding paragraphs, from the Venezuelan border to the confluence with the river Manacacías. From this point the same fault continues upstream with a more westerly direction towards Villavicencio. The river Guatiquía flows along this fault. Parallel to the river Guatiquía and south of it run several other rivers, as for example, the river Guayuriba. They are all aligned parallel to a series of faults, here

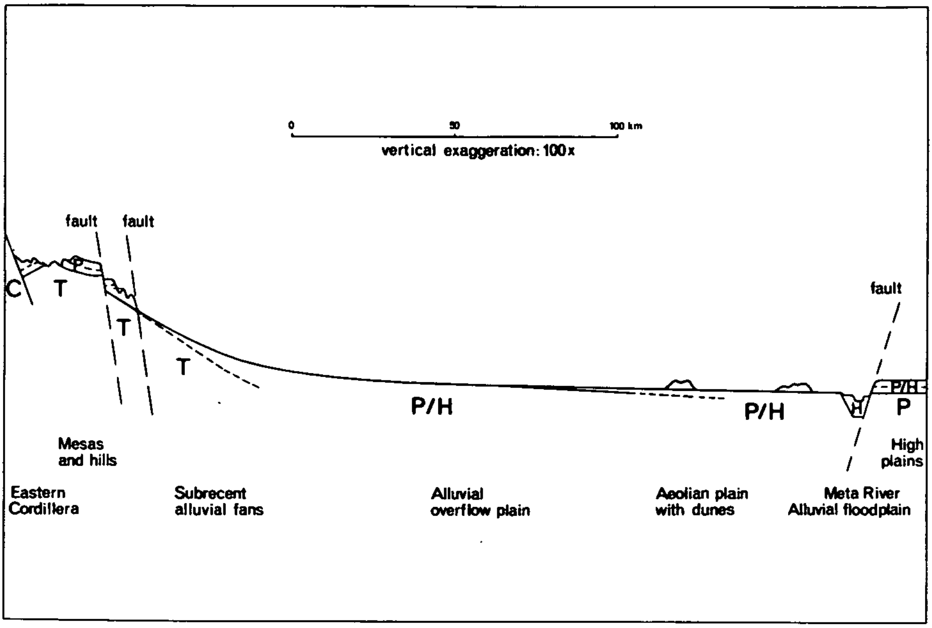


Fig. 5 Schematic section from West (left) to East (right) through Casanare, showing geomorphological units. C - Cretaceous formations of the Andes; T - Tertiary; P - Pleistocene; H - Holocene.
The altitude of the terrain ranges from approx. 500 m in the West to 150 m in the East. (modified after: Goosen, 1964b)

running from West to East. South-East of San Martín the series of faults continues, but its direction changes gradually. They run more from North-West to South-East, parallel to the river Ariari.

Another series of faults runs parallel to the Andes. The lower half of the river Manacacías flows along one of these faults, while the river Metica (the headwater of the river Meta) flows along another one. Many minor faults are found between the river Metica and the Cordillera. They all run approximately in NNE-SSW direction.

The two series of faults mentioned cross each other in the area between Villavicencio, San Martín and the river Metica. For this reason the zone of alluvial terraces and floodplains occurring there has a complicated character. Some terrace levels belong to the Pleistocene, other were formed later, and there is no absolute correlation between level and age (see the following chapter for more details).

The majority of the Early to Middle Pleistocene deposits with the Late Pleistocene cover of 'Llanos loess' to the East, South-East and South of the river Metica, have been severely dissected. The northern limit of this zone of dissection runs from Puerto López more or less eastward.

2.4 HYDROLOGY

The river Meta is the principal river of the area. It collects through a number of tributaries most of the water descending from the Eastern Andes. The most important of these tributaries are, from North to South, the rivers Cravo Norte, Casanare, Ariporo, Pauto, Cravo Sur, Cusiana, Upía, Humea, Guatiquía and Guayuriba. All these rivers join the river Meta at the left bank from the West. Only one major river, the Manacacías, joins the river Meta at the right bank. Where the river Meta leaves the area of study, it flows to the East and forms the border between Colombia and Venezuela. After 225 km it joins the river Orinoco, which flows to the Atlantic Ocean. The area East and South of the river Meta is drained by a number of rivers that flow directly into the Orinoco. From North to South these are the Tomo, Vichada and Guaviare. The first two originate in the Llanos, the last in the mountains. The river Arauca, also originating in the mountains, is the northern-most river of the area, and flows directly into the Orinoco.

All the rivers descending from the mountains receive their water from an area with high precipitation. Moreover, the relief of the Andes Mountains is very rugged. Such conditions are propitious for severe erosion. But the forest cover of the mountains counterbalances this tendency, and the erosion is not as severe as might be expected. In the last 50 years, however, deforestation has rapidly advanced in the mountains, and the inhabitants of the Llanos report increasing floods on the floodplains. Exact data over a number of years are not available. Escher (FAO report, 1965) studied in 1963 some rivers originating not far from Villavicencio, and some of his data are given in Table 2.

This table clearly illustrates the strong variations in discharge as related to the alternation of the short dry season and the long wet season.

RIVER	DISCHARGE IN m^3/sec.	
	maximum	minimum
Humea	---	27.2
Guatiquía	700	14.5
Guayuriba	1500	41.6
Meta (at Orocué)	8600	395

Table 2 Discharge of some rivers as measured in the wet and in the dry seasons of 1963.

In the area around Villavicencio the rivers carry down from the mountains huge amounts of eroded material. Because of the abrupt change in gradient where the rivers leave the mountains, most of this material accumulates in the Piedmont area and in the floodplains. The beds of the rivers are filled rapidly, with the result that they tend to shift in a lateral direction. In the last decades houses and crops have often been destroyed. The present airport of Villavicencio is greatly endangered by the river Guatiqufa, and only by continuous works of river-bank protection has its destruction been avoided.

The clogging-up of river beds also decreases their discharge capacity. Because of this, the adjoining lands are often flooded in the wet season, precisely those lands which otherwise would be the most productive.

As stated, near the mountains, surface water is abundant. However, farther away the rivers are further apart. Here people have to rely more on water from the subsoil. The underground water fortunately forms an almost inexhaustible reserve, at least for the area North of the river Meta. The alluvial character of the terrain ensures that a large number of intertwining aquiferous layers exist below the surface. Most farms have a shallow well with abundant water throughout the year. To the South of the river Meta in the level High Plains the wells must be deeper to have sufficient water supply for human and animal consumption. Here large streams are few, and they are far apart. The groundwater depth in the Level High Plains South and East of the river Meta is at about 10-12 m below the land surface in the dry season. Farther North along the right bank of the river Meta the level High Plains are more poorly drained, and groundwater is found at 3-5 m below the surface in the dry season. In the dissected part of the High Plains to the South, water is confined to the valleys between the hills. On the hills infiltration is much less and surface run-off is high.

The Alluvial Overflow Plain, the Aeolian Plain and the poorly drained level High Plains are extensively inundated in the wet season This is more due to rainfall than to flooding by the rivers, because the rivers with their floodplains are somewhat incised below the level of the older plains.

2.5 VEGETATION AND LAND USE

2.5.1 Vegetation

About 80 % of the area is covered by natural grasses. The rest is under forest or in use as agricultural land. See the land use map, Figure 6.

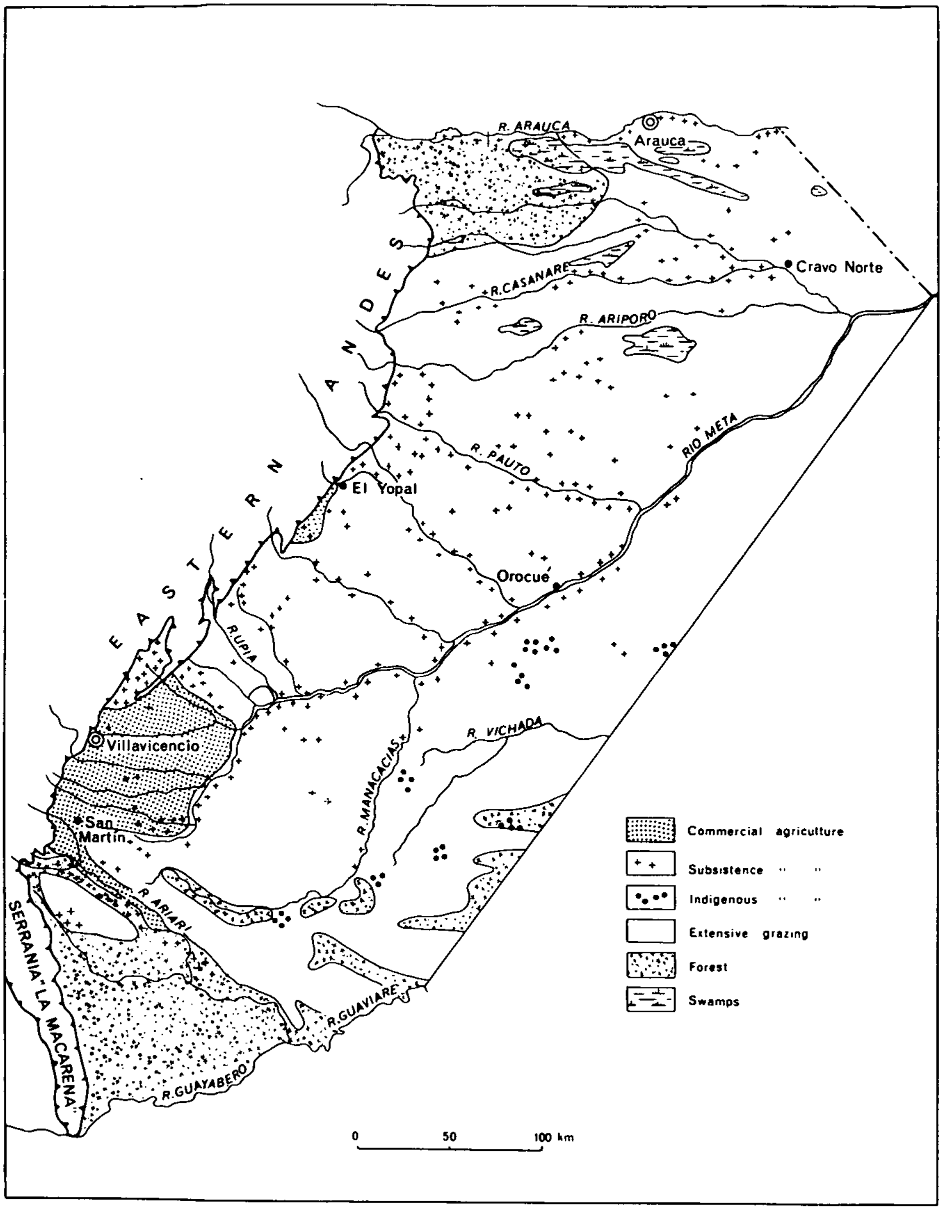


Fig. 6 Land use map. (after: FAO report, 1965)

Gallery forest borders most rivers, streams and the shallow, broad drainage ways, locally called 'esteros'. Apart from that, forest is found mainly in three regions: western Arauca in the North, the Piedmont area and Alluvial Terraces in the West, and the southern part of the dissected High Plains in the South.

The forest on the recent Alluvium along major rivers is the most valuable in terms of timber. The gallery forest along the minor streams is of little value, except near the mountains, where rainfall is high. The forest along the drainage ways has a high percentage of the moriche palm (Mauritia minor). Although the forest in Arauca is not commercially exploitable under the present conditions of difficult access, it contains enough timber to justify its reservation for future use. An inventory has been made by Smit (1963). The forest of the Piedmont area often serves the purpose of protection of local watersheds, and also provides wood for the settlements concentrated along the mountain foot. Sometimes these interests conflict with each other. On the Alluvial Terraces an estimated 95 % of the forest has already been cut down, mostly in the last 100 years. The forest of the dissected High Plains is a poor, semi-deciduous forest. It has every appearance of what may aptly be called 'rachitic forest'. It does, however, protect the area against the rapid spread of fires, although in the long run savannas encroach upon it, because of the savanna fires.

The distribution of the forests corresponds to the climate. The boundary of the forest runs more or less parallel to the isohyet of 2500 mm, at least in the southern and western parts. In the North, in western Arauca, the forest extends far to the East. Espinal and Montenegro (1963) assume that this is due to a higher rainfall in western Arauca. If this is indeed the case, then the map of isohyets (Figure 3) must be amended, although with regard to the isohyets drawn in Arauca, it is also based on data from Venezuela (FAO report, 1965). The southern forest area is the beginning of the Amazon forests (Sioli and Klinge, 1962).

Various types of savanna vegetation have been identified (FAO report, 1965. See also Blydenstein (1967). In the Piedmont area a savanna characterized by Melinis minutiflora is found on well drained lands, such as the higher parts of alluvial fans and terraces. On the natural levees of the Alluvial Overflow Plain, Trachypogon vestitus/Axonopus purpusii savanna is found. In the slackwater areas, locally called 'bajos', Andropogon savanna occurs. These areas are seasonally inundated by rainwater. Andropogon gives a low cover of forage in the dry season. Mesosetum savanna is found on the wet parts of the Aeolian Plain. It develops a forage cover in the wet season. In association with this type occurs the Leptocoryphium lanatum savanna. The same association is found on the poorly drained parts of the level High Plains. The dunes of the Aeolian Plain are covered with Trachypogon ligularis/Paspalum carinatum savanna.

The Trachypogon vestitus/Paspalum pectinatum savanna is typical of the well drained parts of the level High Plains. The hills of the dissected High Plains have mainly the Paspalum pectinatum savanna.

Although the above discussion suggests a close relationship between vegetation and climate and between vegetation and geomorphological units, it should be understood that the correlation is only partial. In particular the boundary between forest and savanna does not correspond to geomorphological boundaries. The question arises whether this vegetation boundary is a natural boundary. Several indications exist that formerly the forest occupied a much larger area. Often the transition from savanna to forest is very abrupt, and the edge of the forest is partially destroyed by fires. On some of the dunes coppices remain. Scattered in the grassy stretches of the Alluvial Overflow Plain, the Aeolian Plain and the High Plains, clusters of trees are found. Many of these 'matas de monte' (clumps of forest) have an elongated, streamlined appearance, parallel to the direction of the wind, which may be explained by the fierce grass fires of the dry season.

On the High Plains, and adjacent to the drainage ways, strips of forest are found to the South and South-West. The strips of forest are absent at the north-eastern side. The fires advance from the North-East, wich is the direction of the wind. The fact that the vegetation along and also in the drainage ways is asymmetrical and that this asymmetry corresponds with wind direction, is good evidence for assumming a high influence of fires in this case. Bates (1948) investigated the vegetation near Villavicencio. He noted that the forest tends to expand, when protected against fire. During the soil survey some farmers in Casanare and Arauca reported the same fact.

From the foregoing it may be concluded that the extension of the forest in the past was far greater than it is at present. This conclusion is supported by pollen-analytical data published by Wymstra & van der Hammen (1966). They investigated samples from two lakes in the valley of the river Ariari, and from two lakes in the valley of the river Meta. Their conclusion is: "Excluding the river valleys, or those savannas that are under heavy influence of river inundations, we believe that the available pollen-analytical data show that a dry forest or a closed savanna woodland was once the climax vegetation in many savanna areas. Human action was important in the formation of open grass savannas out of this forest. Nevertheless, it seems that natural causes, such as periods of very dry climate and lightning, may have had (and eventually locally still have) a similar, semi-permanent or temporary effect on this dry forest".

2.5.2 Land Use

Figure 6 shows the principal types of land use in the area. Most of the land is used for extensive grazing, and its commercial value often is expressed in terms of the number of cattle it carries. Under present systems of management in the less accessible areas, 4 to 10 hectares are needed to feed one head of cattle. In the neighbourhood of Villavicencio, however, some land owners have intensified the grass management so that they can support two head of cattle per hectare.

Basic recommendations on savanna management are given by Blydenstein in the FAO report (1965). An important general conclusion is that most savanna types do not provide a sustained amount of fodder throughout the year. A proper system of grazing must therefore be found in which different types of savanna can be incorporated in each management unit. If this is not possible, improved pastures are necessary for supplementary feeding.

Subsistence agriculture is characterized by the cultivation of a mixture of crops on small farms. The products serve mainly for local use on adjoining ranches or nearby villages. This system of agriculture is scattered throughout the Llanos, usually associated with cattle farms. It is based on the cultivation of forest- or brush-cleared land, or of abandoned cattle corrals. The principal crops are yucca, bananas and corn. Secondary crops are rice, vegetables and fruit. Chickens and pigs form the livestock.

A similar type of agriculture is the indigenous farming practised by the aborigines in the East. A typical feature is the circular form of the plot, contrasting with the irregular rectangles of the subsistence agriculture in the other areas. This indigenous agriculture is of a shifting nature; plots are not used for more than two years. The principal crops are banana and yucca, and the rest of the diet is obtained from the forest or savannas by herb- or fruit-collecting and hunting.

Commercial agriculture is practised on farms, usually between 100 and 2,000 hectares. Mechanization, fertilization, control of pests and diseases, irrigation and drainage are, in varying degrees, accepted practices. This type of agriculture is found on the Alluvial Terraces and floodplains, called 'vegas'. Production is destined for national or international markets. Main crops are rice, cotton, corn and cocoa. The oil-palm (Elaeis Guineensis) has been introduced since 1960, but has not yet proved to be successful. Various fruits are grown in the area, citrus being the most important.

Most cattle farms in this region of commercial agriculture have adopted modern methods of management and increased their production. On the map (Figure 6) these cattle farms are all included in one unit together with commercial agriculture.

Chapter 3

PHYSIOGRAPHY

3.1 INTRODUCTION

The first step in the soil survey of the Llanos Orientales was the compilation of a general landscape map. This work was based on study and interpretation of aerial photographs and photomosaics of the whole area. Corrections were made during the fieldwork, and the final version as published in the FAO report (1965), is shown in Figure 7. It has also been discussed by Goosen (1963, 1964).

The landscapes are physiographic units. Since their geomorphological characteristics are of prime importance for soil survey, these units have been defined, as much as possible, in accordance with the geomorphological features. The vegetation has played a much less important role in determining the units. However, in 1961, when the soil survey started, little was known about the geomorphology of some landscapes. In these cases merely descriptive names were used, such as the 'High Plains'. The nomenclature adopted during the soil survey has been maintained in this study.
The study and recognition of the different landscapes proved to be essential for mapping the soils. Individual landscapes and their subdivisions are, in boundaries and extent, identical with soil associations. The method of Buringh (1954, 1960a) was used to identify these landscapes from the aerial photographs. Details on methods and results have been described by Goosen (1963, 1964a, 1964b, 1967).

The major landscapes and some sub-divisions, as given in the landscape map of Figure 7, are listed in Table 3. The possible age of the surface sediments and of the present landforms is given in the last two columns. This distinction in age is not discussed in the FAO report (1965). The Epochs mentioned in Table 3 are tentative; they are only meant to give an approximate idea of the relative age. To establish an absolute chronology more exact data would be needed. A recent investigation by Wijmstra and van der Hammen (1966) confirms some of our estimates. They analyzed the pollen from samples taken in a small valley of the dissected High Plains. This valley joins the Ariari valley, and has been filled with sediments from the river Ariari. Sedimentation near the main river is more rapid, so the side valley is blocked and a small lake occupies part of it. Wijmstra and van der Hammen (1966) took samples from a boat, in water about one meter deep. Five meters below the lake bottom, sand was reached, and the sand could not be penetrated any deeper. The sediments above this

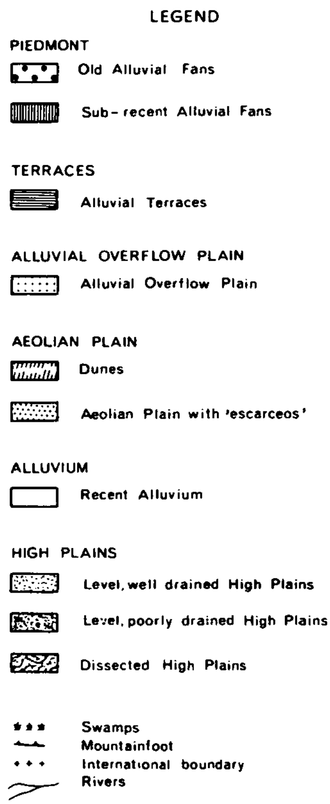
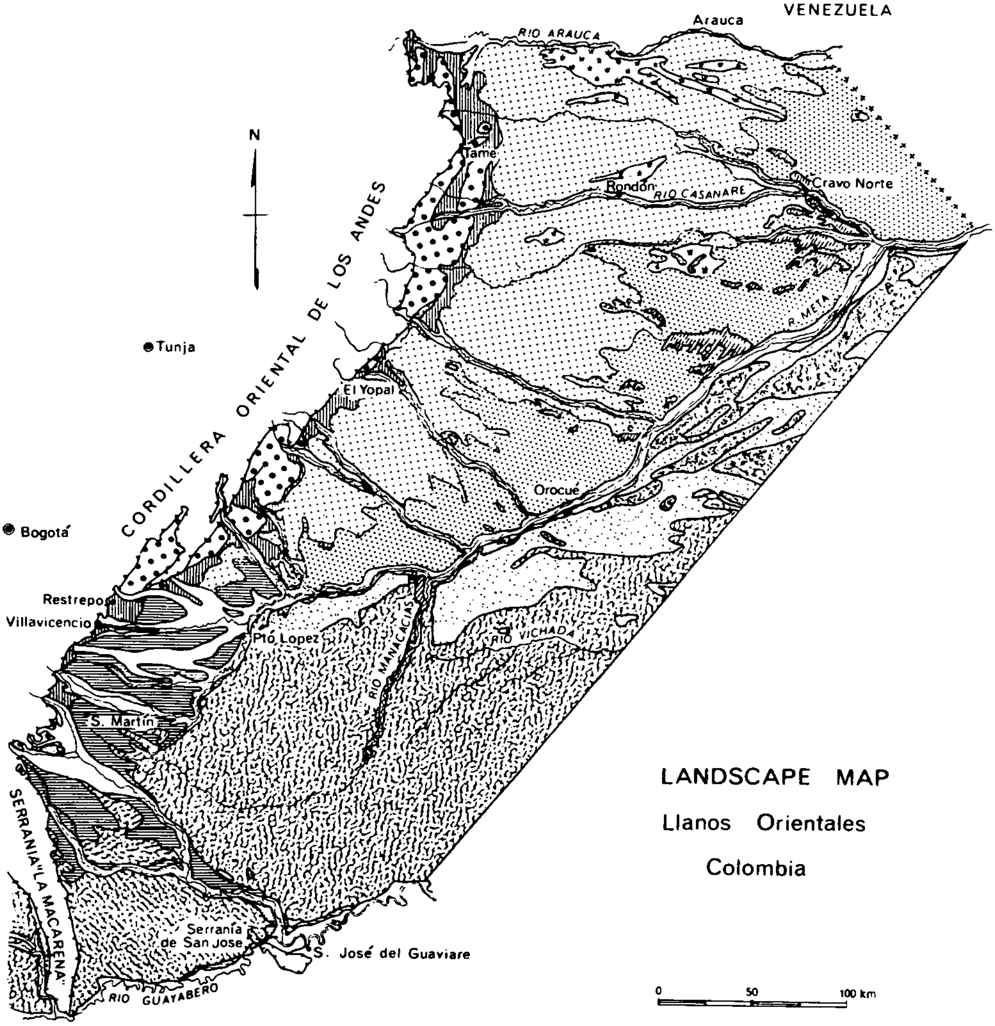


Fig. 7 Landscape map. (after: FAO report, 1965)



LANDSCAPE MAP
Llanos Orientales
Colombia

NAME	AGE OF SURFACE SEDIMENTS	AGE OF MAJOR LANDFORM (1)
PIEDMONT (M, P)		
Old Alluvial Fans	Early to Middle Pleistocene, locally Late Tertiary	Late Pleistocene to Early Holocene
Sub-recent Alluvial Fans	Late Pleistocene to Holocene	Holocene
TERRACES (T)		
Alluvial Terraces	Pleistocene to Holocene	Late Pleistocene to Holocene
ALLUVIAL OVERFLOW PLAIN (D)		
Alluvial Overflow Plain	Late Pleistocene to Early Holocene	Late Pleistocene to Early Holocene
AEOLIAN PLAIN (E)		
Dunes	Late Pleistocene Early Holocene	Late Pleistocene to Early Holocene
Aeolian Plain with "escarceos"	Late Pleistocene to Early Holocene	Late Pleistocene to Early Holocene
ALLUVIUM (V)		
Recent Alluvium	Late Holocene	Late Holocene
HIGH PLAINS (A)		
Level, well drained High Plains	Late Pleistocene to Early Holocene (2)	Late Pleistocene to Early Holocene (2)
Level, poorly drained High Plains	Late Pleistocene to Early Holocene (2)	Late Pleistocene to Early Holocene (2)
Dissected High Plains	Early to middle Pleistocene, locally Late Tertiary	Early Holocene

Note 1 : Only major landforms are considered here. Several minor processes of sedimentation and erosion are still continuing. They do not cause important changes in the major landforms, but will be discussed in following sections and chapters.

Note 2 : The relative uplift of the High Plains probably started in Middle and Late Pleistocene. Subsequently they were covered with aeolian sediments. The age of the latter is given here.

Table 3 Landscapes of the Llanos Orientales.
(Capital letters between brackets are the first component of the symbols used to identify the soil associations within the landscapes).

sand consisted of clays and intercalated peat layers. Based on pollen-analytical data, the authors estimate the age of the layer immediately above the sands, at 5,100 years B.P. The sands most likely represent the original valley bottom, established when the river Ariari was flowing at a much lower level. Most of the valley bottoms in the dissected High Plains consist of sand.

The surface extension of the landscapes is given in Table 4. It may be noted that in this table the marshes, occurring mainly in the Alluvial Overflow Plain and in the Aeolian Plain, are listed separately. The marshes are also indicated in Figure 7. In the following, however, they will not be treated separately.

	HECTARES	PERCENTAGES
Piedmont	653,775	5.1
Alluvial Terraces	666,861	5.2
Alluvial Overflow Plain	2,950,625	23.0
Aeolian Plain	2,076,875	16.1
Alluvium	1,286,875	10.0
High Plains	4,985,625	39.0
Marshes *	210,625	1.6
TOTAL	12,831,261	100.0

* Marshes occur mainly in the Alluvial Overflow Plain and in the Aeolian Plain. They are indicated on the map of Figure 7, but have not been listed in Table 3.

Table 4 Surface extension of landscapes of the Llanos Orientales.

3.2 DESCRIPTION OF THE PHYSIOGRAPHIC UNITS

3.2.1 Piedmont

The Old Alluvial Fans (M) are thought to have been deposited in the Early and Middle Pleistocene. Later tectonic movement has deformed them by folding and faulting and by partial uplift and partial subsidence. Near the Cordillera they were uplifted, while farther away to the East the formation subsided, and was later covered with younger sediments. The remnants at the surface near the Cordillera have an elevated position with respect to the younger sediments. The difference in height is about 50 m (see Figures 5 & 8). The level and undulating parts are called Mesas and Terraces. The name Mésa is used for those extensions of more or less level terrain which are bordered on all sides by downward escarpments. The name Terrace is used when the area is bordered on at least one side by higher terrain.

Much of the Old Alluvial Fans no longer exists in the form of mesas and terraces, but as low hills. These are the result of erosion and these areas are called Strongly Dissected Fans. Locally Tertiary strata are exposed

The original slope of the surface of the Old Alluvial Fans was probably 3 to 5 %. Such slopes are still found on many mesas and terraces usually in an eastern direction. Where folding occurred,

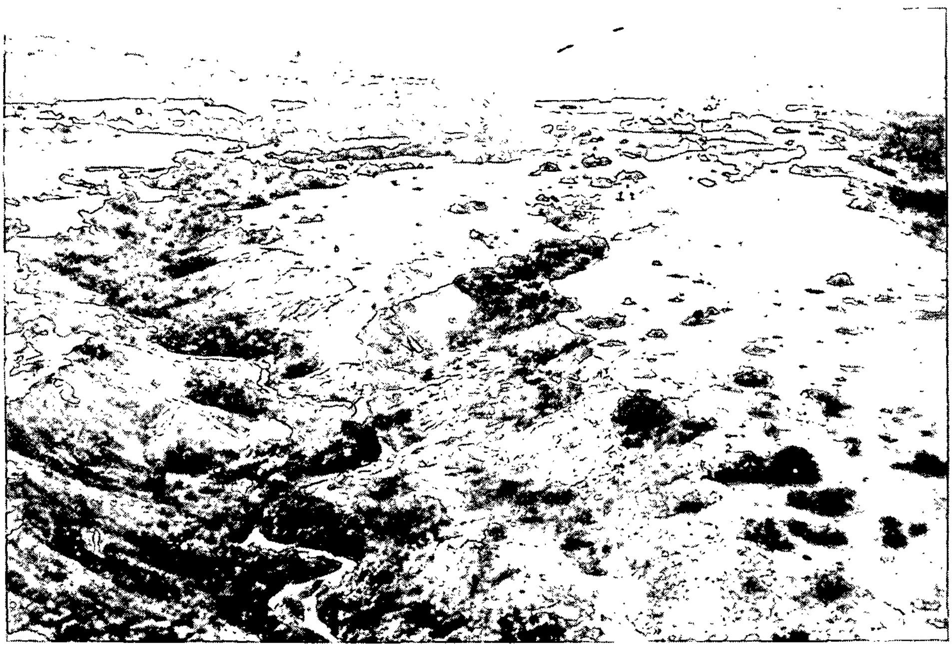


Fig. 8 Oblique aerial photograph of the Piedmont area with partly dissected Mesas and Terraces (M). The dotted line indicates a fault. In the background the Cordillera de los Andes (C) is visible.

greater slopes are found, up to 12 %. Some mesas or parts of them are now sloping to the West.

The strongly Dissected Fans are quite similar to some of the Upper Tertiary formations at the flank of the Cordillera with regard to slope, lithological composition, erosion features and vegetation. Therefore, the limit between the Cordillera and the Old Alluvial Fans can only be traced accurately by more detailed studies. The eastern limit is formed by escarpments corresponding to fault lines parallel to the Cordillera. The Old Alluvial Fans do not occur continuously along the Cordillera. They are absent in several sections.

The material composing the Old Alluvial Fans is very sandy and gravelly. In northern Casanare and Arauca boulders up to two meters in diameter are found at the surface. The drainage is excessive because of the elevated position and the coarse texture.

In southern Casanare and Meta the material is somewhat finer but gravelly material is found everwhere in the subsoil.

The Mesas and Terraces are mainly used for extensive grazing. The dissected area is mostly covered by forest.

The Sub-recent Alluvial Fans (P) were deposited after the Old Alluvial Fans were formed. The oldest parts date probably from Late Pleistocene, when sedimentation was very active at the end of the last glaciation. During the Holocene certain sections were eroded by the rivers, and refilled with younger deposits. This process continues up to the present time.

The differences in height between older and younger sections are slight: often not more than one or two meters. The younger sections have surface characteristics of abandoned braiding rivers.

The older sections are more smooth at the surface than the younger sections. Not so many features of braiding rivers are visible. They also have been deposited by braiding rivers, but the latest surface sediment has most likely been deposited by inundations at the initial stage of the formation of the younger sections. This surface sediment has a finer texture than is found in the beds of braiding rivers in the Piedmont area; it can be compared to 'Hochflutlehm' (Wilckens, 1927 and Schelling, 1951). It is possible that sheet erosion from the lower and often adjoining slopes of the Cordillera has added some fine material to the fans.

Sub-recent Alluvial Fans are the upper part of a vast alluvial plain, the Alluvial Overflow Plain (D), which will be discussed later. Both parts are genetically similar; their formation occurred simultaneously in Late Pleistocene and Early Holocene times, and their boundary is therefore very gradual.

The sediments of the fans are rather coarse in the North, and become gradually finer towards the South. In Figure 9 part of a fan in the South is shown in its surroundings.

Fig. 9 Piedmont area with subrecent Alluvial Fans in the foreground, dissected Tertiary formations in the middle distance, and mountains of Cretaceous sandstones and shales in the background.

(photograph by Richard S. Merritt)

The slope of the land of the Sub-recent Alluvial Fans is up to 5 % near the Cordillera. To the east it becomes gradually less, and at the foot of the fans it is no more than 1 %. In some places gullies were formed, and some of those developed into streams. A few of these streams are spring-fed. Where the streams have cut deep below the surface, slopes are steeper than 5 %. Other gullies were later on refilled with a mixture of fine material derived from local sheetwash and of organic matter accumulating simultaneously under conditions of poor drainage.

The sedimentation pattern of the fans is quite intricate, in the sense that abrupt changes occur within short distances. It follows, however, basic rules of the process of differential sedimentation. Differential sedimentation depends primarily on changes in slopes and velocity of the inundation water. The rivers usually have a braiding form. See Dury (1959) and Thornbury (1954) for a description of fan formation. The final result is a very complex, three dimensional braiding system. It can best be seen in cross-sections perpendicular to the river courses. Sandy, higher-lying bands alternate with lower, concave parts with more clay; gravelly beds of old stream channels are found in between natural levees. Near the apex of an alluvial fan the pattern of old river channels is very intricate, and individual channels cannot easily be traced along their course. Lower down, however, the gradient of the river becomes less, and this is often accompanied by a change in the river form. It changes from a braided into a meandering form. There it is easier to distinguish the different elements of the terrain, and the rhythmic processes of differential sedimentation associated with each of them.

The original vegetation of the Sub-recent Alluvial Fans was forest. Much of this forest has been cleared, the land being converted to pasture or used for agriculture.

3.2.2 Terraces (T)

The area of the Alluvial Terraces is indicated in Fig. 7. The age of the individual terraces is difficult to estimate. Some of the higher ones may be as old as the Early Pleistocene, and some lower ones may date from the Holocene. There is no consistent correlation between level and age, because of the tectonic movements active before, during and after the formation of the terraces, as has been explained in Section 2.3.

Some faults parallel to the Cordillera are only visible in the high terraces. This indicates that the fault was formed after the sediments of this high terrace were deposited, but before the next lower terrace was formed. Other faults cross more than one terrace, and some small faults are even found across recent alluvial sediments. This is a clear evidence that up to the present time tectonic movements have taken place in the area.

At least ten levels of terraces have been recognized (FAO report, 1965). Based on differences in soil conditions, thought to be related to age, these levels were grouped in three main levels, called high, medium and low. Within these main levels sub-divisions have been made according to the soil associations mapped in the field. See FAO report (1965).

Near the mountains the terraces have a cobbly substratum (Fig. 10), an agglomerate of rounded gravel and stones, overlain by a medium- to fine-textured alluvial deposit. This formation is normal for the piedmont area, where alluvial sedimentation has the pattern of a braiding river system. Gravel is deposited in the very wide and shifting channels, and finer material is deposited on and beyond the banks, where an alluvial flat is formed.

Further East the material of the substratum changes gradually into smaller gravel and sand, and the surface is characterized by variations in texture and relief within short distances, corresponding to remnants of natural levees and slackwater areas. One of the lower terraces near Puerto López shows distinct meandering ridges, obviously old natural levees of a meandering river.

Fig. 10 Escarpment of Alluvial Terrace with cobbly substratum.

For the first 30-50 kilometers after descending from the Cordillera the larger of the present rivers have a braiding character, and then they change rather rapidly into meandering rivers. There is only a gradual change in gradient. Hjülstrom (1942) found that fine sand promotes the formation of meanders. As the rivers have lost their coarse material after 30-50 km, the relatively increased content of fine sand may influence their behaviour. This is also consistent with Dury's observation (1959), that with a diminishing load the braiding river system may change into a meandering one. This interrelated adjustment between river load and river form is also discussed by Bloom (1969) and Leopold et al. (1964)

Most of the present surface of the high and medium levels of terraces does not show clear evidence of differential alluvial sedimentation. This might be compared with the 'Hochflutlehm' described by Wilckens (1927) and Schelling (1951).

The high and medium terraces are at present traversed by a number of curving and somewhat parallel shallow drainage channels, called 'esteros'. These esteros are up to 100 m wide, and are flanked by very gentle slopes. The process of erosion, which was responsible for their development, is not very active at present. There is rather a tendency for the esteros to become refilled by sheetwash from the adjoining slopes and by the accumulation of organic matter. Some of the esteros have meandering forms; it is possible that such esteros developed in abandoned meandering rivers, but the evidence is not conclusive.

The rather uniform texture of the surface layers, to a certain extent, could be due to the deposition of a surface layer by the wind. Extensive areas to the North-East of the terraces are covered with an aeolian sediment, as will be explained in the following sections, and the predominant direction of the wind is from the North-East.

The general physiographic aspects of the terraces change in accordance with the geomorphological genesis. Slopes are steepest near the Cordillera, though they do not exceed 5 %, except near and at the escarpments. Towards the East the slope of the land decreases gradually and is not more than 1 % near the Metica River. Most of the high terraces are situated near the Cordillera. They extend towards the East and terminate about 55 km from the mountain foot. Further East only the middle and low terraces remain.

Although rainfall is highest near the Cordillera, the natural drainage of the terraces near the Cordillera is better because of higher surface run-off and better internal drainage due to the stony subsoil. To the East the area of poorly drained soils increases and stagnant water is common in the wet season.

On the high terraces streams are usually intermittent. Streams at lower levels may be spring-fed and permanent.

The original forest vegetation of the terraces has been largely replaced by grasses and crops.

3.2.3 Alluvial Overflow Plain (D)

The Alluvial Overflow Plain forms the natural continuation of the alluvial fans, and can be regarded as the widely spread-out foot of the piedmont alluvial plain. The general gradient of the terrain is less than 1 %, and local mesorelief is determined by the alternation of natural levees and slackwater areas or basins.

The name 'Alluvial Overflow Plain' is derived from a similar formation in The Argentine Pampas, described by Frenguelli (1925) and Stappenbeck (1926), and called 'llano de desborde' or overflow plain. This name is preferred to 'floodplain' or 'meander floodplain'. The latter names are used in most textbooks on geomorphology (see for example Thornbury, 1954) for those floodplains, where lateral erosion is at least prominent enough to cause lateral and downstream shifts of the river meanders, and meander cut-offs. In such a floodplain many inner curves of meanders are characterized by the sedimentation of the so-called 'meander scrolls'. In the Alluvial Overflow Plain of the Llanos Orientales, however, sedimentation of material in the riverbeds and along the banks was the dominating process during the formation of the plain, and lateral erosion did not leave significant traces. Therefore, although the rivers had a meandering form, many beds were completely abandoned and the river started to flow in a lower part of the terrain, before the original riverbed could have shifted by lateral erosion of the outer curves. Because of this distinct mode of alluvial sedimentation, the name 'Alluvial Overflow Plain' is proposed here to indicate such a formation as different from that of a 'normal' meander floodplain.

The gradient of the terrain in the upper part of the Alluvial Overflow Plain is approximately 1 : 500. The rivers belong to the Orinoco system, and Nota (1958) mentions a gradient of 1 : 15,000 of the rivers in the lower Orinoco area in Venezuela. In the riverbeds of the Alluvial Overflow Plain, no gravel is found beyond about 40 km from the foot of the mountain. This indicates the rapid decrease of the capacity of the river to transport large-sized solid material.

The Alluvial Overflow Plain was rapidly built up. The natural levees were elevated faster than the basins, and numerous changes in river courses were the result. Apart from complete changes in the position of riverbeds, many local breaches in the levees occurred as the result of overflow. The water passing through these spillways deposited its suspended load rather quickly, because the water lost soon its velocity in the stagnant water of the basins. In this way a spillway deposit or 'splay' was formed, similar to a miniature levee. Sometimes the splays show branches, similar to a finger delta. Also forms like a shield delta occur. An example of an area where this type of sedimentation is still active is the lower Magdalena Valley in Colombia (Goosen, 1967).

Splays have been described by several authors. Happ et al. (1940) call them floodplain splays or splay deposits, Russell (1942) mentions crevasse deposits, Kruit (1955) talks of crevasse tongues, Allen (1965) describes crevasse splays and basin splays, Coleman (1969) also uses the name crevasse splays, and Havinga (1969) calls them levee splays.

Figure 11 shows a typical part of the Alluvial Overflow Plain in the

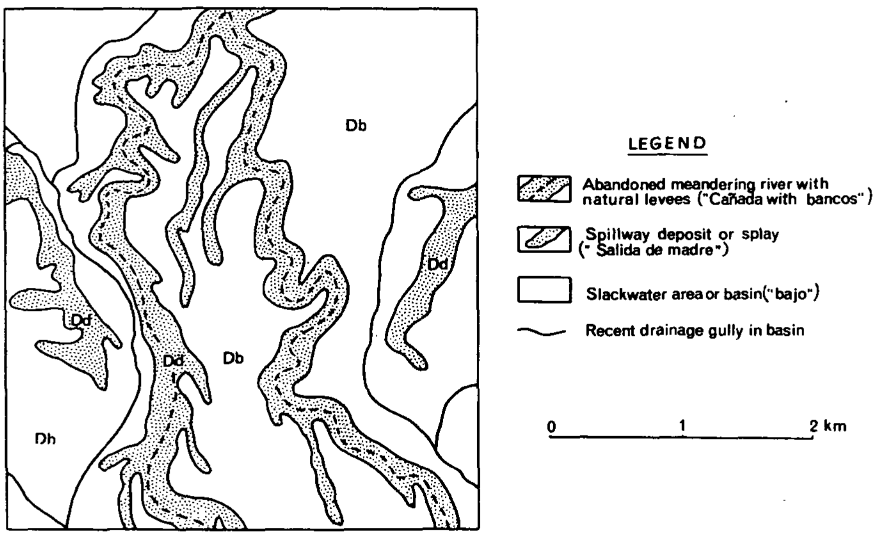


Fig. 11 Detail of the sedimentation pattern of the Alluvial Overflow Plain, drawn from an aerial photograph.
Soil association Dd contains a.o. the soil series Orocué on the levees, and Altimira on the splays. Soil association Db contains a.o. the soil series Corocora. See section 4.2 for their discussion.

Llanos Orientales. In this sedimentation pattern there are no meander cut-offs visible, nor scrolls in the inner curves of the meanders. The nearly total absence of such features is characteristic for the whole plain.

It should be understood that this system of sedimentation is no longer active in the Llanos Orientales. It is a relic of the transitional period Pleistocene/Holocene when the glaciers in the mountains diminished and huge quantities of material came down into the Llanos where they were deposited under very wet hydrological conditions. Once the glaciers had disappeared the flow of the rivers abated, possibly also because of decreasing precipitation (Van der Hammen, 1961).

An example of a river still freely meandering is shown in Fig. 12, an aerial photograph of the forested area in Arauca, approximately

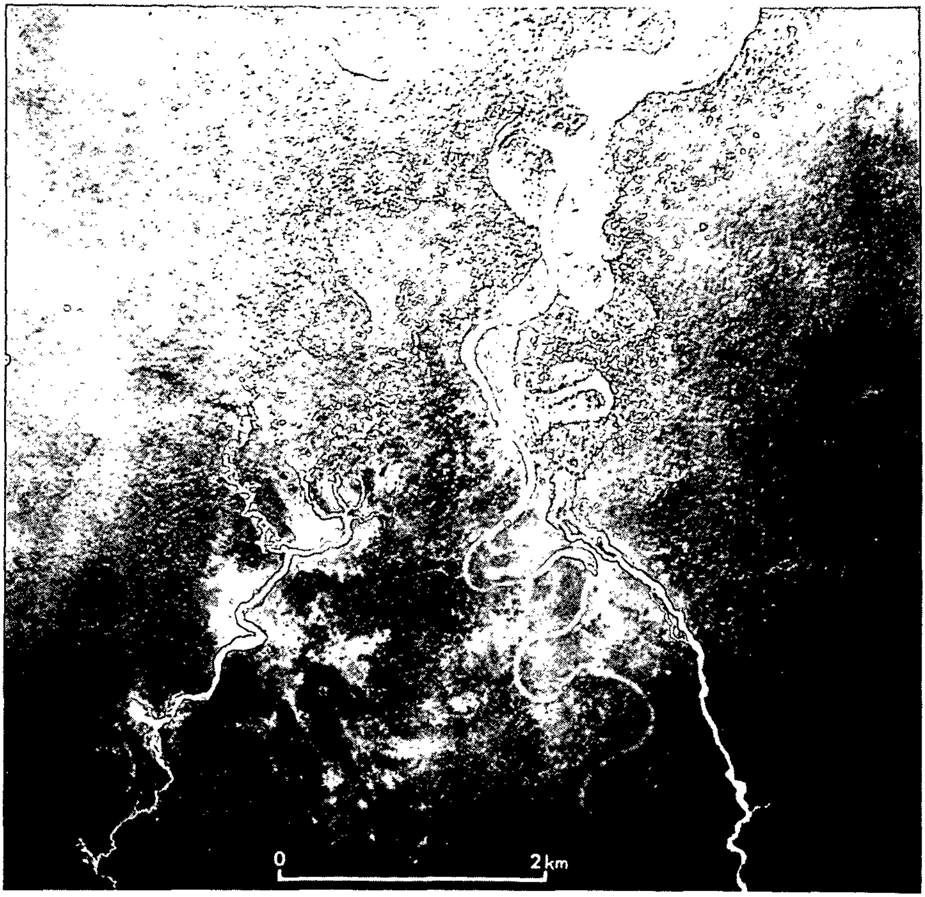


Fig. 12 Aerial photograph of the river Ele in Arauca. The bed is rapidly clogging up through sedimentation of sand. The arrow indicates the direction of stream flow. Seepage water reappears at A at both sides of the river and flows through newly formed channels. Abandoned meanders are visible at B. The vegetation in this area is a mixed forest.

25 km from the mountains. Scrolls and meander cut-offs are visible, demonstrating that lateral erosion has increased relative to a decrease in sedimentation. Still, the latter process is active; much of the amount of solid material carried by the river is trapped in the riverbed. The bed becomes clogged, first at the lower end, and then progressively more upstream. The sediments are extremely sandy and highly permeable. The river loses its water in a stretch of a few kilometers by lateral filtration through the levees. This water comes to the surface and collects a little way downstream on both sides of the original riverbed, and from there on two new streams are formed.

In general, the streams which in the past formed the Alluvial Overflow Plain, did not carry much coarse sand beyond the upper reaches of the Plain, because their gradient became too low downstreams. One of the effects of this system of sedimentation is that very little coarse material probably has ever reached the Orinoco river. This situation remains unchanged at present. A sample of sand taken from the bed of the Meta river at Orocué, contained less than 20 % coarse sand. Nota (1958) thinks it quite unlikely that any but the very finest sediment (which is transported in suspension) from the Andes or western Llanos should at present reach the lower Orinoco, because of the very low gradients of the river system in that area. This feature must be clearly distinguished from Bakker's (1954, 1957) findings in Surinam, where he attributes the lack of coarse material in river material to the typical weathering of tropical soils, which provides predominantly fine material.

As mentioned before, at present the rivers have decreased in size and number, as compared with the Early Holocene. Consequently, a prominent feature of the Alluvial Overflow Plain are the many abandoned riverbeds (Fig. 11). The present rivers, traversing the plain far apart from each other, are now down-cutting slightly. By regressive erosion some gullies penetrate from them into the intervening landscape, forming the start of a new drainage system, superimposed upon the abandoned one. These gullies show preference for the slack-water areas, but sometimes they follow the old meandering riverbeds.

The evidence of the decrease in size and number of the rivers is manyfold. Numerous abandoned riverbeds traverse the Alluvial Overflow Plain, and also in some of the present river valleys traces are found which indicate the former, larger size of the rivers.

The alternation of levees and basins is not only lateral but also vertical. It is a type of three-dimensional wickerwork, probably constructed in more than one phase of sedimentation. Gravel is absent, and the deposits vary in texture between coarse sand and clay. Differential sedimentation according to the different velocity of water is responsible for textural differences which follow the sedimentation pattern. Coarse textures are found nearest the Cordillera in the levees, and farther away to the East the texture of the levees becomes progressively finer. The range in texture in the levees is from coarse sand to sandy loam. The splays have textures somewhat finer than the adjoining levees. Here very fine sandy loam may be found associated with sandy loam in the levee. The basins have distinctly finer textures than the levees and splays, ranging from very fine sand near the Cordillera to clay in the East.

In the transition zone of the Alluvial Overflow Plain and the Aeolian Plain, admixture of Llanos loess to many soils which belong physiographically to the Alluvial Overflow Plain, is a common feature. This is entirely in line with the geomorphological development, according to which there is in general no sharp boundary between the two landscapes.

Similarily, aeolian influence can be noted on the levees. Most soil profiles of the levees do not show a 'normal' (for natural levees) textural composition of fine to coarse from top to bottom, but the topsoil is as light in texture as the subsoil. Homogenization due to biological activity may be partly responsible for this, and also selective erosion by sheetwash, but local aeolian activity must also be considered. Small dunes on top of the levees have been observed in a number of places, for instance, in the neighbourhood of Orocué and Trinidad.

The formation of local dunes, and therefore aeolian influence on levees, is not restricted to the Llanos. Wilhelmy (1957) observed a similar phenomenon in Paraguay, Maarleveld (1966) studied it in

Holland, where it is also described by Brzesowsky (1965). It seems to play a normal part in the sedimentation pattern of alluvial plains, provided that at some season of the year the sandbanks become dry and the wind is strong enough. Along the Meta river this process is still active and can be observed on windy days during the dry season. In this way the banks of the river are locally enriched by windblown sand.

The 'strands' of sandy levees, buried beneath the surface, form a complex of water-bearing deposits offering good prospects for the pumping of subterranean water.

A special feature of more recent origin in the Alluvial Overflow Plain is the occurrence of extensive surface erosion by a network of rills and gullies (see Fig. 13). This erosion pattern occurs

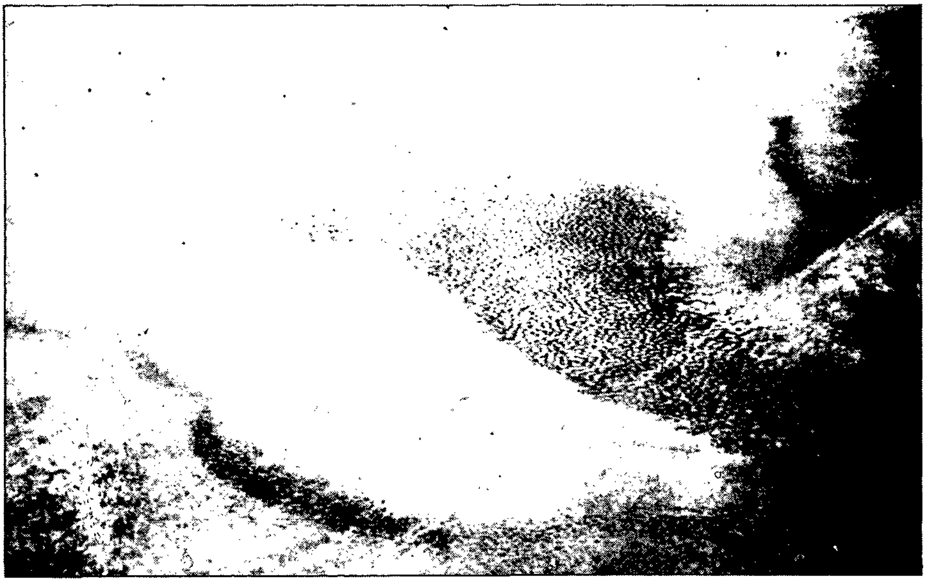


Fig. 13 Reticular gully erosion in the Alluvial Overflow Plain.
In the area of this oblique aerial photograph soil erosion is concentrated in the heavy-textured soils of the slackwater area enclosed by an abandoned meandering river, and in the silted-up old riverbed. The terrain where this type of erosion occurs, is called 'zural'. White lines are trails.

most typically in the basins, but in extensive areas it also encroaches upon the levees and splays. It is clearly different from the spillway pattern. On the soil map of the FAO report (1965) it has been indicated by a special symbol. The mapping was done during helicopter flights, because the individual gullies are too small to be seen on aerial photographs of a scale 1 : 40,000. This type of erosion occurs in varying intensity on about 2,000,000 hectares, which is nearly 70 % of the Alluvial Overflow Plain. Any area where this gully pattern is found is locally called 'zural'. The gullies themselves are collectively called 'zurales', while the term 'zuro' is used to indicate any more or less circular or elongated mound between the gullies. For the phenomenon as a whole the name 'reticular gully erosion' is proposed here, to indicate the network quality of the erosion pattern, so characteristic of the nearly level terrain. In Chapter 5, Section 4, a detailed discussion of this type of erosion is presented.

Most of the abandoned river channels, called 'canadas', only serve in the wet season for local drainage. The 'bajos' are still inundated periodically by rainwater. Only in the northern part are some areas flooded by river water; these areas are permanently marshy. Since more than 60 % of the Alluvial Overflow Plain consists of 'bajos', transport across the plain is very difficult. The natural levees, however, offer better possibilities for traffic.

The natural vegetation is mainly grass. Remnants of forest are found as isolated clusters of trees. The yearly burning of grasses prevents the expansion of the forest. Those farmers who protect their land against fire, report that slow but steady expansion of the forest occurs under these conditions.

Land use in the Alluvial Overflow Plain is mainly restricted to grazing. Around farms and settlements some subsistence agriculture is found. The grazing pattern is seasonal; in the wet season grazing is done mostly on the natural levees and splays, and also in the upper parts of the basins, while in the dry season the cattle graze mostly in the basins.

3.2.4 Aeolian Plain (E)

The Alluvial Overflow Plain, discussed in the preceding section, gradually changes towards the East. Along many of the principal rivers, longitudinal dunes, called 'mêdanos', are found in this eastern zone, extending from the southern banks of the rivers in a south-westerly direction. The dunes are at present covered by grass and forest, and because they are also found alongside several abandoned riverbeds, it is clear that their formation occurred in a former period.

Another feature indicative of a gradual change of the Alluvial Overflow Plain towards the East is the occurrence of a surface deposit of uniformly fine-textured material, the 'Llanos loess', covering the sediments of the Alluvial Overflow Plain.

The zone where the dunes and the Llanos loess occur, is called the Aeolian Plain.

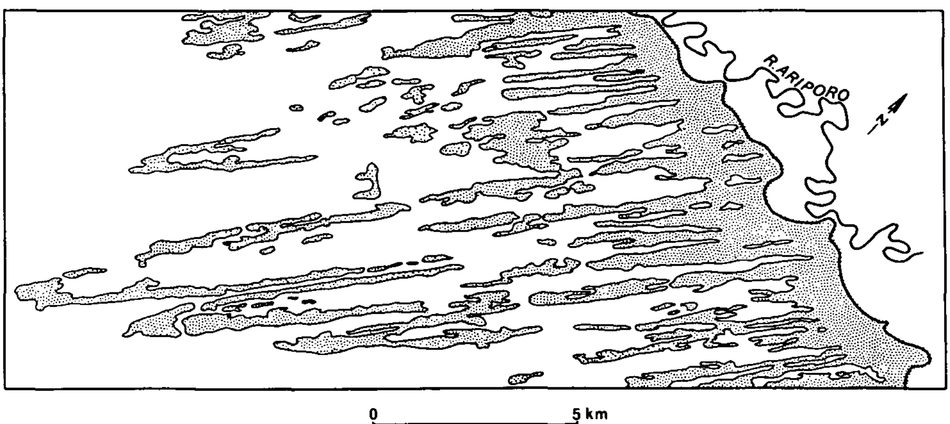


Fig. 14 Map showing pattern of 'mêdanos' (inland dunes), south of the river Ariporo. Between the dune area and the present river valley is an escarpment of five to ten meters.

(after: FAO report, 1965)

An analysis of a large dune area on aerial photographs reveals that there is a slight tendency to parabolic form (see Fig. 14). It also shows that many dune lines are interrupted and crossed by depressions. These depressions are marshy and originate probably from small streams which crossed and partially eroded the dune complexes. Such signs of degradation are recorded here without any attempt to explain or correlate them with climatic changes.

The longitudinal river dunes are formed from sand blown out of the seasonally dry riverbeds. In Melton's classification (Melton, 1940) they are simple dune forms and comparable to whalebacks (Thornbury, 1954 and Bagnold, 1953). Their maximum height is 50 meters and maximum length 25 kilometers. The relief is undulating and the swales between the dunes are often marshy.

The layer of Llanos loess is thinnest in the transitional zone between the Alluvial Overflow Plain and the Aeolian Plain. In this zone only the slackwater areas are covered with it, while the natural levees stick out as low ridges, which can be traced for several kilometers. In the pattern of Figure 15 the alluvial base of the landscape can be recognized from the remnants of levees and the form of the drainage system, which largely follows old meandering riverbeds. Farther to the East the cover of Llanos loess is thicker and covers both the natural levees and the basins.

The Llanos loess covers more than the Aeolian Plain indicated on the landscape map of Figure 7. It continues without interruption in Venezuela (Ramia, 1959), where the texture of the material is somewhat sandier. East of the Meta river the High Plains are also covered with aeolian sediments, and this cover continues without interruption untill the Orinoco river, where the author observed during a field trip in 1968 that the texture of the material is fine sandy. The regional differences in texture of the soils developed in the Llanos loess are consistent with the direction of the north-eastern trade winds. The finest materials were carried farther to the South-West, and there the deposit has the highest clay content. In the North-East and the East more silt and fine sand is found. The textures in the Aeolian Plain, West of the Meta river, range from clay to sandy clay loam, with a predominance of silt loam and silty loam. This gradual sorting of material is typical for wind-blown deposits as has been determined by Chepil (1957), Churchward (1963a) and others. The combination with dunes is also indicative of an aeolian origin of the Llanos loess. Thorp (1965) found a similar combination in China.

Transitional forms between dunes and level parts with loess are evident in the northern part of the Aeolian Plain. Very low 'whalebacks' are found there, with fine sandy textures at the summit and silt loam towards the foot. Such transitional forms are often not visibly related to any specific river valley, but seem to belong to the regional aeolian deposit.

The formation of the Aeolian Plain is related in time to the formation of the Alluvial Overflow Plain. The exceptionally heavy alluvial sedimentation in the Llanos at the end of the Pleistocene period provided an extensive cover of unconsolidated materials. The alternation of wet and dry seasons and the strong winds favoured aeolian transport and sedimentation. The sorting action of the wind resulted in the local formation of dunes and the regional deposition of the Llanos loess. Possibly there is some time difference between the formation of the two elements; no dunes were found on top of the Llanos

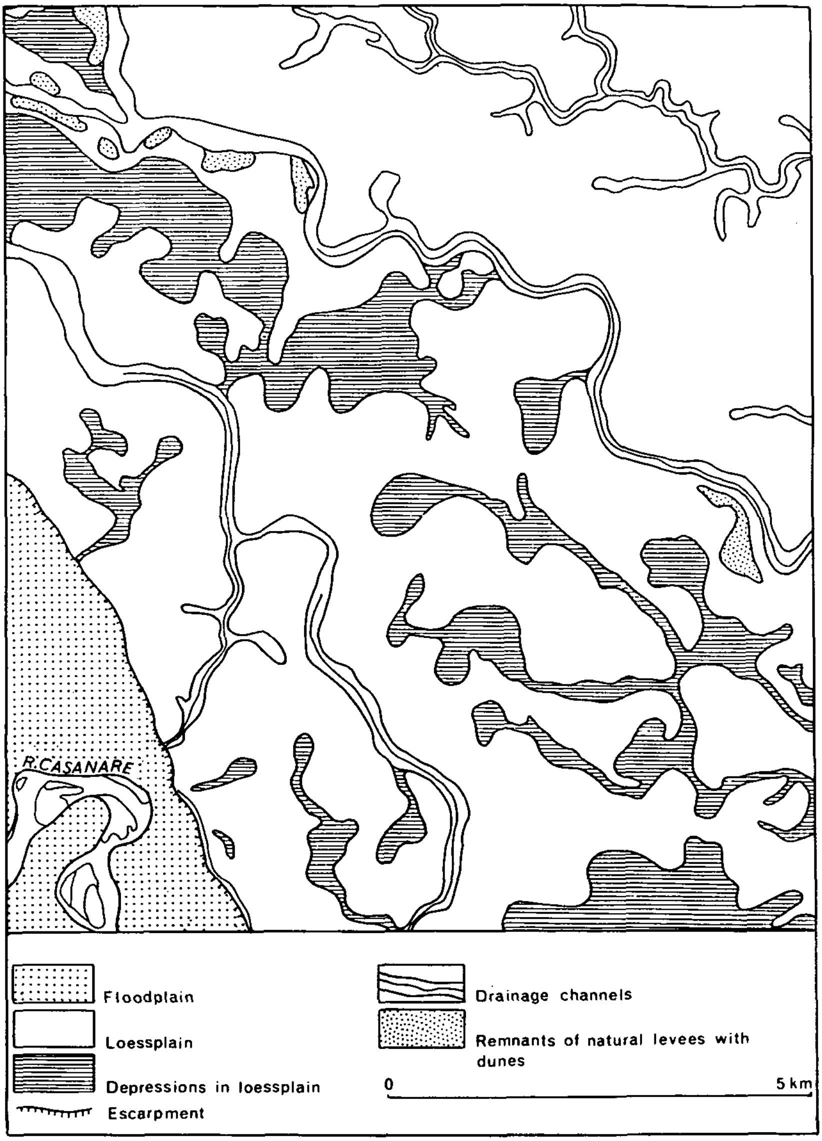


Fig. 15 Map, drawn from aerial photographs, of part of the Aeolian Plain with some visible features of the underlying Alluvial Overflow Plain. The depressions are the centres of former slackwater areas; the drainage channels mainly follow former meandering riverbeds. An escarpment of about three metres separates the recent floodplain of the river Casanare from the Aeolian Plain.

loess deposits, while in some places low dunes were found partially covered by the Llanos loess.

There is also evidence that some alternation in strength occurred between alluvial and aeolian sedimentation. The usual pattern is that towards the East the Llanos loess gradually covers the alluvial sediments, but in some places, especially along the Casanare and Ariporo rivers it is found that the Alluvial Overflow Plain penetrates far to the East. This represents a stage of the Alluvial Overflow Plain which was formed after the adjoining parts to the North and the South were already covered by dunes and Llanos loess. This alternation of alluvial and aeolian sedimentation has not been investigated further.

The occurrence of a vast aeolian cover does not necessarily indicate that at one time the climate in the Llanos Orientales was arid or semi-arid. A very strong influx of alluvial material into the area in combination with seasonally dry conditions and strong winds was sufficient to cause aeolian transport and deposition. In his review on the origin and characteristics of recent alluvial sediments, Allen (1965) states on page 161: "Wind can redistribute sediment lying loose on the surface of a floodplain or on the exposed sides or bed of a stream channel. The requisite conditions are that the sediment be dry or just moist and that the vegetation cover and rootlet bonds be incomplete. Under a wide range of climates these conditions are readily satisfied immediately following periods of overbank flow or of high state in the channel".

Except for the dunes, the relief of the Aeolian Plain is even flatter than that of the Alluvial Overflow Plain. In the wet season shallow inundations caused by rainwater occur everywhere. Some areas are marshy throughout the year. The natural drainage system consists of shallow, broad channels which are called 'esteros'. They are wet throughout the year and organic matter accumulates at the surface. In the eastern zone of the Aeolian Plain some of the 'esteros' have been transformed into deeply incised streams, sometimes up to ten meters below the surface. They affect locally the natural drainage of the soils and are thus accompanied by strips of better drained land.

A characteristic feature of the Llanos loess cover in the Aeolian Plain is the occurrence of low ridges, up to 50 cm high and mostly from two to five meters wide. Their form is asymmetric with the steepest scarp downslope, and their direction is parallel to the contour lines.

Figure 16 gives an overall view of an area where they are very well developed. In Chapter 5, Section 5, their origin will be discussed in detail. During the FAO soil survey (FAO report, 1965) the name 'escarceos' was invented for them, a name subsequently approved by the Colombian Academy of Language. The escarceos also occur East of the Meta river, in the level and poorly drained parts of the High Plains.

It has been mentioned already that the High Plains also are covered with Llanos loess. The soils developed in the poorly drained sections of these High Plains are similar to those developed in the Aeolian Plain.

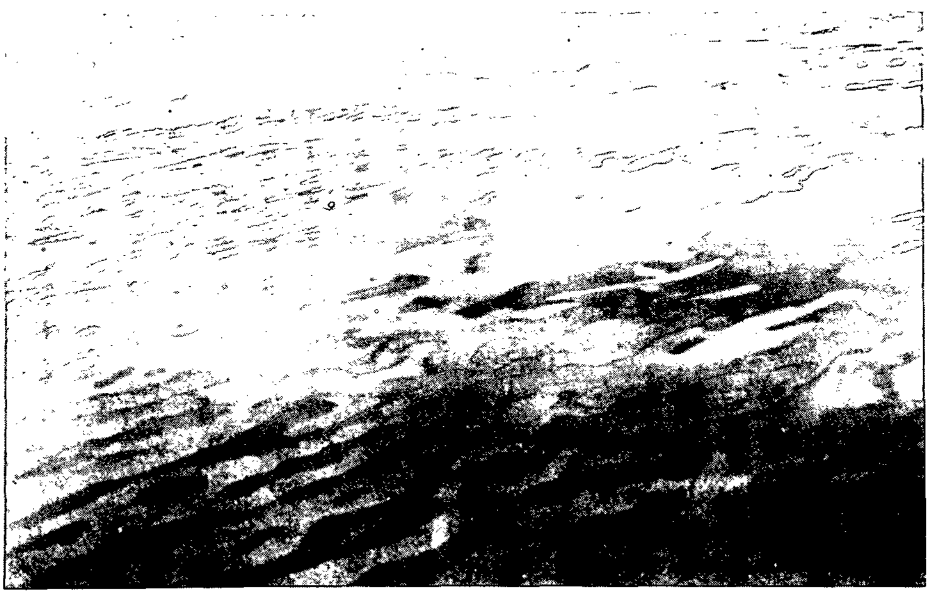


Fig. 16 Oblique aerial photograph of the low ridges ('escarceos') developed in the Llanos loess of the Aeolian Plain. The photograph was taken in the wet season and the area is almost completely flooded, but the higher grass-stand on the 'escarceos' marks the micro-relief of these ridges.

3.2.5 Alluvium (V)

The unit indicated as Alluvium on the landscape map of Figure 7, is composed of recent alluvial plains, called 'vegas'. They are found along the main rivers, mostly in fairly narrow strips, because the rivers are confined between the escarpments of terraces and by the Alluvial Overflow Plain, Aeolian Plain and High Plains, some of which are not very much elevated in relation to the levels of the streams but still form a natural obstacle to river expansion. Within this natural confinement, however, the rivers change their courses frequently, making the cultivation of perennial crops a hazardous undertaking. Although meanders are normal in the lower stretches of the rivers, their full development is impeded by the limited width of the valley, and fresh deposits such as meander scrolls are repeatedly destroyed by the rivers. Such continuous re-working of the material causes an intricate pattern of sedimentation.

Although the 'vegas' have a high agricultural value compared with other lands of the Llanos, a detailed discussion is omitted here, because their physiography and soils are very similar to what is known in general from recent alluvial sediments.

Bordering the vegas in the terrace area are strips of land known as 'vegon'. A 'vegón' is a complex of subrecent alluvium and deposits of the lowest terrace. This terrace was partially invaded by the rivers as a result of a temporary elevation in river level, causing some erosion of the terrace and local deposition of alluvium. Later on the river became lower and now the 'vegones' form a very low terrace composed of relatively recent alluvium in complex with an older terrace formation. For such features Bakker used the term 'overflow terraces' (pers. comm. Jungerius). The 'vegones' are not inundated by river floods at present.

3.2.6 High Plains (A)

The vast alluvial sedimentation of the Tertiary and Early Pleistocene Periods took place without interruption from the Andes Cordillera to the Orinoco river. During the Pleistocene this sedimentation process came to an end for the area East of the Meta river. A long fault established itself approximately along the line where at present the Meta river flows. The area to the West subsided in relation to the area to the East of this fault, and this relative tectonic movement resulted in an escarpment of varying height between 10 and 50 meters, at present located immediately East of the Meta river. This barrier stopped alluvial sedimentation in the Eastern part while this process continued in the western part forming the previously discussed Alluvial Overflow Plain.

The aeolian activity of the Late Pleistocene and Early Holocene periods also affected the area East of the Meta river. The elevated alluvial sediments were covered with a sheet of Llanos loess several meters thick. In a recent erosion gully near the confluence of the Manacacías and Meta rivers this layer was found to be approximately five meters thick, overlying sandier alluvial deposits. Dunes are found in several places along the Meta river and along the Manacacías river. The most southern locality where dunes were found is situated just West of the latter stream, 100 km South from the Meta river and at the same latitude as San Martín.

The uplifted Pleistocene sediments to the East and the South of the Meta river were affected by erosion, which started from the South. This erosion occurred in several phases presumably connected with the tectonic uplift. At one location about five km East of the Manacacías river, seven erosion levels were recognized. The dissected area is now very extensive and reaches North up to a line 50 km South of the Meta river. It continues far South in the Amazon basin (Gross Braun and Ramos, 1959). The local name for the dissected area is 'serranía'.

Because of the erosion, the underlying sediments are exposed in the 'serranía'. Most of those sediments belong to the Early Pleistocene alluvial sediments, but locally Tertiary strata may be exposed. The geological map (Bürgl, 1961) leaves this question open. There most of the Llanos sediments are called 'undifferentiated Cenozoic'.

The whole landscape East and South of the Meta river has been called <u>High Plains</u> (FAO report, 1965). Physiographically three major divisions can be distinguished (Fig. 7). They are, from North-East to South-West:

1. the level, poorly drained High Plains with features including 'escarceos', similar to the Aeolian Plain;
2. the level, well drained High Plains where relief is slightly more pronounced than in the level, poorly drained High Plains;
3. the dissected High Plains, also called 'serranía' with steep hills and V-shaped valleys, partly filled by colluvial wash.

Transitional forms occur between the level, well drained High Plains and the dissected High Plains. Those transitions are the undulating High Plains (see Fig. 17), and in the landscape map of Fig. 7

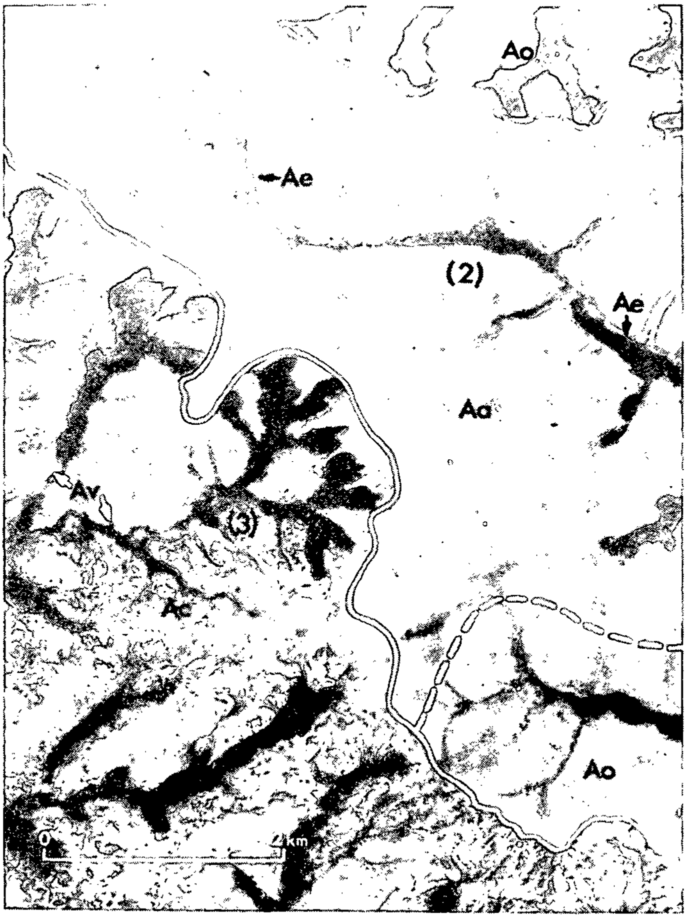


Fig. 17 Aerial photograph of the High Plains. (2) is the level, well drained High Plain with soil associations Aa (level, well drained), Ae ('esteros') and Ao (undulating). (3) is the dissected High Plain with soil associations Ac (strongly dissected) and Av (colluvio-alluvial valleys). The darker patches in unit Ac are outcrops of indurated ironstone. The soil associations are discussed in section 4.4.1.

they have been mostly included in the level, well drained High Plains, but sometimes also in the dissected High Plains. The undulating High Plains are characterized by a distinct soil association Ao, and can therefore be identified on the soil map of the FAO report, 1965.

The level, poorly drained High Plains occupy extensive areas in the north-eastern part of the High Plains. They are intercalated with the level, well drained High Plains, which towards the South-East predominate more and more. Poor drainage in the North-East is due to the very flat relief and the somewhat lower elevation of parts of the terrain as compared with the level, well drained High Plains.

The level, poorly drained High Plains are in many respects similar to the Aeolian Plain, where the latter consists of the level sediment of Llanos loess. The parent material is the same, except that in the level, poorly drained High Plains the silt content is somewhat higher than in the Aeolian Plain. The inundation regime is slightly different, because in the North-East total rainfall is slightly less than in the Aeolian Plain and the dry period is slightly longer (see Fig. 3). None of these differences, however, would on its own justify the separation of two different soil mapping units. Identical soil series occur in the Aeolian Plain and in the level, poorly drained High Plains. But besides the identical soil series, occupying the majority of the areas, other soil series of minor extension occur in each area, that are not found in the other area. This is the reason why the mapped soil associations have been classified differently in the legend of the soil map. An additional consideration has been the existing differences in certain physiographic aspects, such as slightly different hydrological conditions throughout the year, differences in topographic location and differences in position relative to adjoining units, which might play a role in future agricultural development schemes.

In the level, well drained High Plains, the natural drainage system consists of shallow, broad drainage channels, similar to the channels in the Aeolian Plain and in the level, poorly drained High Plains, and are also called 'esteros'. The bottom of these esteros is composed of organic matter mixed with silt and clay. It is wet throughout the year and often inundated in the wet season.

The broad divides between the esteros are level, somewhat convex, at the summit, straighten out and become slightly concave on the long slopes towards the esteros. Near the latter, where drainage becomes gradually poorer, termite mounds are found. Anthills are typical for the better drained higher parts. The surface of the divides is very smooth and it is often possible to drive at high speed through the grass if anthills and termite mounds are not too numerous. Slopes of 0 - 2 % are typical for the unit.

Apart from the regular relief of alternating savannas and esteros, both the level, well drained and the level, poorly drained High Plains show slight differences in elevation of sections several kilometers long. Sometimes a height difference is perceptible because of a very subdued 'escarpment' with a slope not exceeding 5 %, sometimes the height difference is even less conspicuous. The lower sections have a higher percentage of poorly drained soils than the higher ones. This phenomenon has not been studied and analyzed systematically, and its origin has not yet been explained. It might be due to earlier river-terracing, but a more likely explanation is that the fault along which the Meta river runs, is accompanied towards the East by a number of parallel faults. The fault scarps presumably might have been graded by mass movements and erosion.

The soils of those divides that are flattest, have a very uniform texture. Figure 18 shows a bundle of grain-size analyses of twenty soil samples taken from five profiles at regular intervals along a straight line 1,300 m long between two esteros 12 km south of Orocûe. The variation is very narrow. The granulometric distribution is very similar to that of loess, although the samples have a rather high clay content. Such a distribution is an important clue in identifying windblown material on the surface of the level High Plains. Soils derived from alluvial deposits would show more variation in texture for different samples due to the local sedimentation pattern.

Additional evidence for postulating an aeolian origin of the material is found in the fact that the same Llanos loess covers different levels.

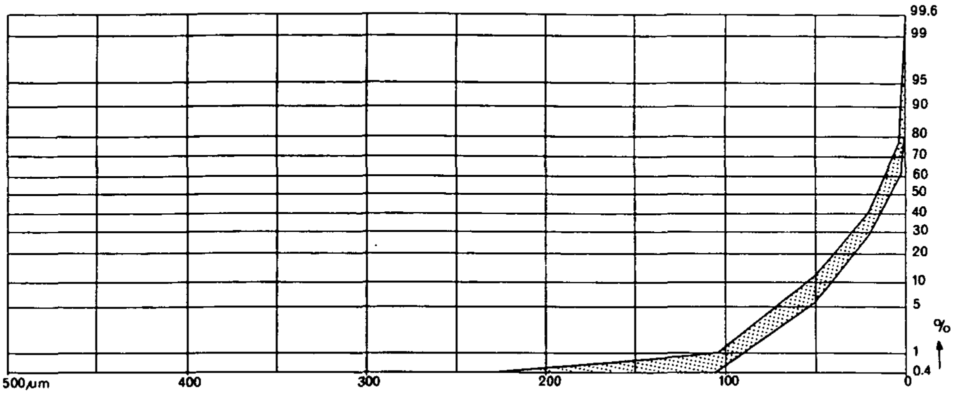


Fig. 18 Cumulative size frequency distribution of clayey Llanos loess. The bundle includes 20 soil samples from 5 profiles, taken at regular intervals along a straight line 1,300 meters long between two 'esteros' on the level, well drained High Plain, 12 km South of Orocué. This granulometric distribution is typical for soil series Horizontes, discussed in section 4.4.

While the soils of the flattest parts show a uniform texture, the more normal relief form with broad, convex summits and gentle slopes has more variation in texture. Selective erosion has been responsible for differentiation according to relief: fine textures are found on the least eroded summits, and coarser textures on the slopes.

On all gentle slopes of the level, well drained High Plains sheet erosion is common. In several places very shallow erosion rills occur, which have an irregular and crossing pattern on the divides, like an irregular network, but become parallel on the gentle slopes. Figure 19 shows this arrangement. The rills are no longer active, and they are filled with local sheetwash materials. They are so shallow that it is difficult to recognize them in the field. The soils in the rills have an A-horizon of 20 to 25 cm, with a colour one value darker than the soils adjacent to the rills. The latter have a 15 to 20 cm thick A-horizon. There were no other differences found.

The dissected High Plains in the southern part of the High Plains are more extensive than the other two units, described in the foregoing, combined. In many places the transition is abrupt, as can be seen in Fig. 17. The process of erosion, responsible for the dissection of the High Plains, is a regional process acting over large extensions of land in South-East Colombia and North-West Brazil. The base level of erosion in the area of this study is mainly formed by the Guaviare river and its tributaries. By regressive action the erosion has penetrated north, and in some localities, e.g. near Puerto López and near the confluence of the Manacacías and Meta rivers, not much is left of the level High Plains. In the level High Plains a layer of ferruginous material is found at depths of eight to ten meters. This layer has been exposed in the dissected High Plains, and has hardened into indurated ironstone. The broken remnants of this layer

Fig. 19 Vertical aerial photograph of the level, well drained High Plain with a pattern of non-active erosion rills. The pattern is reticular on the summits of the divides and parallel on the slopes.
The toposequence of soil series Lagunazo and Nápoles, discussed in section 4.4, is typical for this area.

are now found at the surface of many hills in the dissected High Plains. Where textures are sandy, the pieces of ironstone are often large, up to a few meters in diameter. In finer textures the pieces tend to be much smaller.

Some of the ironstone has been eroded completely and transported towards the colluvio-alluvial valleys traversing the dissected High Plains. Often in these valleys it is covered with colluvial wash deposits, derived from the adjoining hills, and which have frequently a sandy to loamy texture.

The hills of the dissected High Plains are composed of material whose textures range between clay and sand. More textural differentiation is found than in the level High Plains, and a layer like the Llanos loess does not occur. It might have been eroded or it might not have been present at all, or at least in a lesser degree than farther North. No systematic investigations have been made with regard to the extent the Llanos loess was deposited in the south.

The natural vegetation of the High Plains changes gradually from grass in the North-East to forest in the South-West. Most of the level High Plains, whether poorly drained or well drained is covered with grass. Along and in the drainage channels, gallery forest is found. The northern part of the dissected High Plains is also covered with grass, but to the South more forest is found. This forest is the beginning of the Amazonian forests.

The savannas are used for extensive cattle grazing. Most of the farms are concentrated along the road leading East and North-East from Puerto Lôpez. This road is unpaved except for short sections where it traverses poorly drained land, and can be used the whole year with four-wheel drive vehicles. On a trip made in 1968 the author found that several hundreds of new inhabitants had settled in the area East of Orocué since the year 1964. This influx of people originated mainly from Casanare and occurred, according to some settlers, because communications in the Alluvial Overflow Plain and the Aeolian Plain are worse than in the High Plains.

The yearly burning of the savannas is an established practice. On the aerial photographs of Figures 17 and 19 the traces of burning can be seen quite clearly.

Chapter 4

SOILS

4.1 INTRODUCTION

The results of the systematic soil survey of the Llanos have been published elsewhere (FAO report, 1965). In this chapter we intend discussing some principal soils of three landscapes, in order to demonstrate, in Chapter 5, the relation between certain processes of erosion and mass movement, and soils. These processes are:

- reticular gully erosion in the Alluvial Overflow Plain
- sheet erosion in the level, well drained High Plains
- solifluction in the Aeolian Plain and the level, poorly drained High Plains.

Some concepts used in the following sections need some explanation:

The mapping unit used in the soil survey of the Llanos Orientales is the 'soil association'. According to the Soil Survey Manual (Soil Survey Staff, 1951), this is "a group of defined and named taxonomic soil units, regularly geographically associated in a defined proportional pattern". The Soil Conservation Service of the United States of America use in one of their soil survey reports (Soil Cons. Serv., 1967) this definition: "A soil association is a landscape that has a distinctive proportional pattern of soils". The use of soil associations in soil mapping is derived from practical reasons: when the scale of the map does not permit to show the individual members of the soil association. Also, depending upon the intricacy of the pattern, the scale of the map and the ecological importance of the components of the soil association, some soil associations may have a higher degree of variation than others even on the same soil map.

The relation between soil association and taxonomic soil classification has not yet been sufficiently clarified (Knox, 1965). An excellent review of current trends in soil science regarding this problem is given by Schelling (1970).

Confusion often arises when attempts are made to name the mapping units in soil-taxonomic terms, because the mapping unit is not a mosaic of different soils (Morison et al., 1948), but often a continuum of soil variations.

The description of soil profiles forms the proper base for grouping and correlating individual soils in a system of taxonomic classification. This aspect of soil survey can be called 'soil systematics' or 'pedon systematics'.

The description of landscapes associated with the various individual soils often forms the base for grouping natural soil bodies in the legend of a soil map. This aspect of soil survey can be called 'soil geography'.

It can also be said that pedon systematics is concerned with the morphometric and explicative description of 'internal' soil properties (properties of the soil profile), while soil geography is concerned with the morphometric and explicative description of 'external' soil properties (properties of the landscape). That these two aspects are intimately connected, is reflected in the dictum: "Soils, then, are landscapes as well as profiles". (Soil Survey Staff, 1951).

The soil mapping units are usually named in terms of soil taxonomy; but one must clearly distinguish between the nature of the mapping units (a continuum of soil variations) and its nomenclature which refers to precisely defined pedons. If the strict sense of the taxonomic name is adhered to, the result is a mapping unit considered to be composed of one or more (depending on how many have been recognized) polypedons with a certain percentage of impurities. The idea of impurities, however, is, apart from clear cases resulting from the scale of mapping, contrary to the definition of the soil association, in which all variations form an essential component of the unit.

All soil associations in the Llanos have been named first with a physiographic name. Furthermore, there is a short description of the range of some principal soil variations, mainly texture and drainage. The soil series in this study refer to pedons described as occurring typically in the association, and the variations named are indicated in relation to their occurrence in the landscape. The taxonomic classification of the individual pedons is given with each description. The system of taxonomic soil classification used here is the Soil Classification (7th Approximation) of the U.S.A. (Soil Survey Staff, 1960) with its supplement of 1967. The soil profile descriptions (see Appendix II) have been taken from the FAO report (1965). They have been made by different field parties in different seasons, mainly of the years 1962 and 1963. In the descriptions certain changes were made, as follows.

Many subsoil horizons originally defined as C-horizons are now mostly considered to be parts of the B-horizon. Therefore, the horizon designations were modified accordingly.

The taxonomic classification has been changed in most cases because it was based on the 7th Approximation (Soil Survey Staff, 1960), while the Supplement to this classification (Soil Survey Staff, 1967) contains certain changes in the definitions which were followed in this study.

In the original profile descriptions the description of pores was separated into two components:

a. porosity thought to be the result of macro-organisms;

b. all other pores; since this separation was based on an interpretation of the observed features, the author omitted it and combined the two kinds of porosity into one general description of porosity.

The family and series nomenclature of the FAO report (1965) has been maintained in this text. The family names were based only on texture, because insufficient data were available on the mineralogy to apply the latter criterium systematically. The control section for soil series and families with regard to texture was taken arbitrarily from 25-75 cm depth. In the 7th Approximation(1960) the control section mentioned is 15-75 cm, and in the Supplement of 1967 the control section is taken at 25-100 cm. A more exact application, based on future investigations, of the criteria suggested in the 7th Approximation and its Supplement (Soil Survey Staff, 1960 and 1967) may well lead to a separation of some series and families now considered identical.

At the time the profiles were described, no facilities were available for micropedological investigations. Especially the data about microstructures and the presence or absence and nature of cutans are insufficient for a precise taxonomic classification. The latter proved to be very difficult even if certain assumptions were made regarding the nature of the diagnostic horizons within the soil profiles. Field observations as well as analyses clearly show an increase of clay content in the B-horizons of several soils, pointing to the probability of lessivage occurring in these soils. Clay-skins (argillans) were, however, rarely found in the field. Therefore, all indications of Argillic horizons are of a tentative nature. Based on the available data, many soils are intergrades between Inceptisols and Ultisols, while some have properties consistent with Oxic intergrades.

Near the Cordillera, where rainfall is abundant (see section 2.2 and fig. 3), Argillic horizons are found in the soils of the Alluvial Terraces. Towards the East, where the soils discussed in this chapter occur, total rainfall drops below 2,000 mm, while the dry period is longer. It is also in this area where the savannas have existed for a longer time, superseding the forest vegetation (see section 2.5.1). Because of the climatic conditions and of the change in one or more of the state factors of soil formation, it is postulated here that most soils in the Llanos are polygenetic. For the well drained soils the hypothesis about soil formation is as follows.

The original parent material (alluvial and aeolian sediments) was already highly weathered at the time of deposition. The high content of kaolinite is supposedly for a large part inherited from the parent material. Under the forest vegetation prevailing in former times (see section 2.5.1) the soil forming processes were probably both lessivage and ferrallitization, leading to the formation of a 'kaolisol lessivé' (Sys, 1967). The intensity of either of these processes might have been variable according to the succession of wet and dry seasons, but a sharp distinction cannot be made. The typical part of the Argillic horizon formed at several meters depth, although clay cutans might have been present within one or two meters depth. The upper part of the solum had most of the characteristics described by Bennema (1963) for latosols.

The process of ferrallitization had not acted long enough to transform the soil into an Oxisol (cf. Veen, 1970, who discusses some of these problems in Surinam), and the soil probably could be classified as an (Oxic) Tropudult.

With the change of forest into savanna, the state factors changed. The more uniform rooting of grasses, the higher soil temperatures and the increased biological activity of ants presumably resulted in a disturbance of the structure of the soils. The mineralization and dispersion of organic matter contributed to a more acid soil reaction. These factors in combination with a rather high porosity led to a combined silt and clay transport from the upper horizons. In some soil series the granulometric analyses support this hypothesis (e.g. in soil series Comino and Orocué of the Alluvial Overflow Plain). The process is thought comparable to what van Schuylenborgh et al. (1970) describe for a 'Udalfic' Eutrochrept in the Netherlands, where they recognize the formation of illuvial cutans consisting of clay minerals, iron oxide, and fine matric components. These cutans, named 'matriferriargillans' by the authors, do not fulfill the reguirements for recognizing an Argillic horizon because the coatings are not continuous and have a rough surface. The matriferriargillans are easily disturbed by biological activity, and this process is thought to have had a great influence upon the soils of the Llanos during the past centuries. It is thought that at present lessivage is a very active process, but that the formed cutans are quickly destroyed. The finer particles are removed from the surface horizons, while organic matter is dispersed and moves downward. In several profiles dark streaks are noted along pores and root channels. This resembles the formation of an Agric horizon (Soil Survey Staff, 1960), and is also comparable to phenomena occurring in 'sols isohumiques' (Aubert c.s., 1967), although the latter are not as acid and contain a much higher amount of Ca than the Llanos soils. The current soil forming processes of lessivage and dispersion of organic matter give the soil a Palehumultic character, except that an Argillic horizon is absent, presumably because of the quick destruction of the cutans.

The result of the above combination of processes is that a new soil formation is presumably leading to what now properly should be called Inceptisols as developed in earlier formed (Oxic) Ultisols. The Cambic horizon of the Inceptisols is forming in what were once the very deep A1- and A2-horizons of Ultisols. The top of the Argillic horizon may orginally have been within 125 cm. from the surface but most of the cutans may have been destroyed by renewed biological activity. The typical part of the Argillic horizon probably is situated several meters below the surface. This is confirmed by field observations in a deep young erosion gully near the Manacacías River.

For the poorly drained soils of the Llanos a similar hypothesis can be presented. The differences are that the Argillic horizon of the once existing Ultisol is found nearer the surface, often in combination with iron concretions, and that the surface horizons have low chromas due to loss of iron. The soils probably were mainly Plinthaquults. In some soils cutans were recognized in the field, but evidence is lacking about their exact nature, and it is doubtful whether they fulfill the requirements to be met for an Argillic Horizon. The high silt content and the easy dispersion of the soil matrix could have led already from the start of soil development to the formation of matri(ferri)argillans which in a later stage of intensified biological activity were partially or wholly destroyed. In the poorly drained soils it are mainly the termites who are responsible for this process.

The biological activity of ants in the well drained soils and of termites in the poorly drained soils differs with respect to the dispersion of organic matter from the activity of earthworms. The latter seem to have a more stabilizing effect on the soil structure.

The problem around the formation of cutans is reflected in the fact that in some profiles of a soil series (e.g. Guanapalo of the Aeolian Plain and of the level, poorly drained High Plains) cutans were recognized, while in other profiles of the same soil series they were not observed. That such soils were grouped in the same soil series, demonstrates the fact that during the soil survey little diagnostic significance was assigned to the cutans, because their recognition in the field provided an insufficient base for unequivocal classification.

The reasoning above leads to the conclusion that with the insufficient data available the taxonomic classification of the soils in the Llanos can be tentative only. Micropedological investigations are needed to solve the problem. In the meantime, based on the hypothesis put forth above, most soils are classified as Ultic and Oxic intergrades of Inceptisols.

In the following sections 4.2, 4.3 and 4.4 the soils of respectively the Alluvial Overflow Plain, The Aeolian Plain and the High Plains will be discussed. In the first part of these sections the soil associations with the series are listed. The symbols for the soil associations are composed of the initial letters of Spanish words, indicating certain characteristics of the units, as follows:

D - Desborde (overflow)

E - Eólica (aeolian)

A - Altillanura (high plain)

a - ápice; alta (apex; high)

b - baja; bajos (low; basins)

c - colina (hill)

d - dique (levee)

e - estero (broad, shallow drain)

m - médano (inland dune)

o - ondulado (undulating)

r - reborde (border)

s - escarceo (low ridge)

v - valle (valley)

The location of the soil profiles (Appendix II) is indicated in Figure 20.

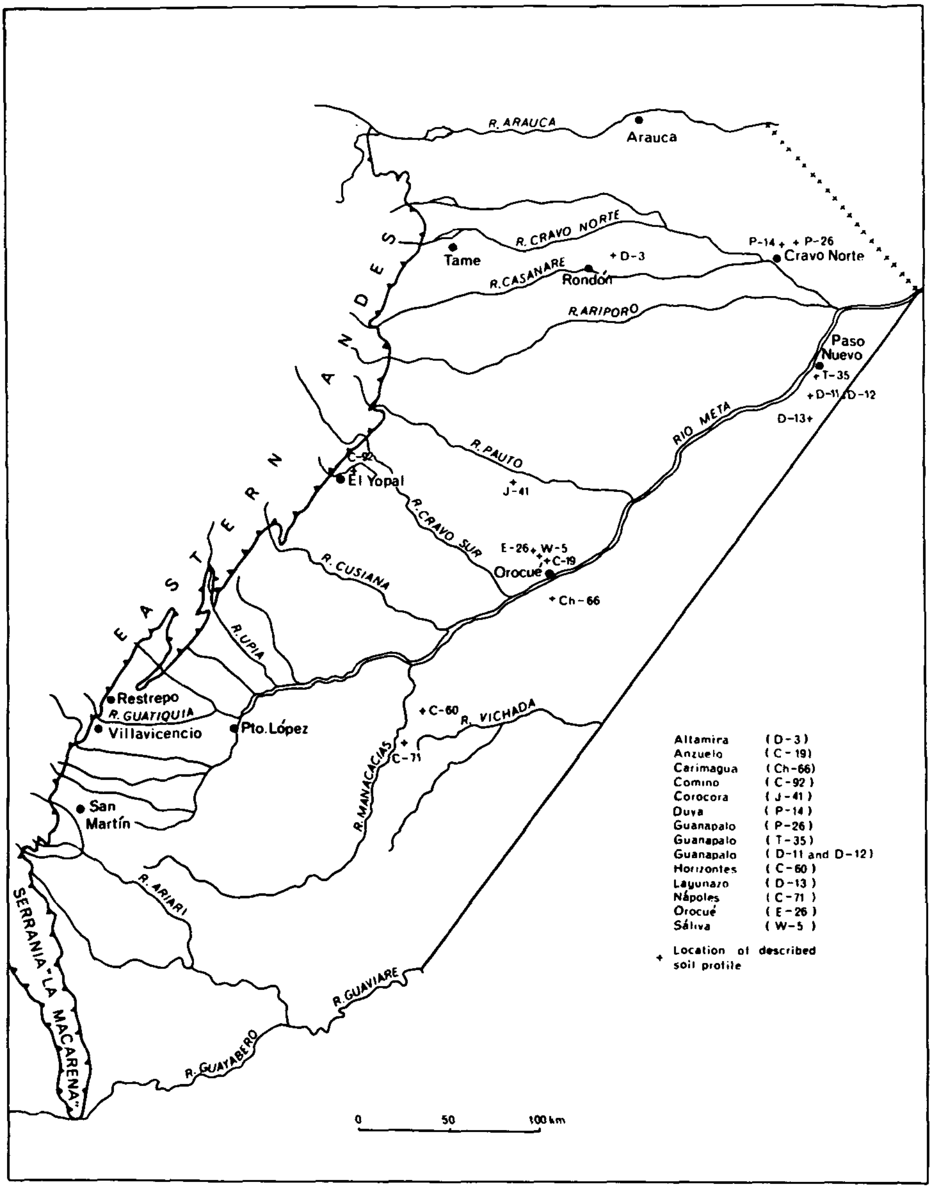


Fig. 20 Map showing the location of the described soil profiles.

4.2 SOILS OF THE ALLUVIAL OVERFLOW PLAIN

4.2.1 Soil Associations

In Table 5 the soil associations of the Alluvial Overflow Plain are listed.

SYM-BOL	SOIL ASSOCIATION	SOIL SERIES
Da	SOILS OF THE NATURAL LEVEES, well to imperfectly drained, coarse to medium textured, associated with SOILS OF THE SLACKWATER AREAS, moderately well to poorly drained, moderately coarse to fine textured	COMINO and 18 others
Dd	SOILS OF THE NATURAL LEVEES AND SPLAYS. well to imperfectly drained, coarse to medium textured	OROCUÉ on levee ALTAMIRA on splay, and 19 others
Db	SOILS OF THE SLACKWATER AREAS, poorly drained, fine textured	COROCORA and 11 others
Dr	SOILS OF THE BORDERS OF STREAMS AND ESCARPMENTS, well to imperfectly drained, coarse to fine textured	3 series

Table 5
Soil associations of the Alluvial Overflow Plain.

The names are according to the FAO report (1965), except for association Dd, where the splays were not mentioned in the original name. Only the names of series described in this study (Appendix II) are mentioned.

In the upper part of the Alluvial Overflow Plain the levees and slackwater areas or basins occur in an intricate pattern. There together they form soil association Da, occupying less than 10 % of the total area of the Alluvial Overflow Plain. Farther East soil associations Dd and Db represent the natural levees and splays, and the slackwater areas. Soil association Dd covers from 25 % to 30 % of the total area; soil association Db covers approximately 60 % of the total area. Soil association Dr is found in the most eastern section, along incised streams where the resultant lowering of the watertable leads to better natural drainage of the soils. It occupies 5-10 % of the area of the Alluvial Overflow Plain.

The large number of soil series reflects the variations in the alluvial sediment, as determined by differential sedimentation in combination with the meso-relief. The general slope of the land is less than 1 %. The natural levees and splays appear as slightly curving, elongated ridges, slightly convex on their crests and are one to two meters higher than the adjoining slackwater areas. The latter have a slightly concave relief. Soil associations Dd and Db together form a typical topsequence of the Alluvial Overflow Plain. Its general pattern has been shown in Fig. 11, and Fig. 21 shows it in cross-section with the type localties of the soil series mentioned.

The reticular erosion pattern ('zurales') develops typically in soil association Db, but it also encroaches upon soil association Dd and is found as well in soil association Da. About two million hectares are affected. This type of erosion is promoted by the fact that new drainage gullies are being formed, which connect the slackwater areas by cutting through the natural levees and splays. These gullies end in the floodplains of the widely spaced rivers, or form towards the East new streams, which are downcutting; soil association Dr is found along these streams.

Fig. 21 Schematic toposequence of soils in the Alluvial Overflow Plain. The height difference between 2 and 4 is approx. two meters. The horizontal length of the cross section is variable (cf. fig. 11).
1 : Abandoned riverbed, deep clay over sand.
2 : Natural levee, fine sand to sandy loam; soil series Comino and Orocué.
3 : Splay, sandy loam over clay; soil series Altamira.
4 : Slackwater area, clay, and clay over loam; soil series Corocora.

4.2.2 Aspects of Soil Formation and Classification

The Alluvial Overflow Plain has been subject to soil forming processes over several thousands of years, after the surface sediments were deposited in Late Pleistocene to Early Holocene periods.

The original forest vegetation has been largely replaced by a very open savanna.

The natural levees are never, and the splays are seldom inundated, but the groundwater may rise to near the surface in the wet season. In the dry season the watertable is low (more than 2 m deep) in the natural levees. The soils of the natural levees and splays are relatively light-textured and this feature facilitates the process of lessivage because percolation of water is easy. Clay is eluviated from the upper horizons and deposited in the lower horizons. This process under the forest vegetation presumably led to the formation of an Argillic horizon, but the change in vegetation from forest to grass was accompanied by an increase in biological activity, higher contrasts in soil temperatures and in moisture content. The original argillans (clay-skins) were probably partly destroyed, and matric components of silt size participated in the continuing lessivage. See section 4.1, where this hypothesis is postulated for most soils of the Llanos.

The organic matter content of the surface horizons remains low because of the high rate of mineralization in the light-textured soils of the natural levees during the warm, sunny, dry season. The porosity and the high biological activity aid to a certain extent in the dispersion of the organic matter into the lower horizons. In the zone where the groundwater level fluctuates, plinthite is formed. This plinthite occurs below one meter in the well drained soils, but may be found at shallower depths in soils which are moderately well drained.

Most soils of the natural levees and splays have an Ochric epipedon and a Cambic horizon. Because of the evidence of clay translocation, the soils are tentatively classified as Tropudultic Dystropepts and Aeric Ultic Plinthaquepts. Near the Cordillera, where soil textures are coarsest, Tropudultic Quarzipsamments occur.

The slackwater areas are flooded in the wet season by rainwater, not by riverwater. The rainwater infiltrating the natural levees probably does not seep in large amounts towards the slackwater areas, because the height difference is small compared with the horizontal distance. The subsoil of the abandoned riverbeds is composed of sand; therefore, water in the levees drains more easily through these aquiferous layers than through the heavy-textured subsoil of the slackwater

areas. On the other hand, the surface run-off from the levees contributes to the hydromorphic conditions in the slackwater areas. In these latter run-off is slow, but not completely impeded because new drainage gullies are developing, and within one month after the start of the dry season most slackwater areas are dry at the surface. During the dry season evaporation is high, and towards the end of the dry season the watertable is usually below 150 cm. The soil dries out and becomes hard, while small cracks develop in the surface horizons.
The accumulation of organic matter in the surface horizon is not very high but still higher than in the soils of the levees. Therefore, in most soils of the slackwater areas an Umbric epipedon is recognized. A few slackwater areas are permanently wet and the soils in those areas have a peaty surface horizon.

With alternating wet and dry periods, some clay translocation also occurs in the soils of the slackwater areas. Argillans were, however, not identified in the field; for the reasons discussed in section 4.1. no Argillic horizon is recognized, but a Cambic horizon. In general, the soils of the slackwater areas show more structural development and more pronounced colour contrast in their profiles than the soils of the natural levees. Usually plinthite is found within a depth of one meter. The principal soils are classified as Ultic Plinthaquepts.

4.2.3 Soil Profile Data

The Comino series (profile C-92, in Appendix II) is typical for the natural levees fairly near the Cordillera, in soil association Da. It is found on the convex, upper part of levees and, because of this position, is a well drained soil. It has a coarse texture, and the surface horizon is dark brown while the sub-surface horizons are pale brown to yellowish brown. There is some evidence of clay eluviation. Structural development in the profile, even in the B-horizon, is weak. The described profile has been tentatively classified as Tropudultic Quarzipsamment. Farther away from the Cordillera, the Orocué series (profile E-26, in Appendix II) is found on the natural levees, soil association Dd. This series occupies a position similar to that of the Comino series, but has a somewhat finer soil texture, while the internal drainage is slightly less. The surface horizon is dark grayish brown and has a weak, medium to fine blocky structure. The subsoil is yellowish brown with no or only very weak structural development. The described profile has been tentatively classified as Tropudultic Dystropept.

The Altamira series (profile D-3, in Appendix II) is found on the splays of soil association Dd. The surface horizons are very dark gray, with a weak structure. Below 25 cm, yellowish brown colours are found, intermixed with strong brown mottles. The structure in the subsoil is loose to a depth of about 75 cm and coherent at greater depth. The tentative classification of this soil is: Aeric Ultic Plinthaquept.

The Corocora series (profile J-41, in Appendix II) is a typical soil of the association Db, found in the poorly drained slackwater areas. It includes fine-textured soils with poor to very poor drainage. The surface horizons are gray with some brown mottling and a prismatic structure. The sub-surface horizons are light gray to brown gray with mottles and concretions and a massive structure. Profile J-41 has been classified as a Cumulic Humic Ultic Plinthaquept.

The textural composition in several profiles points to the alluvial origin of the parent material; differences in sedimentation clearly occurred during the deposition of the material. The Altamira series especially shows that it has been formed in a light-textured sediment deposited on top of a heavy sediment. The clayey material of the slackwater area is found in the subsoil.

In most profiles there is evidence that organic matter has been dispersed and transported towards the lower horizons.

The chemical data point to a low chemical fertility. The phosphorus content of soil series Comino and Corocora is medium, but low in the other soils.

Luna (1962, 1964) analyzed the sand-fraction of some horizons of the four soil series. The results are summarized in Table 6.

SERIES PROF. NO.; DEPTH IN CM.	QUARTZ	FELD SPAR	EPI-DOTE	MICA	ZIRCON	LEUCO-XENE	LIMO-NITE	PYRITE	VOLCANIC GLASS
COMINO J-53									
14-40	xxx			tr			x		
40-112	xxx	tr		tr		tr	x		
OROCUE E-26									
18-40	xxx	tr							
40-73	xxx								
ALTAMIRA C-40									
20-44	xxx			tr	tr	tr			
44-60	xxx				tr				
COROCORA J-44									
70-120	xxx		tr			tr		tr	x

xxx = abundance

x = common

tr = 1-2 grains

Table 6 Mineralogical Analysis of Sand Fraction ($>50\mu$) of Soil Samples from the Alluvial Overflow Plain.

It should be noted that these analyses refer to other profiles than the ones described in the foregoing, except for the Orocué soil series. The occurrence of volcanic glass in profile J-44 remains without explanation. The nearest area with volcanic activity is about 300 km to the West, in the Central Andes Mountains.

Weatherable minerals are scarce, as might be expected in soils derived from highly weathered parent material.

An X-ray analysis was made by Marín and Villegas (1962) of clay fractions from two samples. The first sample belongs to the Orocué soil series, profile E-26, B21-horizon at 18-40 cm depth. The results show the presence of kaolinite, plus a material with the lines of bentonite, but which does not swell. The second sample belongs to the Corocora soil series, profile J-44, B22gcn-horizon at 70-120 cm depth. This sample contains quartz, kaolinite, partially hydrated and weathered mica, and possibly talc.

On the same two samples a total analysis of the clay fraction was done in the soils laboratory of the Instituto Geográfico 'Agustín Codazzi'. The results are presented in Table 7.

SOIL SERIES; PROF. NO.;PHYSIOGRAPHIC POSITION; HORIZON; DEPTH :	OROCUE E-26 NATURAL LEVEE B21t 18-40 cm.	COROCORA J-44 SLACKWATER AREA B22g cn 70-120 cm.
SiO_2 %	41.9	51.0
Al_2O_3 %	32.1	31.1
Total Fe_2O_3 %	9.1	4.1
Free Fe_2O_3 %	6.8	not determined
TiO_2 %	not determined	1.1
CaO %	0.3	0.4
K_2O %	0.6	not determined
MgO %	not determined	0.6
Cation exchange capacity, meq/100 g. clay	18.6	29.0
SiO_2/R_2O_3	1.9	2.6
SiO_2/Al_2O_3	2.2	2.8
SiO_2/Fe_2O_3	12.3	34
Al_2O_3/Fe_2O_3	5.5	12.2

Table 7 Total analysis of Clay Fraction from Samples of Orocué and Corocora Soil Series.

Here again it should be noted that the sample from profile J-44 is not from the described profile of the soil series Corocora. Furthermore, the data are incomplete; without attempting an interpretation it may be pointed out that the clay of Corocora soil series has a lower content of sesquioxides, a higher content of silica and a higher cation exchange capacity than the moderately well drained Orocué soil series.

4.3 SOILS OF THE AEOLIAN PLAIN

4.3.1 Soil associations

In Table 8 the soil associations of the Aeolian Plain are listed.

SYM-BOL	SOIL ASSOCIATION	SOIL SERIES
Em	SOILS OF THE DUNES, excessively to moderately well drained, coarse textured	DUYA and 5 others
Es	SOILS OF THE AEOLIAN PLAIN WITH "ESCARCEOS" poorly drained, medium to fine textured	GUANAPALO and 6 others
Ea	SOILS OF THE AEOLIAN PLAIN, well to imperfectly drained, moderately coarse to medium textured	SALIVA and 6 others
Er	SOILS OF THE BORDERS OF STREAMS AND ESCARP-MENTS, well to imperfectly drained, medium textured	SALIVA and 2 others
Ee	SOILS OF THE "ESTEROS", very poorly and poorly drained, fine to medium textured, with a high organic matter content	ANZUELO and 2 others

Table 8 Soil associations of the Aeolian Plain.

The names are according to the FAO report (1965). Only the names of series described in this study (Appendix II) are mentioned.

The block diagram of Figure 22 shows the soil associations in their appropriate positions, although not in order of size. Soil association Es is really the most extensive one, occupying more than 50% of the entire Aeolian Plain.

Each of the soil associations occupies areas with distinct physiographic features.

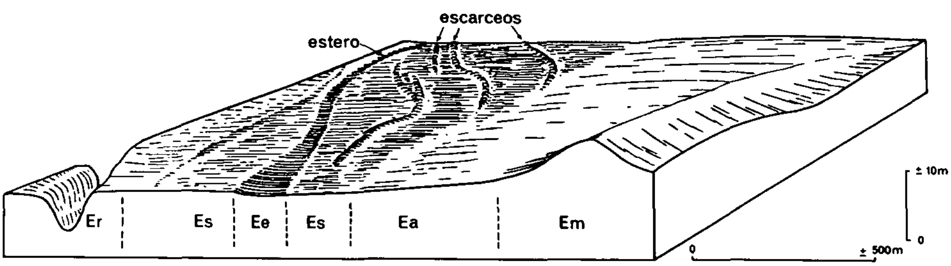


Fig. 22 Schematic block diagram of the Aeolian Plain, showing the different soil associations. For explanation of symbols see Table 8.
(modified after: FAO report, 1965)

Soil association Em is found on the gently undulating, sandy dunes which are situated on the southern banks of former river valleys, and which stretch longitudinally in a south-western direction, completely aligned with the dominant wind direction during the dry seasons. At present dune formation is not active anymore, as has been explained in section 3.2.4, and the dunes are stabilized with a vegetation cover of grasses and trees. The savanna is of the Trachypogon ligularis and Paspalum carinatum types. In the swales Andropogon grasses are found. On several dunes, clusters of mixed forest occur. Except for the swales, the dunes are well drained. They are favoured sites for houses (which are very few in number), and for landing strips. The land is used for grazing, especially during the wet season, when the surroundings are inundated.

This soil association is dominated by soil series Düya, but in the swales poorly drained, dark coloured soils with a sandy loam texture are found. The subsoil of these soils is permanently reduced and has a light gray colour. Around the swales, transitional soils are found with mottling in the subsoil.

The soil series Duya is a well to excessively drained soil with a sandy texture throughout the profile. There is very little structural development. The colours of the surface horizon are brown, and of the lower horizons strong brown to reddish yellow. The cation exchange capacity is very low. Figure 23 shows the physiographic location of soil series Duya. Profile P-14 is a typical profile, of which the description and laboratory analysis is given in Appendix II.

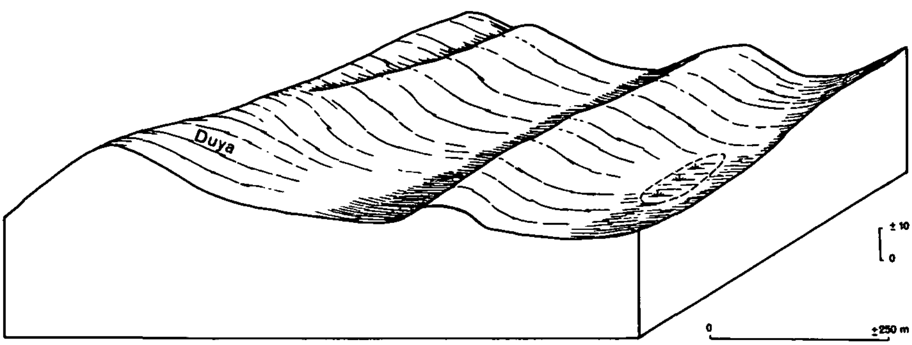


Fig. 23 Schematic block diagram of the physiography of soil association Em of the 'médanos' or longitudinal river dunes. Duya is one of the dominant soil series of the médanos. The concave swales are often poorly drained and contain oval-shaped marshes, as sketched in the right-hand part of the diagram. The soils of the swales are not further discussed in this study.
(after: FAO report, 1965)

During the soil survey of the Llanos, four sites were found where overgrazing had so reduced the vegetation of the dunes that wind erosion resulted. According to the local farmers, deflation of the attacked spots occurred fairly rapidly. In the adjoining areas of Venezuela the Aeolian Plain is similar to that in the Llanos Orientales of Colombia; the dunes are more extensive in Venezuela, and because of the somewhat drier climate, recent wind erosion of the dunes is more common there according to Ramia (1959).

Soil association Es has been developed in the level sediment of Llanos loess. It presents a micro-relief of low, elongated and curving ridges, oriented approximately along contour lines. These ridges have already been mentioned in section 3.2.4, and their origin will be discussed in section 5.5. They are called 'escarceos'. The micro-relief of 'escarceos' is accentuated by many small-sized termite mounds, but otherwise the relief is flat, and slopes do not exceed 0.5 %. As a consequence, this land is inundated by rain in the wet season, and the escarceos, aligned according to contours impede surface runoff. The savanna vegetation is of the Mesosetum and Leptocoryphium lanatum types. The land is used for grazing, which is not intensive in this part of the Llanos.

The dominant soils of this soil association are the soil series Guanapalo and Casanare. Soil series Guanapalo is poorly drained. On the escarceos the horizons are somewhat thicker than between the escarceos, but otherwise there are no differences in soil morphology. The surface horizon is dark gray and has a silt loam texture, while the second horizon is gray with a loamy texture. The lower horizons have mottles and concretions in a gray matrix, and have textures ranging from clay loam to clay. The structure of the soil is mainly moderately blocky. Chemically the soil is very poor. Figure 24 shows the physiographic location of soil series Guanapalo. The description and laboratory analysis of the typical profile P-26 is presented in Appendix II.

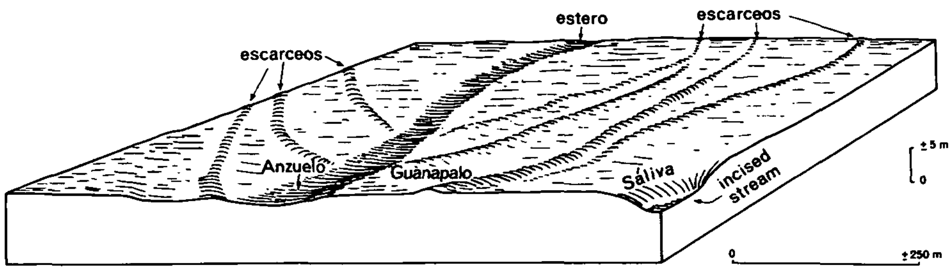


Fig. 24 Schematic block diagram of the Aeolian Plain with 'escarceos' (curved ridges) where soil association Es occurs. Soil series Guanapalo, and soil series Casanare mentioned in the text, are dominant in both the ridges and the intermediate level areas of soil association Es.
The diagram also shows the typical position of some other soil series, occurring in other soil associations, as follows.
An 'estero' traverses the area, and represents soil association Ee, for which soil series Anzuelo is typical.
The lower right-hand corner shows a small part of an incised stream. Along such a stream a strip of well drained land is found, with soil association Er. Soil series Sáliva occurs amongst others in this soil association.
(modified after: FAO report, 1965)

No description of soil series Casanare is included as it differs very little from Guanapalo. The only difference is that the Casanare soil series has somewhat more structural development in the subsoil. The peculiar feature about the Guanapalo and Casanare soils is that they are found both on the escarceos and in the intermediate areas. The physiographic division of ridges and depressions would suggest that different soils ought to be recognized. However, this physiographic division is of such a detailed character (see section 5.5.2) that the accompanying differences in soils are small enough to be included within the permissible variations within one soil series. For a discussion on the problem of the relationships between detail of physiographic divisions and detail of soil profile classification see Goosen (1966).

Within the series there are only minor variations, noticeable in the thickness of the A1-horizon, which in the described profile of soil series Guanapalo (see profile P-26), between two escarceos, is 20 cm thick, while in the adjoining escarceos it is about 35 cm thick. In trenches dug across several escarceos and depressions, no irregularity or break was found along the soil horizons. This fact indicates that soil formation followed the formation of the escarceos. This is important for explaining the origin of the escarceos and the general relation between soils and physiography of areas with escarceos (see section 5.5).

Soil association Ea is a transition between Em and Es. This transitional character is expressed in every physiographic aspect. The relief is nearly level, occasionally very gently undulating, drainage is good to imperfect, textures are medium, inundations are of shorter duration than in the association Es. The individually mapped units of Ea sometimes show an alignment parallel to the dunes, which indicates the aeolian origin of this soil association. The grasses found in this landscape element are the same as those found on the dunes.

The soil series Sâliva is found in slightly convex positions. The surface horizon is a brown sandy clay loam, and in the subsoil horizons, the colours gradually become strong brown to yellowish red, while the texture shows a decrease in sand content and an increase in silt content. The structure is massive to very weak blocky. The soil is well drained, and the chemical characteristics indicate a very low fertility. See Appendix II for the description and laboratory analysis of the typical profile W-5.

Soil association Er is developing as a consequence of the rejuvenating drainage system in the Aeolian Plain. The deeply incised new streams are accompanied by small zones where the watertable is permanently lowered. Due to sheet erosion, a somewhat convex relief has developed. Some streams developed in esteros, and the soils found along their banks formerly belonged to the association Ee. Soil association Er is not subject to inundation. The vegetation is mainly of the Trachypogon ligularis type and the land is used for extensive grazing.

The slightly convex relief and the rather open grass vegetation, which leaves bare about 50 % of the surface, results in moderate, locally severe sheet erosion. Occasionally small erosion rills in a reticular pattern develop. That such erosion occurs where the slopes are around 1 %, indicates the high erodibility of the soils.

The transitional area with soil association Ea, between the dunes and the Aeolian Plain with escarceos, has physiographically many features in common with soil association Er of the borders of streams and escarpments. The main difference is that in soil association Ea somewhat coarser textures prevail than in soil association Er. Otherwise the aspects of drainage, relief and vegetation are very similar, and the fact that soil series Sâliva is found in each association indicates this similarity. Figure 24 shows the location of this series in soil association Er.

The poorly drained plain is traversed by widely spaced, very shallow, and often broad drainage channels. In analogy with similar drainage ways found in other landscapes of the Llanos, these channels are called 'esteros'.

Soil association Ee is found in the esteros. The esteros are permanently wet and characterized by a grass vegetation of the Mesosetum type. Within this grass vegetation grow many palms of the species Mauritia minor. Locally some gallery forest is found. The surface horizon of the esteros is characterized by a high content of organic matter.

Its principal soil is soil series Anzuelo, which occupies a depressional position in the esteros, and is very poorly drained. The organic matter content of the surface horizon is high. This horizon is black in colour and clayey in texture, but the colours are gray in the upper part of the B-horizon, and mottled in the lower part of it. The chemical properties indicate a very low fertility. Its physiographic position is indicated in Figure 24, while the description and laboratory analysis of the typical profile C-19 is given in Appendix II. The Anzuelo soil series has a higher clay content than other soils of the Aeolian Plain. This is because slow sheetwash from the adjoining soil association Es has brought fine particles to the esteros, where they are trapped by the vegetation and accumulate in the soil. It is not known whether in a former period the esteros were incised deeper than they are at present. They often have a meandering form, and this could indicate that they follow the course of old rivers buried below the mantle of Llanos loess. The geomorphological aspects of these questions, which might be related to climatic changes during the Holocene, have not yet been studied.

4.3.2 Aspects of Soil Formation and Classification

The parent material of all the soils in the Aeolian Plain consists of aeolian deposits derived from highly weathered alluvial sediments. These deposits were laid down in the transitional period from the Pleistocene to the Holocene. Since then not much new material has been added. Although locally some sand and silt may be blown out of the present river valleys, this is insignificant compared with the aeolian sedimentation towards the end of the Pleistocene Epoch.

Within the aeolian parent material, notable differences occur between the sandy textures of the dunes on the one hand, and the finer silt loam and clay loam textures of the Llanos loess on the other.

The general relief of the Aeolian Plain is so little pronounced that the soil formation within one association has not been influenced by the soil formation in adjoining associations, with the exception of the soils of the esteros, which continiously receive percolating water from the surroundings. Therefore, the soil associations developed under the local conditions of relief, drainage, vegetation and erosional or sedimentary processes

Luna (1964) studied under the microscope some sand fractions from soil samples of the Aeolian Plain. The results are given in table 9.

It should be noted that most of the samples are not from the profiles described in Appendix II. This is because most of these samples were taken very early in the soil survey in the field, and the type-locations for profile descriptions were selected later. The latter profiles are not always the same as those of which special analyses were made. The same applies to Tables 10 and 11.

The mineralogical analyses of clay fractions were carried out with X rays and with differential thermal analysis. The results are presented and discussed in the FAO report (1965), and in table 10 a summary is given.

Soil association	Soil series; Profile No.; Depth in cm.	Quartz	Feldspar	Hornblende	Volcanic glass
Em	DUYA R-18				
	3 - 25	xxx			
Es	GUANAPALO J-34				
	0 - 20	xxx	x		
	20 - 65	xxx	tr		
	65 - 100	xxx	tr	tr	
Er	SALIVA E-31				
	25 - 47	xxx	tr		
Ee	ANZUELO C-35	xxx		x	tr

xxx = abundance
x = common
tr = 1-2 grains

Table 9 Mineralogical Analysis of sand fractions (>50µ) of soil samples from the Aeolian Plain.

Soil association	Soil series; Profile No.; Depth in cm.	Kaolinite	Quartz	Non-expansible bentonite	Montmorillonite	Weathered and partially hydrated mica
Em	DUYA R-18	x				x
	3 - 25					
Es	GUANAPALO J-34					
	20 - 65	x	x		trace	x
	100 - 130	x	x			x
Ea	SALIVA W-5					
	26 - 80	x		x		
Ee	ANZUELO C-35					
	65 - 110	x		x		

Table 10 Qualitative interpretation of X-ray analysis and differential thermal analysis of the clay fractions of four soil series of the Aeolian Plain.

The mineralogical analyses show that few weatherable minerals are present in these soils. The identification of non-expansible bentonite is questionable; it is also possible that this material is interstratified vermiculite and chlorite (pers. commun. Silva, 1968).

On a number of samples a total analysis of the clay fraction has been carried out. The results are presented in table 11. In this table is also included an analysis of the soil series Casanare, which occurs in close association with the soil series Quanapalo; these two soils are very similar, as explained in section 4.3.1. The analysis of soil series Casanare has been included to show that this soil series has characteristics very similar to those of the series Guanapalo.

Soil association :	Em	Es			Es	Ea
Soil series :	DUYA	GUANAPALO			CASANARE	SALIVA
Profile no. :	R-18	J-34			C-34	W-5
Physiographic position :	dune	on escarceo			between escarceos	level to convex
Horizon :	A3	A2g	B21g	B22gcn	B21g	B1
Depth in cm :	3-25	20-65	65-100	100-130	46-80	26-80
SiO_2 %	41.7	58.3	50.7	42.9	55.1	41.0
Al_2O_3 %	30.3	24.7	23.0	30.2	27.2	30.0
Total Fe_2O_3 %	10.1	1.4	2.2	3.2	1.0	7.2
Free Fe_2O_3 %	7.3	-	-	-	0.2	6.8
TiO_2 %	-	1.2	1.4	1.7	-	-
CaO %	0.2	0.3	0.5	0.4	0.2	0.1
K_2O %	0.5	-	-	-	1.2	0.2
MgO %	-	0.3	0.6	0.3	-	-
Cation exch. cap., meq per 100 g clay	29.7	31.5	26.0	26.5	20.1	11.6
SiO_2/R_2O_3	1.4	3.9	3.5	2.3	3.3	2.0
SiO_2/Al_2O_3	2.3	4.0	3.8	2.4	3.4	2.3
SiO_2/Fe_2O_3	11	108	60	36	153	15
Al_2O_3/Fe_2O_3	6.0	27	16	15	41	6.5

Table 11 Total analysis of the clay fractions of samples from the Duya, Guanapalo, Casanare and Sáliva soil series.

Attention is drawn to the very low iron contents of the poorly drained soil series in soil association Es. The soil series Guanapalo will also be discussed in section 4.4 of this chapter, because a somewhat finer-textured 'variety' of this series is also typical of the poorly drained, level parts of the High Plains, and it will be seen that the low content of iron oxide is a consistently occurring feature of this soil, developed in poorly drained Llanos loess.

The cation exchange capacity of the sample from soil series Duya is surprisingly high; in view of the very low clay content and considering the low SiO_2/R_2O_3 ratio the reliability of this figure for the cation exchange capacity may be questioned.

In general the cation exchange capacities are higher than allowed for Oxisols, except in soil series Sâliva. The SiO_2/R_2O_3 ratios are higher than 2 in most samples, indicating that some weatherable minerals and some 2:1 lattice clays are present besides the dominating occurrence of kaolinite and quartz.

The soils in the dunes, soil association Em, are mainly fine sandy and have an undulating relief. Rain water filtrates rapidly in the soils, and the organic matter, derived from the vegetation, oxidizes quickly under the warm and well drained conditions of the soil. Chemical processes are not very pronounced, because the greatest part of the minerals consists of quartz. There is no pronounced differentiation between the horizons. Most of the soils are Typic Quartzipsamments.

On that part of the Aeolian Plain, where escarceos occur, different soil conditions prevail. The very flat relief and the micro-relief of escarceos impede surface runoff. The hydromorphic conditions prevailing for more than half of the year promote some accumulation of organic matter. Part of it disperses and is carried downwards by percolating water, during the dry season some organic matter mineralizes rapidly. Still, sufficient organic matter remains to fulfill the requirements for identifying an Umbric epipedon.

Below the epipedon mottling is prominent. In this part of the soil profile clay has accumulated. In some profiles cutans were recognized; see the described profile of soil series Guanapalo in the next section. However, in other profiles belonging to the same series during the soil survey no cutans were recognized.

At the time the soil survey was executed, two features were thought to be diagnostic: 1) the low chroma (due to the very low content of iron compounds) in the A2-horizon; 2) the low cation exchange capacity. Based on this most soils of soil association Es were classified as Typic Albaquox (FAO report, 1965). But this subgroup has not been maintained in the Supplement to Soil Classification System (7th Approximation) of 1967; if the evidence of lessivage is assumed strong enough for recognizing an Argillic horizon, then most soils could be classified as (Oxic) Plinthaquults. However, in view of what has been said in section 4.1 about the problem of whether or not an Argillic horizon is present, it may be argued that the recognized cutans are partly remnants of a former soil formation process under a forest vegetation, and partly are newly formed matriargillans, which are rapidly being destroyed in these soils with low cohesion and a high biological activity of termites and worms. See sections 4.4 and 5.5 on data and discussions about the cohesion of soil series Guanapalo.

Based on the foregoing considerations the author prefers to classify most soils of soil association Es as (Oxic) Ultic Plinthaquepts.

The transitional soil association Ea is characterized by soils with sandy loam textures. The soils are well drained, and they have an Ochric epipedon. Some evidence of lessivage is present. The soil association Ea has as a typical member the soil series Sâliva, which is also occurring in soil association Er. In this latter soil association, found along the borders of streams and escarpments, the general drainage and relief conditions are very similar to those in soil association Ea; the textures in soil association Er are somewhat heavier (loam to silty clay loam) and there is more evidence of sheet erosion.

The soil series Sâliva presents similar difficulties in classification as several other soils of the Llanos; the difficulties are described in general in section 4.1. To express the polygenetic development of the soils they are classified as Oxic Tropudultic Dystropepts.

In the esteros with soil association Ee, soil development is governed by the hydromorphic conditions prevailing throughout the year. There is but little seasonal fluctuation of the groundwater level, and in the surface horizon organic matter accumulates. The soils are gleyed showing mottling in the B-horizon. Some cutans are found in root channels and some clay accumulation seems to occur in the B-horizon, but a typical Argillic horizon has not been recognized. The representative soil series Anzuelo has been classified as Umbric Ultic Plinthaquept.

4.4 SOILS OF THE HIGH PLAINS

4.4.1 Soil associations

In Table 12 the soil associations of the High Plains are listed.

Symbol	Soil association	Soil series
Aa	SOILS OF THE LEVEL HIGH PLAIN, well and moderately well drained, moderately coarse to fine textured	HORIZONTES LAGUNAZO NAPOLES and 3 others
As	SOILS OF THE LEVEL HIGH PLAIN, moderately well to poorly drained, moderately fine and fine textured	GUANAPALO and 4 others
Ao	SOILS OF THE UNDULATING HIGH PLAIN, well and moderately well drained, coarse to fine textured, deep to shallow over indurated plinthite	HORIZONTES NAPOLES and 6 others
Ac	SOILS OF THE STRONGLY DISSECTED HIGH PLAIN, excessively to moderately well drained, coarse to fine textured, very shallow to deep over indurated plinthite	3 series
Av	SOILS OF THE COLLUVIO-ALLUVIAL VALLEYS, well to poorly drained, coarse to fine textured	3 series
Ae	SOILS OF THE "ESTEROS", very poorly to imperfectly drained. fine to medium textured, with a moderately high organic matter content	CARIMAGUA GUANAPALO and 2 others

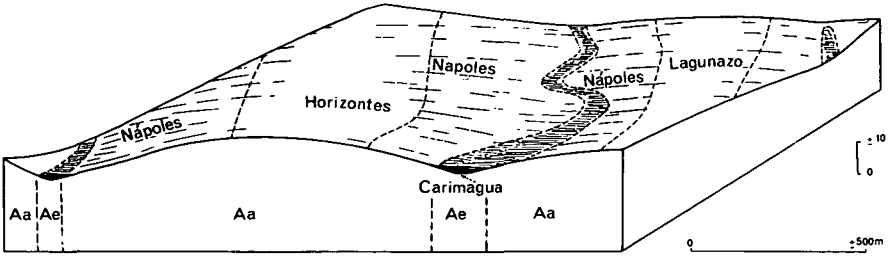
Table 12 Soil associations of the High Plains.
The names are according to the FAO report (1965). Only the names of series described in this study (Appendix II) are mentioned.

In Figure 25 three block diagrams are presented,. which show the geographical relationships of the soil associations.

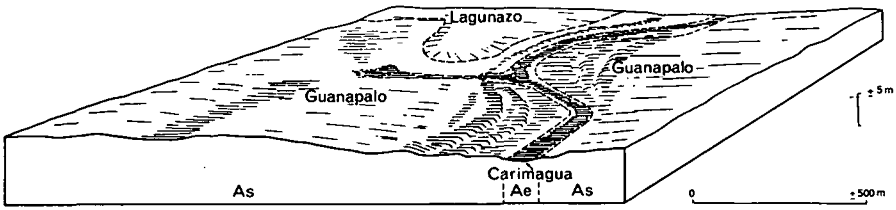
For the purpose of the present study soil associations Aa, As and Ae are the most important ones, because they include the level to very gently undulating savannas where degradational processes are or have been active. Profile descriptions and laboratory analyses of typical profiles from the soil series of these associations, as mentioned in Table 12, are given in Appendix II.

Soil association Aa is typical for the level, well drained High Plains in the central area of the High Plains (see Fig. 7). It stretches in a long zone South of the Meta river, and has a very smooth level to very gently undulating surface, on which a savanna vegetation has developed. On the higher, convex parts this savanna is of the Trachypogon vestitus type, and on the long gentle slopes of the Paspalum pectinatum type. The parent material of the soils is Llanos loess, which on the slopes has become much coarser in texture mainly because sheet erosion has removed much of the finer particles.

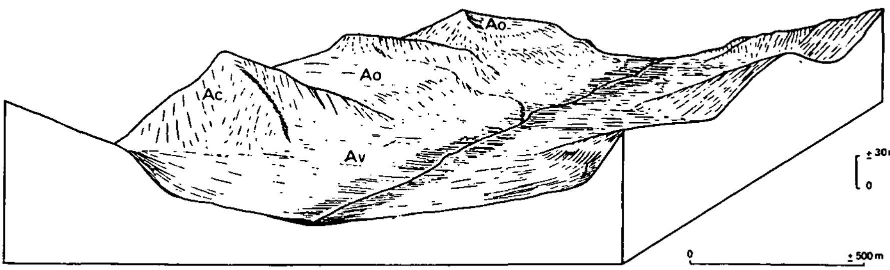
Soil series Horizontes is typical for the broad, level and slightly convex summits of soil association Aa, and occurs principally in the southern parts of this unit. The soils of this series are fine textured and well drained. The surface horizon is very dark gray brown with a weak, fine blocky structure. The subsoil horizons are from brown in the upper part to red in the lower, with gradual boundaries. The structure is from weak to moderate, fine blocky. The clay content is the highest of all soils of association Aa.



a) Level, well drained High Plains. The left-hand side of the diagram represents the southern and southwestern part, the right-hand side the northeastern part. Soil series Horizontes, Lagunazo and Nápoles belong to soil association Aa, soil series Carimagua belongs to soil association Ae.



b) Level, moderately well to poorly drained High Plains. The soil association As is found here, of which only the poorly drained soil series Guanapalo is indicated in the diagram. Soil series Lagunazo belongs to soil association Aa, and soil series Carimagua to soil association Ae. Note that the upper part of the estero is included with soil series Guanapalo.



c) Dissected High Plains. The undulating areas have soil association Ao, the rolling to steep areas have soil association Ac, while in the colluvio-alluvial valleys soil association Av is found. The soil series of these associations are not discussed in the text.

Fig. 25 Schematic block diagrams of the High Plains, showing the geographical relationships between soil associations. Note the different vertical scales in the three diagrams. (modified after: FAO report, 1965)

Towards the North-East soil series Lagunazo is found in identical position as soil series Horizontes, differing from the latter, because of a moderately fine texture and yellowish red colours in the subsoil horizons.

The structure ranges from weak, medium blocky in the surface horizon to weak to moderate, medium blocky in the subsoil.

Associated with both the Horizontes and Lagunazo series the soil series Nâpoles is found on the long, gentle slopes towards the esteros.
Its position and textural composition indicate that it has developed on gentle slopes, where overland flow causes sheetwash material to move over the surface, and that the coarser particles accumulate in a relative sense, giving rise to sandy loam textures. In chapter 5 this process will be discussed in more detail. Soil series Nâpoles has a dark brown surface horizon of fine loamy sand with a weak, medium to fine blocky structure. The lower horizons are strong brown and yellowish brown friable sandy loams with a massive structure. Also this soil is well drained.

The road from Villavicencio to Venezuela runs through the area of soil association Aa. Cattle grazing is the main activity, and settlement has increased during the last decades.

Towards the North-East the relief of the High Plains is flatter. This results in a poorer drainage of the flat summits of the savannas. Therefore, going towards the North-East, soil association As is encountered on these summits. First it occurs as patches in the centre of the summits surrounded on the outer parts and on the lower, very gentle slopes, by soil association Aa. But farther towards the North-East, where the relief becomes even more subdued, soil association As occupies most of the savannas between the esteros.

The most important soil of the poorly drained, level High Plains is the soil series Guanapalo, soil association As. It occurs in the areas with the typical micro-relief of escarceos, both on these low ridges and in between them. The surface horizons are very dark gray silt loam with a medium crumby to massive structure. Downwards in the profile the colours become gray brown, light gray or light brownish gray, mixed with red and partially indurated mottles. The structure of these lower horizons is massive, breaking in weak, fine blocks, with a friable consistence, and the texture is silt loam to silty clay loam. The soil is poorly drained.

The poorly drained areas in the north-eastern part of the High Plains have a savanna of the Mesosetum and Leptocoryphium lanatum types; the Mesosetum type is found on the slightly better drained savannas and the Leptocoryphium lanatum on the poorly drained ones. The poorly drained areas are furthermore characterized by the micro-relief of excarceos, similar to the micro-relief of the poorly drained Aeolian Plain. These areas are seasonally inundated by rain water. The period of inundation is perhaps one or two months shorter than in the Aeolian Plain. Traffic is difficult over these savannas, and a section of the road from Villavicencio to Venezuela, which traverses the area, is only open for about two months every year. The land is used for cattle grazing, and towards the East a number of Indian tribes lead a nomadic existence.

Soil association Ae occupies the esteros, and is found in combination with soil associations Aa and As. The esteros have a level, slightly concave, and broad bottom, in which often a small stream is incised to a few meters depth. The width of the esteros is variable.

In the well drained parts of the level High Plains, where the slopes may be up to 3 %, the esteros are from 50 to 150 meters wide, while in the poorly drained parts of the level High Plains, where the slopes are usually less than 1%, the esteros may be up to 500 meters wide. The broader the estero, the less frequent is the occurrence of a small streamlet in its centre. Also, the broadest part of the esteros are located in their upper stretches. Therefore, it is thought that no relation exists between the intensity of normal stream erosion and the width of the esteros. They are thought to have developed in a different manner, as will be explained in chapter 5.

In the esteros, soil association Ae, a number of soil series is found, of which the soil series Carimagua will be discussed in detail. It occurs predominantly in the esteros traversing the level, well drained High Plains. It is a very poorly drained soil, and has a black to very dark gray surface horizon, in which the organic matter content is high. The texture of this horizon is silty clay loam, and the structure weak, fine crumby. The subsoil horizons are dark gray brown to gray brown silty clay loam to silt loam, with a weak fine blocky to massive structure. Yellowish brown mottles and concretions are common in the lower horizons.

The other soil series of this association are: Chigüiro, a silty clay soil with a dark gray coloured subsoil, very poorly drained; Guanapalo, which already has been mentioned in soil association As; and Manchega, which differs from Carimagua because it has a texture of sandy clay loam. That the soil series Guanapalo occurs also in the esteros, may look somewhat surprising. Soil series Guanapalo, where it occurs in soil association Ae, is found in the very wide (up to 500 meters) upper parts of the esteros traversing the association As. The esteros in this landscape, especially in their upper parts, are very flat, and only slightly below the level of the poorly drained savannas. In 1964 the author made measurements across the upper part of an estero, where the soil series Guanapalo was recognized in the estero as well as in the adjoining poorly drained savannas, and it was found, that the bottom of the estero was only 50 cm lower than the savannas nearby. This feature will be discussed further in chapter 5.

The vegetation of the upper part of the esteros is Mesosetum/ Leptocoryphium lanatum savanna, and the vegetation of the lower part of the esteros is a mixed forest with a high percentage of the Mauritia minor palm. However, grass fires on the savannas have partly destroyed this forest, and a grass vegetation of the Mesosetum type is replacing it. This destruction of the forest proceeds from the North-East, from where the winds blow. As a result, the remaining forest covers the esteros in an asymmetrical way, being more concentrated along the southern and south-western borders. The land is used for grazing in the dry season.

The three soil associations discussed thus far have certain relationships because the individual soils occur in typical topo-sequences. Figure 26 gives two cross sections, both pertaining to soil associations Aa and Ae. Soil series Horizontes and Lagunazo occupy similar positions on the level and slightly convex summits of the savanna divides between esteros; soil series Nápoles occupies the long, gentle slopes and soil series Carimagua is the lowest and wettest member of the toposequences Horizontes/Lagunazo-Nápoles-Carimagua. It is developed in colluvial material derived from the higher members of the toposequences, and its mineralogical and chemical properties are similar. At present the process of colluviation is very slow as is suggested by the presence of a well-developed A1-horizon.

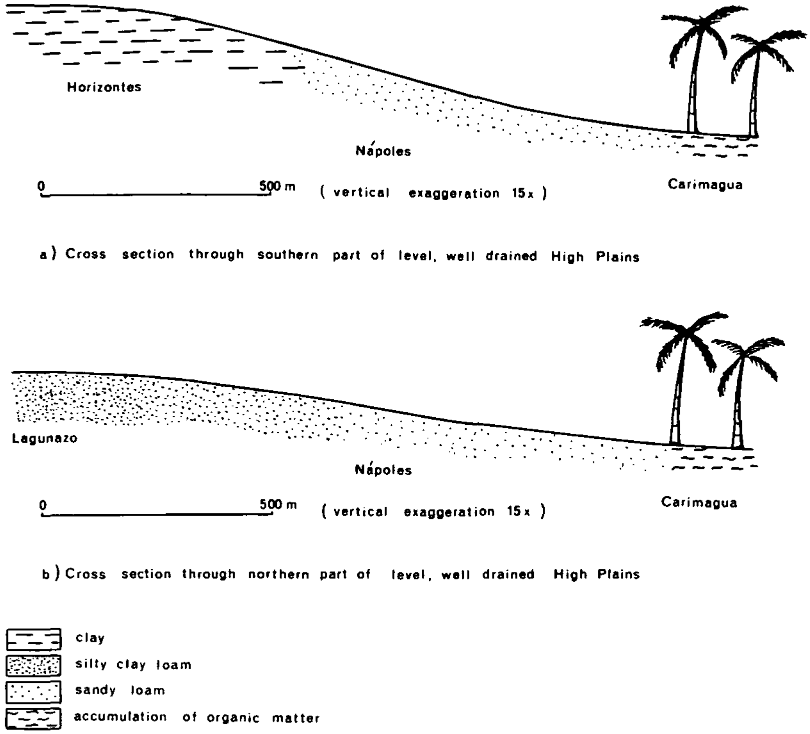


Fig. 26 Characteristic toposequence of the level, well drained High Plains. Both toposequences are typical for soil association Aa with soil series Horizontes, Lagunazo and Nápoles, and for soil association Ae of the 'esteros' with soil series Carimagua.

In Figure 27 two cross sections are drawn to illustrate the toposequences typical for the area where soil association As occurs. The first cross section (Fig. 27a) shows the transition with the level, well drained High Plains. A comparison with Fig. 26b clarifies the relationship. It can be seen, that soil series Guanapalo is very much related to soil series Lagunazo in its physiographic position, but that it occupies a flatter relief and therefore has a poorer drainage. Figure 27b has been drawn with a vertical exaggeration of 30x, in order to show the microrelief of 'escarceos' (indicated by faint undulations) and of the upper part of the 'esteros', where soil series Guanapalo also is found. The 'escarceos' have not been drawn in Fig. 27a, but they are present everywhere on the savanna where soil series Guanapalo is found.

Figure 27b is in the first place typical for the level summits of the poorly drained High Plains and in this sense is simply an enlargment of part of Fig. 27a. In the second place it is typical for slightly lower parts of the poorly drained High Plains, where the soil series Guanapalo is bordered directly by 'esteros'.

In these 'esteros' soil series Guanapalo occupies the upper part and soil series Carimagua is found in the lower part downstream. There is no difference in local physiographic aspects of the two components of soil association As. Vegetation, relief, microrelief, parent material and drainage are alike.

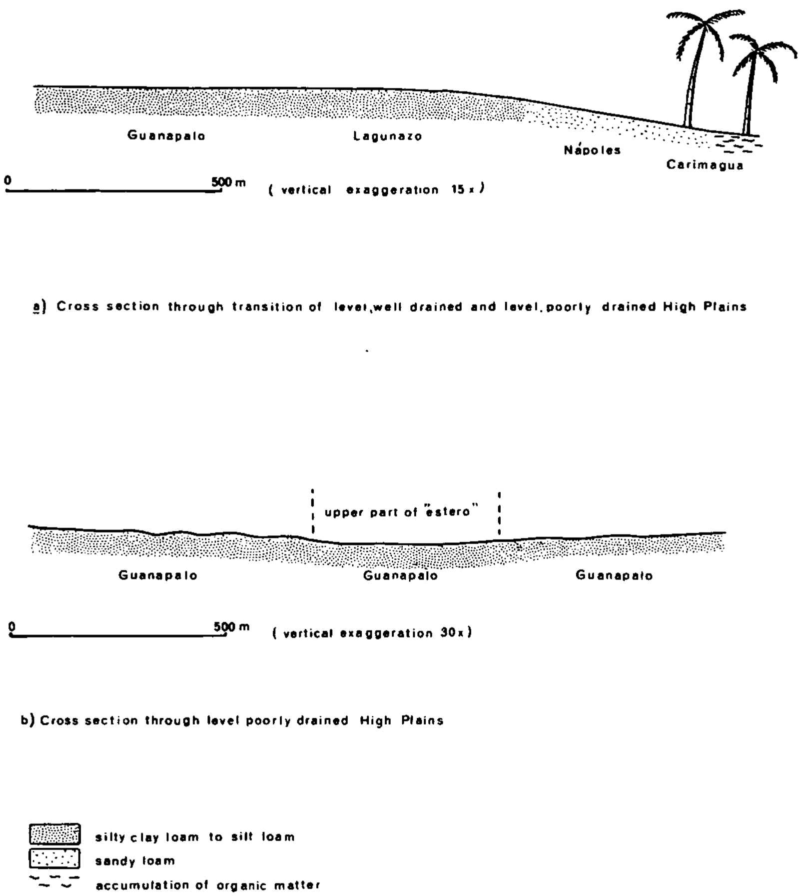


Fig. 27 Characteristic toposequences of the northeastern part of the High Plains, where soil association As with the typical soil series Guanapalo is found in the level, poorly drained High Plain. The right-hand part of cross section a) shows the same toposequence as sketched in Fig. 26b). The cross section b) has a larger vertical exaggeration than a), and shows more detail of the micro-relief of soil association As.

Soil association Ao is found as a transition zone between the level and the dissected High Plains, and also as strips bordering the few rivers which traverse the level High Plains. The landscape evolved out of the level High Plains as the result of erosion. Small, level remnants of the original surface are scattered throughout the area. Outcrops of indurated ironstone are common along the steeper slopes (see section 4.4.2). Most of the slopes in soil association Ao have a mantle of colluvial material of which the finer particles have been washed out by selective sheet erosion. An undulating to rolling phase of soil series Nápoles is typical for the slopes, while on the higher, more gently sloping parts soil series Horizontes is found, although its extent is much smaller than in soil association Aa. In several places the mantle of Llanos loess has been eroded completely, and the underlying alluvial sediments have a variable texture. The soils developed in these parts are mainly Tropepts. For more details see FAO report (1965). The vegetation is of the Paspalum pectinatum type on the summits, Paspalum carinatum and Trachypogon vestitus on the slopes, while along the foot often a mixed forest is found. The land is used for cattle grazing.

Soil association Ac occupies the more strongly eroded High Plains towards the south. The landscape is hilly throughout. Many of the hills are covered with a pavement of fragments of indurated ironstone. The underlying parent material consists of alluvial sediments. The soils developed in this material are variable in texture. The more clayey soils often show fossil gleying. Entisols and Inceptisols are the principal soil orders. For more details see FAO report (1965). The savanna in the northern section of this landscape consists of the Paspalum pectinatum and Paspalum carinatum types. In the south the land is covered with a mixed forest. This forest is composed of many species but the trees are often somewhat stunted, and the general aspect of the forest is 'rachitic'. Very few people live in this area. Settlers of the level High Plains use the northern part of the dissected High Plains for grazing.

Soil association Av has developed in the colluvial and alluvial deposits of the valleys traversing the undulating and dissected High Plains. The central parts of these valleys are often poorly drained and have clayey soils, while the gently sloping sides are better drained and have sandy soils. See FAO report (1965) for more details. Two savanna types are found: Andropogon in the center and Paspalum pectinatum/Leptocoryphium lanatum along the sides. They are used for extensive grazing. Towards the South all these valleys are covered by a mixed forest. Human occupation and use are practically nonexistent for these valleys.

4.4.2 Aspects of Soil Formation and Classification

The parent material of the soils of the High Plains is variable. In the level savanna (soil association Aa and As) it consists of Llanos loess, which covers the underlying Pleistocene alluvial sediments to a depth of several meters. In the undulating and dissected High Plains (soil association Ao and Ac) the parent material is Llanos loess on the summits, and old alluvium on the slopes. The two become somewhat intermixed through erosional processes. In the colluvio-alluvial valleys (soil association Av) the parent material is composed of erosion products derived from the Llanos loess and the underlying alluvium, while in the esteros (soil association Ae) the parent material consists of Llanos loess and sheetwash material from the Llanos loess.

The clay contents (see section 4.4.3) of both soil series Horizontes and Lagunazo are higher than in loess of temperate regions. In this respect the soil material is quite similar to what Butler (1956) and Butler and Hutton (1956) in Australia describe as 'parna' or 'aeolian clay'. The differences in clay content between the two soil series are thought to be related to the character of the aeolian sedimentation. Profile D-13 of soil series Lagunazo is located in the North-East of the High Plains, while Profile C-60 of soil series Horizontes is located 250 km more to the South-West. In other words, soil series Horizontes lies downwind from soil series Lagunazo, because the wind direction is from North-East to South-West.
In an aeolian sediment the finest particles are farther removed from the source than the medium and coarse particles. A similar distribution was found by Butler and Hutton (1956) in the 'aeolian clay' of Australia. They found that the clay content near the source was 35 % and that it reached 70 % at a point 150 miles downwind. Such differences belong to what Kaufmann (1929) calls the 'structural order of sediments'.

On the level, well drained High Plains, where soil association Aa occurs, fine textures prevail on the highest parts. Surface runoff is fairly rapid, because of the smooth surface and the sligtly convex relief. Where sheet erosion is only slight, organic matter accumulates in the surface horizons. Usually, however, this accumulation is not sufficient to form an Umbric epipedon, and the soils have an Ochric epipedon. The water infiltrating the soil causes translocation of mineral particles. The accumulation of clay is in some soils sufficiently high for an Argillic horizon, but in view of what has been said in section 4.1 about the problem of clay skins and the taxonomic classification, the occurrence of a Cambic horizon is presumed as being developed in what formerly was the very deep A-horizon of an Ultisol. The typical soil series Horizontes and Lagunazo are Palehumultic and Oxic Dystropepts. Along the slopes of the well drained savannas, sheet erosion has been responsible for the relative accumulation of sand. The accumulation of organic matter is very small, and the soils have an Ochric epipedon. They belong to the Oxic Dystropepts (soil series Nápoles).

On the level, poorly drained High Plains with soil association As the soil formation is governed by the poor internal and external drainage. The accumulation of organic matter and the very dark gray colours in the surface horizons lead to the recognition of an Umbric epipedon. There is evidence of clay accumulation in the subsoil although clay skins have not always been recognized. Plinthite has been found in the lower subsoil. The poorly drained soils are mainly Ultic Plinthaquepts, such as soil series guanapalo, and the soils with a somewhat better drainage are Aeric Ultic Tropaquepts.

The esteros, soil association Ae, have soils formed under hydromorphic conditions. They have an Umbric epipedon. The soils are gleyed showing mottling in the subsoil horizons. The iron segregation in the subsoil is not always strong enough to form plinthite as a continuous phase or constituting more than half of the matrix. The variations mentioned result in an association composed of Plinthaquepts, and Aeric Tropaquepts.

The undulating and dissected High Plains with the colluvio-alluvial valleys (soil associations Ao, Ac and Av) have so many local variations in relief, texture of parent material, and drainage, that it has been decided to omit a comprehensive discussion of all these aspects. One general feature may be mentioned here. The soil associations Ao and Ac are formed in a landscape, which resulted from erosion of the level High Plains. In the latter plinthite is found at a certain depth, which may be eight or ten meters in the well drained savannas. In the eroded landscape this plinthite has been exposed and hardened irreversibly into indurated ironstone. This ironstone has been fragmented, and many landscape elements are now covered with a pavement of 'laterite gravel'. Part of this gravel has been transported into the colluvio-alluvial valleys (soil association Av) where it can be found buried below sandy or loamy colluvial wash material. On the steeper slopes of association Ao and Ac surface run-off is rapid, and little water enters the soil if textures are heavy, and little or no clay movement takes place within the profile.

From the description of the soil associations in section 4.4.1 and from the considerations in the present section it becomes clear that the soil series Horizontes, Lagunazo and Guanapalo are developed in Llanos loess, which is in a lesser degree affected by erosion than the parent material of other soils. Some differences between the three soils are interesting. The difference in clay content between soil series Horizontes and Lagunazo has already been mentioned earlier in this section. It is furthermore found that the surface horizon of Horizontes has 2.7 % organic carbon, while Lagunazo has 1.7 % in the surface horizon. The difference between the organic matter content in both profiles is possibly due to the difference in length of the dry season. Soil series Horizontes (profile C-60) has been described in the area where the dry season is about three months, while soil series Lagunazo (profile D-13) has been described where the dry season is over four months. Some of the physical properties also differ to some extent. In section 4.4.3 more data will be presented, while a discussion of the effect on erosion will be given in section 5.3.

A comparison between soil series Guanapalo and Lagunazo reveals a number of interesting features. They are summarized in Table 13. The data on soil series Guanapalo in this table are derived from the three profiles D-11, D-12 and T-35; all figures are adjusted according to thickness of sub-horizons.

The soil series Guanapalo and Lagunazo belong to different soil associations, but both occur in the same area and the original parent material of both soils is Llanos loess.

The figures demonstrate that the iron oxides are mainly concentrated in the clay fraction, much of it in the form of goethite. This is thought to be the principal reason for the difference in clay content of the two soils: Lagunazo has a much higher goethite content than Guanapalo. The poor drainage of soil series Guanapalo apparently has resulted in loss of iron.

The range of figures within soil series Guanapalo indicates that certain differences occur between the individual profiles. The organic carbon content is highest in the A-horizon of profile D-11, situated between two 'escarceos' (small ridges). The other two profiles, D-12 and T-35, are both situated on an escarceo. This is as could be expected, because the areas between the escarceos stay wet somewhat longer than the escarceos.

	Soil series GUANAPALO (Oxic) Ultic Plinthaquept		Soil series LAGUNAZO Oxic (Palehumultic) Dystropept	
	A-horizon	B2-horizon	A-horizon	B2-horizon
Organic carbon %	1.4 - 2.0	0.3 - 1.7	1.1	0.5
Texture				
clay %	15 - 22	16 - 27	31	34
silt %	63 - 70	59 - 70	59	57
sand %	12 - 17	12 - 14	10	9
Free Fe_2O_3 in soil, %	0.1	0.1 - 0.2	2.5	2.6
Total Fe_2O_3 in clay, %	1.5 - 1.7	1.5 - 1.6	12.0	11.7
Goethite % in clay	1.6 - 1.7	1.5 - 1.6	13.3	12.9

Table 13 Some characteristics of soil series Guanapalo and Lagunazo. (figures are adjusted for thickness of sub-horizons)

The range in texture is not very large, and the prevalent texture of the members of the series is silt loam. In Figure 28 the range in texture is indicated for profiles D-11, D-12 and T-35 of soil association As of the poorly drained High Plains, and for profile P-26 (also of soil series Gaunapalo) of soil association Es of the level, poorly drained Aeolian Plain.

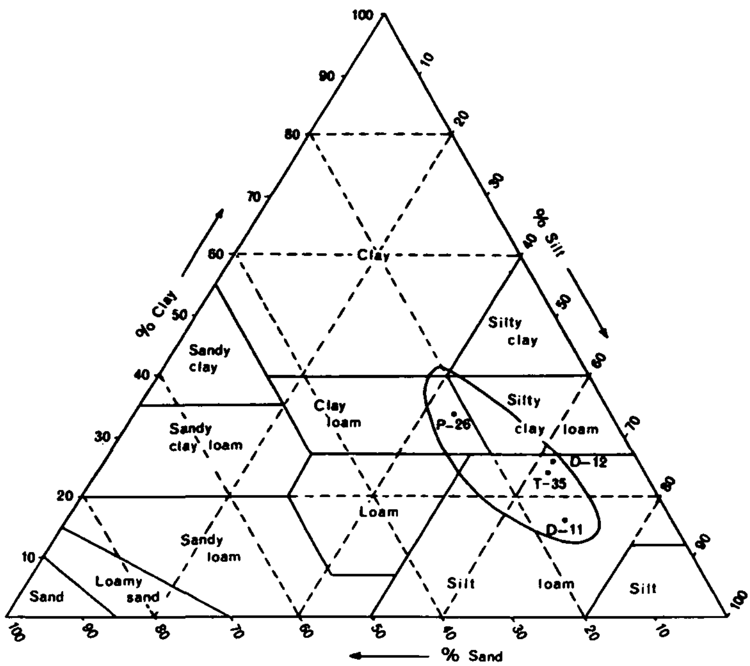


Fig. 28 Graph in which the texture of the upper 50 cm of the B2 horizons from four profiles of soil series Guanapalo is indicated by dots. The oval line encloses the area in which the textures of all samples from the four profiles are located.

The family designation in the taxonomic classification of the profiles is as follows:

D-11 : coarse silty
D-12 : fine silty
T-35 : fine loamy
P-26 : fine loamy

Strictly speaking, if soil profiles are separated at family level, they should also be separated at series level. This has not been done in the case of soil series Guanapalo, because the small differences in texture are thought to have no diagnostic significance; they can easily be explained by assuming small variations in the parent material.

4.4.3 Chemical, Physical and Mineralogical Considerations

Some general data about the profiles are as follows:

	SOIL SERIES	PROFILE NO.	YEAR	SAMPLING	ANALYSIS
*	Horizontes	C-60	1962	Pit	Bogotá
	"	"	1968	Auger	Bogotá and Wageningen
*	Lagunazo	D-13	1968	Shallow pit and auger	Bogotá and Wageningen
*	Nápoles	C-71	1962	Pit	Bogotá
	"	"	1968	Auger	Bogotá and Wageningen
*	Guanapalo	T-35	1962	Pit	Bogotá
*	"	D-11	1968	Auger	Bogotá and Wageningen
*	"	D-12	1968	Auger	Bogotá and Wageningen
*	Carimagua	Ch-66	1962	Pit	Bogotá
	"	"	1968	Auger	Bogotá and Wageningen

The descriptions of the profiles marked with an asterisk are presented in Appendix II, accompanied by the laboratory analyses carried out in Bogotá. To confirm the results of earlier analyses, and for some additional laboratory determinations, sampling and analyses of some profiles were repeated in 1968. In that year the author was invited to participate in a small colombian expedition to the Orinoco river; the available time was not sufficient for excavating pits and therefore, the samples were taken with an 'Edelman' auger. These samples were analyzed both in Bogotá and in Wageningen, and the results are presented in several tables in the present section. The same profile number has been maintained in those cases where in 1968 the auger samples were taken at the same locations of the pits described in 1962.

The soil samples, taken in 1968 were divided in identical, duplicate samples. One set was analyzed in the Soils Laboratory of the Institute Géográfico 'Agustín Codazzi', Bogotá, the other was analyzed in the Laboratory of Regional Soil Science, Wageningen.

In Bogotá the following analyses were carried out:
granulometry
free iron
cation adsorption
cation exchange capacity of the soil
cation exchange capacity of the soil, without buffering
pH (H_2O)
pH (KCl)
mineralogy of sand fractions
mineralogy of clay fractions by X rays
mineralogy of clay fractions by differential thermal analysis
clay and soil dispersion
Atterberg values (Liquid Limit, Plastic Limit, Plasticity Index)
water retention at 15-bar

In Wageningen the following analyses were carried out:
granulometry
free iron
cation exchange capacity of the clay (of three profiles)
pH (H_2O)
pH ($CaCl_2$)
organic carbon
total analysis of clay fractions
mineralogy of clay fractions by calculation from total analysis
mineralogy of clay fractions by X rays
clay dispersion
Atterberg values (of three profiles)

In Tables 14 and 15 the data on granulometry, organic carbon, free iron, cation adsorption, cation exchange capacity and pH are presented, as determined partly in duplicate according to the above list.

Attention is drawn to the high silt contents, especially of the Lagunazo and Guanapalo soil series. Another striking feature is the low content of free iron which reaches extremely low values in the Guanapalo soil series. This is thought to reflect loss of iron from the original parent material, as the result of poor drainage in combination with a rather low pH.

The general chemical properties of all profiles appear to be in accordance with the dominance of kaolinite in the clay fraction.

Mineralogical Analyses of Sand Fractions

The samples taken in 1968 from profiles C-60, D-13, C-71, D-11, D-12 and Ch-66, were analyzed in Bogotá by LUNA (1968) on the mineralogical composition of the sand fractions (45-500 micron). The results are given in Tables 16 and 17.

From Table 16 it can be seen, that quartz is the principal mineral of the sand fraction, comprising around 99 % of the samples. Some surface horizons have an appreciable amount of phytolithic quartz. This accumulation is thought to be due to the chaparro tree (Curatella americana) which has a very high content of fine quartz cristals in its leaves. Fresh leaves of this tree are used by the natives of the Llanos as a very fine-grade sandpaper. The chaparro tree is found scattered throughout the Llanos on the savannas, and is relatively resistant to fires.

Soil association, series & prof. no., depth in cm	clay, 0-2 micron	fine silt, 2-20 micron	coarse silt, 20-50 micron	silt, 2-50 micron	fine and very fine sand, 50-250 micron	medium to very coarse sand, 250-2000 micron	% C	Free Fe_2O_3, %
Aa, HORIZONTES C-60								
0 - 8	46 (42)	16	23	39(48)	10 (6)	5 (4)	(3.3)	2.5 (4.6)
8 - 19	45 (43)	15	25	40(46)	10 (6)	5 (5)	(2.0)	2.4 (4.8)
19 - 35	56 (50)	13	20	33(42)	8 (5)	3 (3)	(1.5)	2.7 (5.8)
35 - 66	56 (53)	12	22	34(40)	7 (5)	3 (2)	(1.0)	2.9 (6.0)
66 - 100	57 (53)	12	21	33(40)	7 (5)	3 (2)	(0.8)	2.8 (5.9)
100 - 125	58 (56)	12	21	33(38)	7 (4)	2 (2)	(0.6)	3.0 (5.8)
Aa, LAGUNAZO D-13								
0 - 15	29 (30)	21	39	60(64)	9 (5)	2 (1)	(1.7)	2.3 (3.0)
15 - 40	32 (31)	21	38	59(64)	8 (4)	1 (1)	(0.8)	2.6 (3.4)
40 - 65	33 (32)	20	38	58(62)	8 (5)	1 (1)	(0.6)	2.6 (3.5)
65 - 95	34 (33)	20	37	57(62)	8 (4)	1 (1)	(0.5)	2.6 (3.6)
95 - 125	35 (33)	20	36	56(63)	8 (3)	1 (1)	(0.4)	2.7 (3.8)
Aa, NAPOLES C-71								
0 - 14	6 (5)	5	12	17(21)	61 (57)	16(17)	(0.8)	1.0 (1.0)
14 - 28	7 (6)	5	15	20(22)	58 (55)	15(17)	(0.4)	1.0 (1.1)
28 - 52	7 (6)	6	17	23(30)	57 (50)	13(14)	(0.3)	1.3 (1.3)
52 - 85	8 (7)	6	17	23(28)	56 (51)	13(14)	(0.2)	1.2 (1.5)
85 - 120	10 (8)	5	19	24(30)	55 (49)	11(13)	(0.2)	1.6 (1.4)
As, GUANAPALO D-11								
0 - 15	13 (9)	26	49	75(86)	11(5)	1 (0)	(3.8)	0.1 (0.2)
15 - 55	16 (12)	23	49	72(82)	12(6)	0 (0)	(0.8)	0.1 (0.1)
55 - 80	16 (13)	23	46	69(80)	13(7)	2 (0)	(0.3)	0.2 (0.1)
As, GUANAPALO D-12								
0 - 20	17 (12)	22	49	71(83)	11 (5)	1 (0)	(0.9)	0.1 (0.1)
20 - 60	25 (16)	22	40	62(79)	13 (5)	0 (0)	(1.8)	0.04 (0.1)
60 - 90	25 (18)	21	42	63(76)	12 (6)	0 (0)	(1.7)	0.1 (0.1)
Ae, CARIMAGUA Ch-66								
0 - 24	46 (46)	30	20	50(52)	4 (2)	0 (0)	(9.4)	2.0 (2.8)
24 - 48	47 (46)	24	22	46(50)	6 (4)	1 (0)	(2.7)	2.4 (1.8)
48 - 67	39 (38)	22	28	50(56)	10(6)	1 (0)	(1.2)	1.1 (1.8)
67 - 100	34 (32)	24	29	53(57)	13(10)	0 (1)	(0.5)	1.5 (2.7)

Table 14 Analysis of granulometry, organic carbon and free iron in soil samples of the High Plains.
The figures between brackets refer to the analysis carried out in the Laboratory of Regional Soil Science, Wageningen; the other figures refer to the analysis carried out in the Soils Laboratory of the Instituto Geográfico "Agustín Codazzi", Bogotá.

Soil association, series & prof. no., depth in cm	Ca	Mg	K	Na	Al	Total exchangeable bases, meq/100 g soil	Cation exchange capacity, meq/100 g soil	Cation exchange capacity in NH_4Cl, without buffering, meq/100 g soil	% Base saturation	p_H (H_2O)	p_H (KCl)	p_H ($CaCl_2$)
Aa, HORIZONTES C-60												
0 - 8	0.3	0.1	0.2	0.4	5.0	0.64	15	8	4.3	4.3(4.2)	3.8	(3.6)
8 - 19	0.2	0.03	0.1	0.02	4.4	0.35	11	7	3.1	4.5(4.2)	4.0	(3.7)
19 - 35	0.2	0.04	0.1	0.03	3.4	0.37	9	6	4.0	4.7(4.5)	4.1	(3.8)
35 - 66	0.2	0.03	0.04	0.03	1.9	0.30	7	6	4.1	5.1(4.7)	4.2	(3.9)
66 - 100	0.2	0.1	0.04	0.04	1.9	0.38	8	5	4.9	5.7(4.9)	4.3	(4.0)
100 - 125	0.2	0.2	0.1	0.1	1.4	0.54	7	5	8.3	5.8(5.1)	4.3	(4.0)
Aa, LAGUNAZO P-9												
0 - 15	0.2	0.1	0.1	0.03	3.6	0.43	10	7	4.5	4.6(4.5)	3.9	(3.8)
15 - 40	0.2	0.1	0.04	0.03	2.9	0.37	8	5	4.8	5.0(4.7)	4.0	(3.9)
40 - 65	0.1	0.1	0.1	0.1	2.5	0.40	6	5	6.9	5.3(4.9)	4.1	(3.9)
65 - 95	0.2	0.1	0.04	0.1	2.6	0.44	6	5	7.4	5.3(4.8)	4.1	(4.0)
95 - 125	0.2	0.1	0.1	0.04	1.8	0.44	6	4	7.0	5.7(5.3)	4.3	(4.2)
Aa, NAPOLES C-71												
0 - 14	0.2	0.3	0.04	0.02	1.4	0.56	3	3	19.3	4.8(4.9)	4.2	(4.1)
14 - 28	0.2	0.04	0.04	0.03	0.9	0.31	2	3	13.5	5.1(5.1)	4.3	(4.1)
28 - 52	0.2	0.04	0.04	0.03	0.7	0.31	2	2	17.2	5.3(5.2)	4.4	(4.1)
52 - 85	0.2	0.1	0.04	0.03	0.5	0.37	2	2	17.6	5.1(5.4)	4.4	(4.1)
85 - 120	0.2	0.1	0.1	0.03	0.4	0.43	2	2	28.7	5.3(5.1)	4.3	(4.1)
As, GUANAPALO D-11												
0 - 15	0.2	0.02	0.1	0.1	2.8	0.42	12	5	3.6	4.9(4.6)	4.2	(4.0)
15 - 55	0.2	0.1	0.1	0.1	2.5	0.55	5	4	10.0	4.9(4.5)	4.2	(4.0)
55 - 80	0.2	0.1	0.1	0.04	2.0	0.44	4	4	11.3	4.8(4.6)	4.0	(3.8)
As, GUANAPALO D-12												
0 - 20	0.2	0.1	0.2	0.1	4.1	0.60	12	6	5.1	4.7(4.4)	4.0	(3.9)
20 - 60	0.2	0.1	0.1	0.1	3.5	0.50	9	5	5.7	4.7(4.4)	4.2	(3.9)
60 - 90	0.2	0.1	0.1	0.6	3.2	1.00	6	5	17.9	4.5(4.3)	4.1	(4.0)
Ae, CARIMAGUA Ch-66												
0 - 24	0.2	0.2	0.4	0.1	3.4	0.90	41	14	2.2	5.3(4.5)	4.4	(4.1)
24 - 48	0.2	0.2	0.2	0.1	4.0	0.60	9	9	3.4	5.1(4.5)	4.2	(3.9)
48 - 67	0.3	0.1	0.1	0.1	3.6	0.60	6	6	6.4	5.0(4.6)	4.2	(3.8)
67 - 100	0.2	0.1	0.1	0.1	3.3	0.50	8	6	6.7	5.3(4.8)	4.1	(3.8)

Table 15 Analysis of cation adsorption, cation exchange capacity and pH in soil samples of the High Plains.
The figures between brackets refer to the analysis carried out in the Laboratory of Regional Soil Science, Wageningen; the other figures refer to the analysis carried out in the Soils Laboratory of the Instituto Geográfico "Agustín Codazzi", Bogotá.

Soil association, series & prof. no. depth in cm	Light minerals in % of total minerals	Quartz	Phytolithic quartz	Weathered particles	Sorting
		in % of light minerals			
Aa, HORIZONTES C-60					
0 - 8	99.3	97	3	tr	medium
8 - 19	98.8	100	tr	tr	"
19 - 35	99.0	100	tr	-	"
35 - 66	99.1	100	tr	-	"
66 - 100	99.0	100	tr	-	"
100 - 125	99.1	100	tr	tr	high
Aa. LAGUNAZO D-13					
0 - 15	99.2	100	tr	-	medium
15 - 40	99.3	100	tr	-	"
40 - 65	98.6	100	tr	-	high
65 - 95	99.3	100	tr	tr	medium
95 - 125	98.6	100	tr	tr	high
Aa, NAPOLES C-71					
0 - 14	99.7	100	-	-	medium
14 - 28	99.1	100	-	-	"
28 - 52	99.2	100	-	-	low
52 - 85	not determined				
85 - 120	99.1	100	-	-	medium
As, GUANAPALO D-11					
0 - 15	97.0	97	3	-	medium
15 - 55	99.2	100	tr	-	high
55 - 80	99.3	100	tr	tr	"
As, GUANAPALO D-12					
0 - 20	99.8	100	tr	tr	high
20 - 60	98.4	100	tr	-	"
60 - 90	n.d.	100	tr	-	"
Ae, CARIMAGUA Ch-66					
0 - 24	n.d.	79	21	tr	high
24 - 48	98.4	95	5	tr	medium
48 - 67	98.9	100	tr	-	"
67 - 100	99.6	100	tr	-	"

Note : n.d. = not determined.
All grains have subangular form.

Table 16 Mineralogical composition of light minerals in sand fractions from soils of the High Plains. Analysis by the Soils Laboratory of the Instituto Geográfico "Agustín Codazzi", Bogotá.

Soil association, series & prof. no., depth in cm	Heavy min., in % of total minerals	Opaque min., in % of heavy minerals	in % of transparent grains														
			Turmaline	Zircon	Rutile	Anatase	Brookite	Chlorite	Mica	Epidote	Zoisite	Hornblende	Clino-pyroxene	Ortho-pyroxene	Volcanic glass	Alterated minerals	Undetermined
Aa, HORIZONTES C-60																	
0 - 8	0.7	38	14	69	tr	-	9	-	-	-	-	-	-	-	-	8	-
8 - 19	1.2	27	25	50	-	tr	4	-	-	-	5	-	-	2	-	16	-
19 - 35	1.0	39	11	68	4	-	tr	-	-	-	-	tr	-	2	-	15	-
35 - 66	0.9	29	23	54	3	-	2	-	-	-	tr	tr	-	-	tr	16	2
66 - 100	1.0	33	13	69	2	-	2	-	-	tr	-	tr	tr	-	tr	14	-
100 - 125	0.9	42	12	48	3	-	-	3	-	-	-	-	-	-	-	26	-
Aa, LAGUNAZO D-13																	
0 - 15	0.8	39	11	45	3	8	-	tr	2	-	-	4	2	-	-	22	3
15 - 40	0.7	37	14	37	2	5	-	tr	3	-	-	5	tr	-	-	34	-
40 - 65	1.4	35	7	51	4	5	-	tr	5	-	-	-	-	-	-	28	-
65 - 95	0.7	32	6	42	5	5	-	tr	tr	-	-	-	-	tr	-	42	-
95 - 125	1.3	36	3	64	2	7	-	-	3	-	-	-	-	2	-	19	-
Aa, NAPOLES C-71																	
0 - 14	0.3	48	7	64	5	-	-	-	-	-	tr	-	-	-	-	24	-
14 - 28	0.9	20	12	52	-	6	-	-	-	-	-	-	-	-	-	30	-
28 - 52	0.8	23	5	77	-	-	-	-	-	-	-	-	-	tr	-	13	-
52 - 85	not determined; similar to 28-52 cm sample.																
85 - 120	0.9	52	8	68	tr	-	-	-	-	-	-	-	-	tr	-	20	-
As, GUANAPALO D-11																	
0 - 15	3.0	37	15	45	tr	tr	-	12	-	tr	-	tr	-	tr	-	26	-
15 - 55	0.8	30	15	49	2	6	-	4	-	-	-	-	-	tr	-	24	-
55 - 80	0.7	28	12	29	tr	tr	2	29	-	-	-	-	-	3	-	25	-
As, GUANAPALO D-12																	
0 - 20	0.2	35	27	35	tr	-	tr	16	-	-	-	-	-	6	-	16	2
20 - 60	1.6	36	16	45	tr	tr	-	2	-	-	-	tr	-	7	-	30	-
60 - 90	n.d.	31	12	62	tr	tr	-	2	-	-	-	-	tr	3	-	20	-
Ae, CARIMAGUA Ch-66																	
0 - 24	not determined; mainly zircon, turmaline and alter. miner.																
24 - 48	1.6	42	15	62	-	-	-	-	-	-	-	-	-	tr	-	23	-
48 - 67	1.1	30	11	55	tr	4	-	-	-	-	-	-	-	-	-	30	-
67 - 100	0.4	20	6	61	2	4	-	-	-	-	-	-	-	2	-	25	-

Note : n.d. = not determined.
The zircon predominantly has a rounded form and strong abrasion on the surface.

Table 17 Mineralogical composition of heavy minerals in sand fractions from soils of the High Plains. Analysis by the Soils Laboratory of the Instituto Geográfico "Agustín Codazzi", Bogotá.

The mineralogy is typical for highly weathered material, presumably mainly inherited from previous weathering cycles, as discussed in chapters 2 and 3.

Table 17 is included to complete the mineralogical picture. Because the data refer to only a very small fraction of the sand, no attempt is made to interpret the data.

Mineralogical Analyses of Clay Fractions

Of the samples from profiles C-60, D-13, C-71, D-11, D-12 and Ch-66 the clay fractions were investigated in Bogotá on their mineralogical composition, by Differential Thermal Analysis (DTA), and by X rays. The qualitative and quantitative interpretation of these analyses, as provided by Silva (1968), is summarized in Table 18.

The presence of vermiculite, probably interstratified with chlorite, and the possible presence of talc and pyrophillite indicates that weathering has not yet reached its final stage, although kaolinite is dominant in all samples. Goethite is absent in the poorly drained soil series Guanapalo.

The samples from profile C-60 (soil series Horizontes) were analyzed by X rays in Wageningen. The analyses of all samples showed the presence of kaolinite, gibbsite, goethite, chlorite and an unknown mineral. This unknown mineral seems to have a structure like zeolite but it also might be a feldspar, which seems to be confirmed by the Goethite-norm composition (see Table 21), in which albite appears (Van Schuylenborgh, 1969).

Total Analyses of Clay Fractions

In the Laboratory of Regional Soil Science, Wageningen, a total analysis of the composition of clay fractions from the samples of profiles C-60, D-13, C-71, D-11, D-12 and Ch-66 was carried out (Van Schuylenborgh, 1969). The results are given in Table 19.

From the data in Table 19 the molecular ratios of silica and sesquioxides have been calculated. These ratios are given in Table 20, with the cation exchange capacity of the clay fractions.

Van Schuylenborgh (1969) also calculated from the total analyses of the clay fractions the mineralogical composition of the clay. This composition is the so-called Goethite-norm composition. See Van der Plas and Van Schuylenborgh (1970). The results are given in Table 21, and are graphically represented in Fig. 29.

The most striking feature in Table 19 is the extremely low content of Fe_2O_3 in the poorly drained soil series Gaunapalo. In Table 20 the well drained soils (Horizontes, Nápoles and Lagunazo) appear to have a low SiO_2/R_2O_3 ratio. A low cation exchange capacity of the clay of soil series Horizontes and Nápoles was found, consistent with the taxonomic classification as Oxic intergrades. However, Table 21 shows the presence of albite in soil series Horizontes and Napoles, and chlorite and illite in all soils. The illite content is highest in the well drained soil series Lagunazo and in the poorly drained soil series Guanapalo and Carimagua. Comparing Table 21 with Table 18, it appears that the identification of clay minerals using different methods remains a problem. Illite was not identified with X rays. Gibbsite was identified with X rays in most samples, but according to the Goethite-norm composition it is absent from the samples of the poorly drained soils.

Soil association. series & prof. no., depth in cm	Qu	V-C	Kaol	Gibb	Goet	Talc ? Pyrophillite ?
Aa, HORIZONTES C-60						
0 - 8	-	xx	xxx	-	-	-
8 - 19	x	xx	xxx	-	x	?
19 - 35	-	xx	xxx	-	x	?
35 - 66	-	x	xxx	x	x	?
66 - 100	-	x	xxx	x	x	?
100 - 125	-	?	xxx	-	-	x
Aa, LAGUNAZO D-13						
0 - 15	not determined					
15 - 40	x	xx	xxx	-	-	x
40 - 65	-	xx	xxx	x	x	x
65 - 95	x	xx	xxx	x	x	-
95 - 125	x	xx	xxx	x	x	x
Aa, NAPOLES C-71						
0 - 14	-	xx	xxx	x	x	-
14 - 28	-	xx	xxx	x	x	-
28 - 52	-	xx	xxx	x	x	?
52 - 85	x	xx	xxx	x	x	?
85 - 120	-	xx	xxx	x	x	?
As, GUANAPALO D-11						
0 - 15	-	xx(x)	xxx	x	-	x
15 - 55	-	xxx	xxx	x	-	x
55 - 80	x	xxx	xxx	x	-	?
As, GUANAPALO D-12						
0 - 20	-	xxx	xxx	x	-	?
20 - 60	-	xxx	xxx	x	-	x
60 - 90	-	xx	xxx	x	-	x
Ae, CARIMAGUA Ch- 66						
0 - 24	x	xx	xxx	-	-	-
24 - 48	x	xx	xxx	x	-	?
48 - 67	x	xx	xxx	x	x	x
67 - 100	x	xx	xxx	x	-	x

Qu = Quartz
V-C = Vermiculite, probably interstratified with Chlorite
Kaol = Kaolinite
Gibb = Gibbsite
Goet = Goethite

xxx = abundant (45 - 70%)
xx = common (10 - 45%)
x = present (5 - 10%)
? = uncertain; the possibility of Talc and Pyrophillite is indicated because of reflections at 9.20, 4.7 and 3.11 Å.

The percentages mentioned give only a rough indication of the proportional presence of the minerals.

Table 18 Qualitative and quantitative interpretation of X-ray analysis and differential thermal analysis (DTA) of the clay fractions from soils of the High Plains. Analysis by the Soils Laboratory of the Instituto Geográfico "Agustín Codazzi", Bogotá.

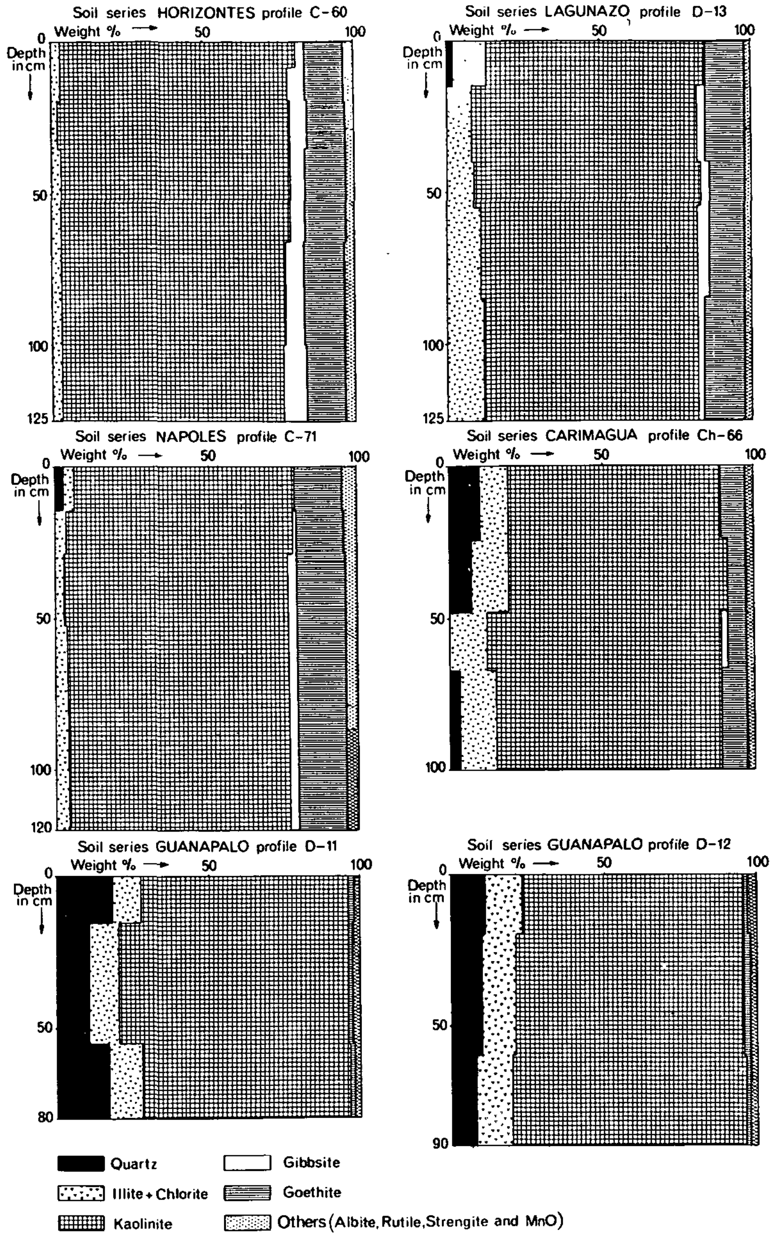


Fig. 29 Goethite-norm composition of clay fractions from soil samples of the High Plains, calculated from the total analyses of the clay fractions.

Soil association, series & prof. no., depth in cm	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	MnO	CaO	MgO	Na_2O	K_2O	FeO	P_2O_5	H_2O
			in	% of	weight							
Aa, HORIZONTES C-60												
0 - 8	38.1	11.4	33.2	1.2	0.1	0.2	0.1	0.2	0.3	0.1	0.3	14.3
8 - 19	37.1	11.4	35.0	1.2	0.1	0.1	0.05	0.2	0.3	0.25	0.3	14.5
19 - 35	35.8	11.2	33.6	1.3	tr	tr	0.05	0.1	0.2	0.2	0.2	14.5
35 - 66	35.8	11.8	33.3	1.3	tr	0.1	tr	0.1	0.3	0.2	0.2	14.8
66 - 100	36.6	12.0	34.5	1.3	tr	0.2	0.1	0.2	0.3	0.3	0.2	14.9
100 - 125	35.6	11.5	34.4	1.2	0.05	0.1	tr	0.2	0.3	0.3	0.2	14.7
Aa, LAGUNAZO D-13												
0 - 15	39.0	11.6	31.7	1.3	tr	-	0.2	0.2	0.6	0.2	0.2	13.4
15 - 40	37.8	12.3	34.0	1.2	tr	-	0.1	0.2	0.55	0.2	0.2	13.7
40 - 65	38.0	11.2	33.7	1.3	0.1	-	0.2	0.2	0.6	0.4	0.2	13.6
65 - 95	38.2	11.5	34.3	1.3	0.1	-	0.2	0.25	0.75	0.5	0.2	13.1
95 - 125	37.6	12.4	32.8	1.3	0.1	-	0.1	0.2	0.9	0.5	0.2	13.0
Aa, NAPOLES C-71												
0 - 14	38.9	14.1	29.1	1.4	0.1	-	0.2	0.2	0.3	0.5	0.55	13.8
14 - 28	36.6	14.0	31.3	1.3	0.1	-	0.2	0.2	0.3	0.5	0.6	14.3
28 - 52	36.6	14.4	32.6	1.2	0.1	-	0.15	0.2	0.3	0.5	0.6	14.6
52 - 85	36.6	14.5	32.3	1.3	0.1	-	0.1	0.2	0.4	0.45	0.5	14.7
85 - 120	36.2	14.3	32.2	1.4	0.1	-	0.1	0.15	0.4	0.55	0.6	14.8
As, GUANAPALO D-11												
0 - 15	52.5	1.7	29.8	1.9	tr	-	0.3	0.2	0.9	0.1	0.1	11.4
15 - 55	49.4	1.7	33.3	1.8	tr	-	0.3	0.2	1.0	0.1	0.2	12.0
55 - 80	53.0	1.5	30.9	1.9	tr	-	0.3	0.2	1.1	0.1	0.1	11.3
As, GUANAPALO D-12												
0 - 20	49.4	1.5	30.9	1.9	tr	-	0.3	0.2	1.1	0.1	0.1	11.3
20 - 60	49.0	1.6	33.0	1.8	tr	-	0.3	0.2	1.1	0.1	0.1	11.9
60 - 90	48.7	1.5	34.5	1.8	tr	-	0.3	0.2	1.2	0.1	0.1	11.7
Ae, CARIMAGUA Ch-66												
0 - 24	45.5	7.8	30.3	1.4	tr	-	0.2	0.15	0.7	0.2	0.55	12.5
24 - 48	43.8	5.8	31.7	1.3	tr	-	0.2	0.3	0.8	0.2	0.3	12.9
48 - 67	41.4	6.2	36.4	1.4	tr	-	0.1	0.3	0.9	0.2	0.2	13.1
67 - 100	42.0	7.9	33.3	1.3	tr	-	0.2	0.25	0.9	0.2	0.2	13.1

Table 19 Total analysis of clay fractions from soil samples of the High Plains. Analysis by the Laboratory of Regional Soil Science, Wageningen.

Soil association, series & prof. no., depth in cm	SiO_2/R_2O_3	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	Al_2O_3/Fe_2O_3	Cation exchange capacity, in meq/100 g clay
Aa, HORIZONTES C-60					
0 - 8	1.6	1.9	8.8	4.5	9.3
8 - 19	1.5	1.8	8.5	4.7	9.3
19 - 35	1.5	1.8	8.3	4.6	8.0
35 - 66	1.5	1.8	8.0	4.4	8.0
66 - 100	1.5	1.8	7.9	4.4	6.0
100 - 125	1.4	1.8	8.1	4.6	6.0
Aa, LAGUNAZO D-13					
0 - 15	1.7	2.1	8.9	4.2	not determ.
15 - 40	1.5	1.9	8.1	4.3	"
40 - 65	1.6	1.9	8.7	4.5	"
65 - 95	1.6	1.9	8.5	4.5	"
95 - 125	1.6	2.0	7.8	4.0	"
Aa, NAPOLES C-71					
0 - 14	1.7	2.3	7.4	3.3	8.0
14 - 28	1.5	2.0	7.0	3.5	8.0
28 - 52	1.5	1.9	6.7	3.6	6.0
52 - 85	1.5	1.9	6.7	3.5	7.3
85 - 120	1.5	1.9	6.8	3.5	6.7
As, GUANAPALO D-11					
0 - 15	2.9	3.0	76	25	not determ.
15 - 55	2.4	2.5	73	29	"
55 - 80	2.8	2.9	90	31	"
As, GUANAPALO D-12					
0 - 20	2.5	2.6	80	31	"
20 - 60	2.5	2.5	78	31	"
60 - 90	2.3	2.4	79	33	"
Ae, CARIMAGUA Ch-66					
0 - 24	2.2	2.6	15	5.9	7.3
24 - 48	2.1	2.4	20	8.3	6.7
48 - 67	1.7	1.9	17	8.9	10.0
67 - 100	1.9	2.2	14	6.5	10.7

Table 20 Molecular ratios of silica and sesquioxides in clay fractions from soil samples of the High Plains. Analysis by the Laboratory of Regional Soil Science, Wageningen.

% weight of clay minerals in clay fraction ($<2\mu$)

Soil association, series & prof. no. depth in cm	Quartz	Albite	Chlorite	Illite	Kaolinite	Gibbsite	Goethite	Rutile	Strengite	MnO
Aa, HORIZONTES C-60										
0 - 8	-	1.6	0.6	2.4	78.1	2.7	12.6	1.2	0.7	0.1
8 - 19	-	1.6	0.6	2.4	74.8	6.3	12.3	1.2	0.7	0.1
19 - 35	-	0.8	0.6	1.5	76.9	5.5	12.8	1.3	0.6	-
35 - 66	-	0.8	0.4	2.6	75.9	5.1	13.3	1.3	0.6	-
66 - 100	-	1.5	0.8	2.4	74.1	6.1	13.2	1.3	0.6	-
100 - 125	-	1.5	0.5	2.4	73.6	7.4	12.8	1.2	0.6	-
Aa. LAGUNAZO D-13										
0 - 15	1.8	-	1.2	7.8	74.3	-	13.0	1.3	0.6	-
15 - 40	-	-	0.9	7.2	74.0	2.7	13.4	1.2	0.6	-
40 - 65	-	-	1.7	7.5	74.5	2.0	12.4	1.3	0.6	-
65 - 95	-	-	2.0	9.6	71.5	2.6	12.4	1.3	0.6	-
95 - 125	-	-	1.6	11.1	70.7	0.9	13.8	1.3	0.6	-
Aa, NAPOLES C-71										
0 - 14	3.1	1.7	1.6	2.6	72.4	-	15.5	1.4	1.6	0.1
14 - 28	-	1.6	1.5	2.4	75.1	1.3	15.1	1.3	1.6	0.1
28 - 52	-	1.5	1.3	2.4	73.7	2.9	15.3	1.2	1.6	0.1
52 - 85	-	1.5	0.9	3.2	73.5	2.5	15.6	1.3	1.4	0.1
85 - 120	-	1.0	1.2	3.2	73.2	2.9	15.3	1.4	1.7	0.1
As, GUANAPALO D-11										
0 - 15	18.3	-	1.4	7.9	68.4	-	1.8	2.0	0.2	-
15 - 55	10.5	-	1.4	8.7	75.5	-	1.5	1.8	0.6	-
55 - 80	16.9	-	1.3	10.0	68.2	-	1.5	1.9	0.2	-
As, GUANAPALO D-12										
0 - 20	11.2	-	1.5	10.7	72.6	-	1.5	2.0	0.5	-
20 - 60	10.4	-	1.3	9.7	74.9	-	1.8	1.7	0.2	-
60 - 90	8.3	-	1.4	10.3	76.6	-	1.5	1.7	0.2	-
Ae, CARIMAGUA Ch-66										
0 - 24	10.2	-	1.3	7.7	69.7	-	8.2	1.3	1.6	-
24 - 48	6.9	-	1.3	11.3	72.0	-	6.3	1.4	0.8	-
48 - 67	-	-	0.9	11.6	77.3	1.5	6.7	1.4	0.6	-
67 - 100	3.0	-	1.3	11.0	74.1	-	8.7	1.3	0.6	-

Table 21 Mineralogical composition of clay fractions from soil samples of the High Plains, calculated according to the Goethite-norm composition. Analysis by the Laboratory of Regional Soil Science, Wageningen.

Additional Analyses (clay dispersion, Atterberg values, water retention)

The first column of Table 22 shows the per cent in water dispersable clay. The figures demonstrate that in general a significant part of the clay disperses, except in soil series Lagunazo, and that therefore no Oxic horizon can be recognized. The fourth horizon of soil series Lagunazo shows an exceptional percentage of dispersion as compared with the other horizons of the profile.

In order to obtain some insight about the strength of the bonds between clay and silt particles the granulometric composition after the destruction of organic matter, but without treatment with a dispersion agent, was determined. Comparing the results with those in Table 14, where the granulometric composition with dispersion is given, it can be seen that in the surface horizons of the well drained soils (Horizontes, Lagunazo and Nâpoles) the clay disperses equally whether or not a dispersion agent is used. In the lower horizons of these soils clay dispersion is not complete when no dispersion agent is used. Apparently the bonds between clay particles in the upper horizons are completely destroyed by oxidation with chromic acid, while in the lower horizons some bonds are too strong to be destroyed by chromic acid. In the poorly drained soil series Guanapalo the clay disperses readily in all horizons after treatment with chromic acid.

The standard for comparison is the granulometric composition given in Table 14. In order to evalute whether the figures of Table 14 are correct, the water retained at 15 bars was determined. The results are given in Table 23. When these values are multiplied by 2.5 and when the products obtained are not higher than the per cent clay determined in the granulometric analysis, it is judged that the clay dispersion in such an analysis has been complete (Soil Survey Staff, 1967). This appears to be the case, except for the surface horizons of the poorly drained soils Guanapalo and Carimagua, where it is probably the organic matter which increases the water retention.

The conclusion of the data discussed above is that the strength of the bonds between particles in the upper horizons of most soils is derived from the organic matter, and that in the lower horizons of the well drained soils a certain degree of cementation occurs, while in the poorly drained soils, especially in the Guanapalo soil series, cementation in the lower horizons is much less. These differences correspond with the difference in content of iron oxides, which is extremely low in the soil series Guanapalo.

From the granulometric data presented in Tables 14 and 22 a 'modified' dispersion ratio has been calculated. See Table 23. The 'normal' dispersion ratio is defined as the ratio between in water dispersable silt and clay, and the total silt and clay (Middleton, 1930 and Baver, 1956). In Table 23 the data refer to the in water dispersable clay and silt, determined after the destruction of organic matter. It is not known to what extent chromic acids destroys bonds other than those derived from organic matter, and therefore the 'modified' dispersion ratio only has a relative value. With this in mind, it may be pointed out that in all samples of the poorly drained soils the 'modified' dispersion ratio is 1.0, while in some samples of the well drained soils it is 0.9.

Soil association, series & prof. no., depth in cm			Granulometric composition with destruction of organic matter, but without dispersion agent % weight					Atterberg values of untreated samples % water		
	% in water dispersable clay (<2µ)	Flocculation Index	clay, 0-2 micron	fine silt, 2-20 micron	coarse silt, 20-50 micron	very fine and fine sand, 50-250 micron	medium to very coarse sand, 250-2000 micron	Liquid Limit	Plastic Limit	Plasticity Index
Aa, HORIZONTES C-60										
0 - 8	18	61	45	16	25	10	4	44	25	19
8 - 19	23	49	40	22	23	10	5	38	24	14
19 - 35	34	39	44	23	22	8	3	43	22	21
35 - 66	31	45	45	22	23	8	2	39	23	16
66 - 100	28	51	44	21	24	9	2	41	22	19
100 - 125	2	97	15	9	61	12	3	42	25	17
Aa, LAGUNAZO D-13										
0 - 15	0.4	99	30	23	34	12	1	34	21	13 (13)
15 - 40	0.3	99	31	14	45	9	1	32	21	11 (16)
40 - 65	0.4	99	27	25	38	9	1	33	20	13 (14)
65 - 95	12	65	25	29	36	9	1	35	20	15 (14)
95 - 125	0.2	99	7	8	67	17	1	35	22	13 (14)
Aa, NAPOLES C-71										
0 - 14	2	67	6	4	11	63	16	non - plastic		
14 - 28	4	43	7	5	12	61	15	"		
28 - 52	6	14	8	6	14	60	12	"		
52 - 85	7	12	9	7	14	59	11	"		
85 - 120	8	20	7	8	16	59	10	"		
As, GUANAPALO D-11										
0 - 15	4	69	14	25	46	15	-	42	30	12 (19)
15 - 55	9	44	16	25	44	15	-	25	19	6 (12)
55 - 80	15	6	16	23	47	14	-	23	19	4 (10)
As, GUANAPALO D-12										
0 - 20	5	71	17	20	50	13	-	42	30	12 (20)
20 - 60	8	68	20	24	42	14	-	34	22	12 (13)
60 - 90	13	48	22	19	46	13	-	30	19	11 (14)
Ae, CARIMAGUA Ch-66										
0 - 24	13	72	19	61	15	5	-	80	75	5
24 - 48	22	53	48	25	20	7	-	51	35	16
48 - 67	1	97	37	27	24	11	1	39	23	16
67 - 100	1	97	33	23	28	14	2	34	20	14

Table 22 Dispersion in water and Atterberg values of soil samples of the High Plains.
Figures between brackets refer to the analysis, carried out in the Laboratory of Regional Soil Science, Wageningen. All other figures refer to the analysis carried out by the Soils Laboratory of the Instituto Geográfico "Agustín Codazzi", Bogotá.

Soil association, series & prof. no., depth in cm	% water retention at 15-bar	ratio % 15-bar water / % clay (<2μ)	"modified" dispersion ratio disp. silt + clay / total silt + clay (dispersion determined after destruction of organic matter)	"activity" ratio Plasticity index / % clay (<2μ)
Aa, HORIZONTES C-60				
0 - 8	16.5	0.36	1.0	0.41
8 - 19	15.4	0.34	1.0	0.31
19 - 35	17.2	0.31	1.0	0.38
35 - 66	14.6	0.26	1.0	0.29
66 - 100	17.6	0.31	1.0	0.33
100 - 125	19.2	0.33	0.9	0.29
Aa, LAGUNAZO D-13				
0 - 15	11.5	0.40	1.0	0.45
15 - 40	10.6	0.33	1.0	0.34
40 - 65	10.9	0.33	1.0	0.39
65 - 95	11.6	0.34	1.0	0.44
95 - 125	13.4	0.38	0.9	0.37
Aa, NAPOLES C-71				
0 - 14	3.0	0.50	0.9	non-plastic
14 - 28	2.8	0.40	0.9	"
28 - 52	3.0	0.43	0.9	"
52 - 85	3.2	0.40	1.0	"
85 - 120	3.7	0.37	0.9	"
As, GUANAPALO D-11				
0 - 15	6.4	0.50	1.0	1.33
15 - 55	6.5	0.40	1.0	0.50
55 - 80	6.7	0.42	1.0	0.30
As, GUANAPALO D-12				
0 - 20	10.8	0.63	1.0	0.44
20 - 60	9.3	0.37	1.0	0.48
60 - 90	8.8	0.35	1.0	0.44
Ae, CARIMAGUA Ch-66				
0 - 24	39.2	0.85	1.0	0.11
24 - 48	20.9	0.44	1.0	0.34
48 - 67	16.2	0.42	1.0	0.41
67 - 100	14.2	0.42	1.0	0.41

Table 23 Water retention, dispersion ratio, and "activity" of soil samples of the High Plains. Analysis by the Soils Laboratory of the Instituto Geográfico "Agustín Codazzi", Bogotá.

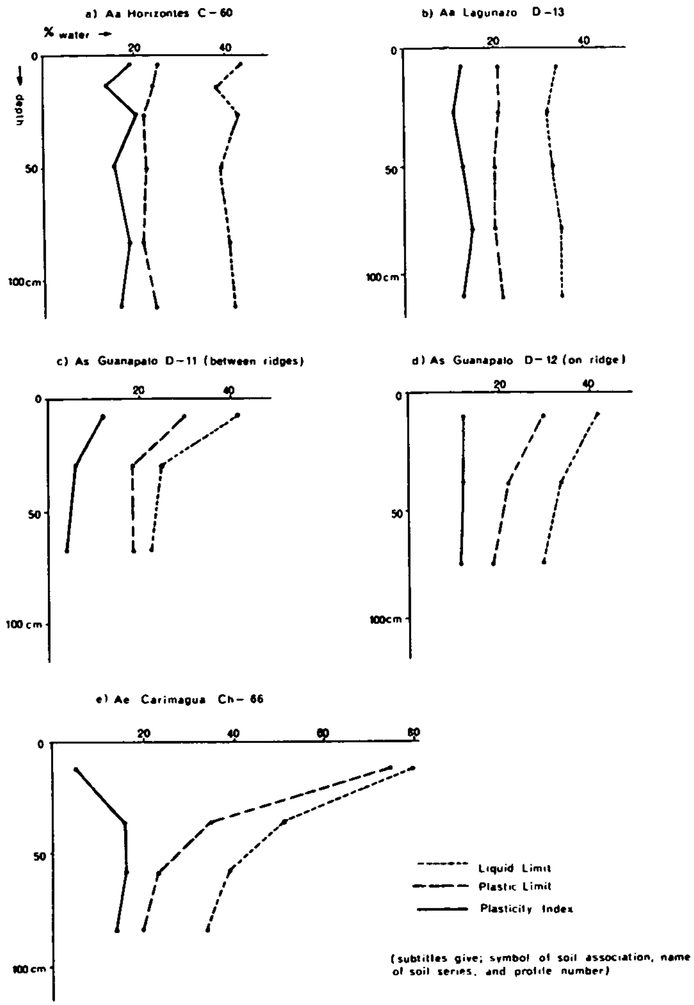


Fig. 30 Graphs showing the Atterberg values of some soil series of the High Plains.

Furthermore, the Atterberg values were determined. See Table 22. The Atterberg values are the Liquid Limit, the Plastic Limit and the Plasticity Index (LL, PL and PI), the latter defined as PI = LL - PL (Atterberg, 1911). The Atterberg values are also graphically represented in Fig. 30. Except in the surface horizon of soil series Carimagua, the Atterberg values of all soil samples are rather low. The Liquid Limit and the Plasticity Index in the subsoil of profile D-11, soil series Guanapalo, are extremely low. A low LL indicates a low friction. A low PI means a short range of plasticity, and is associated with a high instability. See e.g. Terzaghi (1943), Waterways Experiment Station (1953) and Wu (1966).

In Table 23 also the 'activity' is presented. The 'activity' gives a measure of the Plasticity Index of the clay fraction. It is a quantitative expression for the influence of the clay grade upon plasticity of soils, and is defined as the ratio Plasticity Index to per cent <2 micron (Skempton, 1953). Skempton introduced a graph, plotting the Plasticity Index against the clay content, and defining areas within this graph as having low, medium, high and very high 'activity'. Figure 31 gives this graph in which the 'activity' values of the soil samples are plotted. All samples are located within the area of low 'activity', except the two from the surface horizon of soil series Guanapalo, profiles D-11, which lie on the boundary of low and medium 'activity'.

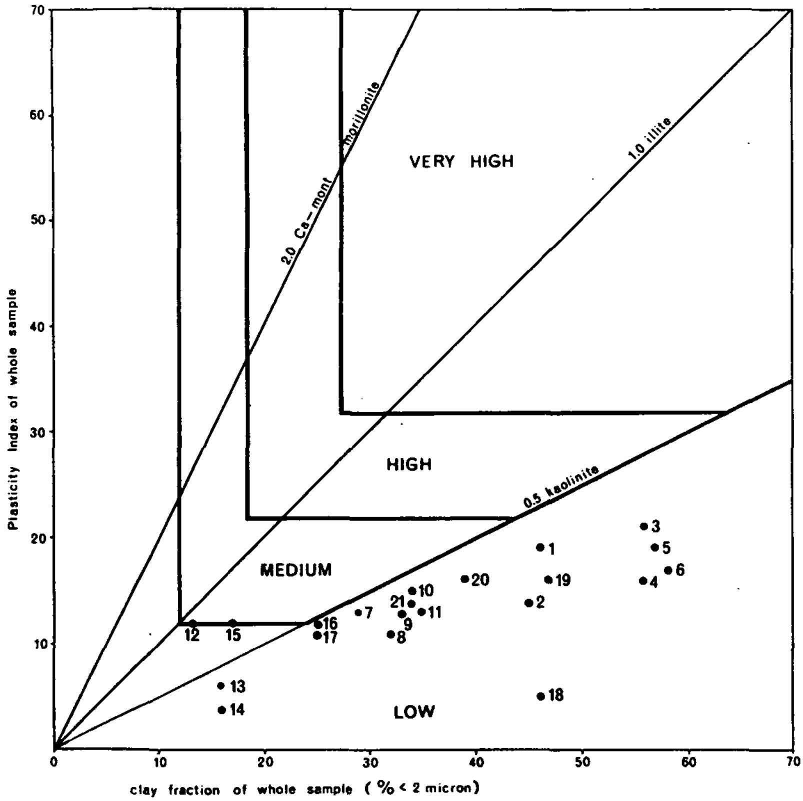


Fig. 31 Graph showing the 'activity' of the clay, by plotting Plasticity Index against per cent clay (Skempton, 1953).

nos.	1 - 6 :	soil series	Horizontes,	profile	C-60
	7 - 11 :	,, ,,	Lagunazo,	,,	D-13
	12 - 14 :	,, ,,	Guanapalo,	,,	D-11
	15 - 17 :	,, ,,	Guanapalo,	,,	D-12
	18 - 21 :	,, ,,	Carimagua,	,,	Ch-66

In the graph of Fig. 31 three additional lines are plotted, which according to Skempton (1953) and Wu (1966) represent the 'activity' of Ca-montmorillonite, illite and kaolinite, with values of 2.0, 1.0 and 0.5 respectively. In this same order they represent active, normal and inactive clays. It is evident that the clay fractions of the soil samples are predominantly of the inactive type with respect to this classification. Gillott (1968) states about the significance of the 'activity': "There is a general correlation between activity and clay-mineral composition but it is inexact owing to the influence of other factors such as composition and concentration of pore solutions and influence of organic soil constituents".

The Liquid and Plastic Limits can only be determined on a remolded soil. At the same water content a soil in the natural, or undisturbed state, may exhibit a different consistency because of its different particle structure. Thus if the Liquid Limit of a soil is found to be 40 per cent, it does not necessarily mean that an undisturbed specimen of the soil would be in the liquid state at that water content (Wu, 1966). The consistency of the soil in the field is therefore usually indicated by its shear strength, as measured on undisturbed samples. Shear strength can be defined as the strength of a body to withstand forces to cause permanent deformation or fracture of that body. It is widely used in soil mechanics (Terzaghi, 1943; Gillott, 1968 and Wu, 1966). In the soil survey of the Llanos no undisturbed samples to measure shear strength, were taken. However, a useful index which reflects the properties of natural soils is the Liquidity Index (LI), defined as

$$LI = \frac{w - PL}{PI}$$

in which w is the in situ water content, PL is the Plastic Limit, and PI is the Plasticity Index (Wu, 1966). It is used in soil mechanics based on Casagrande's (1948) system of soil classification. A value of about 0.5 is found in 'normal' clays; most soils have a Liquidity Index higher than 0.5, but some soils, such as organic soils or montmorillonitic clay soils with a high Plastic Limit, may have a Liquidity Index near zero or even of negative value. A high Liquidity Index is associated with soils of low cohesion and friction, and it means that the soil flows as a viscous liquid, if disturbed or remolded.
Wu (1966) states that it is a characteristic of the quick clays to have a Liquidity Index larger than 1.

No data are available on the in situ water content of the soils of the High Plains. Of course, this water content is very variable according to the season, and also depends on the porosity of the soil. However, to get an indication of the possible values of the Liquidity Index, a calculation was made on the basis of a series of assumed water contents, ranging from 30 % to 70 %. It may be doubted whether the water content would ever reach a value of 70 % in the field, but values of 30 % and more are thought to be feasible, given the rather high porosity mentioned in most of the profile descriptions for the A-horizons and the upper part of the B-horizons. The calculated values for the Liquidity Index are listed in Table 24.

The negative values in soil series Carimagua are evidently associated with the high organic matter content. Attention is drawn to the samples from the subsoil of soil series Guanapalo. Already with 30 % water values of 1 and higher are attained, and with increasing water content the Liquidity Index reaches extremely high values.

Soil association, series & prof. no., depth in cm	Assumed water content in situ (w) 30%	40%	50%	60%	70%
	Liquidity Index $(LI = \frac{w - PL}{PI})$				
Aa, HORIZONTES C-60					
0 - 8	0.3	0.8	1.3	1.8	2.4
8 - 19	0.4	1.1	1.9	2.6	3.3
19 - 35	0.4	0.9	1.3	1.8	2.3
35 - 66	0.4	1.1	1.7	2.3	2.9
66 - 100	0.4	0.9	1.5	2.0	2.5
100 - 125	0.3	1.0	1.5	2.1	2.7
Aa, LAGUNAZO D-13					
0 - 15	0.7	1.5	2.2	3.0	3.8
15 - 40	0.8	1.7	2.6	3.6	4.5
40 - 65	0.8	1.5	2.3	3.1	3.9
65 - 95	0.7	1.3	2.0	2.7	3.3
95 - 125	0.6	1.4	2.2	2.9	3.7
Aa, NAPOLES C-71					
0 - 14	not determined : all samples of this profile are non-plastic.				
14 - 28					
28 - 52					
52 - 85					
85 - 120					
As, Guanapalo D-11					
0 - 15	0	0.8	1.7	2.5	3.3
15 - 55	1.8	3.5	5.2	6.8	8.5
55 - 80	2.8	5.3	7.8	10.3	12.8
As, GUANAPALO D-12					
0 - 20	0	0.8	1.7	2.5	3.3
20 - 60	0.7	1.5	2.3	3.2	4.0
60 - 90	1.0	1.9	2.8	3.7	4.6
Ae, CARIMAGUA Ch-66					
0 - 24	-9.0	-7.0	-5.0	-3.0	-1.0
24 - 48	-0.3	0.3	0.9	1.6	2.2
48 - 67	0.4	1.1	1.7	2.3	2.9
67 - 100	0.7	1.4	2.1	2.9	3.6

Table 24 Liquidity Index at different water content of the soils of the High Plains.

The data presented in this section will further be used in Chapter 5 to explain certain phenomena of erosion and mass movement in the High Plains.

Chapter 5

RELATIONSHIPS BETWEEN SOIL PROPERTIES, EROSION AND MASS MOVEMENT

5.1 INTRODUCTION

As has been explained in Chapter 1, the present chapter will treat the relationships found in the Llanos Orientales between soils and degradational processes occurring or having occurred in the gently sloping savannas. It will be shown that the kind and rate of degradation, and the resulting relief configuration, are related to a number of soil properties. Before proceeding to the discussion of the case studies, a few general remarks will be made on processes of landform development and on soil properties influencing these processes, as far as they are relevant to the case studies.

5.2 PROCESSES OF LANDFORM DEVELOPMENT

The main exogeneous processes responsible for the shape of the earth's surface are degradation and sedimentation or aggradation. They are customarily seen as two contrasting, but complementary processes. Degradation includes weathering, erosion and mass wasting or gravitative transfer (Thornbury, 1954). Holmes (1965) and Scheidegger (1961) use the term 'denudation' instead of degradation, and 'mass movement' instead of mass wasting.

Erosion can be defined as the process of detachment and transportation of materials by erosive agents (Ellison, 1946). The essential difference with mass movement is that the latter mainly occurs under the influence of gravity without a medium of transport. Sedimentation is the aggradation of materials which come to rest in a certain place after having been transported. (Trask, 1950).

In the following we will use the terms 'degradation', 'erosion', 'mass movement' and 'sedimentation' in the same sense as the authors cited above. The discussion will be limited to physical detachment, transportation and sedimentation of soil material.

In practice, superposition or interaction of erosion, mass movement and sedimentation occur quite frequently, and together they form a continuum with total degradation at one extreme and total sedimentation at the other. A particular slope may have the finest materials removed completely, while the coarser particles are only partially removed or come to rest again lower down the slope. This we call selective erosion. Because the coarser materials stay behind, the texture on the slope will become coarser with time, so we may speak of a relative accumulation of coarse particles (see also Jungerius, 1965). The result has been called an erosion pavement or lag deposit (Shaw, 1929). A desert pavement of stones, where wind is the erosive agent, removing sand and finer particles, is an extreme example of this general phenomenon.

Similarly, sedimentation in a particular spot is often incomplete. Differential sedimentation, described for the Alluvial Overflow Plain, is an example of this.

Many textural differences between soils can be explained, on the basis of the foregoing principles, as being the result of the interplay between degradation and sedimentation. Also, the textural differences within a single soil can often be attributed to this effect. Churchward (1961) discusses the principle of it.

5.2.1 Landforms resulting from degradation and sedimentation

Very few landforms exist which are not influenced by degradation or sedimentation, or a combination of both. The variety in form is great, but there exists a number of principles which explain some basic forms.

Depositional forms of sediments laid down when water is the principal medium of transport usually decrease in slope slong the direction of transport. The resulting slopes are said to have a waning gradient and they are essentially the same as the long profiles of rivers. Colluvial fans, alluvial piedmont plains, and the slopes from natural levees towards slackwater areas in a floodplain all show this waning gradient.

Landforms sculptured by erosion have long been and still are the subject of much discussion. Schools of opinion have grown up, in which emphasis is given to one or another explanation of slope forms. Notable among such schools were those started by Davis and Penck. The controversy between them is excellently reviewed by Dury (1959).

As regards the actual forms observed, most authors agree upon the recognition of three basic slope forms:

1. convex slope;
2. straight slope;
3. concave slope.

The three forms often occur together along one slope from top to bottom.

For the purpose of the present study it is important first of all to consider the relative activity of erosion and sedimentation on a given slope.

From a certain point on a slope, material is removed, but on any point except the highest, material from above may be deposited and come to rest, sometimes for a very short period, sometimes for longer. This deposit may subsequently be eroded and replaced by other materials. In fact, the material moves from point to point, being alternately eroded and deposited. Thus, at any point, the active processes are both erosion and sedimentation, and it is their combined activities that count. The net effect of erosion is positive if there is more material removed than added; in other words, if the action of erosion is faster than that of sedimentation. The net effect of sedimentation is positive if there is more material added than removed. However, the action of erosion can be quite rapid, even on a concave part of the slope, but such a slope section is influenced to a greater degree by sedimentation processes than is a convex section. We might say that it has attained a form similar to the depositional, which, as was stated earlier, has a typically waning gradient and is therefore concave.

Mass movement frequently leaves scars with a concave form. The transported material comes to rest lower down the slope; this type of mass sedimentation usually results in an irregular association of convex and concave slopes. Therefore, irregular slope forms are a characteristic feature where mass movement is active.

5.2.2 Soil Properties Influencing Degradation

The behaviour of soil when degradational forces are acting upon it depends, apart from external factors, on many internal properties which together may produce forces counterbalancing the degradational force. Generally speaking, the strength of a soil is derived from two sources,

1. the internal friction developed at the points of contact of the soil particles, and
2. the cohesion, including cementation, which is the ability of soil granules to hold together when unsupported.

In relation to degradational forces it can also be said that internal friction is the capacity of the soil to withstand forces tending to deform the arrangement of the particles, while cohesion is the capacity of the soil to withstand forces tending to break loose the individual particles from the structural aggregates. In soil mechanics it is customary to express the combined effect with the aid of the Coulomb formula (Terzaghi, 1943):

$$s = c + n \tan \Phi,$$

in wich s = shear strength
c = cohesion
n = pressure normal to the plane
$\tan \Phi$ = tangent of the angle of internal friction.

A pile of loose, dry sand has little or no cohesion, and comes to rest at its so-called natural angle of repose, when gravity is in balance with internal friction. Adding a small quantity of water to the pile makes it possible to construct quite steep slopes. The capillary force of the water has increased the cohesion. Adding more water to the pile causes it to collapse, partially or completely. The capillary force has disappeared, and increased buoyancy has decreased the internal friction. Here we see already that one of the soil properties, viz. water content, affects the strength of the soil.

The Coulomb formula, mentioned above, is mainly applied in studying slope stability in relation to gravitational pull, and is therefore applicable in the study of mass movement. When, in the following, certain soil properties related to cohesion and friction are discussed, it should be borne in mind that this discussion is meant principally to lay the foundation for the hypothesis that mass movement has occurred in the poorly drained soils of the Llanos. Several of these properties have bearing upon erosion and will be used to explain certain phenomena of erosion, but it is not deemed necessary to make plausible that erosion in general has occurred. Therefore, no discussion is presented of factors only relevant to erosion, such as intensity of rainfall, rate of overland flow, etc. The reader is referred to e.g. Bennett (1939), Horton (1945) and Baver (1956) for a discussion of these factors.

A PROPERTIES OF MINERAL MATTER

Textural Composition

The behaviour of mineral matter in the soil in relation to the cohesion and friction is dependent upon the textural composition (Boswell, 1961; Varnes, 1950, 1958). Three aspects of the texture are of particular importance: size, sorting and shape.

Other conditions than size being equal, clays have more cohesion than silts and sands. Many investigators have shown this, for example: Ellison, 1946; Gayel and Smirnova, 1965; Gerard, 1965; Russell, 1964; Schuffelen and Koenigs, 1962; Terzaghi, 1943; Trask, 1959. That silts are lower in cohesion than clays, is also indicated in the Unified Soil Classification System (Waterways Experiment Station, 1953).

In specific cases it has been demonstrated that silty and sandy textures are one of the causes of a high instability of the soil mass. Hersh (1963) found this in Pennsylvania, Koppejan et al. (1948) in Zeeland, while Turnbull et al. (1950) describe it in the Mississippi Valley.

The sorting refers to the particle size distribution. Well-sorted material has a low friction, because the number of contact points per unit of volume is lower than in unsorted material. The low friction in sorted material compared to that in unsorted material is clearly demonstrated by the investigations of Büdel (1959), Freundlich and Röder (1938), Pryce-Jones (1948), Spangler (1960), Terzaghi (1950), and Wischmeier and Mannering (1969). In particular cases it has been shown that sorting is related to a high erodibility and a low resistance against mass movement. See, for example, Cross (1964), who studied erosion in Virgina, Jakobson (1952), studying a landslide in Sweden, Kerr and Liebling (1963), referring to landslides in Sweden and Canada, Knight and Dehlen (1963), investigating a 'collapsing soil' in South Africa, and Segerstrom et al. (1964), discussing a mudflow in Chile.

The shape of grains affects the friction. Rounded forms result in a lower friction between grains than angular forms. This has been demonstrated quite clearly by the theoretical and practical considerations of Boswell (1949), Chen (1948), Gillott (1968) and Terzaghi and Peck (1967).

The high friction associated with angularity is called the effect of interlocking action.

Packing

In soil mechanics it is customary to mention packing as one of the properties of a sediment. With respect to soil profiles in the pedological sense, packing is synonymous with density of structure. The term packing, however, is often used when talking about the initial state of the sediment. Therefore, the term can be used even if there has been no soil profile development.

The packing, or the arrangement of the particles with respect to each other, is closely related to friction. The looser the packing, the lower will be the friction, while a dense packing corresponds with a higher friction.

This relation between packing and friction has been found in several studies, such as those of Boswell (1961), Koppejan et al. (1948), Gillott (1968), Rosenquist (1953, 1962), Varnes (1950, 1958), and Zåruba and Mencl (1969).

Mineralogy

The cohesion of a soil material is influenced by the mineralogy. Trask (1959) states: "Montmorillonoid clayey sediments have proved to be stronger than illitic, and illitic than kaolinitic". Gillott (1968) writes that, of clay minerals, kaolinites have the least plastic properties. Kerr (1963) compiled the data of several investigators, and put these together in a graph. See Figure 32. According to this graph kaolinite needs only 50 % water to have its shear strength reduced to near zero, while illite and especially montmorillonite need much more.

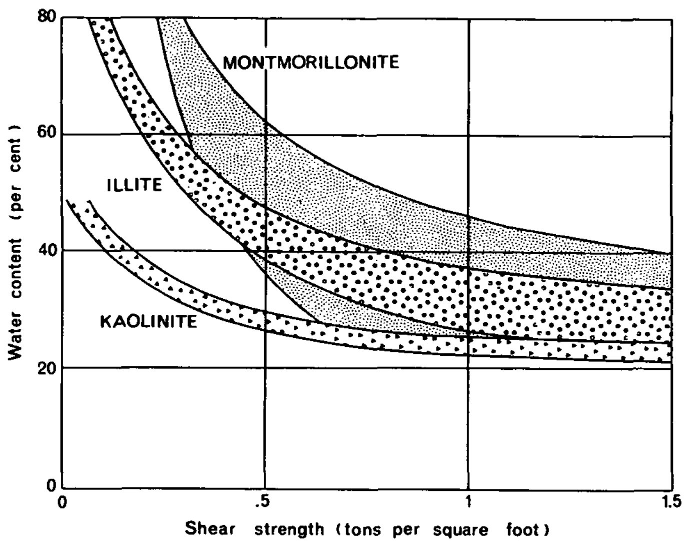


Fig. 32 Diagram of shear strength of some clay minerals under varying water content. (after: Kerr, 1963)

Koenigs (1961) found that kaolinite-colloids generally have a lower stability than e.g. montmorillonite-colloids, while Schuffelen and Koenigs (1962) state, that if sesquioxides are lacking, the structure of soils containing kaolinite is very unstable. In a recent study Ingles (1969) also comes to the conclusion that the strength of montmorillonite is considerably higher than that of kaolinite.

Many properties of clay minerals are derived from the effect of processes occurring on the surface of the minerals. Detailed discussions can be found in Gillott (1968) Spangler (1960), Tchourinov (1945), Terzaghi and Peck (1967 and Varnes (1950). Some important conclusions refer to the influence of water and of bases. Water, when bound to clay in thin layers by electro-chemical forces, tends to increase both cohesion and friction. The behaviour of water in this state is as a solid rather than as a liquid.

A high cation exchange capacity in combination with a high base saturation has the effect of increasing the cohesion, while a low cation exchange and a low base saturation decrease cohesion in a soil. Some of the many authors who have elaborated on this subject, are Crawford (1963) Gerard (1965), Grim (1949), Rosenquist (1962), Russell (1944), Tchourinov (1945), Terzaghi (1943) and Varnes (1958).

The nature of the ions exerts some influence, as indicated by Gillott (1968), Ingles (1969) and Koenigs (1961); calcium, in particular, tends to increase the cohesion.

Type of sediment

Although type of sediment is not in itself a soil property, but rather a combination of properties dependent on various other factors, it is possible to indicate a rank order in terms of strength between different types of sediments.

In soil mechanics, unconsolidated lacustrine sediments have the reputation of being very unstable. (Boswell 1961; Gillott 1968; Varnes 1950, 1958). Classical examples are the periglacial lacustrine sediments in Northern Europe and Northern America. The Leda clay in Canada is a specific case, and for instance, Kindle (1917) and Crawford (1961) report mass movement in the form of earth flows on very gentle slopes in this sediment.

Another type of sediment known to occur in unstable conditions is loess. Terzaghi and Peck (1967) remark on the stability of loess, that loess may have vertical slopes when well drained, but that it is very unstable when submerged. Leaching processes transform the loess into an almost cohesionless material. Similar observations on loess are made by Basset and McDaniel (1967), Russell (1944, 1964), Schönhals (1960), Simonson et al. (1952) and Turnbull et al. (1950), who report on various phenomena of erosion and mass movement.

Not only loess, but aeolian sediments in general are mechanically unstable, especially in an unconsolidated and poorly drained state. The collapsing soils in South Africa described by Harrison and Falcon (1943), Knight and Dehlen (1963), and Mitchell and Van der Merwe (1958) are predominantly found in aeolian sands.

The reason for the instability of aeolian material is related to the sedimentation characteristics of material that has been transported by wind.
The most inportant characteristics in this respect are the textural composition of aeolian material, as a result of the sorting effect of the wind, and the loose packing of the sediment in its initial state. When other materials show the same characteristics, then these may also be unstable. Brink and Kantey (1961) for example, discuss South African cases, and state: "Collapsible grain structure in soils had been associated with aeolian sands, but it also has been found to occur in residual soils developed from decomposed granite".

With respect to the above mentioned characteristics, viz. grain size and packing, alluvial sediments in general are less sorted and have a denser packing than aeolian sediments. This particularly increases the friction and hence the strength.

B SOME EFFECTS OF SOIL FORMATION

Weathering

The physical disintegration of mineral particles leads to a change in the texture of the soil material. The influence of texture on cohesion and friction has already been discussed under 'Textural Composition'. Chemical weathering may result in the formation of clay minerals, the effect of which on soil strength has already been discussed above under 'Mineralogy'.

Structure

The structure of a soil refers to the arrangement of the soil particles with respect to one another. The stability of this arrangement depends upon the kind of bonds existing between the particles. Many of these bonds have already been discussed in foregoing paragraphs.

Apart from cohesive bonds between particles, there are other aspects relating to strength and thus to stability. The number of contact points between particles per unit of volume has a direct relationship to the internal friction. (Baver 1956, Boswell 1961, Freundlich and Röder 1938, Gillott 1968, Varnes 1950, 1958 and Wu 1966). With few contact points per unit of volume the friction is correspondingly low. This aspect has already been discussed under 'Packing', but merits separate treatment, because an open structure in this sense is often the result of leaching processes. When a calcareous loess is subject to decalcification, the loess, which already had an open structure, shows a further decrease in contact points. This reduces the friction. Since the cement (lime in this example) is removed, the cohesion is also reduced. Instability is the result (Russell, 1944).
In many soils, a similar loss in cohesion and friction is associated with the loss of sesquioxides from the surface horizons.

An open structure in cohesionless material is typical for quick clays (Grim, 1962, Kerr, 1963, and Rosenquist, 1953). Porosity is related to an open structure and therefore to a low friction. A porous soil is often considered to have more resistance to erosion (Bennett, 1939 and Ellison, 1946), because its infiltration capacity is higher and hence the surface run-off is reduced. This statement, however, refers to a decrease in an external erosion factor. In many specific cases it has been demonstrated that porosity as such, contributes to an unstable arrangement of the grains. Collapsible structures in relation to porosity are described e.g. by Brink and Kantey (1961), Harrison and Falcon (1943), Mitchell and van der Merwe (1958) and Zâruba and Mencl (1969).

Cementation

Cementation as the result of soil forming processes is called pedocementation (Flack et al., 1969). These authors define it as the aggregation of particles by chemical compounds in the soil. It is, therefore, closely related to structure.

The effect of pedocementation on soil strength is to produce a great increase in cohesion. The absence of pedocementation corresponds with a lower cohesion.

Sesquioxides play an important role in pedocementation in the humid tropics, and the role of sesquioxides, particularly iron oxide, in terms of cohesion is discussed by Marshall (1962), Schuffelen and Koenigs (1962), Spangler (1960) and Varnes (1950, 1958).

It has been demonstrated in specific cases that the leaching out of a cementing agent is directly related to a decrease in aggregate stability. See e.g. Moss (1965), Russell (1944), Schönhals (1960), Uehara, Flach and Sherman (1962).

Organic Matter

Organic matter, by binding together soil particles, contributes to cohesion. On the other hand, soils with a high organic matter content may show an increased plasticity. They often 'smear' easily. This means that the friction is lowered. The interaction of the two effects, viz. increase in cohesion and decrease in friction, has not been measured quantitatively. The function of organic matter in terms of soil strength is discussed by Bentley and Pawluk (1964), Schuffelen and Koenigs (1962), Spangler (1960) and Wischmeier and Mannering (1969).

C EFFECTS OF SOIL MOISTURE

A general discussion on the influence of water upon cohesion and friction can be found in Boswell (1961), Carson (1969), Gerard (1965), Gillott (1968), Koenigs (1961), Pryce-Jones (1948), Sharpe (1960), Spangler (1960), Terzaghi (1943, 1950), Terzaghi and Peck (1967) and White and Pichler (1959).

Most important is the amount of water in the soil. Small amounts of water increase both cohesion and friction, as has been previously discussed under 'Mineralogy'. The fact that the hydration of clay minerals increases soil strength does not contradict the observed fact that the soils with a high amount of swelling minerals often show plastic deformation. The expansion forces due to water are in this case so much larger than the cohesion and friction, that the latter, even though they have become larger, are not able to hold the soil together as a solid mass. The slickensides, so common in these soils, are the evidence of the interaction of large expansion forces on the one hand, and great cohesion and friction on the other.

Capillary water in the soil affects cohesion and friction in diverse ways. In the first place, capillary tension increases the cohesion, and to a small extent the friction. In the second place, the capillarity as a dynamic process may influence the aggregate stability in a negative way. If a dry crumb of soil is suddenly surrounded by water on all sides, the water will penetrate the minute pores. The enclosed air within the crumb cannot escape rapidly, and will be compressed.

When the cohesion of the crumb is low, this compressed air is able to explode the crumb. The investigations of Koenigs (1961) and Janse and Koenigs (1963) are very significant in this respect. On a larger scale, water-entrapped air may play a role in the dynamics of landslides. If a relatively dry soil with a basically low cohesion and friction suddenly receives a high amount of precipitation, and if the pores in that soil are mainly of capillary size, then the water will penetrate the soil by capillary suction. The air in the sub-surface horizons may be compressed in a similar way to that in individual crumbs.

When a landslide is triggered in soil in such a condition, as may occur through an earthquake, the upper soil horizons may move rapidly on this compressed cushion of air. Kent (1966) and Shreve (1966) describe a number of landslides and attribute the transport mechanism to the process described above.

When a soil is saturated with water, most of the water is in a free, liquid state. The cohesion due to capillary tension is reduced to zero, while the friction is lowered due to the 'buoyancy effect' which results in the lowering of intergrain pressure. If the porewater attains a certain hydrostatic pressure, as may occur in an aquiferous layer in the soil on a slope, the buoyancy effect is increased, and the friction is reduced proportionally.

In many types of mass movement it has been shown that water saturation is an extremely important factor. See Bjerrum (1955), Crawford (1961), Hadley and Rolfe (1955), Rosenquist (1953) and Ruhe (1967).

In discussing a number of soil properties related to cohesion and friction, some indications have been given as to the relative importance of these properties. The integrated evaluation of the properties combined remains the subject of many investigations in soil mechanics (Gillott, 1968), but several noteworthy attempts at a comprehensive evaluation and classification of soils in terms of stability have already been made. Based on the work of Terzaghi (1943), Casagrande (1948) proposed a classification which later resulted in the Unified Soil Classification System of the Waterways Experiment Station (1953). For practical purposes much attention is given to a number of indices depending on characteristics already described. We will mention some of them briefly, indicating their significance and referring to the literature for the discussion.

Atterberg values

Atterberg (1911) introduced the Plastic Limit, Liquid Limit and Plasticity Index (resp. PL, LL, and PI). The PL depends mainly on mineralogy, inactive minerals being associated with a low PL. The LL also depends on texture; clays usually have a higher LL than silts. The difference between PL and LL is the PI. It indicates the range of plasticity, and a low PI is associated with a high instability. A low LL is associated with a low friction. Elaborate evidence for the above can be found in Bassett and McDaniel (1967), Boswell (1949), Freundlich and Röder (1938), Gillott (1968), Knight and Dehlen (1963), Scott and Brooker (1968), Spangler (1960), Terzaghi (1943), Van der Merwe (1964), Waterways Experiment Station (1953), White and Pichler (1959) and Wu (1966).

Liquidity Index

The Liquidity Index is the ratio of the natural water content of a soil minus its PL, to its PI. Its meaning has already been discussed in Section 4.4.3. Generally speaking, a high Liquidity Index is associated with low cohesion and friction. Quick clays have a Liquidity Index larger than 1 (Wu, 1966).

Flocculation Index

The Flocculation Index is the ratio, expressed as a percentage, of the non-dispersable clay to the total amount of clay. A flocculated soil has a higher cohesion than a non-flocculated soil (Baver, 1956, and Gillott, 1968).

Dispersion Ratio

In soil mechanics the Dispersion Ratio is used rather than the Flocculation Index. The Dispersion Ratio was introduced by Middleton (1930), and is defined as the ratio of the in water dispersable silt plus clay, to the total silt plus clay. A high Dispersion Ratio is associated with a high erodibility.

'Activity Ratio'

The 'Activity' Ratio, introduced by Skempton (1953), is a measure for the classification of clays in terms of activity. It is the ratio of the PI to the per cent clay. Low values are associated with low cohesion, as the investigations of Crawford (1961), Knight (1963), Spangler (1960) and Záruba and Mencl (1969) have shown.

The discussion in this section mainly has referred to factors and properties relevant to soil mechanics. Of course, several of those are also the subject of study in pedology, and as such there is an overlap between the study of soils for engineering purposes (soil mechanics) and pedology, including the study of soils for land use purposes. In recognizing this overlap, Vink (1963) states that: "these two soil sciences use different definitions for the basic concept of 'soil' and therefore, they are classifying different phenomena". In soil mechanics the soil stability refers to the behaviour of the soil mass as a whole, and the various types of mass movement. In pedology and in soil conservation more attention is paid to erosion, including the dispersing action of rainfall on the surface, overland flow and the resulting removal of individual soil particles. The resistance of the soil to the latter process is usually indicated in terms of erodibility.

An excellent review on erodibility is given by Bryan (1968), who found that the percentage-weight of the water-stable aggregates (W.S.A.) smaller than 3 mm, is a reliable index of erodibility. It should be pointed out that this index does not include friction; the W.S.A. depends only on cohesion. Chorley's (1959) index of erodibility relies on soil shearing resistance, and therefore includes both cohesion and friction.

In the following sections three specific forms of erosion and mass movement in the Llanos Orientales will be discussed. The properties of the soils will be considered in terms of cohesion and friction, and an attempt will be made to explain the different forms as being the result of, amongst other factors, differences in cohesion and friction.

5.3 SHEET EROSION

5.3.1 General

Sheet erosion, also called laminar erosion, surface-wash or sheet-wash, refers to the even removal of material on a slope without gullies or, in general terms, where defined channels are not present. The whole slope acts as an indefinitely wide, level-bottomed channel.

Sheet erosion in tropical and subtropical savannas is generally recognized as an important process. Many authors have described it. We cite a few examples. Harmse (1963, 1967) describes it of aeolian sands in South Africa, Reynders (1964) found it occurring in New Guinea, Holmes (1955) and Mulcahy (1961) describe the process in general; Webster (1965) correlates soil distribution on the Zambia Plateau, South Central Africa, with the effects of surface-wash. In North America, Hersch (1963) mentions it as an important factor in the soil pattern. Cotton (1961) includes it in his theory of savanna planation.

In many cases sheet erosion is not complete. Part of the detached and transported material may come to rest again on the lower slopes. See e.g. Kirkby (1969 a and 1969 b). The mechanism of the whole process can be described in a simplified way as follows.

The erosive forces are provided by rainwater, which loosens soil particles by its physical impact. Part of the water infiltrates the soil and the rest starts to move as surface runoff along slope, carrying with it individual soil particles. The slope also suffers corrasion by the moving sheet of water plus solid particles, and is eroded. The momentum of this sheet is low at the level summit and increases when it moves along to the steeper part of the convex slope, thus increasing the erosive force. The water picks up particles until the carrying capacity has been reached, but at the same time in each lower section more water is added by rain which increases the carrying capacity. A certain maximum is, however, reached, and lower down the same slope sedimentation may start to intervene in a significant way. Evidently there are forces which tend to increase, but also to decrease the carrying capacity.

This decrease in carrying capacity, and hence the decrease in erosion, is often considered to be the result of the protective effect of scree, which is partly in movement, and increases in thickness downslope (Scheidegger, 1961). This moving scree can be considered to be the dynamic counterpart of the more static concept of erosion pavement or lag deposit, which was discussed earlier. It has the tendency to reduce by friction the speed of overland flow. Also, because this erosion pavement is coarser in texture, the rate of infiltration is higher, and the resulting loss of water causes a decrease in the carrying capacity and the erosive force.

The decrease in erosive force may be very gradual, and the convex and straight slope facets, where the effect of sedimentation is small, may therefore be fairly long. The effect of sedimentation becomes most noticeable on the lower, concave slope facet, although even here erosion may dominate sedimentation. See section 5.2.1. A slope, where erosion is dominant in the upper part and sedimentation in the lower, is divided by Holmes (1955) in the convex 'derivation slope' and the concave 'wash slope'.

5.3.2 Sheet Erosion in the Llanos

Areas in the Llanos Orientales where sheet erosion is active on convex-concave associations of slope facets include the better drained parts of the Alluvial Overflow Plain and the Aeolian Plain, and the High Plains.

In the Alluvial Overflow Plain we find the convex-concave succession on the natural levees and the adjoining part of the slackwater areas, as described in sections 3.2.3 and 4.2. This slope association occupies narrow bands in the landscape, and the interplay between sheet erosion and sedimentation occurs, therefore, within a short distance, usually not exceeding hundred meters.

The Aeolian Plain, described in sections 3.2.4 and 4.3, has a convex-concave slope association in the complex of longitudinal dunes. However, the high infiltration rate of the dune sand very much reduces sheet erosion, and the typical interplay between erosion and sedimentation is not very well expressed. The land form of the dunes must rather be considered to be the result of the typical aeolian sedimentation pattern. A part of the Aeolian Plain, where convex slopes associated with sheet erosion are found, is soil association Er (see Fig. 22), occurring along newly formed erosion channels. The concave slope element is largely absent, because the local erosion base is so low that most of the detached material is completely removed from the surface.

In the High Plains the convex-concave slope association is found predominantly in the combination of the two soil associations Aa and Ae of the level, well drained High Plains and the esteros traversing the area. The landscape and typical soil series have been described in sections 3.2.6 and 4.4.

The High Plains have been selected for more detailed discussion because the succession of erosion and sedimentation, as expressed in the resulting convex-concave slope association, is complete along fairly long slopes (often more than one kilometer). In section 4.4.1 the toposequences of soil series from the level, well drained High Plains to the esteros have been described. In Figure 26 two typical cross sections, representative of the southern and northern part respectively, have been presented.

Table 25 combines textural data from the two toposequences Horizontes-Nápoles-Carimagua, and Lagunazo-Nápoles-Carimagua. The typical profiles do not belong to the same individual slope, but display the same sequence as recognized in the FAO report (1965), viz. fine clayey/fine silty - coarse loamy - fine silty.

Soil series	A-Horizon				B2-Horizon			
	% clay	% silt	% sand	% org. C	% clay	% silt	% sand	% org. C
HORIZONTES, on nearly level, convex summit	49	34	17	2.2	61	26	13	0.7
LAGUNAZO, on nearly level, convex summit	31	59	10	1.1	34	57	9	0.5
NAPOLES, on straight to concave lower slope	9	12	79	0.5	13	16	71	0.2
CARIMAGUA, on nearly level, concave estero	34	55	11	6.5	27	57	16	0.3

Table 25 Textures in typical profiles of the convex slope associations in the level, well drained High Plains. (figures are adjusted for thickness of sub-horizons)

As has been explained in Section 4.4, the soil series Horizontes and Lagunazo have been developed in the Llanos loess; the textural differences between the two reflect the regional variations in this parent material. Soil series Nâpoles has been developed in wash material derived from soil series Horizontes and Lagunazo. Soil series Carimagua has been developed in colluvial sediments of the esteros. The variations in the figures suggest that a considerable portion of the clay particles has been removed from the area of the toposequences. If deposition of clay particles were complete in the esteros, one might expect a much higher clay percentage in soil series Carimagua.

Both toposequences are convex-concave in form, and the very gently sloping, convex summits change gradually into very gently sloping, straight and concave slopes. The straight part of the slope is in fact not absolutely straight, but is more a very gradual transition from convex to concave, and it is very difficult to indicate the precise position of the inflection. Correspondingly, the change from dominant erosion to dominant sedimentation is very gradual.

There are some factors which might have contributed to the coarser texture of soil series Nâpoles.

These are: 1. original distribution of parent material;

2. influence of ants

Sub 1. In section 3.2.6 the High Plains are described as being composed of alluvial sediments covered with a layer, several meters thick, of Llanos loess. It is not known whether the deposition of loess took place before or after the uplifted alluvial formation of the Pleistocene had been eroded into more or less the present relief configuration. If the loess was deposited before the present relief had developed, the subsequent erosion would have removed the loess layer from the zones where at present the esteros and lower slopes are found. In that case the parent material of soil series Nâpoles might have been partly of alluvial origin.

Sub 2. The influence of ants is easily demonstrated. Figure 33 shows an oblique aerial view of the toposequence Horizontes-Nâpoles-Carimagua. On the nearly level and gentle slopes where soil series Horizontes and Nâpoles occur, many anthills are found. On the photograph, each of these anthills is visible because of the wash-tail of light colour attached to it at its lower end. The wash-tails are sediments of fine sand derived from sheet erosion. They are more pronounced on the gentle slopes where soil series Nâpoles occurs, than on the nearly level slopes where soil series Horizontes occurs. This is an indication that the effect of selective erosion is greater on soil series Nâpoles than on Horizontes. The total pattern of wash-tails illustrates nicely the direction of sheet erosion. Mac-Fadyen (1950), Glover et al. (1964) and Hagenzieker (1964) report similar wash-tails in Africa, and the first author calls them 'termitaria peppering', because he found them associated with termite mounds. In analogy with this terminology we could call the feature of Figure 33 'formicaria peppering', but the term 'wash-tail', whether connected with termitaria or formicaria is more explicative about the origin of the phenomenon.

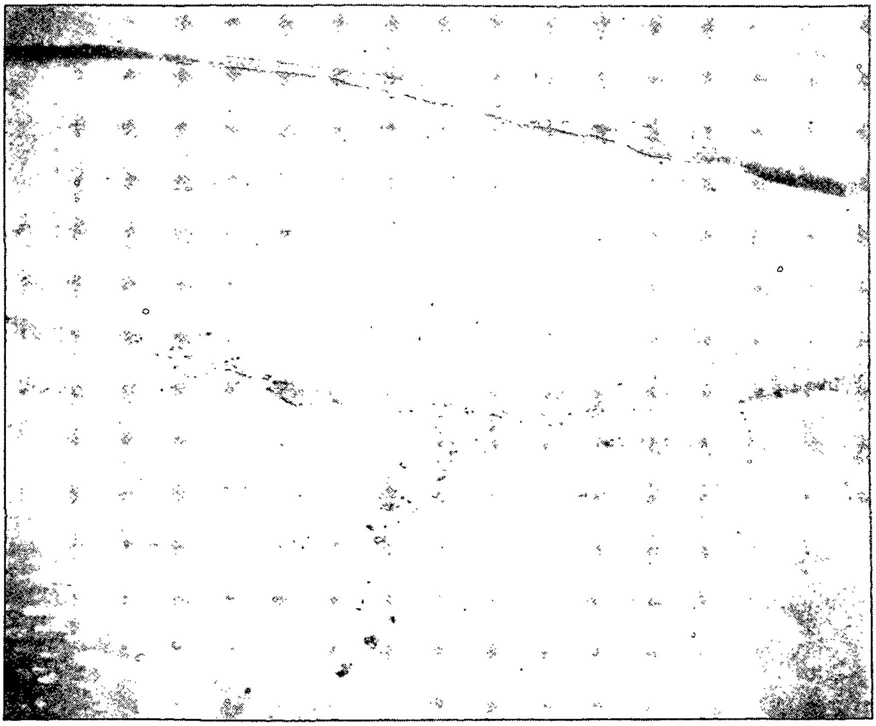


Fig. 33 Oblique aerial photograph of the level, well drained High Plains. In the 'esteros' the vegetation consists of clusters of palms, and gallery forest. The savannas have a grass vegetation. The white spots, especially visible in the lower left-hand corner, are sedimentary wash-tails at the lower end of anthills. (photograph by John Blydenstein)

The activity of ants and termites is enormous. Cf. Nye (1955) who studied the action of the soil fauna in Nigeria. They rework the soil, bring soil material to the surface, and in general, play a very active role in what is called 'biological soil homogenization' (Hoeksema, 1953). One of the effects, when selective erosion acts on the surface, is that the finer particles are washed out from the freshly exposed subsoil material, and with time the whole profile down to the depth of the ants' activity becomes lighter in texture. It is obvious that this process should be taken into account when discussing whether a deep light-textured material is depository or residual. Churchward (1963b), in studying Australian soils, came to the conclusion that homogenization through biotic agencies occurred in the initial phase of profile formation. It is likely that in the Llanos the activity of ants is greater now than in the initial phase of soil formation. The replacement of forest by savanna through human influence, and especially the yearly burning of the savannas, has destroyed and is still destroying many of the natural enemies of the ants, while the ant colonies are relatively little affected. This disturbance of the biological equilibrium results in an explosion of the ant population. It is hard to find a single square meter free of ants.

The foregoing description of the processes of erosion and sedimentation, occurring in the toposequence Horizontes-Nápoles-Carimagua, is equally applicable to the toposequence Lagunazo-Nápoles-Carimagua, typical of the northern part of the level, well drained High Plains, and sketched in Figure 26b. However, in addition to sheet erosion, some rill erosion has also occurred in this toposequence. In section 3.2.6 the pattern of fossil rill erosion on the High Plains has already been described, and illustrated in Figure 19. It should once again be pointed out, that the two toposequences and the associated erosion phenomena have no sharp boundary between them. The transition is very gradual and takes place in a zone several tens of kilometers long.

5.3.3 Soil Properties Related to Sheet Erosion

The fact that sheet erosion is an active process on the very gentle slopes of the two described toposequences, indicates that the resistance of the soil is low in relation to the erosive forces. The individual detachment and transport of particles, occurring in all types of surface erosion, is to a large extent dependent on cohesion, rather than on friction, as has been discussed in the last paragraphs of section 5.2.2. It is therefore of interest to consider those properties of the surface horizons from the upper-slope soil series Horizontes and Lagunazo, which influence the cohesion.

In Table 26 such properties are listed, as derived from the descriptions and determinations presented in section 4.4.3.

In view of what has been said in section 5.2.2 about the significance of the soil properties in terms of cohesion, several of the data in Table 26 are in accordance with a low cohesion in both soils.

	HORIZONTES	LAGUNAZO
Texture	clay	silty clay loam
% clay	47	29
% silt	35	60
% sand	18	11
Predominant minerals (for details see tables 14.15 and 19)	quartz, kaolinite	quartz, kaolinite
Type of sediment	Llanos loess	Llanos loess
Cation exchange capacity in meq/100 g. soil	17	10
Base saturation, in %	5	4
Organic carbon, in %	2.7	1.7
Free iron oxide, in %	2.5	2.3
SiO_2/Al_2O_3 in clay	2	2
SiO_2/Fe_2O_3 in clay	9	9
Moisture content, air-dry basis	3.1	1.9
Water retention at 15-bar	16.5	11.5
Structure	weak fine blocky	weak crumby
dry	hard	hard
moist	friable	friable
Pores	abundant	abundant
PH	4.4	4.6
Plastic Limit	25	21
Liquid Limit	44	34
Plasticity Index	19	13
Liquidity Index (30-70 % water)	0.3 - 2.4	0.7 - 3.8
Flocculation Index	61	99
"Modified" Dispersion Ratio	1.0	1.0
Activity Ratio	0.4	0.5

Table 26 Properties of surface horizons from soil series Horizontes and Lagunazo, related to cohesion.

Although the difference in clay content is considerable, it is highly questionable whether the higher clay content of soil series Horizontes would correspond to a higher cohesion; most of the clay is kaolinite. The differences in moisture content and water retention are directly proportional to the difference in clay content, and the Activity Ratio of the clay from soil series Horizontes is even slightly lower than that from soil series Lagunazo.

There are, however, some properties indicating that the cohesion of the soils in undisturbed state never reaches extremely low values. The organic matter content is fairly high, and certainly, to some extent, contributes to the cohesion. The degree in which the organic matter contributes to cohesion depends on its character which has not been investigated. It is quite possible that the stabilizing function of a considerable part of the organic matter at present is rather low in view of what has been said about the change in vegetation from forest to grass and the resultant changes in other state factors (section 4.1). The Flocculation Index is especially high in the surface horizon of soil series Lagunazo. This indicates, that the clay particles are not readily detached from the structural aggregates. Presumably the binding forces are mainly supplied by the organic matter and the iron and aluminum oxides.

Cementation between particles also depends on the number of particles present, and therefore, on the specific surface area of the minerals (Fripiat, 1965). The difference in texture is in this respect highly significant: Horizontes has 47 % clay, while Lagunazo has only 29 %. This means that per unit of weight, the specific surface area is higher in Horizontes than in Lagunazo. In order to have the same degree of cohesion. Horizontes should have a higher content of organic matter and of sesquioxides than Lagunazo, This is not the case, and that might explain why the Flocculation Index of Horizontes is appreciably lower than that of Lagunazo.

The 'Modified' Dispersion Ratio has been determined after destruction of organic matter. The effect of this last operation has apparently been that the cohesion due to sesquioxides has also been destroyed, as shown by the maximum values of 1.0 for the 'Modified' Dispersion Ratio. This illustrates that the structural stability of aggregates of both soils is easily destroyed, in other words, that the strength of the soil has a very brittle character.

In summarizing the above considerations, we may state that the soil properties point to a low cohesion, and that any cohesion present is mainly due to the cementing effect of organic matter and sesquioxides. The cohesion is higher in soil series Lagunazo than in soil series Horizontes, but is easily destroyed in both soils.

The relation of these findings to the type of erosion observed in the field can now be indicated as follows.

The surface of soil series Horizontes is subject to uniform sheet erosion. The irregularities found in the form of wash-tails (see Fig. 33) are not due to differences in erosion, but to differences in deposition, as explained in section 5.3.2. The regularity of sheet erosion indicates that detachment of particles occurs as the immediate effect of the impact of rain. The cohesion is evidently so low that single raindrops are able to destroy it. The bonds of organic matter and sesquioxides appear to be very weak under the influence of rain.

It is difficult to decide whether most of the detachment occurs as the direct result of the physical impact of raindrops, or as the result of crumb explosion as discussed in section 5.2.2. There is no reason to exclude any of the two manners of detachment from our considerations, but further field investigations would be needed to establish their relative importance.

The type of erosion occurring on the surface of soil series Lagunazo differs slightly from that found on soil series Horizontes. Soil series Lagunazo, in addition to sheet erosion, has suffered some rill erosion, as described in sections 3.2.6 and 5.3.2. Figure 19 illustrates this clearly.

The rill erosion is not active at present; on the aerial photograph of Fig. 19 the rills are very conspicuous, but in the field they are much less so. They do not have distinct edges, and are very shallow, being partly filled in with local surface wash.

No explanation based on soil properties is offered here to account for the fact that rill erosion has occurred in the past more where soil series Lagunazo is found, than where soil series Horizontes occurs. The properties of the two soil series Horizontes and Lagunazo, discussed in Section 4.4, give no unequivocal indication how this difference in behaviour with regard to erosion could be explained. From Table 22 it can be seen that clay dispersion in water is much higher in soil series Horizontes than in Lagunazo. This difference presumably has some influence upon the behaviour of the two soils with regard to erosive forces. However, after destruction of organic matter the clay dispersion is higher in soil series Lagunazo. Compare Table 22 with Table 14. This shows that the clay bonds in soil series Lagunazo are easily destroyed. This is furthermore indicated by the Plasticity Index, which is lower in soil series Lagunazo than in soil series Horizontes, and by the Liquidity Index which is higher in the Lagunazo soil series.

It is also possible that the vegetation in the past is partly responsible for the difference in erosion. As a hypothesis it is possible to assume that the forest vegetation in the less accessible areas in the North-East (where soil series Lagunazo is typical) was destroyed later than in the South-West of the level, well drained High Plains.

5.4 GULLY EROSION

5.4.1 General

Gully erosion has been defined as "the erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depth, ranging from 1 or 2 feet to as much as 75 to 100 feet". A definition of gully, cited from the same source (Soil Sc. Soc. Am., 1965) is as follows: "A channel resulting from erosion and caused by the intermittent flow of water usually during and immediately following heavy rains. Deep enough to interfere with, and not be be obliterated by, normal tillage operations".

It may be noted from the above definitions, that gully erosion is not defined as belonging exclusively to accelerated soil erosion, although it is implied that the process acts fairly rapidly.

When gullies are formed, they usually have sharply delineated edges and steep sides. Lueder (1959) states that the cross sections of gullies developed in all materials, except those having no cohesion, should have vertical to near vertical sides, provided that the critical heights of the eroding materials are not exceeded. The critical heights are estimated by Lueder (1959) for various soil materials as ranging from 0 in clean dry sands to 300 feet in cemented soil materials. The variation is large and depends upon the cohesion and friction of the material.

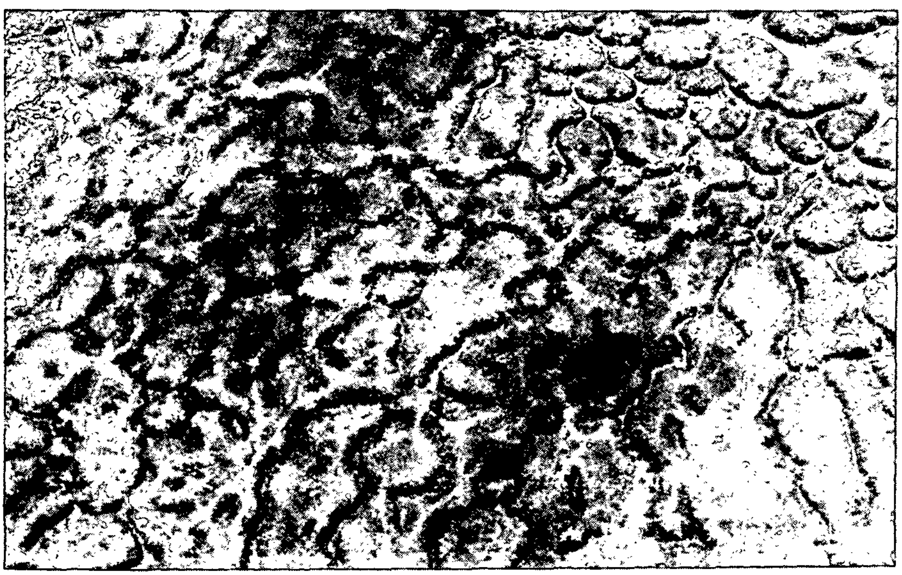
In nature, the vertical sides of gullies are often modified by additional erosion processes. Lateral sheet-wash may round off the sharp edges and lessen the slope of the gully wall, side slippage may occur due to lateral seepage, and temperature-moisture changes may cause swelling and shrinking, resulting in a gradual decrease of slope. In these processes the distribution of rainfall, the vegetative cover of the soil, and other external factors, play a role. It is therefore difficult to establish a universally applicable system of classification of gully form.

Literature on gully erosion in level to nearly level tropical savannas is scarce. In section 5.4.4 a review will be presented of descriptions of phenomena, which might be or are related to gully erosion on nearly level terrain.

5.4.2. Reticular Gully Erosion in the Llanos

Large parts of the Alluvial Overflow Plain are affected by a special form of gully erosion, for which the name 'reticular gully erosion' has been proposed in section 3.2.3. The terrain where it occurs is called locally 'Zural'. The photograph of Figure 13 gives an idea of where this phenomena is found in the landscape. The photographs of Fig. 34 show some more details.

The pattern of reticular gully erosion appears as an intricate network of small natural drainage channels. In their typical form the channels are nearly rectangular in cross section. They are from 50 to 250 cm wide and from 50 to 200 cm deep. The deepest channels are found in the forest of Arauca; a person standing in a channel is completely hidden from view (García, 1963). The surface of the mounds between channels represents the original land surface.



a) Nearly vertical aerial photograph taken from a heigth of 50 m, showing detail of reticular gully erosion in the Alluvial Overflow Plain. Gullies are about 1 m wide and 1 m deep. Direction of drainage is towards the upper right-hand corner, where the erosion pattern is more intense and only rounded mounds remain. Some gullies are partly closed through slumping of the banks.

In Figure 34a it can be seen that some channels do not have a connection with the general system. Investigation in the terrain reveals that such sections are cut off and closed as the result of slumping of the walls, and that the activity of earthworms in some cases aids in the filling of such narrowed sections.

The reticular gully erosion is most characteristic for the subrecent alluvial sediments of the Alluvial Overflow Plain. It is, however, also found in the Aeolian Plain and in the High Plains although in a much less developed state. There, the gullies are less deep, and it is more appropriate to speak of reticular rill erosion. An example of the latter can be seen on the level divides of Figure 19. Some of the lower Alluvial Terraces also show reticular erosion.

In the Alluvial Overflow Plain reticular gully erosion sometimes starts to develop on the borders of the slackwater areas near the natural levees. The upper part has a wavy pattern, gradually changing to reticular. The center of the slackwater area serves as the local erosion base and determines the depth to which the channels are excavated. The loose material accumulating in the lower parts of the

b) Aspect of reticular gully erosion as seen in the field.
(photograph by John Blydenstein)

Fig. 34 Reticular gully erosion in the Alluvial Overflow Plain slackwater areas during the wet season is to a certain extent removed during the dry season by wind action.

Often, however, the slackwater area itself is drained by some channel, and then the bottom of that channel will act as the erosion base. In such a case the whole slackwater area may become affected by reticular gully erosion. The erosion sometimes also encroaches upon the system of splays and natural levees by regression. Independent from this it also develops in the abandoned river beds. In this way the network of gullies sometimes completely covers all the elements of the landscape of the Alluvial Overflow Plain.

In general terms more than 90 % of the extension of reticular gully erosion is found in the slackwater areas. Although it is usually difficult to see the fine pattern of gullies on aerial photographs at a scale of 1 : 40,000, in certain cases it can be identified. An example of this, showing an advanced state of the erosion, is shown in Fig. 35, drawn from an aerial photograph. The newly developing erosion channels are quite typical of the Alluvial Overflow Plain, especially towards the east. The channels connect the slackwater areas and sometimes cut through natural levees, whereby in several cases they follow for a certain length the abandoned river beds. Several parts of the slackwater areas have been eroded completely to the bottom of the channels. The surface of these eroded parts is flat.

5.4.3 Soil Properties Related to Reticular Gully Erosion

The reticular gully erosion, as described, starts with attacking the surface and proceeds downwards into the subsoil horizons. Although in some cases the gully walls are unstable, and the soil material of the remaining mounds slumps down, as mentioned in section 5.4.2, the general behaviour of the soil mass is as a solid, from which individual particles are detached. Soil series Corocora has been described in section 4.3.3 as one of the typical soil series of the slackwater areas. The properties of this soil series will be discussed to illustrate their relationship to the erosion process.

In table 27 such properties are summarized for the surface horizon and for two subsoil horizons combined. Unfortunately no data are available on other physical properties, such as Atterberg values and dispersion.

The texture in the surface horizon shows a high content of silt and clay. The horizons starting at 42 cm depth have a less sorted texture, and are clearly derived from alluvial material belonging to an earlier phase of sedimentation.

The mineralogy of the slackwater area soils is predominantly as indicated for soil series Corocora. Based on the analysis of a number of other samples from soils of slackwater areas, of which no detailed profile descriptions are available, a few additional remarks may be made. Luna (1962) found that the sand fractions from soils in the Alluvial Overflow Plain were mainly composed of irregularly formed quartz, with occasionally rounded forms. Sometimes feldspar was present in minute quantities. For the same samples Marín and Villegas (1962) found by X-ray analysis of the clay fractions, that kaolinite was the dominant clay mineral, while in most samples, a trace of non-expansible bentonite was found. In evaluating the combined influence of texture and mineralogy, only qualitative judgements can be made.

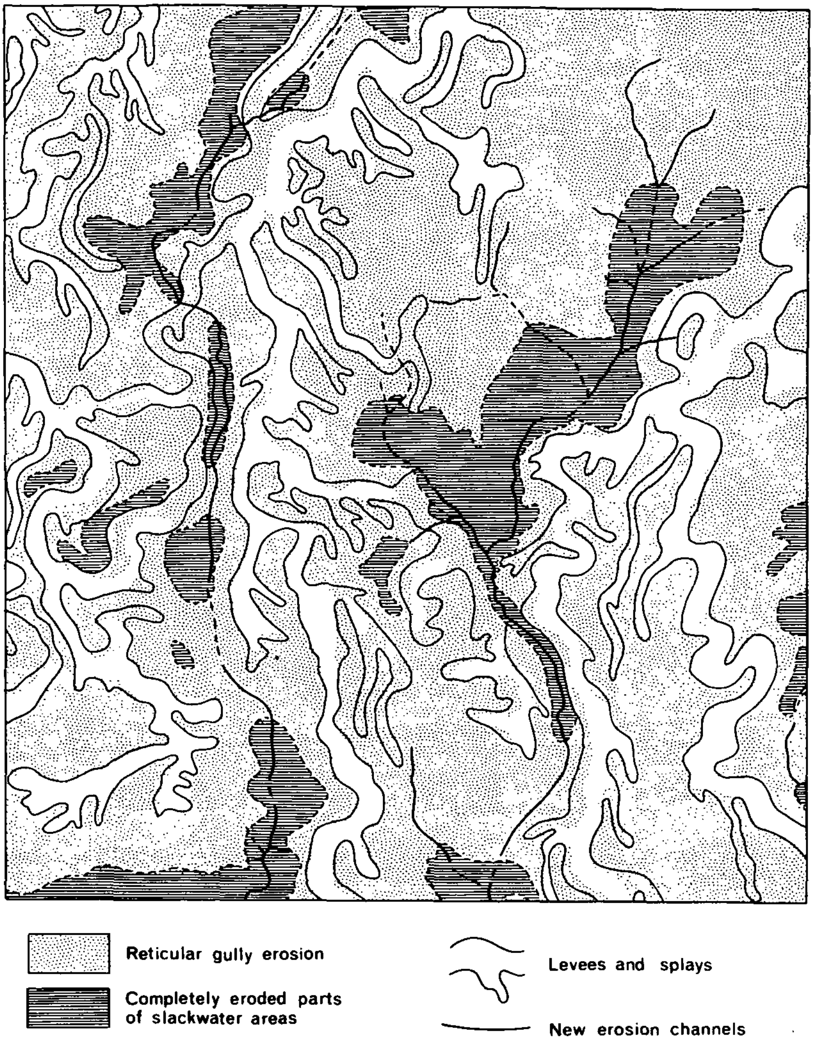


Fig. 35 Map, showing the extension of reticular gully erosion in a part of the Alluvial Overflow Plain, as drawn from an aerial photograph. Approx. scale 1 : 45,000.
The thin lines enclose the pattern of natural levees and splays, the thick lines represent new erosion channels traversing the slackwater areas.
The dot pattern indicates where reticular gully erosion occurs. It can be seen that many splays are completely affected, while the erosion also encroaches upon the natural levees.
The horizontal shading indicates completely eroded parts of the slackwater areas.

	COROCORA 0-10 cm	COROCORA 42-100 cm
Texture	clay	loam to clay loam
% clay	53	26 - 34
% silt	39	43 - 38
% sand	8	31 - 28
Predominant minerals	quartz, kaolinite	quartz, kaolinite
Type of sediment	alluvium	alluvium
Cation exchange capacity in meq/100 g soil	27.5	5.8 - 9.4
Base saturation, in %	33	47 - 80
Organic carbon, in %	2.2	0.1 - 0.1
Free iron oxide, in %	1.2	0.8 - 2.6
Moisture content, air dry basis	5.0	1.5 - 2.4
Structure	massive angular prismatic	massive
dry	very hard	very hard - firm
moist	plastic and slightly sticky	sticky and plastic
Pores	common	few
Cracks	vertical 1 to 2 cm. wide	none

Table 27 Properties related to cohesion and friction of surface and subsoil horizons from soil series Corocora.

The cohesion of the surface horizon in this respect is thought to be larger than of the subsoil horizons, while the friction has the reverse tendency. The cation exchange capacity is not very high nor very low in the surface horizon. In the subsoil it drops to very low values. The organic carbon content in the surface horizon is fairly high.

In correlating the properties discussed above with the process of reticular gully erosion as observed, the following explanation may be presented. Sheet erosion on the surface of soil series Corocora does not occur, or occurs only to a negligible degree. Evidently the cohesion of the surface horizon is too high to allow detachment of individual particles from the surface. Only between the tufts of grass or between trees and along the cracks there is sufficient erosive force present in the accumulated and slowly moving rainwater to detach particles and to cut downward. It is through the interplay of the following factors that a reticular pattern evolves:

a. Prismatic structure of surface horizon;
b. Nearly level relief
c. Cohesion not too weak, which would cause sheet erosion, nor too strong which would prevent gully erosion
d. Vegetation pattern of tufts of grass, or trees.

It is observed that reticular gully erosion also forms on lighter textured soils of splays and natural levees. Evidently also there the water must be concentrated before being able to cut down along lines of low resistance against erosion. In this case the soils do not have a prismatic structure, nor do cracks develop in the dry season.

The differences in soil properties with regard to resistance against erosion have not been further investigated in the Alluvial Overflow Plain. It is, however, evident that the same process of concentrated run-off cutting down may be active in a number of different soils under similar conditions of relief.

In the case of soil series Corocora the erosion, proceeding downward into the soil, soon reaches horizons with a lower cohesion than that of the surface horizon. Therefore, once the reticular gully erosion has started, it easily cuts downward and will continue until equilibrium has been attained between the gradient of any particular point at the gully bottoms and the local base of erosion, and the carrying capacity of the water running along in the gullies.

The nearly vertical walls of the gullies developing in the prismatic structure of the surface horizons, are of interest with regard to friction and cohesion. Other conditions being equal, friction of unsorted alluvial material is relatively high compared to that of aeolian material. The rather dense packing, as implied by the structure, contributes to the friction, and the observed angularity in the sand fraction provides a certain interlocking effect. Movement of particles with respect to one another is not easy under these circumstances and the behaviour of the whole soil mass in this respect is as a solid. The detachment of individual particles from this solid mass readily occurs when erosive forces of water are acting upon the soil mass, but there is still sufficient cohesion to prevent a fall of particles from the gully walls under the influence of gravity alone. Nevertheless, in some cases the walls have collapsed (see section 5.4.2). Evidently the combined influence of cohesion and friction is not always strong enough to retain nearly vertical walls. Undercutting may be an additional process in these cases.

In summarizing the discussion of reticular gully erosion, we may state that the phenomenon occurs in the Alluvial Overflow Plain under conditions of relief, vegetation, soil profile properties and run-off, which together:

a. limit sheet erosion
b. limit infiltration
c. promote surface run-off
d. cause lines of weakness in a reticular pattern
e. are propitious for a vertical deepening of the gullies

The greater surface strength is the reason why erosion attacks only in concentrated form. The cohesion of the subsoil is low enough to get deep gullies, but on the other hand friction is sufficiently high to retain vertical walls.

5.4.4 Comparison of Reticular Gully Erosion with Similar Phenomena

The pattern of gully erosion in the Llanos has been named 'reticular' in this study. It can also be described as 'rounded polygonal'. Polygonal patterns, rounded or angular, have been described in many different parts of the world, under many different conditions of soils and climate. In some cases the polygons are gullies. The following literature review mentions several polygonal patterns often associated with gully formation.

Polygonal patterns are often found under periglacial conditions (Washburn, 1956). Perrin (1962) describes a patterned ground in East Anglia, and notes that on level tracts of land the strictly polygonal pattern dominates, while on adjacent slopes this pattern is deformed into a more linear one. There is no local microrelief, but the lines are filled-up shallow gullies. He attributes the pattern to former periglacial disturbance. Svensson (1963) has studied tundra polygons in Northern Norway. He observes frequently-curved lines, and discusses the possibility that running water might have contributed to the formation of the furrows. The periglacial polygonal pattern shows in its initial state, i.e. without any subsequent erosion, sharp corners. Later on erosion presumably may concentrate in and follow the pre-existing and dominating boundary lines of polygons as caused in one way or another by the periglacial conditions. Sager (1951) describes several phenomena of permanently frozen ground, and explains certain features as the result of erosion of polygonal patterns in the path of local drainage.

On many basalt plateaus in the United States a so-called 'snake-skin' or 'pimple mound' pattern is found. They are described by Ray (1960) and Malde (1964), and are found in the states of Washington, Idaho, Oregon and New Mexico. Pimple mounds are rounded and oblong mounds with convex-concave sloping sides. Their height averages 2 to 3 feet, and the diameter may vary from a few feet to over 20 feet. The authors do not describe the soil of the mounds; they only mention that the soils are fine textured. Ray (1960) finds a polygonal pattern in the pimple mounds on level terrain, while on gentle slopes a more linear pattern is found. Malde (1964) thinks that the pattern has developed under former periglacial conditions.

Pimple mounds are also found on silty or sandy terrain in Louisiana and Texas, according to Bernard and Leblanc (1965). They state that "pimple mounds are very low (6 in. to over 5 ft. high), circular-shaped (occasionally oblong) mounds varying in diameter from a few feet to over 200 ft". Further on: "The alignment of mounds with the drainage in Texas and Louisiana suggests that most mounds in this area are the product of erosion."

On a nearly level prairie plain in the state of Washington are found the so-called Mima mounds, similar to pimple mounds (Ritchie, 1953). Ritchie attributes them to the erosion of partially thawed ice-wedge polygons.

In discussing 'pimpled ground' in general Thornbury (1965) mentions that several recent observers have been inclined to regard the mounds as erosional features of some sort that, rather than being thought of as a complex system of mounds, might equally well be interpreted as uneroded areas within a complicated network of interconnecting furrows made by some erosional process.

In a coastal area in The Netherlands De Roo (1953) describes a form of reticular gully erosion in clay overlying marine sand. The sand liquefies and flows from below, and small scarps develop in the clay.

The steppe areas of the U.S.S.R. have in several places a microrelief closely resembling that of the pimple mounds of the southern United States. Simakova (1959a) and Sokolov (1967) describe numerous examples, and the latter states that the most widespread occurrence is on loess-like loam or sandy loam with a thickness of more than 5 meters. Nosin (1959) describes systems of communicating flat hollows, and calls this an 'erosion microrelief'.

Level areas with swelling clays in the sub-tropics and tropics often present a microrelief called 'gilgai'. This name is of Australian origin. Hallsworth and Beckman (1969) define it as the generic name for all forms of microrelief for which the soil profile shows a high volume expansion on wetting, that increases markedly with depth. In the Soil Classification of the USA (Soil Survey Staff, 1960) the following definition is given: "A microrelief of clays that have high coefficients of expansion with changes in moisture is called gilgai. Such microrelief consists of either a succession of enclosed micro-basins and micro-knolls in nearly level areas,.... , or of micro-valleys and micro-ridges that run with the slope. The micro-ridges commonly range from a very few inches to 1 to 2 feet. Rarely, they appear to approach 5 or 6 feet".

Gilgai microrelief in the form of depressions and mounds has been described by several authors. We cite a few examples. Hallsworth et al. (1955) describe the typical occurrence of gilgai in Australia. Churchward and Flint (1956) mention that typical gilgai relief in Australia has a microtopography of soils with clay on the mounds and loam in the depressions, but that in some cases these textures occur in reverse order. Hallsworth (1968) presents a detailed classification of gilgai forms in Australia.

In the Middle East, gilgai relief is found in many fine textured soils of alluvial areas. Harris (1958, 1959) describes it for Iraq, and states that in gilgai profiles a badly structured horizon is invariably present. Buringh (1960b) also studied gilgai in Iraq. He found it often associated with saline-alkali or alkali soils; the clay in gilgai gullies is dispersed in the wet season. In a study of the Mesopotamian flood plain, Al Rawi et al. (1968) came to the following conclusion: "The surface run-off from adjacent higher situated lands follows the micro-valleys in the gilgai depressions and erodes them gradually to larger gullies".

In Africa gilgai microrelief occurs in several countries. Blokhuis (1963) describes it for Sudan, Hagenzieker (1964) for Ghana and Stephen et al. (1956) for Kenya.

In South America gilgai is also reported to exist on dark coloured clays of level plains, as e.g. Venezuela (Avilân et al., 1960) and Colombia (Reese and Goosen, 1958). The gilgai pattern is called 'bomba' in Venezuela (Comerma, pers. comm., 1965). Lopez Taborda (1967) mentions a microrelief of mounds and depressions, called 'campos de tacuruses', in Uruguay. In the bibliography of a general review on tropical dark clay soils (Dudal, 1965) many references to gilgai can be found. Costin (1956) compares gilgai with frost soils, and is of the opinion that there are similarities in the processes of formation. The same conclusion is reached by Bremer (1965).

It should be pointed out that not in all the cases cited above, reference is made to polygonal gullies and mounds. Erosion gullies may not develop in several cases.

In level areas with non-swelling soils of the tropics a reticular microrelief is very often found, resembling the microrelief of reticular gully erosion and that of pimple mounds. Anou (1950) explains a number of cases as the result of biological activity of earthworms and insects. Similar explanations are given by Beadle (1957), Troll (1936) and Wasawo and Visser (1959). The present author found in the Llanos Orientales of Colombia certain areas with a mound topography, where the mounds were built by termites, ants, or earthworms, each species building a mound of specific form. Such cases are therefore constructional forms, the mounds being erected above the original surface of the land. Even then such a constructional microrelief could easily lead to reticular gully erosion in the lower parts.

Constructional forms may very well be widespread, but the main topic of this section is destructional microrelief in various forms of reticular patterns. Mound and channel topography in level tropical areas with non-swelling soils is reported by Beard (1953) for northern tropical America. He calls it 'hog-wallowed surface'. Van der Eyk (1957) found a similar pattern in Surinam, where it is called 'kawfoetoes'. These authors do not explain the origin of the pattern. Madero (pers. comm., 1966) mentions a mound and channel topography in Venezuela, called 'tatucos', similar to the 'zurales' in Colombia. In his opinion this microrelief is the result of erosion. Sombroek (1966) shows a photo of so-called 'canaletes' in the Amazon forest, but does not explain their origin. Day (1959) believes that the canaletes are the product of erosion. Ojany (1968) describes a mound topography in Kenya, and suggests that the hummocky relief is derived from the original relief of old lava mudflows.
In Barotseland, Zambia, large level areas are found with a microrelief similar to the pimple mounds of Texas (Eggeling, 1966). The parent material of the poorly developed soils is fine aeolian sand and silt.

The polygonal patterns described in the foregoing, although occurring in very different areas with different soils and climates, have a few things in common. They usually occur on level terrain, and, where adjoining land has a somewhat greater slope, the associated pattern becomes more linear. The climate usually has marked seasonal fluctuations in either rainfall or temperature. The subsoil usually allows little inflitration. This may be due to permafrost, to a bad structure, to a heavy texture, to a high groundwater table, or to a combination of some of these features.

The investigations of several authors cited above indicate that in many cases the polygonal pattern is associated with gully erosion along the lines of the pattern. These lines are then lines of weakness, lines of least resistance to erosion. The character of these lines may be determined by alternate freezing and thawing, by rock structure such as hexagonal basalt, by the cracking of vertisols, by the pattern of vegetation, or by a chance combination of some of these causes.

There are some cases where sheet erosion is to a certain extent associated with gully erosion. This is most notable in the pimple mounds of the western and southern United States. The gullies in this case have gently sloping walls, and the mounds are gently convex-concave.

Reticular gully erosion has not developed in all the cases described. Often a polygonal pattern exists without it. Some of the polygonal frost patterns described by Svensson (1963) do not have gullies. Also the gilgai pattern may be devoid of gullies. See e.g. Hallsworth and Beckman (1969), and Reese and Goosen (1958). In these and other cases, the erosive forces of the surface run-off are presumably not strong enough, compared to the soil strength, to cause erosion. Therefore, we should clearly distinguish between the different processes which may cause a polygonal pattern to appear, and the reticular gully erosion which may or may not be associated with this polygonal pattern.

Summarizing, there are a number of different processes which originate polygonal patterns in soils. The polygon boundaries may represent lines of weakness in terms of erosion.
Dependent upon the interaction of relief, vegetation and run-off, and the strength of the soil, erosion may attack along these lines of weakness. When it does, we may speak of reticular gully erosion superimposed upon a pre-existing pattern in the surface soil.

5.5 SOLIFLUCTION

5.5.1 General

Solifluction (literally: soil flow) is the process of flow from higher to lower ground of masses of waste saturated with water. Andersson (1906), who coined the word, stated that it is best visible and most active in 'subglacial' climates.
From the last statement it is sometimes deduced that solifluction is strictly a periglacial process (Büdel, 1959), but this is denied by others. Russell (1964) gives many examples of solifluction from widely different climates and states emphatically that solifluction is not necessarily periglacial. Scheidegger (1961) takes the same position and distinguishes between niveal and aqueous solifluction. Earlier, Schott (1931) showed that solifluction still occurs in warm-temperate climates. Similar observations were published by Bos (1971).

In considering mass movement on slopes, a difference may be made between soil flow and landslide (Terzaghi, 1950). Soil flow involves a plastic deformation of the whole mass of the soil, i.e. the soil acts as a viscous liquid. In landslides the soil breaks up, i.e. it acts at least partly as a solid. Many different froms of both types can be recognized. Solifluction belongs to the soil flow type. With lesser amounts of water solifluction grades into soil creep. The viscosity is in this case higher and the slope must be proportionally greater to induce mass movement.

Sharpe (1960) presents an excellent classification of landslides and related phenomena. Solifluction outside periglacial areas is defined as a usually imperceptibly slow flow of earth or rock plus water. With increasing speed the process changes into what Sharpe calls earthflow and mudflow, the latter having the greatest speed. Speed of flow is a criterium sometimes difficult to apply and this is recognized by Sharpe (l.c.), when he discusses certain post-glacial Alpine deposits, some of which may be the result of mudflow, some of solifluction. We will, therefore, at this point not enter into the problem of speed of movement, and will use the original definition of Andersson (1906).

Solifluction is a particular kind of flow phenomenon, in which the soil, being saturated with water or nearly so, changes from a rigid to a fluid condition. Therefore, solifluction falls under the general theory of rheology, the study of flow phenomena. The principles of rheology applied to the behaviour of soils have been discussed by Pryce-Jones (1934,1948), Freundlich (1935), Freundlich and Röder (1938), and

Boswell (1949, 1961). The kinds of flow phenomena comparable to solifluction are thixotropy and dilatancy. In thixotropy the change from a rigid to a fluid condition is produced at ordinary temperatures by mechanical action. It left to stand, the material sets again to a more rigid condition. In thixotropic systems a certain cohesion is present, which is however easily counterbalanced by destructive forces. The behaviour of yoghurt during and after stirring is a specific example of thixotropy.

If no cohesion is present, the system is called dilatant. In the case of dilatancy the particles, when their arrangement is disturbed by mechanical action, seem to repel one another, and the material remains for a long time in the state of suspension. The forces bringing the particles together in a denser packing, are due only to gravity or similar forces and not to cohesion; it is only the friction through which a certain rigidity is regained.

Dilatancy can easily be imitated at the beach. Patting wet sand near the waterline gently with the toe, causes the sand to become fluid where it was originally solid. However, the action of patting is accompanied by the extrusion of water. This means loss of water from the system, and signifies that the process is not indefinitely repeatable under natural circumstances. The sand grains assume a higher density of packing, and the friction is correspondingly increased.

The study of soil behaviour in natural conditions, as seen in the light of the rheological principles, is an important aspect of soil mechanics. Many authors have contributed to this study. We cite a few: Rosenquist (1953, 1962), White and Pichler (1959), Spangler (1960), Grim (1962), Kerr (1963), Terzaghi and Peck (1967) and Gillott (1968). It appears that in practice the distinction between thixotropy and dilatancy is difficult to make, because of the complex behaviour of the soil. In all cases of soil flow the soil has a high water content and is usually saturated. During the flow water is extruded, the packing becomes denser, and the friction is increased correspondingly. Therefore, the soil mass attains the solid state at a speed proportional to the rate of water extrusion. If this process is quick, the solidification resembles the setting of a thixotropic system, even if no cohesion is present and the system originally was dilatant.

The change from the solid into the liquid state is often called 'liquefaction of soil' or 'spontaneous soil liquefaction' in soil mechanics. The initial structure of the soil is often called 'collapsible structure'. In section 5.2.2 numerous authors have already been cited who discuss these terms.

In order to demonstrate that solifluction may occur on nearly level slopes, its mechanical possibility must first be considered. Penck (1953) and Scheidegger (1961) in their discussions of mass movement do not exclude the possibility of movement on slopes just above 0^o, but do not further elaborate on it. In the theories of Casagrande (1936), Terzaghi (1943), and Terzaghi and Peck (1967), the smallest angle at which a slope is unstable can approach 0^o if the shear strength of the soil is reduced to near zero. This will be the case when both cohesion and friction are at a minimum.

Jungerius (1967) describes solifluction in Canada of slopes less than 2 %. Other recorded examples of mass movement on gentle slopes are given by e.g. Crandell and Varnes (1961), Dury (1959) and Kent (1966). Mass movements on slopes near 0^o are mainly recorded in periglacial lacustrine sediments. Notable examples in Scandinavia and

Canada, are discussed by Jakobson (1952), Rosenquist (1953), Sharpe (1960), Crawford (1961), Kerr and Liebling (1963), and Shreve (1966). The soil transported over nearly level slopes in these cases, has been called 'quick clay' (Kerr, 1963) and it has been shown that several of these mass movements were triggered by some shock, mainly earthquakes, and in some cases by a working pile driver. The soil flow was usually rapid and often had catastrophic consequences for roads and buildings.

The flowage of periglacial lacustrine sediments on nearly level slopes is the result of a combination of factors. These sediments are well sorted, fine-grained, have little or no cohesion, and are situated where climate and relief easily cause water-logging. A permafrost subsoil, if present, aids in the prevention of drainage, but was absent in several of the recorded cases, and is not considered to be a necessary pre-condition for flowage. The theoretical discussion of Kerr (1963) makes this quite clear.

If similar conditions of low cohesion and water saturation are fulfilled elsewhere, similar flows may occur. A recent example is known from Venezuela (Pêrez, personal communication, 1969). An earthquake in northern Venezuela triggered a sudden flow of a lacustrine sediment at the southern coast of Lago de Valencia. The area affected was measured by the author on aerial photographs to be fifty hectares. The distance of movement was rather small; it varied from 20 to 100 meters. The slope of the terrain was less than 1 %.

It appears that in several cases only a certain layer of the subsoil liquefies, while the topsoil remains more or less solid. Casagrande (1936) describes the mechanics of this process as follows: "If a thin fine-grained porous layer underlies or is interbedded with a mass of hard fissured clay, water from rains or melting snows may penetrate down the cracks in the clay, creating hydrostatic pressure there and in the saturated porous layer. Any slight shearing movement within the porous bed may cause a decrease in volume as the result of the rearrangement of the soil particles. The excess water cannot escape sufficiently rapidly and supersaturation results. If the porous stratum slopes toward a river bank, the overlying mass may slide 'as if on roller bearings', or the supersaturated layer itself may flow out allowing the surface material to settle vertically downward. Vibrations from earthquakes or trains, or even the pounding of waves, may cause the initial shear necessary to set off such movement".

This specific case of flowage has the important characteristic that the water in the liquefied layer is under a certain hydrostatic pressure and cannot rapidly escape. The hydrostatic pressure means an increase in the buoyancy of the material. All or part of the normal pressure may be transferred from intergranular to pore pressure. This process very effectively decreases the friction, and movement may be sustained over a relatively long distance.

Russell (1933) discusses similar cases to those treated by Casagrande (1936) and states that liquefaction of subsurface horizons gives a "contest between tensibility of roots and solifluctional movement". Sharpe (1960) describes a case in which the topsoil only partly liquefied. Larger blocks of the topsoil remained stranded as mounds when movement ceased.

The occurrence of hydrostatic pressure is not limited to those cases where only a subsoil horizon liquefies. It may also be present when the whole soil from the surface downward liquefies (Terzaghi and

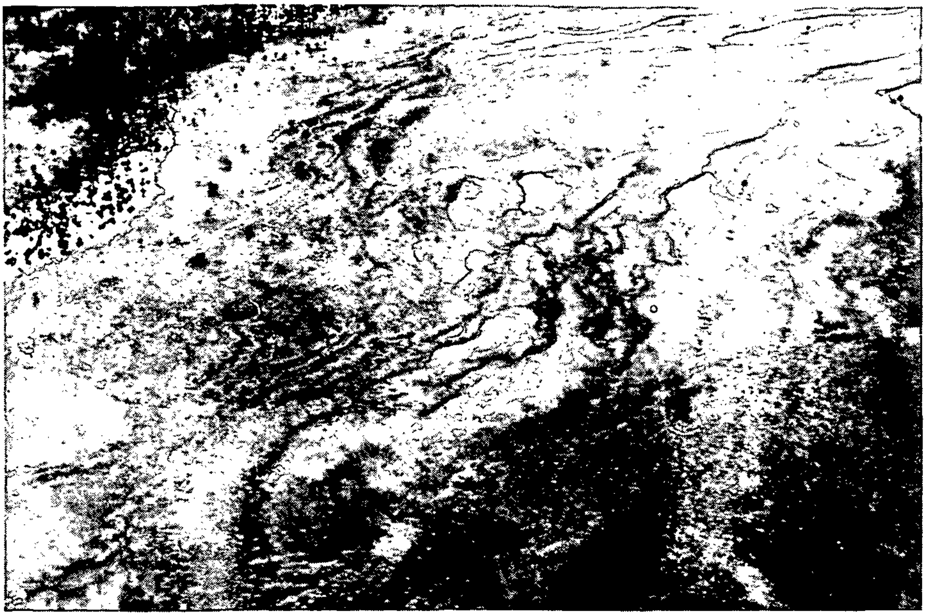
Peck, 1967, and Gillott, 1968). The depth to which liquefaction may affect the soil mass is variable, according to the descriptions. The most common depths range from 0.5 to 10 meters.

The microrelief which results from solifluction often has striking features. When solifluction occurs in periglacial areas on sloping land, parallel stripes in the direction of slope are often formed (Sager, 1951). On gentler slopes, also outside periglacial areas, ridges transverse to the slope are conspicuous features of solifluction. Rettger (1935) did experiments on deformation of soft sediments, and called the transverse features 'drag-folds'. Russell (1944 and 1964) mentions solifluction in Brazil, Martinique and the Mississippi Valley. He calls the microrelief features 'pseudo-anticlines'. Morgan (1951) talks of 'mudlumps' in the Mississippi Delta, Galloway (1961) mentions 'solifluction lobes' in Scotland, Washburn (1956) calls transverse solifluction ridges 'steps', while Butzer (1964) discusses the lobate- or tongue-like configuration of solifluction and calls the transverse undulations 'terracettes'. McElroy (1951) describes 'contour trench formations' on slopes less than 4.5 % in New South Wales and adscribes their origin to solifluction. Cross (1964) discusses flow phenomena in certain soils of Virginia, USA, and talks of subsidence and upheaval, resulting in 'mounds', while Rudberg (1964) mentions 'solifluction lobes' and 'terracettes' in Sweden. The case mentioned from Venezuela (Pérez 1969) also showed small transverse ridges. The similarity with terracettes on hill slopes, as e.g. discussed by Dury (1959), is striking. The differences in terminology are somewhat confusing, but not surprising. The external and internal factors inducive to the formation of transverse undulations may occur in many different quantitative proportions. From the literature it becomes clear that in the observed cases of solifluction undulations are present; these have a tendency to parallel alignment across the slope, when the slope is slight. In other words, the process of solifluction on slight slopes is usually accompanied by a repetitive pattern of ridges transverse to the direction of slope. The speed of movement in this respect is not important. Slow or high speed both produce transverse undulations (Sharpe, 1960). When the slope is greater, transverse ridges are absent, but reappear in the lower, more gently sloping part of the soil mass.

In the following section a certain microrelief of ridges found in the Llanos will be described. Although it is our intention to make it appear plausible that this microrelief has been caused by past solifluction, for the time being we will use the neutral name 'escarceos', as adopted during the FAO soil survey, for the observed ridges.

5.5.2 'Escarceos' in the Llanos

The low ridges called 'escarceos', and briefly mentioned in Chapters 3 and 4, are most typical of the level, poorly drained parts of the Aeolian Plain and the High Plains, where the parent material of the soils is Llanos loess. They have also been observed in a few places in the Alluvial Overflow Plain and in one place on the Alluvial Terraces to the South-East of San Martín. The total area where escarceos are found is estimated at nearly two million hectares.



a) Oblique aerial photograph of an area with escarceos in the wet season. Slope is towards the left where palms mark the estero or drainageway. White patches indicate where surface water collects against the escarceos. Single gray dots are anthills and termite mounds, and often mark the former position of escarceos now partly destroyed by surface wash. (photograph by John Blydenstein)

b) Oblique aerial photograph of escarceos around the head of an estero in the High Plains, taken in the dry season. The forest at the left-hand side is the beginning of the gallery forest marking the estero.

Fig. 36 Some aspects of the escarceos (small ridges) developed in Llanos loess.

Figures 16 and 36 give an overall view of the escarceos, in Figure 37 a map is shown, drawn from aerial photographs of a typical zone with escarceos of the Aeolian Plain. The escarceos are smoothly curved and run more or less parallel to contour lines. They are frequently connected in a manner analogue to a braiding pattern. The dominant soils are (Oxic) Ultic Plinthaquepts and a typical representative is soil series Guanapalo, which is found on the escarceo as well as in between them. See profiles P-26, T-35, and D-11 and D-12 in Appendix II.

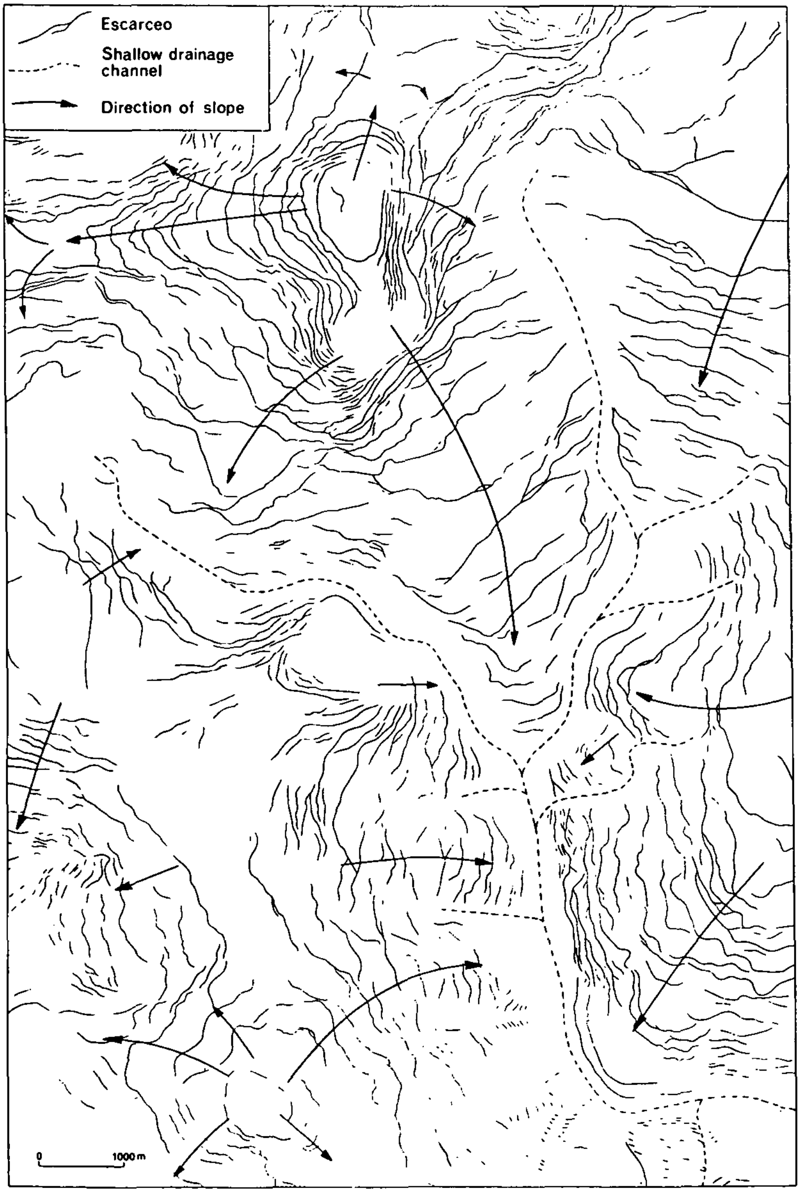


Fig. 37 Map of escarceos North-East of Cravo Norte, near the border between Colombia and Venezuela, in a part of the Aeolian Plain. Drawn from aerial photographs. Approx. scale 1 : 80,000.

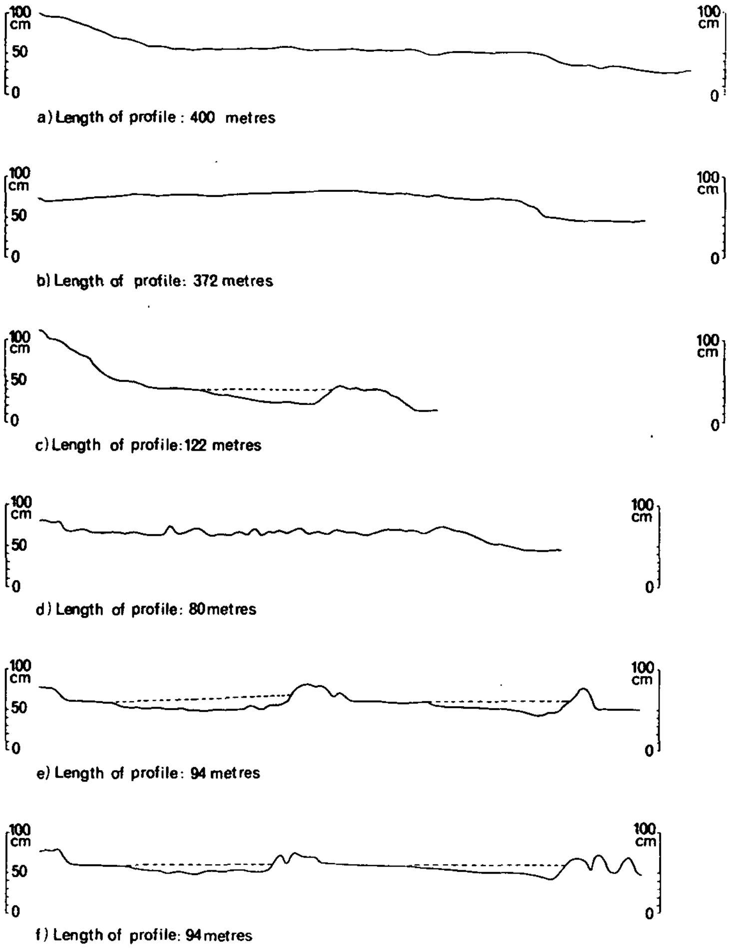


Fig. 38 Cross sections of escarceos. a), b) and c) are from the level, poorly drained High Plains, the others from the Aeolian Plain. Note that the horizontal scale is largest in d), e) and f). The drawings are constructed on the basis of field measurements with a geodetic level, on the average of one measurement per meter length. In all cases the slope of the terrain is towards the right.
The interrupted lines represent approximate reconstructions of the original land surface in areas where lateral surface wash has truncated the soils between the escarceos.
Other irregularities are mainly termite mounds.

Measurements were taken in the field in order to determine the microrelief of the escarceos. The measured profiles are recorded in Figures 38 and 39. The general slope gradients of the profiles in Fig. 38 range from 1 : 350 to 1 : 1,000, with an average of 1 : 750. The escarceos within these slope sections are the smoothly curving undulations, while the small irregularities are mainly termite mounds.

The distance between the escarceos, comparable to wave length, varies considerably from 40 meters in Figure 38e to 250 meters in Figure 38a. In Figure 36b the distance between escarceos is often not more than five to ten meters. In general, this distance is smallest in the Aeolian Plain in the West, and largest in the poorly drained High Plains in the East. These landscapes have, as described in foregoing chapters, the same parent material of Llanos loess, but they differ in some aspects, such as clay content, length of dry season and seasonal drainage conditions. Whether these aspects can be related or not to the differences in the escarceos, is a question which must remain unanswered here.

The profiles show clearly that the escarceos are asymmetrical. Their appearance as narrow ridges in the field and especially on aerial photographs is accentuated by termite activity, by trampling by cattle, and by differences in the vegetation.
These factors are the result of drainage conditions. The convex part of the escarceo is for a shorter time of the year subject to inundation by rain water than the intermediate concave areas. Therefore, termites prefer to establish their living quarters on the convex parts. The concave parts are more sensitive to trampling by cattle, and the upper soil horizon may be destroyed and may disappear by lateral surface wash in the wet season, while in the dry season aeolian removal of the disturbed topsoil possibly takes place.

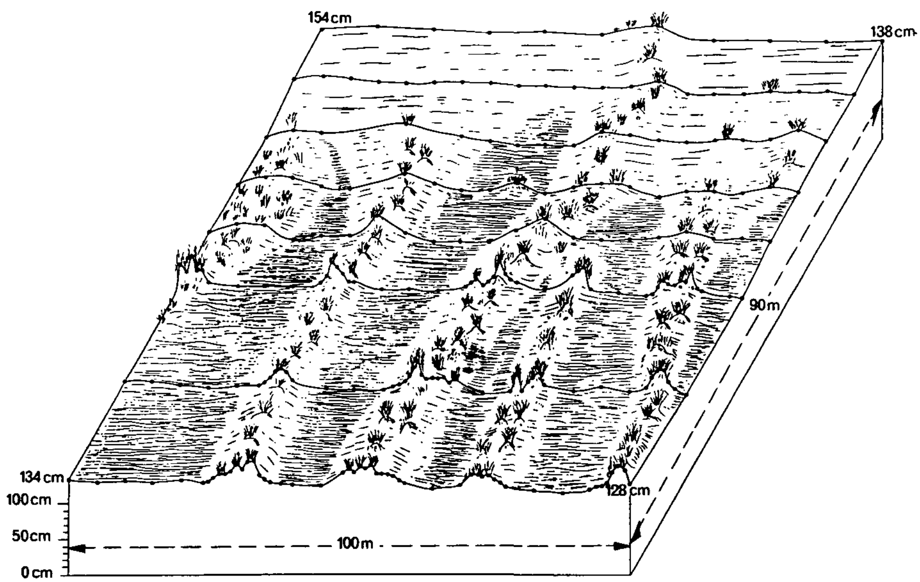


Fig. 39 Isometric block diagram of escarceos in the Aeolian Plain. The drawing is based on field measurements along eight lines. Each black dot indicates where the terrainheight was recorded with a geodetic level. The general terrain slopes towards the right. The area in the background represents a slightly elevated part, where the escarceos are much less pronounced.

In Figure 38c, e and f the soils in the concave areas have been truncated in this manner, and the interrupted lines are an approximate reconstruction of the original relief. The new surface is more irregular because the grass sod is partly destroyed and cattle have left their trampling marks. This process accentuates the microrelief. A similar process is described by Glover (1950) as occurring in Somalia, in fine- to medium-textured soils with easily dispersable clay, where a microrelief similar to escarceos is found. The vegetation difference is sketched in Figure 39. Tall grasses apperently grow by preference on the narrow, convex parts. Table 28 gives the composition of the two savanna types occurring on resp. the convex and the concave part. It is especially the vegetation which, on aerial photographs, enhances the image of escarceos. Figure 40 illustrates how the escarceos look in the field.

Fig. 40 Photograph of escarceos in the vicinity of the area sketched in fig. 39. The low and somewhat curving ridges are accentuated by the tall grasses growing on them.

The microrelief of escarceos transverse to the direction of slope effectively reduces the overland flow. The photograph of Figure 36a was taken in the wet season. White patches represent water accumulating above the escarceos. Although in this particular photograph the escarceos in the foreground are partly destroyed by surface wash, the general pattern of escarceos shows that sheet, rill or gully erosion processes are not dominant.

Site JB 126 August 10, 1963.

Name of species	Frequency % on escarceo	Frequency % in depression
Aristida tincta	1.6	5.5
Axonopus senescens	1.6	-
Bulbostylis junciformis	3.5	-
Caladium macrotites	3.5	-
Dichronema ciliata	1.6	-
Leptocoryphium lanatum	5.0	-
Mesosetum loliiforme	8.5	4.0
Panicum stenodes	-	4.0
Panicum sp.	-	5.5
Paspalum carinatum	22.0	7.5
Paspalum contractum	1.6	-
Paspalum hyalinum	3.5	32.0
Paspalum pectinatum	5.0	-
Paspalum sp.	-	2.0
Rhynchospora barbeta	3.5	9.5
Rhynchospora sp.	-	9.5
Thrasya paspaloides	5.0	-
Trachypogon ligularis	-	11.0
Trachypogon vestitus	24.0	2.0
Xyris savannensis	1.6	-
Bare soil	8.5	7.5

Table 28 Vegetation census on an escarceo and the adjoining depression.
After Blydenstein et al. in FAO report (1965)

5.5.3 Factors Inducive to the Formation of the Escarceos

In order to show that mass movement in the form of solifluction is likely to have caused the escarceos, it should be demonstrated that there are factors in the poorly drained loess areas in the Llanos propitious for this type of mass movement. Such factors can be divided in two groups:

a. soil properties
b. physiographic conditions

The soils have been discussed in Chapter 4. Soil series Guanapalo, an (Oxic) Ultic Plinthaquept, is representative for the poorly drained loess areas of both the Aeolian Plain and the poorly drained, level, High Plains. If this soil has suffered solifluction, then the values for cohesion and friction must have been extremely low during the process, especially in the subsoil horizons.
The largest number of analyses is available from profiles D-11 and D-12. In Table 29 the properties of the subsoil horizons, related to cohesion and friction, are listed. The data are derived from descriptions and tables in section 4.4. The determinations were made on auger samples, but this does not affect the values listed in Table 29.

	GUANAPALO D-11 in depression 55 - 80 cm.	GUANAPALO D-12 on escarceo nearby 60 - 90 cm.
Texture	silt loam	silt loam
% clay	16	25
% silt	69	53
% sand	15	12
Predominant minerals	kaolinite, quartz, illite	kaolinite, quartz, illite
Shape of sand particles	subangular	subangular
Sorting	high	high
Type of sediment	Llanos loess	Llanos loess
Cation exchange capacity, in meq/100 g. soil	3.9	5.6
Base saturation, in %	10	18
Organic carbon, in %	0.3	1.7
Free iron oxide	0.2	0.1
SiO_2/Al_2O_3 in clay	2.9	2.4
SiO_2/Fe_2O_3 in clay	90	79
Moisture content, air-dry basis	0.8	1.6
Water retention at 15-bar	6.7	8.8
Plastic Limit	19	19
Liquid Limit	23	30
Plasticity Index	4	11
Liquidity Index (30 % - 70 % water)	2.8 - 12.8	1.0 - 4.6
Flocculation Index	6	48
"modified" Dispersion Ratio	1.0	1.0
Activity Ratio	0.3	0.44

Table 29 Properties of Subsoil Horizons from Soil Series Guanapalo, Related to Cohesion and Friction.

From the general description of soil series Guanapalo, as given in the FAO report (1965), and from the profiles P-26 and T-35 described in sections 4.3.3 and 4.4.3, the following annotations on the structure can be made.

The subsoil of soil series Guanapalo is in general characterized by a weakly developed, medium to fine subangular blocky structure, often approaching a massive structure. In dry state the structure is somewhat hard, but in moist state it is friable. The consistence is slightly sticky to non-sticky, and slightly plastic. The subsoil has abundant to common large pores, and has many to common fine and medium pores. Dark streaks are usually found within the larger pores. These streaks are supposed to consist of material from the topsoil, having a rather high content of organic matter. This supposition is supported by the analysis of profile D-11 which has 1.7 % organic carbon in the subsoil, against 0.9 % in the topsoil. The low content in the topsoil may be partly due to spontaneous oxidation in the dry season, but is thought to be also partly the result of a rather high dispersion of the organic matter and its consequent eluviation.

The textural composition of the subsoil horizons is in accordance with a low cohesion, especially when considered in combination with the very low values for cation exchange capacity, base saturation, moisture retention and Activity Ratio. The shape and sorting moreover correspond with a low friction. The low Liquid Limits also point to a low friction. The content of iron oxide is extremely low. Given the appreciable amount of quartz identified in the clay fractions, there might be some silification, but the low Flocculation Index, especially in profile D-11, confirms the conclusion that there is hardly any pedocementation in the soil. In profile D-12 the Flocculation Index is higher than in profile D-11; this could be the combined result of the slightly higher content of organic carbon, and the sligthly lower SiO_2/Al_2O_3 ratio in profile D-12.

Similar, and probably related, differences are found in the Plasticity and Liquidity Indices. The differences are relatively small, and the absolute values for these last two Indices are very low and extremely high respectively. The 'Modified' Dispersion Ratio in both profiles reaches the maximum value.

A few remarks should be made on the interpretative use of the structural properties, when considering any past behaviour of the soil. If indeed solifluction has occurred in the areas with poorly drained Llanos loess, then the process of solifluction would have been accompanied by a change in the arrangement of the particles. When soil flows as a viscous liquid, the particles arrange themselves in a denser packing than before the flow. This general feature has been amply described, e.g. by Boswell (1949, 1961), Grim (1949, 1962) and Kerr (1963). Soil series Guanapalo at present has an open packing, but this, strictly speaking, is no argument for or against the possibility of flowage in the past; the soil might have had an even more open packing in its initial state, or the present packing may be the result of a subsequent pedogenetic process, comparable to the 'bioporosity' as defined by Slager (1966).

Of course, a similar reasoning could also be applied to other soil properties. The extremely low content of iron oxide can be explained as the result of lixiviation of iron under conditions of poor drainage, a process which might have taken place after the escarceos had developed. Referring to the statement in section 4.4.2 that soil series Lagunazo and Guanapalo have developed in the same parent material, and referring also to the discussion in that section of the changes in the two soil series, it seems indeed likely that the original Llanos loess did contain more iron than is now found in soil series Guanapalo. The physiographic position and the climatic conditions, however, make it plausible that soil series Guanapalo at any stage of its development was for the larger part of the year in a poorly drained state. See section 3.2.4 and 3.2.6. Under such circumstances pedocementation due to iron oxide is unlikely.

The soil profile properties discussed do not give a single indication which might point to either a high cohesion or a high friction. Rather, all the properties are completely in accordance with the possibility that cohesion and friction can attain extremely low values. Comparison with the literature data of section 5.2.2 leaves no doubt about this point.

With this as a starting point, the physiographic factors are highly significant. The poorly drained loess areas suffer periodically from water saturation. This factor promotes low values for cohesion and friction. In view of what has been said about the physiography in Chapter 3, and also in view of the discussion of the soils in Chapter 4, it is possible to postulate that in the wet periods the instability of the soil mass is extremely high. This would have been already the case immediately after the deposition of the Llanos loess, when the sediment had an open packing, and the vegetation might have been sparse.

In section 4.3.1 mention was made of the fact, that in trenches dug across escarceos and intermediate areas, no irregularities or breaks were found in the soil horizons. This can be explained by assuming a high biological activity after the micro-relief of escarceos was formed, accompanied by other soil forming processes as discussed in sections 4.3.2 and 4.4.2. Based on this reasoning it follows that solifluction (assuming that it did occur) is not a process having taken place in the present period. Otherwise it might be expected that some disturbance of the soil horizons would still be noticeable.

Yet it is not known in what period solifluction might have occurred. There is no doubt that areas with similar factors of soils and physiography have suffered flowage on nearly level slopes. The examples discussed in section 5.5.1 have a combination of factors which can be summarized as follows:

a. The soil material of the subsoil is practically cohesionless.
b. The surface run-off is very slow, and the soil becomes easily saturated with water. Therefore friction in the soil can attain extremely low values.
c. Capillary action in fine pores and resultant entrapped air may promote the destruction of any slight cohesive forces.
d. The friction can be lowered by a certain hydrostatic pressure in the subsoil.

The mechanics of the process of solifluction after liquefaction can be described as follows (Crawford, 1961, and Kerr, 1963). A porous, fine-grained and cohesionless soil, surcharged with water, may stand in a condition of unstable equilibrium. The soil retains its solidity merely by virtue of the friction between the loosely packed particles. When it becomes subject to internal movement, the soil structure collapses and the soil becomes a liquid mass. The particles rearrange themselves with some freedom in the water previously locked up in the pores.

The question remains, when and under what conditions the internal movement, the triggering of the liquefaction, takes place. So-called 'spontaneous liquefaction' does not actually exist; there is always some cause, internal or external.

In marine sediments slow changes in salt content may convert the soil mass into a collapsible soil, and a sudden rise or fall in the water table may be sufficient to trigger liquefaction (Crawford, 1961 and Sharpe, 1960). Normal stream erosion may increase the hydrostatic pressure in adjoining terrain, and a heavy rainfall may then be the cause of liquefaction.

Such and similar phenomena are known to have caused several cases of liquefaction (Terzaghi, 1950).

The above mentioned causes, however, are usually applicable only to limited areas. In the Llanos Orientales of Colombia, the escarceos cover an area of nearly 2 million hectares on both sides of the Meta river, and similar terrain is found continuing into adjoining

Venezuela. If liquefaction and consequent solifluction has occurred, there must have been present some cause, which exerted its influence over a large region and was capable of suddenly triggering liquefaction. The only likely cause of such a kind is earthquakes.

Earthquakes are very consistently mentioned as the triggering cause of recorded cases of liquefaction. We cite, in chronological order, the following authors: Casagrande (1936), Freundlich and Röder (1938), Harrison and Falcon (1943), Pryce-Jones (1948), Terzaghi (1950), Jakobson (1952), Sharpe (1960), Boswell (1961), Kerr (1963), Kerr and Liebling (1963), Common (1966), and Shreve (1966).

Referring to section 2.3.2, we know that the Meta river runs along a fault, where vertical tectonic movement has occurred in recent geological times, and is probably still taking place. Movements of this kind do not usually occur in the form of a slow, continuous movement, but rather as an interrupted series of shocks, as a repeated sudden release of built-up tension. The fact that small faults have been observed in recent alluvial sediments in the Llanos (see section 2.3.2), supports our conclusion that earthquakes have occurred after the Llanos loess was deposited.

Combining the above consideration of soil properties, physiographic features, and tectonic movements in the area of Llanos loess, we arrive at the following hypothesis:

> The escarceos in the poorly drained areas, where the parent material of the soils is Llanos loess, are transverse undulations caused by solifluction. They should, therefore, be renamed; 'solifluction ridges' is proposed here. Liquefaction, probably triggered by earthquakes, preceded solifluction, and the whole process is similar to what has been observed by many authors in areas of more limited extent.

The potential instability needed to induce solifluction may have been promoted by the absence or a change in the vegetation. A more comprehensive study, also of the deeper soil horizons, is needed to arrive at definite conclusions about the details of the process and about the period in which it took place.

5.5.4 Formation of the Esteros by Solifluction

In section 4.4.1 it was mentioned that the broad and shallow drainage-ways (esteros) of the High Plains are exceptionally broad in their upper part. This same feature can also be observed, to a somewhat lesser degree, in the Aeolian Plain. It was further found that soil series Guanapalo occupies both these upper stretches of the esteros and the adjoining areas of the level, poorly drained High Plains (see section 4.4.1).

The esteros are in a broad sense erosion channels forming in the Llanos loess. To illustrate their form and formation, Figure 41 shows a few details of their upper parts as drawn from aerial photographs. Figure 41a represents a simple form, and Figure 41b a more complex form. The longitudinal section A-B is based on detailed field measurements, and shows the transition from the adjoining area to the estero with an accuracy of within 10 cm. The vertical scale is greatly exaggerated, and irregularities, in particular a few termite mounds, have been omitted. The section shows that the head of the estero has small steps, not exceeding 50 cm in height. Similar successions of steps have been drawn in Figure 41b.

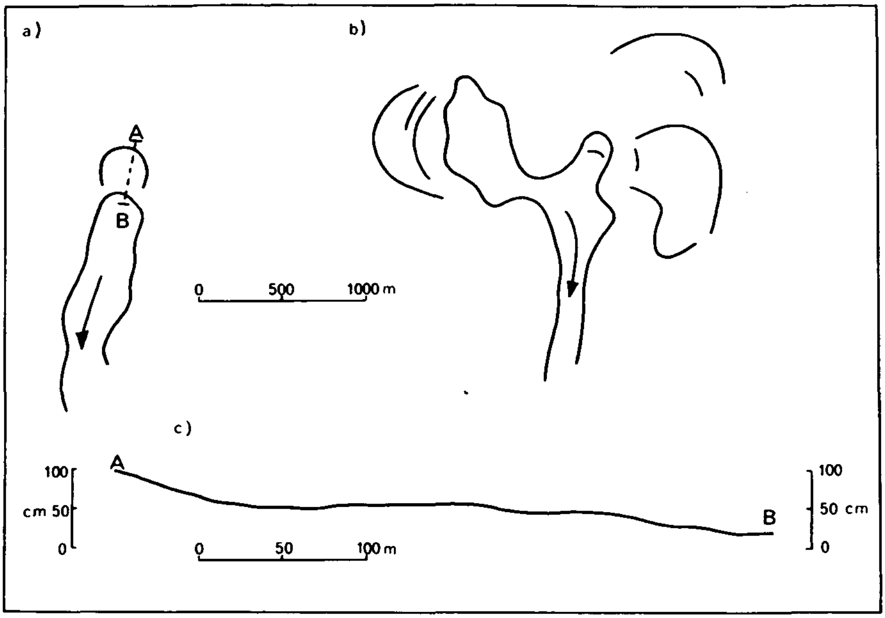


Fig. 41 The upper part of two esteros in the level, poorly drained High Plains, drawn from aerial photographs.
The arrows indicate the direction of the slope in the esteros. The semi-circular lines around the heads of the esteros indicate 'seepage steps' (see text).
The scale of the two upper drawings is 1 : 40,000. The cross section A - B refers to drawing a) and was measured in the field with a geodetic level, taking measurements at horizontal intervals of one meter. The horizontal scale of the cross section A - B is 1 : 4,000, and the vertical scale is 1 : 75. The average slope A - B is 0.02%.

The steps of the heads of the esteros are similar to what Hadley and Rolfe (1955) call 'seepage steps'. Chapman et al. (1965) describe 'slip faces', while Ruhe (1967) talks of 'scarplets'. According to these authors such features are found in the southern United States, especially in Arizona and New Mexico. Hadley and Rolfe (l.c.), and Ruhe (l.c.), explain the features as eroding seepage steps where shallow subsurface flow crops out on a hill slope and saturates the superficial mantle. The wetting action loosens the soil and makes it available for removal by surface flow. The seepage face migrates upslope as seepage loosens material and surface flow transports the soil downslope. Chapman et al. (l.c.) found the slip faces on the lower slopes of a barchan dune. They write: "Little erosion occurred because of the extreme permeability. The saturated surface layers of sand slipped down the bank forming tension cracks above and thrust sheets below. There is no evidence of erosion by running water on active dunes in this area."

The described cases evidently refer to cohesionless soils, and it is our opinion that the steps of the esteros in the Llanos are formed in a manner similar to that described by the authors cited. The regression by semi-circular seepage steps of the esteros is thought to be the principal process of erosion at the heads of the esteros. The seepage steps of the Llanos occur in a much flatter relief than the ones described by the above authors, but the rather high seasonal rainfall and the extremely low cohesion and friction of the subsoil horizons are factors propitious for mass movement in this form on gentle slopes. The subsequent transport of the loosened soil probably happens at a very slow rate and it might take a long time until a gradient sufficient to cause this kind of slip, is again established. But the process is liable to continue right into present times.

Figure 41b demonstrates that the regression of esteros may branch out in different directions. This pattern has been observed many times in the field.

The above explanation of the way in which the esteros are enlarged makes it clear why the heads of the esteros have a typical rounded form. The difference in state factors between the heads of the esteros and the adjoining terrain is so small that little difference exists between the soils. This is the reason why the same soil series has been recognized in the heads of the esteros and in the adjoining area.

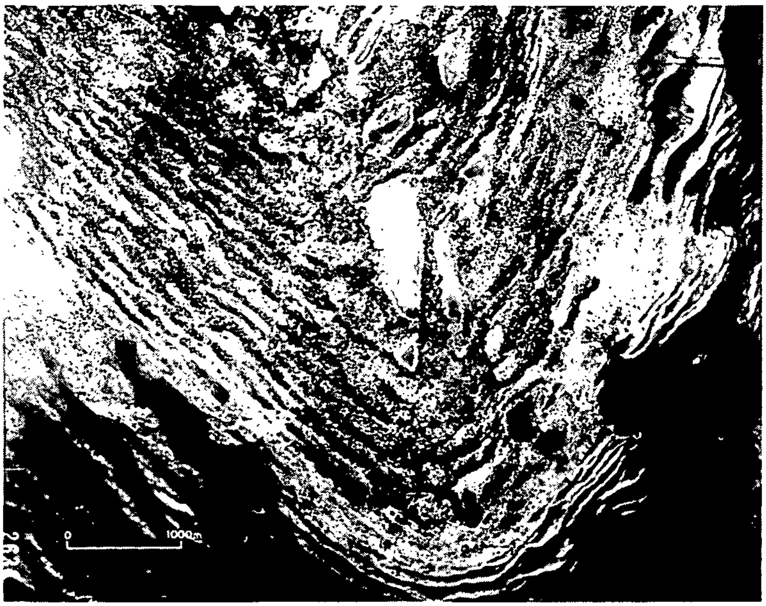
5.5.5 Comparison of Escarceos with Similar Phenomena

A rather large number of references to phenomena similar to escarceos exists. Where these phenomena have been attributed to solifluction, they have already been described in section 5.5.1. Table 30 is a compilation of those references, where the micro-relief of ridges is not clearly adscribed to solifluction. They mainly refer to tropical and subtropical savannas. In all the described cases of Table 30 the ridges, banks, (or any other name, as listed) are orientated in general terms along contours of areas with very gentle slopes, less than 2 %.

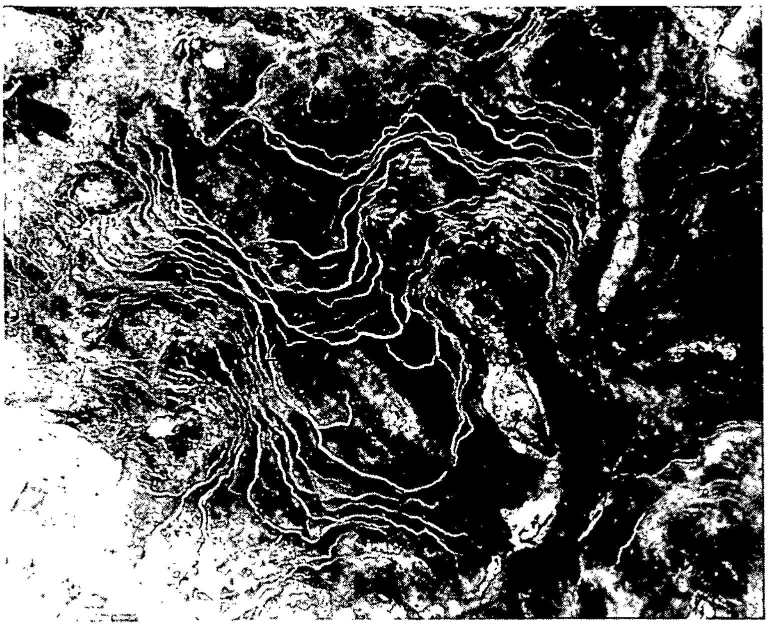
Obvious examples of sand ripples as caused by aeolian sedimentation are excluded from the list in Table 30. Also omitted from the list are the typical gilgai patterns described by Hallsworth (1968) for Australia. The examples listed from Australia refer to areas where the described microrelief is not in the first instance due to the presence of vertisols.

There are, however, two cases where soil churning might be a process wholly or partially responsible for the development of the microrelief under discussion. Worrall (1960) mentions an area in Sudan, where the clay fractions of the soils contain a high percentage of montmorillonite. However, Worrall is also one of the few authors who mention soil flow as a possible cause of the microrelief. Boulaine (1968) describes very silty Grumosols in Uruguay with a microrelief appearing as a series of successive waves. Although he does not explain the cause of it as soil churning, his use of the name 'gilgai' is suggestive in this respect.

From the last column of Table 30 it can be seen that many of the described patterns occur on aeolian plains. One of the finest examples, from Zambia, was brought to our attention by Eggeling (1966). It is shown in Figure 42, accompanied for comparison by an aerial photograph from the Llanos Orientales in Colombia.



a) Solifluction ridges in fine sandy aeolian sediments of the Chambeshi valley, Barotseland, Zambia. The ridges are marked by dark-coloured tree vegetation in the upper part, and by light-coloured grass vegetation in the lower part of the photograph.



b) Solifluction ridges in silty aeolian sediments of the Llanos Orientales, Colombia. The ridges are marked by light-coloured grass vegetation composed of taller species than in the surrounding savanna.

Fig. 42 Vertical aerial photographs showing two patterns of solifluction ridges.

The frequent association with aeolian sediments has brought several authors to the assumption that aeolian activity itself might be responsible for the pattern. But this assumption is hardly tenable. Aeolian ripples either caused by sedimentation, deflation or both, whether they be longitudinal, transverse, or parabolic, always show a distinct relationship to wind direction. None of the described cases have this relationship. The only consistent direction is related to slope.

The objection raised here to the theories that wind action would form the microrelief of ridges, are not meant to imply that the author believes wind action to be absent from those areas. Frequently, and quite probably in most cases, aeolian activity may even help in accentuating the ridges. In many of the recorded cases the depressional areas between ridges are characterized by a vegetation cover with less protective power against wind erosion than the ridges. Material blown from the depressions may easily be trapped by the higher vegetation on the ridges and thus enhance them. But aeolian deflation and sedimentation as such, do not produce the microrelief of ridges.

In one case (Wilhelmy, 1957) biological activity has been mentioned, not as the primary cause, but as a secondary activity superimposed upon the pattern. It appears, in the Mato Grosso of Brazil, that the depressions between ridges are often quite saline, more so than the ridges. Cattle and other animals eat this saline earth, and thereby, the depressions are enlarged. In the Llanos of Colombia termites prefer to build their mounds on the ridges. This activity accentuates the ridges. Also in the Llanos the depressions are more easily trampled by cattle than the ridges. The surface soil becomes puddled, and some of it is removed by surface wash. It is quite likely that such and other forms of biological activity have a similar influence on the existing microrelief in many other savanna areas.

Sheetwash is quite frequently mentioned as being in some way responsible for the formation of the described low ridges along contours. MacFadyen (1950), Greenwood (1957), and Boaler and Hodge (1962) elaborate on this theme for the patterns in Somalia. Bremer (1965) in a general review of patterned ground follows the same line of thought. They suggest that run-off water carries and deposits loose matter on the soil surface; some sorting may take place because sometimes small textural differences are found between the ridges and the depressions. It is an obvious fact that sheetwash occurs in this and similar areas. However, it is an assumption to state that sheetwash is responsible for the formation of the microrelief.

In the cases mentioned the supposition was made that sedimentation occurred initially against some obstacle. There is, however, no valid reason to assume that such a sedimentation would happen uninterrupted for long distances along contours, unless obstacles in that direction were already present. In section 5.3 sheet erosion and sheetwash sedimentation have been dealt with at some length. In none of the examples given, nor in any other part of the Llanos where heavy sheetwash occurs, were features similar to transverse ridges found. The literature cited in section 5.3 is of the same opinion on this point. Scheidegger (1961), in discussing what happens when sheet flood carries material over a nearly level terrain, establishes the general geometry of the resulting slope, from which transverse undulations are conspicuously absent.

Source	Date	Area	Name of the pattern	Suggested Origin	Soils and Physiography
Slatyer	1961	Australia	Groves and intergroves	?	Medium textured red-earth soils
Mabbutt	1961	"	Wanderriebanks; grove	Combined alluv. and aeol.	Various reddish-brown sandy to silty soils on very gentle slopes
"	1963a	"	" " "	sedimentation plus sheetwash	
"	1963b	"	" " "		
Litchfield	1962	"	" " "	" "	ditto; several soils with handpan Reddish members of Grey, Brown and Red Clays on gently sloping tableland
Anon.	1968	"	Shelves and depressions	?	
Wilhelmy	1943	Russia	Pods	Aeolian sedimentation	Poorly drained silt loames on loess plain
Simakova	1959b	"	Meadow complex	?	Meadow carbonate soils and puffy Solonchak on loess plain
Sokolov	1967	"	Aeolian ridges and suffossion depressions	Subsidence sink-holes	Silty and sandy loams on loess plain
Wickens	1966	Sudan	Vegetation pattern	?	Poorly developed soils derived from sandstone on level plain
Worrall	1960	"	Tree pattern	Sheetwash; locally soil flow	Grey-brown sandy loam/clay loam on level plains
Jacks et al.	1939	Somalia	Vegetation pattern	Wind erosion	
Glover	1950	"	Vegetation arcs	" "	(Various loamy
Mac Fadyen	1950	"	Vegetation pattern	Sheetwash	(pedocaled soils (on aeolian plains
Boaler et al	1962	"	Vegetation stripes	Sheetwash or wind action	
Greenwood	1957	"	Vegetation pattern	Sheetwash	
Eggeling	1966	Zambia	Vegetation banks	?	Fine-sandy soils on poorly drained aeolian plain
Romney	1959	Honduras	Terraced microrelief	Sheetwash; locally soil flow	Puletan loamy sand on level aeolian/alluvial plain
Ramia	1959	Venezuela	Banquetas	?	Hydromorphic silt loam soils on aeolian plain
Wilhelmy	1957	Brazil	Barreiros	Aeolian sedimentation plus biological activity	Hydromorphic fine-sandy soils on aeolian/alluvial plain
Boulaine	1968	Uruguay	Campos oleados; gilgai	Soil mulching (?) churning	Very silty Grumosol on Pampa loess plain

Table 30 Literature references to microrelief similar to the solifluction ridges of Colombia.

If transverse undulations were indeed the result of sheetwash, then the process of their formation should be comparable to the processes on the bottom of a river causing the formation of transverse ripples, and to the processes on the bottom of shallow seas causing the formation of sand waves and ridges, sometimes called 'megaripples'.

The formation of transverse undulations on the boundary between a loose sediment and a moving layer of water is the result of turbulence in the boundary layer of the flowing water. It has been clearly established that bed ripples are associated with eddies having quasi-horizontal axes. In the study of Matthes (1947), this and similar phenomena of stream turbulence are analyzed, and Scheidegger (1961) reviews the work of several authors elaborating on the same subject. A more recent review on the dynamic background of the waterflow in open water is given by Allen (1965).

An *important conclusion of these studies is that the transverse* eddies with horizontal axes, while rotating, produce in their lower part near the bottom a motion of water contrary to the general direction of flow. Immediately upstream of the eddy this adverse pressure causes sedimentation, in time forming the ripples. The amplitude of the ripples is of the same order of magnitude as the diameter of the eddies, and the wave length of the ripples is several times the diameter of the eddies.

Applying these principles to the supposed formation of transverse undulations on slopes with sheetwash, we should have to imagine that undulations with an amplitude of up to 50 cm were formed by eddies having a diameter of similar dimension. That would only be possible if the flow of water had a thickness greatly exceeding the amplitude of the undulations. The transverse undulations as described in several areas are found in physiographic positions where it is impossible to imagine sheet flows having occurred with such a thickness.

Based on these considerations, it is our opinion that in the cases where sheetwash occurs associated with a microrelief of transverse undulations, the sheetwash must be considered as a secondary process, superimposed upon the microrelief as formed by another process.

It has been mentioned already that Worrall (1960) considered soil flow to be a possible cause. Romney (1959) is even more clear about this. In the book on land in British Honduras, edited by him, there appears the following description of what happens when during intense rain showers a sheet of water accumulates on the soil surface: "The landscape is usually very gently sloping - so nearly flat that run-off is very slow; the top soil becomes thorougly saturated with water and separate particles begin to flow slowly downhill. Some soil particles are bowled along the surface as the sheet of water moves slowly towards the nearest creek or swamp. In places, the whole of the sandy topsoil flows downhill like a thick 'soup' until either the slope becomes more gentle or until it reaches a spot where sand has been dropped before; here the water runs out of the 'soup' and deposits the sand. In this way a terraced microrelief is built up".

The second part of this quotation aptly describes the process of liquefaction and soil flow, and connects it with the formation of transverse undulations. This process is the same as that postulated by us as being the primary cause of the solifluction ridges in the Llanos of Colombia.

Based on a survey of the aerial photographs and on the comparative study of literature in this section, we suggest that the same process might have been active in many of the cases listed in Table 30.

It is not our intention to presuppose that the soil profiles in all these cases are necessarily identical or even similar. It is manifestly clear that this is not the case; the soils belong to very different taxonomic categories. But it is also clear that several physical and chemical properties, as described by the various authors, indicate a low cohesion and a low internal friction. Many of the soils have developed in aeolian material, which is classically unstable when in nearly level position where saturation with water occurs frequently. All the soils are seasonally poorly or very poorly drained. Easy deflocculation and suspension is mentioned by several authors as one of the soil properties; see Litchfield et al. (1962), Mabbutt (1961), Worrall (1960), Greenwood (1957), Romney (1959), Wilhelmy (1957); or it is implied from circumstantial, but relevant, soil data.

The nomenclature of the process of liquefaction and soil flow is at this stage somewhat uncertain. We propose to apply the term 'solifluction'. If Sharpe's (1960) classification is adhered to, then in each individual case a choice must be made, dependent upon the speed of the process, between solifluction, earthflow and mudflow. In Scheidegger's (1961) terminology it should be called 'aqueous solifluction'.

In the case of the Llanos Orientales, earthquakes were suggested as having triggered the solifluction. 'Spontaneous' local occurrence of soil flow evidently is a fact, as the described case in British Honduras (Romney, l.c.) demonstrates.

It is interesting to speculate on the possibility of earthquakes having supplied the triggering effect in the cases mentioned in Table 30, many of which are located in or near zones of tectonic instability.

5.6 INTERACTION OF SHEET EROSION, RETICULAR GULLY EROSION AND SOLIFLUCTION

In foregoing sections of this chapter the various processes of erosion and mass movement in the Llanos Orientales have been discussed separately. It has been demonstrated that under the prevailing conditions of soils and physiography each process is characteristic of an area with a specific combination of these conditions. A summary of the soils with the associated processes is given in Table 31.

Table 31 should not be considered as a demonstration that only one process is active in a certain area. It has already been mentioned, with several of the cases discussed, that it is quite clear, for instance, that sheet erosion is often superimposed upon gully erosion, or that gully erosion may develop where sheet erosion is the dominant process. Also, sheet erosion is found acting where solifluction is the primary cause of the existing microrelief. Other processes, such as wind action, biological activity, etc., have been shown to intervene in the interaction between physiography and soils in many savanna areas.

Apart from the simultaneous interaction of different processes it is also clear that in different periods different processes may be dominant. The fossil reticular erosion in the well drained High Plains has been followed in time by sheet erosion.

SOIL	DEGRADATION PROCESS
Fine clayey, fine silty and coarse loamy Oxic (Palehumultic) Dystropepts (soil series Horizontes, Lagunazo and Nápoles) developed in Llanos loess of the level, well drained High Plains	Sheet erosion, with some fossil weak reticular and parallel rill erosion on slopes smaller than 3 %
Fine clayey Ultic Plinthaquepts developed in poorly drained (soil series Corocora) slackwater areas of the Alluvial Overflow Plain	Reticular gully erosion on slopes smaller than 1 %
Fine loamy, fine and coarse silty (Oxic) Ultic Plinthaquepts (soil series Guanapalo) developed in Llanos loess of the poorly drained areas of the Aeolian Plain and the High Plains	Solifluction on slopes smaller than 1 %

Table 31 Summary of the Principal Soils with the Associated Processes of Erosion and Mass Movement.

It is important that the different processes should be identified and that their successive occurrence, or their simultaneous interaction, is established. Such an analysis will provide the proper basis for understanding the physical behaviour of the soil.

Chapter 6

AGRICULTURAL EVALUATION

6.1 General

In the FAO report (1965) a land suitability classification has been presented in which the economic possibilities of the present and the near future have been taken into account, together with the physical and chemical limitations of the soils. The main conclusion is that most of the lands discussed so far, are suitable for grazing on natural savannas; improved pastures and subsistence agriculture can be established to a limited extent in order to obtain a balanced management system.

This chapter is meant to point out the physical aspects of soil management based on the technical limitations which result from the soil properties and the processes of erosion and mass movement. These aspects are thought to be basic to the question whether it will be possible to establish a more intensive agriculture in the Llanos. The problem of fertilization will not be discussed.

6.2 Soil management in the Alluvial Overflow Plain

Farm units in the Alluvial Overflow Plain comprise both slackwater areas and natural levees. The latter are used for settlement, and for some subsistence agriculture. The management of the farm units under a system of extensive grazing should include the establishment of improved pastures on the natural levees. At present the cattle graze during the wet season the natural levees and splays, and the borders of the slackwater areas, while during the dry season they penetrate farther into the slackwater areas. The water supply is a problem; surface water is not readily available during the later part of the dry season.

In the Alluvial Overflow Plain at present are two main factors to consider: the seasonal inundations and the reticular gully erosion (zurales). They should be considered jointly, because the reticular gully erosion is a result of the hydrological conditions. The levelling of the microrelief of the zurales is essential to make mechanized cultivation possible. This operation will destroy a great part of the cohesive bonds, and the surface soil after the levelling will have a low resistance against both sheet and gully erosion. Therefore, the speed and amount of overland flow should be reduced to a minimum.

The runoff from the natural levees and splays into the slackwater areas can be decreased to a minimum by providing interceptive drainage along the foot of levees and splays. The overland flow within the slackwater areas can be regulated by a system of ridges parallel to the contours

Provision has to be made for the timely removal of excess water. In section 5.3 it has already been mentioned that a natural drainage system is developing in the centres of many slackwater areas. This system, expanded where necessary, can be used for the removal of water.

All the operations mentioned involve a destruction of the present grass vegetation and the construction of artificial slopes of ditchbanks and ridges. In view of the properties of the soil material in terms of cohesion (see section 5.3), extreme caution should be taken to protect such slopes against erosion.

Another critical point in this respect is the control of water flow from a higher to a lower section and ultimately into the natural drainage system. If narrow spillways are constructed, the speed of the water and the low resistance of the soil material against erosion will cause a renewed gully erosion. Spillways therefore should be broad and shallow, and even then should be protected against erosion.

It should be pointed out that wind erosion in the dry season is a real hazard in the Alluvial Overflow Plain. One of the measures to reduce it, is the establishment of windbreaks on the system of natural levees and splays. This system runs to ESE and is directed approximately at right angles to the direction of the prevailing wind.

The general aspects of physical management mentioned above are based on the natural lay of the land, and on the prediction that wind and water erosion are great problems to be faced whenever a more intense land use is contemplated. The physical evaluation of the soils with regard to profile characteristics and position in the landscape leads to the conclusion that the slackwater areas have a potential for rice cultivation. The possibility of having a wider choice of crops to grow in the slackwater areas involves the problem of large scale artificial drainage. Such a scheme could be executed within the complex of measures discussed. But it should be realized that the hazard of wind and water erosion will be aggravated because more excess water must be removed and the surface soil in dry condition will offer less resistance against wind erosion than when the soil is wet.

Details of the physical soil management should be worked out in experiments.

Once again it must be stipulated that we are considering only the technical aspects of physical soil management. The proposed measures are certainly too costly for execution now or in the near future. It is only on the assumption that all other difficulties, such as communications, supply of fertilizers (cf. Cano, 1963), etc., would be solved, that the above schemes of land reclamation would become practical.

6.3 Soil management in the level, well drained High Plains.

The level, well drained High Plains with soil series Horizontes, Lagunazo and Nápoles have been classed as suitable for grazing.

Improved pastures are possible, and subsistence agriculture may be practised to a limited extent.

In judging soil management under a more intensive land use than extensive grazing, we will omit discussing chemical aspects. The need for heavy fertilization is evident.

The most severe problems of soil management center around the erosion hazard. Sheet erosion at present may be classed as slight to moderate. The following example illustrates that it is easily accelerated.

In 1968 an area of a few hectares was ploughed on the experimental farm 'Las Gaviotas' situated about 100 km southeast of Orocué on the level, well drained High Plains. The land ploughed has a slope of about 1%, and the dominating soil is soil series Horizontes. In September 1968, three months after ploughing, the author had occasion to visit the farm. The plot had suffered severe sheet erosion. Its lowest corner was covered with a 10 cm thick deposit derived from the upper part; the deposit extended beyond the plot for several meters over the adjoining savanna.
Several varieties of corn, sorghum and soya beans had been planted; in between the rows shallow rills had developed, while the rows themselves were mostly flattened as the result of the impact of rain.

This example also demonstrates that rill erosion, now present in a fossil form (see section 3.2.6), is readily reactivated.

Measures to diminish erosion must be directed towards:

1. increasing the resistance of the topsoil to erosion;
2. lessening the amount and speed of the runoff.

The erodibility of the topsoil largely depends on the cohesion of the soil (see section 5.2.2). The problem is to achieve sufficient cohesion in the surface soil. This problem has been discussed extensively in the literature. See e.g. FAO (1952). No additional solutions are offered here.

The decrease of runoff concerns both amount and speed of runoff. To decrease the amount of runoff would mean to increase the rate of infiltration. The soils of the level, well drained High Plains have no impermeable horizons in the subsoil. The only factor limiting the infiltration is the puddling of the topsoil. To some extent this puddling might be reduced by achieving a higher degree of crumb and clod aggregation, but this is, as mentioned above, a very difficult proposition.

A decrease in the speed of runoff can be attained by various means. The surface configuration can be roughened through tillage operations, in combination with furrowing along contours, but this is thought to be of little use. The cohesion and friction of the soil (see section 5.3.3) are so low that the physical impact of the rain is capable of flattening the nanorelief of furrows, as has been demonstrated with the expiriment on the experimental farm, referred to earlier in this section.

Any system of soil conservation directed towards decreasing the speed of runoff involves the construction of barriers along contours.
In the level, well drained High Plains the main concern is to provide these barriers with sufficient cohesion throughout the year. The least costly

method would be to establish a permanent vegetation on the barriers, but practical experiments are needed to give a conclusive answer.

Somewhat independent of sheet and rill erosion is the hazard of wind erosion. Of course, wind erosion as well is most effective when the cohesion of the soil is small, but it occurs in a different season from sheet erosion. Another important difference is the fact that wind erosion attacks flat land just as readily as sloping land. The fine-grained particles of the soils of the High Plains have been transported in the past by wind; when the soil is laid bare, this wind transport may be reactivated, creating a large dust bowl.

It is certain that strip farming would not be effective in preventing wind erosion, because in the dry season many strong wind eddies originate in the Llanos, and the denudation of the bare strips would not be compensated by entrapment of the particles in the covered strips. Therefore a vegetative cover must be maintained during the dry season. To effectuate this, supplementary irrigation will be necessary. There is at present no surface water which can be diverted by gravity into the savannas of the High Plains, but it is known that the streamlets in the esteros seldom dry out in the dry season. The possible utilization of this water and of underground water must be confirmed by thorough hydrological investigations. In addition to this windbreaks should be established. At present the level, well drained High Plains are largely devoid of trees and shrubs. The principal tree found scattered on the savannas of the High Plains is the fire-resistant chaparro (Curatella americana).

The soils of the level, well drained High Plains have no physical impediments for deep-rooting vegetation such as trees. Around many farm buildings in this area fruit trees are numerous. It appears that such trees (mainly citrus and mango) need proper care in their young stages. The seedlings must be watered daily in the dry season for a couple of years until their rooting system has penetrated to a sufficient depth to tap the water available in the lower subsoil. Bones etc. of slaughtered cattle and other household refuse are now used as very effective fertilizers. If these two aspects (water supply and fertilization) are taken care of, the trees develop vigorously.

6.4 Soil management in the level, poorly drained areas of the Aeolian Plain and of the High Plains

The poorly drained areas of the Aeolian Plain and of the High Plains are represented by soil associations Es and As respectively. Both areas have been classified as suitable for extensive grazing, and in this respect are similar to the slackwater areas of the Alluvial Overflow Plain. It has been demonstrated in sections 4.3, 4.4, 5.3 and 5.5 that identical soil series and very similar aspects of physiography are common characteristics of both soil associations Es and As. Within this framework it is possible to take the two soil associations together as a unit for which the physical soil management is identical. For the sake of simplicity, we will use in the following the term "poorly drained loess areas", when referring to the two soil associations Es and As of the Aeolian Plain and of the High Plains respectively.

There are two sets of soil properties in the poorly drained loess areas which are very relevant to the problem of soil management. The first set concerns the soil profile properties, the second set concerns the physiographic aspects of the soils. Both sets can be summarized as follows:

1. The properties of the soil mass are indicative of extremely low values for cohesion and friction.
2. The external soil properties are: nearly level relief, micro-relief of solifluction ridges, and seasonal inundation by rainfall.

If only the external, physiographic properties of the soils of the poorly drained loess area are considered, the conclusion might be drawn that it would be possible to cultivate rice with a minimum of investment. A certain amount of water control and fertilization might seem all that would be required to establish a highly mechanized rice cultivation.

This conclusion would be very unsound. When a more intensive system of agriculture is introduced in the poorly drained loess areas, serious problems of physical soil management will result from the extremely low soil strength in terms of cohesion and friction. It should be stressed here that soil series Guanapalo, typical of the poorly drained loess areas, is even more susceptible to erosion than the soils in the other two areas discussed in sections 6.2 and 6.3. Under present conditions the upper soil horizons of soil series Guanapalo have a certain cohesion, due to the organic matter content and the root system of the grasses; all other properties of the soil, however, are typical of cohesionless, and in watersaturated conditions of frictionless material. These aspects have been amply discussed in section 5.5.

Cultivation of such a soil means a partial or total destruction of the present cohesion in the soil, and water, wind and gravity would have a catastrophic effect upon the land of the poorly drained loess areas. The exact values to which the cohesion and friction still have to go down before the danger point is reached are not known. It is certain, however, that cultivation and irrigation, by disturbing the structure and saturating the soil, will lower the values for cohesion and friction. It remains a speculation whether or not under such conditions the soil mass would liquefy, and renewed solifluction occur. In our opinion it is virtually certain that walls of irrigation ditches and canals would collapse.

It is highly questionable whether any solution, short of the construction of solid retaining walls of concrete or similar material, will be found to protect the walls of ditches against complete failure. The most obvious line of investigation for finding a solution with more 'natural' management practices than the use of concrete, is to study the possible use of a dense and deeprooting vegetation to increase the physical coherence of the soil along the ditches.

Artificial drainage might remove the danger of renewed solifluction because the internal friction would then be increased due to the increase in apparent weight of the soil mass, and capillary water would add to the cohesion. This is certainly worth considerable attention in future investigations. However, under a system of artificial drainage the hazard of sheet and rill erosion should be considered. The cohesion of the surface soil in the poorly drained loess areas is lower than in the other areas of the Llanos. On the other hand, the relief is flatter in the poorly drained loess areas. If an intensive system of drainage canals, ditches and furrows would be installed, it means that in an artificial way the relief is accentuated. With the low cohesion of the surface soil the result inevitably would be that sheet and rill erosion would start along the banks of the open drains, and that it would work itself backward, affecting ultimately the whole surface area.

The conclusion is that an artificial system of drainage should have a minimum of open drains, and that these open drains should be protected against erosion of the banks. Whether a subsurface drainage with tiles is feasible, remains to be concluded only after experiments.

Wind erosion can be expected to act severely upon the surfaces of the soils of the poorly drained loess areas, whenever these soils are ploughed and dry. The general hazard of wind erosion is therefore the same as for the level, well drained High Plains and the slackwater areas of the Alluvial Overflow Plain. Based on the soil properties of the poorly drained loess areas which are indicative of the lowest values for cohesion of all soils of the Llanos, and based on the climatic conditions (the poorly drained loess areas generally have the longest dry season, as is shown by a comparison of the maps of figures 3 and 7), the conclusion may be drawn that the hazard of wind erosion, other conditions being equal, is greatest in these poorly drained loess areas.

6.5 Final remarks

In all the areas considered, there are a number of management problems concerned with soil stability. Soil stability is a somewhat loose termwhich may refer to the stability of structural aggregates and also to the stability of the soil mass as a whole. Both of these aspects have been considered and have been found to be important in the Llanos. The stability of structural aggregates largely depends upon the cohesion, and plays a major role in determining the degree to which sheet, rill and gully erosion may attack the soils. The stability of the soil mass as a whole depends not only upon the cohesion, but also upon the internal friction and is a very important factor with regard to mass movement of the soil.

The combined study of internal soil profile properties and physiographic aspects has led to a number of conclusions about past and present physical behaviour of the different soils, conclusions which are thought to be of the utmost importance in recommending soil management practices for application in future agricultural development.

Little attention has been paid to the socio-economic aspects of agricultural development. When incorporating these aspects in the considerations on potentialities of the Llanos, we reach the same conclusion as that expressed in the land suitability classification of the FAO report (1965). This conclusion is that the lands of the eastern part of the area surveyed in the Llanos are suitablemainly for extensive grazing. With proper management practices cattle production can be considerably increased.

Appendix I

METHODS

I. 1 SOIL SURVEY METHODS

The study of the soils in the Llanos Orientales was done on the basis of 'selective sampling'. The fundamentals of this method are that 'sample areas' are selected during airphoto interpretation, and that in these sample areas semi-detailed soil surveys are carried out. Each sample area is representative of a certain landscape or physiographic unit, and in it the principal soil series are studied, together with their variations and distribution. In extensive landscapes, more than one sample area was mapped in order to study regional changes in the soils. On the basis of the results of the surveys in the sample areas, mapping was extended over the total area of the landscapes by means of photo interpretation. Between the field-work and the photo interpretation continuous adjustment was done, comparable to the methodology described by Vink (1963).

Additional field checks were made during several trips by ground or air vehicle, including helicopters. A total of 380,000 ha, divided into 20 sample areas, was surveyed in semi-detail.

For photo interpretation, panchromatic aerial photographs at scales ranging from 1 : 20,000 to 1 : 60,000 were used. The majority of the photos were at a scale 1 : 40,000. Infrared aerial photographs at 1 : 40,000 for about 5,000 sq. km were also available. These were taken specially to investigate small differences in drainage conditions. Photomosaics were available for most of the area. These were used at a scale 1 : 50,000 as field maps, at the scale 1 : 100,000 as plotting maps for photo interpretation, and at the scale 1 : 250,000 to compile the final soil map.

The various landscapes were recognized on the aerial photographs and drawn on the landscape map which formed the basis for subsequent studies. The subdivision of the landscapes into units, thought to be soil associations resulted in semi-detailed maps of the sample areas, which were verified during the field-work. By interpolation and extrapolation the final soil map at the scale 1 : 250,000 was prepared. It has been published by the FAO (FAO report, 1965).

I. 2 LABORATORY METHODS

Together with the description of the soil profiles a number of chemical and physical analyses are given.

These are:

- particle size distribution;
- organic matter (C, N and C/N);
- exchangeable cations (Ca, Mg, K, Al, Na, H);
- total exchangeable bases;
- cation exchange capacity;
- base saturation;
- acidity (pH);
- available phosphorus (not in all samples);
- free iron (Fe_2O_3) (not in all samples).

The following additional analyses have been executed on some samples of selected profiles.

- X-ray analysis of clay fraction;
- Differential thermal analysis (D.T.A) of clay fraction;
- Elemental analysis of clay fraction;
- Molecular ratios of silica and sesquioxides in clay fraction;
- Calculation of clay mineral percentages from elemental analysis (Goethite-norm composition);
- Particle size distribution without dispersion;
- Cation exchange capacity of clay fraction;
- Water retention at 15-bar;
- Liquid Limit (LL);
- Plastic Limit (PL);
- Plasticity Index (LL - PL = PI);
- Mineralogical composition of sand fraction by microscope;
- Dispersable clay in water.

Some of the analyses of this second list have been carried out on soil samples from other soil profiles than the described ones, but belonging to the same soil series. To indicate whether a certain analysis refers to the described profile or to another one within the same soil series, the field symbol of the profile is given together with the name of the soil series in each table or graph where the analytical data are represented.
The soil samples were analyzed in the Soils Laboratory of the Instituto Geográfico Agustín Codazzi in Bogotá. The methods followed in this laboratory have been published (Instituto Geográfico Agustín Codazzi , 1963). In addition to the analyses done in Bogotá, duplicate soil samples of selected profiles were analyzed in the Laboratory of Regional Soil Science, Wageningen.

Below is a short description of the methods followed in Bogotá.

Granulometric analysis
Pipette method. Destruction of organic matter with H_2O_2 (30%); dispersion with sodium-hexametaphosphate plus sodium-carbonate; separation of sand by wet sifting over 325-mesh sieve. Drying of sand in oven and determination of 5 fractions with sieves of 18, 35, 60, 140 and 325 mesh. Determination of silt and clay in suspension by Lowy pipette of 25 and 10 ml, drying and weighing the residue (Kilmer et al., 1949).

Free iron oxide, modified DEB (Fe_2O_3)
Stirring of 2 g sample with 2 g dithionite (sodium-hydrosulphite) for 16 hours in 40 ml water. Adjustment of pH in 3.5 and 4.0; centrifugation; oxidation with H_2O_2 in a 5 ml saturated solution. Iron evaluation with versenate, with sulphosalicylic acid as indicator (Kilmer, 1960 and Cheng et al., 1953).

Organic carbon (C)
By oxidation with chromic acid, no external heating, and evaluation of the dichromate excess with ferrous solution in the presence of O-phenanthroline (Walkley and Black, 1934).

Total nitrogen (Modified Kjeldahl (N)
By saturating the sample with H_2O_4 (conc.) and accelerating Jackson's mixture. Absorption of distilled ammonia over boric acid and evaluation by titration with HCl 0.1 N in the presence of Jackson's mixed indicator (Jackson, 1958).

Acidity (pH)
Potentiometre, in water-saturated soil sample (paste), with glasselectrode (Jackson, 1958).

Cation Exchange Capacity (CEC)
Modified method of ammonia acetate 1N (pH = 7). Saturation of 10 g soil sample with NH_4OAc 1 N by agitation and filtration. Replacement of adsorbed NH_4^+ on the complex by sodium from NaCl (sol. 10%) via filtration; distillation of the ammonia by steam in the Quickfit equipment over the filtered solution (Peach et al., 1947).

Cations in meq/100 g soil, exchangeable cations.
By displacement with NH_4OAc 1N (pH = 7), using the filtrate obtained when determining the cation exchange capacity, before treatment with NaCl. Evaporation until dry. Treatment with Aqua Regia and calcination, dissolution in HCl 6N, drying and recovery of bases with HCl 1N by filling until 50 ml (Peech et al., 1947).

Exchangeable calcium and magnesium (Ca, Mg)
Flame spectrophotometrically (Spectrophotometer Beckman D. U.) in the solution obtained as indicated for the exchangeable cations (US Soil Salinity Lab., 1954).

Exchangeable aluminium (Al)
By extraction with KCl 1N, agitating the sample with KCl during 5 minutes, and after 30 minutes, filtration in vacuum, rinsing the residue 5 times with extracting solution (KCl). Neutralization with NaOH approx. 0.1N with indicator phenolphtalein. Treatment with 10 ml of NaF (sol. 4%) which procudes the complex Fluo-aluminate, under liberation of OH. Estimation with HCl 0.1N (Yuan, 1959).

Exchangeable hydrogen (H)
Calculated from the difference between the cation exchange capacity (CEC) and the total of Ca, Mg, K and Na.

Total exchangeable bases (TEB)
Sum of the exchangeable cations Ca, Mg, K and Na.

Base saturation (%)
Saturation of the cation exchange capacity of the soil with the sum of the cations Ca, Mg, K and Na (100 TEB/CEC).

Available phosphorus (P)
By extraction of the soil with extracting solution of ammonium fluorate 0.03N plus hydrochloric acid 0.025N. Colorimetric determination of the phospho-molybdic complex between 5 and 20 minutes at 660 millimicrons in photocolorimeter Coleman Jr. (Bray et al., 1945).

The Laboratory of Regional Soil Science, Wageningen follows methods as described in its Laboratory Manual (*van Schuylenborgh and Begheyn, 1965). Below is a short description of the pertinent analyses as carried out in* Wageningen.

Granulometric analysis
Binding materials (humus, $CaCO_3$) are removed by oxidation with H_2O_2 and treatment with 0.1 N HCl. The dissolved salts are removed by decanting. Peptization in 0.03 N $Na_4P_2O_7 \cdot 10H_2O$. Separation of sand by wet sieving over 0.05 mm sieve and determination of sand fractions with vibrating sieves. Determination of silt and clay in suspension by pipette of 50 and 20 ml, drying and weighing the residues.

Free iron oxide (Fe_2O_3)
Extraction by reduction of Fe (III) with Na-dithionite and complexing of Fe (II) with oxalate-buffer. Colorimetric estimation of Fe (II) with O-phenanthroline (Duchaufour et Souchier, 1966; Schwertmann, 1964).

Organic carbon (C)
The organic substance is oxidized with chromic acid. The concentration of the formed ions (Cr^3, green) is measured by colorimetric evaluation (Allison, 1935; Van Schuylenborgh & Begheyn, 1965).

Cation exchange capacity
Equilibration of the extracted soil obtained for the determination of exchangeable cations, with 0.2 N solution of $Ca(OAc)_2$ to replace Li-ions by Ca-ions. Determine in this extract Li and Cl (Yaalon et al., 1962).

Exchangeable cations
The adsorbed cations are replaced by Li through mixing with a 0.5 N solution of LiCl/LiOAc at pH 7 for non-calcareous soils. In the extract are determined: Na, K, Ca, Mg (Yaalon et al., 1962).

Determination of Fe
Reduction of Fe (III) to Fe (II) by means of hydroquinone. Fe (II) reacts with 1,10-ortho-phenanthroline to form an orange-red complex at pH 3.5. Colorimetric evaluation (Sandell, 1959).

Determination of SiO_2
Colorimetric determination of Si as the yellow silicomolybdenic acid complex in a strongly acid NH_4-molybdate solution (Jackson, 1958).

Determination of Fe (II) and Fe (III)
Fusion with HF and H_2SO_4 under reductive conditions. Determination of Fe (II) with O-phenanthroline without addition of reductant (hydroquinone) and of Fe (II) + Fe (III) after addition of reductant (Clemency and Wagner, 1961).

Determination of Al
Al forms with pyrocatechol violet ($C_{19}H_{14}O_7S$) at pH 6.0 - 6.1 a brown coloured complex. Colorimetric evaluation (Wilson and Sergeant, 1963)

Determination of Ti
Tiron reacts with Ti to form an intensive yellow complex in the pH-range 4.3 - 9.6. Colorimetric evaluation (Sandell, 1959).

Determination of Mn
Formaldoxime (H-CH=NOH) produces with Mn, Ni, Co, Fe and Cu in alkaline solution coloured components. Ni, Co, Fe and Cu are converted into complexes with KCN after reduction with ascorbic acid. Colorimetric evaluation (Jackson, 1958).

Determination of Ca
Glyoxal bis(2-hydroxyanil) reacts with Ca in alkaline, aethanolic medium at pH 12.4 to form a strongly red coloured complex (Peaslee, 1964).

Determination of Mg
Mg forms with titan yellow in alkaline medium a red coloured lake. Colorimetric evaluation (Meyrowitz, 1964; Van Schouwenburg, 1965).

Determination of Na and K
Flame-photometric determination of Na and K according to the 'Kurvenschar' method (Schuhknecht, 1961).

Determination of P
Phosphorus forms in sulfuric acid medium a blue coloured complex with ammonium-molybdate. Methol reduces the MoO_3-group of this complex to MoO_2, which gives the blue colour. Colorimetric evaluation (Jackson, 1958).

Appendix II

SOIL PROFILE DESCRIPTIONS

Profile No.	Soil series	Taxonomic classification	Soil association
	Alluvial Overflow Plain		
C-92	Comino	Tropudultic Quartzipsamment	Da
E-26	Orocué	Tropudultic Dystropept	Dd
D-3	Altamira	Aeric Ultic Plinthaquept	Dd
J-41	Corocora	Cumulic Humic Ultic Plinthaquept	Db
	Aeolian Plain		
P-14	Duya	Typic Quartzipsamment	Em
P-26	Guanapalo	(Oxic) Ultic Plinthaquept	Es
W-5	Sáliva	Oxic Tropudultic Dystropept	Er
C-19	Anzuelo	Umbric Ultic Plinthaquept	Ee
	High Plains		
C-60	Horizontes	(Oxic) Palehumultic Dystropept	Aa
D-13	Lagunazo	Oxic (Palehumultic) Dystropept	Aa
C-71	Nápoles	Oxic Dystropept	Aa
T-35	Guanapalo	(Oxic) Ultic Plinthaquept	As
D-11	,,	,, ,, ,,	As
D-12	,,	,, ,, ,,	As
Ch-66	Carimagua	Aeric Plinthaquept	Ae

Profile C-92, described October 11, 1962 by Marco Cano.

COMINO Series, sandy Tropudultic Quartzipsamment.

Area: 16 km E of El Yopal on a natural levee of the Alluvial Overflow Plain, soil association Da, elevation 300 m.

Vegetation: Savanna of the Trachypogon ligularis type.

Topography: Very slightly undulating, somewhat convex.

Parent material: Alluvial sediments.

Drainage: Well drained.

A11	0- 7 cm	Dark brown (10YR 4/3) fine sand; single grain with some very weak crumbs; loose, abundant roots and pores; pH 4.7; clear and smooth boundary.
A12	7- 28 cm	Pale brown (10YR 6/3) fine sand; single grain, loose; common roots and pores; pH 4.6; diffuse and smooth boundary.
B1	28- 70 cm	Yellowish brown (10YR 5/4) fine sand; single grain; loose; common roots and pores; pH 4.7; diffuse and wavy boundary.
B21cn	70-110 cm	Light yellowish brown (10YR 6/4) loamy sand with dark red (7.5R 3/6) concretions; massive structure; very friable; few roots, some medium pores; pH 4.6; diffuse and wavy boundary.
B22cn	110-130 cm	Very pale brown to light gray (10YR 7/3); 7/1) loamy sand, (colours indicate partly gleyization), with dark red (7.5R 3/6) large concretions and mottles; massive structure; very friable; no roots, some medium pores; pH 4.5.

Note: All horizons are non-sticky and non-plastic.

Diagnostic horizons: 0- 28 cm Ochric epipedon;
70-110 cm Cambic horizon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %)					%C	%N	C/N	pH H_2O	P ppm
		clay < 2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000					
A11	0- 7	3	4	2	55	36	0.5	0.05	10	5.3	25.0
A12	7- 28	4	2	3	54	37	0.2	0.03	7	4.9	11.0
B1	28- 70	5	4	3	55	33	0.2	0.03	7	5.0	68
B21cn	70-110	10	6	4	45	35	0.1	0.02	5	4.9	24
B22cn	110-130	7	6	4	38	45	0.1	0.02	5	5.1	30

Exchangeable cations (meq/100 g soil)						Total exch. bases (meq/100 g soil)	Cation exch. cap. (meq/100 g soil)	Base sat. %	PW %
Ca	Mg	K	Na	Al	H				
0.4	0.4	0.2	0.1	0.2	1.4	1.1	2.4	46	0.4
0.1	0.2	0.1	0.05	0.4	1.2	0.45	1.6	28	0.3
0.2	0.3	0.1	0.1	0.7	1.2	0.7	1.8	39	0.4
0.1	0.1	tr	0.05	0.9	2.2	0.25	2.5	10	0.6
0.1	0.1	0.1	0.05	0.8	1.5	0.35	1.8	19	0.5

Profile E-26, described January 26, 1962 by Elvers Marin.

OROCUE Series, coarse loamy Tropudultic Dystropept.

Area: 15 km NW of Orocué on a natural levee of the Alluvial Overflow Plain, soil association Dd, elevation 180 m.

Vegetation: Savanna of the Trachypogon vestitus - Axonopus purpusii type.

Parent material: Alluvial sediments.

Topography: Nearly level, somewhat convex.

Drainage: Moderately well drained.

A1	0- 10 cm	Dark grayish brown (2.5Y 4/2) sandy loam; weak medium and fine blocky structure; very friable; abundant roots and pores; pH 4.8; clear and smooth boundary.
A3	10- 18 cm	Olive brown (2.5Y 4/4) sandy loam; weak fine blocky structure; friable; common roots and abundant pores; pH 5.0; clear and smooth boundary.
B21	18- 40 cm	Yellowish brown (10YR 5/6) sandy loam; very weak blocky structure with some clay skins in the pores; very friable; common roots and abundant pores; some darker streaks leached from above; pH 5.0; clear and smooth boundary.
B22	40- 73 cm	Yellowish brown (10YR 5/8) sandy loam, with dark gray (N4) vertical streaks and veins; massive structure; very friable; few roots and common pores; pH 5.0; clear and smooth boundary.
B23	73-130 cm	Yellowish brown (10YR 5/8) matrix with strong brown (7.5YR 5/6, rubbed: 10YR 5/6) sandy loam; massive structure; very friable; no roots and few pores; pH 5.2; clear and smooth boundary.
B3	130-160 cm	Strong brown (7.5YR 5/6) with yellowish red (5YR 5/8) mottles, (rubbed: 10YR 5/8) sandy loam; massive; very firm; no roots and few pores; some dark streaks; pH 5.0.

Note: All horizons are non-plastic and non-sticky. Quartz grains are visible throughout the whole profile.

Diagnostic horizons: 0-18 cm Ochric epipedon;
18-130 cm Cambic horizon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %) clay < 2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000	%C	%N	C/N	pH H_2O	P ppm	Free Fe_2O_3 %
A1	0- 10	9	9	9	47	28	1.0	0.08	12	5.0	2.4	0.9
A3	10- 18	8	6	29	38	19	0.8	0.07	11	5.0	3.0	1.2
B21t	18- 40	12	10	11	46	21	0.4	0.04	10	5.1	1.6	1.0
B22	40- 73	11	13	12	46	18	0.2	0.03	7	4.9	1.1	1.2
B23	73-130	8	10	9	43	30	tr	0.01	-	5.5	0.4	1.8
B3	130-160	10	11	4	43	32	tr	0.01	-	5.4	0.7	2.3

Exchangeable cations (meq/100 g soil) Ca	Mg	K	Na	Al	H	Total exch. bases (meq/100 g soil)	Cation exch. cap. (meq/100 g soil)	Base sat. %	PW %
0.2	0.2	0.1	0.1	0.9	3.3	0.6	3.8	16	0.7
0.1	0.1	0.1	0.1	0.9	3.3	0.4	3.6	11	0.7
0.1	0.1	0.1	0.05	0.6	2.3	0.35	2.6	13	0.7
0.1	0.1	0.1	0.05	0.5	1.9	0.35	2.2	16	0.6
0.1	0.1	0.1	tr	0.2	1.1	0.3	1.4	21	0.6
0.1	0.1	0.1	tr	0.2	1.6	0.3	2.0	15	0.6

Profile D-3, described March 27, 1962 by Doeko Goosen.

ALTAMIRA Series, sandy Aeric Ultic Plinthaquept.

Area: 12 km ENE of Rondon, on a spillway deposit of the Alluvial Overflow Plain, soil association Dd, elevation 160 m.

Vegetation: Savanna of the Trachypogon vestitus - Axonopus purpusii type.

Parent material: Alluvial sediments.

Topography: Slope 0-0.5%, slightly convex ridge extending from natural levee into depression.

Drainage: Imperfectly drained.

A11	0- 5 cm	Very dark gray (10YR 3/1) loamy sand; few light gray streaks; weak crumb structure; very friable, non-sticky, non-plastic; abundant roots and common pores; pH 4.8; clear and smooth boundary.
A12	5- 25 cm	Very dark gray (10YR 3/1) loamy very fine sand, dark yellowish-brown (10YR 3/4) mottles in root channels; very weak blocky structure breaking easily in crumbs; very friable, non-plastic, non-sticky; common roots and pores: pH 4.8; gradual and smooth boundary.
A21	25- 50 cm	Yellowish brown (10YR 5/4) loamy fine sand, with strong brown (7.5YR 5/6) mottles in root channels; single grain; very friable, non-sticky and non-plastic; few roots and pores; pH 4.9; gradual and smooth boundary.
A22	50- 77 cm	Yellowish brown (10YR 5/6) very fine sand, with 50% irregular formed strong brown (5 YR 4/8) and brown (10YR 5/3) mottles in root channels; single grain; loose, non-sticky and non-plastic; few roots and pores; pH 5.0; abrupt and smooth boundary.
B21gcn	77- 91 cm	Gray brown (2.5Y 5/2) very fine sandy loam, with yellowish brown (10YR 5/8) and red (2.5YR 4/8) mottles and some yellowish brown iron concretions; single grain; friable, non-plastic and non-sticky; few roots and pores; pH 4.8; clear and smooth boundary.
B22g	91-121 cm	Gray (10YR 5/1) very fine sandy loam, with 50% yellowish brown (10YR 5/8) and red (2.5YR 4/8) mottles as vertical streaks; massive structure; very friable, non-plastic and non-sticky; few roots and no pores; pH 4.8; abrupt and smooth boundary.
IIB31g	121-133 cm	Dark gray (10YR 4/1) clay, with dark yellowish brown (10YR 4/4) mottles; massive structure; firm, slightly plastic and slightly sticky; no roots and pores; pH 4.7; clear and smooth boundary.
IIB32g	133-150 cm	Gray to light gray (10YR 5/1; 6/1) clay, with yellowish brown (10YR 5/8) and light olive brown (2.5Y 5/6) mottles; massive structure; friable, slightly plastic and slightly sticky; no roots and pores; pH 4.2.

Diagnostic horizons: 0-25 cm Ochric epipedon;
77-121 cm Cambic horizon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %)					%C	C/N	pH H_2O	P ppm	Free Fe_2O_3 %
		clay < 2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000					
A11	0- 5	3	7	11	76	3	1.2	7	4.4	7.0	
A12	5- 25	3	6	11	77	3	0.4	7	5.0	3.8	
A21	25- 50	3	5	9	78	5	0.1	3	5.2	1.6	
A22	50- 77	6	7	5	75	7	0.1	3	5.1	3.0	
B21gcn	77- 91	13	6	9	68	4	0.1	3	5.0	2.2	
B22g	91-121	18	12	13	56	1	0.1	2	4.5	1.3	
IIB31g	121-133	48	23	16	12	1	0.1	1	4.2	1.6	
IIB32g	133-150	48	23	18	10	1	0.1	1	4.2	0.7	

Exchangeable cations (meq/100 g soil)						Total exch. bases (meq/100 g soil)	Cation exch. cap. (meq/100 g soil)	Base sat. %	PW %
Ca	Mg	K	Na	Al	H				
0.2	0.05	0.2	0.4	0.8	4.3	0.85	5.2	16	0.8
0.2	tr	0.1	0.2	0.4	1.5	0.5	2.0	25	0.4
0.2	0.05	0.1	tr	0.1	1.2	0.35	0.5	70	0.2
0.2	0.1	0.2	0.1	0.4	0.6	0.6	1.1	55	0.4
0.2	0.1	0.2	0.1	1.6	1.9	0.6	2.6	23	0.7
0.2	0.5	0.3	0.2	3.5	2.8	1.2	4.0	30	0.9
0.3	0.4	0.2	0.4	14.6	13.9	1.3	15.2	9	3.7
0.3	0.4	0.2	0.6	12.4	12.0	1.5	13.5	11	2.9

Profile J-41, described February 8, 1962 by Jaime Villegas.

COROCORA Series, fine loamy Cumulic Humic Ultic Plinthaquept.

Area: 60 km NNW of Orocué, in a slackwater area, soil association Db.

Vegetation: Savanna of the Andropogon type, elevation 180 m.

Topography: Level, slightly depressional.

Parent material: Alluvial sediments.

Drainage: Very poorly drained.

A1g	0- 20 cm	Gray (10YR 5/1; moist : 3/2) clay with yellowish brown (10YR 5/8) mottles along root channels; massive angular prismatic fragments breaking apart along cracks in fine blocks; very hard, plastic and slightly sticky; abundant roots and common pores; pH 4.6; abrupt and wavy boundary.
B2g	10- 42 cm	Gray (10YR 5/1; moist: 7.5YR 3/2) clay with 25% strong brown (7.5YR 5/8) mottles; massive prismatic fragments breaking in medium blocks; hard, sticky and plastic; few roots and common pores; pH 4.6; gradual and smooth boundary.
IIB21gcn	42- 68 cm	Light gray (7.5YR 7/1; moist: 10YR 6/2) loam, with large yellowish brown (10YR 5/8) mottles and 2-5% small red (2.5YR 4/8) concretions; massive structure; very hard, sticky and plastic; few roots and pores; pH 4.9; gradual and smooth boundary.
IIB22gcn	68-100 cm	Gray brown (10YR 5/1.5) clay loam, with strong brown (7.5YR 5/8) mottles and 15%red (2.5YR 5/8) mottles and 15% red (2.5YR 4/8) concretions in the centre of the mottles; massive structure; firm, sticky and plastic; few roots and pores; pH 5.0; gradual and wavy boundary.
IIB3	100-130 cm	Light brownish gray (10YR 6/2) loam with 3% yellowish brown (10YR 5/6) and red (2.5YR 4/8) mottles; massive structure; sticky and plastic; few roots and pores; pH 4.7.

Note: Cracks 1 to 2 cm wide are visible on the surface.

Diagnostic horizons: 0- 42 cm Umbric epipedon;
42-100 cm Cambic horizon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %)					%C	%N	C/N	pH H_2O	P ppm	Free Fe_2O_3 %
		clay < 2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000						
A1g	0- 10	53	19	20	7	1	2.2	0.28	8	4.7	15.7	1.2
B2g	10- 42	53	24	9	14	0	0.8	0.11	7	5.1	24.7	1.6
IIB21gcn	42- 68	26	30	13	30	1	0.1	0.08	1	5.2	2.9	0.8
IIB22gcn	68-100	34	27	11	26	2	0.1	0.04	3	5.4	1.6	2.6
IIB3	100-130	27	22	13	37	1	0.1	0.02	5	5.3	2.6	1.1

Exchangeable cations (meq/100 g soil)						Total exch. bases (meq/100 g soil)	Cation exch. cap. (meq. 100 g soil)	Base sat. %	PW %
Ca	Mg	K	Na	Al	H				
5.7	2.7	0.6	0.1	3.7	18.4	9.1	27.5	33	5.0
3.0	1.6	0.3	0.2	5.4	16.0	5.1	21.0	24	4.2
1.8	0.7	0.1	0.1	1.3	3.1	2.7	5.8	47	1.5
3.2	4.0	0.2	0.1	3.2	1.9	7.5	9.4	80	2.4
2.0	1.1	0.2	0.1	1.9	7.4	3.4	10.8	31	1.8

Profile P-14, described March 14, 1963 by Ricardo Bernal.

DUYA Series, sandy Typic Quartzipsamment.

Area: 10 km NE of Gravo Norte, on a dune in the Aeolian Plain, soil association Em, elevation 200 m.

Vegetation: Savanna of the Trachypogon ligularis - Paspalum carinatum type, with some shrubs.

Parent material: Quartzose aeolian sand.

Topography: Undulating, mainly convex slopes.

Drainage: Excessively drained.

A1	0- 10 cm	Brown (10YR 5/3) fine sand; loose, granular; non-sticky, non-plastic; abundant fine and medium pores and abundant roots; pH 4.6; gradual and wavy boundary.
A3	10- 75 cm	Strong brown (7.5YR 5/6), rubbed and moist; reddish brown (5YR 4/4) fine sand; loose, granular; non-sticky, non-plastic; few roots and common fine pores; pH 4.8; diffuse and wavy boundary.
B11	75-135 cm	Reddish yellow (5YR 6/8), rubbed and moist: yellowish red (5YR 5/8) fine sand; loose, granular (occasionally very weak blocky); non-sticky, non-plastic; very few roots, some fine pores; pH 4.8; diffuse and wavy boundary.
B12	135-x cm	Strong brown (7.5YR 5/8) with about 15% light brown (7.5YR 6/4) mottles, fine sand; weak massive structure, breaking apart in loose grains; very few roots and pores; pH 4.8.

Diagnostic horizon: 0-10 cm Ochric epipedon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %)					%C	%N	C/N	pH H_2O	P ppm
		clay < 2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000					
A1	0-10	2	2	3	72	21	0.3	0.04	8	4.8	3.0
A3	10-75	3	2	4	68	23	0.15	0.02	8	5.0	10.5
B11	75-135	4	2	3	68	23	0.05	0.01	5	5.0	6.1
B12	135-170	4	3	4	72	17	tr	0.01	-	5.0	7.5

Exchangeable cations (meq/100 g soil)						Total exch. bases (meq/100 g soil)	Cation exch. cap. (meq/100 g soil)	Base sat. %	PW %
Ca	Mg	K	Na	Al	H				
0.1	0.1	0.05	0.05	0.4	0.3	0.3	0.6	50	0.2
0.1	0.2	0.1	0.1	0.3	0.2	0.5	0.6	83	0.3
0.1	0.1	tr	0.05	0.5	0.5	0.25	0.8	31	0.3
0.1	0.1	tr	0.1	0.4	0.5	0.3	0.8	38	0.2

Profile P-26, described March 29, 1963 bv Ricardo Bernal.

GUANAPALO Series, fine loamy (Oxic) Ultic Plinthaquept.

Area: 18 km NE of Cravo Norte, between two "escarceos" (low ridges) of the Aeolian Plain, soil association Es, elevation 170 m.

Vegetation: Savanna of the Mesosetum type.

Parent material: Llanos loess.

Topography: Flat.

Drainage: Poorly drained.

A1g	0- 20 cm	Dark gray to very dark gray (10YR 4/1 and 10YR 3/1) silt loam; medium to fine weak blocky structure; friable, non-sticky, non-plastic; abundant roots and large to medium pores; pH 4.8; clear and wavy boundary.
A2g	20- 39 cm	Dark gray to gray (10YR 4/1 and 10YR 5/1) loam; medium moderate to strong blocky structure; hard, non-sticky and slightly plastic; abundant roots and common fine pores; pH 4.8; gradual and wavy boundary.
B21g	39-119 cm	Brownish yellow (10YR 6/6), light gray (10YR 7/1) and red mottles (2.5YR 5/8), all these colours in equal proportion, giving reddish yellow (5YR 6/6) when rubbed, clay loam; medium to fine moderate subangular blocky structure with clay skins; hard, slightly sticky and slightly plastic; few roots and common fine pores; pH 4.8; clear and wavy boundary.
B22gcn	119-160 cm	Light gray (10YR 6/1) with 50% dark yellowish brown and reddish yellow (10YR 4/6 and 5YR 6/6) mottles and concretions, clay; massive structure breaking into weak to moderate fine blocks with clay skins; friable, slightly sticky and slightly plastic; common fine and medium pores and no roots; pH 4.8.

Diagnostic horizons: 0- 39 cm Umbric epipedon;
39-160 cm Cambic horizon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %)					%C	%N	C/N	pH H_2O	P ppm
		Clay <2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000					
A1g	0- 20	19	22	32	24	3	1.4	0.15	9	4.8	7.0
A2g	20- 39	28	19	29	23	1	0.7	0.08	9	4.7	5.7
B21g	39-119	34	18	26	21	1	0.2	0.03	7	5.0	0.5
B22gcn	119-160	41	16	21	21	1	0.1	0.03	3	5.1	0.3

Exchangeable cations (meq/100 g soil)						Total exch. bases (meq/100 g soil)	Cation exch. cap. (meq/100 g soil)	Base sat. %	PW %
Ca	Mg	K	Na	Al	H				
0.3	0.1	0.05	0.2	1.5	6.2	0.65	5.8	11	1.4
0.2	0.05	0.1	0.2	2.0	5.2	0.55	5.7	10	1.0
0.2	0.05	tr	0.1	2.8	5.3	0.35	5.7	6	1.6
0.2	0.1	tr	0.1	4.0	6.7	0.4	7.1	6	2.0

Profile W-5, described March 1962 by Armand van Wambeke.

SALIVA Series, fine loamy Oxic Tropudultic Dystropept.

Area: 12 km NW of Orocué, 150 metres from a deeply incised stream, on the Aeolian Plain, soil association Er, elevation 180 m.

Vegetation: Savanna of the Trachypogon ligularis type, with scattered chaparro trees (Curatella americana).

Parent material: Llanos loess.

Topography: Nearly level, slightly convex, smooth.

Drainage: Well drained.

A1	0 - 8 cm	Brown (10YR 3/2; rubbed: 3/3) sandy clay loam; medium and fine, moderate, blocky structure; soft to hard, non-plastic, non-sticky; common roots; pH 4.7; diffuse and smooth boundary.
A3	8 - 26 cm	Strong brown (7.5YR 5/6; same rubbed) sandy clay loam; massive structure; soft to hard, non-plastic and non-sticky; common roots, no large pores; pH 4.6; diffuse and smooth boundary.
B1	26 - 80 cm	Strong brown (7.5YR 5/6) sandy clay loam; massive, hard; non-plastic and slightly sticky; few roots and no large pores; pH 5.0; diffuse and smooth boundary.
B21	80 - 120 cm	Yellowish-red to strong brown (6.25YR 5/6) loam; massive; friable, slightly plastic and slightly sticky; few roots and no large pores; pH 5.0; diffuse and smooth boundary.
B22	120 - 190 cm	Yellowish-red to strong brown (6.25YR 5/6) loam; very weak, fine, blocky structure breaking in crumbs; very friable, slightly plastic and slightly sticky; no roots or large pores; pH 4.8.

Note: *All horizons have common, fine to medium pores.*

Diagnostic horizons: 0-26 cm Ochric epipedon;
26-80 cm Cambic horizon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %) clay < 2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000	%C	%N	C/N	pH H_2O	P ppm	Free Fe_2O_3 %
A1	0- 8	23	9	11	48	9	1.1	0.11	10	5.0	2.6	1.4
A3	8- 26	24	9	12	45	10	0.7	0.07	10	5.1	1.5	1.4
B1	26- 80	29	12	12	37	10	0.3	0.02	15	5.6	0.4	1.5
B21	80-120	21	15	19	37	8	0.2	0.02	10	5.8	0.6	1.8
B22	120-190	21	16	18	37	8	0.2	0.02	10	5.7	0.3	0.8

Exchangeable cations (meq/100 g soil) Ca	Mg	K	Na	Al	H	Total exch. bases (meq/100 g soil)	Cation exch. cap. (meq/100 g soil)	Base sat. %	PW %
0.2	0.1	0.2	0.1	1.5	5.1	0.6	5.6	11	1.5
0.1	0.1	0.1	0.05	1.4	3.8	0.35	4.2	8	1.5
0.1	0.1	0.1	tr	0.8	2.7	0.3	3.0	10	1.0
0.1	0.1	0.2	0.1	0.5	3.7	0.5	4.1	12	1.3
0.2	0.1	0.2	0.1	0.8	3.0	0.6	3.5	17	1.4

Profile C-19, described January 22, 1962 by Marco Cano.

ANZUELO Series, fine clayey Umbric Ultic Plinthaquept.

Area: 10 km NW of Orocué, in an "estero" of the Aeolian Plain, soil association Ee.

Vegetation: Savanna of the Mesosetum type.

Parent material: Sheetwash material, derived from Llanos loess, mixed with organic matter.

Topography: Flat, elongated depressional.

Drainage: Very poorly drained.

A11g	0-20 cm	Black (10YR 2/1) clay; medium and fine, weak, blocky structure; friable, non-sticky and non-plastic; abundant roots and common pores; pH 5.2; clear and smooth boundary.
Abg	20-36 cm	Dark gray (10YR 4/1) clay; medium and fine, weak, blocky structure with clay skins in root channels; very friable, sticky and slightly plastic; abundant roots, common pores; pH 4.8; clear and smooth boundary. Note: in this horizon some irregular inclusions of the first horizon are found.
B21g	36-75 cm	Gray (5Y 5/1) clay with 2% irregular olive (5Y 5/3) mottles in root channels; medium and fine, weak, blocky structure with clay skins in root channels; very friable, sticky and slightly plastic; common roots and no pores; pH 4.8; gradual and wavy boundary.
B22g	75x cm	Dark yellowish brown (10YR 4/8) and gray (5Y 5/1) clay, rubbed: dark reddish-brown (5YR 3/4); massive structure with some pores; plastic and sticky; no roots and pores; pH 4.8.

Note: Depth of profile limited to 80 cm because of excess water in pit.

Diagnostic horizons: 0- ± 25 cm Umbric epipedon;
36-75 cm Cambic horizon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %)					%C	%N	C/N	pH H_2O	P ppm
		clay < 2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000					
A11g	0-20	not determined					5.2	0.77	7	5.1	0.3
ABg	20-36	54	26	13	6	1	0.7	0.13	5	5.1	0.8
B21g	36-75	66	17	9	7	1	0.4	0.09	4	5.1	0.7
B22g	75-x	64	19	12	5	0	0.3	0.08	4	5.2	-

Exchangeable cations (meq/100 g soil)						Total exch. bases (meq/100 g soil)	Cation exchn. cap. (meq/100 g soil)	Base sat. %	PW %
Ca	Mg	K	Na	Al	H				
0.2	0.2	0.1	0.2	2.3	34.1	0.7	34.7	2	6.4
0.1	0.1	0.1	0.1	0.4	14.2	0.4	14.6	3	3.5
0.2	0.4	0.4	0.1	5.1	14.8	0.8	15.4	5	3.2
0.2	0.2	0.2	0.1	7.0	15.1	0.7	15.7	4	4.0

Profile C-60, described June 12, 1962 by Marco Cano.

HORIZONTES Series, fine clayey (Oxic) Palehumultic Dystropept.

Area: 10 km E of the river Manacacías, 25 km S of the river Meta, on the broad summit of the level High Plains, soil association Aa, elevation 200 m.

Vegetation: Savanna of the Trachypogon vestitus type.

Parent material: Llanos loess.

Topography: Level, with convex gentle slope towards the broad and shallow drainage ways.

Drainage: Well drained.

A11	0- 8 cm	Very dark gray brown (10YR 3/2) clay; weak fine, blocky structure; friable, slightly plastic, slightly sticky; abundant roots and pores; pH 4.8; smooth and clear boundary.
A12	8- 19 cm	Dark brown (7.5YR 4/4) clay; weak, fine and medium blocky structure; friable, slightly plastic, slightly sticky; abundant roots and common pores; pH 4.8; smooth and clear boundary.
B21	19- 35 cm	Strong brown (7.5YR 4/5) clay; moderate fine, blocky structure with clay skins in channels of roots and macro-organisms; friable, plastic, and sticky; common roots and pores; few dark coloured streaks from A horizon; pH 5.0; smooth and gradual boundary.
B22	35- 66 cm	Yellowish red (5YR 5/8) clay; weak, fine, blocky structure; friable, slightly plastic and slightly sticky; common roots and pores; some dark-coloured streaks of upper horizons; pH 5.1; smooth and gradual boundary.
B23	66-100 cm	Red (2.5YR 5/8) clay; massive structure; very friable, slightly plastic and slightly sticky; common roots and pores; pH 5.2; smooth and gradual boundary.
B31	100-125 cm	Red (2.5YR 5/8) clay, with 2% strong brown (7.5YR 5/6) mottles along root channels; massive structure; very friable, slightly plastic and slightly sticky; few roots and pores, pH 5.2.

Diagnostic horizons: 0-19 cm Ochric epipedon;
19-100 cm Cambic horizon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %)					%C	%N	C/N	pH H_2O	P ppm	Free Fe_2O_3 %
		clay < 2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000						
A11	0- 8	47	17	18	13	5	2.7	0.17	16	4.4	3.3	2.5
A12	8- 19	51	23	10	13	3	1.8	0.13	14	4.4	2.2	2.4
B21	19- 35	62	10	12	13	3	1.0	0.11	9	4.7	0.9	2.9
B22	35- 66	65	8	13	10	4	0.7	0.07	10	5.0	1.6	3.1
B23	66-100	56	12	21	9	2	0.5	0.06	8	5.4	0.5	2.8
B31	100-125	59	7	22	9	3	0.4	0.05	8	5.7	-	3.0

Exchangeable cations (meq/100 g soil)						Total exch. bases (meq/100 g soil)	Cation exch. cap. (meq/100 g soil)	Base sat. %	PW %
Ca	Mg	K	Na	Al	H				
0.3	0.2	0.3	0.1	3.3	16.0	0.9	16.8	5	3.1
0.2	0.1	0.2	0.1	2.6	13.8	0.6	14.4	4	2.7
0.2	0.2	0.2	0.1	2.3	8.8	0.7	9.4	7	2.0
0.2	0.05	0.1	0.1	2.1	9.4	0.45	9.9	5	2.1
0.1	0.1	0.1	0.1	1.1	7.1	0.4	7.5	5	2.1
0.2	0.1	0.2	0.1	5.6	6.7	0.6	7.3	8	2.4

Profile D-13, described 26 February 1968 by Doeko Goosen and Marco Cano.

LAGUNAZO Series, fine silty Oxic Palehumultic Dystropept.

Area: 30 km SW of Paso Nuevo, on the broad summit of the level High Plains, soil association Aa, elevation 200 m.

Vegetation: Savanna of the Trachypogon vestitus type.

Parent material: Llanos loess.

Topography: Level, on three sides surrounded by convex and straight, very gentle slopes towards the local drainage ways.

Drainage: Well drained.

A11	0- 15 cm	Dark grayish brown when moist to dark yellowish brown when dry (10YR 4/2 - 10YR 4/4) silty clay loam; weak crumby structure; hard when dry; non-plastic, non-sticky; abundant roots and fine to medium pores; pH 4.6; smooth and gradual bouncary.
A12	15- 40 cm	Strong brown (7.5YR 5/6) silty clay loam; massive, breaking in weak, medium to fine blocky structure; slightly plastic and slightly sticky; common roots and common fine to medium pores; pH 5.0; smooth and gradual boundary.
B21	40- 65 cm	Yellowish red (5YR 5/8) silty clay loam; massive, breaking in weak, medium to fine blocky structure; slightly plastic and slightly sticky; few roots and common fine pores; pH 5.3; smooth and diffuse boundary.
B22	65- 95 cm	Yellowish red (5YR 4/8) silty clay loam; massive, breaking in moderate to weak, medium to fine blocky structure; plastic and slightly sticky; very few roots and common fine pores; pH 5.3; smooth and diffuse boundary.
B23	95-125 cm	Yellowish red (5YR 4/8) silty clay loam; massive structure; friable to very friable; plastic and slightly sticky; no roots, few pores; pH 5.7.

Note: This profile was described in a 40 cm deep pit. The lower horizons have been described from samples taken with the "Edelman" auger.

Diagnostic horizons: 0- 40 cm Ochric epipedon;
15-125 cm Cambic horizon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %)					%C	%N	C/N	pH H_2O	P ppm	Free Fe_2O_3 %
		clay < 2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000						
A11	0- 15	29	21	39	9	2	1.7	0.16	11	4.6	2.0	2.3
A12	15- 40	32	21	38	8	1	0.8	0.07	11	5.0	0.7	2.6
B21	40- 65	33	20	38	8	1	0.6	0.04	15	5.3	0.4	2.6
B22	65- 95	34	20	37	8	1	0.5	0.04	13	5.3	0.3	2.6
B23	95-125	35	20	36	8	1	0.4	0.04	10	5.7	0.1	2.7

Exchangeable cations (meq/100 g soil)						Total exch. bases (meq/100 g soil)	Cation exch. cap. (meq/100 g soil)	Base sat. %	PW %
Ca	Mg	K	Na	Al	H				
0.2	0.1	0.1	tr	3.6	9.1	0.4	9.5	4	1.9
0.2	0.1	0.05	tr	2.9	7.3	0.35	7.7	5	1.8
0.1	0.1	0.1	0.1	2.5	5.4	0.4	5.8	7	1.4
0.2	0.1	tr	0.1	2.6	5.5	0.4	5.9	7	1.5
0.2	0.1	0.1	tr	1.8	5.9	0.4	6.3	6	1.2

Profile C-71, described July 8, 1962 by Marco Cano.

NAPOLES Series, coarse loamy Oxic Dystropept.

Area: 40 km south of the river Meta, 10 km east of the Manacacias river, on the lower slope of the gently undulating High Plains, soil association Aa, elevation 200 m.

Vegetation: Savanna of the Paspalum pectinatum type.

Parent material: Migratory sheetwash material, derived from Llanos loess.

Topography: Nearly level lower slope.

Drainage: Well drained.

A1	0- 14 cm	Dark brown (10YR 3/3) and very dark gray brown (10YR 3/2) fine loamy sand; weak medium and fine blocky structure; friable, non-plastic and non-sticky; abundant roots and common pores; pH 4.8; smooth and clear boundary.
A3	14- 28 cm	Brown and yellowish brown (10YR 4/3 and 5/6) fine loamy sand; weak medium and fine blocky structure with common fine and very fine pores; non-plastic and non-sticky; common roots and large pores; pH 4.8; smooth and gradual boundary.
B21	28- 52 cm	Strong brown (7.5YR 5/6) with some dark streaks from above, sandy loam; massive structure breaking easily in crumbs, common fine and very fine pores; very friable, non-plastic and non-sticky; common roots and large pores; pH 4.9; smooth and gradual boundary.
B22	52- 85 cm	Strong brown (7.5YR 5/8 and 5/6) with some dark streaks from above, sandy loam; massive structure, common fine and very fine pores; very friable, non-plastic and non-sticky; few roots and pores; pH 4.9; smooth and diffuse boundary.
B23	85-150 cm	Yellowish red (5YR 5/8) sandy loam, 2% irregular olivebrown mottles and some darker streaks from above; massive structure; friable, non-plastic and non-sticky; few roots and pores; pH 5.0.

Note: Below 150 cm follows a layer of iron concretions.

Diagnostic horizons: 0-28 cm Ochric epipedon;
28-150 cm Cambic horizon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %)					%C	%N	C/N	pH H_2O	P ppm	Free Fe_2O_3 %
		clay < 2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000						
A1	0- 14	8	3	8	62	19	0.6	0.06	10	4.7	10.2	1.0
A3	14- 28	10	5	7	63	15	0.4	0.04	10	4.9	10.0	1.0
B21	28- 52	12	5	9	58	16	0.4	0.04	10	5.0	9.3	1.3
B22	52- 85	13	4	11	57	15	0.2	0.03	7	4.6	5.7	1.2
B23	85-150	14	5	13	55	13	0.1	0.05	2	4.5	2.6	1.6

Exchangeable cations (meq/100 g soil)						Total exch. bases (meq/100 g soil)	Cation exch. cap. (meq/100 g soil)	Base sat. %	PW %
Ca	Mg	K	Na	Al	H				
0.2	0.1	0.1	0.1	0.6	1.9	0.5	2.3	22	0.5
0.2	0.1	tr	0.1	0.6	1.6	0.4	1.9	21	0.5
0.1	tr	tr	0.1	0.4	1.2	0.2	1.5	13	0.4
0.2	0.1	tr	0.2	0.3	0.8	0.5	1.3	38	0.4
0.1	0.1	0.1	0.2	0.3	0.7	0.5	1.1	45	0.4

Profile T-35, described March 29, 1963 by Humberto Toquica.

GUANAPALO Series, fine silty (Oxic) Ultic Plinthaquept.

Area: 6 km E. of the river Meta, 15 km S of Paso Nuevo, on an escarceo of the level, poorly drained High Plains, soil association As, elevation 180 m.

Vegetation: Savanna of the Leptocoryphium lanatum type.

Parent material: Llanos loess.

Topography: Flat, very gently undulating micro-relief of escarceos.

Drainage: Poorly drained.

A1g	0- 10 cm	Very dark gray (10YR 3/1) silt loam; medium crumby structure; friable, non-sticky, non-plastic; abundant roots and large pores; many fine pores; pH 4.4; gradual and smooth boundary.
A2g	10- 35 cm	Very dark gray (10YR 3/1) silt loam; massive structure; very friable, slightly plastic and slightly sticky; abundant roots and large pores; common fine pores; pH 4.4; gradual and smooth boundary.
B21g	35- 83 cm	Gray brown (10YR 5/2), rubbed; dark gray (10YR 4/1) silt loam; streaks of organic matter along pores and roots channels; massive structure; friable, slightly plastic and slightly sticky; few roots, abundant large pores; many fine and medium pores; pH 4.6; diffuse and smooth boundary.
B22g	83-113 cm	Light gray (10YR 6/1), rubbed: gray (10YR 5/1) silty clay loam; massive structure; friable, slightly plastic and slightly sticky; no roots, common pores; pH 4.6; gradual and smooth boundary.
B31gcn	113-153 cm	Light brownish gray (10YR 6/2) with 30% red (2.5YR 4/8), partially indurated mottles, rubbed; light reddish brown (2.5YR 6/4), silty clay loam; massive structure; firm, slightly plastic and slightly sticky; no roots, common pores; pH 4.6; gradual and smooth boundary.
B32gcn	153-170 cm	Light gray (10YR 6/1) with 50% red (10YR 4/8), partially indurated mottles, rubbed: red (10YR 5/6) silty clay loam; massive structure; firm, slightly plastic and slightly sticky; no roots, common fine pores; pH 4.6.

Diagnostic horizons: 0- 35 cm Umbric epipedon;
35-113 cm Cambic horizon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %)					%C	%N	C/N	pH H_2O	P ppm
		clay < 2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000					
A1g	0- 10	14	25	43	18	0	2.5	0.18	14	4.5	12.9
A2g	10- 35	17	26	40	17	0	1.4	0.12	12	4.6	5.9
B21g	35- 83	24	22	40	14	0	0.4	0.05	8	4.7	8.2
B22g	83-113	31	22	32	15	0	0.2	0.04	5	4.7	3.6
B31gcn	113-153	31	24	31	13	1	0.1	0.04	3	4.7	1.5
B32gcn	153-170	34	20	31	13	2	0.1	0.02	5	5.0	0.5

Exchangeable cations (meq/100 g soil)						Total exch. bases (meq/100 g soil)	Cation exch. cap. (meq/100 g soil)	Base sat. %	PW %
Ca	Mg	K	Na	Al	H				
0.2	0.2	0.2	0.1	2.0	10.4	0.7	11.0	6	1.6
0.1	tr	0.1	0.1	1.9	7.2	0.3	7.5	4	1.3
0.2	0.1	0.2	0.1	2.0	7.4	0.6	8.0	8	1.2
0.2	0.1	0.2	0.1	2.4	4.4	0.6	5.0	12	1.4
0.2	0.2	0.1	0.1	3.0	6.0	0.6	6.6	9	1.7
0.3	0.2	0.1	0.1	3.2	5.2	0.7	5.8	12	1.7

Profile D-11, described February 29, 1968 by Doeko Goosen and Marco Cano.

GUANAPALO Series, coarse silty (Oxic) Ultic Plinthaquept.

Area: 20 km S of Paso Nuevo, between two escarceos of the level, poorly drained High Plains, soil association As, elevation 190 m.

Vegetation: Savanna of the Mesosetum type.

Parent material: Llanos loess.

Topography: Flat, very gently undulating microrelief of escarceos.

Drainage: Poorly drained.

A1g	0-15 cm	Very dark gray silt loam; weak, fine subangular blocky structure; non-sticky, non-plastic; abundant roots and pores.
A2g/B21g	15-55 cm	Dark gray brown to gray brown silt loam; non-sticky, slightly plastic; few roots, abundant pores.
B21g/B22g	55-80 cm	Light gray silt loam, with red mottles increasing downwards; non-sticky, slightly plastic; no roots, common pores.

Note: This incomplete profile description is based on auger samples.

Diagnostic horizons: 0-± 35 cm Umbric epipedon;
35- 80 cm Cambic horizon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %)					%C	%N	C/N	pH H_2O	P ppm	Free Fe_2O_3 %
		clay < 2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000						
A1g	0-15	13	26	49	11	1	3.8	-	-	4.9	-	0.1
A2g/B21g	15-55	16	23	49	12	0	0.8	-	-	4.9	-	0.1
B21g/B22g	55-80	16	23	46	13	2	0.3	-	-	4.8	-	0.2

Exchangeable cations (meq/100 g soil)						Total exch. bases (meq/100 g soil)	Cation exch. cap. (meq/100 g soil)	Base sat. %	PW %
Ca	Mg	K	Na	Al	H				
0.2	tr	0.1	0.1	2.8	-	0.4	11.7	3	1.7
0.2	0.1	0.1	0.1	2.5	-	0.5	0.5	10	1.0
0.2	0.1	0.1	tr	2.0	-	0.4	3.9	10	0.8

Profile D-12, described February 29, 1968 by Doeko Goosen and Marco Cano.

GUANAPALO Series, *fine silty (Oxic) Ultic Plinthaquept.*

Area: 20 km S of Paso Nuevo, 5 m W of profile D-10, on an escarceo of the level, poorly drained High Plains, soil association As, elevation 190 m.

Vegetation: Savanna of the Leptocoryphium lanatum type.

Parent material: Llanos loess.

Topography: Level, very gently undulating microrelief of escarceos.

Drainage: Poorly drained.

A1g	0-20 cm	Dark gray silt loam; weak to medium, fine subangular blocky structure; non-sticky, non-plastic; abundant roots and pores.
A2g/B21g	20-60 cm	Gray brown silt loam; non-sticky, slightly plastic; few roots, abundant pores.
B21g/B22g	60-90 cm	Light gray silt loam, some reddish brown mottles in the lower part; non-sticky, slightly plastic; no roots, common pores.

Note: This incomplete profile description is based on auger samples.

Diagnostic horizons: 0- ± 35 cm Umbric epipedon;
35- 90 cm Cambic horizon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %)					%C	%N	C/N	pH H_2O	P ppm	Free Fe_2O_3 %
		clay < 2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000						
A1g	0-20	17	22	49	11	1	0.9	-	-	4.7	-	0.1
A2g/B21g	20-60	25	22	40	13	0	1.8	-	-	4.7	-	0.04
B21g/B22g	60-90	25	21	42	12	0	1.7	-	-	4.5	-	0.1

Exchangeable cations (meq/100 g soil)						Total exch. bases (meq/100 g soil)	Cation exch. cap. (meq/100 g soil)	Base sat. %	PW %
Ca	Mg	K	Na	Al	H				
0.2	0.1	0.2	0.1	4.1	-	0.6	11.8	5	1.6
0.2	0.1	0.1	0.1	3.5	-	0.5	8.7	6	1.5
0.2	0.1	0.1	0.6	3.2	-	1.0	5.6	18	1.6

Profile Ch-66, described August 29, 1962 by José Chaparro.

CARIMAGUA Series, fine silty Aeric Plinthaquept .

Area: South of the river Meta, 11 km due south of Orocué in an "estero" (broad, shallow drainage way), soil association Ae, elevation 200 m.

Vegetation: Savanna of the Andropogon virgatus type and palm-forest of the Mauritia minor type.

Parent material: Sheetwash material derived from Llanos loess, mixed with organic matter.

Topography: Flat and depressional.

Drainage: Very poor.

A1g	0- 24 cm	Black to very dark gray (10YR 2/1 and 3/1) silty clay loam with a high amount of organic matter; weak fine crumb structure with few fine pores in crumbs; slightly plastic and non-sticky; common roots and pores; pH 4.4; smooth and gradual boundary.
ABg	24- 48 cm	Dark gray brown (10YR 4/2) silty clay loam; weak fine crumb structure with common fine pores; friable, slightly plastic and slightly sticky; few roots and common pores; pH 4.6; smooth and gradual boundary.
B1gcn	48- 67 cm	Dark gray brown (10YR 4/2) silt loam, with 20% yellowish brown (10YR 5/6) mottles and 3% dark yellowish brown (10YR 4/4) strong concretions; weak fine blocky structure with many fine pores, slightly plastic and slightly sticky; few roots and common large pores; pH 4.8; smooth and gradual boundary.
B2gcn	67-100 cm	Gray brown (10YR 5/2) silt loam, with 25% yellowish brown (10YR 5/6) mottles and 5% dark yellowish brown (10YR 4/4) concretions; massive structure with common fine pores; slightly plastic and slightly sticky; no roots, few large pores; pH 5.0.

Diagnostic horizons: 0- ± 30 cm Umbric epipedon;
48- 100 cm Cambic horizon.

Analytical data:

Horizon	Depth in cm	Particle size distribution (microns, %)					%C	%N	C/N	pH H_2O	P ppm	Free Fe_2O_3 %
		clay < 2	fine silt 2-20	coarse silt 20-50	fine sand 50-250	coarse sand 250-2000						
A1g	0-24	34	27	28	11	0	6.5	0.52	13	4.2	0.1	2.3
ABg	24-48	28	27	34	11	0	0.9	0.12	8	4.3	1.6	0.6
B1gcn	48-67	25	27	33	14	1	0.4	0.08	5	4.3	0.4	1.1
B2gcn	67-100	27	23	34	14	2	0.3	0.07	4	4.5	0.9	1.4

Exchangeable cations (meq/100 g soil)						Total exch. bases (meq/100 g soil)	Cation exch. cap. (meq/100 g soil)	Base sat. %	PW %
Ca	Mg	K	Na	Al	H				
0.7	0.3	0.4	0.2	4.2	29.8	1.6	31.4	5	13.3
0.4	0.1	0.1	0.1	2.5	6.3	0.7	7.0	10	1.6
0.3	0.1	0.1	0.1	1.9	3.8	0.6	4.4	14	0.9
0.4	0.1	0.1	0.1	1.5	3.5	0.7	4.2	17	0.9

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