SOIL GENESIS IN THE HIGHVELD REGION
SOUTH AFRICA

H. J. VON M. HARMSE

STELLINGEN

I

The problems which face a pedologist are peculiarly complex. It is rare that they consist of a single unitary phenomena explicable by a particular elementary cause. The true explanation is therefore necessarily multiple, and often involves an estimate of the measure of participation of each agent. The pedologist must be constantly on the alert for mutations and for the insidious incursion of new factors.

II

Clay accumulation and clay skins should not be regarded as arising exclusively from a physical translocation of clay. Criteria for differentiating between the various modes of accumulation are as yet too subtle to allow an exclusive classification or even an evaluation of the relative importance of each.

III

Thermodynamic considerations substantiate the contentions of Mohr (1944) and Jackson (1965), concerning the importance of soil-climate in the genesis of tropical soils and the weathering sequence of clay minerals, respectively.

E. C. J. Mohr (1944) Soils of Equatorial Regions.
Ann Arbor, 765 p.
M. L. Jackson (1965) Soil Sci., v. 99, 15—22.

IV

Amorphous minerals and mineral colloids occur more extensively in soils than has hitherto been believed.

V

From a genetic point of view the classifications of soils according to the American System (7th Approximation) does not allow an exclusive differentiation between soils with an aquired and an inherited horizonation.

USDA., Soil Survey Staff: Soil Classification a comprehensive system.
7th Approximation, August 1960.

VI

Mineralogical studies of the sand fraction i.e. heavy- and light- fractions are a necessity in pedological studies.

VII

Chromium radiation (Cr-Kα 2.28Å) due to the long spacings involved in some mixed-layer minerals may be profitably employed in clay-mineral investigations.

VIII

The distribution of garnet in the arenaceous members of the Karroo System of South Africa is suggestive of a source of derivation south of the present confines of the continent. Furthermore, sedimentary petrological investigations, owing to the ubiquity of garnet in the above mentioned strata may provide useful additional information to the eventual establishment of the tenability of the hypothesis of a former physical link between Africa and South America.

This thesis and T. G. Wardaugh (1960) M. Sc. Thesis, Univ. O.F.C., Bloemfontein, 71 p.

IX

Converging evidence coming from many independent and interdependent facts suggest that the statement by Dietz, "The peerless Vredefort ring structure of South Africa defies rational interpretation by tectonic, volcanic and magmatic forces", has only a modest probability of being true.

R. S. Dietz (1961) J. Geol., v. 69, 499—516.

X

The possibility of locating oil in commercial quantities in the Karroo basin, is remote.

XI

A question relevant to the earth sciences: Metaphorically speaking, is the anatomy of an elephant reconstructable by means of a microscopical examination?

3 May, 1967

H. J. VON M. HARMSE.

SOIL GENESIS IN THE HIGHVELD REGION SOUTH AFRICA

PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR
IN DE WISKUNDE EN NATUURWETENSCHAPPEN
AAN DE RIJKSUNIVERSITEIT TE UTRECHT,
OP GEZAG VAN DE RECTOR MAGNIFICUS,
PROF. DR. A. R. HULST,
VOLGENS BESLUIT VAN DE SENAAT
IN HET OPENBAAR TE VERDEDIGEN
OP WOENSDAG 3 MEI 1967,
DES NAMIDDAGS TE 4.15 UUR

DOOR

HENDRIK JOHANNES VON MOLTITZ HARMSE

GEBOREN OP 26 MAART 1934 TE
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1967
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PROMOTOR:

PROF. DR. IR. F. A. VAN BAREN

This thesis will be published in the Transactions of the
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PREFACE

Not so many years ago, one could have searched the literature without finding much reference to paleo-soils or complex profiles. Many local investigations concerned with soil classification have regarded the different horizons of soil profiles as genetic soil-horizons, though little has been done to substantiate this view. As a consequence, the major concept in vogue was that the vertical succession of horizons was for the most part engendered in situ by pedogenesis. Lately it has, however, become more and more apparent that certain horizons, thought to be pedogenetic, were in fact caused by the interference of extraneous agents associated with periods of landscape instability. A new situation is developing in which there is ample scope for new concepts and the application of geomorphological and ecostratigraphic principles in pedogenetic thinking. As befits any branch of the earth sciences due recognition will have to be given to the ever-changing interplay of the processes which shape the face of the earth. Owing to their susceptibility to relative slight changes in climate or even in the amount of precipitation, landscapes in the semi-aird subtropical regions are relatively more unstable. In South Africa, as in Australia, soil studies may play an important role in the unravelling of the events of the recent past. The identification of horizons not attributable in all their aspects to pedogenetic processes only, and the evaluation of the influence of layering of strata with different permeabilities — as far as current knowledge permits — in determining the geographical distribution of soils, has been the theme of this investigation.

In the years since 1953, Professor P.B. Ackermann (University of Potchefstroom, South Africa) has been a constant source of information, encouragement, constructive critisism and useful advice. To him I express my warm thanks.

ADDENDA and ERRATA.

Page 101	To footnote add: For a comparison with the criteria of the 7th Approximation (and supplements) the percentage of organic carbon should be multiplied by a factor 100/77.
Page 127	Add: These soils are provisionally regarded as belonging to the great group Ustochrepts (Paraquic Ustochrepts).
Page 138	Lines 2 to 6 should read: These epipedons have lower carbon contents than 0.58 per cent and lack strong structures. Profiles 4/7, 43/47 and 182/185 would therefore, mainly in consideration of the dubious argillic identity of the B horizons and gley colours, seem to meet the minimum requirements of an Inceptisol (Aquepts). Owing to the fact that chromas are higher than that of the Typic Aquepts and organic matter content does not decrease regularly with depth, Aeric Cumulic Normaquepts seems to be the most appropriate great group. Profiles 143/145, 129/132 and 157/161 may also be regarded as Inceptisols because of the B horizons (cambic), underlying the Mollic epipedons, being less than 50 per cent saturated with bases. These pedons are provisionally classified as Mollic Aeric Cumulic Normaquepts.
Page 157	Line 15 to 18 should read: Profile 19/21r does not qualify as Vertisol (sensu stricto). It meets the minimum requirements of a Mollisol (Ustolls) more accurately. Andic Haplustoll seems to be an appropriate great group owing to the possible presence of amorphous colloids and a cambic horizon. Sub-ordinate vertisolic characteristics such as those vested in the tendency to granulate (mulch), weakly developed cracks and a clay content of more than 30 per cent could be denoted by the adjective "vertic" (Vertic Andic Haplustoll).
Page 157	Profile number 19/20 should read: Profile number: 19/21r.
Page 164	Add: Profile 86/88, owing to the presence of detectable quantities of amorphous colloids, qualifies as an Andic Aridic Haplustoll.
Page 170	Line 3: replace great group by suborder and add adjective "aeric" to Aquept Psamments in parentheses.

Utrecht, April 1967.

Professor Dr. F.A. van Baren, I was greatly privileged to work under your guidance. I am aware of the fact that more problems have been identified than could adequately be explained at this stage. I believe, however, that the basic philosophy of this investigation may be as important as the specific conclusions. I tender my sincere appreciation for the many helpful suggestions and encouragement during the course of this study and also for the organization of material aid.

Mr. W.L.P.J. Mouthaan, I am more deeply indebted to you than could be adequately expressed. I must thank you for the many ways in which you have aided me and for your most excellent advice. A special word of thanks is also due to your family, on behalf of mine, for the cordial hospitality extended to us.

Dr. Ir. J.J. Reynders, I thank you for your assistance and cooperation in helping to analyse some problems encountered during the investigation.

Grateful acknowledgement is made for help received from Dr. J.H. Grobler (Potchefstroom, South Africa), Jhr. Mr. L.A. Quarles van Ufford, Dr. C.J. de Mooy, Drs. H. Bent, Dr. C. Luna, Mr. G. Hermans (Utrecht), Dr. A. Jongerius (Bennekom), Dr. A. Herbillion (Louvain, Belgium), Dr. Gewehr (Bonn, Germany), Prof. A.P.A. Vink (I.T.C. Delft), Ir. A. Muller (Royal Tropical Institute, Amsterdam), Drs. A de Vries, Messrs. Koekebier and Böinck (Application Laboratory, Philips Eindhoven), Miss D. van der Geest, Miss A. Masselink and Mr D. Schreiber (Soil Science Institute, Utrecht). To all of these I express my sincere appreciation for help and useful suggestions.

It is a pleasure to declare my gratitude to Messrs. F. Henzen, M. van Silfhout and H. Bakker of the drawing room for the skill and speed with which they have prepared the illustrations and maps.
To Mr. H. van Kooten and the "UNFI" I owe my appreciation for the

making and multiplication of the photographs. I also wish to thank Mrs. M. Sondaar-Swart for her expert assistance in the typing of the manuscript.

Thanks are extended to the members of the "N.Z.A.V.", especially to Dr. F. de Waard and Mrs. de Waard, for all they did to make our visit to Holland a stimulating and memorable experience.

I owe much to Mr. C.F.G. Kirstein for his friendship and encouragement. To him and also to the families Lategan and Botha, with whom we shared accomodation, I express my warm thanks.

Finally, but above all, I am indebted to my wife and children. As a token of what I owe to their inspiration this work is dedicated to Marina, Barthlo and Almarie.

The work was supported by the Maize Board (South Africa) and I received a grant from the Ministry of Education (The Netherlands) for the multiplication of the manuscript.

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I. INTRODUCTION

A. General

The fundamental problem confronting students of soil genesis, is the evaluation of the dominating factor or combination of factors which causes morphologically different soils and determine their geographical distribution. The principal genetic factors contained in most definitions of soils are: climate, vegetation, parent material, relief and time. The relative importance of these "soil formers", especially climate, parent material and time, has been a point of controversial debate ever since the inception of pedology as an independent science. Perusal of the relevant literature on soil genesis seems to reveal that the above mentioned controversy may pertain to the question of soils in terms of principles based on world-wide interpretations.

The most emphatic denunciations of the application of the concept of zonality, as a basis for soil studies, are to be found in the literature on tropical soils (Erhart, 1947; Milne, 1947; Mohr and Van Baren, 1954). The strongest support of parent material as a basis for soil differentiation is contained in the literature on soils of the semi-arid sub-tropical regions (Du Toit, 1954; Butler, 1958 and 1959; Van Dijk, 1958; Beater, 1962; Stephens, 1965; De Villiers, 1965; Maud, 1965). The general consensus amongst these authors seems to regret the present weak bonds between pedology and its allied earth sciences. It seems a reasonable inference that the prevailing climate as well as paleoclimates, in these areas are not conducive to the clear expression of the ectodynamic forces (Glinka, 1927) in soil morphology because of the relatively low biological activity and the fact that the pedological processes operate in liaison with an ensemble of factors associated with landscape instability; for instance:

1. The forces of ablation are more intense in the semi-arid subtropical and tropical regions than in their temperate counterparts.

According to Fournier's calculations (cited by Maignien, 1964), the removal of one meter of the outermost crust of the earth by erosion can be expressed by the following estimated figures:

16,666 years in Europe;
5,126 years in Australia;
2,300 years in Asia;
2,000 years in Africa;
2,000 years in South America.

2. In contrast to temperate- and tropical- regions, soil landscapes in the semi-arid sub-tropical regions frequently include elements of instability owing to recurrent aeolian-sculpturing, re-sorting, winnowing of clay, deposition of sand, intense colluvial drifting and pedimentation (Loxton, 1962; De Villiers, 1965; Stephens, 1965 and Maud, 1965).
3. The middle latitudes of the Southern Hemisphere were subject to paleo-climatic changes which oscillated between wet and dry. The higher latitudes of the Northern Hemisphere, where soil properties led to the development of the concept of zonality, were subject to paleo-climatic changes which ranged from pluvial to glacial (Zeuner, 1959 and Schwarzbach, 1963).
4. In the semi-arid sub-tropical regions, clear skies, sparse vegetation and a relatively dry atmosphere allow nearly full penetration of solar radiation (Rozanov, 1951). Pauli (1964) pointed out that the intense radiation, with an energy peak around 1000mμ, stimulates the mineralization of organic matter. High temperatures are known to stimulate microbial activity and the consequent mineralization of organic residues (Broadbent, 1962 and Pauli, 1964).
5. Reference may also be made to the generally sparse nature of the vegetation cover and tendency of floristic associations to adapt itself to soil conditions (Acocks, 1953). Factors such as the negative balance between yearly precipitation and evaporation (Buol, 1965),

as well as the torrential rainfalls and the differential effect of sandy soils with good permeability in contrast to soils with heavy texture and slow permeability, on the movement of moisture could hardly fail not to accentuate the influence of parent material (Mohr and Van Baren, 1954).

When the conditions summarized above are contrasted with those in areas with temperate- and tropical- climates, there is scarcely need to reiterate that the failure of the climatic concept to become acceptable as a basis for soil classification in these regions, could be attributed to a considerable extent to the prevailing climate as well as to paleo-climatic conditions. As a consequence, factors of a strictly local nature, combined with climatically induced periods of landscape instability intervene with the normal pedological processes; or dominate the characteristics of soils (De Villiers, 1965; Stephens, 1965; Maud, 1965). Most soil scientists working in the semi-arid sub-tropical regions, Butler (1968 and 1959); Churchward (1961); Loxton (1962); De Villiers (1965); Thorp (1965) and Stephens (1965) — to mention a few— referred to recurrent periods of landscape instability and argued that many soils exist in transitional stages while others still retain aspects attributable to paleo-environments. It seems likely that the conflicting views, to which allusion was made earlier, have arisen mainly from the study of different objects representing unrelated pedogenetic processes.

Contrasting evidence with regard to the relative importance of the obvious ectodynamic factors, especially parent material and climate, served the long overdue purpose of shifting the emphasis from the prematurely conceived deductive approach to the inductive, in the evaluation of the relative importance of the genetic factors. The latter approach gave rise to a number of approximations, mainly the effort of the United States Department of Agriculture, towards the development of a comprehensive system of soil classification (Soil Survey Staff, 1960 and supplements). It gained currency in many countries and should be acclaimed by more, if only for the purpose of providing an example for the collection of relevant data on soils. As a classification system applicable on a world-wide basis it is, however, doubtful whether it has outgrown its provisional character. Its application to soils, particularly those of the semi-arid sub-tropical regions which has not yet been subjected to intensive study, should be practiced with restraint (Soil Survey Staff, 1960 and supplements).

One of the first questions arising in any research program, concerned with soils, is that of criteria for classification. Criteria in turn refer back to problems in methods, techniques, interpretations and — most important — to justification for generalization. Generalization frequently reflects the need for practical working rules, but unfortunetaly even more often, a too enthusiastic aspiration towards the elegance of form. Their too eager acceptance and application could form barriers to a detailed understanding of soil genesis. Furthermore, the application of standard methods may easily lead to standard interpretations, creating the delusion that both had been strengthened by additional investigation.

Techniques and interpretations are dependent upon considerations as to whether "purely" pedological processes are responsible for profile differentation (Churchward, 1961). The inductive approach, which considers soil profiles as an expression of the genetic factors, has led to the recognition of more and more polymorphic and complex profiles (Butler, 1959; Soil Survey Staff, 1960 and Stephens, 1965). For a satisfactory explanation of the genesis of polygenetic profiles, it is necessary to direct attention to local factors, particularly in their paleoclimatic, tectonic and ecostratigraphic context. Consideration of paleoclimate and ecostratigraphy involves the principle of actualism, which considers the presence as a key to the past (Gillispie, 1951; Hooykaas, 1959; Van Bemmelen, 1961), in pedological thinking. The susceptibility of semi-arid sub-tropical regions to vicissitudes in climate and the associated recurrent periods of landscape instability and aeolian activity may elucidate the importance of considering soil-forming factors in a historical context; though not necessarily as a basis for soil classification. The accumulative effects of these factors are likely to be more enhanced in the old continents.

Whether the incessant mutations associated with the conditions mentioned in the previous paragraphs and their influence on the three dimensional arrangement of profiles, could be integrated into an international system of classification—without due consideration to local factors—should be an interesting point of debate. From a soil-genesis point of view, it should be borne in mind that any part of the earth may represent a special case. No evidence exists that Quaternary climates varied in a concordant manner, neither has it been proved that eustatic movements are controlled by an underlying pulse of the earth. The world pattern of orogenic belts (Holmes, 1965) suggest the contrary, thus limiting the possibility of finding isochronous land-surfaces for a comparison of soils on an intercontinental basis.

In order to evaluate genetical factors responsible for the geographical distribution of morphological distinct soils, the soils have to be considered and classified in the context of local factors. Any attempt to force soils into the units of a classification system to which they clearly do not belong would have no scientific value. A feasible approach, at least as far as soil genesis is concerned, seems to be the use of simple descriptive terms to depict the salient features of soils (Mohr and Van Baren, 1954). D'Hoore, in collaboration with the pedologists of African territories, published a soil map of Africa in 1964 on which, true to the recommendations of afore-mentioned authors with regard to soils of the tropical regions, "soils are designated by descriptive terms indicating the trend of soil development and parent material". The demarcation and classification of the soils is scientifically justified, since due regard has been given, though in a rather general sence, to the outstanding aspects of the environmental factors peculiar to the continent (Alimen, 1957; King, 1963; Haughton, 1963 and D'Hoore, 1964). Nevertheless, it is generally regarded only as a first approximation towards the knowledge of the soils of Africa. The inventary of the soils on the map is, however, such that it provides a useful framework for more detailed regional studies.

For the purpose of this investigation the author studied the soils of a portion of the Highveld Region. The Highveld Region forms part of one of the most extensive physiographic provinces in Southern Africa; the Highveld. It lies at an average elevation of 1500 meters, is demarcated on the south by the Basuto-Highlands and the Great Escarpment, and on the north by the Witwatersrand (Plate I). The latter consists of a range of hills which forms the boundary between the Highveld and the Bushveld. Its north-western boundary is characterized by a gradual transition into the Kalahari semi-desert.

The entire area is subjected to a highly vicissitudinous rainfall with a pronounced seasonal incidence. Furthermore; the entire Southern Africa, from the Congo to the Vaal-River basin and beyond, has been singularly susceptible to paleo-climatic changes (Söhnge and Visser, 1937; Bond, 1948; Cooke, 1949; Van Riet Lowe, 1952; Janmart, 1953; Wayland, 1954; Mabbutt, 1957; Van Zinderen Bakker, 1957; and Alimen, 1957). Three major periods of aeolian activity, transportation of sand, aeolian sculpturing and the formation of calcareous crusts; intervened by wetter conditions characterized by soil formation, are generally recognized. The result of these fluctuating climatic conditions and consequent periods of landscape instability is a vast array of buried soils and soil relics as well as crusts. Textural contrasts between A and B horizons often depend on the degree of truncation of buried horizons, and the texture of burying layers. The discordant eluvial-illuvial relationship, due to layering, defy the indiscriminate application of chemical and textural criteria. Hence, considerable use has been of mineralogical methods and criteria in an attempt to evaluate profile development and to prove the distinctness of horizons not attributable to pedogenetic processes.

B. Genetic Unity of Profiles[1]

The concept of normal soils which implies a profile in equilibrium, its topmost layers being removed by erosion as fast as formed through weathering at the lithic contact, forms the basis of the geographic concept of soils. The occurrence of different horizons along the vertical axis of the pedon is an expression of the combined effects of the ectadynamorphic factors upon parent material. The horizons are interdependent on the basis of an eluvial-illuvial relationship. A prerequisite for the correlation of such profiles with the ectadynamorphic factors is that the pedon developed on homogeneous parent material.

If it is accepted that all the major soil-types in the Highveld Region actually represent soil profiles with strictly interdependent horizons there is an obvious problem to account for the diversity of soils occurring in juxtaposition. This investigation has led to the conclusion that there is more to soil burial by aeolian sand than the

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(1) With special reference to problems associated with interference of extraneous agents in the Highveld Region.

mere recognition of its polymorphic origin, identification of the component layers and inferences on their ecostratigraphic significance. Deposition of the permeable aeolian sand created new environmental conditions. Depending upon the thickness, texture and mineralogy (often modified by local admixture) of the sand cover and the buried horizons as well as relief, new pedological units develop from the assemblages of independent layers. The genetic processes are closely linked with the resulting hydromorphic regime. Their geographical distribution can be related to the resulting soil climate rather than rainfall isohyetes. The present climate does not appear to be a major factor in determining soil variations. The evolution of some of these soils has not progressed far enough to obliterate characteristics acquired through the heterogeneity of the parent material or inherited during former climatological cycles.

Complex and truncated profiles are the rule rather than the exception in the aeolian landscapes. The sand fractions are commonly better sorted at the surface than deeper down. When aeolian action ensued there was apparently a maximum incorporation of relatively unweathered locally-derived detritus. Destruction of the vegetation cover will also have been accompanied by intensive surface colluviation and a consequent thorough mixture of aeolian sand and locally-derived detritus. Sys (1961) who observed a similar transitional layer in the Congo, between the underlying rock and overlying better sorted aeolian-sand, suggested that the mixing was brought about by a sort of desert eluviation. As aeolian activity continues a progressive dilution, as manifested in the grain-size distribution of sand fractions and heavy-mineral composition, of locally derived detritus with respect to those transported from further afield occurs towards the surface.

Weathering of detritus deposited in the manner described above will, without any translocation of clay or leaching, correspond with the depth function of pedogenetic profiles in which the dominating process has been podzolisation. Subsequent mobilization of aeolian sand at the surface has similar effects. Seldom, however, is the depositional fabric preserved and the salient features of profiles bear no evidence as to their complex geological history. It is only revealed by the grain-size distribution of the sand fraction and the heavy-mineral composition.

If the layering described above is associated with abrupt transitions in the profile, the situation as encountered in the field presents no indication as to the relative age of similar features in profiles occurring in juxtaposition.

Successive drifts of aeolian sands were derived from the same sources, consequently differences in heavy-minerals composition are not as striking as it would have been if different sources were involved or volcanoes or orogenic disturbances introduced fresh material. The technique of tracing the lateral continuity of a layer across a diversity of strata to prove its seperateness, represents no problem for the aeolian sands, despite the fact that the sands are not homogeneous owing to the incorporation of locally derived material. It is the effects of disturbances within the layer of aeolian sand that thwarts the study of soils in this area.

Differential susceptibility of different soil types to wind erosion has been proved by Chepil (1946, 1953 and 1958), Smirnova (1960) and Kokubun, et al., (1957) and is apparent in the Highveld Region even to the causal observer. Often the effect is limited to a winnowing of clay and silt and increase in sandiness at the surface. Chepil and Woodruff (1957) determined the dust load in tons per square mile during a single dust storm. They calculated that efflation of sandy soils by winds with an average velocity of 41 km.p.h. may yield as much as 1290 tons of dust per square mile.

Clear breaks in profiles of the fersiallitic soils are likely to represent major effects caused by wide-spread periods of aeolian activity. Aeolian activity, like water transport and erosion, is not everywhere represented by simultaneous deposition or erosion. Mere reference of discontinuities in the profile to an established local sequence of climatic changes, without clear evidence as to its relative position is thus an unsatisfactory method of approach. Fossils are no help at all; unlike Europe where aeolian deposits are relatively fossiliferrous, the aeolian sands are devoid of fossils. These complexities and problems must be solved before generalization and synthesis can be afforded about a stratigraphic approach to pedological problems.

The composition of the original material on which the soil developed; mixtures of quartz with subordinate amounts of sesquioxides and primary minerals, restrict the application of the weathering criteria $\frac{SiO_2}{Al_2O_3}$ (S.P.I. 1961) in defining the ferruginous soils on aeolian sand. As a result of the poorly developed structures clay skins are not discernible in the field. Microscopic investigation of thin sections only reveals a red earthy-continuous mass such as described by Kubiena (1950). Trace element work by Oertel (1961) casts doubt on the validity of the illuvial horizon in ferruginous tropical-soils. The suggestion of Maignien (1961 and 1964) that the whole solum be considered for classification purposes, rather than separate horizons, seems a tenable practice. Soil colour, structure, clay minerals and the base saturation of the exchange complexes are pedological characteristics of equal importance as illuviation of clay. Unlike the wetter tropical regions (Maignien, 1961) the evolution of organic matter in terms of carbon and nitrogen content and ratios provides no clear basis for differentiation. The different horizons coincide with the geological layers but the whole solum reflects the effect of the soil climate resulting from the layering of material with different permeabilities and relief.

The aeolian-sand cover is not continuous and soils that may be regarded as normal with respect to climate and parent material are encountered. The heavy texture of these soils explains their preservation in a relatively undisturbed state. Experimental work on the threshold velocities of the transporting agents for different size-grades of soils and sediments verifies this contention (Hjulström, 1939 and Bagnold, 1960). These authors and Chepil (1958) found that high silt- and clay- content accounts for the differential resistance of soils without a protective plant-cover and sediments to water- and wind- erosion. Factors such as type of clay and degree of base-saturation has been proved by Kokubun, et al., (1957) to be complementary factors. The effect of these factors are clearly revealed in Plate II, Fig.1.

Dust and sand on the surface of the soils with heavy texture are more susceptible to disturbances by water-erosion than are the sandy soils. Terracettes caused by mass movement of the more porous top layer along the surface of the slowly permeable sub-surface clay-layers are obvious features associated with these soils. It also accounts for their high susceptibility to sheet erosion.

These soils can be regarded as being in equilibrium with their present environment, only because the passage of time is not detectable in them. The possibility that they are paleo-soils which retain many aspects not attributable to the present environment is not excluded. Incorporation of sandy material by argillipedoturbation and anisotropy of the sedimentary parent-material are important factors which need consideration in an evaluation of their analytical data. They are exclusively associated with argillaceous sediments and dolerite.

Rather than being too much preoccupied with problems without emphasizing the generalities, the pedological processes operative in the Highveld Region in liaison with landscape instability seems to be best embodied in a diagrammatical illustration (Plate III), of the assumed pedological cycle in which provision has been made for factors associated with landscape instability (after G.G.Stephens, with grateful acknowledgement; personal communication and Hallsworth, 1965). Table 1 gives a key to soil associations in the Highveld Region.

ns in the Highveld Region.

Parent Material		Numbers of representative profiles
nprising aeolian sand intermingled with colluvium		73/76; 109/113; 200/205; 222/225; 235/244
		63/65
nprising aeolian sand and/or colluvium	on Sandstone	117/120
e weathering products of dolerite	on Dolerite	12/15; 59/62; 90/93
nprising different periods of aeolian	on Ventersdorp lava	208/211
s are usually intermingled with	on Calcareous crusts	212/216
	on Karroo Sandstone	30/33; 52/55; 121/125
om rocks in the vincinity)	on Karroo Shale	204/207
		19/21; 94/96; 154/156
shales, siltstones and mudstones (Profiles disturbed at the surface)		22/25; 86/89; 105/108; 133/136
luvium affected by aeolian sorting	on Vertisols (Da)	4/7; 157/161
	on Vertisols (Db)	43/47; 129/132; 182/1
andy-loess) and colluvium affected by he truncated stumps of lighter	on the truncated stumps of lighter textured soils	143/146
n sand on calcareous crusts		218/220
luvium on miscellaneous rocks		8/11; 174/176
luvium on Vertisols (Db) and colluvium		165/168
ent alluvium on flood plains		
uted aeolian sand associated with Soils in the landscape		226/233
ent alluvium forming the sandy levees along river channels ling ancient gullies along the escarpment		
nbrian rocks with exception of Dolomite		
l chert rubble		
ones along escarpments		
ong escarpments, isolated Inselbergs on pediplains and sandstone beds		
eistocene calcareous crusts in some localities decalcified pproaching the characteristics of silicious crusts (Kunkar)		

Table 1: Key to soil associatio

logical gime	Soil Type		Symbol on Map	
and internal drainage	Reddish-brown Fersiallitic Soils		Jd	Different layers, co
	Reddish-brown Regosols		Bh	"Recent" colluvium
	Eutrophic Reddish-brown Soils		Hd	Different layers, co intermingled with th
Impeded internal drainage	Yellowish-brown Fersiallitic Soils		Ja	Different layers, co drifts (deeper layer colluvium derived fr
	Vertisols, Sensu Lato, on Crystalline Basic Rocks		Da	Karroo Dolerite
	Vertisols, Sensu Lato, on Calcareous Rocks		Db	Slightly calcareous of the Karroo System
	Highveld Pseudo-podzolic Soils		Fa	Aeolian sand and col on Vertisols
	Highveld Pseudo-podzolic Soils	intergrade	Fa'	Aeolian sand (fine s aeolian sorting on t textured soils
	Pseudo Rendzina		Ca	Thin layer of aeolia
and internal drainage	Mineral Hydromorphic Soils		Na	Aeolian sand and col
	Solodized Solonetz		Ma	Aeolian sand and col
	Vertisols, Sensu Lato, of topographic depressions		Dj	Narrow strips of rec
	REGOSOLS OTHER THAN Bh			
	Yellowish-brown Regosolic Sands		Bq	"Recently" redistrib Mineral Hydromorphic
	Juvenile Soils on Recent Sediments		Bo	Narrow strips of rec and sandy, loess fil
	LITHOSOLS, ROCKS and ROCK DEBRIS			
	Lithosols on miscellaneous rocks		Bd	Miscellaneous pré-Ca
	Lithosols on Dolomite		Bc	Dolomite and residua
	Lithosols on Karroo Sediments		Bd'	Mainly mature sandst
	Lithosols on Karroo Dolerite and Basalt		Bb	Dolerite outcrops al basalt capping. Cave
	Lithosols on Calcareous Crusts		Bc'	Tertiary to early-Pl at the surface and a

II. PHYSIOGRAPHY

A. Climate

The climate of the Highveld Region, according to the official climatic classification of South Africa (Schulze, 1965), varies from semi-arid in the north-west to sub-tropical in the south-east.

The classification is based on precipitation and temperature. Because of the vicissitudinous character of both these properties, especially the mean annual rainfall, the above mentioned subdivision tends to be somewhat arbitrary. The variation from the semi-arid extreme to the sub-tropical extreme, within the confines of the area, represents in reality a gradual transition. According to the classification of Finch, et al., (1957) the climate of the entire Highveld Region may be regarded as transitional between the "Humid Mesothermal Climates (Cw) and Dry Climates (Bsh)". It is therefore deemed advicable to discuss the climate with reference to these two extremes only. The geographical distribution of the average annual precipitation is given in Map 1 (in pocket).

(i) Semi-arid Western Region

The average annual precipitation ranges from 450mm to 500 mm (Map 1 and Table 2). Rainfall is mainly in the form of localized showers and thunderstorms; falling in the summer months from October to March. The peak of the rainy season is from December to March (Table 2). Annual totals deviate as much as 40 per cent from the annual mean. Of the yearly total, 84 per cent falls in summer.

Sunshine hours amount to about 70 per cent of the possible day light. Air temperatures are subjected to large diurnal and seasonal variations. During January and December average daily maxima vary from 29°C to 30°C. In June and July it is about 18°C. Average minimum daily temperatures are in the order of 15°C in January and 0°C in July (Table 4). Extremes in maximum and minimum temperatures may vary from 35°C to -6°C respectively. The frost free period is 265 days.

Table 2: Average monthly and annual rainfall in mm (M) and monthly percentage of total (P).

Month	Western part of Highveld Region (9 stations)		Middle part of Highveld Region (8 stations)		Eastern part of Highveld Region (10 stations)	
	M	P	M	P	M	P
January	88	16.3	110	16.2	118	17.3
February	76	14.1	93	13.7	102	14.9
March	83	15.5	90	13.3	85	12.4
April	42	7.9	49	7.2	40	5.7
May	19	3.5	26	3.8	21	3.1
June	6	1.2	9	1.3	9	1.3
July	9	1.6	11	1.7	10	1.4
August	9	1.6	13	1.9	9	1.3
September	15	2.7	26	3.9	25	3.6
October	47	8.5	64	9.5	64	9.3
November	70	12.9	89	13.0	91	13.3
December	77	14.2	98	14.4	111	16.2
Year	539		679		688	

Table 3: Average annual evaporation from open water surfaces.

Period	Western part of Highveld Region	Middle part of Highveld Region	Eastern part of Highveld Region
	A (%)	A (%)	A (%)
Sept. - Nov.	33 - 30	30	30
Dec. - Feb.	30	30	30
March - May	19 - 20	20 - 23	20 - 23
June - Aug.	15 - 17	15 - 17	15 - 17
	S mm	S mm	S mm
Year	2500 - 2250	2250 - 2000	2000 - 1750

Average annual evaporation from class 'A' pans in mm (S) and average seasonal evaporation (A) expressed as a percentage of the annual average.

Table 4: Monthly variation of 1) mean daily temperature, 2) mean daily maximum temperature and 3) mean daily minimum temperature.

Month	Western part of Highveld Region			Middle part of Highveld Region			Eastern part of Highveld Region		
	1	2	3	1	2	3	1	2	3
January	22.9	29.8	15.3	21.3	27.8	12.6	20.8	27.4	12.9
February	22.0	28.7	15.3	19.9	26.7	11.9	20.0	26.5	12.2
March	20.1	26.7	13.6	18.2	25.0	10.0	18.9	25.7	10.9
April	16.7	24.2	9.2	14.9	22.4	5.5	15.7	23.6	6.5
May	12.7	21.4	4.1	10.7	19.1	1.0	12.1	20.9	2.0
June	9.5	18.6	0.4	7.6	16.1	-2.3	9.2	18.5	-1.5
July	9.2	18.4	-0.4	7.3	16.1	-2.8	8.8	18.1	-1.8
August	12.2	21.5	3.0	10.2	19.1	-0.5	11.6	21.2	-2.4
September	16.1	25.0	7.3	13.6	21.9	3.4	15.0	23.9	4.5
October	19.8	27.9	11.6	17.4	25.2	7.9	18.1	25.9	8.7
November	21.0	28.3	13.8	18.4	25.5	9.6	19.2	26.2	10.6
December	22.4	29.5	15.3	20.3	27.5	11.8	20.4	27.0	12.3
Year	17.0	25.0	17.0	15.0	22.7	5.7	15.8	23.7	6.2

Remark: In compiling these Tables 2, 3 and 4 very free and frequent use has been made of the work of the following authors:

(1) Coetzee, J.H. (personal communication)

(2) Schulze, 1965

Winds, attaining their maximum speed in the afternoon, are usually north-westerly. Dust storms, similar to those in the Sudan (Schulze, 1965), occur in the late spring and in association with the forefronts of thunderstorms (Plate II, Fig.2). Winds attain their maximum average speeds during October.

Relative humidity varies from approximately 40 per cent in January to below 30 per cent in October. Mean annual evaporation from class "A" evaporation pans exceeds 2250 mm per annum (Table 3).

(ii) Sub-tropical South-eastern Region

Average annual precipitation varies from 500 - 700 mm (Table 2). Deviations of annual totals from long-range averages are smaller in the east than in the north-west. Precipitation is almost exclusively due to showers and thunderstorms. Thunderstorms are often accompanied by strong gusty winds and hail. The wintermonths are normally dry, almost 85 per cent of the annual precipitation falls in summer; from October to March. Heavy falls of up to 150mm within a day or even a few hours are not exceptional.

Sunshine duration is in the order of 70 - 80 per cent of the possible. Average maximum temperatures in December and January is 27°C (Table 4). During June and July average maximum temperatures are roughly 18°C. Average minima range from 12°C to 13°C during January and December. In July average minima and maxima are -2°C and 16°C respectively. Extremes can sink to -9°C. The frost-free period lasts for approximately 245 days.

Winds are on the whole light but can be strong during thunderstorms. Dust storms, similar to those in the drier area, are a detrimental feature of the climate.

Relative humidity varies from approximately 50 per cent in January to below 30 per cent in October. Mean annual evaporation from class "A" evaporation pans ranges from 1750 mm to 2250 mm per annum (Table 3).

(iii) Paleoclimate

Vicissitudes in the paleoclimate of Southern Africa during the Quaternary has excercised a determining influence on the biological, geomorphological and pedological evolution of the sub-continent (King, 1962).

Widely dispersed evidence of oscillations in paleoclimate has accrued mainly from archaeological and palaeontological investigations. Comprehensive surveys into this field was stimulated by an interest in human and humanoid fossils as well as associated implements. Despite some not totally unjustified objections such as regional trends in skills of the makers, to the use of artifacts as a guidance in correlation problems, it still seems the only material available. A disadvantage, however, is a tendency for it to be restricted to the proximity of open water.

That relative dating and correlation of Quaternary deposits may only be achieved by the use of human remains is logical. Only this species was subjected to evolution, sufficiently rapid, to provide a biostratigraphic timescale for the subdivisions of the Quaternary. The fossil remains of other fauna, because of their slow evolution are only capable of indicating broad homotaxial equivalences. The possibility and feasibility of the use of artifacts for above mentioned purposes is endorsed by available C^{14} datings of widely dispersed occurrences (Clark, 1962a and 1962 b; Mason, R., personal communications). These ages were obtained by the dating of carbonaceous matter which occur in association with Middle Stone-Age artifacts (Table 5); the Rhodesian Still-Bay culture is coeval, in time with the Middle Stone-Age culture in South Africa (Cooke, 1957 and Oakley, 1957).

Table 5: C^{14} dates of widely dispersed deposits associated with the occurrence of Middle Stone-Age implements.

Culture	Type of deposit	locality	Radio Carbon dates(B.C.)
Middle Stone-Age	Spring deposit	Florisbad, Orange Free State	29,000 years (x)
Still Bay	Cave	Kalamba, Zambia	30,000 - 27,000 years (x)
Middle Stone-Age	Cave	Olieboom, Transvaal	33,000 years (*)

(x) Clark, 1962 a and 1962 b

(*) R.Mason, personal communication.

Another interesting development, which may provide an ultimate key to the formulation of an acceptable theory of Pleistocene climatology, is the concept of Zeuner (1959). He proposed the use of the period of the precession of equinoxes as a basis for an absolute chronology of the Pleistocene. According to this concept the vicissitudes in climate is dependent on variation in the heat received from the sun as a result of cyclic changes in the orbit and axis of rotation of the earth. Zeuner has made out an excellent case for the paleoclimate of South Africa based on the qualitative lines published by the astrophysicist Milankovich.

With reference to the afore mentioned facts and interesting theories, as well as with due regard to the warning of Malan (1943) with respect to "the dangers of assuming too wide a geographical extension of the climatic sequence established for any particular area" the author feels justified in drawing the following (Table 6) conclusion from field observations. Further reference to the table will be made in the discussion of the Pleistocene deposits and geomorphology.

Nothing can be said about the magnitude of climatic changes, mainly because of uncertainties about the ecological tolerance of soils and the fauna. It is felt that presentation and interpretations of the evidence should remain objective. Over-simplified theories which are

Table 6: Tentative chronology of Quaternary events in the Highveld Region.

Etage	Events (1)	Culture (2)	Climate	Suggested East African Parallels (3)
Recent	Human interference, liberation of sand at the surface by cultivation and its detrimental influence on the natural vegetation. Aeolian deflation of derubefied sand. Barchan dunes and small wale-back dunes.	Present	Semi-arid Sub-tropical	---
Epi-Pleistocene	Formation of mineral hydromorphic soils (derubefication) in areas where the drainage was impeded by the accumulation of river-border dunes. Denudation and cutting down to present contours. Soil formation.	Later Stone Age	Fluctuating Wet and Dry	Nakuran Wet Phase
Upper Pleistocene	Aggradation of rivers. Limited redistribution of aeolian sand. Accumulation of garnet-bearing sand in the form of river-border dunes. Formation of younger pans. Colluviation.	---	Dry	Nakuran Dry Phase
	Accumulation of grit and fluviatile sands along rivers. Removal of aeolian sand from regional slopes. Soil formation.	Middle Stone Age	Fluctuating Wet	Makalian Wet Phase
	Large scale aeolian activity. Accumulation of rubefied desert sands, redistribution of older aeolian sands. Filling in of gullies along the escarpment by fine sandy loess. Deepening of pans by wind-deflation.	---	Very Dry	---
	Erosion of calcareous crusts. Deposition of youngest gravels along Vaal River and tributaries. Large scale gulley erosion of alkali terminal-stream basins along escarpment. Soil formation.	Last Phase of S.A.Acheulian (Fauresmith)	Wet	Gamblian Pluvial
	Formation of calcareous crusts in the west and takyr in the terminal wadis along the escarpments.	---	Fluctuating Dry	---
Middle Pleistocene	Deposition of several facies of younger gravels along Vaal River. Removal of pans along regional slopes. Formation of calcareous crusts in the west and accumulation of alkali in terminal wadis along escarpment during intervening dry phase	Early Phases of S.A. Acheulian	Wet Dry Wet	Kanjeran Pluvial --- Kamasian Pluvial
Lower Pleistocene	Deposition of rubefied aeolian sand. Large scale desert colluviation, consequent mixture of aeolian sand and colluvium which form the horizons of maximum clay content in many profiles. Formation of large deflation basins and pans	---	Dry	---
	Pediplanation. Deposition of older gravels along Vaal River. Soil formation.	Pre-Acheulian	Wet	Kangeran Pluvial

(1) Van Riet Lowe, 1937 and 1952; Söhnge and Visser, 1937; Cooke, 1940, 1946, 1949 and 1957; Clark, 1954; Van Zinderen Bakker, 1957; Alimen, 1957; Harmse, 1963.

(2) Mason, 1962 and Mason, R. (personal communication).

(3) Mortelmans, 1950; Van Zinderen Bakker, 1957; Cooke, 1957.

not yet adequately substantiated will as far as possible not be allowed to influence the outcome. It is, however, the author's considered opinion that the importance of the influence of paleoclimate and associated pedological and geological events on the trend of profile development should not be underestimated. Many of the soil profiles present part of an unfinished pageant wherein their present status is an inexorable consequence of past events.

Contemporary climatic conditions do not appear to be a major factor in determining the distribution of soils in the Highveld Region. Most variations in soil profiles are due to the superposition of different layers of aeolian sand or their absence. The hydromorphic regime resulting from the superpositioning of strata with different permeabilities and variation in relief appear to be the most significant soil-forming factor.

B. Vegetation

A salient feature of the flora of the Highveld Region is the general tendency for scrubs and trees to grow on lithosols and skeletal soils. Grass, in contrast, is the predominant form of vegetation over large tracts of country on the undulating plains. Encroachment of Karroo Vegetation, mainly in the form of non-succulent scrublets is conspicuous on poorly managed pastures. A typical pioneer on sandy soils is Chrysocoma Tennifolia (linn). The vertisols on the other hand are susceptible to an invasion by Karroo Thorn (Acacia Karroo). Apart from the above mentioned changes there are vague and insidious shifts in the grass population.

Because of the wide tolerance of certain grass species, particularly Themeda Triandra, only broad distinctions between floristic associations are possible. According to Acocks (1953) rainfall and soil type, in liaison with an ensemble of phenomena such as overgrazing and erosion, are the major factors which determine the geographical distribution of the flora.

Higher rainfall in the south-eastern and southern parts of the Highveld Region favours the mixed grassveld, the Cymbopogon Themeda Veld. Further to the east, concomitant with an increase in thickness of the aeolian-sand cover, the Cymbopogon Themeda Veld merges gradually into the Sour Sandveld. To the west it is replaced by a floristic association described by Acocks (1953) as the Dry Cymbopogon Themeda Veld. An association, transitional between the above mentioned associations, streches down the middle of the Orange Free State, It coincides with the minor escarpment which demarcates the transition from the early-Tertiary pediplain to the late-Tertiary pediplain (Map 3 in pocket).

The Dry Cymbopogon Themeda Veld is progressively replaced, towards the north-west, by the Eastern Variation of the Kalahari Thornveld. The latter consists essentially of open savanna with occasional tall camelthorn trees (Acacia Giraffae). The floristic associations on the skeletal-lithosol complex associated with the pre-Cambrian formations has been grouped into a single unit by Acocks (1953), under the name Bankenveld.

Some of the flora show a preference for certain soil types and geological formations. This association as well as its variation with annual precipitation, merits further elucidation:

1. The flora on the vertisols, despite a variation in annual precipitation from 500 to 700 mm, are singularly dominated by particularly pure stands of Themeda triandra. A noticable increase in the species Heteropogon contortus takes place with a concomitant increase in rainfall. In the west, mainly due to overgrazing, an increase in Eragrostis obtusa and Eragrostis chloromelas becomes apparent. The presence of species such as Panicum coloratum according to Acocks (1953), however,"shows it to be, actually and

in effect, of a drier type".

2. The transition from the *Cymbopogon Themeda Veld* to the Dry *Cymbopogon Themeda Veld* which is, in reality, associated with an increase in lithosols and a more patchy distribution of aeolian sand (due to removal by erosion) is characterized by the occurrence of, besides *Themeda triandra*, *Eragrostis chloromelas* and *Oxalis depressa*. Lithosls and skeletal soils are covered by *Acacia Karroo* (on dolerite) and *Grewia occidentalis*, *Celtis Kraussiana* and *Olea Africana* (on sandstone and shales).

3. As the depth of the aeolian sand increases to the north-west *Eragrostis Lehmanniana* becomes the dominating species. Sub-dominant species include *Setara flabellata*, *Themeda triandra* and *Cymbopogon plurinodis*. *Acacia giraffae* has a clear affinity to grow on well-drained regosolic-sands. The floristic association on hydromorphic soils, on the other hand, is dominated by a profusion of *Imparata cylindrica*.

4. The transition from vertisols to lighter-textured soils in the south-east coincides with important increases in the species *Tristachya hispida*.

5. The vegetation on lithosols and skeletal soils in the Bankenveld (Acocks, 1953) is subject to some interesting variations. Basic- and intermediate- igneous rocks are almost without exception sparsely populated by particularly pure stands of Acacia scrub. Species such as *Acacia Karroo*, *Acacia caffra* and *Acacia spiro carpoides* are the most abundant.

6. Skeletal soils associated with arenaceous sedimentary-rocks and granite are populated by trees and scrubs such as *Celtis Kraussiana*, *Olea africana*, *Kiggelaria africana* and *Myrsine africana*. *Acacia*

giraffae grows luxuriously on above mentioned soils, but is restricted to the area with an annual precipitation of less than 600 mm. The abundance of *Protea* (spp) increases with mean annual precipitation.

7. A conspicuous association exists between the lithosols on dolomite (Map 3) and the occurrence of Karree (Rhus spp).

8. *Tarchonanthus camphoratus* shows preference for areas occupied by calcareous crusts. *Grewia* (spp) grows in clumps and has a distribution similar to *Acacia giraffae*.

9. The grass communities of the Bankenveld association are mainly subject to variations, concomitant with variations in rainfall. The western (drier) variation are dominated by species such as *Eragrostis chalcantha*, *Digitaria tricholaenoides* and *Setaria flabellata*. Typical species of the central variation include *Trachypogon capensis*, *Tristachya hispida*, *Elyonurus argenteus* and *Heteropogon contortus*. A gradual transition toward the Sour Sandveld characterizes the grass community from Vereeniging to Delmas. *Tristachya hispida*, *Eragrostis chalcantha*, *Heteropogon contortus* and *Digitaria tricholaenoides* comprise the dominant grass species of the eastern variation of the Bankenveld.

C. Geomorphology

Widespread concordance of summit levels, straight skylines and expansive tracts of country consisting of essentially featureless plains are the conspicious aspects of the scenery in the Highveld Region.

A sequence of three erosion surfaces and associated topographic features constitute, in liaison with resurrected topography, the major geomorphological features (Map 3, in pocket). These erosion surfaces, described and deliniated by King (1962 and 1963), are defined with reference to the chronology of the eustatic movements responsible for their initiation at the coast. The eustatic movements were in the form of major upheavels on a continental scale with negligible differential-components in the Highveld Region (King, 1963).

The successive surfaces are known by the following names, the uppermost being the youngest; alternative names are given in parentheses:

Main Erosion Surfaces.	General altitude above sea level of plains in the Highveld Region.
(1) Post-African Surface (Late-Cainozoic or late-Tertiary)	1200 - 1500 meter
(2) African Surface (Early-Cainozoic or early-Tertiary)	1450 - 1620 meter
(3) Gondwana Surface (Jurassic-Cretaceous Surface)	1800 - 2100 meter

Overlapping in altitude, of the general elevations of these plains, is according to King (1963) partly because the original drainage was towards the interior. Downwarping of the interior with respect to the continental devide, which constitute the present water shed, has to some extend also been instrumental in inaugurating this phenomenon.

The preservation and co-existence of the flat remnants of old erosion surfaces, in the case of the Gondwana surface for something like 140 million years, is attributed to the process of pediplanation and the quiscent orogenic history of the sub-continent (King, 1962 and 1963 and Holmes, 1965). These plains are vulnarable to denudation only from their flanks. Transition between successive erosion surfaces is demarcated by dissected escarpments consisting of well-developed hill slopes and pediments which develop along the sides of subsequent valleys. Ultimate coalescence of adjoining pediments give rise to essentially featureless pediplains.

Anomalous features on these plains or erosion surfaces are produced by resurrected topography; the differential resistance of rocks and the effects of oscillations in paleoclimate. Both resurrected topography and differences in resistance of rocks pertain to specific properties of certain geological formations and rock-units. These are, therefore, elucidated under the discussion of the geology. It will suffice to mention here only, that the hilly aspects of the country north of the Vaal River are entirely attributable to re-exposure of pre-Karroo topography (King, 1963).

Transition from the Gondwana surface, which lies at an average altitude of between 1800 - 2100 meter along the border of Basutoland, to the plains of the younger African surface is characterized by several "terraces". The altitude of the plain-sections of these are controlled by resistant bands in the Stormberg Series, viz the Molteno Beds and Cave Sandstone Beds. The Molteno structural-plain, which is the most extensive of the two (Map 3), lies at an average altitude of 1650 meters and represents a local phase of the African surface (King, 1963). In comparison with the surrounding country, with respect to map coverage, the transition between the African surface and its local structural phases is the geographical locality of the maximum occurrence of solodized solonetz, lithosols, and regosols. Similary is the low escarpment that runs down the middle of the Orange Free State (Map 3). This low escarpment constitutes the transition zone between the post-African- and the African- surface.

The transition between these two erosion surfaces are extremely vague on the northern side of the Vaal River. King (1963) attributed this to relative basining in the interior during the eustatic events which elevated the African surface to its present altitude. Paleotopography has, however, much to do with this phenomenon. Du Toit (1954) for instance ascertained that the configuration of the present

Harts-River Valley consists largely of re-excavated glacial features. The smothering effect of the aeolian sands and calcereous crusts, which obliterated much of the properties of the erosion surfaces disappearing underneath them, has undoubtedly also played a major role.

The aeolian sand and calcrete transgresses both surfaces and extend down to the margin of the present flood plain of the Vaal River. It was, therefore, deemed advisable to consider all areas where aeolian sands occur as aggradational phases of the major erosion surfaces (Map 3).

On the southern banks of the Vaal River, the younger garnet-bearing sands (Harmse, 1963), which accumulated in the form of river-border dunes (Table 6), form an "escarpment" on the flood plain. Further afield, south of the Vaal River, the dominant aspect of the aeolian sands is that of seif dunes following the physical grain of the country on the post-African surface.

Above-mentioned facts tend to support the contention of Du Toit (1954) and King (1963) that denudation during the Quaternary were restricted to the removal of surficial deposits from the retreating escarpments and other areas with positive topography.

Fluctuations in paleoclimate during the Pleistocene induced a further crop of divergences. The most conspicuous and important of these besides the aeolian sands and calcareous crusts, are the large number of pans[1] and less well-defined "floors (Du Toit, 1954). The problem of the genesis of these "topographic depressions" has been dealt with comprehensively in the literature. In South Africa as well as in Australia (Du Toit, 1954; Jessup, 1960), wind deflation is being regarded as the major factor responsible for their formation.

Some of the pans attain a size exceeding 600 hectares, depression below the surrounding country may often reach 40 meters. The highest occurrence of larger pans is in the western part. In the east,

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[1] In South Africa, topographic depressions formed by wind deflation.

though smaller, pans are equally abundant (Van Eeden, 1937; Du Toit, 1954; Visser, et al., 1949).

The presence of these pans on the early-Tertiary erosion surface as well as the late-Tertiary erosion surface; sets a lower limit of late-Tertiary or early-Pleistocene on the time of their formation. The occurrence of numerous artifacts belonging to the Fauresmith culture and Middle Stone-Age culture, along and, in the pans is according to S.H.Haughton (personal communication) an indication that some of the larger pans, if not formed completely (with regard to their present dimensions), were at least initiated during a period which pre-dates these cultures. His contention is that the people who made the tools would only have been able to live away from the river valleys, after the establishment of the inland water sources; even during wetter periods (Table 6).

Smaller pans or deflation hollows are at present forming in poorly-drained areas. This is mainly due to the mobilization of aeolian sands which became derubefied under anaerobic conditions as a result of water stagnation. The susceptibility of the hydromorphic soils to wind erosion is further manifested in the associated hummocky topography and barchan dunes (Tabel 6).

The detrimental influence of human activity, to a large extent also instrumental in creating above-mentioned situation, on the vegetation cover is everywhere noticable. Consequent increase in run-off is manifested in the scouring out of river valleys and in sheet erosion. Lowering of the local base levels of erosion results in the valley sides being dissected by gulley erosion. This is particularly the case at the relative youthful ungraded river-sections which coincide with the low escarpments.

III. GEOLOGY

A. General

Corroboration of the exceptionally quiescent orogenic-history of the area during the Karroo and post-Karroo period is found in a correlation between an ascending order in the stratigraphic column and elevation. Anomalies arise through the removal of softer Karroo rocks by erosion and exposure of the more resistant pre-Cambrian rocks (King, 1963). The resurrected topography dominates the scenery north of the Vaal River (Map 3).

The various geological formations represented by outcrops in the area are given in a descending order in Table 7. The topographical expression of the rocks is undoubtedly a major factor in determining the geographical distribution of soils, skeletal soils and lithosols. Consequently considerable attention will be given to the topographic expression and petrography of each stratigraphic- and/or rock- unit. The distribution of the main geological formations is given on a generalized geological map (Map 2, in pocket).

B. Archaean Granite

These granitic rocks, styled "old granite" to distinguish them from younger granite-bodies of restricted size, show mainly in the form of windows in a mantle of younger strata. Except for the centre of the Vredefort Dome where the old granite has been "jacked" up in the form of a solid hub, outcrops of pedological interest are restricted to the area between Klerksdorp and Lichtenburg. Outcrops are comparitively rare and restricted to drainage channels. On the interfluves the terrain is extensively covered by poorly-sorted aeolian-sand. The sand consists partly of extraneous material introduced by the wind which became thoroughly mixed with locally derived weathering-products of the granite (Profile 200/203).

Table 7: Simplified stratigraphic column.

Late-Tertiary to early-Pleistocene				Terras gravels, Calcareous and Siliceous crusts, Aeolian sands.
Triassic to Carbon	Karroo System	Dwyka Series		Tillite and Shale.
		Ecca Series		Shale (calcareous, carbonaceous and arenaceous), Coal seems, Immature sandstone and Mudstone.
		Beaufort Series		Shale, Mudstone, Arenaceous shale and Immature sandstone.
		Stormberg Series	Molteno Stage	Mature sandstone, Grits and Shale.
			Red Bed Stage	Immature sandstone, Grits and Mudstone.
			Cave Sandstone Stage	Massive mature sandstone.
			Drakensberg Bed Stage	Basaltic lavas.
			Dolerite	Dykes and Sheets.
Pre-Cambrian	Dominion Reef System			Conglomerates, Lavas and Quartzite.
	Witwaters Rand System	(Five Series)		Conglomerates, Quartzites, Shale and Slates.
	Ventersdorp System			Andesitic lavas, Agglomerates, and tuffaceous Sediments.
	Transvaal System	Black Reef Series		Quartzite, Shale and Conglomerates.
		Dolomite Series		Dolomitic limestone and Chert.
		Pretoria Series		Quartzite, banded Ironstones, Shale and Lava.
Basement Complex				Granite.

Investigation of thin sections of the granite reveals a hypidiomorphic coarse-grained texture. The constituent minerals are mainly orthoclase and quartz (with undulatory extinction) with subsidiary amounts of microcline and sodium plagioclase. Accessory minerals consist of chloritized biotite, magnetite, ilmenite and allanite. The crop of heavy minerals, obtained from the crushing of weathered rock and by bromoform separation, consists entirely of idiomorphic grains of zoned zircon. The presence of this variety of zircon in the heavy fractions of the soil horizons as well as the poor sortating of the sand fraction substantiate the contention that the aeolian sand is extensively mixed with detritus derived from the granite. Of further significance is an increase, with depth, in the angular quartz-grains which exhibit undulatory extinction. This indicates a progressive increase towards the surface in extraneous aeolian-sand. Absence from the C horizon of angular felspar-fragments implies that the whole solum has been subject to wind transportation. This may also explain the absence of twinned grains of felspar and microcline occurring abundantly in the granite. The felspar and microcline grains could be expected to be more susceptible to mechanical destruction, considering the vigour of aeolian attrition (Kuene, 1960).

C. Dominion Reef System and Witwatersrand System

The occurrence of these formations are restricted to the vicinity of the Vredefort Dome, the area between Klerksdorp and Wolmaransstad and the Wiwatersrand. Consisting entirely of a series of alternating quartzites, shales and some intercalated lavas these rocks have a topographic expression that is not conducive to soil formation. Commonly associated with the terrain are skeletal soils, lithosols less than 30 cm thick and regosols (profile 63/65). Through mechanical disintegration and mass wasting these rocks have contributed detritus for subsequent distribution by the wind. Aeolian-sand sheets commonly extend from the south-eastern boundaries of outcrops over the featureless plains associated with the Dolomite Series and the miscellaneous rocks of the Karroo System.

D. Ventersdorp System

Rocks of the Ventersdorp System occupy a considerable area in the Transvaal. Three types, mainly volcanic rocks comprise the system, namely lavas, pyroclastic agglomerates and tuffaceous sediments. The lavas may be subdivided into andesitic lavas and quartz porphyries. In terms of map coverage, the andesitic lava is the most extensive in this area. It is characteristically strongly epidotized and sericitized (Von Backström, et al., 1953; Van Eeden, et al., 1963). The andesitic lava never rises into conspicuous prominences beyond Wolmaransstad. The undulating plain is extensively covered by a layer of aeolian aand (Map 3). King (1963) pointed out that this extensive plain represents a fossil feature which dates back to pre-Karroo times. His contention seems to be substantiated by the presence of glaciated pavements and outlayers of Karroo Sediments (Von Backström, et al., 1953).

An exception to the above mentioned generalization with respect to the topographic expression of the lava, is evident from Wolmaransstad to the south. Here the rocks of the Ventersdorp System (mainly amygdaloidal andesites, quartz porphyries as well as some tuffaceous sediments) form characteristic low rounded-hills which are often densely covered by Acacias, thus extending the area characterized by diversified topography and skeletal soils beyond the confines of outcropping members of the Witwatersrand- and Dominion Reef- Systems.

The Ventersdorp lavas in general, despite their high weatherable mineral-reserves, only form skeletal soils. It has,however, contributed detritus to the aeolian sands. Complete deflation by wind of existing soils and their incorporation into the aeolian sands may explain the high epidote-content of aeolian sands on the andesitic lava (Profile 208/211).

E. Transvaal System

(i) Black Reef Series.

The Black Reef Series consists of a persistant band of rather mature[1] quartzites and conglomerates. This rock-unit is of little interest both with respect to map coverage and soil formation. Its presence in the landscape is usually betrayed by a tree-covered range of low hills which demarcates the featureless plains associated with the underlying lava and the overlying dolomite.

(ii) Dolomite Series

As the name implies it consists almost entirely of a thick succession of dolomitic limestone with sub-ordinate chert-bands. Solution and weathering of the dolomite results in an accumulation of loose chert-rubble on the surface which exhibits a characteristic dark-brown staining due to the presence of manganese oxides. The manganese oxide is a product of residual accumulation caused by the selective solution of magnesium- and calcium- carbonates (King, 1963; Du Toit, 1954).

In general the dolomite plains deviate little in height from the surrounding general plain. In detail, however, important differences are apparent. The drainage is not co-ordinated and the topography is more diversified owing to the presence of numerous sinkholes. These are disposed in a pattern that coincides with the drainage system. Owing to the typical karst phenomena, described above, these plains have been demarcated as "karst phases" of the early-Tertiary erosion surface (Map 3).

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[1] A term used by Pettijohn (1957); meaning sediments or sedimentary rocks with low content of easily-weatherable minerals.

The accumulation of residual chert resulted in the dolomite plains being extensively covered by lithosols and skeletal soils. North-west of Lichtenburg large tracts of dolomite country are covered by aeolian sands. Aeolian sands also occur on dolomite in the rest of the Highveld Region, where the plains occur in the down-wind direction (south-east) of hills formed by rocks of the Witwatersrand System and Pretoria Series of the Transvaal System.

(iii) Pretoria Series

This stratigraphic unit consists of a thick succession of quartzites with intercalated beds of banded iron-stone, ferruginous shales and some lavas. It has a topographic expression similar to the rocks of the Witwatersrand System, which consists mostly of fossil features exposed by the removal of the softer Karroo rocks. The terrain is dominated by skeletal soils.

F. Karroo System

By far the most important rocks in the area, both with respect to map coverage and parent material of soils is this thick succession of arenaceous and argillaceous sedimentary rocks, which are extensively invaded by dykes and sheets of dolerite. Its accumulation commenced with the deposition of glacial conglomerates and culminated in the outflow of basaltic lava. The intervening beds, between the tillite at the bottom and the basaltic lava at the top are subdivided mainly upon lithological and paleantological grounds (Table 7). Owing to regional planation (with exceptions) the country occupied by the horizontally disposed Karroo strata is usually characterized by extensive-undulating plains.

(i) Dwyka Series

In the area the only rocks of the Dwyka Series occur in the vicinity of Lichtenburg. It is completely covered by aeolian sand and was only encountered in profile pits (Profile 204/207).

(ii) Ecca Series

Perusal of the relevant literature (Visser et al., 1949; Nel and Jansen, 1957; Sehlke and Van der Merwe, 1959; Coetzee, 1960; Nel and Verster, 1962) reveals a variation in lithology from predominantly argillaceous in the north-west to largely arenaceous in the north-east. Interesting is the exact opposite tendency in the distribution of light- and heavy- textured soils. In general, despite the regional trend mentioned above, argillaceous sediments predominate. In the north-west the lithological units, though well-bedded, are thicker than in the north-east. In this region they consist of thinly-bedded alternations of micaceous shale, carbonaceous sediments, dirty arkosic-sandstones and calcareous mudstones. The following salient features of the Ecca Series, because of their importance to its soil-forming characteristics, need further recapitulation:

1. A general feature of the arenaceous rocks is its textural and mineralogical immaturity (a term coined by Pettijohn (1957). Although some regional trends may be recognizable, argillaceous sediments predominate.
2. These sedimentary rocks disintegrate and weathers readily, giving rise to the formation of heavy-textured soils (Profiles, 22/25, 86/89, 105/108, 133/136).
3. On account of the above mentioned characteristics extensive plains, though to a certain extent attributable to planation on a regional scale, are the salient topographic features associated with the geographical distribution of the Ecca Series.

4. The argillaceous sediments have a lower garnet content than the arenaceous members. The lower Middle-Ecca sandstones contain little garnet, but garnet becomes the predominent heavy-mineral higher up in the succession. A similar trend is noticable in the garnet content of the Lower Middle-Ecca sediments from the north-west to the east (Table 8). The heavy-mineral fraction of the Ecca sediments contain only resistant minerals such as zircon, rutile, garnet, tourmaline and some accessories. A salient feature is the angularity of the constituent minerals. This phenomenon was also observed and reported by Hardaugh (1960), Koen (1956) and Visser, et al., (1949).
5. The Ecca Series is extensively covered by aeolian sands. Judging from the low garnet content of the aeolian sands, the heavy-mineral composition in general, the roundness of constituent minerals and the form of the aeolian sedimentary-bodies, transport must have been from the north-west.

(iii) Beaufort Series

The similarity in lithology between the sediments of the Ecca- and Beaufort- Series has been emphasized by Du Toit (1954), Haughton (1963) and Van Eeden (1937). Of significance is the thick succession of mudstones and siltstones. Siltstones become the predominent component towards the north-east. The area occupied by these sediments is mainly devoid of any excesses in diversity of topography. The terrain is, however, slightly more undulating. This is due to the fact that it represents an older pediplain (King, 1963).

The similarity between the Ecca- and Beaufort- Series is also manifested in the heavy-mineral composition. The arenaceous rocks yielded crops of heavy-minerals which consist practically entirely of angular grains of garnet. The garnet content of the argillaceous sediments are significantly lower (Table 8).

Table 8: Heavy-mineral composition of Karroo Sediments.

Sample number	Zircon	Tourmaline	Garnet	Monazite	Topaz	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Alterites	Accessories	Type of Sediment	Stratigraphic Horizon		Locality	Magistrate District
1	32	13	1	tr	-	10	2	4	-	2	1	2	6	-	3	-	-	24	-	X	Lower Middle Ecca Series		Maquassi	Wolmaransstad
2	27	30	1	-	-	18	-	8	2	tr	-	tr	-	-	1	-	1	12	-	X			Stilfontein	Klerksdorp
3	36	4	18	-	-	27	-	2	-	-	-	-	8	-	-	-	1	4	-	X			Grootvlei	Heidelberg
4	24	8	21	-	tr	18	-	2	2	-	-	-	9	3	-	1	6	6	-	X			Balfour	Heidelberg
5	21	12	25	-	-	16	-	8	14	tr	-	tr	4	tr	-	tr	tr	-	-	+			Devon	Springs
6	73	tr	5	tr	-	4	-	3	5	tr	-	tr	5	-	-	-	1	4	-	X			Brakfontein	Delmas
7	-	40	2	-	-	2	-	-	-	-	-	-	1	-	-	-	-	55	-	X	Middle Ecca Series		Susanna	Wesselsbron
8	32	10	12	-	-	10	5	tr	tr	3	-	3	6	2	7	-	-	10	-	A			Wolwehoek	Heilbron
9	12	11	48	-	-	5	tr	-	-	-	-	-	tr	-	1	-	3	20	-	X			Heilbron	Heilbron
10	13	11	30	-	-	15	1	tr	-	1	-	-	tr	-	-	-	10	19	-	X			Rooirant	Sasolburg
11	25	14	18	-	-	8	-	tr	-	tr	-	8	19	1	tr	-	-	7	-	A			Rooirant	Sasolburg
12	22	24	13	-	-	24	-	-	10	-	-	1	1	tr	-	tr	-	5	-	X			Oranjeville	Frankfort
13a	23	9	43	-	-	13	tr	-	-	-	-	-	1	-	-	-	1	10	-	+			Hartebeesfontein	Heidelberg
13b	23	4	4	3	-	12	tr	-	tr	-	-	-	36	7	-	-	tr	11	-	A			Hartebeesfontein	Heidelberg
14	10	8	45	-	-	7	-	3	6	-	-	-	tr	-	-	-	tr	21	-	+			Trichard	Bethal
15	1	5	69	-	-	6	-	4	tr	-	-	-	tr	-	-	-	2	13	-	X			Trichard	Bethal
16	-	5	65	-	-	3	-	-	tr	-	-	-	tr	-	tr	-	tr	27	-	X			Bethal	Bethal
17	6	-	68	-	-	5	-	-	-	-	-	-	-	-	-	-	-	21	-	X	Lower Beaufort		Riebeeckstad	Welkom
18	3	1	89	-	-	4	-	-	-	-	-	-	-	-	-	-	-	3		X			Sand-River bridge	Ventersburg
19	24	10	45	-	-	3	-	tr	1	-	-	-	3	-	-	-	-	14	-	+	Middle Beaufort		Schuttesspruit	Senekal
20	25	11	tr	2	-	20	7	1	-	2	1	-	5	5	-	-	-	21	-	A			Rietspruit	Senekal
21	25	14	27	-	-	13	1	-	tr	1	tr	-	1	2	-	-	-	16	-	X			Reitz	Reitz
22	1	1	65	-	-	3	1	-	1	-	-	-	-	-	-	-	15	13	-	X	Upper Beaufort		Buddalphsberg	Senekal
23	4	9	40	-	-	20	-	3	2	-	-	-	5	-	-	-	tr	17	-	+			Trentham	Bethlehem
24	14	17	2	-	-	32	1	1	-	3	2	-	3	-	-	-	5	15	5	X	Moltena Stage	Stormberg Series	Montividio	Senekal
25	13	14	tr	-	-	57	tr	tr	1	1	-	-	tr	-	-	-	2	12	tr	X			Paul Roux	Bethlehem
26	28	3	1	1	-	39	4	5	tr	-	-	-	1	-	-	-	1	17	-	X	Red Bed Stage		Paul Roux	Bethlehem
27	28	6	-	-	-	30	8	6	2	-	-	-	3	3	-	-	-	14	-	X			Paul Roux	Bethlehem
28	20	9	11	-	-	38	9	6	1	-	-	-	tr	-	-	-	-	6	-	X			Slabberts	Bethlehem
29	14	53	4	tr	-	8	1	10	-	-	-	1	tr	-	-	-	4	5	tr	X	Cave Sandstone Stage		Paul Roux	Bethlehem
30	16	29	2	1	-	12	7	1	-	-	-	2	-	-	-	-	tr	30	tr	X			Slabberts	Bethlehem

REMARKS: A = Sandstone; + = Siltstone; X = Mudstone and Shale.

Percentages of opaque minerals are not given since their regional trends could not be correlated with sedimentary properties of the rocks.

The entire area occupied by these sediments, except some regional slopes, is covered by a veneer of aeolian sand and surface drift (Profiles 182/185 and 143/146).

(iv) Stormberg Series

The filling of the Karroo basin culminated in the deposition of the Stormberg Series. The area in the South Orange Free State exceeding 1650 meters in altitude is composed of this formation. Corroboration of a complete change in the environment of deposition is not only found in the salient aspects of these sediments but also in the heavy-mineral composition. A striking feature is the low garnet content of the arenaceous rocks (Table 8).

a. Molteno Stage.- This resistant band of massive grits and sandstone rests with no apparent unconformity upon the softer Upper-Beaufort shales. It forms a bold escarpment consisting of nearly vertical cliffs. As a result of the incision of subsequent streams and valley broadening numerous mesas, capped by Molteno sandstone, became detached from the continuous low-escarpment demarcating the Molteno structural-plain (Map 3).

The mesas as well as the escarpment are not covered by soils.

b. Red Bed Stage.- These sediments consist of alternating bands of friable reddish to brilliant-purple argillaceous and arenaceous sediments. Judging from their topographic expression these rocks are apparently highly susceptible to denudation. The plains associated with the geographical position occupied by the Red Beds are covered by a thin layer of sandy loess (Profile 165/168).

c. Cave Sandstone Stage.- The name of this stratigraphic unit has been derived from the presence of hollow cliffs near the base of the escarpments which are unvariably associated with this resistant

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sandstone horizon. The sandstone is normally massive and mature with well-rounded, almost spherical,quartz grains. These facts support the contentions of Van Eeden (1937), Du Toit (1954) and Wardaugh (1960) that it is an aeolian deposit.

Like the Molteno Beds these rocks form bold, nearly vertical, cliffs devoid of any soils. Another common aspect is outlayers in the form of mesas which rise abruptly above the undulating plains. Some of the mesas are capped by pinacles of basalt, others have level tops covered by skeletal soils. Sandy loess which accumulated in protected places such as hollows give rise to the formation of hydromorphic soils (Profile 174/177). The heavy mineral fractions are characterized by the presence of important quantities of blue, green and purple tourmaline (Table 8).

d. Drakensberg Basalt.- Van Eeden (1937) and Du Toit (1954) emphasized the similarity in mineralogy and chemical-composition between the basaltic lavas and its plutonic equivalent the dolerites. The topographic position occupied by the lava is, however, such that the outcrops consist only of bare rock.

e. Karroo Dolerite.- The disposition of the intrusive dolerite bodies, which were the feeding channels of the basaltic effusives, with respect to the sediments is diverse. Nearly vertical dykes ramifying through the sediments and sheets concordant with their bedding planes, have the highest incidence of occurrence. Although dolerite dykes may be encountered in rocks representing the entire stratigraphic column, sheets tend to be more numerous in the Karroo sediments with well-developed bedding planes. This explains the relatively large tracts of country occupied by this rock type and soils derived from it (Profiles 19/21; 94/96; 154/155) in areas where the well-bedded sediments of the Ecca Series are encountered (Visser, et al., 1949; Du Toit, 1954; Coetzee, 1960; Nel and Verster, 1962).

The texture of the dolerite varies with the size of the intrusive bodies. Normally, dykes and thin sheets are fine-grained. The thicker sheets, which may in some instances approach the dimensions of laccoliths (Visser, et al., 1949) are coarse-grained.

Mineralogical investigations with the aid of a Federov universal stage reveals the presence of plagioclase with an anorthite content which varies from 55 to 83 per cent. Zonation is evidently responsible for variations within single grains. Larger grains tend to be more basic than smaller ones. The pyroxenes exhibit a large variation in optical properties. Grains with nearly parallel extinction have a large incidence of occurrence. Many grains, however, has an extinction angle of about 38°. The 2V is small and ranges from about 25 - 55°. On account of these optical properties the pyroxenes may be classified as pigeonites (Poldervaart and Hess, 1951). Some discrete grains of augite were also encountered. Detrital grains of pigeonite and augite could not be differentiated satisfactorily due to the large variation in optical properties of the pigeonite and the well-developed cleavage which causes preferred orientation. Accessories consist of olivine, ilmenite and titanomagnetite.

On account of a large variation in situations, generalization with regard to the topographic expression of the dolerite poses a difficult problem. In many instances dolerite sheets cap low mesas creating the impression of the dolerite being inconducive to weathering. These situations are, however, only encountered in areas where incision was rapid and the rate of removal outstripped the rate of soil formation. Dolerite is resistant to mechanical weathering but highly susceptible to chemical weathering. In the Highveld Region these dolerite hills occur most extensively along the minor escarpment which demarcates the transition from the early-Tertiary erosion surface to the late-Tertiary surface (Map 3).

Dykes usually form slight elevations, these as well as the sheets which cap the low mesas contributed substantially towards soil formation through mass wastage of easily-weatherable material down the slopes giving rise to the formation of the eutrophic reddish-brown soils. Profiles 12/14, 59/62, 117/120 and 90/93 are examples of some of the soils.

The dolerite sheets normally tend to be unconspicious in the landscape. If not contaminated with arenaceous material or covered by aeolian sands it gives rise to the formation of vertisols - Da (D'Hoore, 1964). Profiles 19/21, 94/96 and 154/156 are representative examples.

When contaminated with arenaceous material or buried underneath a layer of aeolian sand, various situations may arise. These apparently depend upon the relief, thickness of the sand cover and probably whether rock or a former vertisol has been buried. Profiles 4/7, 8/11, 59/62, 12/15 and 157/161 were selected as representative examples.

G. Tertiary and Pleistocene Deposits

(i) General

Practically all Pleistocene-geologists, archaeologists, palaeontologists and soil scientists working in Africa, South of the Equator, have noticed the widespread occurrence of aeolian sands and calcareous crusts, and deliberated upon its climatic significance (D'Hoore, 1964; Loxton, 1962; Van Sys, 1961; Botelho Da Costa and Azevedo, 1960; Du Toit, 1954 and Van Riet Lowe, 1937). Alimien (1957) gave a review of the literature of Pleistocene chronology in Africa which provides an indication of the spectrum of opinion on the subject. There seems to be unanimous agreement that the widespread occurrences of aeolian sands, and associated features such as the deflation basins, were formed under conditions of widespread aridity.

Climate itself is not fossilized. In making deductions upon the magnitude of paleoclimates use is made of climatic indicators, such as calcareous- and ferruginous-crusts as well as climatically displaced soils (Flint, 1959; Magnien, 1964; Stephens, 1965). Great caution is necessary in the interpretation of such evidence as prove of former more-humid climates because such phenomena, as has been pointed out by Milne (1947), Mohr and Van Baren (1954) and Brink, et al., (1959), may reflect soil climate and not external climate.

The aeolian sands overlying older landsurfaces, upon which in some localities there occur stone-age artifacts, bears no relationship to the topography and underlying strata (Cooke, 1949; Harmse, 1963). The disposition of the aeolian sands, with respect to the various terrace levels along the Vaal River (Van Riet Lowe, 1937; Cooke, 1949) is such that it provides evidence of three alternating periods of deposition of aeolian- and fluviatile-sediments (Table 6).

The Highveld Region had an exceptionally quiescent orogenic-history during the Pleistocene (Du Toit, 1954; Haughton, 1963; King, 1963). Thus, the deposition of the fluviatile sediments could not have been due to orogeny. According to Hollingworth (1962) fluctuation between aeolian- and aquous-transport, especially in the absence of orogenic disturbances, are bound to be climatically induced.

Although the accumulation of ferruginous concretions may have no significance with regard to the contemporary climate, their presence at lithological discontinuities would indicate periods of relative landscape stability and soil formation. In the Highveld Region these periods may be interpreted as wetter climatic-phases following or preceding drier phases. If associated with stone-age artifacts these layers of concretions have the paleoclimatic significance implied by Van Riet Lowe (1937), Sohnge and Visser (1937); Cooke (1946 and 1949). Furthermore, the theories of paleo-climatology and the relative chronology of the sequence of events in the Vaal River valley, and in Africa South of the Equator, are based on converging evidence such as the alternating deposition of water and wind-transported material (Van Riet Lowe, 1937; Sohnge and Visser, 1937, Alimien, 1957), palaeontology (Cooke, 1949), archaeology and stratigraphy (Janmart, 1953; Wayland, 1954; Bond, 1957; Poldervaart, 1957; Bosazza, 1957) and pollen-analytical investigations (Van Zinderen Bakker, 1957).

The wetter phases have probably never oscillated far from the present semi-arid mean. In contrast, however, the widespread occurrence of aeolian sands, calcareous crusts and deflation basins bears evidence of intense aridity. Caution is unquestionably necessary in making deductions on the magnitude of climatic changes because landscapes in semi-arid sub-tropical regions are sensitive to relatively slight changes in amount and intensity of precipitation.

(ii) Ferruginous Crusts and Concretions

The subject of "laterites", both from a genetical and morphological point of view, has been extensively dealt with. A review of the existing literature by Maignien (1964) confirmed the extreme diversity of these occurrences as well as the divergency in opinion with regard to their genesis. He concluded (p.9) that "the word laterite covers a wide variety of aspects of tropical soil formation and is too general. It appears increasingly difficult to give a purely morphological, purely physical or purely chemical definition".

For the purpose of elucidating the genesis of ferruginous crusts and concretions, encountered in profiles, the following contentions and observations of various authors need mentioning:

1. D'Hoore (1955) distinguished two principal modes of accumulation; relative accumulation and absolute accumulation. The process of relative accumulation embraces an export of non-sesquioxides under

conditions of high humidity and good aeration. Absolute accumulation, on the other hand, implies an import of mobilized sesquioxides. According to D'Hoore (1955), Maignien (1964), Van Schuylenborgh (1965) and Sombroek (1966) mobilization of sesquioxides is enhanced by the biotic factor and anaerobic conditions caused by fluctuating water-tables. Iron and manganese are more mobile in a reducing environment than aluminium (Maignien, 1964).

2. Relative- and absolute-accumulation may occur simultaneously or successively (D'Hoore, 1955). Although the process of relative accumulation is largely determined by climate. The type of initial material is the dominating factor which determines the extent. Basic-igneous rocks give rise to more extensive accumulation than rocks with lesser amounts of easily-weatherable minerals.

3. The concept of atmospheric precipitation, being the major factor in determining the geographical distribution of "laterites", is subject to reservations (Mohr and Van Baren, 1954; Maignien, 1964). In contrast to aluminous-crusts, the occurrence of ferruginous- and manganiferrous-crusts extend to below the 540 mm isohyet in poorly drained regions (Maignien, 1964).

4. A high iron-content seems to be the predominant factor which favours rapid induration (D'Hoore, 1955; Alexander, et al., 1956; Maignien, 1958).

5. According to Jackson, et al., (1948) the dominant factor in the mobilization of iron is deficiency in oxygen. Reducing conditions are created by an accumulation of organic matter. Accumulation of organic matter is enhanced by low temperatures or an excess of water. The process of laterization differs from podzolization only in that iron is not mobilized owing to a higher oxidation potential. These authors proposed a continuous podzol - podzolic laterite -

laterite weathering sequence. The redox potential of the environment determines the trend of the sequence. Experimental work done by Bloomfield (1965) led him to similar conclusions.

6. The contentions of the above mentioned authors seem to be also substantiated by experimental work on the mobility of sesquioxides by Van Schuylenborgh (1965). He suggested that the accumulation of iron oxides are not likely to have resulted from the translocation of ferric oxides in the absence of organic matter. Furthermore, that the translocation of iron in the form of the ferrous iron is possible under anaerobic conditions, even in the absence of organic matter. Oades (1963) differentiates between two types of iron accumulation. One type is formed under alternating reducing and oxidizing conditions as a result of temporary water-stagnation. A second type owes its translocation and precipitation to biological processes. Whether these two processes operate to the mutual exclusion or enhancement of one another would be difficult to ascertain. Mitchell (1964) suggested that the mobilization of iron and trace elements, in subsurface gleyed-horizons, does not appear to be influenced by the presence of organic matter.

Finally Maignien (1964) emphasized the need to distinguish between aluminous accumulations on the one hand and ferruginous accumulations on the other. Conflicting views and results have arisen mainly from the study of different objects representing unrelated pedogenetic processes.

The advantage of the term "plinthite" (Soil Survey Staff, 1960) over "laterite" is dubious and probable only lies in the fact that it differentiates between processes and resulting materials. According to the definition, which does not differentiate between ferruginous and aluminous crusts and concretions, hard concretionary forms are considered to be a product of induration of the soft mottles. Hard- and soft- concretions encountered in the same horizon during this investigation, differ in chemical composition (Table 9). The usage of the term plinthite[1] may thus only result in an undesirable conformity of nomenclature. For reasons mentioned above the term ferruginous concretions and crusts, considering the dominance of iron over aluminium (Table 9), is thought to be more appropriate.

These concretions and crusts exhibit the following morphological and chemical characteristics:

1. The segregation and/or accumulation of iron is in the form of hard concretions consisting of discrete pisolites, commonly more than 2 mm in diameter, or slag-like continuous layers. The slag-like layers comprise hard discrete pisolites cemented by ferruginous material.
2. Although the concretions are generally distributed throughout the profile, the maximum incidence of occurrence is at lithological discontinuities. At this level the hard, often rounded and glossy, pisolites form a continuous layer. Profiles in which two layers of concretions occur exhibit characteristics which may be interpreted as evidence of more than one lithological discontinuity.
3. The presence of concretions and crusts is predominantly associated with a, relatively thick, cover of unconsolidated aeolian-sand or colluvium on comparatively unweathered, slowly permeable B-horizons (Profiles 182/185; 129/132), shales (Profile 204/207),

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[1] Since the preparation of this manuscript a supplement to the 7th Approximation has been received (restricted distribution) in which the term "plinthite" has been redefined. The "term" in the context of the amended definition is applicable without reservation to what has been described as ferruginous crusts and ferruginous concretions throughout this manuscript.

dolerite or vertisols on dolerite (Profiles 4/7; 8/11; 12/15; 59/62; 157/161).

4. Concretions were not encountered at lithological discontinuities in profiles with distinct solonetzic affinities. The sandcover is usually of limited thickness or the profiles are situated on slopes (Profiles 165/169; 43/45; 86/89). The thin sandcover in such profiles may prevent the penetration of an adequate quantity of water to evoke anaerobic conditions.
5. Profiles occur in which the accumulation consists of an unusually thick layer (more than 10 cm) of concretions, cemented into a slag-like continuous phase (Profile 204/207). These profiles exhibit evidence which may be interpreted as an indication of more than one period of accumulation of aeolian sand, intervened by soil formation and complete truncation.
6. Discrete concretions and lumps of hard concretions occur in gravels dating back to the late-Tertiary (Von Backström, et al., 1953; Du Toit, 1954).
7. Topographic depressions filled in by aeolian sand are the foci of maximum development of ferruginous crusts and concretions. Seepage water emanating from underneath such sand-filled depressions is covered by a thin film of hydrated iron.
8. The above mentioned situation has been observed under a mean annual-precipitation of 450 mm on the Waaifontein farm in the Hoopstad district.
9. Profiles with fine-textured slowly-permeable A horizons, even on heavy clayey-horizons that exhibit prominent mottling, are apparently not subjected to the accumulation of continuous layers of ferruginous concretions (Profile 208/211).
10. Concretions are scattered throughout the horizon of maximum clay-content in profiles in which the mottled zone has a low

Table 9: Chemical composition of ferruginous concretions

Profile number	Sample number	SiO_2	Al_2O_3	Fe_2O_3	MnO_2	TiO_2	CaO	K_2O	Total	Mol.ratio $\frac{Al_2O_3}{Fe_2O_3}$	Colour (Munsell notations)	Remarks
4/7	4	41.5	7.4	42.0	0.10	0.36	0.20	0.30	91.86	0.27	5YR4/6 (dry) yellowish red	Hard
	5	28.1	12.4	34.4	5.10	0.54	0.21	0.40	81.15	0.56	10YR3/4 (dry) dark yellowish brown	Soft
	6	26.5	11.5	42.0	0.60	0.54	0.40	0.65	82.19	0.43	10YR5/8 (dry) yellowish brown	Hard
8/11	9	30.5	5.2	38.0	0.10	0.38	0.25	0.60	75.03	0.21	5YR5/6 (dry) yellowish red	Hard
	10	28.5	6.0	40.0	0.81	0.35	0.20	0.30	76.16	0.23	10YR5/8 (dry) yellowish brown	Hard
	11	27.2	11.4	38.8	0.20	0.48	1.00	0.40	79.48	0.46	10YR5/8 (dry) yellowish brown	Hard
157/161	157	39.5	4.2	29.3	1.80	0.66	0.16	0.70	76.32	0.22	7.5YR4/4 (dry) dark brown	Soft
	159	50.0	10.5	27.9	0.70	0.64	0.25	0.90	90.89	0.58	10YR5/8 (dry) yellowish brown	Hard
44/47	44	56.5	4.9	29.3	0.11	0.41	0.21	0.75	92.18	0.26	10YR5/8 (dry) yellowish brown	Hard
	45	55.0	12.2	29.3	0.45	0.46	0.20	0.80	98.41	0.65	10YR5/8 (dry) yellowish brown	Hard
	46	53.0	12.2	25.0	1.25	0.48	0.25	0.87	93.05	0.76	10YR4/4 (dry) dark yellowish brown	Soft
	47	60.3	8.9	27.0	1.75	0.48	0.23	1.10	99.76	0.51	10YR4/4 (dry) dark yellowish brown	Soft
201/202	201	48.5	7.8	35.8	0.20	0.48	0.80	0.70	94.28	0.34	5YR4/4 (dry) yellowish red	Hard
	202	47.5	8.2	24.7	0.80	0.48	0.70	0.72	93.10	0.52	5YR4/4 (dry) yellowish red	Hard
165/168	167	60.0	13.1	12.1	2.20	0.64	0.54	1.75	90.33	1.69	10YR3/3 (dry) dark brown	Soft
212/216	214a	54.5	6.1	24.8	0.51	0.50	0.14	0.36	86.91	0.38	10YR5/8 (dry) yellowish brown	Hard
	214b	65.5	8.3	12.8	6.75	0.42	0.24	0.39	94.40	1.01	10YR3/4 (dry) dark yellowish brown	Soft
221/225	224a	58.0	7.4	30.7	0.75	0.40	0.13	0.85	98.28	0.37	10YR5/8 (dry) yellowish brown	Hard
	224b	51.0	8.4	14.2	5.20	0.35	0.14	0.76	80.05	0.92	10YR3/4 (dry) dark yellowish brown	Soft

clay-content or the clay consists practically entirely of kaolinitic minerals (Profiles 52/55; 73/76; 200/203; 221/225). Some profiles with similar morphology and mineralogical properties, however, do have continuous layers of concretions at lithological discontinuities (Profile 30/33).

The data summarized above leads to the following conclusions:

1. A spectrographic analyses of 35 samples, of which some are represented in Table 9, indicate that the hard concretions consist, besides silicium, predominantly of iron oxides with subordinary amounts of aluminium and manganese. Soft concretions have a higher aluminium or manganese content than hard concretions.
2. The accumulation of discrete ferruginous concretions and continuous layers of discrete concretions cemented by ferruginous-material does not seem to reflect external climate, as has been advocated by Flint (1959). In the area under consideration the accumulations are more likely to reflect the influence of soil climate (Mohr and Van Baren, 1954; Brink, et al., 1959; Maignien, 1964).
3. Although most profiles probably contain first- and second-generation concretions, those which form continuous layers at lithological discontinuities are essentially the product of absolute accumulation (D'Hoore, 1955). Wind deflation to the depth of the fluctuating water-table may cause additional concentration at this level. This manner of absolute accumulation may not be readily distinguishable from the layer of continuous concretions formed at lithological discontinuities.
4. The lithological discontinuities result from the deposition of relatively more permeable windblown-sand and colluvium affected by aeolian sorting on relatively unweathered stumps of trucated

soils or heavy-textured soils not affected by aeolian sculpturing (Profiles 182/185; 4/7; 204/207). These conditions cause stagnation of water in the profile and reduction of unbound ferric-oxides. The ferric oxides are present in the form of thin pellicles around mineral grains or fillings in microscopic cracks. Ferruginous dust as suggested by Vine (1949) may be responsible for the importation of ferric oxides.

5. In well-drained sites, if the buried horizons or rocks are rich in easily-weatherable minerals, absolute accumulation is effective only for relatively short periods. Lateritic weathering ensues as a result of the more favourable soil-climate, caused by the deposition of the permeable sands. A zone of relative accumulation develops below the zone of absolute accumulate (Profiles 12/15; 59/62; 109/113; 90/93). The pedological significance of the chemical composition of successive horizons in these profiles are thwarted by admixture of detritus of local origin during transportation and argillipedoturbation after deposition. Illuviation on a limited scale undoubtedly also contribute to the complexity.
6. A thin layer of aeolian sand or colluvium is apparently not sufficient to produce the above mentioned situation (Profile 157/161), neither is the deposition of a thicker layer of aeolian sand on horizons which contain little or no easily-weatherable primary-minerals (Profiles 182/185; 129/132; 204/207). The time factor could be instrumental in causing some of these variations.
7. Scattered concretions occurring in horizons, containing a mixture of water-transported pebbles and aeolian-transported detritus, is considered to represent collovium comprising a mixture of aeolian sands and material derived from the soils and

autochtonous rocks in the vicinity (Profiles 200/203; 73/76; 63/65; 52/53).

8. Mobilization of iron seems to be solely dependent upon anaerobic conditions brought about by water stagnation in the profile (Van Schuylenborgh, 1965; Bloomfield, 1965 and Sombroek, 1966). This weakens the contention of D'Hoore (1955), who considered the biotic factor and organic matter as a pre-eminent pre-requisite for the mobilization of iron.
9. Immobilization is brought about by physical adsorption on active surfaces of clays and flocculation of hydroxides at the iso-electric pH (D'Hoore, 1955).
10. Transportation by free water under the influence of gravity (D'Hoore, 1955) though probably the major process, does not seem to be the sole mechanism of translocation. Ionic migration in free solution could also be important.
11. Differences in chemical composition between soft and hard concretions in the same profile, exclude any comment on the induration of the ferruginous crusts and concretions. A high iron-content, however, seems to be the major factor favouring rapid induration (D'Hoore, 1955; Alexander, et al., 1956; Maignien, 1964). The silica and aluminium content of hard ferruginous-concretions in different horizons in the same profile, apparently, reflects variations in these elements between horizons (Table 9).
12. Absolute accumulation of ferruginous concretions in the Highveld Region is predominantly a process associated with water stagnation and a reducing environment. Consequently the name "ground-water laterites" is considered unappropriate for the characterization of these soils. Truncation to the level of absolute accumulation and exposure of the ferruginous crusts may conceivably be mistaken as evidence of laterization and a more humid climate in the past, but in reality, this does not seem to be the case.

(iii) Calcareous- and Siliceous- Crusts

Calcareous- and siliceous- crusts in the Highveld Region are confined to the north-western part with an average precipitation of less than 600 mm per annum.

a. Calcareous Crusts.- The calcareous crusts do not exhibit any distinct bedding but an irregular lamination is common. At the surface it is usually hard and massive rather similar to the Australian Kunkar (Blackburn, et al., 1965). Viewed from the top the hard surface-layer has a macro colloformstructure which is, in some instances, rather reminiscent of the columnar structures of natric horizons. Deeper down the material becomes soft and massive with a weak tendency towards stratification. Very often, lenticles and layers of water-transported material occur in juxtaposition with limestone. Oolitic structures are encountered under the microscope but the great mass consists of finely devided amorphous particles with varying amounts of microcrystalline constituents lining cracks and hollows. The harder surface crust consists mostly of microcrystalline constituents richer in siliceous material than the more amorphous mass deeper down. Gastropod shells are often encountered, as well as rests of plants which are partly or completely replaced by lime.

These crusts, normally, only attain limited thickness. Variations from a few centimeters to 5 meters were, however, observed. Von Backström, et al., (1953) reported maximum thicknesses from bore-hole records of up to 37 meters.

The distribution of the calcareous crusts are restricted to topographic depressions in close proximity to rocks rich in lime such as andesitic lava, dolerite, tillite and Karroo shales (Von Backström, et al., 1953; Du Toit, 1954; Von Backström, 1962; Van Eeden, et al., 1963 and Harmse, 1963). In the Kalahari, Mabbutt (1957) observed that the calcareous sediments obtain their greatest thicknesses in drainage lines. Travertine, formed by the evaporation of lime charged waters, reported by Van Eeden, *et al.*, (1963), is being formed at present under lower annual rainfall towards the west. The introduction of extraneous material by wind is not impossible, however. On the southern perimetre of nearly every pan (deflation basin) there occur low rounded-hills which rise up to 10 meters above the surroundig country. These hills represent an accumulation of material blown from the pans. The constituent material is characteristically even-grained and consists of an impure mixture of sand and nodular fragments rich in lime. On one such a locality on the Deelpan farm, a thick layer of hard silicified limestone (calcrete) overlies a layer of Tertiary gravels. Outside the Highveld Region, west of Zweitzer Reneke, Van Eeden, *et al.*, (1963) reported long straight ridges of calcareous material. The trend of these ridges are north-west to south-east. The accumulation of lime-rich deposits around the south-eastern perimeter of the pans and the fact that the above mentioned ridges have an orientation similar to that of the seif dunes (Harmse, 1963), suggests at least limited distribution of lime by the wind.

The calcareous crusts are extensively exploited for cement manufacturing and road-building purposes. The crusts are well exposed and a great many analyses are available. An average $CaCO_3$ content which ranges between 83 - 91 per cent has been reported from widely separted localities (Von Backström, *et al.*, 1953; Coetzee, 1960; Van Eeden, *et al.*, 1963).

The mode of formation of these calcareous crusts seems to be the evaporation of water saturated with $CaCO_3$. Harmse (1963) suggested that the formation of the pans and large depressions formed by wind deflation (styled "floors" by Du Toit, 1954), provided an ideal physiographic setting for the formation of these crusts, away from the drainage courses (Table 6). The drainage courses itself are shallow hollows with low gradients and in many instances mere connections between deflation basins. The calcareous crusts may thus be compared with lacustrine evaporites. Archaeological evidence supports the contention that the deflation basins as well as the calcareous crusts antedates the Fauresmith Stage of the South African Acheulian (Cooke, 1946; Mabbutt, 1957; Harmse, 1963; Van Eeden, et al., 1963).

It seems a point of unanimous agreement amongst pedologists, familiar with these particular occurrences that, whatever the true mode of formation, it should be regarded as rock and rock debri (Van der Merwe, 1962; Loxton, 1962; D'Hoore, 1964). The fact that the calcareous crusts are restricted to an area with a present average annual-rainfall of less than 600 mm should not be regarded as of any genetic significance as implied by Flint (1959). They may have been formed under a much drier climate (Rogers, 1936; Du Toit, 1954 and Mabbutt, 1957).

They represent distinct fossil crusts which have no bearing on the present pedological environment. Deposition of thin layers of aeolian sand on these calcareous crusts give rise to the formation of soils best described as pseudo rendzina (Profile 227/229) or lithomorphic soils on calcareous crusts (D'Hoore, 1964).

b. Siliceous Crusts.- The occurrences of siliceous crusts are intimately associated with calcareous crusts, but are usually covered by a thick layer of aeolian sand (Rogers, 1936; Mabbutt, 1957; Von Backström, 1960 and Boocock and Van Straten, 1962). Some occurrences in the Highveld Region has been the subject of an intensive investigation by Von Backström (1960). Like the calcareous crust, the siliceous crusts are extensively covered by aeolian sand which overlies it with a marked unconformity. A siliceous hardpan was encountered in the position of a soil horizon at a depth of 164 - 185 cm on the farm Lushof 17 (Profile 212/216). Microscopic investigation of thin sections reveals an equigranular microcrystalline texture. A striking feature (Plate II, Fig.3) is the complete absence of well-rounded grains of aeolian sand overlying this hardpan.

These observations tend to support the contention of Rogers (1936) that a pre-requisite for the formation of siliceous crusts (silcretes) from calcareous crusts is the presence of an overlying layer of sandy sediments or thick soil-covers. That this is not a premise for generalization is indicated by the presence, in some localities, of thin hard crusts richer in silica at the surface of calcareous crusts whether covered or not. To reach exclusion on this point is not possible without absolute dating of the sand cover. Truncation to the depth of the crusts and redeposition of sand on calcareous crust previously not covered, is still taking place. These siliceous crusts resemble the Australian Kunkar described by Blackburn, <u>et al</u>., (1965).

(iv) Aeolian Sand

a. General.- The terrace gravels along the Vaal River have played an important part in the unravelling of the Quaternary history of the area and the establishment of a relative chronology of climatic events. Away from the Vaal River, however, the question of establishing relative ages of aeolian deposits occurring in juxta- and superposition poses a serious problem. It is aggrevated by the usual absence of fossils or, if present, by insufficient organic-carbon for absolute dating. Lack of stratification in the aeolian sands eliminate the possibility of making use of conventional stratigraphic criteria to delineate or recognize different layers occurring in superposition. Numerous dust storms (Plate II, Fig.2) and dust devils are testimony to the fact that the "aeolian-sandy soils" are highly susceptible to wind erosion. Bosazza (1953), during a severe dust storm, collected dust particles in an aircraft at an altitude of 1000 meters. Complex and truncated profiles are the rule rather than the exception in the aeolian-sand landscapes. Liberation of the sand at the surface by cultivation and the detrimental effect of human influence in general is the factor responsible for the present cycle of landscape instability.

The thickness of the sand-cover is limited except where it has accumulated in depressions. Thickness of up to 10 meters were encountered in an old drainage channel near the village Koppies. On the whole, however, the aeolian sands blanket large tracts of the Highveld Region in the form of a thin layer.

b. Provenance.- Samples subjected to investigation were not selected with a view of establishing the provenance of the aeolian sands. Owing to the incorporation of detritus derived from the autochtonous rocks along the route of transport the aeolian sands are not homogeneous. Earlier work (Harmse, 1963) showed that the provenance of the aeolian sands may not be elucidated by the investigation of widely-spaced samples. Neither can aeolian sands be identified by the granulometric analyses of the sand fraction nor can the grain-size distribution be expected to correspond to the curves of ideally sorted sand, such as those published by Bagnold (1960). The following factors have a profound influence on the mineralogy, grain-size frequency-distribution as well as on soil formation.

1. Progressive sorting in the direction of transport.
2. Progressive dilution due to admixture of detritus, derived from autochtonous rocks, along the route of transport (Profile 208/211; 200/203).
3. Progressive destruction of minerals with well-developed cleavage.

Despite these difficulties a pattern has emerged which could stimulate future work and elucidate problems with regard to this aspect of the aeolian sand. The problem will be discussed in the widest sense, in full awareness of the difficulties raised by such a heterogeneous phenomenon.

c. Distribution of the Aeolian Sands.- Transport has been from the north-west. This is manifested in the occurrence of extensive sheets of aeolian sand, extending from the south-eastern extremities of outcrops of arenaceous rocks over flattish ground. Seif dunes in the Kalahari and the Highveld Region have a west-north-western trend (Mabbutt, 1957; Harmse, 1963). The distribution of aeolian deposits are shown on Map 3.

1. The featureless plains in the Western Transvaal are extensively covered by aeolian sand derived from the Kalahari; transport took place in a south-eastern direction. This fact is illustrated in the similarity in heavy-mineral composition between the Kalahari sand (Poldervaart, 1957) and the aeolian sands occurring in the area around Lichtenburg (Profiles 200/203; 204/207; 208/211; 212/216). Evidence of admixture with the autochtonous rocks has been given under the description of the various autochtonous rocks in the area (see subdivisions B and D under the heading Geology). Morphological differences between profiles 200/203; 208/211; 204/207; 212/216; 218/220 are attributed to mineralogical and textural differences acquired by the aeolian sand through admixture with autochtonous rocks. These as well as the effect of the horizons or rocks on which deposition took place has resulted in different soil-climates and variation in parent material (aeolian sand).
2. In the north-western Orange Free State the distribution of aeolian sand is in the form of a number of sub-parallel seif dunes. The sand attains its maximum thickness in the seif-dune landscapes and give rise to typical fersialitic soils without diagnostic horizons (Loxton, 1962; Van der Merwe, 1962). Between the seif dunes the sandcover is thin and discontinuous (Plate IV). The median grain-size of the sandfraction is smaller and admixture from local sources is evident in the grain-size distribution

of the sand fraction (Harmse, 1963). Depending on the underlying rock or buried soils two types of soils are formed. Deposition of aeolian sand on "vertisols of lithomorphic origin derived from calcareous rocks - Db" (Loxton, 1962; D'Hoore, 1964) giveseffect to the formation of the Highveld pseudo-podzolic soils - Fa. Profiles 22/25; 105/108 are representative for the mapping unit Db on the soil map of Africa, and profiles 43/47; 129/132 and 182/185 of the mapping unit - Fa. Plate IV gives an illustration of the situation as encountered in the field.

The situation developing, owing to burial of Karroo Dolerite by aeolian sands and colluvium affected by aeolian sorting has been discussed under the sub-heading Karroo dolerites(page 39).

3. Along the Vaal River, wherever the river flows transverse with respect to the west-northwestern winds, a younger deposition of aeolian sand occurs in the form of river-border dunes (Harmse, 1963). This younger deposit of aeolian sand transgresses the recent erosion-surface along the Vaal River down to the River banks. Deposition of the younger sands (styled "younger garnet-bearing sands" by Harmse, 1963) has blocked the drainage which resulted in the development of mineral hydromorphic soils. The soils are susceptible to wind-erosion. Redistributed sands havebeen blown into small dunes which impart a hummocky appearance to the topography. These sands as well as the younger sands give rise to soils, best described as yellowish-brown regosolic-sands (Profile 226/233).

   In well-drained sites a layer of younger garnet-bearing sand on older aeolian sands results in the formation of reddish-brown fersiallitic soils - Jd, with textural B-horizons (Profile 221/225).

4. The area beyond Kroonstad, between Bethlehem and Senekal, is characterized by the presence of a thin layer of sandy loess (Map 3). The resulting landscape features are rather reminiscent of

European loess-covered areas.

The layer of sandy-loess has been encountered in all profiles examined and sampled. Profiles 143/146; 165/169; 174/177 and 182/185 are representative examples.

Large scale erosion and the formation of badlands took place before the deposition of the aeolian sandy-loess. This was followed by a period of aggradation during which the ancient gullies were covered by a thick layer of sandy-loess (Plate V, Fig.1). The filling or covering of the gullies and river-valleys indicates a period of large scale aggradation. No evidence of eustatic movements could be found. This would imply a change in climate and a consequent increase in detritus or decrease in the transporting capacity of the rivers. The presence of the sandy-loess on the interfluves implies that the former is the more likely explanation, the latter being only of secondary importance.

Soils with distinct solonetzic morphology occur on the lower slopes (Profile 165/168) but are also encountered on the crests of interfluves. Here their distribution assumes the pattern of small deflation basins. The occurrence of "boulders" consisting of prisms of the natric-horizon within the layers of loose sediments implies that it is a fossil-horizon (Plate V). Its formation is largely attributable to vanished conditions.

Human interference has rendered this area particularly susceptible to erosion. Removal of the loose sediments from the valleys has resulted in renewed gulley formation. Sheet wash has removed much of the sand cover and consequently exposured the sterile prismatic-layer of the solodized solonetz (Plate V, Fig.2).

The characteristics and occurrence of the layer of sandy-loess supports a wind-blown origin. It, however, exhibits variations (compare the mineralogy and grain-size distribution of the sandfraction of profiles 165/169 and 174/177) which do not support a strictly extraneous source. Such differences may indeed be achieved by sorting, considering the difference in altitude between the two sample sites (Chepil, 1957). Bozazza (1957) reported similar sediments on the foot-hills of the mountains in Basutoland and described it as an aeolian deposit. Nevertheless, the presence of deflation basins on sandstone (Van Eeden, 1937) as well as the numerous sandstone outcrops would indicate considerable admixture of locally-derived detritus.

5. From Vereeniging towards Delmas in the east, aeolian sands were derived from the arenaceous rocks of the Witwatersrand- and Transvaal- Systems as well as from the sandstones of the Middle-Ecca series (Map 3). The sand covers these sediments with a marked unconformity (Profiles 4/7; 8/11; 30/33; 43/47; 109/113; 117/120; 121/125; 129/132).

An extensive seif-dune or sand-sheet extends from Delmas in a south-eastern direction across dolomite and the strike of the Karroo sediments which dips a few degrees to the south (Profiles 52/55 and 59/62).

The remainder of the area is devoid of discrete aeolian deposits (Map 3). A-horizons of practically all profiles examined were, however, subject to sorting by aeolian action and influenced by surface drift (Profiles 90/93; 86/89; 157/161). This fact is manifested in the grain-size distribution of sand-fractions, the mineralogy of the heavy-fractions and clay fractions. The presence of abraded and frosted grains in A horizons and the presence of numerous small deflation basins (Visser, et al., 1949) bears testimony that this phenomena have been caused by wind-action.

IV. MINERALOGY

A. Clay Minerals

(i) General

The occurrence of different soil groups reflects the various pedological and geochemical factors operative on their genesis. Distinctly different soil groups probably do not imply that the soil-forming reactions are radically different, but that the relative importance of different soil-forming reactions is different in each. The morphological characteristics of profiles, in so far as they are not purely attributable to sedimentary processes, serves as an index of the balance of the intensities of the environmental forces.

An important set of differences between soil groups lies in their vastly different clay-mineral content (Jackson, 1959; Fieldes, 1962; Toth, 1964 and Jackson, 1964). The frequency distribution of these minerals in soils is a function of the principle soil-forming factors; climate, biotic factor, parent material, relief and time. The dominant role of the phyllosilicates in determining the physical and chemical behaviour of soils has been pointed out by all concerned with the study of soils.

The overriding importance of parent material during the initial stages of soil formation, both in supplying the necessary geochemical ingredients for the synthesis of the clay minerals and the determination of the permeability has been emphasized by Jackson, et al., (1948); Jackson, et al., (1952); Mohr and Van Baren, (1954) and Jackson, (1964). The successive stages in the weathering sequence of Jackson, et al., 1948 and Jackson, 1964 is controlled by the product "intensity" x time".

The importance of permeability pertains especially to the removal of soluble substances from the profile. Lack of stoichiometry between the successive phyllosilicate stages in the sequence is determined by the relative mobility of the elements. Relative mobility of elements is a function of their ionic potential (Mason, 1958) and the environmental conditions. Elements with low ionic potential such as sodium, potassium and magnesium are highly soluble and apt to be removed from the environment, The ions of elements with intermediate ionic potential are associated with hydroxyl groups in solution. The solubility of these are dependent upon pH, the presence of organic matter and the redox potential of the environment (Mason, 1958, Van Schuylenborgh, 1965 and Bloomfield, 1965) as well as its association with other sesquioxides (Acquaye and Tinsley, 1965 and Barshad, 1964).

The mechanism by which colloidal silica reacts with colloidal alluminium to form clay minerals is not clearly understood (Gastuche, 1964). Barshad (1964) postulated that the formation of clay minerals is catalyzed by the presence of other aluminium-silicate minerals of the soil through adsorption on their surfaces. Gastuche (1964) emphasized the role of ionic radius as an important factor which controls the pre-organization of somatoids and the influence of pH on their stabilization.

From the point of view of the weathering sequence it is necessary to consider the various environmental conditions affecting the relative mobility of silica and aluminium. The reason for the accelarated rate of desilication in the laterization process has been a point of much debate. Chemically, the solubility of silica would be expected to decrease with increasing acidity. There can, however, be little doubt that the following sequence is controlled by desilication and/or alumination:

$$\text{Montmorillonite} \quad \underset{\longleftarrow}{\xrightarrow{\text{desilication}}} \quad \text{kaolinite}$$

Generally the process to the right is more pronounced in tropical soils. Under the high temperatures prevailing in these areas, rapid mineralization of organic matter enhances the oxidation of ferrous iron (Mohr and Van Baren, 1954). The influence of a high iron-content (Fe_2O_3) on the stability of soil aggregates and porosity has been emphasized by Mohr and Van Baren, (1954), Friedland, et al., (1964), Pauli, (1964) and Jackson, (1964). Increase in porosity greatly increases circulation of moisture through the profile. This in turn promotes the removal of metallic cations (Ca^{++} Mg^{++}, K^{+} and Na^{+}) which envokes an increase in the hydroxylation of primary minerals. This fact is amply manifested in the occurrence of large amounts of weathering products in the light fraction of eutrophic reddish-brown soils - Hd (Profiles 12/15; 59/62) in contrast to their absence in the vertisols - Da (Profiles 19/21; 94/96; 154/156) developed on the same parent material. The weathering products consist of amorphous relics of feldspars, depleted of the metallic cations but still held together by the stronger Si-O and Al-O bonds. Barshad (1964), on the basis of the poor fit of Al^{3+} in fourfold coordination, proposed that it would be the next to leave the structure of the primary minerals, Al^{3+} may precipitate as $(AlOH)_3$ or become hydroxylized which promotes its polymerization into strongly polyvalent cations. These are absorbed on the exchange sites of minerals as well as in the interlayers of 2 : 1 layer silicates (Jackson, 1964). The polymerized positively charged aluminium, according to Barshad (1964), reacts readily with polymerized negatively charged silica to form amorphous precipitates which upon aging crystallize to form the clay minerals. This view is also held by Sherman (1962) and Fieldes (1962).

Oxidation greatly reduces the stability of minerals containing Fe^{2+} (Marshall, 1964 and Barshad, 1964). Oxidation of Fe^{2+} to Fe^{3+} causes disruption in the mineral lattices in that it disturbs the electrostatic neutrality and geometric stability. Consequent expulsion of cations, leaving open sites, promotes decomposition or alteration to other minerals species. Once Fe^{2+} became oxidized to Fe^{3+} it rarely participate in clay-mineral formation but remains as free Fe2O3 (Gastuche, 1964).

The weathering products are presumable the "permutite-like" minerals described by Burgess and McGeorge (1926) or the hydrous feldspar of Fieldes (1962). The silica in these metamicts or relics is essentially in an amorphous state. The solubility of quartz according to Marshall (1964) lies much below that of colloidal silica, or ortho-silicic acid, H4SiO4 (Reynders, 1964).

From what has been said it would appear that the increased degree of desilification associated with lateritization should not be regarded from the point of view of silica only as has been emphasized by Acquaye and Tinsley (1965). Oxidation of iron, formation 1 : 1 layer silicates and amorphous precipitates and relics are all factors which has a major influence on soil porosity. These factors as well as increased leaching, owing to higher permeability, has a determining influence on the weathering of minerals and release of silica and aluminium. Rapid mineralization of organic matter and slightly acid to neutral soil reactions may be responsible for the relatively lower mobility of aluminium. Experimental work by Pedro (1962), Acquaye and Tinsley (1965), Van Schuylenborgh (1965) and Hénin and Pedro (1965) as well as summaries on solubility data of silica in the literature (Iler, 1955; Marshall, 1964 and Reynders, 1964) gives the impression that this is the case.

(ii) Mica

Primary micas occur abundantly in some igneous, metamorphic and sedimentary rocks, their occurrence in soils is mainly due to inheritance (Barshad, 1964). Weathering of mica in soils entails a loss of interlayer potassium. Weathering of allogenic micas follows the following sequence (Jackson, 1964):

$$\text{mica} \rightleftarrows \text{illite} \longrightarrow \text{vermiculite} \longrightarrow \text{montmorillonite}$$

Coincident with the progress of the reaction to the right, and a release of interlayer potassium is a reduction in layer charge. The mechanism by which it is brought about is apparently dependent upon a number of interdependent factors. In this respect Jackson (1964) emphasized hydroxylation and leaching of K^+ and Mg^{++}, oxidation of ferrous iron, dealumination or resilication. Experimental work by Rausell-Colom, *et al.*, (1965) has confirmed the determining influence of the presence of potassium in solution on the affinity of the reactions to the left; between illite and mica. Adsorption of ions, other than H^+, such as Ca^{2+}, Mg^{2+} and Na^+ on mica surfaces may be expected to counteract the interlayer charges causing the crystal lattice to expand in the direction of the C axis. Such expansion will promote the removal of interlayer K^+ and result in crystal structures similar to vermiculite and montmorillonite. The fact that micas seem to be more stable in acid environments seems to support this contention.

(iii) Illite, Vermiculite, Montmorillonite and 2 : 2 Intergrades

Investigations by Jackson, *et al.*, (1952) and Jackson (1964) have led to the proposal of the preferential weathering plain. Meaning, that any given mica interlayer either remain completely filled with potassium or become completely affected by interlayer swelling. This process leads to the formation of either illite or hydrous micas. Jackson (1964) proposed that the mineral illite should be regarded as a group-name referring to minerals that consist of an interstratification of mica with expansible layer-silicates rather than a discrete monomineralic structure.

Replacement of potassium by hydroxyl ions, leads to the formation of expansible micas. Precipitation of magnesium, aluminium, iron and allophane in the interlayers of the expansible 2 : 1 layers of soil clays is regarded by Jackson (1964) as genetic stage in the $2 : 1 \longrightarrow 2 : 2 \longrightarrow 1 : 1$ weathering sequence. Homogeneous or monospecies interlayers in layer-silicates such as potassium in mica, magnesium in vermiculite and water in montmorillonite is according to Jackson (1963) essentially a product of diagenesis in closed systems:

$$\text{Homogeneous interlayers} \xrightleftharpoons[\text{diagnesis}]{\text{chemical weathering}} \text{Heterogeneous interlayers}$$

Such interstratification results in weakening of the 10Å spacing of the micas. Continued weathering, decrease in layer charge, release of potassium, and expansion to vermiculite and montmorillonite spacings give rise to x-crystalline zones consisting of mica, vermiculite and montmorillonite. Spacings intermediate between mica, vermiculite and montmorillonite phases are a result of average electron density nodes caused by the interstratification of x-crystalline zones of mica, vermiculite and montmorillonite respectively (Jackson, *et al.*, 1952; Hendriks and Teller, 1942; Sudo and Hayashi, 1956 and MacEwan, *et al.*, 1961). Random interstratification or random zonal-interstratification (Jackson, *et al.*, 1952) cause a scattering of X-rays without any discrete diffraction maxima within the limit of spacings of the individual components. Such random sequences of mixed-layer minerals has been described as X-amorphous.

The theoretical possibility of mixed lattices of "mica-like" minerals has been postulated by Pauling (1930). Gruner (1948) suggested that interstratification of any or all combinations of recognized mica and clay minerals might be possible within a single crystal, depending on cation supply and composition of the chemical environment. MacKenzie, *et al.*, (1941) concluded that the weathering sequence feldspar ——> illite ——> montmorillonite progresses with some interlayering. Jackson (1963) and Jackson (1964), on the basis of extensive surveys, proposed the general occurrence of interstratification in soil clays.

Application of the Hendriks and Teller hypothesis to a strong 9.5Å reflection by Hseung, *et al.*, (1952) led them to propose a binary mica-montmorillonite mixed-layer structure. The 9.5Å peak was attributed to 003 of a 28.5Å $\frac{10+18.5}{3}$ spacing. Intermediate spacings observed by other workers (MacEwan, 1949 and MacEwan, *et al.*, 1961) have been explained in the same manner. A weak 19.6Å diffraction maxima observed by Jackson, *et al.*, (1954) was thought to be caused by a super structure consisting of 2Vm+ 2Chl + 1 Mi. This structure gives a 156Å spacing of density nodes of which the eight order is 19.5Å. An alternative sequence of 3Mt + 1Chl + 1 Mi gives a super structure with spacing at 78Å of which the fourth order is 19.5Å.

It is well known from the X-ray diffraction theory that a nearly regular repitition of similar layers should be present to yield such integrally-spaced peaks as described above. That is a regular repetition of periods consisting of an identical sequence of individual layers. When these periods consist of a random repetition of layers, the basal reflections will be unresolved and consist of broad diffraction maxima or plateaux (Jackson,,*et al.*, 1954; MacEwan, 1956; MacEwan, *et al.*, 1961).

The X-ray powder diagrams of these X-amorphous clays are normally characterized by weak unresolved maxima of the 001 reflections, strong (hko) maxima at 4.45Å and broad maxima at 3.5Å. The latter corresponds to 005 of 18Å, 004 of 14Å, 003 of 10Å and 002 of 7Å density nodes (Plate IX).

The presence of strong (hko) diffraction maxima and of weak integral basal-spacings suggest random interstratification. It is caused by limited regularity along the c-axis while the a - b plane still gives the reflections common to all layer silicates at 4.45Å. Dilution with amorphous material and particle size may, however, cause similar features. Considerable analytical difficulties are associated with the investigation of such material (MacEwan, et al., 1961 and Jackson, 1964). Jackson, et al., 1954 maintained that "X-ray analysis is virtually without quantitative reliance because of the general occurrence of interstratification among the 2 : 1 and 2 : 2 layer silicates".

Lattice building of the 2 : 2 type, which is formed through the precipitation of alumina, iron, magnesium and allophane as interlayers in the expansible 2 : 1 layer silicates is regarded by Jackson (1963) and Jackson (1964) as of widespread occurrence. Precipitation of aluminium, polymerized into hexaluminohydroxy-hydronium units, in 2 : 1 expansible interlayers lead to the formation of the incipient chlorites described by Grim and Johns (1954). Chlorite characteristically yield a relatively strong second order diffraction maxima at 7.2Å owing to the interlayered "brucite-like" structure. The presence of a 14Å peak which does not disappear upon heating to 550°C and the absence of the 7.2Å peak is according to the afore-mentioned authors an indication of the presence of incipient chlorites. Interlayering, through precipitation in the interlayers may prevent peaks from collapsing upon heating to 550°C; even beyond 18Å (Jackson, 1963). Precipitation of aluminium in the interlayers, the anti-gibbsite effect, may preclude the formation of gibbsite in soils containing mixed-layer silicates. The fact that reducing conditions tend to "clean up" the interlayers strongly suggests that iron may play an important part in the formation of the incipient chlorites (Dixon, et al., 1962). Jackson (1963) emphasized the difference between ferromagnesium chlorites and the chlorites formed by the precipitation of aluminium, iron, allophane and magnesium in vermiculite and montmorillonite interlayers. He proposed the following position of these 2 : 2 layer silicates in the weathering sequence:

Mica ——> Illite ——> Vermiculite and Montmorillonite ——> Pedogenetic 2 : 1 - 2 : 2 intergrades ——> Kaolinite.

(iv) Kaolinite and Halloysite

Kaolinite is a dioctahedral mineral in which the aluminium ions occupy identical position in all the layers. Although the general concensus of opinion among investigators has been that no direct relationship exists between kaolinite, metahalloysite and halloysite, Bates, et al., (1950) and Brindley and Robinson (1947) concluded that some British fire-clays are intermediate between kaolinite and halloysite. The transition from halloysite according to these authors proceed with increasing order via fire-clay to kaolinite.

Brindley, et al., (1963) obtained four recognizably different X-ray patterns from essentially monomineralic materials. The morphological forms of these four distinct types, as revealed by the electron microscope, range from platy through lath-like and curved to rounded and tabular forms. These authors warned against the ambiguous conclusions which may be reached when this material occur in mixtures or in association with other material. Radoslovich (1963) criticized the concept of the ideal clay-mineral structure and pointed out that random displacement and rotation of the tetrahedral layer, contraction and expansion of the octrahedral layer to reach the lowest possible internal energy, affects the symmetry. Sudo (1957) and Sudo, et al., (1962) proposed the concept of the intermediate mineral in clay mineralogy. Implying, a mineral which behaves as mineral A with respect to some properties but as mineral B with respect to others. The concept of the weathering sequence seems to support Sudo's suggestion. Clay minerals in soil are the product of the chemical environment. The continuous oscillation in the environmental conditions affecting the solubility of ions, both on a seasonal and long term basis in the open system which constitutes soil profiles, could hardly fail to introduce effects which do not exist in closed systems where pure deposits have formed (Jackson, 1963).

Halloysite has a structure rather similar to kaolinite with the exception that the octahedral and tetrahedral layer are separated by a layer of water which is hydrogen-bounded between these layers. Bates, et al., (1950) explained the characteristic curvature of halloysite by postulating unequal dimensions of the octahedral and tetrahedral sheets. According to these authors the six hydroxyls on one side of the unit cell of kaolinite occupy slightly shorter distances than the corresponding oxygen atoms on the opposite side. This is, however, unlikely. The kaolinite layers exist as sheets of symmetrical hexagonal rings of silica tetrahedra on aluminium octahedra. Any strain due to unequal dimensions of the two structural sheets would be equal in all directions in this symmetrical sheet. The fact that curvature takes place in one direction only should be regarded as unequal strain during crystallization. Honjo, 1954 (cited by Brindley, 1961) found that kaolinite may coil up around different axis to form halloysite tubes. Curvature perpendicular to the tubes owing to dehydration may conceivably cause the rounded forms often reported to occur in association with halloysite tubes (Sudo and Takahashi, 1956). Simultaneous two directional curvature caused by the chemical environment may also be responsible for the rounded particles. Another, more likely, possibility seems to be that the spherical particles consist of poorly organized allophanic gels which will eventually age to form 1 : 1 layer silicates or that they exist in various stages of transformation to halloysite and disordered kaolinite. Spherical particles encountered in this investigation have an irregular fluffy appearance with discrete halloysite rods often protruding from their sides. These spherical particles are mostly associated with random mixed-layers, montmorillonoids and allophane (Plates, VI - VIII).

An association between halloysite, montmorillonite, mixed-layer minerals and allophane has been reported by many authors (Sudo and Ossaka 1952; Sudo and Hayashi, 1956; Sudo, 1956; Kanno, 1959; Kanehiro and Whittig, 1962; Higashi and Aomine, 1962; Chukhrov, et al., 1963; Gastuche, 1964; De Mumbrum and Chester, 1964 and Jackson, 1965.

(v) Allophane

Allophane is a term used in a rather general sense to depict the amorphous aluminiumsilicate-gels with a wide range in composition. According to Jackson (1964) and Chukhrov, et al., (1963) the molecular ratio SiO_2/Al_2O_3 of these amorphous gels varies from 0.5 to 1.9. Their other properties, such as degree of hydration and cation exchange-capacity, are subjected to equally wide fluctuations (Kanehiro and Sherman, 1956).

The presence of amorphous mineral-colloids in soils has been neglected for a long time after the discovery of X-rays. The reason is probably because it is mostly associated with crystalline compounds which tend to mask their presence.

Ross and Kerr (1934) described allophane as an amorphous solid-solution of silica and aluminium. As has been pointed out, it is considered by most authors to be closely associated with the 1 : 1 layer silicates. The question, however, whether allophane precedes halloysite in a sequence of alteration from allophane to halloysite and kaolinite (Sudo and Hayashi, 1956 and Chukhrov, et al., 1963) or whether it results from the weathering of kaolinite seems to be a debatable point. On account of the fact that allophane was found in regions of high gibbsite accumulation Tamura and Jackson (1953) and Bates (1962) inferred that allophane was formed through an alteration of kaolinite or halloysite.

Sherman (1962) held the view that amorphous gels form as an intermediate stage between an ionic phase and crystalline phase. This he visualized to consist of the following stages:

ionic ——> amorphous ——> cryptocrystalline ——> crystalline

Barshad (1964) endorsed this possibility which was also proposed by Sudo, et al., (1962). Ross and Kerr (1934) and most reports on clay minerals from Japan (Sudo, 1951, 1954 and 1959; Sudo and Takahashi, 1956 and Sudo, et al., 1962) indicate that allophane changes to halloysite. Birrel and Fieldes (1952) Fieldes and Swindale (1954) and Fieldes (1955 and 1962) proposed the following sequence of weathering

primary minerals ——> allophane ——> metaholloysite ——> kaolinite

The contention of these authors is that the primary minerals (aside from the micas) can not form clay minerals without passing through an amorphous stage. This view is endorsed by observations made during this study. Weathering products or amorphous relics of feldspars in the sand fractions of soils are presumable the hydrous feldspars described by Fieldes (1962). The term "tekto allophanes" is proposed for these weathering products, considering their predominant association with the tecto silicates (Plate VI). Chukhrov, et al., (1963) reported on allophane from Russia and concluded that halloysite is formed at the expense of allophane. They discussed the contrasting behaviour of allophane from different localities. Some allophanes change to halloysite when heated, others became even more amorphous. Gastuche (1964) obtained spherical particles of allophane and halloysite during an attempt to synthesize kaolinite.

Electron micrographs of allophane showed that it consists mostly of spherical particles with a fluffy outline, with some halloysite rods protruding from it (Plates VI and VII)(Bates, 1958; Sudo, 1959; Kanehiro and Whittig, 1962 and Chukhrov, *et al.*, 1963), The differential thermal curves reported for the spherical particles of allophane are closely related to that of halloysite (Grim and Rowland, 1942; Mac Kenzie, 1957; Sudo, 1954; Sudo and Takahashi, 1956 and Chukhrov, *et al.*, 1963).

The status of the mixed-layer mineral, allophane and kaolinite relationship is vague and would well support further intensive study. Likewise is the X-ray and thermal criteria for differentiating between constituent minerals and the nomenclature. Evidence obtained during this investigation tends to confirm the general presence of mixed-layer minerals and their transformation into 1 : 1 minerals which is regarded as a manifestation of the concepts of Jackson (1964), Jackson (1965) and Sudo, *et al.*, (1962) with regard to the weathering sequence and intermediate minerals in clay mineralogy, respectively (Plate VIII).

(vi) Analytical Procedure

X-ray diffraction analysis of the clay fraction (>2µ) were made at the Philips' Application Laboratory in Eindhoven. A stabilized generator (PW1310) with wide-angle goniometer (PW1050), pulse-height selector (PW1355) and recorder (PW1352/1353) were used. The experimental conditions may be summarized as follows:

Radiation	Cobalt K
High tension	30kV
Current	30mA
Filter	Fe
Divergence slit	1°
Receiving slit	.2mm

Scatter slit	1°
Detector	proportion counter
Scanning speed	1° (2θ) per minute for random power specimens and ½° (2θ) per minute for orientated specimens
Full scale	400, for random powder specimens and 200, for orientated specimens
Time constant	4 counts per second
Sample holders	flat aluminium sample-holder and glass slides

Saturation with potassium and magnesium as well as ethyleneglycol solvation were performed according to the procedures outlined by Jackson (1956). All orientated samples were heated for two hours at the temperatures indicated on the diffraction patterns (Plate VIII).

Differential thermal analyses were made on a Linseis DTA-apparatus with automatic recorder. Heating rate was 10°C per minute. A number of characteristic curves obtained from the clay fractions of different soil types are represented in Plates X and XII.

Not having had recourse to the facilities, the electron micrographs of selected samples (Plates VI and VII) were kindly made by the staff of Prof.Dr. E.Mückenhausen, Friedrich-Wilhelm University in Bonn. Dr.A.Herbillon, of the Agronomic Institute of the University of Louvain kindly carried out the differential-dissolution treatment of two samples (numbers 87 and 154) for the confirmation of the presence of amorphous material.

(vii) Discussion of Results

On account of the general presence of regular and random mixed-layer minerals and poor crystallinity the quantitative reliability of X-ray and DTA analysis are dubious. It provides, however, an excellent indication of the important differences in the clay-mineral content of different soil types (Plates IX - XII). In the analytical tables clay minerals are denoted by the following abbreviations:

Mt	Montmorillonite
Mi	Mica
Vm	Vermiculite
Chl	Chlorite (+)
Ml	Mixed-layer minerals
At	Attapulgite
K	Kaolinite
dK	disordered kaolinite
H	Halloysite (hydrated and dehydrated)
Al	Allophane (*)
Q	Quartz
C	Cristobalite
G	Goethite
Hem	Hematite

(+) Not incipient-chlorites, or chloritic intergrades, these are reported as Ml, if the constituent minerals of the mixed-layer sequences were not identified.

(*) Only in those instances where the presence of allophane has been confirmed by differential dissolution or where in the absence of halloysite peaks on the diffraction patterns the DTA curves are characterized by a low temperature endothermic peak at ± 150°C.

Relative amounts of clay minerals have been quantitatively evaluated as xx (dominant) and x (sub-ordinate). Clay minerals present in small amounts are not denoted by special marks.

The X-ray diffractometer patterns of some samples which contain spherical particles, behave in the following manner when ethylene-glycol solvated and orientated:

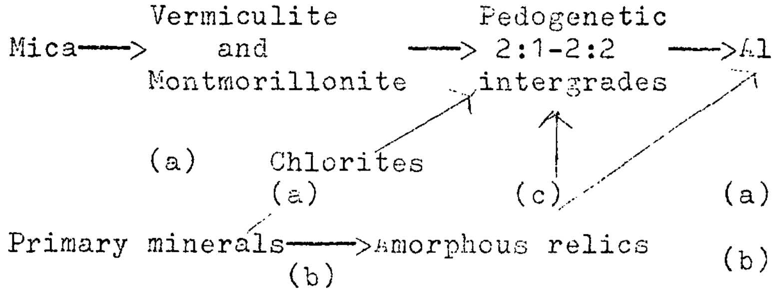
1. Random-powder patterns are characterized by broad, though in some instances well-defined diffraction maxima at around 7.35Å. Upon potassium saturation, solvation with ethylene-glycol and orientation a change in the relative heights of the diffraction maxima around 7Å and those at lager d-spacings becomes apparent.
2. If the upper portion of the precipitate on the glass slide is stripped-off with the aid of cellotape, the X-ray pattern of

the residue on the glass slides only give broad maxima at 7.35Å and practically no diffraction maxima at higher d-spacings.

3. It is concluded that the spherical particles, on account of their form or probably higher specific gravity (?), may be subject to faster settling than the plates of associated mixed-layer minerals. Disappearance or weakening, upon solvation and orientation of the 7Å diffraction maxima of clays containing rounded particles, was also reported by Sudo and Hayashi (1956).

On the basis of evidence at hand it seems that the rounded particles may represent amorphous material in various stages of crystallization to halloysite and kaolinite. Sudo and Takahashi (1956, p.78) proposed that: "In the initial stages, extremely fine particles of allophane will coagulate into rounded grains. Gradually, each of these rounded grains will change into aggregates of hydrated halloysite with a low degree of crystallinity .... With progressive crystallization, extremely fine fibers will have sharp edges and rounded grains will change into aggregates consisting entirely of well-crystallized halloysite minerals".

Spherical particles in clay fractions studied were always associated with diffraction maxima at aroung 7Å (Plates VI to VIII). This precludes the definite confirmation of some of these particles being amorphous. Furthermore, their association with mixed-layer minerals which do not collapse to 10Å upon heating to 550°C seems to support the contention of Jackson (1964) and Jackson (1965) that these mixed-layer minerals represent intermediate genetic stages in the sequence of transformation of the 2 : 1 layer silicates to the 1 : 1 minerals. From results obtained during this investigation and from the literature (Fieldes, 1962; Sherman, 1962; Sudo, et al., 1962 and Jackson, 1964; and Jackson, 1965) the following sequence of weathering is proposed (Plates VI - XII):



(a) Weathering of primary minerals in alkaline environments
(b) Weathering of primary minerals in acid environments
(c) Precipitation in interlayers

B. Mineralogy of Sand Fractions

(i) General

The importance of the mineralogical composition of the sand fraction of soils does not only pertain to the aid it may provide in the ① evaluation of profile development, ② identification of the parent material and as an expedient of ③ soil fertility, but it also furnishes useful criteria for the checking of the ④ uniformity of the parent material (Mohr and Van Baren, 1954; Fieldes, 1962; Marshall, 1964 and Barshad, 1964).

According to Edelman and Van Beers (1939, page 3): "Mineralogical analysis is primarily suitable for checking the autochtony of soil section. A general checking on the autochtony of soil sections to be analysed for the sake of theoretical or other examinations would lead to a purification of our theories of soil formation". Reynders (1964) postulated that the soundness of the interpretation of chemical analyses of soil profiles, in terms of the weathering depth function and profile differentiation, is dependent upon the checking of the homogeneity of profiles with the aid of mineralogical analyses. That this precaution is of utmost importance with regard to soils of regions subjected to landscape instability, volcanic activity, and recent eustatic movements is logical.

Three distinct techniques, usually applied in liaison with one another, for checking the homogeneity of profiles and which involve the sandfraction are:

1. Mineralogical analyses of the light- and heavy- mineral fractions (5 - 05 mm) with the aid of a polarizing microscope.

2. Determination of the particle size-distribution of the sand fraction.
3. Supplementing the above mentioned methods by a general checking of the surface texture of constituent minerals.

The techniques used in the mineralogical analyses of sand fractions are standard procedure The results, which will be discussed with reference to individual soil types, are represented in tables with other analytical data of individual profiles. Inspection of these tables reveals an excellent qualitative correlation between the results of the mineralogical and chemical analyses.

(ii) Relative Stability of Minerals

a. General.- The interpretation of the results of mineralogical analyses would be greatly facilitated if more were known about the stability of minerals. Stability of minerals is a relative property; all the minerals encountered in the sand fraction of individual profiles are not contained in a single profile for a direct comparison of their stability. Most of the available data on the relative stability of minerals (Pettijohn, 1957) are based on their persistence in the geological record and thus assume an indifferent environment of weathering. Although these stability orders are probably sound, it is nevertheless deemed necessary to review the theoretical factors which may control the relative stability of minerals, particularly the silicate minerals constituting the bulk of minerals in soils.

b. Classification of the silicates.- In all silicate minerals, the silica ions are in fourfold coordination with oxygen. The bonds between oxygen and silica are strong enough for the oxygen ions to be located at equal distances, i.e. at the corners of tetrahedra. The silica tetrahedron forms the basic unit of the architecture of all silicate minerals. Different silicate minerals arise from the way in which the silica tetrahedra are linked. The type of linkage forms the basis for the structural classification of the silicate minerals given in Table 10

Table 10: Structural classification of the silicates

Classification	Basic equivalent of Greek root	Structural Arrangement	Examples	Si : O
Nesosilicates	Island	Independent tetrahedra	Sphene, Olivine Garnet, Andalusite, Kyanite, Staurolite, Zirkon and Sillimanite	1:4
Sorosilicates	Group	Two tetrahedra sharing one oxygen	Epidote group Lawsonite	2:7
Cyclosilicates	Ring	Closed rings of tetrahedra each sharing two oxygen	Tourmaline Cordierite and Axinite	1:3
Inosilicates	Chain	Continuous single chains of tetrahedra each sharing two oxygens	Pyroxenes and Pyroxynoids	1:3
		Continuous double chains of tetrahedra sharing alternatively two and three oxygens	Amphibole	4:11
Phyllosilicates	Sheet	Continuous sheets of tetrahedra each sharing three oxygens	Biotite Muscovite and Clay minerals	2:5
Tektosilicates	Framework	Continuous framework of tetrahedra each sharing all four oxygens	Quartz, Feldspars Feldspathoids	1:2

Ions of other elements in the silicate structures such as additional oxygen, hydroxyl groups, water molecules and cations are incorporated to render the structures electrically neutral and mechanically stable. Factors determining the type of mineral that will crystallize are, amongst others, the chemical environment, temperature and pressure. The combined effects of these are contained in the mineralogical phase rule.

In general, minerals may be considered to have a predominant ionic structure; at least as far as the cations, which bind the silica tetrahedra together, are concerned. The type of structure is determined by the charge and specific size of ions that enters it. Ions with approximately the same size are capable of proxying for one another. The controlling factor is ionic radius (Berry and Mason, 1959). Such ions are called diadoch. In the event of the charge on diadochic ions not being equal, electric neutrality is maintained by coupled ionic substitution. Thus, in the albite - anorthite ($NaAlSi_3O_8$ - $CaAl_2Si_2O_8$) series, Al^{3+} substitutes for Si^{4+}, because at high temperature these structures tend to be more open. Electrical neutrality is maintained by coupled substitution of Ca^{2+} for Na^+. In general, however, little or no ionic substitution takes place when the difference in charge exceeds one.

Ionic substitution is of more widespread occurrence in minerals formed at high temperature, since structures tend to be more "open". Depending on the rate of cooling, some minerals that are stable at high temperature and unstable at low temperature, separate into two distinct phases. Important examples are anorthoclase, encountered in lavas only. Upon slow cooling two feldspars, albite and microcline, are formed. Both are more stable than anorthoclase. The same argument is applicable to pigeonite; the low-temperature more-stable equivalents are augite and hypersthene (Turner and Verhoogen, 1960).

As general statements with regard to the stability of minerals the following factors may be taken as of preponderant importance:

1. The structure of a mineral formed under a particular set of environmental conditions possesses the lowest potential energy

for the specific environment.

2. According to the principles enunciated by Pauling (1960) the lowest potential energy is obtained when electrical charges are balanced over the shortest possible distances. This condition ensures the geometric stability of minerals and is controlled by the coordination principle.
3. The total number of ions of all kinds in any stable structure, must be such that the crystal is electrically neutral.

c. Coordination Number.- The predicted and observed coordination numbers of the ions of elements commonly contained in minerals, encountered in soils, are given in Table 11 (partly after Berry and Mason, 1959).

Table 11: Relationship between ionic size and coordination with oxygen of important elements and zirconium in silicates

Ion	Radius	$r^{(+)}/r\,O^{-2}$	Predicted Coordination Number	Observed Coordination Number
Si^4	0.42	0.30	4	4
Al^3	0.51	0.36	4	4-6
Fe^3	0.64	0.46	6	6
Mg^2	0.66	0.47	6	6
Ti^4	0.68	0.49	6	6
Fe^2	0.74	0.53	6	6
Zr^4	0.79	0.56	6	6
Mn^2	0.80	0.57	6	6
Na^1	0.97	0.69	8	6-8
Ca^2	0.99	0.71	8	6-8
K^1	1.33	0.95	8	8-12
Rb^1	1.34	0.96	12	8-12

Many cations occur exclusively in a particular coordination. Al^{3+}, however, whose radius is near the theoretical boundary between a fourfold and sixfold coordination may occur in both. The type of coordination in which aluminium occurs is controlled by the temperature and pressure at which crystallization took place (Berry and Mason, 1959 and Jackson, 1964).

High temperature and low pressure favour the more open fourfold coordination. Low temperature, on the other hand, favours sixfold coordination; so do high temperature and high pressure. The metamorphic minerals andalusite, kyanite, sillimanite, garnet and staurolite are examples. Minerals in which aluminium occurs in fourfold coordination, such as is the case in the majority of minerals occurring in igneous rocks, will have a higher potential energy in soils than those minerals in which aluminium is in sixfold coordination. These minerals may be expected to be less stable.

The above mentioned principle forms a theoretical basis for a consideration of the origin of clay minerals in soils containing Al^{3+} in tetrahedral coordination and clay minerals having portions without Al^{3+} in fourfold coordination. For example, montmorillonite and vermiculites containing Al^{3+} in fourfold coordination can only be expected to represent the weathering products of micas. Whereas portions of vermiculite and montmorillonite without Al^{3+} in fourfold coordination would be the product of neogenesis in soils (Barshad, 1964).

The manner in which the oxygens are packed around the cations in positions other than the tetrahedral position is considered by Barshad to be of considerable importance. The tighter they are packed the more stable is the structure at low temperature. Barshad (1964) for instance attributed the greater stability of microline in comparison with orthoclase, to its triclinic symmetry; orthoclase has a monoclinic symmetry. The importance of ionic size in these tektosilicate structures is manifested by the lack of ionic substitution between cations with an ionic radius of less than a 9Å. Only bivalent or monovalent cations with coordination numbers of eight or more can balance the negative charges on the tektosilicate framework. On account of its larger size the K^+ ion seems to fit in without undue distortion. This may be one of the factors which contribute to the difference in relative stability between potassium feldspars and the plagioclase feldspars.

d. Electrical Neutrality.- The presence of cations which may become oxidized upon weathering has a profound influence on the structural stability of minerals (Marshall, 1964; Barshad, 1964 and Jackson, 1964). Oxidation of Fe^{2+} to Fe^{3+} causes a disturbance of both the electrical neutrality and geometrical stability. Disturbance of geometrical stability is caused by the change in ionic radius of Fe^{2+} to that of Fe^{3+} (Table 11).

The difference in relative stability between olivine and the other minerals of the nesosilicate group (Table 10) may to a large extent be controlled by the oxidation of Fe^{2+} to Fe^{3+}. The difference in relative stability between epidote and the pyroxenes, basaltic hornblende and ordinary hornblende is controlled by the same factor. In the soil profile the preponderant influence of the oxidation of iron on profile development and stability of minerals is probably largely attributable to the influence of ferric oxides on soil structure (Kubiena, 1962; Fridland, et al., 1964 and Jackson, 1964) and the consequent improvement of the permeability.

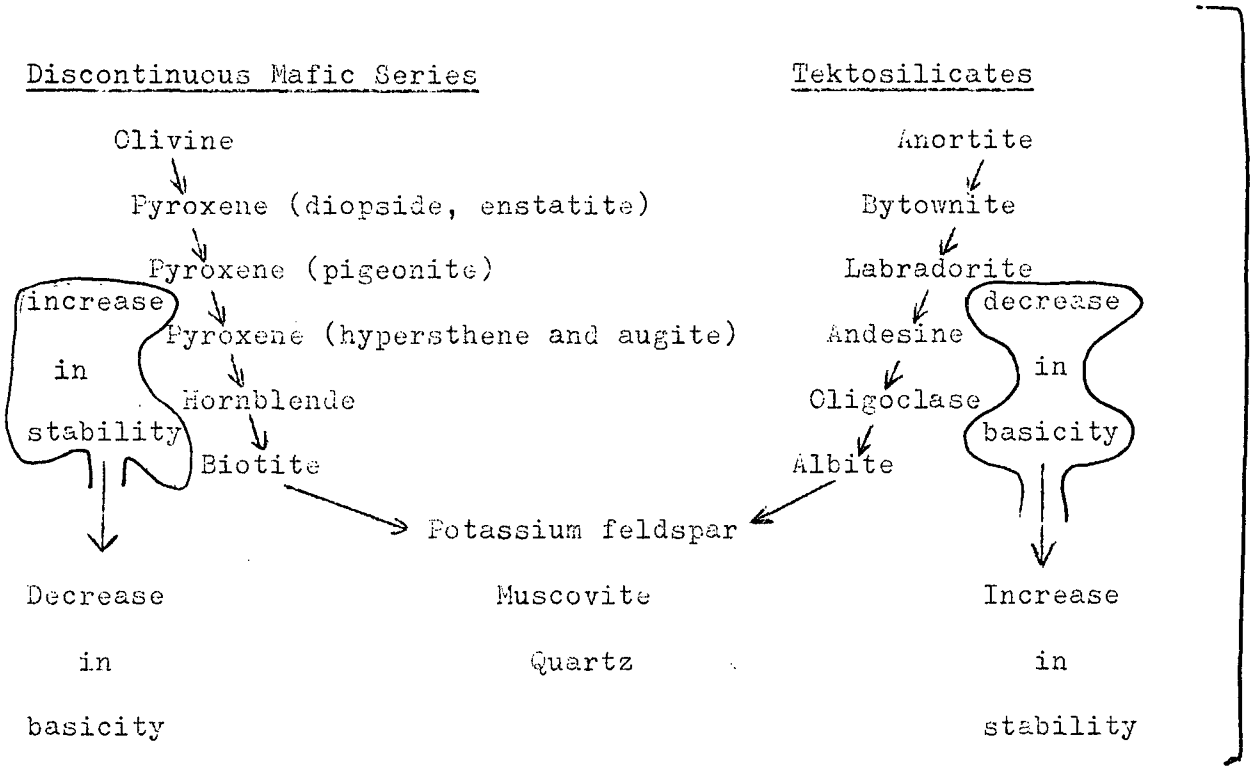
The order of crystallization of the ordinary igneous rockforming-silicates, in which temperature determines the structure, the chemical environment and temperature the extent of ionic substitution, corresponds well to the observed and calculated relative stability of minerals (Mohr and Van Baren, 1954 and Pettijohn, 1957). The order of crystallization from a structural point of view is as follows:

independent tetrahedra ——> single chains ——> double chains ——> sheets.

The larger the number of independent tetrahedra the larger the ratio of basic cations to Si^{4+} and the more basic the mineral.

acid

The larger the number of Al^{3+} ions in the tetrahedra the more basic the mineral. The following order of crystallization is generally recognized (Jackson, 1964 and Barshad, 1964):



Increase in stability of the mafic series is caused by an increase in silica linkage which represents a decrease in basicity. Decrease in basicity of the tektosilicates results from a decrease of Al^{3+} in fourfold coordination. The poor fit of Na^+ and Ca^{++} in eightfold coordination in comparison with K^+ (Table 11) could be an important additional factor in determining the relative stability of these minerals.

Although the above mentioned factors explain to a considerable extent observed and reported differences in the relative stability of minerals, consideration of individual minerals within a particular structural group reveals important discrepancies. This fact becomes particularly apparent when the relative stability of individual minerals in the nesosilicate group is compared (Table 10). The difference in stability between olivine and zircon for instance may be due to oxidation of iron in the olivine structure. This on the

factor is, however, not involved in the weathering of forsterite (Mg_2SiO_4) and andalusite. Thus, other factors which need consideration are involved. Although these are not to be divorced from the silicate structures it is deemed advisable to discuss them under the behaviour of the minerals and ions in the weathering cycle. It is convenient to recognize two types of weathering, though neither operates to the complete exclusion of the other.

e. Physical Weathering.- Physical weathering may be considered to consist of a physical disaggregation of the original rock and a physical reduction in the size of constituent minerals. Pettijohn (1957) reviewed the different size-reducing agents operating in sedimentary transport.

The importance of grain-size in determining the resistance of minerals against chemical weathering has been elucidated by Jackson (1959) and Barshad (1964). The resistance of minerals to physical size-reducing agents depends on their hardness and cleavage. In sediments this may be an important factor in determining the disappearance of certain minerals (Pettijohn, 1957). The absence of microcline and twinned fragments of feldspar in the aeolian sands is thought to be attributable to the intense abrasive action of aeolian transport (Kuenen, 1960).

f. Chemical Weathering.- From the point of view of soil genesis more interest is centered around chemical weathering. The principle agent in chemical weathering is water. The first step in weathering is one of hydration or adsorption of water on the surface of the crystals. This is followed by hydroxylation which involves the dissociation of the watermolecule and the adsorption of H^+ and OH^- and its association with negative and positive charged sites respectively on crystal surfaces. When sufficient bonds are broken the cation is liberated from the mineral lattice. The ease with which it is liberated depends on two factors which have many [illegible] characteristics in common.

They are:

1. The ionic potential of the particular cation.
2. The relative strength of the cation-oxygen bond.

g. Ionic Potential.- The factor charge/radius for an ion is known as the ionic potential and is a measure of the intensity of the positive charge on its surface. It is of great significance for many of its properties in water (Mason, 1958). Elements with an ionic potential of 3.0 and less (Table 12) belong to the group of soluble cations and is easily removed in solution. Thus, it will become detached more easily from crystal surfaces. The rate at which this happens is an integral function of precipitation, drainage, permeability and the biotic factor. Elements with intermediate ionic potential are precipitated by hydrolysis and are less soluble. They form the amorphous skeletons of defunct lattices representing the weathering products, which in time disintegrate. The liberated silicium and sesquioxides polymerize to form clay minerals via amorphous stages or the relative insoluble hydroxydes. Structures in which these elements, especially aluminium, form the cation linkage between silicon as in andalusite, sillimanite and kyanite will thus be more stable than for instance olivine. Similar conclusions may be reached by a consideration of the relative strength of the cation-oxygen bond.

h. Relative Strength of the Cation-oxygen Bond.- Almost all rock-forming minerals encountered in soil profiles involve cation-oxygen bonds. The breakdown or alteration of silicate structures, depends on the strength of the weakest bonds. Breaking of these bonds supplies the activation energy causing the ultimate breakdown of the silicates that are meta-stable phases. Although the coordination plays an important part in the determination of the strength with which a cation is held in the different types of structures (Barshad, 1964), it may be concluded that the weakest bond in all structures represents the cation-oxygen bond which links the tetrahedra. The approximate relative strength, assuming a perfect ion bond, may be calculated from the following formula (Nicholls, 1963):

$$\text{relative bond strength} = \frac{2Z}{(r + 1.4)}\,^{2}$$

where Z is the valence of the metallic cation and r its radius.

Table 12: Ionic potential Z/r and the relative strength of the element-oxygen bond $\frac{2Z}{(r+1.40)}\,^{2}$ assuming a perfect ionic bond

Ion	charge Z/r radious	$\frac{2Z}{(r + 1.40)}\,^{2}$
Si^4	9.5	2.4
Al^3	5.9	1.65
Ti^4	5.9	1.8
Zr^4	5.1	1.7
Fe^3	4.7	1.4
Mg^2	3.0	0.9
Fe^2	2.7	0.85
Mn^2	2.5	0.8
Ca^2	2.0	0.7
Na^1	1.0	0.35
K^1	0.75	0.25
Rb^1	0.68	0.24

ionic potential

11

From the data calculated by application of this formula (Table 12) it may be concluded that the relative strength of the weakest bond in all minerals could be expected to follow this order. Removal of constituents in the order of Ca > Na> K > Al from feldspar structures upon electrodialyses of microcline and albite reported by Marshall (1964) indicate a structural influence as was explained aarlier.

The general trend of the data in Table 12, with respect to principles elucidated in the previous paragraphs, clearly reveals the anomalous behaviour of zircon. Zircon is regarded by the majority of petrographers (Mohr and Van Baren, 1954 and Marshall, 1964) as one of the most weather-resistant minerals. It is concluded that its resistance is attributable to the strong covalent nature of the zircon-oxygen bond. Its hardness, high melting point and the small size of its unit cell is a manifestation of this. Despite the relatively small differences in ionic radia between magnesium- and zircon- ions, the dimensions of the unit cell of olivine is 291Å^3 in comparison to 231Å^3 of that of zircon. Pauling (1960) has assigned to each element a value of electronegativity. The greater the difference in electronegativity between two elements the more ionic the bond between them. Consideration of this principle and its application as an indication of relative bond-strength corresponds well to those calculated by Nicholls (1963) except for zircon which corresponds to the strength of the Ti-O bond in order of magnitude. The size of a sphere which would just fit into sixfold coordination is 0.70Å, zirconium with an ionic radius of 0.79Å seemsto fit in without undue distortion.

i. Conclusion.- Stability of minerals is a relative property and should not be considered in the context of their persistence in the geological record. Most discussions on the relative stability of minerals of sand fractions in the literature (Pettijohn, 1957) assume an indifferent environment of weathering. The relative stability of the minerals of sand fractions is not predictable on this basis.

From structural considerations it may be deduced that most of the primary minerals formed at higher temperatures and pressures than those existing in soil profiles are meta-stable. Metastability in a thermodynamic context implies a phase or system with more than the minimum free energy for the phase, but in which the rate of change to a phase or system with lower free energy is so slow as to be undetectable. An input of energy is required to make the transformation take place at a finite rate (Turner and Verhoogen, 1960). This input of energy is known as activation energy. The susceptibility of minerals to weathering depends on the magnitude of the structural instability at ordinary temperatures and the environmental conditions which may supply the activation energy to cause disintegration. The factors influencing the structural stability of minerals have been discussed. The activation energy may be provided by:

1. Breaking of the weakest bond in the structure, that is breaking the cation-oxygen bonds which link the silica tetrahedra, through hydroxylation. The relative strength of these bonds may be regarded as a function of the difference in electronegativity between the element and oxygen. The rate of weathering depends on the rate at which the liberated cation is removed from the crystal surface. The higher the rainfall the greater the circulation of water through the soil profile and the greater the rate of removal. It is, however, clear that the rate of removal will not be a linear function of precipitation due to differences in permeability of soil material and internal drainage. In the Highveld Region where precipitation is mostly in the form of torrential falls the permeability and drainage may be expected to be of overriding importance.

2. Factors which may disturb the electrical neutrality of a mineral structure will also act as activation energy. The oxidation of Fe^{2+} to Fe^{3+} is the dominating process affecting the electrical neutrality of crystal structures (Barshad, 1964). In the Highveld Region were rapid mineralization of organic matter is an indisputable fact, a high redox potential will be synonymous with high permeability and good internal drainage during the initial stages of soil formation. Furthermore, as soon as oxidation of Fe^{2+} to Fe^{3+} takes place permeability will increase because of the influence of ferric-oxides on the stability of soil aggregates (Jackson, 1964). This greatly accelerates weathering, and explains the low content of primary minerals in ferruginous tropical soils and the accumulation of

aluminium, iron, titanium and quartz.

(iii) Grain-size Distribution of the Sand Fraction

Differences in particle-size distribution and in ratios between different size separates of the sand fraction of successive horizons in soil profiles usually suggest layering of the parent material (Mohr and Van Baren, 1954; Soil Survey Staff, 1960 and Barshad, 1964).

Grain-size distribution has been used extensively in sedimentary petrology as an expedient to arrive at conclusions about the environment of deposition, paleotopography and the physical nature of the transporting medium (Doeglas, 1946; Van Anderl, 1950; Pettijohn, 1957; Harris, 1958 and Folk, 1962 and 1966). Quantification of the results is achieved by means of descriptive statistics or grain-size parameters which provide measures for quantification of deviations from log-normal distributions. These deviations are related to admixture from different sources, progressive sorting, distance of transport, fluctuations in the competency of the transporting medium and genesis of sediments in general (Friedman, 1962; Spencer, 1963; Brenzina, 1963; Harmse, 1963 and Tanner, 1964).

To achieve the above mentioned aim as well as statistically reliable results, sedimentary deposits have to be sampled according to their variability (Griffith, 1955 and 1962; Steinmetz, 1962 and Ehrlich, 1964). Furthermore, intensive sampling is necessary to typify the variations in the sedimentary characteristics of aeolian sand and to interpret them in terms of provenance (Harmse, 1963). Samples investigated during this study were not collected with a view to establishing the provenance and variability of the aeolian sand cover but according to the variability between soils. The sample sites are too wide-spread to comply with the above mentioned pre-requisites. Consequently statistical recasting of results has been omitted. The desired aim, to check the homogeneity or heterogeneity between different horizons of profiles is easily achieved by a visual comparison of the results. These are tabulated with other analytical data of individual profiles.

a. Methods.- In testing the uniformity of the parent material it is desirable to eliminate sand-size particles originating in soil profiles as a result of katamorphic processes, such as concretions and pseudo-sands. This necessitates the employment of cleansing agents and treatment which may have a detrimental effect on the normal grain-size distribution of colloidal fractions. Furthermore, as has been demonstrated by Sys (1961), stratification of parent material usually involves horizons with differential susceptibilities to chemical weathering. If the silt and clay fraction is included in granulometric analysis it will have a masking effect on the grain-size distribution. Similar effects are introduced by processes normally associated with profile differentiation and the winnowing of clay from the surface horizons (Harmse, 1963).

Consequently it was deemed advisable to subject only the sand fractions to grain-size analysis. Total sand fractions (2 - 0.5mm) retained on the 0.5mm sieve during the standard granulometric analysis of soils were used. These were treated with a boiling solution of stannous chloride and 0.2N HCl to remove coatings of iron-oxides from the grains (Van Andel, 1950). Samples were then washed and dried and rubbed gently with a rubber stopper to facilitate the disaggregation of lumps. Following this treatment grains were checked with the aid of a binocular microscope to make sure that composite grains and aggregates were dispersed.

Samples were then fractionated into different size grades with the aid of a nest of sieves spaced at 1/2 phi intervals (phi = $-\log_2$ diam. (mm). The merits of closely-spaced sieve apertures in revealing the properties of sediments were discussed by Doeglas (1946), Harris (1958) and Folk (1966). The nest of sieves was shaken for 15 minutes on a mechanical shaker with a pronounced jarring motion.

b. Results.- The principle of hydraulic equivalence elucidated by Rittenhouse (1943) and McIntyre (1959) and applied in modified form as the linear-approximate hydraulic-equivalence by Harmse (1963), to include aeolian sediments transported by saltation, traction and suspension, implies that any variation in grain-size distribution in sediments should be accompanied by a concomitant variation in the size-distribution of heavy minerals. This concept is only applicable to sediments. Such variations may be due to mixing of materials from different sources, oscillations in the type of transport or fluctuations in the capability of the transporting medium. Selective weathering of minerals in the soil profile may have a profound influence. Should the variation in heavy-mineral composition, however, coincide with concomitant variation in grain-size distribution the cause is most likely attributable to sedimentation. Although pedoturbation may be held responsible in some instances, progressive sorting of mixtures of detritus derived from the autochtonous rocks and extraneous aeolian sand explains the vertical succession described below. As in the Congo (Sys, 1961) and Southern Rhodesia (Watson, 1964) the geological profile, (which in the drier Highveld Region with rapid mineralization of organic matter mostly comprises also the pedological profile) consists in ascending order of:

1. Weathered autochtonous rocks which, depending on its permeability and petrography, comprises the mottled zone in many profiles or horizon of relative accumulation of sesquioxides.
2. A transitional horizon between the better-sorted overlying aeolian sand and the underlying rock. This horizon contains material of aeolian origin as well as detritus derived from the underlying rock. In many instances also water-transported pebbles. In most cases

it comprises the horizon of maximum clay and iron content. The explanation of Sys (1961) that it represents a type of desert eluvium is acceptable. The heavy-mineral composition, grain-size distribution and surface texture of the constituent minerals substantiate the contention that it consists of a mixture of aeolian sand and material of local origin. Pedoturbation, especially in the instances where the autochtonous rocks consist of argillaceous sediments or dolerite, explains the mixed origin of this horizon. The mineralogy and the grain-size distribution provides no direct evidence of admixture if the underlying rocks consists of dolerite. The only indication there-of is an increase in the number of angular non-opaque minerals (Plate XIII, fig.1-4 and profiles 4/7; 12/15 and 59/62).

3. Overlying the horizon described above, in most profiles there is a layer which consists of better-sorted aeolian sand. Only in one instance could definite information be obtained as to differences in age between this layer and the underlying layer of mixed origin. Near Ventersdorp some stone-age artifacts belonging to the Fauresmith Culture (Table 6) occur on the layer of mixed origin.
4. The surface horizons of all profiles in the aeolian landscape and even in areas where discrete aeolian deposits are absent, are better sorted and the constituent minerals more abraded than in any of the underlying horizons (Plates XIII - XVII).

One is indeed tempted to correlate each of the three geological horizons described above with each of the three major arid-periods recognized in Southern Africa (Table 6); which is more than likely the case. The fact, however, that all three horizons are not encountered in superposition in all profiles calls for restraint. Furthermore, in many profiles the mixed horizons undoubtedly consist of material mixed by pedoturbation. In such instances the mixed horizons would have no stratigraphic significance.

(iv) Surface Texture of Minerals

a. General.- Some of the most characteristic properties of mineral grains subject to prolonged sedimentary transport are their surface texture (Pettijohn, 1957). Kuenen (1960) demonstrated by experiment the greatly sustained effect of aeolian abrasion on quartz grains. He concluded that aeolian abrasion is from 100 to 1000 times more effective over the same distance of transport than is abrasion in rivers.

According to the contentions elucidated under the grain-size distribution of the sand fraction, it may be expected that surface horizons of soils affected by admixture of aeolian sand should exhibit signs of more intensive abrasion (page 90).

It has become almost unanimously accepted that aeolian transport introduces frosting, which is diagnostic of wind transportation (Cailleux, 1942; Bond, 1954 and Holmes, 1965). Kuenen and Perdok (1962) concluded from experimental observations, that frosting may also be caused by chemical solution. They pointed out that the different types of frosting may not be readily distinguishable. These authors mentioned the chemical frost they observed on quartz grains from South Africa. Since some profiles (on granite 200/203) investigated comprises a mixture of aeolian sand and sedentary granitic-material it was thought an excellent opportunity to give some attention to this aspect. The electron micrographs (Plate XIV) of replicas of grain surfaces, prepared by the use of Triafel film by J.D. van Wijgaarden of the Philips' Application Laboratory in Eindhoven, illustrates the differences between chemical etching and frosting by aeolian attrition.

Bond (1954) found that aeolian sands from the Kalahari are polished when smaller than 0.15 mm, while coarser grains are frosted. The same phenomena were observed during this investigation (Plate XV). This seems to be a powerful argument against the chemical origin of frosted grains in aeolian sands.

b. Discussion of Results.- Neither the degree of roundness nor the degree of frosting can be evaluated quantitatively. It has, however, undoubted merits in providing additional evidence to be used in conjunction with the results of other methods of investigation.

Frosting as such, owing to the low resolution power of the binocular microscope used, cannot be taken as an absolute proof of aeolian attrition. Electron micrographs, however, provides clear evidence of the difference between frosting caused by aeolian and chemical etching of quartz grains respectively. The fact that quartz grains from granite show frosting due to chemical attact should not be taken too generally. These quartz grains show undulous extinction which indicates that the grains are under strain and may be more susceptible to chemical solution, neither is resorption in the magmatic environments or during granitization excluded. The percussion bulbs described by Cailleux (1942) are clearly visible on the electron micrographs (Plate XIV). Water-transported grains, although etched by chemical attact and exhibiting a mat surface, are clearly devoid of the percussion bulbs seen on the surface of aeolian sands (Plate XIV).

The sand-fraction of horizons consisting of mixtures of aeolian sand and dolerite provides little evidence of such admixture. The only indication of such happenings, in the sand-fraction, is the presence of large amounts of angular non-opaque minerals (Profiles 59/62, 4/7, 7/8, 12/15 and Plate XIII). From the heavy-mineral analysis and grain-size distribution of profile (200/203) on granite it may be deduced that the parent material consists of an admixture of extraneous aeolian sand and detritus derived from the autochtonous rocks. Furthermore, that the amount of admixed granitic material decreases progressively towards the surface. The amount of angular grains in the different size grades confirms this (Plate XV). Similar explanations are given for the differences in roundness of mineral grains, heavy-mineral composition and grain-size distribution of other profiles (Plate XVI and XVII).

MAPPING AND ANALYTICAL METHODS

A. Mapping

The accompanying soil map (Map 4, in pocket) has been compiled from field observations, supplemented by air-photographic interpretation, over a period of three years. During this period the area has been subjected to a systematic routine analyses of air-photographs followed by regular checking in the field of the deliniated areas. This procedure resulted in the acquisition of considerable experience concerning the identity of certain consistent features associated with soil types and their image on the air-photographs.

The broad and specific patterns caused by relief, drainage, patterned ground, tone differences, vegetation, landuse, erosion and the physiographic expression of rock- and stratigraphic- units were demarcated on the photographs. The demarcated areas were checked in the field with the aid of an auger and by pitting, to ascertain the extent of their direct positive relationship to soil types.

Compilation maps on a scale of 1:30.000 and 1:45.000, on which farm boundaries are shown, were available for the area. The farm boundaries are visible on the photographs because strips along fences are not cultivated and also on account of tone differences caused by differential grazing. Transpositioning of data from the photographs to the maps was further facilitated by slight variations in elevation over vast tracts of the terrain.

As has been pointed out elsewhere, differences between soil types in the aeolian landscapes are intimately dependent upon the thickness of the sandcover and the hydromorphic regime which resulted from the deposition of permeable sand on diverse rock-types and buried soils, as well as upon relief. On account of these factors the transition between soil types are extremely gradational. Although the map (in pocket) has been generalized and the scale reduced it should only be regarded as a reconnaissance map. It is the considered opinion of the author that extensive use will have to be made of catenary complexes as mapping units, even in the event of detailed surveys.

E. Analytical Methods

In the following paragraphs the chemical methods and other analytical procedures followed in compiling the data tabulated with the morphological description of representative profiles will be described briefly, together with an explanation of the abbrevations and symbols given in the tables. The analyses were carried out at the Royal Tropical Institute in Amsterdam and in the laboratory of the Soils Institute of the University of Utrecht. All determinations, excepting the microscopical analyses, were performed on fine-earths (<2 mm) and clay fractions (>2μ).

(i) Particle Size-distribution Analyses

The fine-earths were fractionated into different size grades by the pipette method and by sieving. The different size grades used and the procedures followed are according to the USDA Scheme of Classification:

Coarse sand:	2.0 - 0.5 mm
fine sand:	0.5 - 0.05 mm
silt:	0.05 - 0.002 mm
clay:	smaller than 0.002 mm

Soil samples were boiled in H_2O_2 and acidified in excess of the carbonate content. The pastes were neutralized by successive washing with distilled water and washed through a 50 micron sieve into 500ml cylinders. The dispersion-agent used was sodiumpyrophosphate ($Na_4P_2O_7 + 10H_2O$). The cylinders were filled with distilled water and, after thorough shaking, suspensions were checked for good dispersion. The determinations then continued according to standard procedure.

The analytical data reveal variations with depth of the cation-exchange capacities which do not change concomitantly with the granulometric clay content. It is doubtful whether this could be attributed to a lack of dispersion only. From the discussions in the following paragraphs it may safely be inferred that the above mentioned discrepancies are mainly an attestation of the weathering-depth function.

The cation-exchange capacities of the C horizons of vertisols - Db on mudstone and siltstone are practically equivalent to that of A and AC horizons, with higher granulometric clay content. These phenomena are to some extent attributable to an increase in 2 : 1 layer-silicates with depth. Judging, however, from the molecular ratios (SiO_2/Al_2O_3) of the fine-earth fractions of A and AC horizons, it is apparent that the higher clay content of these horizons is caused by argillification (Scheffer, 1962). Meaning, that the clay-size particles are formed by disintegration of layer-silicates with a larger diameter. Rather similar variations in the C.E.C. in comparison with clay content, are caused by the presence of amorphous relics of primary minerals in C horizons of soils formed on rocks with a high content of easily-weatherable primary minerals (Table 13).

Table 13: Variation of C.E.C. of the fine sand fractions (0.5 - 0.05 mm) of C horizons of some profiles, with amount (expressed as percentages of the total mineral content) of amorphous relics in light-mineral fractions.

Profile number	Sample number	Percentages amorphous relics (*) in the light fraction	C.E.C. of fine-sand fractions (clay and silt removed by dispersion and wet sieving)
4/7	7	62	57.4 meq./100gm oven-dried sand
59/62	62	51	36.5 " " " "
157/161	160	38	32.2 " " " "

(*) In the analytical tables these amorphous relics are grouped together under the heading "Weathering Products". meaning, primary minerals which exist in various stages of decomposition. These relics often still exhibit the outlines of the original minerals, but are altered to such an extent that the optical properties are completely destroyed (Plate VI).

(ii) Soil Reaction

The pH-H_2O was determined by glass electrode in 1 : 5 soil-water suspensions and the pH-KCl in 2 : 5 soil-1N KCl suspensions. The qualitative classes which may be referred to in the discussion of soil types or individual profiles are:

Class	pH-H_2O	Class	pH-H_2O
Extremely acid	below 4.5	Neutral	6.6 - 7.3
Very strongly acid	4.5 - 5.0	Mildly alkaline	7.4 - 7.8
Strongly acid	5.1 - 5.5	Moderately alkaline	7.9 - 8.4
Medium acid	5.6 - 6.0	Strongly alkaline	8.5 - 9.0
Slightly acid	6.0 - 6.5	Very strongly alkaline	below 9.1

(iii) Cation-exchange Capacity (C.E.C.) and Total Exchangable Bases (T.E.B.)

Soil samples were mixed with purified sand to facilitate percolation in percolation tubes. Water-soluble salts were removed with a 1 : 1 alcohol/water mixture and the exchangeable bases leached with NH_4-acetate/alcohol at pH 8.2. Calcium, potassium and sodium in the leachates were determined with a flame photometer, and magnesium by the colometric thyazol method.

Following the above mentioned procedures, the soils were saturated with sodium, using sodium acetate at pH 8.2. Samples were freed from excess sodium by one or more washings with 100 per cent ethanol. The adsorbed sodium was subsequently replaced by ammonium acetate. Sodium in the leachates was determined by flame photometer. The results, calculated in meq./100gm oven-dried soil, give the cation-exchange capacity (C.E.C.). The exchangeable sodium percentage (E.S.P.) was calculated from $\frac{\text{exh. Na}}{\text{C.E.C.}} \times 100$

It is known that the C.E.C. and **T.E.B.** determined by the methods described above, may only be regarded as an approximate estimate owing to the following reasons:

1. According to Summer (1963) the charge of Fe_2O_3 is positive at low, and negative at high pH values. This accounts for a considerable portion of the pH-dependent negative charges in soils. The Fe_2O_3 increases the buffer capacity of all soils and of kaolinite-Fe_2O_3 complexes. A considerable proportion of the surfaces of clay fractions are covered by Fe_2O_3 which result in a decrease in the negative charges on clays.
2. Swindale (1964) pointed out that amorphous mineral-colloids have pH-dependent charges. The C.E.C. measured at pH 5, for instance, differs widely from that determined at pH 7.
3. Soils containing carbonates are known to present problems in the determination of exchangeable calcium and magnesium. The reason is that calcium- and magnesium- carbonates are only sparingly soluble in water, but highly soluble in the ammonium acetate used for the leaching of the exchangeable bases. This results in too high values for these cations. Hence an alcohol ammonium-acetate mixture at pH 8.2 was used for the leaching of the exchangeable cations. It is thought that the solubility of carbonates are restricted, though not prevented, at a pH of 8.2[1].
4. A conspicious correlation exists between the pyroxene content of the sand fractions and the amount of exchangeable magnesium of some horizons. According to F.A. van Baren (personal communication and 1963) this correlation may conceivably be caused by the release of magnesium from the surfaces and lattices of sand- and silt-

size grains. Similar observations were made with regard to the amount of calcium released and the presence of basic-plagioclase in sand fractions. McClelland (1950) reported on the release of bases from primary minerals and found a correlation between the amount of bases released and the type of crystal structure.

(iv) Organic Matter

The percentage of carbon was determined according to the Walkley Black method. American investigators found that the application of this method to a number of soils from the USA resulted only in 77 per cent of the carbon being oxidized. On account of this observation it has become almost standard practice to multiply the percentage of carbon by the factor 100/77. Whether this also holds for the carbon occurring in the organic fractions of the soils of tropical, subtropical and semi-arid regions is not certain[1]. Little is known about the nature of organic compounds in the soils of these regions, especially the semi-arid regions (Pauli, 1964). It is considered that some basic investigations into the physico-chemical nature of organic compounds in these areas and their variation with soil type, are of eminent importance and long overdue.

$\frac{100}{77} \times C =$ [illegible]

The percentage of nitrogen was determined according to the Kjeldal method. The very low nitrogen content bears testimony to the high degree of mineralization under the conditions which prevail in the Highveld Region. From the literature (Broadbent, 1962 and Pauli, 1964) it is clear that these conditions are singularly favourable to rapid mineralization.

(v) Elemental Analyses

Chemical analyses of the clay fractions and the unfractionated fine-earths (finer than 2 mm) were carried out with a Philips' X-ray

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[1] A.Muller (personal communication)

fluoroscence- spectrograph according to the procedure described by Reynders (1964b).

(vi) Mineralogical Analyses

The procedure followed and the methods used for the determination of the clay minerals are described under the heading "Clay Minerals". Determination and counting of the minerals of the sand fraction proceeded according to standard methods (Kerr, 1959: Wahlström, 1960; Milner, 1962 and Heidenreich, 1965). One important aspect, however, needs some comment, namely: the method whereby the fractions, for bromoform separation and subsequent mounting on slides, are separated from bulk samples. Mere pouring out from a container, of the amount of sand or heavy-minerals required, introduces variations which impair the diagnostic value of mineral counts. Owing to differences in size and specific gravity minerals in loose sands are apt to settle selectively in containers. All samples were therefore cone-quartered down to the amounts required for bromoform separation and preparation of slides.

VI. DISCUSSION OF SOILS

A. General

The system of soil classification currently in use in the Republic of South Africa is based on the S.P.I. system (D'hoore, 1964) which does not differ substantially from the system used by Van der Merwe (1962) and Loxton (1962). Subdivision has only been to higher categories and is based on morphology, physico-chemical properties and genesis. Soil genesis is deduced from profile morphology in terms of soil history, processes of development and the influence of environmental- and parent- material factors (Table 1).

Owing to landscape instability, gradual transitional changes (catenas) concomitant with variations in relief, thickness and texture of the aeolian sand cover, petrography and texture of buried horizons and the variation in soil climate caused by these variables, a considerable spectrum of soils is included in each group. The "morphological variables" represent transitional types which interdigitate laterally with the modal types.

The gradual transitional spectra have been differentiated only in those instances where morphological variables have pedological relevance. Justification and criteria for subdivison into lower categories based on differentiae which have agronomic pertinence are not relevant to this study, which considers the soils from a genetic point of view only. The soil properties used as basis for differentiation were selected on the ground of their relevance to soil genesis, and their natural recurrent propinquity.

Adhering to the procedure of making the most logical fit, the soils were grouped into the categories defined by D'Hoore (1964) and his collaborators, since it seems to reflect the present stage of knowledge of the soils on the African continent. It may be argued that too much emphasis has been placed on soil genesis and that the system followed (D'Hoore, 1964) is essentially a mapping legend, lacking the precision of definition of soil categories which are essential for the exclusive classification of soils. It should, however, be borne in mind that the soils of Africa are not well known and for this very reason soil scientists have to be content with a "rudimentary" system. It permits a comparative way in which soils may be regarded, and allows the communication of data. Furthermore, the fact that it is based on soil genesis provides a working hypothesis which acts as a stimulant for field and laboratory research. The soundness of genetic classification may be disputed on the ground that it leads to speculation and places soil science on an unsafe basis. There is, however, a distinguished difference between speculation and a working hypothesis if genetic inferences are based on soil properties and morphological characteristics.

In this study considerable evidence has been gathered from an investigation of sand fractions, which indicates that the geographical distribution of soils in the Highveld Region is largely attributable to the layering of aeolian deposits or their absence. This does not nullify the existing classification system because the morphology and other properties remain the same. It will merely result in a reappraisal or re-interpretation of the genetical factors; soil genesis involves processes not properties.

In the discussion of the soil groups the analytical and morphological characteristics of each group is considered in the context of the criteria and definitions given by Van der Merwe (1962) and D'Hoore (1964).

The possibility of finding a place in the U.S.D.A. system of classification (7th Approximation and supplements) is considered for some of the soils. Such correlations should, however, be regarded as tentative and of academic interest only.

B. Reddish-brown Fersiallitic Soils - Jd

The geographical distribution in the Highveld Region of the soil type was shown on the S.P.I. map as fersiallitic soils - Jd, undifferentiated. The salient features as well as analytical data show it to denote a stage of soil formation which evolves towards ferrallitic characteristics. It compares well with D'Hoore's (1964) ferrisols but for the absence of structural B horizons with glossy ped-surfaces. In all other respects i.e. clay mineralogy, colour, base saturation and cation-exchange capacity it resembles the ferrisols more closely than it does fersialitic soils as defined by D'Hoore. A more appropiate taxa, according to the concept of Sys (1959) would therefore seem to be xero-ferrisol; the prefix denotes a drier climate. Van der Merwe described it as "reddish-brown ferruginous laterites".

All profiles have an ABC type morphology and are complex. The parent material usually comprises different deposits consisting of well-sorted aeolian sand, aeolian sand redistributed by colluviation or poorly-sorted aeolian sand affected by admixture of locally derived detritus. Increase in clay with depth as has been pointed out by Van der Merwe (1962) is mainly attributable to the weathering of detritus of local origin, which has been incorporated in the aeolian sand, or the weathering of buried horizons (see subdivisions: Grain-size distribution of the sandfractions and surface textures of minerals). The soil climate resulting from this ensemble of factors and good internal as well as external drainage is the dominating agent affecting the geographical distribution and genesis. In the presence of yellowish-brown fersiallitic soils the red soils are exclusively situated on the crestlines of interfluves or on sub-surface layers, which through their permeability, do not permit prolonged periods of water stagnation. In such situations the yellowish-brown fersiallitic soils are usually individualized on the lower slopes.

Temporary stagnation and the consequent mobilization of iron and its segregation into iron concretions explain the variation in the molecular ratios Al_2O_3/Fe_2O_3 with depth. Some concretions, considering their association with colluvium, may conceivably be of extraneous origin. Accumulation of concretions between barchan dunes along the Vaal River and on the floors of smaller pans (Harmse, 1963) shows that aeolian deflation gives rise to extensive accumulations of concretions as lag-deposits. Furthermore, water-transported concretions are a prominent constituent of all fluviatile gravels in the area (Söhnge and Visser, 1937 and Von Backström, et al., 1953). In general it may be concluded that these soils exhibit a marked tendency for the immobilization of iron. The presence of pseudo-sands is detectable in the field. Concretions with low Al_2O_3/Fe_2O_3 ratios (Table 9) are the result of temporary water-stagnation, some are of sedimentary origin.

The characteristic features of the reddish-brown fersiallitic soils (see profile descriptions and analytical tables) consist of:

1. Colours of all horizons, excepting the C horizons of some pedons, are dominated by reddish hues and fall in the 10R and 5YR range. A-horizons usually have lower values, hues, or chromas than B horizons, presumably owing to the presence of dispersed humus. The C/N ratio of A horizons are extremely variable and narrow, it ranges from 6.0 to 15 and decreases rapidly with depth.
2. All pedons have textural B horizons; clay illuviation, as evidenced by the presence of clay skins, could not be ascertained in the field and laboratory. Porosity is good and consistence friable to slightly hard. Structures, which are usually weakly developed, range from fine granular to nut-like. A-horizons are usually apedal.
3. The silt/clay ratios ($20/_2\mu$), as a consequence of the complexity of the parent material, are extremely variable. Generally, it

exceeds 0.4 in A horizons; B horizons in contrast, often have silt/clay ratios of less than 15.

4. Molecular ratios SiO_2/Al_2O_3 of colloidal fractions in all horizons exceeds two. The $\frac{SiO_2}{R_2O_3}$ ratios are, however, slightly below two or just two, depending on the degree of local admixture and sorting of the aeolian sand.
5. The exchange complexes of B horizons are less than 40 per cent saturated (ammonium-acetate method). Exchange capacities of clay f fractions exceed 30 meq/100g and fall in the 30 - 55 meq/100g range.
6. Crystalline components of colloidal fractions consist of comparatively well-ordered kaolinite with subordinate amounts of halloysite, hematite, goethite and detectable quantities of mica, mixed-layer minerals and other 2 : 1 layer silicates. Gibbsite is absent. The presence of allophane was confirmed in a number of profiles. Colloidal fractions of A horizons usually contain feldspar and larger amounts of quartz than B horizons.
7. Weatherable-mineral reserves of sand fractions (250-20µ) are low but exceeds 2 per cent.
8. Soil reactions of A horizons are strongly acid to slightly acid and fall in the 5.1 - 6.4 pH range. The pH increase with depth; C horizons unvariably have neutral soil reactions. The pH values in KCl solution do not exceed pH values in water.

The base saturation of B horizons ~~of B horizons~~ of less than 35 per cent, presence of detectable quantities of 2 : 1 layer minerals and allophane, low percentage of weatherable minerals in sand fractions and moist colour-values of 4 or less in A and B horizons require these soils to be classified as Rhodochrults. On account of the fact, however, that B horizons do not seem to constitute argillic horizons they would fit in better amongst the Inceptisols (Orthic Ustrochrepts—1960), although their genesis does not seem to comply with the central concept of Inceptisols.

SOIL TYPE: Reddish-brown fersiallitic soil - Jd

Sample nrs. 73/76

Sample number	Horizon	Depth in cm	Particle size distribution: sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
73	A1	0-19	22.6	45.1	7.9	4.2	20.2	5.5	4.7	0.4	0.03	13.3	1.51	0.66	0.09	0.04	2.3	7.0	32.7	-
74	B11	19-147	17.8	40.4	8.9	7.7	25.2	6.2	5.7	0.2	0.02	10.0	1.92	1.08	0.08	0.01	3.1	5.7	54.3	-
75	IIB21	147-181	28.0	30.9	10.7	12.9	17.5	6.0	5.4	0.1	0.03	3.3	2.23	1.10	0.07	0.05	3.5	9.7	35.0	-
76	IIIC	181-245	51.0	26.0	5.2	6.9	10.9	6.1	5.7	0.1	tr	-	1.10	0.68	0.07	0.05	1.9	3.1	62.0	-

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
73	43.8	32.1	11.7	1.16	0.42	1.20	90.38	2.15	9.96	1.68	K^{++} Ml^{+} Mi Q^{+} Hem G
74	43.5	32.5	12.2	1.09	0.35	1.00	90.64	2.25	9.46	1.83	K^{++} Ml Mi Q^{+} Hem G
75	41.0	30.1	12.0	1.01	0.47	1.00	85.58	2.30	9.09	1.84	K^{++} Ml^{+} Mi Q Hem G
76	47.4	37.6	4.3	0.52	0.60	1.40	91.82	2.0	24.90	1.69	K^{++} Al Ml Q F^{+} Ilm

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
73	82.5	7.3	3.6	0.41	0.14	0.55	94.70	19.17	57.67	3.0
74	79.0	10.0	4.6	0.49	0.16	0.65	94.90	13.40	45.72	3.4
75	66.0	12.2	10.2	0.53	0.15	0.60	89.68	9.18	17.19	1.7
76	88.5	7.5	1.0	0.18	0.11	0.80	98.09	20.02	235.23	11.8

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500µ-50µ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
73	63	44	22	-	17	-	1	2	4	tr	tr	4	-	4	-	-	-	-	2	-
74	61	41	17	-	11	-	1	1	7	-	4	-	-	13	-	1	-	-	4	-
75	67	23	32	tr	16	-	tr	4	3	tr	2	7	-	5	-	tr	1	-	5	-
76	75	40	12	5	28	tr	5	2	3	-	-	1	-	3	-	-	-	-	1	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
73	97	2	-	-	-	-	-	-	1
74	95	2	-	-	-	-	-	-	3
75	86	4	-	1	1	-	-	4	4
76	90	6	1	-	-	-	tr	3	-

Accessories:

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000µ-50µ)

Sieve appertures in mm.	Sample numbers 73	74	75	76
1.400	-	-	-	-
1.000	0.4	1.1	1.2	-
0.840	0.4	0.8	0.8	-
0.590	1.8	2.5	2.1	0.2
0.500	3.7	3.6	3.3	2.4
0.420	4.1	3.7	3.3	9.2
0.290	14.6	14.2	13.1	43.8
0.210	16.8	13.1	15.3	17.7
0.150	19.4	17.4	17.6	15.2
0.100	15.2	16.1	14.3	5.8
0.074	16.2	18.0	19.0	3.5
0.050	7.4	9.5	10.0	2.2

Profile number: 73/76
Soil type : Reddish-brown fersiallitic soil - Jd.
Location : Lat. 26°51', Long. 26°46' on the farm Hartebeestfontein 422, Klerksdorp district.
Site : grass-covered featureless aggradation surface; less than 2 per cent slope.
Rainfall : 565mm.
Elevation : 1350m.
Parent material: 0-147cm: aeolian sand; 147-181cm: colluvial admixture of pediplain drift and aeolian sand; below 181cm: sediments of Lower Ecca Series (Karroo System).

Sample No.	Horizon	Depth cm.	
73	A1	0 - 19	reddish-brown 2.5 YR4/4 (dry) sandy loam; friable; apedal; porous; abundant roots; gradual boundary.
74	B11	19-147	red 2.5YR4/6 (dry) sandy clay loam; friable; weak tendency towards nuciform structure; porous; frequent roots; abrupt transition.
75	IIB21	147-181	reddish-brown 5YR5/3 (dry) sandy loam; slightly hard; weak nuciform structure; pseudo sand; porous; hard iron concretions scattered throughout horizon; scattered chert pebbles; abrupt transition.
76	IIIC	181-245	light-grey 2.5Y7/2 (dry) sandy loam; friable; apedal; sandstone floaters.

SOIL TYPE: Reddish-brown fersiallitic soil - Jd

Sample nrs. 109/113

Sample number	Horizon	Depth in cm	Particle size distribution: sand 2 mm-200μ	sand 200μ-50μ	silt 50μ-20μ	silt 20μ-2μ	clay < 2μ	pH H_2O	pH KCl	Organic matter %: C	N	C/N	Cations adsorption complex meq./100 gram: Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
109	Ap	0- 24	20.2	53.2	11.7	3.6	11.2	4.9	4.3	0.3	0.02	15.0	1.21	0.50	0.12	0.02	1.8	6.1	30.0	0.33
110	IIA3	24- 69	21.8	41.9	13.3	5.8	17.2	5.0	4.3	0.3	0.03	10.0	1.61	0.53	0.20	0.03	2.4	7.9	30.0	0.38
111	IIB11	69-107	18.5	37.3	12.4	4.0	27.8	6.2	5.6	0.1	0.02	5.0	1.32	1.34	0.03	0.03	2.7	7.1	38.0	0.42
112	IIB12	107-149	12.9	35.4	17.2	7.0	27.5	6.2	5.6	0.1	0.02	5.0	1.02	1.10	0.13	0.01	2.3	6.6	34.0	0.15
113	IIIB23	149-212	21.4	29.7	15.9	7.9	25.1	7.0	5.5	-	-	-	-	-	-	-	-	-	-	-

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
109	54.6	24.9	10.3	1.51	0.35	1.00	92.66	3.72	14.06	2.95	K^{++} H Ml Q^{++} F Hem G
110	39.5	28.9	10.4	1.40	0.14	0.68	81.02	2.32	10.10	1.87	K^{++} H Ml^{+} Q Hem G
111	38.6	30.8	13.2	1.21	0.08	0.55	84.44	2.12	7.76	1.67	K^{++} H Ml Q Hem G
112	38.6	31.1	13.5	1.33	0.09	0.57	85.19	2.10	7.60	1.65	K^{++} H Ml Q Hem G
113	39.1	31.0	14.4	1.11	0.09	0.69	86.39	2.20	7.20	1.64	K^{++} H Ml^{+} Q Hem^{+}

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
109	88.1	3.7	2.3	0.40	0.13	0.20	94.83	40.40	101.80	2.52
110	82.4	4.4	3.0	0.40	0.13	0.21	90.54	31.76	72.99	2.28
111	77.5	8.3	4.2	0.53	0.13	0.24	91.00	15.46	48.90	3.16
112	78.6	9.8	4.9	0.71	0.13	0.30	94.44	13.44	42.52	3.16
113	66.4	11.4	12.2	0.60	0.13	0.31	91.04	9.37	14.45	1.46

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
109	58	54	6	-	17	-	-	2	tr	tr	4	11	1	-	-	5	-	-	tr	tr
110	53	59	8	-	24	-	-	tr	-	2	tr	tr	tr	-	-	7	-	-	tr	tr
111	67	50	11	2	28	-	-	tr	2	tr	1	3	tr	-	-	tr	-	-	3	tr
112	63	47	17	tr	28	-	-	tr	1	tr	4	tr	tr	2	-	tr	-	1	tr	tr
113	67	35	22	4	18	2	3	3	1	-	2	2	1	3	-	-	-	tr	4	tr

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
109	95	2	-	-	-	-	-	3	-
110	95	1	-	-	-	-	-	4	-
111	96	3	-	-	-	-	-	1	-
112	97	3	-	-	-	-	-	-	-
113	84	9	-	-	-	-	-	7	-

Accessories:

number 109: Clinochlore
number 110: Clinochlore
number 111: Clinochlore
number 112: Axinite
number 113: Axinite

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers: 109	110	111	112	113
1.400	-	-	0.5	0.9	1.2
1.000	0.6	1.4	1.9	1.8	4.2
0.840	0.6	1.2	1.4	0.9	2.6
0.590	2.4	3.9	4.1	2.9	5.1
0.500	3.7	4.9	4.5	3.4	5.0
0.420	3.4	4.4	3.9	3.0	4.0
0.290	10.7	13.2	11.0	8.8	10.2
0.210	13.0	14.6	12.8	10.7	10.7
0.150	16.5	17.1	15.6	13.6	12.1
0.100	23.1	19.3	18.2	16.7	14.0
0.074	17.3	12.7	14.4	19.2	14.9
0.050	8.7	7.3	11.7	18.1	16.0

Profile number : 109/113
Soil type : Reddish-brown fersiallitic soil - Jd.
Location : Lat. $26^{\circ}44'$, Long. $28^{\circ}18'$ on the farm Goedgedacht 443, Heidelberg district.
Site : disturbed grass-covered verge of maize field (dominant species <u>Tristachya</u> (spp)), on mid slope of long pediment to outcrop of andesitic lava; more than 6 per cent slope.
Rainfall : 675mm.
Elevation : 1600m.
Parent material: 0-24cm: colluvium comprising a mixture of aeolian sand and sedentary material: 24-149cm: colluvium and aeolian sand (probably more than one period of accumulation); 149-212cm: colluvium; below 212: andesitic lava of the Ventersdorp System (apparently not epidotized in this area).

Sample No.	Horizon	Depth cm.	
109	Ap	0 - 24	dark-brown 75.YR4/4 (moist) fine sandy loam; friable; apedal; abundant roots; indistinct boundary.
110	IIA3	24- 69	dark-reddish brown 5YR3/3 (moist) fine sandy loam; friable; apedal and porous; frequent roots; gradual transition.
111	IIB11	69-107	reddish-brown 2.5YR4/4 (moist) fine sandy clay loam; friable; apedal and porous; few roots; gradual transition.
112	IIB12	107-149	red 10R4/6 (moist) fine sandy clay loam; friable; apedal and porous; some pseudo sand; scattered hard iron concretions; few roots; clear boundary.
113	IIIB23	149-212	dusky-red 10R3/2 (moist) fine sandy clay loam; slightly hard; porous; weakly developed nuciform structure; some pseudo sand; fine dark reddish-brown mottles; frequent soft concretions; clear boundary.
	IVCcn	212+	dark reddish-brown 2.5YR2/4 (moist) some-what undurated crust forming alveolar skeletons around highly weathered rock fragments (andesitic lava).

SOIL TYPE: Reddish-brown fersiallitic soil - Jd

Sample nrs. 200/203r

Sample number	Horizon	Depth in cm	Particle size distribution: sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
200	A1	0- 15	24.6	57.1	6.1	3.4	8.6	6.4	5.5	0.2	0.03	6.7	1.90	1.37	0.16	0.04	3.5	7.0	50.0	0.57
201	B1	15- 87	28.8	49.8	6.0	4.2	11.2	6.1	5.1	0.1	0.02	5.0	0.95	0.45	2.37	0.01	3.8	5.3	72.0	0.19
202	IIB21	87-162	27.8	35.8	6.2	10.1	20.1	5.5	5.4	0.1	0.02	5.0	1.52	1.23	0.09	0.01	2.9	7.9	36.0	0.13
203	IIIC	162-183	30.2	33.4	7.8	10.4	18.2	5.1	4.8	0.1	0.02	5.0	1.21	0.51	0.06	0.04	1.8	5.3	35.0	0.76
203r	IVCR	183+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
200	45.0	28.5	12.7	1.16	0.88	1.27	89.51	2.66	9.41	2.09	K^{++} Mi Vm Q^{+} F Hem^{+} G
201	41.5	27.8	13.9	1.08	0.72	1.13	86.13	2.52	7.92	1.92	K^{++} Ml Q F Hem^{+} G
202	40.5	30.0	14.8	0.91	0.45	0.82	87.48	2.29	7.25	1.74	K^{++} Al Ml Q Hem^{+} G
203	42.5	29.1	11.2	0.70	0.54	1.12	85.16	2.47	10.07	1.99	K^{++} Al Mi^{+} Q Hem G
203r	-	-	-	-	-	-	-	-	-	-	-

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
200	88.5	4.6	2.4	0.30	0.06	0.97	96.83	32.58	97.81	2.99
201	85.0	5.9	3.2	0.40	0.05	0.87	95.42	24.44	70.43	1.88
202	78.5	9.0	8.1	0.51	0.05	0.81	96.97	14.79	25.52	1.72
203	76.0	11.9	3.2	0.32	0.06	3.60	95.08	9.80	63.13	5.79
203r	56.5	10.8	2.6	0.26	0.22	3.70	74.08	8.67	57.76	6.49

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500µ-50µ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
200	45	30	30	-	5	tr	tr	2	12	tr	13	3	tr	2	tr	-	-	-	3	-
201	50	35	23	-	9	-	-	-	8	-	22	3	-	tr	-	-	tr	-	tr	-
202	60	40	20	-	6	-	tr	2	11	tr	15	1	-	3	-	-	-	-	2	-
203	59	27	24	-	2	-	-	2	7	tr	26	3	-	2	-	-	tr	-	5	2
203r	85	45	1	-	-	-	-	1	tr	tr	2	2	tr	-	-	-	-	tr	47	1

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
200	97	2	1	-	-	-	-	-	-
201	94	5	1	-	-	-	-	-	tr
202	91	7	tr	-	-	-	-	-	2
203	63	30	3	2	1	-	-	-	1
203r	-	-	-	-	-	-	-	-	-

Accessories:
number 203: Clinochlore
number 203r: Xenotime

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000µ-50µ)

Sieve appertures in mm.	Sample numbers 200	201	202	203	203r
1.400	-	-	-	-	-
1.000	6.6	9.4	17.4	14.7	-
0.840	-	-	-	-	-
0.590	15.5	19.3	19.4	20.5	-
0.500	-	-	-	-	-
0.420	2.2	3.1	2.9	4.9	-
0.290	5.5	6.3	6.3	8.2	-
0.210	4.8	4.9	4.4	5.5	-
0.150	6.1	5.7	4.5	5.3	-
0.100	21.3	18.0	11.1	10.8	-
0.074	25.8	21.8	20.2	19.0	-
0.050	12.2	11.5	13.8	12.0	-

Profile number	200/203
Soil type	Reddish-brown fersiallitic soil - Jd.
Location	Lat. 26°16', Long. 26°14' on the farm Vlakfontein 4, Lichtenburg district.
Site	grass-covered headland of maize field; on level surface of gently undulating aggradation surface.
Rainfall	570mm.
Elevation	1514m.
Parent material	0.87cm: aeolian sand with slight admixture of detritus derived from the underlying granite; 87-183cm: aeolian sand intermingled with colluvium derived from the underlying granite (more than one period of drift might have been involved); below 183cm: granite.

Sample No.	Horizon	Depth cm.	
200	A1	0 - 15	dark reddish-brown 2.5YR3/4 (moist) loamy coarse sand; loose and friable; many roots; gradual boundary.
201	B1	15- 87	red 10R4/6 (moist) coarse sandy loam; friable; weak fine granular structure; porous; scattered hard iron concretions; many roots; clear boundary.
202	IIB2	87-162	dark reddish-brown 5YR3/4 (moist) coarse sandy loam; friable; porous, some pseudo sand; moderately developed granular structure with distinct nuciform characteristics; abundant scattered iron concretions; some scattered small quartz fragments; few roots; clear boundary.
203	IIIC	162-183	reddish-yellow 5YR6/6 (moist) gravelly sandy loam; friable; apedal; porous; frequent hard iron concretions; abundant angular to sub-angular quartz and quartzite fragments and pebbles; indistinct boundary.
203r	IVCR	183+	pink 5YR7/4 (dry) coarse gravel of weathered granite.

Remark: Horizons A1 and B1 may also represent different periods of drift.

SOIL TYPE: Reddish-brown fersiallitic soil - Jd
Sample nrs. 221/225

Sample number	Horizon	Depth in cm	Particle size distribution: sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
221	Ap	0- 15	17.2	68.7	3.4	2.6	8.0	6.2	5.3	0.2	0.03	6.7	1.41	0.92	0.14	0.01	2.48	5.71	39.0	0.18
222	A12	15- 63	17.5	64.8	3.1	2.6	12.0	6.1	5.3	–	–	–	–	–	–	–	–	–	–	–
223	IIB11	63-109	18.2	55.0	3.2	2.3	21.3	6.0	4.8	0.2	0.03	6.7	2.45	0.25	0.13	0.10	2.93	10.00	29.0	0.10
224	IIB12	109-138	17.5	57.7	4.6	3.1	17.1	6.5	5.6	0.1	0.02	5.0	2.73	2.05	0.08	0.06	4.92	8.80	56.0	0.68
225	IIIC$_g$	138-159	15.6	48.9	4.7	4.7	26.1	7.1	5.5	0.1	0.02	5.0	6.87	4.89	0.50	0.13	12.40	16.10	77.0	0.81

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
221	47.5	26.2	12.2	1.02	1.13	1.97	90.02	3.07	10.34	2.37	K^{++} H Ml^{+} Chl Mi^{+} Q^{++} Hem G
222	46.2	26.4	12.1	1.00	1.21	1.80	88.71	3.00	10.15	2.30	K^{++} H Ml Mi^{+} Q^{++} Hem G
223	41.5	24.8	11.8	0.78	0.69	1.74	81.31	2.85	9.33	2.20	K^{++} H Ml Mi^{+} Q^{+} Hem G
224	45.4	26.3	11.4	0.85	0.95	1.83	86.73	2.93	10.60	2.31	K^{++} H Ml Mi^{+} Q^{+} Hem G
225	49.0	24.2	11.0	0.76	0.87	2.05	87.88	3.43	11.83	2.66	K^{++} H Ml Mi^{++} Q^{+} Hem G

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
221	84.5	4.7	1.80	0.40	0.07	0.88	92.35	30.51	124.66	4.08
222	84.0	5.3	1.81	0.42	0.07	0.88	92.48	26.89	123.33	4.58
223	79.5	7.9	3.80	0.42	0.08	0.98	92.67	17.07	55.60	3.24
224	82.0	6.2	3.10	0.46	0.08	0.93	92.77	22.40	61.72	3.13
225	72.2	8.0	3.20	0.43	0.16	1.20	85.19	15.27	59.80	3.91

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500µ-50µ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
221	55	25	17	5	23	–	1	tr	2	4	1	8	–	1	–	11	–	2	tr	–
222	57	22	18	6	27	–	–	tr	2	3	1	9	–	1	–	7	–	–	4	–
223	73	40	21	1	26	–	1	–	5	–	tr	4	–	2	–	tr	–	tr	tr	–
224	70	39	15	3	28	1	–	2	1	–	tr	5	–	2	–	tr	–	2	2	–
225	75	23	25	6	28	–	–	tr	3	–	2	8	–	–	–	4	tr	tr	1	tr

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
221	88	7	tr	4	–	–	–	1	–
222	86	8	tr	4	–	–	–	2	–
223	76	13	tr	6	2	–	–	3	–
224	77	12	tr	8	2	–	–	1	–
225	67	14	–	13	3	–	1	2	–

Accessories:
number 225: Lawsonite

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000µ-50µ)

Sieve appertures in mm.	Sample numbers 221	222	223	224	225
1.400	–	–	–	–	–
1.000	0.3	0.3	0.5	0.3	0.1
0.840	–	–	–	–	–
0.590	3.0	2.9	3.9	3.8	4.3
0.500	–	–	–	–	–
0.420	2.2	2.2	2.4	2.8	2.3
0.290	9.0	9.0	10.2	9.6	9.1
0.210	17.5	17.6	17.5	16.8	15.7
0.150	25.5	25.6	25.1	24.5	23.4
0.100	22.2	22.3	20.5	21.0	20.3
0.074	13.3	13.1	13.5	13.8	17.5
0.050	7.0	7.0	7.1	7.3	7.3

Profile number : 221/225

Soil type : Reddish-brown fersiallitic soil - Jd.

Location : Lat. 27°45', Long. 26°01' on the farm Vrede 746, Hoopstad district.

Site : grass-covered verge of maize field (disturbed), profile pit was situated on the upper slope of long pediment to the flood-plain of Vaal River.

Rainfall : 455mm.

Elevation : 1300m.

Parent material: three different ages of aeolian sand; 0-63cm: younger garnet-bearing sand; 63-138cm: aeolian-flat sands; below 138cm: older garnet-bearing sand (Harmse, 1963).

Sample No.	Horizon	Depth cm.	
221	Ap	0 - 15	yellowish-red 5YR4/6 (moist) fine sand; almost single grain; apedal; abundant roots; indistinct boundary.
222	A12	15- 63	yellowish-red 5YR4/6 (moist) fine sand; loose; apedal; frequent roots; indistinct boundary.
223	IIB11	63-109	red 10R4/6 (moist) fine sandy clay loam; friable; apedal; porous; few roots; indistinct boundary.
224	IIB12	109-138	reddish-brown 2.5YR4/4 (moist) sandy loam; friable; apedal; porous; fine yellowish-brown mottles; hard iron concretions (10YR5/8) and soft Fe-Mn concretions (10YR3/4); clear boundary.
225	IIICg	138-159	light brownish-grey 2.5Y6/2 (moist) fine sandy clay loam; friable; massive; medium to coarse yellowish-brown mottles, fine bluish-grey mottles; scattered soft Fe-Mn concretions.

Profile number : 235/241
Soil type : Reddish-brown fersiallitic soil - Jd.
Location : Lat.27°07', Long. 26°47' on the farm Brakkuil 432, Viljoenskroon district.
Site : upper slope (>1%) of gentle aggradation surface; maize field.
Rainfall : 600mm.
Elevation : 1360m.
Parent material: aeolian sand; only one period of accumulation.

Sample No.	Horizon	Depth cm.	
235	Ap	0 - 20	dark reddish-brown 5YR3/4 (moist) loamy sand; friable; apedal; abundant roots; gradual boundary.
236	A3	20- 40	dark reddish-brown 5YR3/6 (moist) loamy sand to sandy loam; porous; friable; apedal; frequent roots; gradual transition.
237	B11	40- 60	dark-red 2.5YR3/6 (moist) sandy loam; friable; apedal; porous; roots rare; gradual transition.
238	B12	60- 80	dark-red 2.5YR3/6 (moist) sandy loam; friable; apedal; porous; roots rare; gradual boundary.
239	B13	80-100	dark-red 2.5YR3/6 (moist) sandy loam; friable; apedal; roots absent; porous; gradual transition.
240	B14	100-120	dark-red 2.5YR3/6 (moist) sandy loam; friable; apedal; porous; gradual transition.
241	B15	150+	dark-red 2.5YR3/6 (moist) sandy loam; friable; apedal; some hard iron concretions.

OIL TYPE: Reddish-brown regosol - Bh
ample nrs. 63/65

ample number	Horizon	Depth in cm	Particle size distribution sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
63	A1	0- 18	32.2	44.2	8.7	3.7	11.2	5.7	4.7											
64	C1	18-111	27.5	41.0	11.1	3.8	16.6	5.5	4.7											
65	C2	111-153	31.1	30.8	13.1	8.3	16.7	4.9	4.2											

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
63	46.5	29.3	12.1	1.26	0.51	1.40	91.07	2.68	10.10	2.13	K^{++} Ml Mi^{+} Q^{++} F Hem
64	43.8	29.4	12.3	1.21	0.61	1.35	88.67	2.61	9.30	1.99	K^{++} Ml Mi^{+} Q^{+} F Hem
65	44.0	31.2	11.9	1.20	0.52	1.80	90.62	2.40	9.83	1.92	K^{++} Ml Mi^{+} Q^{+} F Hem

Chemical analyses of the total soil sample (< 2 mm).

ample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
63	87.5	3.6	2.2	0.28	0.15	0.30	94.03	41.23	105.52	2.55
64	85.4	5.1	2.9	0.38	0.10	0.25	94.13	28.33	78.14	2.75
65	82.0	8.2	5.9	0.49	0.10	0.53	97.22	16.97	36.95	2.13

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500µ-50µ)

eavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
63	85	55	8	-	20	-	-	-	5	tr	3	1	-	2	-	-	-	tr	6	-
64	60	50	16	-	14	-	1	-	8	tr	tr	2	-	4	-	1	-	tr	5	-
65	60	50	16	-	19	-	1	-	5	tr	1	tr	-	6	-	-	-	-	2	-

ight mineral analyses.

ample umber	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert

Accessories:

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000µ-50µ)

Sieve appertures in mm.	Sample numbers 63	64	65
1.400	1.3	0.4	2.4
1.000	4.0	1.5	5.9
0.840	2.6	1.6	2.8
0.590	6.5	6.0	6.4
0.500	6.5	8.1	8.3
0.420	4.4	5.7	6.2
0.290	10.0	13.5	13.5
0.210	9.4	11.3	9.6
0.150	8.9	9.7	7.2
0.100	12.5	13.7	9.1
0.074	22.0	17.8	18.9
0.050	11.9	10.7	9.6

C. Reddish - brown Regosols - Bh

This soil type with (A) C profiles occurs along slopes mainly in the "mountainous" landscapes associated with pre-Cambrian formations. The parent material comprises coarse textures colluvium. It is differentiated from the reddish-brown fersiallitic soils - Jd, with which it has been grouped in Table 1 on account of their propinguity in landscapes, on the absence of any structure or signs of aggregation. Erosion of the reddish-brown fersiallitic soils supplies the detritus. These soils meet the minimum requirements of the great group Ultic Quarzipsamments.

Profile number: 63/65

Soil type : Reddish-brown regosol - Bh.

Location : Lat. 26°50', Long. 26°43' on the townlands of Klerks-

Site dorp, Klerksdorp district.

Site : grass-covered pediment, midslope of long pediment to outcrop of quartzite (Main-Bird Series, Witwatersrand System).

Rainfall : 565 mm.

Elevation : 1360 m.

Parent material: 0-153 cm; recent colluvium (different periods); below 153 cm; andesitic lava of the Ventersdorp System.

Sample No.	Horizon	Horizon cm	
63	A1	0 - 18	reddish-brown 2.5YR4/4 (dry) sandy loam; loose; apedal; many roots; gradual transition.
64	C1	18-111	red 2.5YR4/6 (dry) sandy loam; loose;apedal freguent roots; gradual transition.
65	C2	111-153	weak-red 10R5/3 (dry) gravelly sandy laom; loose; apedal; very fine yellowish-brown mottles; scattered hard iron concretions; lava, quartzite and quartz pebbles; abrupt boundary.
	IIR	153+	hard unweathered andesitic-lava of the Ventersdorp System.

D. Eutrophic Reddish-brown Soils - Hd

These soils are the equivalent of what has been described by Van der Merwe (1962) as "red soils" associated with sub-tropical black clays. It more or less qualifies as a "brown soil" of arid or sub-tropical regions, not differentiated as to parent material, of the S.P.I. legend (Loxton, 1962). The fact, however, that the crystalline constituents of the clay fraction consist primarily of poorly-ordered kaolinite,as well as the absence of carbonate precludes them from being regarded as a "brown soil" as defined by D'Hoore (1964). It is associated in landscapes with reddish-brown fersiallitic soils - Jd and its genesis is controlled by practically the same factors. The exception being that the detritus of local origin were derived from basic igneous-rocks and buried vertisols - Da. In the Highveld Region it is predominantly associated with the weathering products of dolerite which became intermingled with aeolian sand or arenaceous sediments. It forms either as a result of the direct weathering of aeolian deposits on dolerite and, providing the run-off is not impeded, on vertisols - Da or around dolerite outcrops. The last mentioned situation arises from an intermingling of arenaceous sediments and mass-wasted material of dolerite down the slopes of dolerite koppies[1].

It is of most frequent occurrence in aeolian landscapes in which the air-borne sands have been deposited on Karroo rocks, because of the fact that the dolerite is most extensively intruded into these well-bedded sedimentary formations.

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[1] South African word meaning hillock, which rises above pediplains or upper slopes of pediments. It is of the geomorphic family of inselbergs, monadknocks or mesas.

The pedogenetic development is dependent upon the thickness of the aeolian sand-cover, the proportion of intermingled ingredients and relief. The time factor could be of preponderate importance. As a result of lateral variations in these variables catenary changes over relatively short distances, without any concurrent variation in the exogenic soil-forming factors, is one of the important considerations which militates against the use of the external climate in a denominative function. With decrease in thickness of the sand cover it merges into vertisols - Da or lithosols - Bb via phases which may, barring for the absence of carbonate, compare exactly with D'Hoore's, "brown soils of semi-arid regions". In topographic positions with impeded external-drainage the ensemble of factors described in preceding paragraphs give effect to the formation of Highveld pseudo-podzolic soils (Profiles 4/7 and 157/161).

Good drainage and aeration causes oxidation of unbound ferrous oxides. The ferric oxides act as a flocculation agent under the hot climate, and stabilize soil structures (Mohr and Van Baren, 1954; Van der Merwe, 1962; Jackson, 1964; Maignien, 1964 and Pauli, 1964). Stabilization of structures improves permeability and facilitates the leaching of soluble cations. Depletion of the adsorption complex in soluble cations enhances the hydroxylation of primary minerals. Silicium is released and leached from profiles, resulting in an enrichment of the colloidal fractions in oxides and hydroxydes of aluminium and iron (relative accumulation) Fe+Al. Precipitation of the hydrous oxides of sesquioxides on the surfaces and interlayers of layer silicates and on amorphous silica result in the formation of chloritic intergrades, allophane and kaolinite respectively (Jackson, 1965). Precipitation of alumino-silicate gels on structural elements imparts the glazed appearance on ped surfaces (see profiles descriptions). A similar explanation has been given by Fripiat (cited by Maignien, 1964) for identical phenomena in ferrisols derived from basic-igneous rocks. The views expressed above do not signify a categorical denial of the possibility that limited translocation of clay has been involved.

The presence of considerable amounts of "tekto-allophane" (feldspars depleted of bases, weathering products in the analytical tables) in sand fractions as well as the presence of silicium-sesquioxides gels, explain the high cation-exchange capacities of C horizons (Table 13). Furthermore, aluminium existing in fourfold coordination in the "tekto-allophane" could conceivably be held responsible for the low pH values in KCl solutions, albeit the high base saturation (see analytical tables). Aluminium in fourfold coordination in such structures (Fieldes, 1962 and Egawa, 1964) has the tendency to obtain octahedric stability through coordination of the oxygen of water-molecules. This causes a lowering of the pK of dissociation of hydrogen of the coordinated water molecules. As a consequence weak acids are formed, these provide the bonding mechanism responsible for the fixation of potassium.

Stratification of parent material in all profiles is manifested in the heavy-mineral composition. Differences in clay content between A and B horizons are accompanied by concurrent increases in angular non-opaque minerals (Plate XIII). These (ilmenite and magnetite) were examined under reflected light to ensure that they do not comprise material of katamorphic origin but primary constituents of dolerite. Complete weathering of plagioclase and clinopyroxene (mostly pigeonite) leaves no reliable trace as to the original rock in B horizons, other than the angular grains of ilmenite and magnetite. Dolerite contains no zircon, tourmaline, rounded non-opaque minerals or rounded grains of quartz. Hence it could be inferred with reasonable certainty that the variation in the molecular ratios (SiO_2/Al_2O_3) of fine-earth fractions as well as the clay content down the vertical axis of these pedons are, mainly, attributable to progressive admixture of the overlying aeolian-sand or colluvium with the underlying dolerite or former vertisols - Da. The reversal of the trend at depth is caused by the presence of partly-weathered basic-rocks. Periodic waterlogging, as manifested in the duller colours of C horizons, mobilization of iron and its segregation into concretions, explains variations in the molecular ratio Al_2O_3/Fe_2O_3.

Profile 117/120 represents a notable exception. The colluvial mixture of aeolian sand, arenaceous sediments and doleritic detritus in this profile has been deposited on Karroo sandstone. B-horizons, however, exhibit the typical angular blocky structure with glazed ped surfaces.

The moderately to well developed, friable to slightly hard, blocky structure with glazed ped surfaces is the most diagnostic characteristic in the field. The colour of B horizons ranges from red 10R, reddish-brown 2.5YR to dark brown 10YR. Values from 3.4 to 5.6.

The structure and higher base saturation of exchange complexes, exceeding 60 per cent, in all profiles analyzed, are the criteria whereby the reddish-brown fersiallitic soils - Jd are differentiated from the eutrophic reddish-brown soils - Hd. The higher base saturation has also been a determining factor in the problem of designating these soils. Eutrophic reddish-brown soils seemed particularly appropriate since it possesses many characteristics in common with the ferrisols. According to D'Hoore (1964) the eutrophic brown soils occupy a stage of evolution intermediate between lithosols and ferrisols.

The crystalline constituents of clay fractions consist of disordered kaolinitic-minerals, hematite, goethite and quartz as well as mixed-layer minerals. The weatherable-mineral reserves of sand fractions (250-50µ) are higher than those of the reddish-brown fersiallitic soils - Jd. C-horizons contain important quantities of plagioclase besides the "tekto-allophanes". Pigeonite is generally absent and the more resistant grains of augite exhibit typical ragged outlines.

Exchangeable cations consist of magnesium and calcium. A sharp increase in these cations in C horizons seems to correlate with increases in the amount of pyroxenes, plagioclase and "tekto-allophanes". Investigations with the aid of an electron probe showed that the "tekto-allophanes" consist of basic and intermediate plagioclases in various stages of decomposition. Some grains still have cores of unaltered plagioclase. Release of cations from the primary minerals (altered and unaltered) may explain the above mentioned increase concomitantly with increases in primary minerals (Van Baren, 1963). This soil could, be it with some hesitation, classified as a Typic Hapludoll.

SOIL TYPE: Eutrophic reddish-brown soil - Hd

Sample nrs. 12/15

Sample number	Horizon	Depth in cm	Particle size distribution					pH		Organic matter %			Cations adsorption complex meq./100 gram							
			sand		silt		clay													
			2 mm-200μ	200μ-50μ	50μ-20μ	20μ-2μ	< 2μ	H_2O	KCl	C	N	C/N	Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
12	A1	0- 31	9.0	51.7	2.4	3.2	33.7	6.0	4.9	-	-	-	-	-	-	-	-	-	-	-
13	IIB2	31- 76	7.0	34.5	3.9	11.5	43.1	6.2	5.2	0.3	0.05	6.0	9.35	4.54	0.21	0.02	14.1	15.0	94.0	0.13
14	IIIC	76-122	15.3	18.0	13.3	30.1	23.3	6.5	4.8	0.3	0.05	6.0	5.18	21.50	0.64	0.32	27.6	42.8	64.5	0.75
15	IIIR	122+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
12	43.7	28.2	15.8	0.65	0.51	0.50	89.36	2.63	7.33	2.07	dK^{++} H^{+} Ml Q Hem
13	42.9	27.8	17.1	0.66	0.40	0.36	89.22	2.61	6.64	1.88	dK^{+} H^{++} Ml^{+} Hem^{+}
14	46.7	28.4	11.9	0.57	0.52	0.34	88.44	2.78	10.42	2.22	dK^{+} H^{++} Al? Ml^{++} Hem
15	-	-	-	-	-	-	-	-	-	-	- - - - - -

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
12	78.0	10.2	6.1	0.52	0.20	0.20	95.22	13.24	33.76	2.57
13	66.2	14.4	9.3	0.71	0.25	0.40	91.26	7.67	18.87	2.45
14	49.1	20.2	12.2	0.99	1.55	0.75	84.79	4.10	10.66	2.53
15	52.4	15.6	9.7	1.23	4.72	0.89	84.54	6.09	14.35	2.52

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
12	80	45	10	1	23	–	4	tr	1	–	1	tr	1	–	–	5	–	4	5	–
13	99	49	8	2	18	–	3	–	1	–	2	3	–	–	–	11	–	3	tr	–
14	25	1	tr	–	tr	–	–	–	–	–	–	–	–	–	–	97	–	–	2	–
15	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
12	94	3	–	tr	tr	–	–	3	–
13	90	6	–	–	tr	–	–	4	–
14	2	–	–	–	11	16	–	71	–
15	–	–	–	–	–	–	–	–	–

Accessories:

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers			
	12	13	14	15
1.400	–	–	–	–
1.000	0.1	0.1	0.3	–
0.840	0.1	0.1	0.0	–
0.590	0.4	0.4	0.4	–
0.500	0.9	0.9	0.6	–
0.420	0.9	1.0	1.7	–
0.290	5.7	6.6	3.3	–
0.210	17.8	17.8	10.0	–
0.150	35.4	32.0	24.4	–
0.100	23.4	23.3	30.9	–
0.074	8.5	10.9	17.0	–
0.050	6.8	6.8	11.4	–

Profile number : 12/15
Soil type : Eutrophic reddish-brown soil - Hd.
Location : Lat. 26°49', Long. 28°01' on the farm Smaldeel 683, Sasolburg district.
Site : upper erosion-slope (8%) of short pediment to dolerite outcrop.
Rainfall : 650mm
Elevation : 1530m.
Parent material: 0-31cm: colluvium comprising a mixture of aeolian sand and the weathering products of dolerite; 31-76cm: dolerite with admixture of aeolian sand (mechanism of admixture is apparently argillipedoturbation); below 76cm; dolerite.

Sample No.	Horizon	Depth cm.	
12	A1	0- 31	reddish-brown 2.5YR4/4 (dry) fine sandy loam; friable to slightly hard; coarse granular structure; scattered hard iron concretions, increase in abundance with depth, attain maximum abundance at 26-31cm; quartzite pebbles and some artifacts associated with concretions at 26-31cm; abundant roots; abrupt transition.
13	IIB2	31- 76	dark reddish-brown 2.5YR3/4 (dry) fine sandy clay; slightly hard; well-developed angular blocky structure; glazed ped surfaces; porous; few roots; indistinct boundary.
14	IIIC	76-122	yellowish-brown 10YR5/6 (dry) gravelly loam of weathered dolerite; friable; porous; fine yellowish-red mottles; many floaters of hard dolerite; gradual transition.
15	IIIR	122+	hard, exfoliated loosely-packed dolerite.

SOIL TYPE: Eutrophic reddish-brown soil - Hd

Sample nrs. 59/62r

Sample number	Horizon	Depth in cm	Particle size distribution: sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter %: C	N	C/N	Cations adsorption complex meq./100 gram: Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
59	Ap	0- 20	16.4	42.7	12.9	5.9	22.1	5.3	4.4	0.7	0.05	14.0	4.27	2.04	0.40	0.04	6.8	8.8	76.0	0.45
60	B11	20- 79	14.7	32.1	10.0	6.0	37.2	6.3	5.3	0.3	0.06	5.0	7.02	1.77	0.21	0.01	9.0	10.6	85.0	0.09
61	IIB22	79-134	7.4	17.8	8.0	11.2	55.6	6.3	5.4	0.2	0.06	3.3	10.60	6.32	0.50	0.02	17.4	19.3	90.0	0.10
62	IIC1	134-169	8.8	20.1	14.3	36.4	20.4	7.0	4.8	0.2	0.04	5.0	23.70	17.40	1.04	0.52	42.7	38.5	100.0	1.35
62r	IIC2R	169+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
59	45.9	25.1	14.6	1.28	0.40	1.00	88.28	3.10	8.34	2.26	dK^{++} H^{+} Ml Q^{+} F Hem
60	43.6	25.3	14.1	0.99	0.41	0.76	85.16	2.92	8.21	2.16	dK^{++} H^{+} Ml Q F Hem^{+}
61	42.3	26.2	13.7	0.90	0.55	0.77	84.42	2.73	8.18	2.05	dK^{++} H^{++} Ml Q Hem^{+}
62	46.6	24.2	12.0	0.71	0.69	0.76	84.96	3.26	10.31	2.52	dK^{++} H^{++} Al? Ml^{+} Q Hem
62r	-	-	-	-	-	-	-	-	-	-	- - - - - - -

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
59	81.0	6.8	4.8	0.64	0.24	0.89	94.37	20.19	44.84	2.22
60	73.4	13.5	6.6	0.66	0.28	0.85	95.29	9.33	29.58	3.19
61	56.5	15.8	9.2	0.68	0.32	1.35	83.85	6.05	16.32	2.69
62	57.0	22.0	11.2	0.80	0.92	0.65	92.57	4.39	13.53	3.07
62r	50.9	16.1	9.1	0.94	2.46	0.59	80.09	5.36	14.86	2.77

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
59	60	50	8	1	24	-	-	3	-	-	tr	2	-	-	tr	12	-	tr	tr	-
60	80	43	4	2	43	tr	tr	5	-	-	-	1	-	-	tr	1	-	-	1	-
61	95	36	8	3	35	-	-	6	-	-	-	5	-	-	-	4	-	-	3	tr
62	77	11	tr	3	4	-	tr	tr	-	-	-	tr	-	-	-	81	-	-	1	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
59	87	11	1	tr	1	-	-	-	-
60	83	15	tr	tr	-	-	-	2	-
61	70	11	10	-	6	-	-	3	-
62	26	3	1	-	8	11	-	51	-

Accessories:
number 61: Lawsonite

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers 59	60	61	62
1.400	-	-	-	-
1.000	0.6	0.8	0.8	0.6
0.840	0.7	0.9	0.5	0.8
0.590	2.5	3.1	2.4	2.4
0.500	3.4	4.4	3.8	3.3
0.420	3.2	3.6	3.0	2.4
0.290	10.7	11.3	10.2	7.8
0.210	13.4	13.1	12.2	9.5
0.150	18.8	18.9	16.3	16.7
0.100	23.3	21.1	21.7	23.5
0.074	14.0	14.7	17.8	18.9
0.050	9.4	8.1	11.3	14.1

Profile number : 59/62

Soil type : Eutrophic reddish-brown soil - Hd

Location : Lat. 26°19', Long. 29°30' on the farm Uitgedacht 279, Bethal district.

Site : disturbed grass-covered verge of maize field; on midslope (>2%) of slight rise in gently undulating aggradation surface.

Rainfall : 725mm.

Elevation : 1650m.

Parent material : 0-79cm: aeolian sand intermingled with pediplain drift, which includes the weathering products of dolerite; 79-169cm: dolerite with admixture of aeolian sand (mechanism of admixture is apparently argillipedoturbation); below 169cm: dolerite.

Sample No.	Horizon	Depth cm.	
59	Ap	0 - 20	dark reddish-brown 5YR3/3 (dry) fine sandy loam; friable; apedal; porous; abundant roots.
60	B11	20- 79	dusky-red 2.5YR3/2 (dry) fine sandy clay; friable; moderate angular blocky structure; glazed ped surfaces; scattered hard and soft Fe-Mn concretions (attain maximum abundance at 70-79cm), associated with quartzite pebbles; porous; few roots; abrupt transition.
61	IIB22	79-134	dark reddish-brown 2.5YR3/4 (moist) clay; friable; moderate sub-angular blocky structure; glazed ped surfaces; porous; gradual transition.
62	IIC1	134-169	yellowish-red 5YR4/6 (moist) loam; friable; fine granular structure; porous; coarse yellowish-brown mottles; gradual transition.
62 r	IIIC2R	169+	light yellowish-brown 10YR6/4 (moist) gravel; granular structure of decomposed dolerite; scattered floaters of hard dolerite; porous.

SOIL TYPE: Eutrophic reddish-brown soil - Hd

Sample nrs. 90/93

Sample number	Horizon	Depth in cm	Particle size distribution sand 2 mm-200μ	sand 200μ-50μ	silt 50μ-20μ	silt 20μ-2μ	clay < 2μ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.
90	A1	0- 15	25.0	33.4	9.5	7.9	24.2	6.7	5.7											
91	B11	15- 38	17.9	23.2	8.8	8.1	42.0	6.2	5.6											
92	IIB22C	38- 95	17.5	21.5	9.0	11.0	41.0	6.5	5.5											
93	IIC	95-132	24.2	13.0	15.4	16.1	31.3	6.8	4.8											

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
90	50.0	21.9	15.7	1.73	0.36	0.93	90.62	3.87	8.45	2.67	dK^{++} H^{+} Ml Q^{+} Hem_{+}
91	43.2	25.8	18.4	1.14	0.30	0.63	89.47	2.82	6.22	1.95	dK^{++} H^{++} Ml Q^{+}_{+} Hem^{+}
92	44.0	25.1	14.3	1.18	0.30	0.61	85.49	2.97	8.16	2.18	dK^{++} H^{++} Ml_{+} Q^{+} Hem^{+}_{+}
93	47.3	24.3	14.1	1.10	0.29	0.87	87.96	3.15	8.93	2.42	dK^{++} H^{++} Al? Ml^{+} Q Hem^{+}

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
90	79.1	6.8	5.8	0.86	0.25	0.95	93.76	19.43	36.14	1.84
91	66.0	12.4	8.1	0.97	0.25	0.83	88.55	9.03	21.58	2.38
92	66.2	13.3	9.9	1.00	0.26	0.70	91.36	8.43	17.75	2.10
93	58.5	17.3	11.1	0.94	0.61	0.95	89.40	5.73	14.01	2.42
93r	45.5	21.0	9.8	0.86	8.25	0.82	86.23	3.66	12.33	3.35

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
90	73	48	5	9	23	–	–	3	–	–	–	tr	–	–	–	6	–	4	2	–
91	78	52	4	6	23	–	–	7	1	–	1	–	1	–	–	1	–	2	2	–
92	90	44	5	7	26	–	2	4	–	–	–	1	–	–	–	9	–	–	2	–
93	75	25	2	8	7	–	tr	4	–	–	tr	2	–	–	–	49	–	–	3	–

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
90	96	3	–	–	–	–	–	1	–
91	87	8	1	tr	3	–	–	1	–
92	82	8	1	tr	4	–	–	5	–
93	14	2	–	–	10	5	–	69	–

Accessories:

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers 90	91	92	93
1.400	–	–	–	–
1.000	0.8	1.7	1.3	1.8
0.840	1.9	2.7	2.7	4.5
0.590	6.8	7.4	7.2	20.8
0.500	6.4	6.0	6.3	8.6
0.420	5.2	4.7	5.3	4.6
0.290	14.3	12.6	14.2	8.1
0.210	15.4	14.7	15.4	7.8
0.150	16.2	15.4	16.5	8.6
0.100	17.0	17.1	16.5	14.0
0.074	10.7	11.0	9.5	12.1
0.050	4.4	6.7	5.1	8.9

Profile number : 90/93

Soil type : Eutrophic reddish-brown soil - Hd.

Location : Lat. 26°22', Long. 29°04' on Kwaggaslaagte farm, Bethal district.

Site : uncultivated grass-covered pediment to dolerite outcrop; 3 per cent slope.

Rainfall : 700mm.

Elevation : 1650m.

Parent material: 0-38cm: colluvial admixture of sedimentary material affected by aeolian sorting and dolerite; 38-132cm: sedimentary material, affected by aeolian sorting, incorporated by argillipedoturbation into the weathering products of dolerite; below 132cm: dolerite.

Sample No.	Horizon	Depth cm.	
90	A1	0- 15	dark-brown 10YR3/3 (dry) fine sandy clay loam; slightly hard; weak fine angular blocky structure; frequent roots; gradual boundary.
91	B11	15- 38	weak-red 10R4/3 (dry) clay loam; slightly hard; fine angular blocky structure; glazed ped surfaces; scattered hard iron concretions; distinct boundary.
92	IIB22C	38- 95	reddish-brown 2.5YR4/4 (dry) clay loam; slightly hard; moderate blocky structure; glazed ped surfaces; fine yellowish-brown mottles; abundant Fe-Mn concretions; isolated floaters of weathered dolerite fragments; gradual boundary.
93	IIC	95-132	yellowish-brown 2.5YR6/4 (dry) gritty sandy loam; loose; large amount of dark-stained dolerite floaters; gradual boundary.
93r	IIIR	132+	hard gravel of weathered dolerite.

SOIL TYPE: Eutrophic reddish-brown soil - Hd

Sample nrs. 117/120

Sample number	Horizon	Depth in cm	Particle size distribution sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
117	Ap	0- 21	73.5		8.8	4.2	13.5	5.5	4.6											
118	IIB21	21-103	46.0		8.8	8.6	36.6	6.1	5.2											
119	IIB22	103-125	51.9		10.9	8.7	28.5	6.1	5.3											
120	IIIC	125+	-		-	-	-	-	-											

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
117	45.0	26.5	14.1	1.21	0.89	1.01	88.71	2.86	8.48	2.15	dK^{++} H^{+} Ml^{+} Q^{++} Hem
118	42.4	29.3	13.7	0.87	0.55	0.86	87.68	2.46	8.24	1.89	dK^{++} H^{+} Ml Q^{+} Hem^{+}
119	45.1	27.6	14.0	0.98	0.77	0.97	89.42	2.75	8.50	2.10	dK H^{++} Ml Mt^{+} Q^{+} Hem

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
117	85.1	5.7	3.6	0.55	0.09	0.62	95.66	24.86	62.73	2.52
118	73.5	12.1	7.4	0.66	0.10	0.63	94.39	10.30	26.39	2.55
119	73.6	12.1	6.6	0.72	0.10	0.96	94.08	10.21	29.58	2.83
120	91.7	4.3	1.2	0.01	0.05	1.60	98.86	36.18	203.10	5.61

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
117	86	36	20	1	13	-	-	1	1	-	4	2	-	-	-	15	-	2	5	-
118	90	58	3	1	24	-	-	1	-	-	2	1	-	-	-	5	-	3	2	tr
119	84	61	4	-	30	-	-	-	1	-	-	1	-	-	-	tr	-	1	2	tr
120	55	38	4	18	27	-	-	-	-	-	-	8	-	-	-	1	-	-	4	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
117	82	15	tr	2	-	-	-	1	-
118	89	9	tr	tr	-	-	-	2	-
119	72	21	-	2	-	-	-	5	-
120	49	35	5	6	3	-	tr	2	-

Accessories:
number 118: Xenotime
number 119: Xenotime

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers			
	117	118	119	120
1.400	-	-	-	-
1.000	0.3	0.4	0.3	2.0
0.840	9.3	16.6	10.9	2.7
0.590	-	-	-	-
0.500	-	-	-	-
0.420	4.5	3.2	6.0	21.5
0.290	14.9	11.9	13.5	44.8
0.210	16.8	13.6	11.8	9.6
0.150	19.8	15.5	13.9	7.3
0.100	16.9	14.5	14.5	6.4
0.074	12.8	12.3	14.8	3.5
0.050	4.7	12.0	14.3	2.2

Profile number : 117/120

Soil type : Eutrophic reddish-brown soil - Hd.

Location : Lat. $26^{\circ}46'$, Long. $28^{\circ}27'$ on farm Eureka (subdivision of Grootvlei 453) Heidelberg district.

Site : disturbed grass-covered verge of maize field, middle of long slope (4%) of pediment to dolerite outcrop.

Rainfall : 670mm

Elevation : 1570m.

Parent material : 0-21cm: recent colluvium, comprising a mixture of aeolian sand and the weathering products of dolerite; 21-125cm: colluvial mixture of aeolian sand, sediments derived from Karroo sediments and the weathering products of dolerite; below 125cm: sandstone of Middle Ecca Series.

Sample No.	Horizon	Depth cm.	
117	Ap	0 - 21	dark reddish-brown 2.5YR3/4 (dry) fine sandy loam; slightly hard; weak angular blocky structure; abundant roots; abrupt transition.
118	IIB21	21-103	dark reddish-brown 2.5YR3/4 (dry) clay loam; slightly hard; medium blocky structure; glazed ped surfaces; scattered hard iron concretions; abundant roots; clear boundary.
119	IIB22	103-125	red 2.5YR4/6 (dry) fine sandy clay loam; friable; weak tendency towards angular blocky structure; glazed ped surfaces; scattered hard iron concretions; fine yellowish-red mottles; few roots; some fragments of weathered sandstone on lower boundary; abrupt transition.
120	IIIC	125+	reddish yellow 7.5YR7/8 (dry) loose gritty sand; weathered sandstone of the Middle Ecca Stage.

E. Yellowish-brown Fersiallitic Soils - Ja

D'Hoore (1964) defined fersiallitic soils as - "Soils with ABC profiles of which some have an A_2 horizon and a textural B horizon showing nuciform or weakly prismatic structure. There is frequently observed a marked separation of free iron oxides, which may either be leached out of the profile or precipitated within the profile in the form of concretions......... Their clay is mostly kaolinite but often contains small amounts of 2 : 1 lattice clays. Gibbsite is generally absent. The SiO_2/Al_2O_3 ratio is near 2 or slightly higher, while the SiO_2/R_2O_3 ratio is always below 2. The cation-exchange capacity of the mineral complex is low but higher than of ferrisols and ferrallitic soils having comparable (granulometric) clay content ....Colours are duller than those of ferrallitic soils, and fall in the 10YR and 7.5YR range, exceptionally in the 5YR range".

Van der Merwe (1962) classified type - Ja as fersiallitic soils on sandy parent-material. This taxa has been adopted in the S.P.I. legend and its geographical distribution shown on the map. Strictly regarded, however, the soils classified by Van der Merwe as fersiallitic soils comply with the definition given by D'Hoore (1964) with respect to colour, the tendency for the mobilization of iron and minimum requirements of the physico-chemical properties only. Structures are vaguely sub-angular blocky. The fact that the $\frac{SiO_2}{R_2O_3}$ ratios of colloidal fractions usually exceeds two, could be attributed to the parent material; aeolian sand. Although kaolinitic minerals and quartz are the dominating crystalline constituents in clay fractions, it is dubious whether the quantity of 2 : 1 layer silicates and mixed-layer minerals may be considered as small. As a consequence, consideration has been given to the possibility of classifying it as "brown soils of the arid and semi-arid regions - Ga".

The fact, however, that it occurs in association with soils that are clearly more evolved than the name fersiallitic as defined by D'Hoore (1964) implies (compare profiles 200/203; 208/207; 208/211 and 212/216) would make them classifiable as "brown-soils - Ga", an unscientific choice. The sample sites are comparable as far as relief and other exogenic factors are concerned. The parent material comprises aeolian sands (compare the heavy-mineral composition of the above mentioned profiles). With regard to the last mentioned factor important differences are, however, noticable, viz in the case of profile 200/203 deposition of aeolian sand took place on coarse-grained granite and some detritus derived therefrom were incorporated into the aeolian sand (compare the grain-size distributions). This could be expected to enhance the permeability of the parent material (Krumbein and Sloss, 1951). In the case of the other three profiles mentioned the aeolian sands are well sorted, have a finer texture, and deposition took place on slowly permeable sub-surface layers. As a consequence it may be concluded with reasonable certainty that the internal drainage (soil climate), is the major factor affecting the differences. Impeded drainage and percolating waters rich in alkaline-earth cations retards the development of well-ordered 1 : 1 layer silicates as was pointed out by Leneuf (1960) and Jackson (1965). Incomplete leaching of bases result in layer charges on 2 : 1 minerals being neutralized, electric neutrality enhances the stability of the minerals.

In view of the fact that these soils compare very well with the extensive "aeolian sandy soils" - Ja of Van der Merwe (1962) and it also meets the minimum standards for "Fersiallitic soils on sandy parent-material" - Ja of the S.P.I. legend (excepting for the molecular ration $\frac{SiO_2}{R_2O_3}$ of colloidal fractions) the term "yellowish-brown fersiallitic soils - Ja" (Table 1) seems more appropriate than "brown soils of arid and semi-arid regions".

All profiles terminate at depth in pallid or bleached zones which comprise the decomposed autochtonous rocks, or fossil crusts. Although no phreatic water has been encountered, it seems that the genesis is influenced by hydromorphic conditions, as evidenced in the dull colours, mottles and concretions. The extent of accumulation or intensity of mobilization is a function of relief, permeability of the decomposed clayey-products of buried horizons and the texture of the aeolian sands. Depth to the zone of accumulation usually exceeds 100cm, but may be shallower owing to truncation. The concretions are scattered throughout this zone, normally there is a tendency for the maximum accumulation to occur at lithological discontinuities. The association of concretions with layers exhibiting evidence of water transportation and colluviation, calls for restraint in interpreting their presence in terms of a single cycle of soil formation only.

Clay increases with depth, clay illuviation as evidenced by the presence of clay skins could, however, not be ascertained in the field, neither in the laboratory. The increase in clay is presumably only to a limited extent caused by illuviation, as the absence of clay skins would suggest that the phenomenon is mainly the result of the original stratification. Winnowing of clay at the surface by contemporary wind deflation, considering the poor cohesion and structural stability of A horizons, could be a complimentary factor. The tendency of sand fractions of A horizons to be better sorted, seems to be an attestation of this possibility.

Dominant hues of one of the B horizons are as yellow as 10YR, others in the same profile may be as red as 10R. B-horizons usually have weakly to moderately developed blocky-structures.

Total organic matter content is low, C/N ratios are usually higher than those of the reddish-brown fersiallitic soils and decrease with depth is more gradational. Considering the higher base saturation, which may normally be expected to stimulate biological activity, it would appear that temporary anaerobic-conditions could be the factor inhibiting microbial activity. No individualization of a horizon of accumulation of organic matter coinciding with maximum iron content, has been observed. Differential movement of iron with respect to aluminium is apparent from the molecular ratios $\frac{Al_2O_3}{Fe_2O_3}$ of the fine earths. Judging from these ratios there is a weak tendency for an eluvial horizon to develop. In terms of clay content, structure and colour it does, however, not qualify as an A_2 horizon. The $\frac{SiO_2}{Fe_2O_3}$ and Al_2O_3/Fe_2O_3 ratios of the fine earths is considered an unreliable indication of the true extent of iron accumulation. Iron concretions, being usually hard, have been removed by sieving. In the hard concretions Fe_2O_3 is the dominating sesquioxide (Table 9).

The SiO_2/Al_2O_3 and $\frac{SiO_2}{Fe_2O_3}$ ratios (molecular) of clay fractions are above two, partly because of the presence of large quantities of quartz of colloidal dimensions but also owing to the presence of 2 : 1 layer silicates and mixed-layer minerals. Increases in the above mentioned ratios with depth coincide with concomitant increases in 2 : 1 layer silicates and mixed-layer minerals. This is caused by the weathering-depth function and admixture, the relative influences of which could not be ascertained.

Crystalline components of clay fractions consist of disordered kaolinite, halloysite, goethite, mixed-layer minerals, mica and quartz. Hematite is conspicuously absent. Feldspar, of colloidal dimensions, is occasionally present. The reserves of weatherable minerals in sand fractions (250 - 50μ) are appreciable. The content of primary minerals is, however, too obviously dependent upon the sedimentary history of the aeolian sands to be useful as a reliable criterium of weathering.

The cation-exchange capacity (ammonium acetate method) is mostly higher than that of the reddish-brown fersiallitic soils with a comparable clay content. Base saturation of exchange complexes usually exceeds 40 per cent. A notable exception, also with regard to colour, is profile 30/33. This profile has obviously been affected by recent aeolian-sculpting and is at present developing under changed hydrological conditions.

Soil reactions of A and B horizons are strongly acid to neutral and fall in the 5.2 - 6.6 pH range. The pH values in KCl solutions of some C horizons are very low (Profiles 208/211; 204/207; 30/33). The presence of a high content of "tekto-allophanes" (see euthrophic reddish-brown soils - Hd) explains this phenomenon in the case of profiles 204/207 and 208/211. In profile 30/33 it may be caused by the presence of allophane in the clay fraction. Owing to the occurrence of halloysite, the presence of allophane could not be ascertained beyond doubt.

Along slopes, in areas with impeded external-drainage, the yellowish-brown fersiallitic soils interdigitate with mineral hydromorphic soils - Na and with a decrease in the thickness of the sand cover with Highveld pseudo-podzolic soils - Fa. The profiles selected as examples differ considerably in detail. This is largely attributable to differences resulting from the complexity of the aeolian sand, variation in the type of buried rock or crusts and relief.

SOIL TYPE: Yellowish-brown fersiallitic soil - Ja

Sample nrs. 30/33

Sample number	Horizon	Depth in cm	Particle size distribution sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
30	A1	0- 25	11.0	62.2	11.6	3.4	11.8	5.7	4.6	0.2	0.03	6.7	1.61	0.91	0.11	0.04	2.7	6.1	43.0	0.65
31	IIB21	25-124	11.3	52.5	8.6	3.5	24.1	6.1	4.9	0.3	0.03	10.0	2.89	3.56	0.36	0.09	6.9	8.9	77.0	1.01
32	IIIB22	124-153	6.2	37.2	6.1	7.5	43.0	6.0	5.2	0.2	0.02	10.0	2.23	1.85	0.27	0.05	4.4	15.4	28.0	0.32
33	IVC	153-183	35.7	39.2	14.0	2.4	8.7	6.3	4.6	0.1	tr	-	2.73	3.31	0.18	0.09	6.3	8.8	72.0	1.02

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
30	52.5	28.5	7.3	1.43	0.70	1.80	92.23	3.12	19.11	2.69	dK^{++} H^{++} Mi^{++} Q^{++} F
31	47.4	34.9	7.8	1.07	1.30	1.28	93.75	2.31	16.13	2.02	dK^{++} H^{++} Mi Q^{+} F
32	42.2	28.1	10.6	0.69	0.32	0.85	82.76	2.56	10.58	2.06	dK^{++} H^{++} Ml^{+} F G
33	46.5	30.0	9.3	0.58	0.72	0.85	87.95	2.63	13.29	2.19	dK^{+} H^{++} Ml^{++} Al?

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
30	87.0	6.1	1.6	0.38	0.15	2.05	97.28	24.20	144.33	5.96
31	77.3	9.4	2.6	0.43	0.17	2.00	91.90	13.95	78.94	5.65
32	65.5	17.3	6.3	0.52	0.16	2.05	91.83	6.41	27.64	4.29
33	76.0	15.0	2.9	0.06	0.18	4.60	98.74	8.58	69.64	8.09

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500µ-50µ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
30	60	45	13	2	22	1	3	4	-	-	-	2	-	2	-	-	-	6	tr	tr
31	65	39	9	4	27	tr	3	4	1	-	tr	2	-	1	tr	-	1	8	1	-
32	67	38	21	4	24	tr	tr	5	1	-	-	1	-	tr	tr	-	-	3	2	1
33	88	12	27	19	6	-	1	1	2	tr	-	4	-	2	8	2	-	tr	15	1

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
30	78	17	tr	2	1	-	-	2	-
31	80	18	-	tr	-	-	-	2	-
32	64	32	-	2	-	-	1	1	-
33	55	37	-	-	-	-	4	4	-

Accessories:
number 30: Apatite
number 32: Sillimanite
number 33: Sillimanite

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000µ-50µ)

Sieve appertures in mm.	Sample numbers			
	30	31	32	33
1.400	-	-	-	-
1.000	1.5	-	-	-
0.840	0.3	0.2	0.3	0.1
0.590	0.8	0.4	0.4	0.9
0.500	1.6	0.7	0.6	3.0
0.420	0.2	0.8	0.7	3.9
0.290	7.3	7.5	5.8	22.3
0.210	22.8	21.4	21.6	33.7
0.150	31.3	31.1	35.2	22.6
0.100	20.6	18.3	18.9	7.5
0.074	9.6	11.6	8.9	3.7
0.050	4.0	8.0	7.6	2.1

Profile number : 30/33
Soil type : Yellowish-brown fersiallitic soil - Ja.
Location : Lat. 26°56', Long. 28°12' on the farm Vaaldam Settlement 1777, Heilbron district.
Site : grass-covered slope (5%), aggradation surface.
Rainfall : 625mm.
Elevation : 1526m.
Parent material: 0-25cm: recently redistributed aeolian sand; 25-124cm: aeolian sand; 124-153cm: colluvial mixture of aeolian sand and pediment drift; below 153cm: arkosic sandstone of the Middle Ecca Stage.

Sample No.	Horizon	Depth cm.	
30	A1	0 - 25	light reddish-brown 5YR6/3 (moist) loamy fine sand; friable; apedal; scattered iron concretions increasing in abundance with depth, attain maximum abundance at 23-25cm; abundant roots; abrupt transition.
31	IIB21	25-124	yellowish-brown 10YR5/6 (moist) fine sandy clay loam; friable; apedal; porous; rare soft Fe-Mn concretions; fine yellowish-red mottles; frequent roots; indistinct boundary.
32	IIIB22	124-153	red 10R4/6 (moist) clay; friable; weak angular blocky structure; porous; medium reddish-brown (ocre) mottles; scattered large (soft) Fe-Mn concretions; clear boundary.
33	IVC	153-183	brownish-yellow 10YR6/6 (moist) fine sandy loam; friable; platy structure of weathered arkosic sandstone; coarse dark yellowish-brown mottles.

SOIL TYPE: Yellowish-brown fersiallitic soil - Ja

Sample nrs. 52/55

Sample number	Horizon	Depth in cm	Particle size distribution: sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter %: C	N	C/N	Cations adsorption complex meq./100 gram: Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.I
52	A1	0- 18	18.9	41.2	10.9	5.0	24.0	5.2	4.2	0.6	0.04	15.0	4.88	0.67	0.41	0.02	6.0	8.9	67.0	-
53	B11	18- 94	13.0	33.5	10.2	6.6	35.7	5.3	4.8	0.4	0.04	10.0	4.72	1.52	0.39	0.02	6.7	10.5	63.0	-
54	IIB22	94-140	11.4	24.6	10.9	9.0	44.1	6.0	4.9	0.2	0.02	10.0	5.40	2.20	0.62	0.02	7.3	12.2	60.0	-
55	IIIC	140+	27.3	45.3	10.0	11.0	6.4	6.4	5.3	0.1	tr	-	5.57	5.03	0.30	0.04	10.9	12.8	85.0	-

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
52	45.9	28.9	11.3	1.03	1.38	1.60	90.11	2.69	12.22	2.16	dK^{++} H^{+} Ml^{+} Mi Q^{+}
53	45.1	28.8	11.2	0.94	0.43	1.53	88.00	2.63	10.63	2.12	dK^{++} H^{+} Ml^{+} Mi Q^{+} F G
54	42.4	29.3	11.9	0.55	0.35	1.50	86.00	2.46	9.49	2.02	dK^{++} H^{+} Ml^{+} Mi^{+} Q F G
55	50.7	28.9	7.2	0.28	1.25	3.35	91.68	3.00	18.60	2.57	dK Ml^{++} Mi^{++}

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
52	77.4	7.2	4.2	0.53	0.18	0.70	90.21	18.51	48.91	2.81
53	72.5	13.2	5.5	0.64	0.20	0.85	92.89	9.31	34.82	3.83
54	66.1	14.7	8.1	0.70	0.21	1.10	90.91	7.56	21.93	2.82
55	77.2	10.7	1.8	0.66	0.25	3.17	93.58	12.20	114.29	3.20

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
52	65	54	11	1	21	-	1	2	2	-	2	4	-	-	-	2	-	-	tr	-
53	65	57	8	3	20	-	1	tr	1	-	1	7	-	-	-	1	-	-	1	-
54	80	61	9	1	22	-	1	-	-	-	1	tr	-	-	-	1	tr	1	3	-
55	94	79	tr	6	4	-	2	-	tr	-	tr	5	-	-	-	2	tr	tr	2	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
52	88	10	tr	2	-	-	-	tr	-
53	86	9	2	1	-	-	-	4	-
54	82	8	1	2	-	-	-	7	-
55	70	4	1	11	2	-	1	13	-

Accessories:

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers			
	52	53	54	55
1.400	-	-	-	0.4
1.000	0.9	0.9	0.9	0.8
0.840	1.0	0.6	0.9	1.1
0.590	2.7	2.7	2.4	2.0
0.500	4.0	3.8	2.7	4.0
0.420	3.2	2.7	2.5	3.9
0.290	10.7	10.1	9.5	15.6
0.210	16.2	15.1	15.5	23.6
0.150	22.9	22.7	21.5	25.0
0.100	21.6	21.4	20.3	14.4
0.074	10.5	10.5	13.6	5.9
0.050	6.2	9.5	10.2	3.3

Profile number : 52/55
Soil type : Yellowish-brown fersiallitic soil - Ja.
Location : Lat. 26°13', Long. 28°50' on the farm Brakfontein 264, Delmas district.
Site : grass-covered slope (1-2%) of featureless aggradation surface.
Rainfall : 650mm.
Elevation : 1620m.
Parent material: 0-140cm: aeolian sand (two periods of accumulation); below 140cm: sandstone of the lower Middle Ecca Stage (Karroo System).

Sample No.	Horizon	Depth cm.	
52	A1	0- 18	greyish-brown 10YR5/2 (dry) fine sandy loam; friable; apedal; porous; abundant roots; gradual transition.
53	B11	18- 94	yellowish-brown 10YR5/6 (dry) fine sandy clay; friable to slightly hard; porous; frequent roots; scattered hard iron concretions; quartzite pebbles on boundary; clear boundary.
54	IIB22	94-140	brownish-yellow 10YR6/6 (dry) sandy clay; slightly hard; moderate angular blocky structure; abundant hard iron concretions which are scattered through the horizon; scattered fragments of water transported grit; clear boundary.
55	IIIC	140+	white 5Y8/2 sandy loam of weathered sandstone.

SOIL TYPE: Yellowish-brown fersiallitic soil - Ja

Sample nrs. 121/125

Sample number	Horizon	Depth in cm	Particle size distribution: sand 2 mm-200μ	sand 200μ-50μ	silt 50μ-20μ	silt 20μ-2μ	clay < 2μ	pH H_2O	pH KCl	Organic matter %: C	N	C/N	Cations adsorption complex meq./100 gram: Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
121	Ap	0- 26	21.6	54.9	8.6	1.8	13.1	5.2	4.3	0.5	0.04	12.5	2.41	0.88	0.13	0.01	3.4	9.6	35.0	-
122	B11	26- 59	19.2	45.2	9.3	2.5	23.8	6.2	5.4	0.6	0.05	12.0	5.08	2.14	0.06	0.10	7.4	11.9	62.0	-
123	B12	59-143	17.0	40.5	9.2	4.2	29.1	6.6	5.6	0.3	0.03	10.0	6.44	2.81	0.26	0.10	9.6	12.4	77.0	-
124	IIB23	143-179	17.0	38.8	11.7	8.8	23.7	7.2	5.9	0.1	0.01	10.0	7.00	4.33	0.35	0.09	11.8	18.4	64.0	-
125	IIIC	179+	44.5	18.8	6.4	15.0	15.2	7.6	6.0	-	-	-	-	-	-	-	-	-	-	-

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
121	50.0	26.0	11.4	1.05	0.53	1.10	90.08	3.26	11.69	2.55	dK^{+} H^{++} Ml^{+} Q^{++} F G
122	48.6	27.6	11.5	0.90	0.62	1.00	90.22	2.98	11.16	2.37	dK^{++} H^{+} Ml^{+} Q^{+} G
123	48.6	27.6	11.5	0.87	0.52	1.05	90.14	2.98	11.16	2.37	dK^{++} H^{+} Ml^{+} Q^{+} G
124	49.9	26.5	12.0	0.98	0.51	1.05	90.94	3.17	11.16	2.48	dK^{++} H^{+} Ml^{++} Q^{+}
125	50.1	25.4	8.1	0.60	0.85	1.17	86.22	3.34	16.42	2.79	dK^{++} H^{+} Ml^{++} Q F

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
121	88.0	3.0	2.0	0.31	0.17	0.60	94.08	49.77	116.95	2.35
122	83.3	6.7	3.3	0.40	0.25	0.65	94.60	21.09	66.98	3.18
123	74.6	7.8	4.1	0.44	0.26	0.68	87.88	16.22	48.37	2.97
124	64.0	8.6	8.5	0.55	0.26	0.85	82.76	12.62	20.01	1.58
125	72.8	9.6	3.2	0.08	0.40	1.90	87.98	12.86	60.30	4.69

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500µ-50µ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
121	69	37	12	3	32	–	tr	–	–	3	–	4	–	4	–	5	–	tr	–	–
122	72	53	10	tr	24	–	–	1	tr	tr	tr	7	–	2	tr	2	–	tr	1	–
123	69	57	5	tr	27	–	tr	1	tr	tr	2	3	–	5	–	tr	–	tr	tr	–
124	55	43	10	tr	32	tr	1	1	1	1	2	tr	–	4	–	tr	–	4	1	tr
125	71	39	6	12	9	–	5	2	–	–	3	6	–	–	1	3	–	6	8	tr

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
121	89	8	–	2	–	–	–	–	–
122	94	6	–	tr	–	–	–	–	–
123	87	11	–	1	–	–	–	1	–
124	75	5	–	tr	–	–	–	20	–
125	53	2	tr	5	tr	–	10	30	–

Accessories:

number 124: Sillimanite

number 125: Apatite

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000µ-50µ)

Sieve appertures in mm.	Sample numbers				
	121	122	123	124	125
1.400	–	–	–	–	–
1.000	0.2	0.3	0.2	0.3	–
0.840	0.2	0.3	0.4	0.3	0.1
0.590	1.3	1.8	1.9	1.8	0.1
0.500	3.1	3.6	4.1	3.5	4.4
0.420	3.3	4.0	3.8	3.5	10.9
0.290	13.4	12.6	12.3	12.3	40.8
0.210	16.3	16.3	14.2	12.8	20.4
0.150	21.8	21.7	20.1	16.3	9.0
0.100	18.1	17.0	20.4	16.1	5.9
0.074	14.5	11.8	10.7	13.7	4.5
0.050	7.8	10.6	11.8	19.4	3.9

Profile number : 121/125
Soil type : Yellowish-brown fersiallitic soil - Ja.
Location : Lat. 26°44', Long. 28°29' on the farm Irenedal (subdivision of Grootvlei 453), Heidelberg district.
Site : disturbed grass-covered verge of maize field (dominant grass-species Themeda triandra and Tristachya (spp), featureless aggradation surface.
Rainfall : 670mm.
Elevation : 1560m.
Parent material: 0-143cm: aeolian sand (different periods of accumulation?); 143-179cm: colluvium comprising a mixture of aeolian-transported sand and the weathering products of Karroo sedimentary rocks in the vicinity; below 179cm: arenaceous sediments of the Middle Ecca Stage.

Sample No.	Horizon	Depth cm.	
121	Ap	0 - 26	dark-brown 10YR4/3 (dry) fine sandy loam; loose; apedal; abundant roots; gradual transition.
122	B11	26- 59	dark yellowish-brown 10YR4/4 (dry) sandy clay loam; slightly hard; weak sub-angular blocky structure; porous; frequent roots; gradual boundary.
123	B12	59-143	yellowish-brown 10YR5/6 (moist) fine sandy clay loam; medium sub-angular blocky structure; porous; scattered iron concretions (hard) increasing in abundance with depth, attains maximum abundance at 140-143cm; few quartzite pebbles at this depth; fine yellowish-red mottles; few roots; abrupt transition.
124	IIB23	143-179	light olive-brown 5Y6/2 (moist) fine sandy clay loam; friable; weak blocky structure; medium yellowish-brown mottles; scattered soft and some hard Fe-Mn concretions; clear boundary.
125	IIIC	179+	light-grey 2.5Y7/2 (moist) sandy loam of weathered sandstone.

SOIL TYPE: Yellowish-brown fersiallitic soil - Ja

Sample nrs. 204/207r

Sample number	Horizon	Depth in cm	Particle size distribution sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
204	A11	0- 15	16.7	60.2	9.3	3.5	10.3	6.6	5.3											
205	A12	15- 62	16.2	53.8	10.6	4.1	15.3	6.6	5.3											
206	A33	62-107	21.0	44.9	12.3	6.7	15.1	6.7	5.6											
207	IIB2cn	107-143	–	–	–	–	–	–	–											
207r	IIICg	143+	25.9	21.1	10.6	19.7	22.7	7.2	4.9											

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
204	38.1	24.1	15.5	1.05	0.29	1.13	80.17	2.68	6.53	1.90	dK^{++} H^{+} Ml Mi^{+} Q^{+} G
205	41.4	24.0	13.1	0.92	0.41	1.02	80.80	2.91	8.42	2.18	dK^{++} H^{+} Ml Mi^{+} Q G
206	41.5	28.1	13.0	1.02	0.21	0.97	85.05	2.51	8.32	1.92	dK^{++} H Ml Q G
207	–	–	–	–	–	–	–	–	–	–	– – – – – – –
207r	45.0	23.8	15.9	0.50	0.37	1.02	86.64	3.20	7.49	2.25	Ml(Mi-Mt-Vm)$^{+}$ Mt^{++}

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$	
	in weight percentages										
204	87.5	3.4	3.5	0.42	0.16	0.38	95.36	43.66	66.45	1.52	
205	83.0	5.4	4.3	0.46	0.30	0.45	93.91	26.18	51.30	1.95	
206	74.2	5.4	6.6	0.23	0.17	0.45	87.05	23.31	29.87	1.28	
207	61.1	5.6	28.8	0.44	0.11	0.44	96.49	18.51	5.63	0.30	(total crust)
207r	62.6	11.2	12.7	1.02	0.65	1.63	89.80	9.48	13.13	1.38	

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500µ-50µ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
204	60	20	40	1	5,	-	-	-	5	-	13	8	2	4	tr	-	-	-	2	tr
205	55	35	30	1	4	-	1	-	8	1	11	2	2	3	2	-	-	-	-	-
206	70	31	34	-	5	-	-	-	4	1	16	3	-	-	-	-	-	-	tr	1
207	80	25	30	7	10	tr	tr	tr	7	tr	12	3	-	6	tr	-	1	tr	tr	tr
207r	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
204	90	5	-	tr	-	-	-	tr	5
205	91	3	-	1	tr	-	-	2	3
206	82	9	-	-	-	-	-	1	8
207	65	11	1	5	2	-	-	5	11
207r	44	2	1	1	5	-	1	46	-

Accessories:
number 204: Chloritoid
number 206: Sillimanite
number 207: Diaspore

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000µ-50µ)

Sieve appertures in mm.	Sample numbers				
	204	205	206	207	207r
1.400	1.7	1.6	1.9	15.0	1.5
1.000	3.7	3.7	3.8	8.1	6.7
0.840	1.8	1.8	1.9	2.8	4.2
0.590	4.0	4.1	3.3	4.1	6.8
0.500	2.7	2.9	2.8	3.1	5.8
0.420	1.7	1.9	1.9	2.8	4.6
0.290	3.6	4.2	3.9	5.3	3.2
0.210	4.1	4.3	4.8	3.8	7.3
0.150	6.6	6.6	5.9	6.2	8.2
0.100	23.4	25.7	23.7	22.1	18.5
0.074	32.3	32.9	29.0	17.6	21.4
0.050	14.4	10.3	17.1	9.0	6.8

Profile number : 204/207
Soil type : Yellowish-brown fersiallitic soil - Ja.
Location : Lat. 26°11', Long. 26°13' on the farm Rietgat 111, Lichtenburg district.
Site : grass-covered headland of maize field; featureless aggradation surface; less than 1 per cent slope.
Rainfall : 550mm.
Elevation : 1460m.
Parent material: 0-107cm: aeolian sand (different periods of accumulation?); 107-143cm: fossil-crust, colluvium and aeolian sand (mechanism of admixture may be due to falling of aeolian sand into cracks in the fossil crust); below 143cm: Dwyka shale.

Sample No.	Horizon	Depth cm.	
204	A11	0 - 15	dark-brown 7.5YR4/2 (dry) loamy fine sand; friable; apedal, almost single grain; scattered hard iron concretions; frequent roots; gradual boundary.
205	A12	15- 62	dark-brown 7.5YR4/2 (dry) fine sandy loam; friable; apedal; scattered small, hard iron concretions; frequent roots; gradual boundary.
206	A33	62-107	yellowish-brown 10YR5/6 (dry) sandy loam; slightly hard; weak angular blocky structure; frequent hard iron concretions; fine yellowish-red mottles; few small chert, tuff, quartz and quartzite pebbles; abrupt, though wavy, boundary.
207	$IIB12^{cn}$	107-143	yellowish-brown 10YR5/6 (moist) variegated ferruginous crust, indurated; well developed pisolitic structure (dark yellowish-brown 10YR5/8) cemented by softer earthy ferruginous-material (yellow-ocre 2.5YR6/8); abundant fine sub-angular chert, tuff, lava, quartz and quartzite pebbles; the horizon is warped, presumably caused by swelling and shrinking of the underlying montmorillonite clay; abrupt, though wavy, boundary.
207r	IIICg	143+	brownish-yellow 10YR6/6 (moist) loam; friable; massive; coarse brownish-black and yellowish-brown mottles; shale fragments.

SOIL TYPE: Yellowish-brown fersiallitic soil - Ja

Sample nrs. 208/211

Sample number	Horizon	Depth in cm	Particle size distribution: sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
208	Ap	0- 28	75.8		5.9	3.8	14.5	6.4	5.7	0.2	0.03	6.7	2.93	1.36	0.33	0.03	4.7	7.9	59.0	-
209	B11	28- 79	63.5		7.8	4.3	24.4	6.3	5.2	0.3	0.03	10.0	4.71	3.37	0.16	0.01	8.3	12.5	66.0	-
210	IIB22	79-131	56.4		9.1	9.7	24.8	6.6	5.6	0.2	0.03	6.7	7.49	5.82	0.29	0.14	13.7	20.8	66.0	-
211	IIIC	131-152	42.2		19.5	18.0	20.3	7.5	4.3	0.1	tr	-	41.50	23.70	0.29	0.73	66.2	61.8	100.0	1.18

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
208	44.4	23.1	14.8	1.29	0.86	1.13	85.58	3.27	7.97	2.31	dK^{++} H Ml^{+} Mi^{+} Q^{++} F G
209	40.2	23.4	13.2	0.97	1.03	0.85	79.65	2.86	8.10	2.14	dK^{++} H Ml^{+} Mi Q^{+} G
210	38.6	21.7	12.3	0.93	0.64	0.73	74.90	2.98	8.32	2.21	dK^{+} H^{+} Ml^{++} Q G
211	46.5	13.9	16.0	1.03	1.63	0.68	79.74	5.70	7.73	3.28	dK^{+} Ml(Chl-Vm-Mt)$^{++}$

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
208	88.1	4.2	3.5	0.32	0.10	0.44	96.66	42.42	66.45	1.88
209	75.4	4.8	5.2	0.43	0.12	0.55	86.50	24.60	38.54	1.44
210	66.0	10.4	10.9	0.53	0.22	0.60	88.65	10.75	16.85	1.48
211	55.2	11.6	12.7	0.54	10.10	2.22	92.36	7.91	12.38	1.41

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
208	20	16	30	-	3	tr	tr	1	10	tr	12	15	3	6	3	1	-	-	tr	-
209	32	22	26	-	2	-	-	1	7	tr	10	17	tr	9	tr	3	-	-	2	1
210	40	17	22	-	2	-	-	-	9	tr	10	24	tr	9	1	1	-	-	2	3
211	4	tr	tr	-	-	-	-	-	tr	-	-	95	-	tr	-	-	-	-	5	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
208	94	3	-	tr	-	-	-	-	3
209	95	2	-	-	-	-	-	1	2
210	80	2	-	2	1	-	-	10	5
211	17	-	-	tr	tr	-	-	83	-

Accessories:

number 209: Hyperstene

number 210: Sillimanite
Enstatite
Lawsonite

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers			
	208	209	210	211
1.400	0.5	-	-	2.0
1.000	1.0	2.0	3.4	4.5
0.840	0.6	1.0	0.9	3.8
0.590	1.3	1.6	1.7	6.7
0.500	0.9	1.3	1.1	5.9
0.420	0.6	0.9	0.7	2.5
0.290	1.6	2.1	2.2	9.5
0.210	3.4	3.4	3.2	8.5
0.150	11.9	12.2	15.3	20.0
0.100	38.2	36.9	28.7	14.3
0.074	28.7	26.9	29.5	13.0
0.050	11.3	11.2	13.3	9.3

Profile number : 208/211

Soil type : Yellowish-brown fersiallitic soil - Ja.

Location : Lat. 26°18', Long. 25°46' on the farm Nooitgedacht 18, Lichtenburg district.

Site : grass-covered headland of maize field (disturbed); featureless aggradation surface.

Rainfall : 500mm.

Elevation : 1445m.

Parent material : 0-79cm: well sorted aeolian sand; 79-131cm: aeolian sand and colluvium derived from the underlying andesitic lava; below 131cm: andesitic lava of the Ventersdorp System (the lava has been epidotized).

Sample No.	Horizon	Depth cm.	
208	Ap	0 - 28	dark yellowish-brown 10YR4/4 (dry) fine sandy loam; friable; apedal; slightly porous; abundant roots; gradual boundary.
209	B11	28- 79	yellowish-red 5YR4/6 (moist) fine sandy clay loam; friable; weak angular blocky structure; porous; scattered hard and soft Fe-Mn concretions; frequent roots; abrupt transition.
210	IIB22	79-131	yellowish-brown 10YR5/6 (moist) fine sandy clay loam; friable; weak angular blocky structure; porous; diffuse light yellowish-brown mottles; abundant hard and soft Fe-Mn concretions; frequent sub-angular quartzite and chert pebbles; clear boundary.
211	IIIC	131-152	light yellowish-brown 10YR4/6 (moist) loam; friable; massive; coarse yellowish-red mottles; scattered, soft Fe-Mn concretions and dark-brown speckles; many highly weathered floaters of epidotized lava; gradual transition.
	IIIR	152+	hard, partly weathered epidotized andesitic-lava

SOIL TYPE: Yellowish-brown fersiallitic soil - Ja

Sample nrs. 212/216

Sample number	Horizon	Depth in cm	Particle size distribution sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P
212	B11	0- 50	72.2		6.1	2.3	19.4	6.0	5.3											
213	B12	50-103	64.1		7.3	5.4	23.2	5.8	5.2											
214	II?B13	103-164	61.4		7.3	5.7	25.6	6.4	5.8											
215	II C1	164-185	53.3		10.1	19.2	17.4	7.7	6.6											
216	III C2si	185+	-		-	-	-	-	-											

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
212	85.6	5.7	3.4	0.39	0.07	0.45		25.5	67.8	2.61
213	82.4	7.4	4.1	0.45	0.11	0.38		18.9	54.3	2.81
214	71.3	7.7	5.8	0.53	0.19	0.37		15.8	33.2	2.06
215	67.5	7.5	5.0	0.57	0.82	0.32		15.3	36.4	2.35
216	64.9	6.0	4.6	0.46	0.46	0.14		18.4	38.1	2.03

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
212	46	38	20	–	7	–	–	1	5	tr	11	7	tr	6	2	tr	–	–	3	–
213	30	18	35	–	5	–	–	–	4	tr	22	8	tr	5	–	–	–	–	2	1
214	40	23	37	–	5	–	–	tr	9	–	21	4	tr	tr	–	–	–	–	1	–
215	45	35	17	tr	7	–	–	2	10	tr	11	12	2	2	tr	1	–	–	tr	1
216	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
212	96	tr	–	2	–	–	–	–	2
213	95	2	1	1	–	–	–	–	1
214	94	1	–	1	–	–	–	–	4
215	46	4	tr	1	–	–	–	–	49
216	–	–	–	–	–	–	–	–	–

Accessories:
number 213: Alunite
number 215: Enstatite

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers 212	213	214	215
1.400	–	0.4	0.3	0.5
1.000	0.4	0.2	0.6	2.0
0.840	0.3	0.4	0.4	2.5
0.590	0.9	0.9	0.8	2.5
0.500	0.6	0.6	0.7	2.0
0.420	0.6	0.5	0.6	2.6
0.290	1.7	1.7	1.6	5.2
0.210	3.6	3.3	3.1	6.6
0.150	11.5	10.7	9.8	11.4
0.100	39.0	35.0	33.8	26.5
0.074	29.2	34.0	32.2	24.4
0.050	12.2	12.3	16.1	13.8

Profile number : 212/216
Soil type : Yellowish-brown fersiallitic soil - Ja.
Location : Lat. 26°11', Long. 25°47' on the farm Lushof 17, Lichtenburg district.
Site : bare patch caused by recent wind deflation; featureless aggradation surface.
Rainfall : 500mm.
Elevation : 1490m.
Parent material: 0-164cm: aeolian sand; 164-185cm: aeolian sand with admixed colluvium; below 185cm: duripan, consisting of hard microcrystalline silicious-crust (decalcified calcareous crust - see Plate 111).

Sample No.	Horizon	Depth cm	
212	B11	0 - 50	yellowish-red 5YR4/6 (dry) fine sandy loam; slightly hard; weak angular blocky structure; porous; few roots; gradual transition.
213	B12	50-103	reddish-brown 5YR4/4 (dry) fine sandy clay loam; slightly hard; weak angular blocky structure; porous; scattered hard and soft Fe-Mn concretions; few roots, gradual boundary.
214	II(?)B13	103-164	yellowish-brown 10YR5/6 (dry) fine sandy clay; slightly hard; weak angular blocky structure; medium yellowish-brown and yellowish-red mottles; frequent hard iron concretions (10YR5/8) and soft Fe-Mn concretions (10YR3/4); abrupt transition.
215	IIC1	164-185	greyish-white 2.5Y5/2 (dry) loam; friable; apedal; frequent quartz, quartzite and chert pebbles; large detached fragments of microcrystalline silcrete; abrupt, though wavy, boundary.
216	IIIC2si	185+	white; hard duripan of silcrete (decalcified calcareous crust).

Remark: Profile truncated by recent wind deflation.

F. Highveld Pseudo-podzolic Soils - Fa and Intergrade - Fa'

The Highveld pseudo-podzolic soils or "Highveld prairy soils" (Van der Merwe, 1962) form one of the most extensive soil groups in the Highveld Region. D'Hoore (1964) gave the following definition:

"Highveld pseudo-podzolic soils are of the ABC type with textural B horizons. The A horizons are generally loose and friable and contain less than 20 per cent clay. The A_1 horizons are brown or dark grey and the weakly developed A_2 horizons are light in colour. Between 40 and 90 cm depth there is a clear or abrupt change to a textural B horizon of blocky or prismatic structure often with a yellow-brown colour. The clay content of horizon B is more than double that of horizon A. The zone of transition from A to B may present spots of pseudogley sometimes associated with concretions of iron and manganese. The saturation of the exchange complex exceeds 50 per cent especially in horizon B. Horizon A is neutral or weakly acid and horizon B may be weakly alkaline".

The genesis is mainly affected by the deposition of aeolian sand or colluvium influenced by aeolian sorting on vertisols and the truncated stumps of lighter-textured soils, as is the case with intergrade Fa'. Textural contrasts between A and B horizons often depend on the degree of truncation of buried horizons. The consequent hydromorphic conditions are responsible for the differential illuviation of iron. A secondary maximum of C/N ratios, often, though not as a rule, concide with a horizon of iron accumulation. As has been pointed out by Bloomfield (1965) this does not necessarily signify a causative relationship. Total organic matter content is low, and decreases less rapidly with depth than in associated well-drained soils. As is the case in the yellowish-brown fersiallitic soils - Ja, this is more than likely caused by more frequent water-stagnation; permanent saturation is, however, atypical.

Its distribution has, as far as could be ascertained, no climatic relevance. With increase in the thickness of the sand-cover it grades into the yellowish-brown fersiallitic soils - Ja. On slopes, especially if the sand-cover is thin, it interdigitates with solodized solonetz - Na. In the event of the sand-cover being thicker, the only indication of the former presence of a solonetz is the well-developed columnar structures (Profile 43/47). In terms of ESP-values this profile does not qualify as solodized solonetz.

With decrease in the thickness of the sand-cover it merges into vertisols. In areas with impeded external-drainage it interdigitates with mineral hydromorphic soils - Ma.

Generally regarded, the Highveld pseudo-podzolic soils have many characteristics in common with the yellowish-brown fersiallitic soils, especially intergrade Fa'. This intergrade has been differentiated since it evolves towards the above mentioned type. This is brought about by the deposition of aeolian sand on underlying rocks or buried horizons which are more permeable than the vertisols. The lithological discontinuities are, however, always shallower than 100cm, resulting in more frequent saturation. Transition to underlying textural B horizons is more abrupt, and there are significant differences with regard to clay development(Profile 143/146).

Highveld pseudo-podzolic soils are typically individualized at the down-wind direction of seif dunes, sand sheets and between seif dunes. Owing partly to the phenomenon that the thickness of aeolian sands thins out in the direction of transport. The main reason is, however, that the mean grain-size of sand fractions decreases as a result of selective or progressive sorting in the direction of transport. Eventually, at a mean grain-size of approximately 3 phi, aeolian sand behave progressively more like loess, splays out and tend to be deposited in a rather similar manner as loess (Harmse, 1963). Samples located more east-ward, in the down-wind direction of the prevailing north-western winds, have conspicuously high silt content (Profiles 182/185 and 143/146).

Some profiles, especially those situated on slopes have lighter textured and light coloured A_2 horizons (Profile 43/47). Clay skins and coatings are usually discernable on ped surfaces of B horizons. Micromorphological investigations, however, showed them to consist mostly of stress cutans (according to criteria described by Bruwer, 1964 and A.Jongerius, personal communication) with only sub-ordinate amounts of translocated clay. Comparison of the molecular ratios SiO_2/Al_2O_3 of fine earths, discounting the possibility of weathering in B horizons and pedoturbation, substantiate this contention. Hence B horizons in profile descriptions, were not designated as argillic horizons. Differential illuviation of sesquioxides, especially iron and manganese, is apparent in the form of concretions at lithological discontinuities and mottles deeper down. The high silica content, mainly owing to the presence of quartz of colloidal dimensions, as well as the high titatium oxide content of colloidal fractions of A horizons complete the impression of a selective removal of sesquioxides. The phenomenon is, to a considerable extent, attributable to the aeolian sand; or even lateral illuviation considering the impervious nature of B horizons (Hallsworth, 1965). The strong mottling and gley colours of B and C horizons may be taken as reliable indications of their genesis being mainly the result of hydromorphic conditions. On account of the false podzol characteristics described above, the name pseudo-podzolic soils seems justified. The adjunct "Highveld" is, however, superfluous and engenders the wrong impression that its geographical distribution is unique and restricted to conditions within the confines of this physiographic entity.

Horizonation is excellent, A_1 horizons are commonly very thick.

Soil reaction ranges from strongly acid to slightly acid and falls in the pH range 5.1 - 6.6. Horizons B and C are neutral to moderately alkaline. The exchange complexes of one of the B horizons are 50 per cent saturated. The cation-exchange capacity of clay fractions is usually above 40 meq/100g. Variations in these properties and in morphology seems to be largely attributable to variations in the thickness of the sand-cover, relief and the nature of buried horizons. The time factor could be instrumental in generating some of these variations. The type of underlying rock or buried horizons could be useful criteria for subdivision into lower categories (compare profiles 182/185, 4/7 and 143/146). Structures of B horizons especially seem to vary with the type of underlying material.

The weatherable-mineral reserves of sandfractions (250 - 50µ) are high. Clay fractions of A horizons contain important quantities of quartz besides random mixed-layer minerals, disordered kaolinite and halloysite. Quartz is present in B horizons only as traces, Clay minerals are mainly of the random mixed-layer types, giving weak diffraction maxima at around 19Å, 17.2 - 17.8Å, 16.6Å, 14.0 - 14.7Å, 13.3 - 13.8Å, 12.2 - 12.8Å, 11.2 - 11.8Å, 10Å, 9.2 - 9.5Å and 7.15 - 7.8Å. These have been shown by Jackson (1956); Osada, et al., (1960); Shimosaka, et al., (1960); Smith (1960); Jackson (1963) and Wilson (1966) to consist of intermediate spacings of complexly interstratified minerals. Resistance against collapse upon heating to 550°C and broadened plateaux forming from 10Å to larger d-spacings suggest the widespread occurrence of chloritic intergrades in these soils (Plates VIII and IX).

As for their possible place in the 7th Approximation (and supplements), although strictly of academic interest only, the morphology in general requires them to be classified among the Mollisols. In view of the periodic wetness and the doubtful argillic nature of B horizons it would seem to meet the minimum requirements of the suborder Aquolls (Haploquolls). Some epipedons, qualify as mollic only with respect to thickness, base saturation and colour. Carbon/nitrogen ratios are extremely narrow and the epipedons do not have a strong structure. A second possibility, mainly in consideration of the doubtful mollic characteristics of epipedons and argillic nature of B horizons, seems to be Inceptisols. [illegible]

SOIL TYPE: Highveld pseudo-podzolic soil - Fa

Sample nrs. 4/7

Sample number	Horizon	Depth in cm	Particle size distribution sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
4	A1	0- 48	91.5		3.4	1.0	4.1	5.3	4.8	0.2	0.02	10.0	2.72	0.70	0.10	-	3.5	4.0	89.0	-
5	A3	48- 74	85.9		4.0	1.9	8.2	6.1	5.5	0.3	0.03	10.0	3.21	0.30	0.12	-	3.6	6.1	59.0	-
6	IIB2	74-120	33.0		6.5	10.4	50.1	5.8	4.8	0.2	0.03	6.7	12.60	11.90	0.44	0.33	25.3	30.2	83.0	1.36
7	IIICg	120+	20.1		19.9	35.3	24.7	6.2	4.6	0.1	0.02	5.0	20.80	16.20	0.59	0.33	37.9	51.4	73.0	0.64

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
4	58.0	25.2	9.1	1.26	1.53	1.10	96.19	3.22	14.01	2.63	K^{++} H Ml Q^{++}
5	45.5	29.0	10.1	1.11	1.53	0.89	88.13	2.65	11.96	2.18	K^{++} H Ml Q^{+}
6	44.5	29.4	10.4	0.79	0.70	0.74	86.53	2.56	11.35	2.10	dK^{++} H Ml^{+} G
7	45.0	28.1	10.0	0.64	1.31	0.66	85.71	2.71	11.96	2.22	dK^{+} H^{++} Al? Ml^{++}

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
4	87.0	1.9	1.3	0.34	0.05	0.30	90.89	77.5	184.99	2.38
5	84.0	3.6	3.2	0.40	0.05	0.30	91.55	39.51	69.77	1.75
6	59.0	17.5	9.3	0.71	0.21	0.53	87.25	4.75	16.85	2.97
7	47.5	20.9	14.0	1.10	0.59	0.64	84.73	3.56	9.01	2.55

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
4	68	41	11	3	27	tr	tr	1	tr	–	2	2	tr	–	–	3	–	5	5	–
5	60	40	10	3	24	1	–	2	2	–	2	1	1	–	–	1	–	6	7	–
6	90	40	11	tr	25	1	–	1	1	–	1	2	1	–	–	tr	–	6	10	1
7	98	16	2	4	5	–	–	–	–	–	–	2	–	–	–	67	–	tr	2	2

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
4	87	4	1	7	–	–	–	1	tr
5	85	5	–	7	2	–	–	1	–
6	62	2	–	3	15	–	1	15	2
7	3	–	–	–	29	6	–	62	–

Accessories:
number 6: Lawsonite
number 7: Lawsonite

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers 4	5	6	7
1.400	–	–	–	–
1.000	–	0.2	0.1	–
0.840	–	0.1	0.1	–
0.590	0.4	0.4	0.7	0.7
0.500	1.3	1.2	1.6	0.5
0.420	2.2	2.1	2.7	1.1
0.290	13.5	14.4	15.7	4.2
0.210	24.6	28.9	29.1	4.3
0.150	30.4	27.7	25.1	7.3
0.100	16.4	13.6	13.7	15.7
0.074	6.8	6.6	6.8	25.5
0.050	4.3	4.9	4.6	40.7

Profile number : 4/7

Soil type : Highveld pseudo-podzolic soil - Fa.

Location : Lat. $26^{\circ}49'$, Long. $27^{\circ}50'$ on the farm Montrose 2131, Sasolburg district.

Site : poor <u>Themeda— Cymbopogon</u> Veld with scattered occurrences of <u>Imperata cylindrica</u>; undisturbed patch between low hummocks.

Rainfall : 650mm.

Elevation : 1496m.

Parent material: 0-48cm: aeolian sand; 48-74cm: aeolian sand with some admixed dolerite; 74-120cm: dolerite with some admixture of aeolian sand (mechanism of admixture is argillipedoturbation); below 120cm: dolerite (see Plate XIII).

Sample No.	Horizon	Depth cm.	
4	A1	0- 48	light brownish-grey 10YR6/2 (dry) fine sand; loose; apedal, single grain; frequent roots; indistinct boundary.
5	A3	48- 74	dark reddish-brown 5YR3/3 (dry) loamy fine sand; slightly hard; weak sub-angular blocky structure; medium yellowish-brown mottles; frequent hard and soft Fe-Mn concretions increasing in abundance with depth, attains maximum abundance at approximately 70-74cm; abrupt transition.
6	IIB2	74-120	light-grey 10YR6/1 (dry) clay; slightly hard; medium to coarse blocky, breaking into fine granular structure; glazed ped surfaces; coarse diffused yellowish-brown and bluish-grey mottles; rare soft Fe-Mn concretions; indistinct transition.
7	IIIC$_g$	120+	yellowish-brown 10YR5/6 (moist) silt loam; friable; medium granular structure of weathered dolerite; coarse bluish-grey mottles.

SOIL TYPE: Highveld pseudo-podzolic soil - Fa

Sample nrs. 43/47

Sample number	Horizon	Depth in cm	Particle size distribution					pH		Organic matter %			Cations adsorption complex meq./100 gram							
			sand		silt		clay													
			2 mm-200µ	200µ-50µ	50µ-20µ	20µ-2µ	< 2µ	H_2O	KCl	C	N	C/N	Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
43	A1	0- 38	77.1		12.3	3.7	6.9	5.6	4.8	0.4	0.04	10.0	3.91	0.23	0.12	-	4.3	5.2	82.0	-
44	A2	38- 60	81.1		10.7	2.3	5.9	6.3	6.0	0.1	0.02	5.0	3.00	-	0.10	-	3.1	3.3	95.0	-
45	I-IIB21	60- 87	63.6		8.6	4.3	23.5	6.7	5.5	0.2	0.03	6.7	9.16	3.38	0.52	-	13.1	10.5	100.0	-
46	IIB22	87-109	36.4		5.9	2.2	55.5	6.7	5.3	0.3	0.05	6.0	8.81	0.96	0.73	0.27	10.8	19.2	56.0	1.41
47	IIB23g	109+	37.8		10.1	6.7	45.4	7.7	6.2	0.2	0.04	5.0	9.41	1.07	1.00	0.82	12.3	18.7	66.0	4.39

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
43	55.7	18.6	8.0	1.68	1.34	1.72	87.04	5.07	18.50	3.93	dK^{+} H Ml^{++} Mi Q^{++} F
44	57.0	17.6	8.2	1.83	1.16	1.76	87.55	5.48	18.47	4.24	dK H Ml^{++} Mi Q^{++} F
45	52,5	22.2	8.9	1.29	1.16	1.77	87.82	4.00	15.65	3.20	dK^{++} H^{+} Ml^{++} Mi Q^{+} F
46	45.5	22.8	9.3	0.93	0.85	1.53	80.91	3.37	12.99	2.60	dK^{++} H^{+} Ml^{++} Mi Q^{+} G
47	49.0	26.8	9.4	0.93	0.80	1.50	88.43	3.19	13.84	2.69	dK^{++} H^{+} Ml^{++} Mi Q

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
43	86.5	3.2	1.6	0.44	0.08	0.87	92.74	45.82	139.30	3.04
44	95.0	2.6	1.3	0.44	0.01	0.61	99.94	61.94	197.22	3.18
45	83.0	6.8	3.7	0.52	0.11	1.00	95.13	20.74	59.54	2.88
46	63.5	13.8	11.1	0.66	0.21	1.21	90.48	6.63	15.20	1.94
47	65.0	16.6	6.8	0.59	0.16	1.00	90.15	4.48	25.38	3.82

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
43	50	34	16	4	27	tr	tr	9	tr	-	tr	2	-	2	-	tr	tr	6	-	tr
44	48	28	19	6	26	tr	tr	10	-	-	tr	4	-	2	-	tr	tr	5	-	-
45	43	40	10	5	20	-	1	12	-	-	tr	3	-	-	-	-	-	7	tr	tr
46	48	29	5	2	35	-	-	17	-	-	-	11	-	-	-	tr	-	tr	tr	1
47	57	31	3	2	39	-	tr	16	-	-	-	17	-	-	-	tr	-	tr	tr	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert

Accessories:

number 42: Xenotime

number 44: Lawsonite

number 45: Alunite

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers				
	43	44	45	46	47
1.400	0.1	0.2	0.1	0.4	0.3
1.000	0.5	1.0	0.5	0.5	0.7
0.840	0.5	0.7	0.7	0.3	0.2
0.590	1.6	1.9	1.8	1.0	0.6
0.500	1.8	2.0	2.0	1.5	0.8
0.420	1.5	1.6	1.8	1.5	1.0
0.290	6.7	6.7	7.1	6.3	5.5
0.210	14.8	14.8	15.2	11.0	17.2
0.150	25.9	25.6	25.6	33.2	32.7
0.100	21.1	20.7	20.8	23.0	23.2
0.074	14.3	14.4	13.9	12.8	11.0
0.050	11.2	10.5	10.5	8.5	6.8

Profile number : 43/47
Soil type : Highveld pseudo-podzolic soil - Fa.
Location : Lat. 27°06', Long. 28°32' on Alma farm 1247, Frankfort district.
Site : uncultivated <u>Themeda triandra</u> veld, lower slope (3%) of dissected pediplain.
Rainfall : 650mm.
Elevation : 1534m.
Parent material: 0-60cm: colluvium comprising a mixture of aeolian sand and the weathering products of sedentary rocks; 60-87cm: mixture of overlying and underlying material, mechanism of admixture; loose overlying material falling into openings between structural elements; below 87cm: argillaceous sediments of the Middle Ecca-Stage (Karroo System).

Sample No.	Horizon	Depth cm.	
43	A1	0- 38	greyish-brown 10YR5/2 (moist) loamy fine sand; loose; apedal; abundant roots; indistinct boundary.
44	A2	38- 60	light-grey 10YR7/1 (moist) loamy fine sand; loose; apedal, almost single grain; scattered hard iron concretions; very fine and diffused yellowish-brown mottling; frequent roots; abrupt boundary.
45	I-IIB21	60- 87	greyish-brown 2.5Y5/2 (dry) fine sandy loam; extremely hard; coarse columnar, breaking to medium angular blocky structure; sand coatings and dark-brown stains on peds; prominent clay skins (predominantly stress cutans); scattered hard and soft Fe-Mn concretions; few roots which are restricted to openings between structural elements; wavy boundary.
46	IIB22	87-109	pale-olive 5Y6/3 clay; hard; moderate blocky structure; medium yellowish-brown mottles; distinct stress cutans (determined by microscopic investigation); scattered soft Fe-Mn concretions; wavy boundary.
47	IIB23g	109+	pale-olive 5Y6/3 (dry) clay; hard; medium to fine angular blocky structure;coarse yellowish-brown and bluish-grey mottling;frequent soft Fe-Mn concretions.

N.B. Considerable admixture by argillipedoturbation, or simply falling into cracks between the coarse structual elements, are apparent in the IIB21 horizon.

SOIL TYPE: Highveld pseudo-podzolic soil - Fa

Sample nrs. 129/132

Sample number	Horizon	Depth in cm	Particle size distribution: sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
129	Ap-A1	0- 35	9.0	68.3	9.3	4.0	9.4	5.3	4.4	0.6	0.06	10.0	4.22	0.40	0.45	-	5.1	7.0	72.0	-
130	IIB11	35- 64	8.6	47.6	7.2	3.2	33.4	6.1	4.9	0.4	0.06	6.7	4.10	0.58	0.50	0.40	5.6	11.6	48.0	3.45
131	IIIB22	64-112	4.7	31.7	6.3	3.9	53.4	7.4	6.0	0.2	0.05	4.0	15.10	11.50	0.84	0.37	27.9	20.5	100.0	1.80
132	IIIC	112-131	7.0	45.3	8.2	9.7	29.8	8.4	7.0	0.2	0.04	5.0	9.50	0.99	0.42	-	10.9	16.6	65.0	--

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
129	46.7	23.9	9.5	1.42	0.41	0.97	82.90	3.31	13.05	2.65	dK^{++} H Ml^{++} Mi^{+} Q^{++} F
130	42.2	25.9	9.9	0.83	0.12	1.40	80.35	2.76	11.32	2.22	dK H^{+} Ml^{++} Mi^{+} F
131	44.9	26.7	8.9	0.69	0.13	1.45	82.77	2.85	13.39	2.35	dK H Ml^{++} Mi^{+} F G
132	45.2	25.7	7.2	0.74	0.27	1.40	80.51	2.98	16.66	2.52	dK H Ml^{++} Mi^{+} C F

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
129	87.4	3.1	2.0	0.35	0.16	0.90	93.91	47.84	116.15	2.42
130	75.1	10.8	4.6	0.46	0.24	1.20	92.40	11.79	43.38	2.87
131	64.9	15.3	5.8	0.24	0.36	1.40	88.00	7.19	29.76	4.10
132	69.2	13.4	3.2	0.42	0.55	2.75	89.52	8.75	57.41	6.55

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
129	54	45	3	11	33	–	–	tr	–	–	–	4	tr	tr	–	2	–	1	1	–
130	55	40	15	13	17	–	tr	tr	1	–	4	5	–	–	–	1	tr	tr	4	–
131	49	21	11	39	16	–	1	1	tr	–	–	6	–	tr	–	tr	–	–	5	–
132	32	16	11	53	14	–	–	–	–	–	–	tr	–	–	–	tr	–	1	4	–

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
129	82	9	1	3	2	–	–	2	1
130	72	13	5	4	5	–	–	1	–
131	80	9	1	4	1	–	–	4	1
132	63	6	2	2	5	–	7	15	–

Accessories:

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers			
	129	130	131	132
1.400	–	–	–	–
1.000	0.2	0.3	0.4	–
0.840	0.2	0.2	0.4	0.2
0.590	0.7	0.9	0.9	0.1
0.500	0.9	1.2	3.9	0.1
0.420	1.0	1.3	1.2	0.3
0.290	4.2	5.1	4.3	3.1
0.210	10.7	11.9	10.2	13.2
0.150	28.6	26.0	26.7	36.9
0.100	33.0	32.7	28.6	28.9
0.074	14.0	12.3	15.3	11.1
0.050	6.5	8.1	8.1	6.1

Profile number : 129/132
Soil type : Highveld pseudo-podzolic soil - Fa.
Location : Lat. 26°51', Long. 28°33' on the farm Leeuspruit 601, Heidelberg district.
Site : disturbed grass-covered (<u>Themeda triandra</u>) verge of maize field; upper slope (<1%) of slight rize in slightly undulating pediplain.
Rainfall : 650mm.
Elevation : 1560m.
Parent material: 0-35cm: more or less uncontaminated aeolian sand; 35-64cm: mixed colluvium, comprising aeolian sand and Ecca sediments; below 64cm: sediments of the Middle Ecca Stage (Karroo System)(see Plate XVI).

Sample No.	Horizon	Depth cm.	
129	Ap-A1	0- 35	dark-grey 10YR4/1 (moist) fine sandy loam;friable; apedal; loose; abundant roots; indistinct boundary.
130	IIB11	35- 64	yellowish-brown 10YR5/6 (moist) fine sandy clay; firm; weak medium blocky structure; fine yellowish-red mottles, increasing to medium with depth; frequent hard iron concretions increasing to abundant with depth, attain maximum concentration at 59-64cm; frequent roots; abrupt transition.
131	IIIB22	64-112	dark yellowish-brown 10YR3/4 (moist) clay; friable; moderate blocky, breaking into fine angular structure; shiny ped surfaces (stress cutans or clay skins?) medium to coarse light yellowish-brown mottles (2.5Y6/4); scattered soft Fe-Mn concretions; few roots; clear boundary.
132	IIIC	112+	very pale-brown 10YR7/3 (moist) sandy clay loam; friable; weak platy structure of weathered siltstone of the Middle Ecca Stage.

SOIL TYPE: Highveld pseudo-podzolic soil, intergrade - Fa'

Sample nrs. 143/146

Sample number	Horizon	Depth in cm	Particle size distribution: sand 2 mm-200μ	sand 200μ-50μ	silt 50μ-20μ	silt 20μ-2μ	clay < 2μ	pH H_2O	pH KCl	Organic matter %: C	N	C/N	Cations adsorption complex meq./100 gram: Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
143	Ap	0- 26		69.1	13.2	5.0	12.7	5.9	5.0	0.5	0.05	10.0	3.21	1.52	0.39	0.04	5.2	11.9	43.0	0.34
144	IIB21	26- 57		50.1	12.9	10.4	26.6	6.0	4.8	0.3	0.06	5.0	4.14	2.49	0.82	0.09	6.7	17.3	30.0	0.52
145	IIIB22	57- 81		42.1	17.9	15.9	24.1	6.6	5.3	0.2	0.04	5.0	4.00	3.08	0.91	0.13	8.1	12.8	63.0	1.02
146	IIIC	81-105		49.4	17.5	11.9	21.2	7.0	5.7	0.3	0.05	6.0	4.05	2.79	1.04	0.10	7.9	9.4	84.0	1.08

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
143	50.0	25.4	8.2	1.04	0.98	2.77	88.39	3.32	16.21	2.77	dK^{++} Ml^{+} Mi^{++} Q^{++} F
144	45.6	27.2	9.8	0.84	0.81	3.23	87.48	2.83	12.33	2.31	dK^{++} Ml^{++} Mi^{++} Q^{+} F G
145	43.4	25.4	10.7	0.79	0.72	2.77	83.78	2.90	10.79	2.28	dK^{+} Ml Mi^{++} Q G^{+}
146	45.8	26.3	9.4	0.75	0.97	3.36	86.58	2.93	12.86	2.38	dK^{+} Ml Mi^{++} Q G

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
143	87.5	5.8	2.4	0.47	0.80	0.93	97.90	25.59	96.75	2.98
144	72.7	12.3	7.1	0.56	0.80	1.53	94.99	10.03	27.59	2.52
145	72.0	14.1	6.2	0.60	0.10	1.84	94.84	8.65	31.89	2.31
146	74.1	12.1	4.5	0.57	0.13	1.74	93.14	10.28	43.59	4.59

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500µ-50µ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
143	45	40	15	2	30	tr	5	tr	-	tr	tr	2	tr	-	-	3	-	tr	3	-
144	45	49	3	1	40	2	1	1	-	-	-	1	-	-	-	-	-	1	1	-
145	40	31	1	28	32	1	4	2	tr	-	-	1	tr	-	-	-	-	tr	tr	-
146	19	16	9	38	23	tr	tr	2	-	-	-	2	-	-	tr	3	-	-	7	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
143	69	8	-	13	7	-	-	3	-
144	65	2	-	15	7	-	-	11	-
145	65	3	-	17	6	-	1	8	-
146	52	2	-	16	13	-	1	16	-

Accessories:

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000µ-50µ)

Sieve appertures in mm.	Sample numbers			
	143	144	145	146
1.400	0.5	-	-	-
1.000	0.6	0.3	0.1	0.2
0.840	0.3	0.3	0.1	0.1
0.590	1.1	1.0	0.3	0.3
0.500	1.2	0.9	0.3	0.3
0.420	1.2	0.4	0.2	0.3
0.290	4.0	0.3	1.0	1.1
0.210	7.4	6.0	1.8	2.2
0.150	13.7	10.7	3.1	1.5
0.100	22.4	22.0	8.8	18.3
0.074	25.6	31.5	31.0	42.7
0.050	22.0	26.6	53.3	33.0

Profile number : 143/146
Soil type : Highveld pseudo-podzolic soil, intergrade - Fa'.
Location : Lat. $28^{\circ}07'$, Long. $28^{\circ}21'$ on the farm Trentham 470, Bethlehem district.
Site : cultivated maize field, level (>1% slope) of undulating pediplain.
Rainfall : 625mm.
Elevation : 1550m.
Parent material: 0-57cm: fine sandy loess (two periods of accumulation); 57-105cm: siltstone of the Upper Beaufort Stage (Karroo System).

Sample No.	Horizon	Depth cm.	
143	Ap	0- 26	dark-brown 10YR4/3 (moist) fine sandy loam; friable; apedal to weak blocky; abundant hard iron concretions at 20-26cm; dolerite pebbles; abundant roots; abrupt transition.
144	IIB21	26- 57	yellowish-brown 10YR5/6 (moist) fine sandy loam; very friable; weak medium blocky structure; shiny ped surfaces; diffused yellowish-red mottles; scattered hard and soft Fe-Mn concretions; abundant roots; clear boundary.
145	IIIB22	57- 81	light olive-brown 2.5Y5/6 (moist) loam; friable; moderate blocky structure; shiny ped surfaces; diffused yellowish-brown mottling; few roots; gradual transition.
146	IIIC	81-105	pale-olive 5Y6/3 (moist) loam; friable; weak platy structure of weathered sediments of Upper Beaufort Stage.

SOIL TYPE: Highveld pseudo-podzolic soil - Fa

Sample nrs. 157/161

Sample number	Horizon	Depth in cm	Particle size distribution sand 2 mm-200μ	sand 200μ-50μ	silt 50μ-20μ	silt 20μ-2μ	clay < 2μ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
157	Ap	0- 27		74.2	10.5	5.9	9.4	5.8	4.8	0.6	0.06	10.0	2.63	1.20	0.26	0.04	4.1	12.3	33.0	0.33
158	IIB21	27- 65		49.5	6.3	3.7	40.5	5.9	4.8	0.4	0.06	6.7	8.37	5.71	0.76	0.14	15.0	30.5	49.0	0.46
159	IIB22	65- 84		29.6	7.4	3.1	59.9	6.4	5.1	0.4	0.07	5.7	3.20	11.90	1.12	0.34	16.6	45.8	36.0	0.74
160	IIIC	84-111		39.4	16.6	21.2	22.8	7.3	5.1	0.2	0.03	6.7	22.10	17.00	0.97	0.73	40.8	40.0	100.0	1.83
161	IIICR	111+																		

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
157	58.7	17.6	4.5	2.80	1.35	1.64	86.59	5.65	34.66	3.24	H^+ Ml^{++} Q^{++} F An
158	48.5	22.9	9.1	1.19	0.77	1.22	83.68	3.58	14.16	2.87	dK^+ H^+ Al? Ml^{++} Q^+ F G
159	47.5	20.1	13.7	0.90	0.70	1.08	83.98	4.00	9.19	2.79	dK^+ H^+ Al? Ml^{++} Q F G
160	47.0	21.6	16.2	0.88	0.94	1.09	87.71	3.73	7.71	2.49	H^+ Al? Ml^{++} Mt^+ F
161	-	-	-	-	-	-	-	-	-	-	

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
157	86.5	3.4	8.3	0.70	0.12	0.98	100.00	43.10	51.03	0.64
158	70.0	11.4	12.0	0.78	0.22	1.09	95.49	10.42	20.44	1.48
159	55.5	17.1	11.4	0.82	0.37	1.21	86.40	5.49	10.46	2.35
160	50.0	16.6	13.5	0.52	2.20	1.26	84.08	5.11	8.18	1.92
161	50.9	16.6	9.5	0.67	10.28	0.73	88.68	5.19	14.19	2.72

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
157	46	40	6	5	25	–	1	2	–	–	1	2	tr	–	–	16	–	2	tr	–
158	75	37	6	12	25	tr	1	1	–	1	tr	1	–	–	–	16	–	tr	–	–
159	80	25	6	16	20	–	–	3	–	–	–	3	1	–	–	20	–	1	5	–
160	85	2	2	tr	1	–	–	–	–	–	–	–	–	–	tr	73	–	–	22	–
161	9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	96	–	–	4	–

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
157	71	7	–	tr	12	–	–	10	–
158	74	5	–	–	14	tr	–	7	–
159	57	–	–	–	19	9	–	15	–
160	2	–	–	–	28	32	–	38	–

Accessories:

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers 157	158	159	160
1.400	0.7	1.1	0.4	–
1.000	3.5	2.9	1.8	0.2
0.840	2.1	2.2	2.1	0.3
0.590	6.8	6.3	7.6	1.0
0.500	7.4	8.3	7.5	1.9
0.420	5.9	6.1	5.8	2.4
0.290	14.7	15.9	14.1	4.4
0.210	14.5	15.2	13.9	6.6
0.150	15.4	16.5	15.4	15.1
0.100	15.8	14.2	16.4	26.2
0.074	7.8	6.8	9.2	22.8
0.050	5.4	4.5	5.8	19.1

Profile number : 157/161
Soil type : Highveld pseudo-podzolic soil - Fa.
Location : Lat. 26°35', Long. 29°36' on the farm Klipfontein 422, Bethal district.
Site : disturbed grass-covered (Themeda triandra and Tristachya hispida) headland of maize field, upper slope (2%) of short pediment to minor structural plain formed by dolerite sill.
Rainfall : 700mm.
Elevation : 1670m.
Parent material: 0-27cm: colluvial drift, of material affected by aeolian sorting and dolerite; below 27cm: dolerite with admixture of overlying detritus (mechanism of admixture is argillipedoturbation). Buried vertisol - Da.

Sample No.	Horizon	Depth cm.	
157	Ap	0- 27	very dark-grey 10YR3/1 (dry) fine sandy loam;loose; scattered small Fe-Mn concretions increasing in abundance with depth, attains maximum abundance at25-27cm (associated with dolerite pebbles at this depth); abundant roots;abrupt boundary.
158	IIB21	27- 65	light olive-brown 2.5Y5/4 (dry) fine sandy clay; slightly hard; medium angular blocky structure; medium yellowish-brown mottles;dark stained ped surfaces;scattered fine Fe-Mn concretions;roots present; gradual transition.
159	IIB22	65- 84	dark greyish-brown 10YR4/2 (moist) clay;slightly hard;moderate prismatic, breaking into fine angular blocky structure; shiny ped surfaces (stress cutans);frequent soft Fe-Mn concretions, increasing in abundance with depth, attains maximum abundance at 82-84cm; clear wavy boundary.
160	IIIC	84-112	dark greyish-brown 10YR4/2 (moist) gravelly loam of weathered dolerite;firm;granular structure;medium yellowish-red mottles; gradual boundary.
161	IIICR	112+	light yellowish-brown 10YR6/4 (moist) gravel of weathered dolerite; abundant floaters of hard dolerite fragments.

SOIL TYPE: Highveld pseudo-podzolic soil - Fa

Sample nrs. 182/185

Sample number	Horizon	Depth in cm	Particle size distribution sand 2 mm-200μ	sand 200μ-50μ	silt 50μ-20μ	silt 20μ-2μ	clay < 2μ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
182	Ap-A1	0- 33	74.4		15.4	3.6	6.6	5.4	4.4	0.2	0.03	6.7	3.40	7.44	0.18	-	11.0	5.0	100.0	-
183	A2	33- 48	65.3		16.1	4.5	14.1	6.3	5.0	0.3	0.04	7.5	4.43	0.49	0.27	-	5.2	6.2	84.0	-
184	IIB2	48- 70	19.7		7.4	12.1	60.8	7.2	5.5	0.3	0.07	4.3	1.12	12.60	0.46	0.75	14.9	24.1	62.0	3.11
185	IICg	70-102	22.6		12.0	46.3	19.1	8.3	6.7	0.1	0.04	2.5	14.90	15.80	0.58	1.21	32.5	30.6	100.0	4.86

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
182	57.0	22.1	6.8	1.48	0.91	2.05	90.34	4.37	22.27	3.66	dK^{++} H^{+} Ml Mi^{++} Q^{++} F
183	51.0	23.5	8.2	1.32	1.15	1.96	87.13	3.68	16.53	3.02	dK^{++} H^{+} Ml Mi^{++} Q^{++} F G
184	47.5	27.5	9.0	0.85	0.42	1.66	86.93	2.91	14.03	2.43	dK^{++} H^{+} Ml^{++} Mi F G
185	48.5	26.8	8.4	0.83	0.46	1.83	86.82	3.07	15.33	2.56	dK^{++} H^{+} Ml^{++} Mt^{+} Mi

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
182	90.5	3.5	1.57	0.53	0.80	0.92	97.82	43.87	153.10	3.49
183	85.2	5.5	2.50	0.60	0.10	1.06	94.96	26.28	90.37	3.44
184	57.0	21.4	7.60	0.70	0.22	1.64	88.56	4.51	19.93	4.00
185	60.1	19.1	7.10	0.68	0.30	1.78	89.00	5.33	22.46	4.05

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
182	41	36	23	12	17	-	tr	1	-	tr	tr	2	1	-	-	5	-	1	2	-
183	50	34	29	2	17	-	tr	-	2	-	-	8	2	4	-	2	-	-	-	-
184	71	36	27	2	23	1	-	-	1	1	-	5	2	-	-	tr	-	-	2	tr
185	78	31	15	tr	39	-	tr	3	tr	1	-	6	2	-	-	tr	-	-	1	2

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
182	72	13	-	7	2	-	-	6	-
183	74	13	-	7	-	-	-	6	-
184	80	3	-	13	-	-	-	4	-
185	67	7	-	13	1	-	-	12	-

Accessories:
number 184: Allanite
number 185: Allanite

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers			
	182	183	184	185
1.400	-	-	-	-
1.000	0.2	-	0.4	0.3
0.840	0.1	0.1	0.2	0.2
0.590	0.5	0.3	0.8	0.4
0.500	1.2	0.5	0.7	0.5
0.420	0.7	0.4	0.8	0.6
0.290	3.3	2.7	4.5	3.5
0.210	8.8	8.6	11.2	10.0
0.150	22.0	20.0	20.8	21.0
0.100	29.2	25.5	24.4	24.5
0.074	21.9	23.6	21.8	22.3
0.050	12.0	18.3	14.4	16.7

Profile number : 182/185
Soil type : Highveld pseudo-podzolic soil - Fa.
Location : Lat. 28°25', Long. 27°22' on the farm Rietspruit 935, Senekal district.
Site : cultivated land, less than 2% slope, undulating pediplain.
Rainfall : 625mm.
Elevation : 1520m.
Parent material: 0-48cm: mixed aeolian and colluvial sand (more than one period of drift); below 48cm: mudstone of the Middle Beaufort Series.

Sample No.	Horizon	Depth cm.	
182	Ap-A1	0- 33	dark-brown 10YR4/3 (moist) fine sandy loam; loose; apedal; scattered hard iron concretions; abundant roots; gradual boundary.
183	A2	33- 48	dark-brown 10YR3/3 (moist) fine sandy loam; loose, almost single grain; hard iron concretions, increasing in abundance and size with depth; maximum abundance at 45-48cm; frequnet roots; abrupt transition.
184	IIB2	48- 70	dark greyish-brown 10YR4/2 (moist) clay; firm, plastic; weakly developed prismatic, breaking into angular blocky structure; medium yellowish-brown (2.5Y6/4) mottles; prominent clay skins (mainly stress cutans); scattered soft and hard Fe-Mn concretions; indistinct boundary.
185	IICg	70-102	light olive-brown 2.5Y5/4 (moist) silt loam; firm; moderate medium blocky, breaking into soft equidimentional fine blocky structure; strong yellowish-brown and light bluish-grey mottles; mudstone fragments.

Ⓖ Pseudo Rendzina - Ca

These soils have been described by Van der Merwe (1962) as Kalahari sand on lime. It is typically associated with the fossil calcareous-crusts, the occurrence of which is restricted to extremely level topography or areas with slightly impeded surface run-off and to the western part with a mean annual-precipitation of less than 600 mm. The formation of the soils is associated with the deposition of a relatively thin layer of aeolian sand on the crusts. The main problem with regard to their genesis centers around the origin of the indurated horizon or crust (richer in silicium than the underlying powdery carbonate) which often demarcates the upper part of the crust below the unconformably overlying sand. The fact that this indurated layer is also present at the surface of exposed calcareous crusts calls for restraint in regarding it as of contemporaneous pedogenetic origin.

A conspicuous feature of the landscapes in which these soils are individualized is the presence of closely spaced clusters of low transverse dunes of rather "dunetts". Calcareous crusts are often exposed in the interdune areas.

Profile (28/220) represents an example of an exceptional case where the silicious crust is absent. The fragments of carbonate in the A horizon do not represent concretions but a residue of dissolved carbonate intermingled with aeolian sand.

In view of the factors responsible for the genesis of these soils they had better be regarded as pseudo rendzina. Regosols (Kalahari sand on lime) would probably be equally appropriate for those intergrades where no direct evidence could be found of the indurated layer resulting from a dissolution of carbonate. In a taxonomic classification such as the 7th Approximation these soils could be classified under Mollisols (Rendolls) and in those instances where the indurated crust represents no clear evidence that the indurated crust is to be attributed to contemporaneous pedogenesis (cambic horizon) as a result of burial by aeolian sand, an appropriate taxa could be Thapto Rendollic Hapludent.

Profile number : 218/220
Soil type : Pseudo rendzina - Ca
Location : Lat.26°12', Long. 26°09' on the farm Olivenhoutsfontein 56, Lichtenburg district.
Site : on the side of limestone quarry; level surface of undulating aggradation surface.
Rainfall : 570mm
Elevation : 1479m
Parent material : 0-30 cm; mixture of aeolian sand and fragments of calcareous crust; below 30 cm fossil calcareous crust.

Sample No.	Horizon	Depth cm	
218	A11ca	0-15	dark-brown 7.5YR3/2 (moist) sandy loam; soft; apedal; roots present; rare carbonate fragments; gradual transition.
219	A12ca	15-30	dark-brown 7.5YR3/2 (moist) sandy loam; soft; apedal; frequent carbonate fragments; abrupt transition.
220	IICca	30+	variegated mixture of sand and large chunks of carbonate.

H. Solodized Solonetz - Ma

D'Hoore (1964) gave the following definition of solodized solonetz: "Halomorphic soils with a textural B horizon of columnar structure in the case of solonetz, and with at least one of the B horizons more than 15 per cent saturated with sodium. The upper horizons are generally alkaline except in the solodized solonetz".

Halomorphic soils or solodized solonetz, with characteristics as defined above, occur on lower slopes in association with Highveld pseudo-podzolic soils. This soil type is also characteristically developed on interfluves where it is individualized in patterns which assume similar dimensions and a pattern of distribution as the small deflation basins.

A-horizons are thinner than that of the Highveld pseudo-podzolic soils. The coarse columnar structure and absence of iron concretions or mottles at lithological discontinuities facilitates differentation in the field. All profiles examined and sampled are complex, individual horizons consist of stratified material. Van der Merwe (1962) came to a similar conclusion with regard to soils with solonetzic morphology in the drier parts of the Orange Free State. A-horizons are light textured, vary extremely in thickness and the exchangeable complex contain no sodium. Transitions to B horizons, with typical coarse columnar structures, are abrupt. Ped surfaces of B horizons are dark-stained owing to the deposition of organic matter which are soluble as a result of the high concentration of soluble salt (Seatz, et al., 1964). Soil reaction of A horizons are neutral to slightly acid and that of B horizons fall in the mildly alkaline to strongly alkaline range.

On account of the presence of stratified parent-material it is impossible to decide as to whether these soils are true solonetzes, in a pedogenetic sense, or whether they merely possess solonetz-like morphology(acquired).

In the Highveld Region solodized solonetz are typically individualized on the lower slopes of the unattenuated ephemeral drainage-courses along the escarpments. Away from the escarpments they do not occur in extensive areas but are found in small patches. Typical localities are the small deflation basins and the interridge corridors of areas with less accentuated relief.

Columnar structural-elements of solonetz are contained in the sediments filling ancient gullies along the escarpment. The genetic theory and sequence of events which seems to fit the field evidence is that the accumulation of sodium took place during the periods of formation of the calcareous crusts in the west (Table 6). During these dry periods salt accumulated on the middle and lower slopes of the drainage coarses of ephemeral streams (then wadis) along escarpments and, in a more "intrazonal" sense, in the areas with less accentuated relief. The colluvium which often comprises B horizons are reminescent of desert eluvium. Consequently, the possibility that originally solontchaks were formed does not seem too far-fetched. Neither is an extraneous source for the salt excluded, considering the presence of playa lakes formed by wind deflation to the west. The formation of sterile solontchaks would have rendered the area particularly susceptible to erosion; the gullies formed during subsequent wetter periods. Large-scale incursion of aeolian sand in the form of sandy loess, presumably during post Fauresmith times (Table 6) caused the gullies to be filled with sandy loess. That these conditions may have taken place recurrently is clearly illustrated by the occurrence in superposition of three buried profiles with solonetzic structural-horizons (Plate II). As a consequence of the inimical influence of human activity on the vegetation cover, the loose sediments are at present being removed by gulley erosion and the sterile B horizons of solodized solonetz are exposed by sheet erosion (Plate V).

In consideration of their morphology the solodized solonetz seem to comply, with the exception of the doubtful argillic nature of B horizons and the absence of albic horizons, reasonably well with the minimum requirements of the subgroup Aquolls (Mollisols). The presence of natric horizons would require them to be classified as Natraquolls.

SOIL TYPE: Solodized solonetz - Ma

Sample nrs. 165/168

Sample number	Horizon	Depth in cm	Particle size distribution sand 2 mm–200μ	sand 200μ–50μ	silt 50μ–20μ	silt 20μ–2μ	clay < 2μ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P
165	A1	0- 23	67.4		21.9	5.0	5.7	7.2	6.3	0.5	0.04	12.5	5.12	0.10	0.29	-	5.4	5.2	100.0	-
166	IIB21	23- 45	40.4		18.9	8.0	32.7	8.0	6.3	0.4	0.07	5.7	9.81	3.29	0.16	1.74	15.4	12.5	100.0	13.9
167	IIIB22	45- 75	30.2		13.3	16.5	40.0	9.0	7.4	0.1	0.03	3.3	10.40	5.93	0.53	4.07	21.2	17.2	100.0	23.7
168	IVCR	75+	79.5		11.8	3.9	4.8	8.0	7.9	0.1	tr	-	6.30	0.73	0.83	-	7.7	4.8	100.0	-

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
165	50.7	25.7	9.3	1.29	1.32	2.72	91.03	3.34	14.44	2.72	dK Ml(Mi-Vm)$^+$ Mi^{++} At Q^{++} F
166	47.5	27.2	9.5	0.86	0.78	2.94	88.78	2.95	13.25	2.42	dK$^+$ Ml(Mi-Vm)$^+$ Mi^{++} Q$^+$ F
167	49.2	27.3	8.8	0.84	0.60	3.20	89.94	3.05	14.80	2.53	dK Ml(Chl-Vm-Mi)$^+$ Mi^{++} Q F
168	55.0	26.8	12.3	0.72	1.02	2.52	98.36	3.47	11.84	2.70	Mt^{++} Mi^{++} Q$^+$ F

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
165	88.5	4.3	1.44	0.54	0.18	1.30	96.26	34.78	162.70	4.66
166	75.0	11.6	4.60	0.60	0.18	1.91	93.89	10.96	43.30	3.94
167	63.5	13.4	5.80	0.65	0.98	2.07	86.40	8.03	28.88	3.61
168	87.5	6.2	1.35	0.42	0.26	1.45	97.18	23.94	171.70	7.18

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500µ-50µ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
165	38	33	10	3	35	1	10	1	tr	-	-	3	-	-	-	3	-	tr	1	-
166	73	36	36	2	13	tr	2	4	-	tr	tr	1	-	-	-	3	-	tr	3	tr
167	33	33	1	1	27	tr	2	tr	tr	-	-	-	-	-	-	36	-	tr	tr	-
168	32	28	1	3	52	3	5	3	-	tr	-	tr	-	-	-	tr	-	tr	5	tr

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
165	93	4	-	tr	1	-	-	2	-
166	65	13	-	4	4	5	-	9	-
167	69	12	-	10	5	3	-	1	-
168	85	8	-	4	1	-	-	2	-

Accessories:

number 166: Allanite
Ottrelite

number 168: Diaspore

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000µ-50µ)

Sieve appertures in mm.	Sample numbers			
	165	166	167	168
1.400	-	-	-	-
1.000	0.1	-	-	-
0.840	0.1	-	-	-
0.590	0.2	0.3	0.2	0.1
0.500	0.4	0.5	0.2	0.3
0.420	0.5	0.7	0.4	0.2
0.290	2.5	3.5	2.2	0.3
0.210	4.8	5.8	3.8	1.4
0.150	10.1	11.1	7.9	44.5
0.100	22.8	21.1	27.2	41.3
0.074	32.6	34.1	33.3	10.1
0.050	26.4	22.9	24.8	1.9

Profile number	: 165/168
Soil type	: Solodized solonetz - Ma.
Location	: Lat. 28°15', Long. 28°01' on the farm Grefeld 908, Bethlehem district.
Site	: grass-covered lower slope(2%) of short pediment between the Molteno structural plain and Cave Sandstone mesa.
Rainfall	: 620mm.
Elevation	:1570m.
Parent material	: 0-23cm: sandy loess; 23-45cm:colluvium comprising a mixture of doleritic material and sediments from the Cave Sandstone Stage of the Stormberg Series (see heavy-mineral composition Table 8); 45-75cm: colluvium comprising a mixture of doleritic material and sediments derived from the Transition Beds; below 75cm: sandstone of the Transition Beds.

Sample No.	Horizon	Depth cm.	
165	A1	0-23	pale-brown 10YR6/3 (dry) fine sandy loam; extremely loose; single grain; apedal; abundant roots; abrupt transition.
166	IIB21	23-45	dark-grey 10YR4/1 (dry) clay loam; extremely hard; coarse columnar, breaking to coarse angular blocky structure; rare soft dark-brown Fe-Mn concretions; dark-stained ped surfaces; few roots (restricted to cracks); clear wavy boundary.
167	IIIB22	45-75	pale-olive 5Y6/3 (dry) clay; hard; coarse angular blocky structure; diffused yellowish-brown mottles; scattered fine soft Fe-Mn concretions; scattered artifacts, sandstone, dolerite and agate fragments; clear boundary.
168	IVCR	75+	light grey 5Y7/1 (dry) weathered sandstone of the Transition Beds of the Stormberg Series (Karroo System).

I) Vertisols - Da, Db and Dj

(i) General

D'Hoore (1964, p. 78) gave the following general definition for vertisols:

"Soils with an A_1 horizon, at least 20 cm thick and dark in colour though the organic matter content is usually low. Calcareous accumulations are frequent. Permeability is slow and internal drainage is poor at least at some depth, even though external drainage may be favourable. Profiles show the effect of mechanical reworking such as dry season cracks, slickensides and often by gilgay microrelief. The structure is prismatic or coarse blocky throughout most profiles. The surface horizons have a fine structure. The reserve of weatherable minerals is appreciable. The clay fractions usually consist of 2 : 1 lattice clays, especially montmorillonite and mixed-layer minerals. The cation-exchange capacity is high and is generally more than 50 per cent saturated, mostly with bivalent cations".

In the Highveld Region soils designated on the map and differentiated according to parent material have the following characteristic properties, some profiles with lighter textured A_1 horizons are included in unit Db as intergrades, since the A_1 horizons present colluvium affected by aeolian sorting which is too thin to exert a definite influence on the trend of pedogenesis:

1. They have an A_1, AC, C horizon sequence.
2. Clay minerals consist predominantly of X-amorphous mixed-layered compounds. The clay fractions of A_1 horizons of type Da contain important quantities of spherical amorphous-material (Plate VI).
3. Soil colours are dark, values to a depth of 40 cm range from 5

when dry to 2 when moist. The C/N ratios are not wider than 12.

4. Structure is prismatic or blocky and some dry-season cracks are present. The formation of gilgay microrelief is absent. Judging from from the mineralogy of sand fractions some more extensive churning might have taken place in the past.
5. The clay content of genetic A horizons exceeds 30 per cent.
6. Cation-exchange capacities of genetic horizons is more than 30 meq/100g of air-dried soil for type Da and less than 30 meq/100g for type Db in some instances.
7. The base-exchange complexes (ammonium acetate method) of all horizons are more than 50 per cent saturated, predominantly with calcium and magnesium.
8. No mottling was observed, iron concretions are normally absent. Some profiles, however, do have iron concretions but their presence is clearly not attributable to contemporary genetic processes.
9. Most profiles are characterized by the presence of carbonate.
10. Internal drainage is impeded and permeability slow.
11. Weatherable-mineral reserves are high.
12. Some surface horizons have a fine structure, which resembles self granulation[1].
13. Although not a premise for generalization, since only two samples were subjected to differential dissolution of amorphous substances, the presence of an excess of easily-extractable silica and iron (Table 14) seems a characteristic feature. Extraction does not modify the cation-exchange capacity appreciably because it only affects the aluminium content slightly. The pH dependent

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[1] From a semantic point of view the term "mulching", since no organic matter is involved, is regarded as inappropriate to depict the tendency of some vertisols to form a loose granular surface, or even the tendency of soils to form a granular surface when cultivated.

charges (Table 14) are also indicative of the presence of amorphous components in colloidal fractions. An interesting point of speculation arises as to the properties of amorphous components forming as a result of the co-precipitation of free silica and ferrous oxides (Jackson, 1965). Judging from the importance attached to aluminium in fourfold coordination by Fieldes (1962) and Egawa (1964), in explaining the chemical and physical behaviour of allophane, it is certain that these properties would not be vested in amorphous components formed through a co-precipitation of free silica and ferrous oxides (or manganese). Although highly speculative this aspect may justify further consideration, especially with a view of establishing the origin of the dark colours of vertisols; in spite of their low organic-matter content.

Table 14: (A) Percentages easily-extractable amorphous silicium and sesquioxides of clay fractions and (B) Modification of C.E.C. and pH dependence of C.E.C. (meq/100g) of clay fractions.

A.

Sample no.	% SiO_2	% Al_2O_3	%Fe_2O_3
87 (profile 86/88)	8.3	0.9	6.1
154 (" 154/156)	9.6	1.6	5.8

B.

Sample no.	C.E.C. before extraction		C.E.C. after extr.
	pH7.3	pH8.2	pH7.3
87 (profile 86/88)	60.5	100	57.1
154 (profile 154/156)	80.7	99	70.3

14. A review of the soils, described as black clay soils of tropical and subtropical regions, by Dudal (1963) has once more stressed the fact that the predominant factors determining their genesis are drainage and parent material. The latter usually consist either of highly argillaceous sediments or igneous rocks with a high content of ferromagnesium minerals and plagioclase (Hagenzieker, 1963; Kunze, et al., 1963; Raychaudhur, et al., 1963; Reeve, et al., 1963; Bunting, et al., 1962; Chu, 1962; Roy and Barde, 1962 and Van der Merwe, 1962). The fact that all these authors emphasized the importance of the factors mentioned above, appears to represent impressive evidence of their significance. From a thermodynamic point of view, as a result of the slow permeability, these soils may be regarded as closed systems. As a consequence response to the intensity factors (ectodynamorphic factors) is extremely gradual. As is probable in the Highveld Region some of these soils may predate more-developed associated soils. Considering the principles elucidated by Hjulström (1939) and Bagnold (1960) with regard to the influence of texture on erodibility by water and wind respectively, erosion is likely to have a minimum effect.

(ii) Vertisols, Sensu Lato, on Crystalline Basic Rocks - Da

The group of soils described by Van der Merwe (1962) as "subtropical black clays" show indistinct horizons with A_1, AC and C sequences and originated from the weathering of basic igneous-rocks; dolerite in the Highveld Region. They are clayey, plastic and sticky when wet and extremely hard when dry. Organic matter content, despite the dark colour, is low. Soil reaction ranges from slightly acid in A_1 horizons to alkaline in C horizons. The cation-exchange capacity of clay fractions is above 90 meq/100 g and 30 meq/100 g of air-dried soil. Base saturation of all horizons exceeds 50 per cent. The exchangeable complex is predominantly saturated with bivalent cations: mainly calcium and magnesium. The structure is blocky with weak prismatic tendencies. The soils contain free carbonate in C horizons, either as discrete concretions or white specks of powdery carbonate.

The weatherable-mineral reserves are very high. The pyroxenes consist mostly of pigeonite and the minerals of light fractions, besides some admixed rounded-grains of quartz, are practically dominated by the presence of labradorite and andesine.

Clay fractions contain mixed-layer minerals which exhibit characteristics of what has been described as carderite by MacEwan (1954), though no. 1.53Å line indicating the presence of trioctahedral minerals has been observed. Sudo and Hayashi (1956) described minerals with similar spacings as acid clays. Wilson (1966) investigated the mineral described by MacEwan (1954) and concluded that it behaves rather characteristically like minerals regarded as chloritic intergrades by Jackson (1963). G.F.Walker (1954 - comment on the paper read by MacEwan) reported the wide-spread occurrence of such minerals in soils derived from basic rocks in the north-east of Scotland. Hayashi, et al., (1960) instanced a complexely interstratified vermiculite-chlorite-montmorillonite mineral, occurring in the amygdales of basalt, with similar properties.

The high silicium content, on account of the presence of considerable quantities of easily-extractable amorphous silicium, of colloidal fractions does not reflect the composition of the crystalline components neither does the iron-oxide content (Table 14). The pH dependent charge of the exchangeable complexes (Table 14) is suggestive of the presence of allophane (Jackson, 1964 and Swindale, 1964). The clay fractions of the A_1 horizons of profile 154/155 contain rounded particles (Plate VI) giving a weat diffraction maxima at 7.4Å when heated to 350°C. This maxima disappears when heated to 550°C (Plate VIII). This suggests the presence of halloysite. Further indications of the presence of halloysite and/or allophane is the low-temperature exotherm at approximately 140 - 170°C (Plate X). In Cca horizons the low-temperature exotherm occurs at 200°C and the differential-thermal curve is rather similar to that of beidellite (Plate X). The presence of weak diffraction maxima from 10.0Å to 19.8Å, which do not collapse completely upon heating to 550°C and the absence of a 7.2Å (Plate VIII) points to the presence of interlayer contaminants or chloritic intergrades (Jackson, 1963 and 1965). A feature of the diffraction patterns is the strong hko reflections in contrast to very weak 001 reflections (Plate IX).

In general it may be stated that significant changes were apparent in the degree of crystallinity of clay fractions with depth. Interlayer contamination increases towards the surface,and the presence of halloysite was observed in A_1 horizons. The montmorillonite component of the randomly-interstratified mixed-layer sequence increases with depth (Plate VIII).

The molecular ratios $\frac{SiO_2}{R_2O_3}$ of colloidal fractions are higher than three. Variation of the molecular ratios SiO_2/Al_2O_3 of fine earths with depth are mainly the result of contamination with detritus of sedimentary origin. These ratios of colloidal fractions indicate a slight mobilization of silicium. The variation of Al_2O_3/Fe_2O_3 ratios with depth is suggestive of limited mobilization of iron and its accumulation in AC horizons.

This soil type measures up to the criteria and concepts of vertisols only as far as colour, base saturation, cation-exchange capacity and clay content are concerned. The structure, although the solum is subject to some expansion and the surface layers to some granulation, does not comply completely with the requirements of vertisolic characteristics as defined in the 7th Approximation(and supplements): The obvious reason for this is the advanced stage of weathering of the clay minerals. Similar observations were made with regard to the clay fractions of vertisols in Tanganyika by Anderson (1963). Guerassimov (1962) instanced some allophanic regurs in U.S.S.R. which formed on basic-igneous rocks.

In the event of the vertisols character of this soil group being to sub-ordinate an alternative classification could be degraded vertisols or black-clay soils on dolerite.

According to the 7th Approximation (and supplements) it seems inevitable that these soils should be classified amongst the Mollisols and vertisols, otherwise the weak horizonation would entail a classification as Entisols. Considering the weak tendency to granulate at the surface Grumestert seems the most logical suborder. Profile 19/21, owing to more intensive admixture, also meets the minimum requirements of a Mollisol (Udolls) and could be designated a Vertic Entic Hapludoll to denote the subordinate vertisolic characteristics.

Profile number	: 19/20
Soil type	: Vertisol, sensu lato, on crystalline basic rocks - Da.
Location	: Lat. 27°56', Long. 28°03' on the farm Dankbaar 1242, Sasolburg district.
Site	: upper slope (3%) of slight prominence in gently undulating pediplain, uncultivated Themeda triandra veld.
Rainfall	: 620mm
Elevation	: 1526m.
Parent material	: dolerite with admixture of pediplain drift; below 17 cm: dolerite.

SOIL TYPE: Vertisol, Sensu Lato, on crystalline basic rocks - Da

Sample nrs. 19/21r

Sample number	Hori-zon	Depth in cm	Particle size distribution					pH		Organic matter %			Cations adsorption complex meq./100 gram							
			sand		silt		clay													
			2 mm-200µ	200µ-50µ	50µ-20µ	20µ-2µ	< 2µ	H_2O	KCl	C	N	C/N	Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
19	A11	0- 17	10.8	27.3	10.3	13.1	38.5	6.0	5.1	2.1	0.19	11.1	10.7	13.0	0.81	0.23	24.7	30.9	80.0	0.74
20	IIA12	17- 42	12.1	18.1	9.4	8.4	52.0	7.1	5.7	0.9	0.09	10.0	13.0	16.9	0.58	0.70	31.2	53.6	58.0	1.31
21	IICca	42- 60	41.9	20.6	9.1	7.4	21.0	7.8	6.4	0.5	0.05	10.0	10.7	17.3	0.27	0.46	28.7	24.5	100.0	1.88
21r	IIR	60+																		

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
19	56.5	19.4	10.2	0.94	0.85	1.15	89.04	4.93	14.72	3.70	H^+ Al? Ml(Chl-Vm-Mt-Mi)$^{++}$ Q^+
20	55.0	20.7	10.9	0.81	0.65	0.92	88.98	4.51	13.39	3.35	Al? Ml(Chl-Vm-Mt)$^{++}$ Q
21	54.8	20.2	11.7	0.80	1.40	0.91	89.81	4.59	12.44	3.36	Al? Ml(Chl-Vm-Mt)$^{++}$ Mt^+ Q
21r											

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
19	72.0	9.4	5.6	0.68	1.25	0.82	89.75	12.99	34.02	2.63
20	64.5	13.0	7.7	0.66	1.65	0.81	88.32	8.41	22.06	2.63
21	56.0	14.2	10.2	0.99	6.55	0.66	88.60	6.17	14.59	2.17
21r	52.5	12.6	11.5	0.94	9.75	0.42	87.71	7.06	12.12	1.70

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500µ-50µ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
19	11	8	2	4	2	-	-	-	-	-	-	-	-	-	-	73	-	-	11	-
20	4	tr	tr	tr	tr	-	-	-	-	-	-	-	-	-	-	100	-	-	-	-
21	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	-	-	-	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
19	89	3	-	-	3	-	-	5	-
20	40	-	-	-	24	26	-	10	-
21	10	-	-	-	12	70	-	8	-

Accessories:

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000µ-50µ)

Sieve appertures in mm.	Sample numbers
1.400	
1.000	
0.840	
0.590	
0.500	
0.420	
0.290	
0.210	
0.150	
0.100	
0.074	
0.050	

Sample No.	Horizon	Depth cm.	
19	A11	0-17	very dark-brown 10YR2/2 (dry) clay loam; fine angular blocky structure; mass loosely packed, crumbles readily into fine hard granular fragments (may be regarded as granulation); weakly developed cracks at lower end of horizon; abundant roots; distinct boundary.
20	IIA12	17-42	black 5YR2/1 (dry) clay; hard; weak prismatic, breaking into fine angular blocky structure; weakly developed cracks; abundant fine dolerite grit; few roots; wavy boundary.
21	IICca	42-60	olive-brown 2.5Y5/4 (dry) gritty sandy loam; friable; weatherable dolerite floaters; white mottles of soft carbonate; indistinct boundary.
21r	IIR	60+	hard, loosely packed, partly weathered dolerite.

OIL TYPE: Vertisol, Sensu Lato, on crystalline basic rocks - Da

ample nrs. 94/96r

ample number	Horizon	Depth in cm	Particle size distribution sand 2 mm-200µ	 200µ-50µ	 silt 50µ-20µ	 20µ-2µ	 clay < 2µ	pH H_2O	 KCl	Organic matter % C	 N	 C/N	Cations adsorption complex meq./100 gram Ca	 Mg	 K	 Na	 T.E.B.	 C.E.C.	 % Sat.	 E.S.P.
94	A11	0- 15	11.0	13.5	14.5	13.0	48.0	6.1	5.1											
95	A12	15- 37	16.0	12.4	9.9	12.1	49.6	6.6	5.5											
96	Cca	37- 50	59.0	18.3	10.2	6.7	5.8	7.3	6.0											
96r	R	50+																		

hemical and mineralogical analyses of the clay fraction (< 2 microns).

ample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
94	47.0	16.6	13.7	0.57	0.56	0.52	78.95	4.80	9.11	3.14	H^+ Al? Ml(Chl-Vm-Mt)$^{++}$ F
95	51.0	17.2	12.0	0.59	0.60	0.41	81.80	5.02	11.16	3.49	Al? Ml(Chl-Vm-Mt)$^{++}$ F
96	52.4	13.7	15.4	0.76	1.55	0.90	84.71	6.44	9.04	3.79	Al? Ml(Chl-Vm-Mt)$^{++}$ Chl F^+

hemical analyses of the total soil sample (< 2 mm).

ample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
94	62.5	11.1	7.9	0.93	2.50	0.65	85.58	9.55	21.02	2.28
95	59.3	12.8	9.3	0.89	3.86	0.60	86.75	7.86	16.93	2.15
96	53.3	14.4	10.0	0.83	9.25	0.80	88.58	6.28	14.16	2.25
96r	52.1	14.1	9.7	1.07	9.66	0.55	87.18	6.24	14.27	2.28

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
94	8	3	tr	2	2	-	-	-	-	-	-	-	-	-	-	93	-	-	tr	-
95	3	tr	-	tr	-	-	-	-	-	-	-	-	-	-	-	99	-	-	1	-
96	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	-	-	-	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
94	76	3	-	-	18	tr	-	3	-
95	39	-	-	-	8	42	-	11	-
96	-	-	-	-	3	92	-	5	-

Accessories:

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers
1.400	
1.000	
0.840	
0.590	
0.500	
0.420	
0.290	
0.210	
0.150	
0.100	
0.074	
0.050	

Profile number	: 94/96
Soil type	: Vertisols, sensu lato; on crystalline basic rocks - Da.
Location	: Lat.26°19', Long. 28°40' on the farm Nooitgedacht, Nigel district.
Site	: uncultivated Themeda triandra veld, on level top of low rise formed by dolerite sill.
Rainfall	: 700mm.
Elevation	: 1642m.
Parent material	: fine-grained dolerite (thin sill) with distinct horizontal jointing, intermingled with some colluvium at the surface.

Sample No.	Horizon	Depth cm.	
94	A11	0-15	black 10YR2/1 (dry) clay; hard; well developed fine angular blocky structure which crumbles readily into hard granular fragments (may be regarded as granulation); weak discontinuous surface cracks; many roots; indistinct boundary.
95	A12	15-37	black 5Y2/1 (dry) clay; hard; well developed medium angular blocky structure; narrow discontinuous cracks; no visible slickensides; frequent roots; wavy boundary.
96	Cca	37-50	light olive-brown 2.5Y5/4 (dry) gritty coarse sandy loam; friable; white speckles of powdery carbonate; fragments of unweathered dolerite comprises more than 50 per cent of horizon; indistinct boundary.
96r	R	50+	very hard, loosely packed weathered dolerite, distinct horizontal jointing still discernible.

SOIL TYPE: Vertisol, Sensu Lato, on crystalline basic rocks – Da

Sample nrs. 154/156r

Sample number	Horizon	Depth in cm	Particle size distribution sand 2 mm–200µ	sand 200µ–50µ	silt 50µ–20µ	silt 20µ–2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
154	Ap	0– 20	37.1		10.9	15.5	36.5	6.2	5.0	1.7	0.16	10.6	12.70	14.30	0.70	0.28	28.0	31.3	89.0	0.89
155	A12	20– 55	30.5		10.0	21.0	38.5	7.3	5.9	0.9	0.10	9.0	22.40	37.30	0.59	0.48	60.8	46.5	100.0	1.03
156	Cca	55–125	71.9		7.4	6.4	14.3	8.2	7.1	0.2	0.03	6.7	18.70	20.20	0.26	0.46	39.6	22.8	100.0	2.02
156r	R	125+																		

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
154	48.5	15.5	15.0	0.96	1.25	1.10	82.31	5.31	8.58	3.28	H^+ Al? Ml(Chl-Vm-Mt)$^{++}$ Mt Q
155	51.0	15.8	15.2	0.91	1.40	0.84	85.15	5.48	8.90	3.40	Al$^+$ Ml(Chl-Vm-Mt)$^{++}$ Mt
156	47.5	15.1	15.7	0.71	2.02	0.90	81.93	5.32	8.03	3.21	Al? Ml(Chl-Vm-Mt)$^{++}$ Mt$^+$
156r											

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
154	63.0	12.2	8.9	1.44	2.50	1.29	89.33	8.76	18.82	2.14
155	57.5	13.4	10.8	1.29	2.70	1.26	86.95	7.28	14.14	1.94
156	52.5	14.2	10.2	1.24	8.64	1.10	87.88	6.23	13.66	2.17
156r	51.9	14.1	10.1	1.03	8.81	0.76	86.70	6.23	13.79	2.17

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
154	11	tr	tr	2	tr	-	-	-	-	-	-	tr	-	-	-	98	-	-	tr	-
155	2	tr	-	tr	-	-	-	-	-	-	-	-	-	-	-	100	-	-	tr	-
156	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	98	-	-	2	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
154	31	tr	tr	-	23	42	-	4	-
155	13	-	-	-	30	57	-	-	-
156	1	-	-	-	24	75	-	-	-

Accessories:

GRAIN-SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers
1.400	
1.000	
0.840	
0.590	
0.500	
0.420	
0.290	
0.210	
0.150	
0.100	
0.074	
0.050	

Profile number : 154/156

Soil type : Vertisols, sensu lato, on crystalline basic rocks - Da.

Location : Lat.$26^{\circ}36'$, Long. $29^{\circ}34'$ on the farm Klipfontein 422, Bethal district.

Site : disturbed grass-covered (<u>Themeda triandra</u>) headland of maize field, upper slope (3%) of undulating pediplain.

Rainfall : 700mm

Elevation : 1656m.

Parent material : dolerite with slight admixture of surface drift.

Sample No.	Horizon	Depth cm.	
154	Ap	0-20	black 10YR2/1 (moist) clay loam; slightly hard; coarse angular blocky structure which crumbles readily into coarse granular structure; weak irregular cracks extending to the C horizon; abundant roots; gradual boundary.
155	A12	20-55	very dark-grey 5Y3/1 (moist) clay loam; firm, plastic; weakly prismatic, coarse angular structure; mass crumbles readily into firm angular peds; weakly developed slickensides on ped surfaces; cracks more evenly spaced than in Ap ; frequent roots; clear boundary.
156	Cca	55-125	light olive-brown 2.5Y5/4 (dry) gritty sandy loam; friable decomposed dolerite; white speckles of powdery carbonate; floaters of hard dolerite.
156r	R	125+	hard, loosely packed gravel of partly weathered dolerite.

(iii) Vertisols, Sensu Lato, on Calcareous Rocks - Db and Intergrades (Profile 86/88)

The group of soils, classified as vertisols - Db by Loxton (1962), developed on slightly calcareous argillaceous-sediments of the Karroo System. The problem which arises, and which is probably universally experienced wherever sediments are considered as a basis for the grouping of soils, is the lateral variation within stratigraphic units (facies changes) of lithological and petrographic aspects as well as anisotropy along the vertical axis i.e. bedding. From a consideration of the "Statement of Principles" by the International Subcommission on Stratigraphic Terminology (Hedberg, edit., 1961) it is apparent that, whatever kind of stratigraphic unit is used for the subdivision of sedimentary strata, a considerable latitude of variation is allowed in defining the dominating aspects on which separation from adjacent strata is based. Lithofacies changes within a specific stratigraphic unit over relatively short distances are the rule rather than the exception (Dunbar and Rodgers, 1958). Facies changes are a function of local conditions. Igneous rocks, on the other hand, are classified according to texture and petrography. These variables are functions of the chemical and physical environment and are independent of local conditions. Igneous rocks, being definable within narrow limits, permit more latitude in the appraisement of the effects of the geographical variation of soil-forming factors on profile development.

As a consequence, in a genetic classification, these soils can only be incompletely compared with the soils of the rest of Africa. It seems, however, to meet the minimum requirements of a vertisol as defined by D'Hoore (1964), profile 22/25 and 133/136 in particular. Profile 86/88 evolves towards the Highveld pseudo-podzolic soils and is regarded as an intergrade of vertisols - Db. Differentiation from the Highveld pseudo-podzolic soils is based on the first appearance of concretions or spots of pseudo-gley at lithological discontinuities.

The A_{11} horizons of all profiles examined have been disturbed by extraneous agents. Soil reactions range from strongly acid to medium acid in these horizons. AC horizons are mostly moderately alkaline. The cation-exchange capacity of A_{11} horizons is below 30 meq/100g. Base saturation of all horizons exceeds 50 per cent, excepting A_{11} horizons of the intergrades (Profile 86/88). The exchangeable complexes are predominantly saturated with bivalent cations. Structure of A_{12} horizons ranges from blocky to prismatic, A_{11} horizons often have platy structures. Although some expansion is evident from the structure, such as the loosely-packed structural elements of dry soils in comparison with the massive appearance when wet as well as the development of some dry-season cracks, no slickensides or gilgai microrelief has been observed (Loxton, 1962). Free carbonates, either in the form of powdery covers on ped surfaces or discrete concretions, are always present at depth, Soil colours are dark, chromas of A_{11} horizons are not higher than 2, values are commomly 5 or lower. Colours of A_{12} horizons are even darker with either values or chromas usually one or two units lower than in A_{11} horizons. The percentage carbon and the C/N ratios are similar to that of vertisols - Da.

The weatherable-mineral reserves are high, feldspar of colloidal dimension is a common constituent of clay fractions. Besides feldspar and quartz, the crystalline components of clay fractions are dominated by the presence of mixed-layer minerals. The degree of crystallinity of these minerals are comparable to the mixed-layer minerals occurring in vertisols - Da. Mica is, however, unvariably present as a constituent in the mixed-layer lattices. The mica component increases with depth concomitantly with a decrease in randomness. Qualitative estimation of the relative quantities of mica (see analytical tables) was based on relative intensities of 5.0Å peaks.

Variation in the molecular ratios SiO_2/Al_2O_3 of clay fractions with depth suggest mobilization of colloidal silica. This may, however, also be caused by the weathering-depth function. The clay fraction of one horizon (Profile 86/88) has been subject to selective dissolution of amorphous material. It contained large amounts of easily-extractable amorphous silica and iron (Table 14). Quartz is a prominent constituent of clay fractions of A_{11} horizons. This could be taken as an indication of sesquioxides being mobilized or/and of clay illuviation having taken place. The latter, particularly, since A_{12} horizons commonly have a higher content of clay than A_{11} and AC horizons. Comparison of the molecular ratios of the fine earths, however, show it to be unlikely.

Increases in clay in A_{12} horizons are, mainly, the result of argillification (Scheffer, 1962). Variation of the above mentioned ratios with depth in all profiles examined shows it to be principally a consequence of layering of parent material. Meaning that A_{11} horizons are not strictly autochtonous in origin. Owing to argillipedoturbation the more friable material has been incoporated into the underlying horizons. The heavy-mineral composition of sand fractions supports this contention. The SiO_2/Fe_2O_3 and Al_2O_3/Fe_2O_3 ratios are suggestive of a slight mobilization of iron in A_{12} horizons.

Types Da and Db occur under comparable climatic conditions, in fact often in juxtaposition. Both soils are populated by grass communities in which Themeda Triandra is the dominant species. Topographic positions are comparable as well as internal drainage. It may thus be inferred, with reasonable certainty, that parent material is the controlling factor.

These soils, owing to the absence of slickensides on ped surfaces, gilgai microrelief and prominent cracks do not seem to measure up (exactly) to the diagnostic criteria and concepts of a vertisol as defined in the 7th Approximation (and supplements). Owing to the presence of some cracking at the surface and the weakly developed platy surface-crusts profiles 22/25 and 133/136 could be regarded as a minimal Mazaquert (Udultic Mazaquerts). Profiles 105/108 and 86/88 would not qualify as vertisols. They meet the requirement of Ustolls (Aridic Haplustolls) more accurately.

(iv) Vertisols, Sensu Lato of Topographic Depressions - Dj

This soil type, described by Van der Merwe (1962) as "Highveld Intrazonal Black Clay of Hydrogenic Origin", meets the minimum requirements of a vertisol of the S.P.I. legend. It is predominantly associated with the narrow strips of essentially level flood-plains with poor external drainage behind the sandy levels, along major drainage-courses, dismembered river-channels and unattenuated poorly-defined drainage courses. In terms of map coverage it is only of limited importance and no specific attention has been given to this soil type.

SOIL TYPE: Vertisol, Sensu Lato, on calcareous rocks - Db

Sample nrs. 22/25

Sample number	Horizon	Depth in cm	Particle size distribution: sand 2 mm–200μ	sand 200μ–50μ	silt 50μ–20μ	silt 20μ–2μ	clay < 2μ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram: Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.
22	A11	0- 20	29.6		19.4	18.6	32.4	5.6	4.7	1.4	0.12	11.7	11.3	3.89	0.47	-	15.7	18.8	83.0	-
23	IIA12	20- 70	17.2		12.6	13.5	56.7	6.7	5.6	1.0	0.11	9.9	18.5	13.90	0.51	1.20	34.2	29.0	100.0	4.14
24	IIAC	70-127	13.5		15.6	39.6	31.3	7.8	7.0	0.1	0.02	5.0	19.1	16.20	0.57	1.80	37.7	26.1	100.0	6.90
25	IICca	127-160	6.5		22.9	46.4	24.2	8.2	7.2	0.1	0.03	3.3	18.9	13.30	1.05	1.55	34.7	24.1	100.0	6.43

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
22	56.5	17.2	8.3	1.13	1.43	0.99	85.55	5.56	18.10	4.28	Ml(Mt-Vm-Mi)$^{++}$ Mi Q^{++} F
23	54.5	20.9	8.0	0.71	1.26	2.95	88.32	4.43	18.07	3.56	Ml(Mt-Vm-Mi)$^{++}$ Mi^{+} Q^{+} F
24	57.0	17.8	7.3	0.69	1.45	3.25	87.49	5.42	20.73	4.33	Ml(Mt-Vm-Mi)$^{++}$ Mt^{+} Mi^{+} Q F
25	61.5	16.2	5.5	0.68	1.27	3.20	88.35	6.44	29.71	5.30	Ml(Mt-Vm-Mi)$^{+}$ Mt^{++} Mi^{+} Q F

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
22	77.5	8.4	3.8	0.63	0.36	1.57	92.26	15.64	54.19	3.46
23	69.5	11.7	4.5	0.60	0.86	2.27	89.43	10.08	41.04	4.08
24	69.7	12.6	4.6	0.65	0.92	2.27	90.74	9.38	40.27	4.29
25	55.0	11.3	3.6	0.41	4.50	2.26	77.07	8.24	40.66	4.92

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500µ-50µ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topas	Monazite	Alterites	Accessories
22	59	36	8	6	8	-	-	1	tr	-	tr	16	-	-	-	16	-	3	6	-
23	71	31	10	4	14	tr	tr	1	-	-	-	25	3	-	-	4	-	1	7	-
24	68	30	5	6	20	2	1	-	-	-	-	24	3	-	-	1	-	1	10	-
25	54	30	4	7	18	1	1	-	-	-	2	21	4	-	-	-	-	-	8	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
22	92	4	-	1	-	-	-	3	-
23	92	5	tr	-	-	-	-	3	-
24	93	4	1	-	-	-	-	2	-
25	58	8	-	2	2	-	-	20	-

Accessories:

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000µ-50µ)

Sieve appertures in mm.	Sample numbers			
	22	23	24	25
1.400	-	-	-	-
1.000	-	0.8	1.0	1.2
0.840	0.5	0.7	2.0	0.8
0.590	0.5	2.6	2.4	2.4
0.500	1.6	3.1	2.6	2.4
0.420	1.8	2.7	2.0	1.9
0.290	6.7	7.9	8.3	8.4
0.210	10.0	11.5	11.4	11.8
0.150	16.2	17.4	17.4	17.5
0.100	18.2	19.6	19.3	19.7
0.074	29.1	17.6	17.5	17.6
0.050	15.4	16.1	16.1	16.3

Profile number : 22/25

Soil type : Vertisol, sensu lato, on calcareous rocks - Db.

Location : Lat.27°58', Long. 28°06' on the farm Verdun 674, Sasolburg district.

Site : uncultivated Themeda triandra veld, upper slope (3%) of slight rise in gently undulating pediplain.

Rainfall : 620mm.

Elevation : 1522m.

Parent material: 0-20cm: pediplain drift; below 20cm: mudstone of the Middle Ecca Stage (Karroo System).

Sample No.	Horizon	Depth cm.	
22	A11	0 - 20	dark-grey 10YR4/1 (dry) clay loam; slightly hard; medium platy, breaking to fine platy structure; weak irregular surface cracks; abundant roots; clear boundary.
23	IIA12	20 - 70	black 5Y2/1 (dry) clay; very hard; coarse blocky structure; frequent roots which are restricted to openings between structural elements; gradual boundary.
24	IIAC	70 -127	light olive-grey 5Y6/2 (moist) clay loam; hard; coarse angular blocky structure; gradual boundary.
25	IICca	127 -160	light olive-brown 2.5Y5/4 (moist) silt loam; slightly hard; weak blocky structure; frequent carbonate concretions and pockets of powdery carbonate; frequunt concoidal and platy mudstone fragments; gradual boundary.
	IIR	160+	pale olive-grey, loosely packed concoidal mudstone fragments and pockets of powdery carbonate.

SOIL TYPE: Vertisol, Sensu Lato, on calcareous rocks - Db

Sample nrs. 105/108

Sample number	Horizon	Depth in cm	Particle size distribution sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
105	Ap	0- 20	44.7		9.9	21.1	24.3	5.1	4.1	1.4	0.12	10.0	6.11	3.02	0.51	-	9.7	17.9	54.1	2.23
106	IIA12	20- 65	22.0		9.0	21.7	47.3	6.8	5.6	1.0	0.11	7.5	22.40	9.12	0.95	1.34	33.9	33.9	100.0	3.37
107	IIACca	65-128	18.7		16.4	42.9	22.0	8.0	6.6	0.1	0.02	3.3	21.30	11.60	1.40	1.95	36.3	30.6	100.0	4.70
108	IICR	128-160	8.2		14.4	49.8	27.6	7.9	6.7	0.1	0.03	5.0	22.40	11.20	1.30	2.00	37.0	41.5	89.0	4.80

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
105	57.0	18.8	7.7	1.17	1.02	2.10	87.79	5.14	19.66	4.09	dK Ml(Chl-Vm-Mt-Mi)$^{++}$ Mi^{+} At Q^{++} F
106	52.7	21.4	9.1	0.78	1.20	2.08	87.26	4.17	15.39	3.28	dK Ml(Chl-Vm-Mt-Mi)$^{++}$ Mi^{+} At Q^{+} F
107	51.5	18.8	8.6	0.75	1.04	2.46	83.15	4.65	15.89	3.60	Ml(Chl-Vm-Mt-Mi)$^{++}$ Mi At Q^{+} F
108	53.5	20.4	8.5	0.72	0.84	2.56	86.52	4.44	16.71	3.52	Ml(Chl-Vm-Mt-Mi)$^{++}$ Mi At Q F

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
105	81.5	6.4	3.2	0.59	0.16	0.98	92.83	21.55	67.50	3.13
106	68.0	14.1	6.2	0.63	0.36	1.42	90.71	8.18	28.97	3.55
107	68.0	14.1	5.8	0.66	0.55	1.90	91.01	8.18	31.09	3.80
108	62.5	16.2	6.5	0.66	0.66	2.55	89.07	6.48	25.54	3.75

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
105	68	48	5	3	18	2	1	2	tr	-	-	5	tr	-	-	10	-	2	4	-
106	60	36	18	7	15	2	tr	2	3	-	tr	8	4	-	-	3	-	1	3	-
107	54	36	9	13	18	1	2	1	1	-	1	5	9	-	-	-	-	-	3	tr
108	55	35	10	12	10	5	1	5	1	-	3	6	7	-	-	-	-	-	5	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
105	87	7	1	1	-	-	-	4	-
106	97	1	tr	tr	-	-	-	2	-
107	78	5	-	1	-	-	-	16	-
108	58	11	-	2	-	-	-	29	-

Accessories:
number 107: Ottrelite.

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers 105	106	107
1.400	-	-	-
1.000	1.1	-	-
0.840	0.4	2.2	2.2
0.590	0.6	9.0	9.0
0.500	1.5	0.4	0.2
0.420	1.9	2.2	1.7
0.290	8.2	8.5	6.6
0.210	12.7	11.2	10.8
0.150	15.7	14.7	14.0
0.100	18.7	17.0	17.2
0.074	21.2	17.8	17.9
0.050	18.0	17.0	20.4

Profile number : 105/108

Soil type : Vertisol, sensu lato, on calcareous rocks - Db.

Location : Lat. 27°05', Long. 27°52' on the farm Boomplaas, Heilbron district.

Site : disturbed headland of maize field (natural vegetation *Themeda triandra* grass-veld), level surface of extensive pediplain, somewhat impeded surface run-off.

Rainfall : 620mm.

Elevation : 1500m.

Parent material: 0-20cm: pediplain drift; below 20cm: mudstone of Middle Ecca Stage (Karroo System).

Sample No.	Horizon	Depth cm.	
105	Ap	0-20	greyish-brown 10YR5/2 (moist) fine sandy loam; loose; structureless; abundant roots; clear boundary.
106	IIA12	20-65	very dark-grey 10YR3/1 (moist) clay; hard; coarse blocky, with tendency towards prismatic, structure; narrow irregular cracks; frequent roots; indistinct boundary.
107	IIACca	65-128	light olive-grey 5Y6/2 (moist) silt loam; firm; medium angular blocky structure; irregular cracks; scattered greyish-brown, some with white powdery carbonate coatings, hard silicious concretions; frequent concoidal mudstone-fragments; indistinct transition.
108	IICR	128-160	pale-olive 5Y6/3 (dry) gravelly silt loam; very hard; loosely packed mudstone fragments comprise more than 50 per cent of the horizon.
	R	160+	pale-olive 5Y6/3 (dry) loosely-packed concoidal carbonaceous-mudstone.

SOIL TYPE: Vertisol, Sensu Lato, on calcareous rocks - Db (intergrade)

Sample nrs. 86/89

Sample number	Horizon	Depth in cm	Particle size distribution sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
86	A1	0- 19	33.9	41.8	9.1	4.6	10.6	5.4	4.1	0.5	0.06	8.3	2.42	0.77	0.23	0.04	3.46	12.80	27.81	0.31
87	IIA12	19- 44	25.4	27.7	6.2	7.1	33.6	8.0	6.3	0.4	0.06	6.7	7.94	9.62	0.78	1.91	20.25	28.20	71.80	6.77
88	IIACca	44- 70	26.9	24.9	5.5	5.1	37.6	8.6	7.1	0.1	0.03	3.3	9.33	10.20	1.07	3.55	24.15	33.30	72.52	10.70
89	IIICR	70+	54.5	28.3	3.5	6.0	7.7	9.2	7.6	-	-	-	-	-	-	-	-	-	-	-

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
86	56.0	20.7	9.1	1.62	0.82	0.65	88.89	4.58	16.40	3.58	dK$^+$ H Ml(Chl-Vm-Mt-Mi)$^{++}$ At Q^{++} F
87	44.7	24.2	13.3	0.88	0.30	1.26	84.64	3.13	8.90	2.32	Chl Al Ml(Chl-Vm-Mt-Mi)$^{++}$ Q F
88	47.3	24.5	12.0	0.86	0.32	1.51	86.49	3.33	10.44	2.50	Chl Ml(Chl-Vm-Mt-Mi)$^{++}$ Q F
89	50.9	27.2	5.9	0.57	1.30	3.35	89.22	3.17	22.91	2.79	Chl Mi^{++} Ml(Chl-Vm-Mi)$^+$ Q C F

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
86	88.1	4.3	2.8	0.50	0.04	0.93	96.67	34.75	83.62	2.39
87	76.5	10.4	5.9	0.54	0.15	1.04	94.53	12.47	34.44	2.75
88	76.4	10.0	8.0	0.55	0.38	1.34	96.67	12.96	25.38	1.96
89	75.2	11.2	10.6	0.30	0.38	2.30	99.98	11.38	18.84	1.64

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
86	55	51	8	12	18	–	–	1	–	–	–	–	–	–	–	3	–	4	3	tr
87	58	33	7	26	25	–	1	1	1	–	–	tr	–	–	–	1	–	5	tr	–
88	44	20	10	26	14	1	9	6	–	–	–	2	–	–	–	3	–	9	tr	tr
89	2	4	1	72	2	tr	9	3	–	–	–	–	–	–	–	–	–	tr	9	tr

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
86	88	8	–	1	1	–	–	2	–
87	81	13	–	3	1	–	–	2	–
88	71	11	tr	7	1	–	–	10	–
89	52	11	1	5	1	–	4	26	–

Accessories:
number 86: Chlorite
number 88: Xenotime
number 89: Xenotime

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers			
	86	87	88	89
1.400	–	–	1.2	–
1.000	1.0	1.2	2.8	0.6
0.840	1.2	1.4	1.3	0.8
0.590	5.6	5.5	5.2	4.3
0.500	6.6	6.6	6.5	8.9
0.420	5.8	10.4	6.0	9.5
0.290	16.6	16.2	17.5	26.8
0.210	17.2	16.9	18.6	24.3
0.150	18.9	16.5	16.8	13.1
0.100	15.1	13.8	13.0	6.8
0.074	6.1	7.6	7.3	3.0
0.050	5.6	3.8	4.0	1.9

Profile number : 86/89

Soil type : Vertisol, sensu lato, on calcareous rocks - Db (Intergrade).

Location : Lat.26°22', Long. 29°04' on the farm Kwaggaslaagte 91, Bethal district.

Site : uncultivated *Themeda triandra* veld, on level top of slight rise in gently undulating pediplain, less than 2 per cent slope.

Rainfall : 700mm

Elevation : 1660m.

Parent material: 0-19cm: colluvium affected by aeolian sorting; 19-70cm: colluvium; below 70cm: sediments of the Middle Ecca Stage (Karroo System).

Sample No.	Horizon	Depth cm.	
86	A11	0-19	greyish-brown 2.5Y5/2 (dry) fine sandy loam; loose, almost single grain; abundant roots; abrupt transition.
87	IIA12	19-44	very dark-grey 2.5Y3/1 (dry) fine sandy clay; very hard; prismatic, breaking into coarse angular blocky structure; dark stained ped surfaces; few roots, restricted to cracks between structural units, wavy boundary.
88	IICca	44-70	greyish-brown 2.5Y5/2 (dry) sandy clay; firm; coarse blocky structure; dark stained ped surfaces; frequent hard iron concretions; dolerite floater; soft powdery carbonate concretions; abrupt boundary.
89	IIICR	70+	very pale-brown 10YR8/3 (dry) loamy fine sand; friable; structureless; highly weathered argillaceous sandstone.

SOIL TYPE: Vertisol, Sensu Lato, on calcareous rocks - Db

Sample nrs. 133/136

Sample number	Horizon	Depth in cm	Particle size distribution: sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
133	A11	0- 22	5.4	32.2	14.3	15.6	32.5	5.4	4.4	1.1	0.11	10.0	9.24	3.51	-	0.02	12.8	17.4	73.6	0.11
134	IIA12	22- 60	4.2	20.5	8.1	9.7	57.5	5.9	4.6	0.4	0.04	10.0	13.70	6.91	1.08	0.02	21.7	25.3	85.8	0.08
135	IIACca	60-103	3.9	17.5	9.3	16.8	52.5	8.0	7.0	0.2	0.05	4.0	21.30	13.50	0.47	0.42	35.7	24.1	100.0	1.74
136	IICca	103-129	-	-	-	-	-	8.3	7.2	0.1	0.04	2.5	18.70	9.76	0.82	0.22	29.5	24.6	100.0	0.89

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
133	73.7	9.1	4.9	0.74	0.41	1.58	90.43	13.73	39.97	2.89
134	63.2	14.9	5.0	0.62	0.55	2.31	86.58	7.19	33.59	4.54
135	63.6	14.8	6.6	0.61	1.72	2.12	89.45	7.28	25.62	3.50
136	30.5	8.8	3.3	0.14	28.20	1.35	72.29	5.80	24.56	3.69

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500µ-50µ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
133	68	22	7	17	13	-	-	-	-	1	1	10	-	5	-	3	-	-	21	-
134	60	31	4	22	10	-	-	tr	-	tr	tr	10	-	2	-	6	-	tr	15	-
135	60	37	4	18	9	-	-	3	1	1	1	8	-	-	-	8	-	tr	10	-
136	55	36	5	13	9	1	tr	2	tr	tr	tr	8	-	-	-	9	-	tr	15	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
133	66	20	2	5	tr	-	-	6	1
134	69	22	-	3	1	-	-	5	-
135	64	19	tr	5	1	-	-	10	1
136	62	18	2	7	2	-	-	9	-

Accessories:

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000µ-50µ)

Sieve appertures in mm.	Sample numbers 133	134	135
1.400	-	-	-
1.000	0.6	0.6	0.1
0.840	0.3	0.4	0.6
0.590	0.8	1.5	1.8
0.500	1.3	1.8	1.8
0.420	1.3	1.8	1.8
0.290	4.9	5.8	5.6
0.210	8.2	9.0	9.1
0.150	16.9	16.7	17.4
0.100	33.0	31.5	33.8
0.074	17.7	18.9	17.4
0.050	15.0	12.0	10.6

Profile number : 133/136
Soil type : Vertisol, sensu lato, on calcareous rocks - Db.
Location : Lat. 26°55', Long.28°37' on the farm Hartebeestfontein 637, Heidelberg district.
Site : uncultivated verge of maize field, covered with practically pure stands of Themeda triandra. Level top of low rise in undulating pediplain.
Rainfall : 650mm.
Elevation : 1590m.
Parent material: siltstone of the Middle Ecca Stage with large oval blocks of septarian carbonate.

Sample No.	Horizon	Depth cm.	
133	A_{11}	0 - 22	very dark greyish-brown 10YR3/2 (moist) clay loam; friable; weak platy structure; narrow surface cracks; abundant roots; gradual boundary.
134	IIA_{12}	22- 60	black 10YR2/1 (moist) clay; slightly hard, plastic; coarse blocky structure; narrow cracks; frequent roots; gradual boundary.
135	IIACca	60-103	olive-brown 2.5Y4/4 (moist) clay; firm; coarse blocky structure; scattered pockets of soft carbonate; frequent small fragments of siltstone; large oval blocks of septarian carbonate; few roots; gradual boundary.
136	IICca	103-129	light-grey 10YR7/1 (moist) gravelly silt loam; abundant siltstone fragments cemented by massive lime; large oval blocks of septarian carbonate comprises more than 70 per cent of horizon.

J. Mineral Hydromorphic Soils - Na

Considerable tracts of the Highveld Region are characterized by the occurrence of soils having free-water for most part of the year, albeit a period of intense desiccation ranging from midwinter to early summer. The hydromorphic soils are individualized in topographic depressions and unattenuated drainage ways resulting from the inundation of fossil depressions by aeolian sand. There are, however, no swamps. In view of the extremely level topography this is surprising. The profusion on it of (Imperata cylindrica (L) Beauv var. Africana (Anders) and other water-loving plants is indicative of hydromorphic conditions severe enough to exert inhibiting influences on plant growth (Chippendall, 1956).

Besides the above mentioned properties, another extremely detrimental characteristic is its susceptibility to wind erosion. Sand mobilized by aeolian activity is blown into small dunes, imparting a rather hummocky appearance to the topography and giving rise to the formation of yellowish-brown regosolic sands - Bq. As a consequence of recurrent seasonal-disturbances at the surface by aeolian activity A horizons, besides being usually extremely variable in thickness, have little diagnostic value. B-horizons, in all profiles examined, consist predominantly of buried layers comprising either the weathering products of autochtonous rocks or colluvium. Chromas of B horizons are commonly around one. Another feature is the presence of coarse mottles and stains as well as iron concretions at lithological discontinuities. Structures, like those in the Highveld pseudo-podzolic soils are apparently dependent upon the type of buried horizon. Both the Highveld pseudo-podzolic soils - Fa and yellowish-brown fersiallitic soils - Ja interdigitate into this soil type.

Correlation according to the 7th Approximation presents a decided enigma owing mainly to the constant mobilization at the surface. The absence of diagnostic A horizons require them to be classified as Entisols. In view of the evidence of wetness and sandy textures they would seem to fall in the great group Psamments (Aquipsamments).

SOIL TYPE: Mineral hydromorphic soil - Na

Sample nrs. 8/11

Sample number	Horizon	Depth in cm	Particle size distribution sand 2 mm-200μ	sand 200μ-50μ	silt 50μ-20μ	silt 20μ-2μ	clay < 2μ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
8	Ap	0- 29	91.1		3.2	3.8	1.9	5.1	4.4											
9	A2	29-124	87.8		3.6	1.2	7.4	5.0	4.4											
10	IIB2G	124-164	59.7		4.7	4.3	31.3	5.9	4.9											
11	IIICG	164+	41.8		16.0	23.8	18.4	6.3	4.7											

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
8	55.5	19.7	7.6	0.88	1.74	0.80	86.22	4.76	19.40	3.85	dK^{++} H Ml Q^{++} G
9	44.2	26.2	11.2	0.98	2.06	0.85	85.49	2.81	10.42	2.22	dK^{++} H Ml Q^{++} G
10	41.5	25.2	10.0	0.85	1.04	0.76	79.35	2.78	11.03	2.24	dK^{+} H^{+} Al? Ml^{++} G^{+}
11	42.0	27.1	9.8	0.70	1.10	0.66	81.36	2.61	11.37	2.14	dK^{+} H^{+} Al? Ml^{++} G

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
8	89.5	2.7	1.46	0.31	0.09	0.31	94.37	56.25	162.93	2.89
9	91.0	3.0	1.60	0.42	0.05	0.34	96.41	51.42	151.16	2.93
10	75.6	10.8	6.30	0.56	0.12	0.46	93.84	11.86	31.63	2.68
11	53.3	19.2	13.10	1.04	1.44	0.62	88.70	4.68	10.73	2.28

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500μ-50μ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
8	55	22	18	1	12	1	-	2	tr	-	1	4	-	-	-	26	-	3	10	-
9	57	19	16	1	21	1	-	-	-	-	3	tr	-	2	-	26	-	5	6	tr
10	70	32	18	4	28	2	1	-	-	-	3	3	-	2	-	1	-	3	3	tr
11	55	3	tr	-	1	-	tr	-	-	-	-	-	-	-	-	90	-	tr	6	-

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
8	93	4	-	2	1	-	-	-	-
9	82	8	4	1	2	-	-	2	1
10	72	5	-	tr	13	3	2	3	2
11	9	-	-	-	8	13	5	65	-

Accessories:
number 9: Lawsonite
number 10: Green Spinel

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000μ-50μ)

Sieve appertures in mm.	Sample numbers			
	8	9	10	11
1.400	-	-	-	-
1.000	0.6	-	0.1	-
0.840	0.6	-	0.1	0.1
0.590	0.3	0.4	0.5	0.4
0.500	0.7	1.3	1.1	0.6
0.420	1.2	1.3	1.7	0.9
0.290	8.7	7.6	9.9	4.6
0.210	24.0	23.4	25.6	17.9
0.150	31.3	31.8	31.1	15.8
0.100	20.2	20.7	17.7	15.1
0.074	7.6	8.9	7.6	18.0
0.050	4.5	4.6	4.6	26.6

Profile number : 8/11

Soil type : Mineral hydromorphic soil - Na.

Location : Lat.26°46', Long. 28°00' on the farm Modderfontein 1311, Sasolburg district.

Site : cultivated land; extremely level aggradation surface with isolated low hummocks; recent wind-blown sand accumulated against fence about 20 meters from sample site.

Rainfall : 650mm.

Elevation : 1500m.

Parent material: 0-124cm: aeolian sand; 124-164cm: aeolian sand and colluvium intermingled with dolerite (mechanism of admixture is apparently argillipedoturbation); below 164cm: dolerite.

Sample No.	Horizon	Depth cm.	
8	Ap	0 - 29	greyish-brown 10YR5/2 (moist) fine sand; loose; single grain; abundant roots; gradual transition.
9	A2	29-124	yellow 10YR7/6 (moist) fine sand; loose; apedal; frequent large iron concretions, which increase in abundance with depth; scattered quartzite pebbles at 120-24cm; few roots; free water; abrupt transition.
With auger			--
10	IIB2G	124-164	light-grey 10YR7/1 (moist) fine sandy clay loam; friable; weak medium blocky structure; coarse yellowish-brown and bluish-grey mottles and stains; scattered soft Fe-Mn concretions; gradual transition; free water.
11	IIICG	164+	pale-olive 5Y6/3 (moist) silt loam; friable; massive with weak granular structure; coarse bluish-grey mottles and fine yellowish-brown mottles; free water.

SOIL TYPE: Mineral hydromorphic soil - Na

Sample nrs. 174/177

Sample number	Horizon	Depth in cm	Particle size distribution sand 2 mm-200µ	sand 200µ-50µ	silt 50µ-20µ	silt 20µ-2µ	clay < 2µ	pH H_2O	pH KCl	Organic matter % C	N	C/N	Cations adsorption complex meq./100 gram Ca	Mg	K	Na	T.E.B.	C.E.C.	% Sat.	E.S.P.
174	A1	0- 30	84.8		8.7	2.3	4.2	5.0	4.3											
175	A2	30- 89	88.0		9.2	1.3	1.5	5.2	4.6											
176	IIB2G	89-107	43.1		15.5	6.6	34.8	5.8	4.5											
177	IIICG	107+	70.3		15.3	5.1	9.3	6.7	6.3											

Chemical and mineralogical analyses of the clay fraction (< 2 microns).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{R_2O_3}$	Clay minerals:
	in weight percentages										
174	48.0	23.5	7.7	1.10	1.30	2.10	83.70	3.5	16.6	2.87	dK^{++} Ml Mi^{+} Q^{++}
175	48.4	25.3	7.5	1.10	1.05	2.38	85.73	3.2	17.1	2.73	dK^{++} Ml Mi^{+} Q^{++}
176	47.0	27.1	10.2	0.91	1.01	2.13	88.35	2.9	12.2	2.37	dK^{+} Ml^{+} Mi^{+} Q^{+} G^{+}
177	51.0	24.1	5.5	0.82	1.69	2.53	86.64	3.6	24.6	3.26	Ml^{++} Mi^{+} Q^{++}

Chemical analyses of the total soil sample (< 2 mm).

Sample number	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	Total	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Al_2O_3}{Fe_2O_3}$
	in weight percentages									
174	88.0	4.2	1.05	0.34	0.06	1.16	94.81	35.52	222.76	6.32
175	91.0	3.3	0.70	0.31	0.06	1.17	96.54	46.73	345.53	7.40
176	76.0	11.5	8.60	0.59	0.14	1.71	98.54	11.26	23.45	2.15
177	80.5	5.4	8.90	0.31	0.12	2.03	97.26	25.37	23.91	1.00

MINERALOGICAL ANALYSES OF THE SAND FRACTION (500µ-50µ)

Heavy mineral analyses.

Sample number	Opaque	Zircon	Tourmaline	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Epidote	Zoisite	Clino-zoisite	Hornblende	Clino-pyroxene	Topaz	Monazite	Alterites	Accessories
174	37	53	15	tr	18	tr	6	1	tr	–	–	–	–	–	–	3	–	–	4	tr
175	35	55	17	tr	20	tr	5	1	–	–	–	tr	–	–	–	–	–	–	2	–
176	60	30	21	3	27	1	8	1	1	tr	tr	–	–	–	tr	5	–	1	2	–
177	45	14	60	3	8	1	10	tr	tr	tr	tr	tr	tr	–	–	3	tr	tr	1	–

Light mineral analyses.

Sample number	Quartz	Orthoclase	Microcline	Soda-plagioclase	Intermediate-plagioclase	Basic-plagioclase	Mica	Weathering-products	Chert
174	82	16	–	1	–	–	–	1	–
175	86	13	–	–	1	–	–	–	–
176	86	14	–	–	–	–	–	–	–
177	79	17	–	–	–	–	–	4	–

Accessories:

number 174: Xenotime

GRAIN SIZE DISTRIBUTION OF THE SAND FRACTION (2000µ-50µ)

Sieve appertures in mm.	Sample numbers 174	175	176	177
1.400	–	–	–	–
1.000	–	–	–	–
0.840	–	–	–	–
0.590	–	–	–	0.2
0.500	–	–	–	0.1
0.420	–	–	–	0.1
0.290	0.2	0.2	0.2	0.3
0.210	0.3	0.3	0.5	0.4
0.150	1.2	1.1	1.2	2.6
0.100	14.8	15.0	19.6	32.9
0.074	68.0	63.3	53.5	53.0
0.050	15.5	20.1	25.0	10.4

Profile number : 174/177
Soil type : Mineral hydromorphic soil - Na.
Location : Lat. 28°15', Long. 28°01' on the farm Grefeld 908, Bethlehem district.
Site : grass-covered (<u>Imperata cylindrica</u>) hollow on the top of mesa formed by Cave Sandstone.
Rainfall : 620mm
Elevation : 1750m.
Parent material : 0-89cm: loess; 89-107cm: intermingled loess, sandstone and colluvium; below 17cm: sandstone of Cave Sandstone Stage (Stormberg Series, Karroo System).

Sample No.	Horizon	Depth cm	
174	A1	0-30	yellowish-brown 10YR5/6 (moist) fine sand; loose; single grain; abundant roots; gradual transition.
175	A2	30-89	yellow 10YR7/6 (moist) fine sand; loose; apedal; medium yellowish-brown mottles; free water; abrupt transition.
With auger			--
176	IIB2G	89-107	light-grey 10YR7/1 (moist) clay loam; firm; apedal; coarse yellowish-brown and bluish-grey mottles; free water; indistinct transition.
177	IIICG	107 +	very pale-brown 10YR7/3 (moist) fine sandy loam; coarse yellowish-brown and bluish-grey mottles; free water.

K. Yellow-brown Regosolic Sand - Bq

The name is self-explanatory. This soil type with no diagnostic horizons, except for some reddish-brown mottles at depth is associated in the landscape with mineral hydromorphic soils - Na. The susceptibility of the hydromorphic soils to wind erosion explains the association. Included in this category are the relatively recent accumulations of aeolian sand along the Vaal River.

Entisolic identity is more clearly apparent than in the associated hydromorphic soils. In view of the sandy texture an appropriate sub-order seems to be the Psamments (Quartzipsamment).

Profile number : 226/233
Soil type : Yellow-brown regosolic sand - Bq.
Location : Lat. 27°30', Long. 26°30' on the farm Goede Hoop 227, Bothaville district.
Site : lower slope (1.5%) of depression with impeded external drainage; hydrophytic grass (*Imperata cylindrica*).
Rainfall : 600mm.
Elevation : 1300m.
Parent material: aeolian sand, recently redistributed; below 130cm: Karroo mudstone.

Sample No.	Horizon	Depth cm.	
226	A11	0 - 20	dark-brown 7.5YR4/4 (moist) sand; loose; apedal; abundant roots; gradual transition.
227	A12	20- 40	yellowish-brown 10YR5/4 (moist) sand; loose; apedal; abundant roots; gradual transition.
228	C11	40- 60	brownish-yellow 10YR6/6 (moist) sand; loose; apedal; rare fine strong-brown mottles; frequent roots; gradual transition.
229	C12	60- 80	brownish-yellow 10YR6/8 (moist) sand; loose; apedal; rare fine strong-brown mottles; frequent roots; gradual transition.
230	C13	80-100	yellow 10YR7/8 (moist) sand; loose; apedal; rare fine strong-brown mottles; roots rare; gradual boundary.
231	C14	100-120	variegated yellow (10YR7/8) and white (2.5Y8/2) (moist) sand; friable; apedal; common strong-brown mottles; rare soft Fe-Mn concretions; gradual transition.
232	C15g	100-130	variegated yellow (10YR7/8) and white (2.5Y8/2) (moist) sand; friable; apedal; common strong-brown mottles; rare soft Fe-Mn concretions; abrupt transition.
233	IIC16G	130-140	light brown-grey 2.5Y6/2 (moist) sandy clay; very firm; plastic; weak coarse blocky structure; frequent soft Fe-Mn concretions; many strong mottles.

L. Juvenile Soils on Recent Sediments - Bo

The uniform, weakly stratified, rather well-drained alluvial soils associated with the narrow strips of sandy levees along river banks meets the minimum requirements as defined by D'Hoore (1964). The limited areal-extent of these soils, however, does not permit them to be differentiated on even large scale maps. Of more importance, though not of recent origin, are the regosols associated with sandy loess which covered the ancient gullies along the escarpment demarcating the transition from the African surface to the remnants of the Gondwana surface south of Bethlehem (Map 3, in pocket).

These soils may also be considered to belong to the Entisols, and in view of the absence of features indicating impeded drainage as well as the fine texture (sandy loess) they seem to meet the minimum requirements of the great group of the Ustifluvents fairly accurately.

M. Lithosols and Litholic Soils - Bd, Bc, Bc', Bd and Bd'

All soils with a depth of less than 30 cm to solid rock as well as unweathered rock are included under this category. Differentiation is according to rock type (Table 1).

VII SUMMARY

Soils of the Highveld Region are developed on landsurfaces formed during the early-Tertiary, late-Tertiary and their Pleistocene aggradational phases. Aeolian aggradation , formation of calcareous crusts, deflation basins and accompanying periods of landscape instability have been engendered by three periods of intense aridity. A sequence of climatic events, as manifested in the superpositioning of alternating aeolian and fluviatile deposits in some local sections, is given. The lack of fossils and fragmentary distribution of the aeolian sands, however, did not allow a deciphering of the chronotaxial relationship between aeolian deposits occurring in juxtaposition. Consequently an attempt at evaluating the relative influence of the time factor would have been mere speculation. Nevertheless, it could be inferred with reasonable certainty that soils (mostly vertisols) occurring on those tracts of country lacking aeolian deposits, may easily date back to at least the early-Pleistocene.

Contemporary climatic-conditions do not appear to be a major factor affecting the divergency in soils. Most variations and differences between profiles are attributable to the superpositioning of different layers of aeolian sand, colluvium affected by aeolian sorting or their absence. Textural contrasts between A and B horizons are largely dependent upon the degree of truncation of buried horizons, its petrography and the texture of burying layers. The stratification of layers with different porosities created new environmental conditions. Depending upon the thickness, texture and mineralogy of the sand cover and buried horizons as well as relief, new pedological units developed from the assemblage of independent layers. The genetic processes are closely linked with the hydromorphic regime evoked by the above mentioned stratification and relief. Clay enrichment of B horizons accrue mainly from the vigorous in situ weathering of buried horizons under the favourable soil-climate, rather than from an accumulation by illuviation. Mobilization of iron and manganese is dependent upon water stagnation evoking anaerobic conditions. Organic matter content is low, owing to the sparse vegetation cover and to conditions favouring rapid mineralisation. C/N ratios are generally narrow. The geographical distribution of floristic associations is determined by soil type and precipitation.

The close relationship between soils, rocks, surface geology and geomorphology is illustrated by a comparison of the soil map with the accompanying geological, geomorphological and climatological maps. In genetical studies, in order to determine the history of the region within the timespan of the soils, it is deemed warranted that soil surveys should be supported by parallel sedimentary petrological, stratigraphical and geomorphical investigations.

Owing to the ever-present drift phenomena and recurrent periods of aeolian activity, considerable attention has been apportioned to mineralogical methods and techniques with a view to establish the homogeneity or heterogeneity of soil sections. The significance of variation in heavy-mineral composition, grain -size distribution and surface textures of minerals of sand fractions are discussed and the factors affecting their stability reviewed. It is concluded that the relative stability of these minerals are not predictable on the basis of their persistence in the geological record.

Much attention was allotted to the mineralogy of colloidal fractions. X-ray spectrographs, differential thermograms and electron micrographs of representative samples of clay fractions of the main soil types as well as of "tekto allophane" occurring in sand fractions, are given. The high frequency of occurrence of interlayer contamination, formation of chloritic intergrades and their transformation under conditions of intense leaching, via X-amorphous phases into halloysite, disordered kaolinite and kaolinite could be verified. These observations appear to be an attestation of the concepts of Jackson, Sudo and Fieldes, with regard to the weathering of clay minerals, intermediate clay-minerals and the weathering of feldspars; respectively.

The genetic significance of recurrent periods of aeolian activity, associated periods of landscape instability and discordant eluvial-illuvial relationships is elucidated. Descriptions of 33 profiles and analytical data of representative pedons of the main soil types are included. The results of laboratory investigations (chemical analyses, elemental analyses, frequency distribution of sand-size particles, grain-size distribution analyses and mineralogical analyses) are used to confirm the distinction of the main soil types and to illustrate some of the variations in each. The results are also discussed in the context of the definitions contained in the monograph accompanying the soil map of Africa. The possibility of finding a place in the U.S.D.A. system of classification for some of the soils, is considered.

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