THE APPLICATION OF GEOMORPHOLOGY TO PEDOLOGY

by R. R. MAUD

The fact that soils result from the interaction of the five relatively independent and variable genetic factors of climate, vegetation and topography (environmental factors), and parent material and time (inherited factors), has been appreciated since the foundation of the Russian school of pedologic thought by Dokuchaiev (1897). Prior to that time, because of the frequent obvious relationship between geologic parent material and the soil, those systems of soil classification that had been evolved, were basically geological. (Robinson, 1949).

It is to the Russian school then that recognition of the actual soil profile as such is to be credited, together with the realisation of the frequently predominant role of climate in the formation of soils, although this latter factor has subsequently been rather over-emphasised primarily as a result of local conditions prevailing in soil formation in Russia. Because of the recognition that the morphological characteristics of the soil profile are the reflection of the genetic factors, the system of soil classification as evolved in Russia is in essence, the genetic system of classification.

This system has subsequently been modified and used on an increasingly world-wide scale, primarily as a result of the work of Marbut (1927) and later workers in the United States of America. The system has thus, for example, been applied to the soils of South Africa by van der Merwe (1940), as well as in Australia by Prescott (1931, 1944) and Stephens (1956, 1961).

In spite of its basis on genetic principles, which could reasonably be expected to clearly indicate the morphologic history of the soil concerned, this system of soil classification has been found in an increasing number of instances to be unreliable in the explanation of distribution of many frequently occurring soil patterns. In spite of this, the system continues to have much direct practical and economic agronomic application. It is this consideration that has necessarily resulted in a largely agronomic approach to the study of soils in many instances with the concommitant accumulation of information mainly of an empirical nature.

In many instances, a clearer understanding of some particular characteristic or facet of agronomic behaviour of a soil would undoubtedly result from a greater appreciation of the fundamental genetic history of the soil in question. In addition, greater extrapolation of significant agronomic results might also often be possible than would be the case on barely empirical evidence alone. Such an instance is afforded by the recognition in Australia that the most spectacular responses to applications of superphosphate and trace-elements including molybdenum, were obtained on lateritic soils that had a long history of exposure to weathering processes and which consequently had undergone most leaching of plant nutrients by comparison with other soils. (Stephens and Donald, 1958).

It has become increasingly apparent over recent years that the study of geomorphology can make a significant contribution to pedology. In the past geomorphology has tended to have been regarded either a branch of geology or geography, and not a discipline in its own right. With the tendency of geology to become an applied science and the concentration of geography more and more on socio-economic studies, geomorphology is now emerging as a distinct branch of science. In addition, geomorphology is now tending away from the older classic mainly descriptive approach and is becoming increasingly based on sound quantitative principles.

Geomorphology is the study of the relief of the earth and its evolution. This may be contrasted with geology which is concerned with the ages and characteristics of the various rocks comprising the earth as a whole. Soils occurring as they do on the surface of the earth are therefore clearly directly related to geomorphology, so that the geomorphologist can make a direct contribution to pedology and similarly, the pedologist can contribute significantly to a fuller geomorphic understanding of many problems.

The basic genetic factors reflected in the morphology of soils are included in the geomorphic processes that act for varying periods of time on earth materials. If the combination of circumstances is favourable, soils may be one product of geomorphic processes.

This may be appreciated from the following outline of geomorphic processes. (Thornbury, 1956).

- Epigene or exogenous processes: (processes originating outside of the earth's crust).
  - Gradation.
    - Degradation.
      - Weathering
      - mass wasting or gravitative transfer.
      - Erosion (including transport) by:
        - Running water.
        - Groundwater.
        - Waves, currents, tides and tsunami.
        - Wind.
        - Glaciers.
    - Agradation by :
      - Running water.
      - Groundwater.
      - Waves, currents, tides and tsunami.
      - Wind.
      - Glaciers.
  - Work of organisms including man.

Hypogene or endogenous processes: (processes originating within the earth's crust).
- Diastrophism.
- Vulcanism.

Extraterrestrial processes.
- Infall of meteorites.

Workers in Australia were among the first to appreciate the contribution geomorphology could make towards the elucidation of certain pedologic problems (Crocker, 1946, and Stephens, 1946), and much of the pedologic investigation recently undertaken there reflects this tendency. (Mulcahy, 1960, Butler, 1959, and Ward, 1965). Indeed Stephens (1958), was able to summarise much of the previous pedologic work in Australia in terms of geomorphology.

In Africa, except for the work of Tricart (1956) in Senegal, Ruhe (1954) in the Congo and Ollier (1959) in Uganda and although appreciated by Milne (1935) to some extent in his catena concept, not many pedologic investigations in the light of geomorphic evidence have been undertaken. In South Africa, appreciation of the significance of geomorphology in pedologic studies is an even more recent innovation.

Thus Macvicar (1962) in the upper part of the Tugela Basin of Natal has found a relationship between the pedological and the geomorphic elements of this region. A much more detailed investigation into pedologic processes in the light of geomorphic landscape development was undertaken by de Villiers (1962), also in Natal, where he tentatively correlated the sequence of depositional and pedogenetic events in the light of climatic changes in the Quaternary geologic period.

Similarly, Maud (1964), by the interpretation of geomorphic evidence in the coastal area of Natal has been able to elucidate the pattern of soil distribution occurring there, which had long proved anomalous in terms of the conventional, although genetically based, morphological system of soil classification.

In this region, the dependence of soil characteristics on parent material, in most cases parent rock, had been remarked upon for a considerable time. (Beater, 1957, 1959, 1962). This dependence of the soils on parent material is made the more evident by the occurrence over very short distances of very dissimilar rock-types, the result of intense mid-mesozoic diastrophism. Nevertheless, even in terms of a classification of the soils occurring in this region on the basis of parent material, one notable anomalous situation persisted. This was the occurrence on the dominantly siliceous Table Mountain sandstone formation of three markedly different soils. One a highly ferruginous clayey soil, one a silicious and sandy soil and another soil of intermediate characteristics. These soils were tentatively correlated with the climate prevailing in the localities of their occurrence for the clayey ferruginous soil was confined to certain elevated plateau areas, the upper slopes below these plateaux carried the soil of intermediate characteristics and the lower deeply incised valleys the sandy silicious soil.

The recognition that the ferruginous clayey soil was in fact derived from the decomposition of an ancient geomorphic laterite that rests on the Table Mountain sandstone formation in the few places where an old erosion surface, on which the laterite was originally developed, had escaped destruction by the younger erosion cycles that had largely destroyed it, led to the appreciation of the role of geomorphology in detemining the soil pattern of the region.

Thus the soil of intermediate characteristics was recognised to be formed on materials that constituted the zone of deep weathering in the sandstone beneath the original laterite. Below this zone, previously unweathered rock is now exposed and yields the silicious sandy soil most of the widely differing other rock types such as granite, tillite, dolerite and basalt and various shales and sandstones, that now occur at the surface and yield their characteristic soils, occur below the zone of the old laterite profile because of the deep dissection of the area following a number of episodes of continental uplift. These soils therefore are still young and consequently reflect very strongly the influence of their parent material.

The situation obtaining with regard to soils in coastal Natal in the light of geomorphic evidence is diagrammatically illustrated in the Figure.

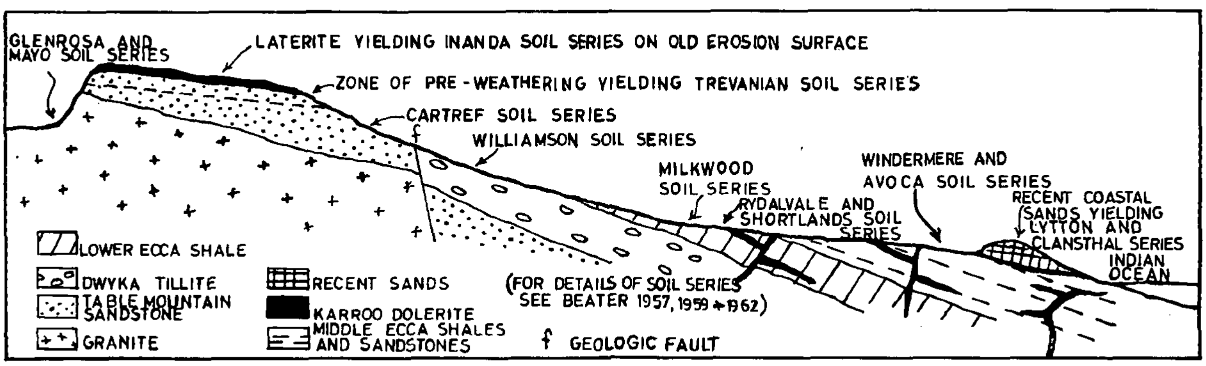

DIAGRAM ILLUSTRATING RELATIONSHIP BETWEEN GEOMORPHOLOGY AND SOILS IN COASTAL NATAL

The recognition that the ferruginous clayey soil is derived from laterite, itself the endproduct of a prolonged weathering cycle, has important implications in some of the hitherto seemingly inexplicable nutritional characteristics of this soil, notably with regard to potassium response and trace-element status, especially zinc.

In addition to those soils developed on consolidated rock parent materials in coastal Natal, there are a number of soils developed on younger unconsolidated parent materials such as coastal aeolian sands and river alluvial terraces, whose characteristics and pattern of distribution will be more fully appreciated by their further study in the light of other geomorphic evidence.

The fact that climatic conditions have not been constant even in the fairly recent past has become increasingly evident since the original recognition of the role of climate in soil formation by the Russian school of pedology. Many soils occurring today certainly cannot have formed under present-day conditions obtaining in the situations where they are found. This is especially so with regard to many lateritic soils. In addition many soil profiles may be the results of a number of climatic conditions that prevailed in the past in addition to the climatic conditions under which they are seemingly being formed at present.

Much of the relatively more recent climatic changes are referable to at least four major onsets of glaciation in regions of higher latitude during the last million years, or that period of geologic time known as the Quaternary. The Quaternary period is subdivided further into periods referred to the Pleistocene and Recent. These glaciations in the regions of higher latitude caused corresponding climatic changes in other regions and also affected world wide sea-levels.

These climatic changes as well as being reflected in the characteristics of many soils are also detectable by geomorphic investigation. For example, a study of superficial sediments on which a certain soil may be developed, may reveal a flora or fauna characteristic of warmer or colder environments than those currently prevailing locally. Thus it may be possible to establish a relative age for the soil in terms of the age of its parent material. Similarly a study of the degree of soil profile development on this parent material may enable a relative chronology to be established. In addition a study of the nature of the sediment on which the soil is developed may reveal whether it was formed under cold conditions, for example, ill-sorted cryological debris, or under an arid environment, for example, aeolian sands.

A study of faunal characteristics would include the study of archaeology as this period of climatic change was also the period during which the human race evolved to its present form. The association of differing archaeological cultures with various climatic environments has been made abundantly clear in South Africa by the evidence of the Vaal River gravels as well as the association of Anthropoid remains in cave deposits related to the various phases of activity of the Kalahari sands. (Cooke 1941). These phases of activity of the Kalahari sands have had a very marked effect on the pedology of much of the interior of southern Africa.

Another study which is interrelated with pedology, geomorphology and archaeology is that of palynology, the study of fossil floral pollens.

In the absence of other suitable evidence in some localities, this study also enables a climatic environment to be established for any one time on the basis of warmer or cooler affinities of the floral populations as indicated by the pollen preserved in strata of that age. Notable advances in this regard in South Africa have been made by van Zinderen Bakker (1961).

In addition to the establishment of former climatic environments and relative chronologies of sequences of events, the combination of all these studies has been further aided by the evolution of absolute chronological measurements as the results of measurement of the amount of radioactive decay of certain characteristic chemical elements, the most important of which is the isotope of carbon C^{14}. Thus it is now becoming possible to estimate the actual age of a soil in terms of years by a consideration of a combination of a number of these interrelated studies. For example, it is possible to obtain an estimate of the age of a soil developed on a landscape feature that may be correlatable with some former sea-level that is specifically datable by means of radio-carbon analysis of certain marine fossils associated with its former shoreline.

It is therfore clear that for the Quaternary period, in order to be able to elucidate many problems in geomorphology, pedology and archaeology, the mutual interdependence of these fields of research has to be recognised. That this is being increasingly recognised on a world-wide scale is shown by the establishment of the International Association for Quaternary Research (INQUA) which has as its object the interdisciplinary scientific research of the several physical, chemical and biological factors that control present-day natural environment and with the history of changes in these environmental controls during the past million or so years, that is the Quaternary Epoch.

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Mr. McCarthy: In replying to Dr. Maud's paper I would like to refer briefly to a subject which is of great interest to both of us, namely the age of the old erosion surface which the author claims gives rise to the Inanda soil series. Much of Dr. Maud's work revolves round his assumption that the Inanda series is derived from a laterite crust which occurred on an as yet unproven Late Cainozoic surface, which arched up from sea level to 2,000 feet at Hill Crest. In my view this reasoning is, to say the least, arbitrary and in need of proof to establish its validity. This may appear somewhat negative criticism, but so much positive theorising has taken place in recent years that the speculative and sometimes dogmatic character of the theories is often overlooked.

I'm sorry Dr. Maud is away overseas and not able to present his paper personally as there are a number of points on which I would like to have taken him to task, particularly as I believe this publication is being followed up by another one overseas on this very subject.

I have laid particular stress on this aspect of Dr. Maud's paper, as he himself attaches much importance to it, as for example in the diagram presented with the paper.

As regards the remainder of the paper I think we are indebted to the author for drawing our attention to the need for the various sciences, geology, geomorphology, pedology and so forth to work more closely together. It is only thus that science can arrive at facts and supersede mere scientific speculation.