Lesotho
Geology, Geomorphology, Soils

Gerard Schmitz
Firouz Rooyani

National University of Lesotho

To WRI

F. Rooyani

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The Authors:

Gerard Schmitz, Ph.D.
Professor of Geography, Applied Environmental Sciences Programme
Department of Geography, National University of Lesotho

Firouz Rooyani, Ph.D.
Team Leader, Education Component of Lesotho Agricultural Production and Institutional Support Project
Adjunct Assistant Professor, Department of Soil and Water Science, University of Arizona
Honorary Lecturer, National University of Lesotho

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Preface

This publication has been written for all those interested in the characteristics and dynamics of Lesotho's natural environment, especially for teachers, fieldworkers, and for students at the National University of Lesotho and at the Lesotho Agricultural College.

A glossary has been added to facilitate the reading of the text, as well as a summary of the U.S. soil classification system, as the Lesotho Government has adopted it for the classification of its soils.

The reader will discover that relatively little is known about the geomorphology of Lesotho, as not much research into this topic has so far been undertaken in the country.

More is known about the geology of Lesotho. In 1947, G.M. Stockley published the first comprehensive study on "the geology of Basutoland". Since then, the Government's Department of Mines and Geology has undertaken to map the country and has published a good number of geological reports and maps of different scales. Much information has been obtained from studies of areas with a similar geology in the immediate surroundings of Lesotho.

Soil analysis, soil mapping and soil classification have been undertaken quite extensively in Lesotho, and a comprehensive general picture of the soils of Lesotho is arising.

As agriculture is a major economic activity in Lesotho, and as soils are being eroded in a drastic way, a chapter on recent processes and forms of accelerated erosion and deposition has been included.

The authors have undertaken an extensive literature survey, and to a large extent this publication is based on studies undertaken by other researchers.

We hope to have given due acknowledgement to the many authors quoted, and apologise if some references have been erroneously omitted.

We invite comments and criticisms of this publication, so that we may improve on our understanding of the natural environment of Lesotho.

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Section One

Geological Evolution

Chapter One

The General Framework

1.1 Cratonisation

The structural development of the African continent has been marked by several periods of mountain building. During each period, large areas became folded, metamorphosed and were subjected to deepseated intrusions. The regions thus affected ultimately became stable continental blocks, or cratons, which were fused together by subsequent orogenic events and formed the African Shield.

This cratonisation of the African continent had been virtually completed by the lower Palaeozoic Era, by which time a sequence of five regional orogenic events had taken place.

One craton of great stability, the Kaapvaal Craton, is thought to underlie the northern part of Lesotho and certainly underlies large areas to the north, east and west of the country.

Figure 1.1 shows the position of the Kaapvaal Craton without its cover of younger rocks.

In fact, the part of the craton underlying Lesotho is considered to form a cratonic margin, or shelf. Its rock sequences were affected by folding and regional plutonic events 2 700 million years ago. It forms a complex schist belt of folded, and subsequently eroded, sediments and volcanics, intruded by basic and ultrabasic rocks and by extensive granites.

The granites are, in fact, dominant in the larger part of the craton and consist of true granites, granodiorites and quartz-diorites, many of which are gneissic (Truswell, 1977). The volcanics contain green minerals and are therefore referred to as "greenstone belts". The greenstone belts, together with the sediments, form the host rocks and belong to the Swaziland System. It is believed that rocks belonging to the Swaziland System, and which are known as the Fig-Tree Group, form part of the cratonic margin underlying Lesotho.

To the south of the Kaapvaal Craton lies a belt of younger, originally geosynclinal sediments, known as the Namaqualand – Natal Mobile Belt, which were affected by linear orogenesis 1 100 million years ago and later were welded to the stable Kaapvaal Craton (Clifford, 1970). This Namaqualand – Natal Mobile Belt most probably underlies the southern part of Lesotho (Figure 1.1). In general, this belt consists largely of gneisses and contains rocks which have been metamorphosed more strongly than those of the Kaapvaal Craton.

Although the basement of Lesotho can be regarded as having been stable for the past 1 100 million years, an exception may be the contact zone between the Kaapvaal Craton

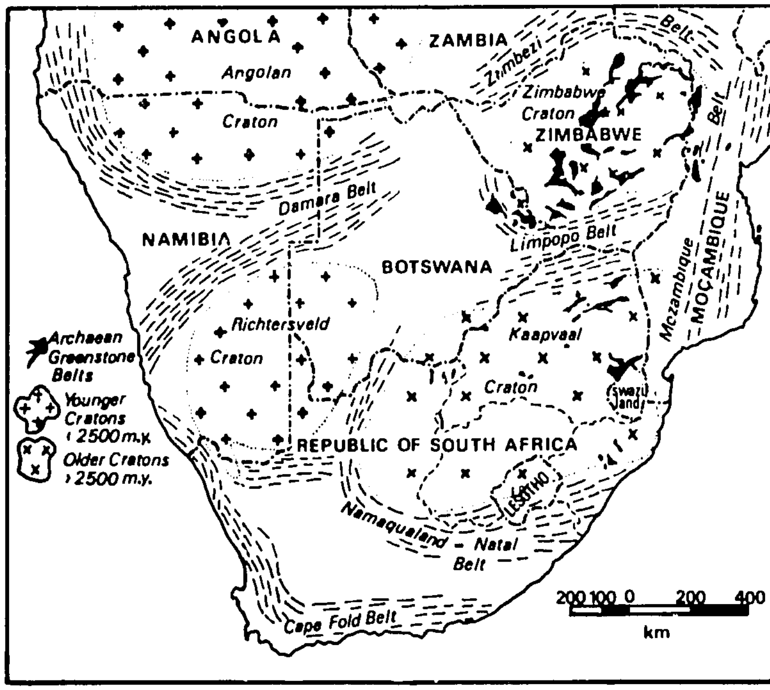

Figure 1.1: Cratons and mobile belts in Southern Africa (source: Anhauesser and Button, 1974)

and the Namaqualand – Natal Mobile Belt, which may have been affected by minor differential movements.

1.2 Gondwanaland

During late Palaeozoic and early Mesozoic Eras (Geological Time Scale, Figure 3.16), the continent of Africa formed part of the larger landmass of Gondwanaland. This supercontinent was composed of what are presently the continents of Africa and South America, together known as West Gondwana, and Antartica, Australia, peninsular India and Madagascar, which together are termed East Gondwana (Figure 1.2).

On Gondwanaland's cratonised surface a number of vast continental basins, surrounded by swells, served as the receptacles for the degradational products of the higher lands.

These products were the result of weathering and erosion and were transported partly by marine incursions, but primarily by glaciers, running water and wind, and deposited in the basins in various forms of glacial, fluvial and aeolian sediments. These sediments now form widespread and thick, largely sub-horizontal, strata of mainly continental origin.

Lesotho is situated in one such tectono-sedimentary basin, the Karoo Basin (Figure 1.3). According to Anderson and Schwyzer (1977), Gondwanaland was situated in the South Polar region from the lower Carboniferous Period to the lower Permian Period, with the South Pole actually positioned in Southern Africa during the lower Carboniferous Period, causing widespread glaciation in this region.

By the lower Permian Period, Gondwanaland had drifted some 10° further north and glaciation had waned. Anderson and Schwyzer also mention that, at the Permian – Triassic boundary, a 30° clockwise rotation of East Gondwana resulted in an impact between Antarctica and the Falkland Plateau. The compressional stresses which occurred from

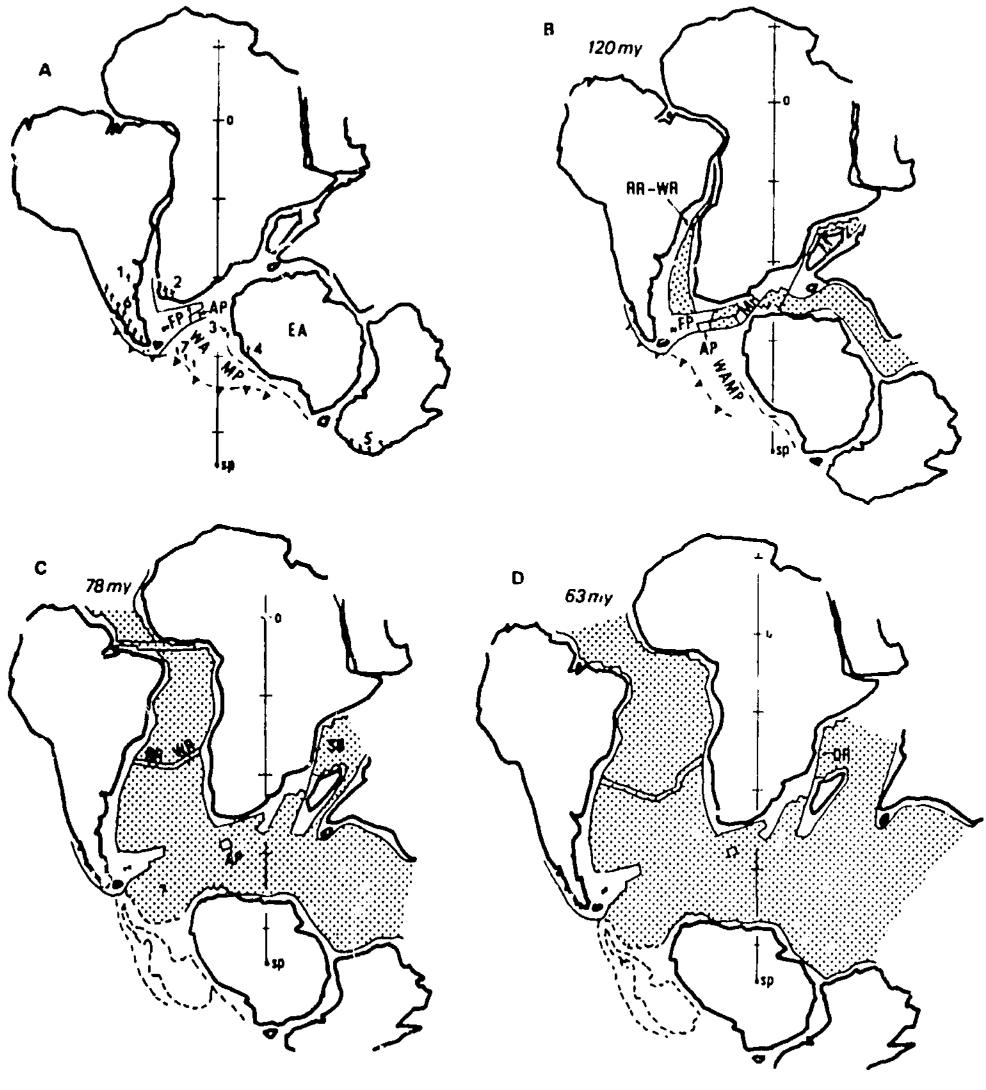

Figure 1.2: Gondwana palaeographies

A: Pre-Drift (early Triassic)	FP: Falkland Plateau	EA: East Antarctica
B: early Barremian	AP: Agulhas Plateau	SB: Somali Basin
C: late Santonian/early Campanian	MR: Mozambique Ridge	RR: Rio Grande Rise
D: Early Pal.eocene	M: Madagascar	WR: Walvis Ridge
	WAMP: West Antarctica Microplates	SP: South Pole
		DR: Davie Ridge

(source: Dingle et al, 1983)

this impact led to the first phase of folding and uplift in the Cape Fold Belt. As will be shown later, this had important consequences for the formation of sedimentary strata in Lesotho.

Anderson and Schwyzer also claim that during the Triassic Period a clockwise/counterclockwise wobble of East Gondwana led to an alternating onset and release of compressional stress against the southern tip of Africa. Rust and Turner (1970) mention that this alternation is reflected in the cyclic nature of sedimentation in the Molteno Formation for which they consider repetitive uplift and denudation of the Cape Fold Belt to be the cause.

Anderson and Schwyzer (1977) think that this episode of relative movements within Gondwanaland may have a bearing on the general volcanic activity in this area in the lower Triassic Period.

A summary of recent reconstructions of Gondwanaland in the early Triassic Period and of its later dismemberment has been made by Dingle et al (1983) (Figure 1.2). The breaking apart of Gondwanaland, accompanied by seafloor spreading, probably began with the separation of southeast Africa from Antarctica approximately 132 million years ago about a rotation pole at 11° N, 41° W (Bergh, 1977) and continued with the separation of Africa from South America 128 million years ago about a rotation pole 46° 45′ N, 32° 39W (Martin et al, 1981). Small oceanic basins existed in the South Atlantic, subdivided by the Walvis Ridge – Rio Grande Barrier, and off southeast and east Africa (Figure 1.2 B).

According to Dawson (1970) the final breaking apart of Gondwanaland involved the uplift of the African continent, marginal downwarping and the deepening of the ocean basins, with convection cells rising beneath the continents and descending at their margins. The rising convection cells were accompanied by melting in the upper mantle, kimberlite being one of the products of this melting. Fundamental fractures resulted from dilatation caused by subcrustal flow and it was this dilatation which apparently controlled the kimberlite emplacements in Lesotho.

With the split up of Gondwanaland, new "African" coastlines were formed and large scale reorientation of drainage and deposition, from interior basins towards the new coastlines, was set in motion, a process which is still going on (Schmitz, 1968 and Chapter 7.2).

Other significant environmental changes took place when, with the widening of the Atlantic, the Walvis Ridge – Rio Grande Rise barrier became gradually less important as an obstacle to deep water circulation between the northern and southern Atlantic, and also when South America moved away from West Antarctica and Australia parted from East Antarctica, thus opening the way for circum – South Polar circulation.

All these environmental changes must have had a very important impact on the climatic regimes of Southern Africa, notably a moistening and cooling effect, and have led, by about the Miocene Epoch, to the present climatic regime of the Southern Hemisphere (Dingle et al, 1983).

1.3 The Karoo Basin and basin floor characteristics

Rust (1975) describes the Karoo Basin as a tectono-sedimentary basin, that is a terrain of tectonic origin, which measures several hundred thousands of square kilometres,

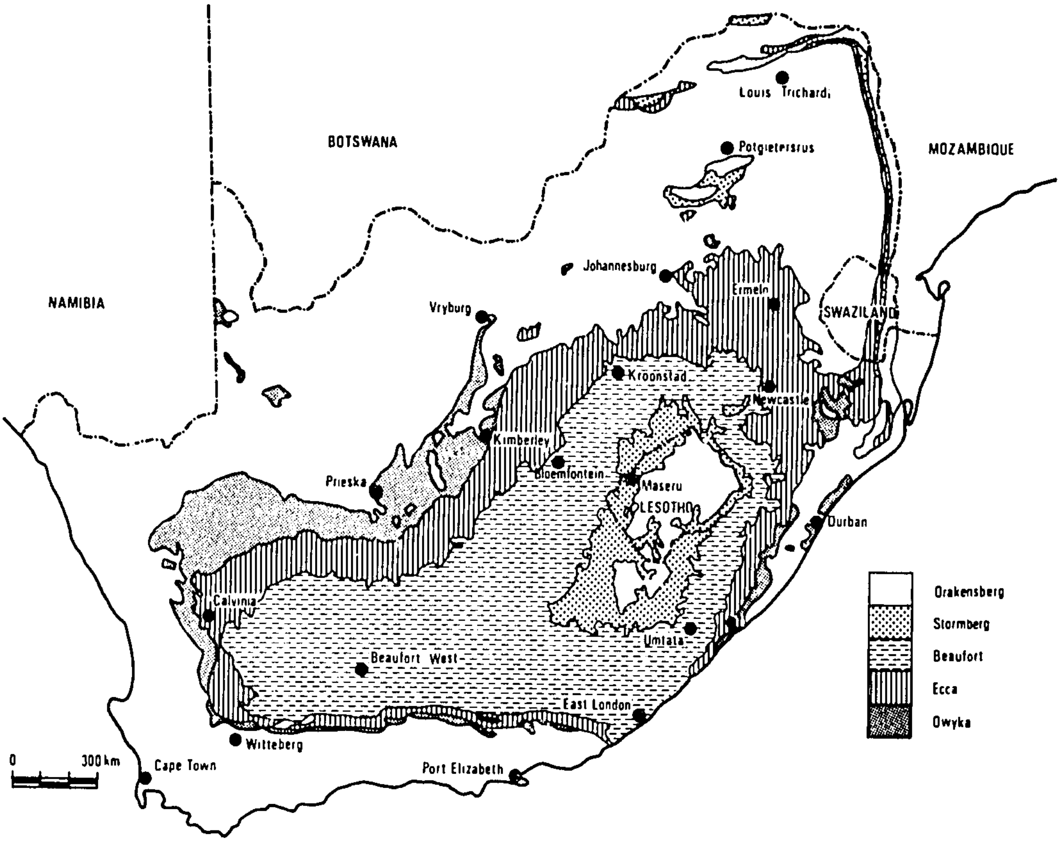

Figure 1.3: The distribution of the Karoo.

containing a cluster of sedimentary basins which are almost identical.

As erosion has strongly removed the Karoo Basin's original sedimentary content, the limits of this tectonic basin are not well defined and the basin may well have extended far beyond its present boundary.

A glance at the geological map (Figure 1.3) reveals the remainder of the sedimentary Karoo Basin and Lesotho's position in it. The sedimentary strata exposed in Lesotho or those present below the surface can be seen in surrounding areas.

The basin geometry shows two axes: one axis runs from north-east to south-west, and represents a broad basin in which Lesotho is situated and which is part of a cratonic marginal shelf terrain which deepens in south-western direction. The other axis runs from east to west, and represents a narrow trough along the northern edge of the Cape Fold Belt, a tectonically much more active miogeosynclinal environment (Rust, 1975). The two axes merge near Queenstown, from where one single axis continues in south-eastern direction and crosses the present shoreline near East London.

Several tectonically defined subunits can be recognized in the Karoo Basin (Rust, 1975; Dusar, 1979). The higher ones served as sediment source areas in the early stages of Karoo sedimentation, whereas the lower ones received sediments from the early days of Karoo sedimentation.

On the shelf area, the Lesotho Rise was for a long time a fairly strong positive element. It was probably composed of several smaller basement highs, the western one of which is the Clocolan Dome (Ryan, 1967) (Figure 1.4). This Dome coincides with an extensive gravity low anomaly, which is interpreted as caused by a granite dome.

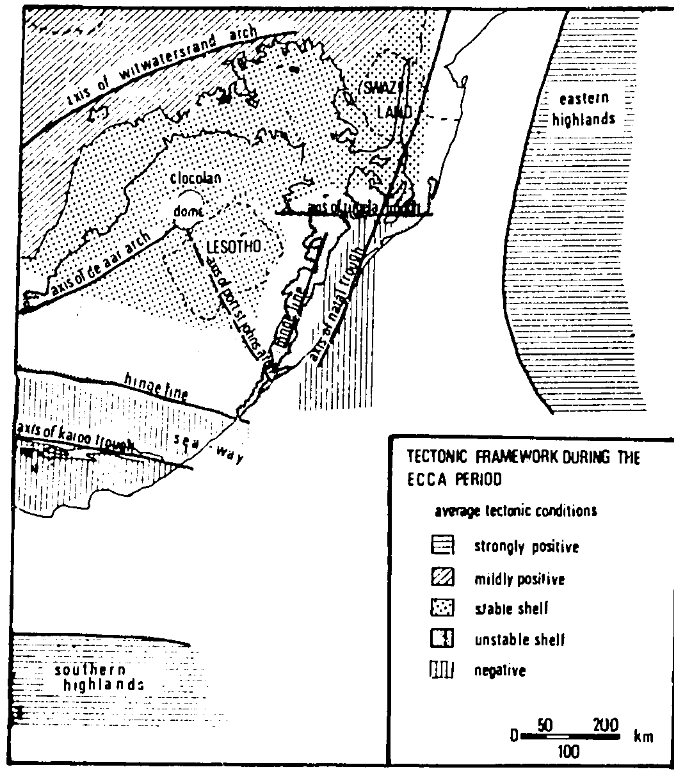

Figure 1.4: Tectonic framework during the time of the Ecca deposition (source: Ryan, 1967).

According to Ryan (1967) two broad subsurface palaeotectonic arches, the north-east trending De Aar Arch and the south-east trending Port St. John's arch intersect at the Clocolan Dome (Figure 1.4). These two arches were only mildly positive and did not represent sediment source areas.

The Mount Moorosi area consists of a deep sedimentary trough in which up to 100 metres of Stormberg sediments accumulated.

A small structural dome exists near Mafa and is characterised by a much reduced thickness of, at least, the Elliot and the Clarens beds (Dusar, 1978).

Other structural domes may well exist in the central part of Lesotho. They may have been uplifted and subsequently eroded during the time when Beaufort- and Molteno sediments were formed and may have been a source of the basement pebbles which were deposited in the Molteno conglomerate (Dusar, 1978).

Except for the southern margin of the Karoo Basin, tectonic activity in the Basin was restricted to small vertical movements and local uplift. Subsidence, due to accumulation of Stormberg sediments, was concentrated on and around the Lesotho Rise.

Within the boundaries of Lesotho there is no direct evidence available on the composition, the structure and the morphology of the pre-Karoo basement. No drill holes have reached this pre-Karoo basement in Lesotho and conclusions about its characteristics have to be inferred from drill hole data from areas of South Africa surrounding Lesotho, from Xenoliths in Kimberlites and from magnetic surveys. It may be assumed from this evidence that the basin floor consists of cratonic structures, the surface of which is formed by the irregularly eroded roots of folded schist belts and associated granitic rocks (Clifford, 1970).

Stratten (1970) published the first geological map of the pre-Karoo basement. This map is based on what at present is known of the surface geology of areas surrounding Lesotho, on borehole information and on the composition of tillites in Southern Africa. By extrapolation he suggests that the karoo basement in Lesotho could be made up of basement granite and of gneiss, as a large part of the land surrounding Lesotho is made up of those rocks. There could also be an extension of rocks of the Swaziland System, or one of its associated formations, underneath the whole of the northern part of Lesotho, as those rocks do occur to the north-east of Lesotho.

A U.N. exploration for diamonds revealed, in one of the kimberlite pipes near Butha-Buthe, inclusions of baked shale, phyllite ferruginous quartzite and banded ironstone, which suggests that rocks belonging t the Swaziland System do indeed underlie the northern part of Lesotho (Diamond Exploration Technical Report No. 5, 1974).

Ryan (1967), Rust (1975), and Theron (1975) inferred the presence of basement domes, concealed below the younger Karoo strata, and recent research has revealed an uneven basement floor in the western lowlands of Lesotho. In 1977 the Northway Survey Corporation undertook a regional magnetic survey, from which it was possible to recognise five basement provinces in the lowlands (Figure 1.5), which reflect higher and lower positions of the basement in that area.

Dusar distinguishes the magnetic provinces as follows:

1. The Northern Plutonic Province

This Province is characterised by large intense magnetic anomalies, probably corresponding to a highly variable geology in the basement complex. The western boundary is abrupt and may be fault-controlled and coincides with a north-south anticlinal axis in the Stormberg Group. This Northern Province has the highest recorded depth to basement. The magnetics are dominated by a large linear magnetic anomaly, over 30 kilometres long, and trending north-east to north-north-east, which may be caused by a large magnetically induced body, from 2,3 to 2,5 kilometres wide and from 2,0 to 2,3 kilometres below the surface. This could be a banded ironstone formation of the Swaziland System, pieces of which have been found as xenoliths in a kimberlite pipe near Butha-Buthe, or an ultramafic intrusion along a major zone of weakness. The eastern boundary of this body is marked by the Siepe Fault. To the north the magnetic anomaly fades out where it is surrounded by a syncline in the Stormberg structure.

2. The Basin and Range Province

This Province is characterised by moderate magnetic activity which could correspond to a granitic terrain. This inference is also made by Ryan (1967). This granitic basement terrain may link up, by means of the Port St. John's Arch, with the, possibly granitic, Clocolan Dome (Figure 1.4). The main magnetic and structural trend is north-south, while the subsidiary trend is east-west. This latter trend is principally followed by synclinal axes in the Stormberg Group.

3. The Central Province

This Province is characterised by short wavelength activity. The depth to the basement is not great.

4. The Southern Plutonic Province

This Province is characterised by large intense magnetic anomalies. The depth to the basement is considerable. To the south, the Province is delimited by the Helspoort Fault. There is an indication of a change in the basement lithlogy across the Helspoort Fault.

5. The Southern Province

This Province has not been interpreted for its basement characteristics. It is thought that the basement rock is composed of metasediments of greenschist age. The most striking feature is an east-west linear anomaly, north of Mohale's Hoek and underlying the parallel Qalaheng dolerite dykes.

1.4. The boundary between the Kaapvaal Craton and the Namaqualand-Natal Circumcratonic Belt

As was mentioned before, the boundary between the Kaapvaal Craton and the Namaqualand-Natal Belt probably underlies Lesotho, but the precise position of this boundary is not known. It has been postulated that the Tugela Fault, which marks the contact in Natal between the Kaapvaal Craton and the Natal Belt and trends east-west, continues underneath the Lesotho Formation and links up with the Helspoort Fault (Barthelemy and Dempster, 1975; Barthelemy, 1976). (figure 1.5)

The Tugela Fault, a steeply dipping normal fault with a downthrow on the southside of as much as 450 metres, can be followed in south-west direction, but there is in fact no evidence that it continues underneath Lesotho. This Fault has affected Karoo strata in Zululand and must therefore have been active in post-Karoo times (Truswell, 1977) and as late as 200 to 100 million years ago (Van Eeden, 1972). Dusar mentions that no extensive fracture zones with an east-west or west-south-west direction, starting from the known Fault, are recorded in Lesotho, and he believes that it is possible that the boundary between the Kaapvaal Craton and the Namaqualand-Natal Belt is irregular in Lesotho and not necessarily fault-controlled. It may even be that the Namaqualand-Natal Belt also underlies part of northern Lesotho, which would explain the presence of gneissic xenoliths found in several kimberlite pipes in the area (Dusar, 1979).

Drilling has also shown that south of Letšeng the contact between the Stormberg Group and the Lesotho Formation dips southward from an altitude of 2 075 metres on the anticlinal axis north of the Drakensberg Escarpment (Figure 1.5) to 1 635 metres at Letšeng and to 1 560 metres at Tlokoeng, near Mokhotlong. This southward dip, according

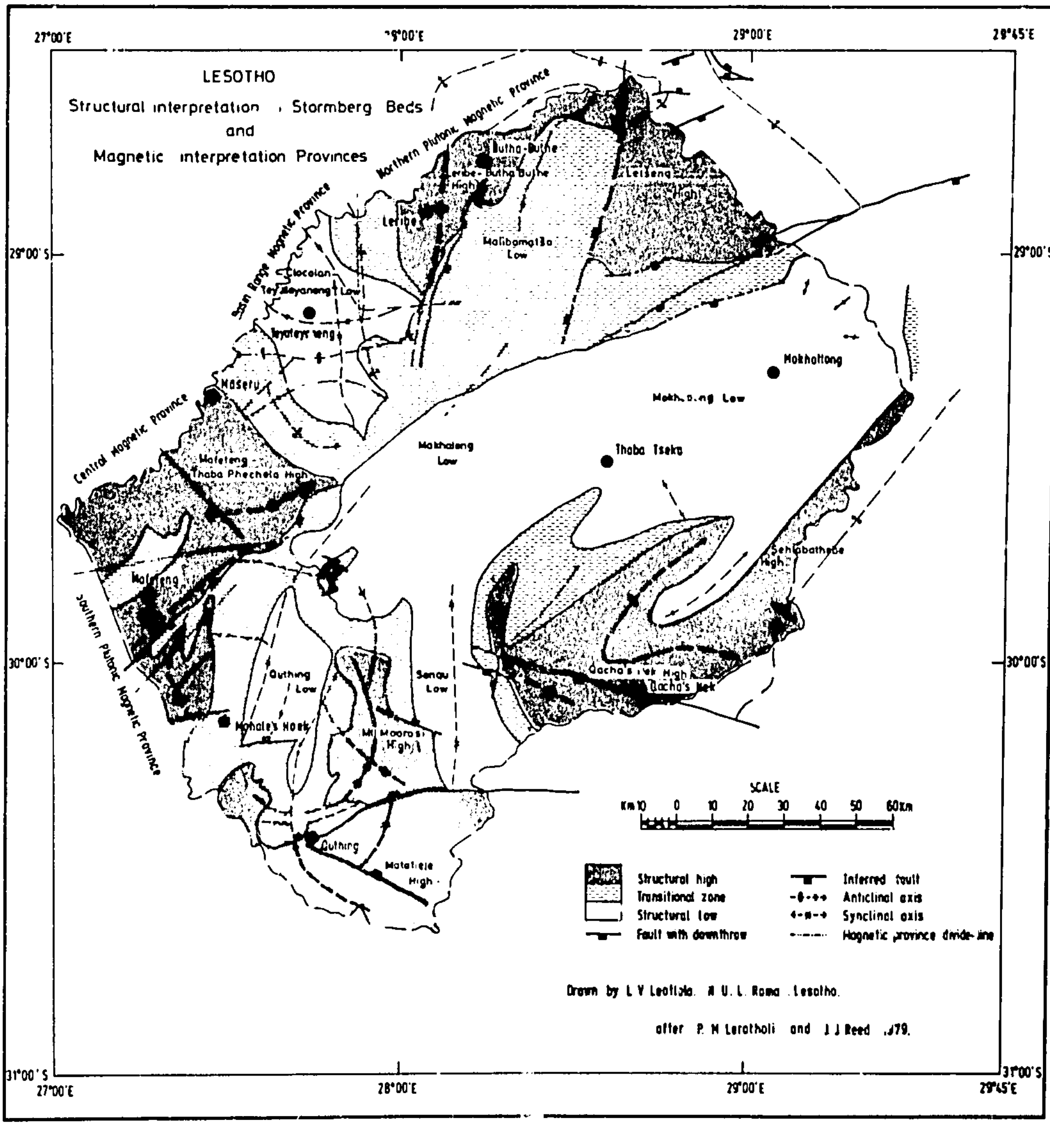

Figure 1.5: A structure interpretation of Stormberg Beds together with Magnetic Basement Provinces as interpreted from a regional magnetic survey (source: Dusar, 1979).

to Dusar (1979), shows that there is no important fault zone displacing this contact zone south of Letšeng.

Chapter Two

Basin Sedimentation

2.1 Karoo sedimentary history and basin floor characteristics

The sedimentation and palaeogeography of the Karoo sequence overlying the Basin floor has been very much influenced by the morphology, the structure and the composition of the precambrian basement floor.

From the early phases of sedimentation in the Karoo Basin until the upper Beaufort/ Molteno sedimentation, the Kaapvaal Craton was the main sediment source, and the Karoo Basin sedimentary content of that period strongly reflects the mineral and rock composition of the Craton. The Kaapvaal Craton formed an epeirogenetically uplifted area with the Lesotho Rise at its southern margin (Rust, 1975).

The lowest strata of the Karoo sequence lie unconformably on the basin floor. They were probably deposited in a number of discrete basins, separated from one another by basement highs, these latter providing the detrital material to fill the basins. This uneven basement floor influenced the sedimentary pattern of the lower Karoo. On the basis of palaeogeographic evidence Ryan (1975) inferred the existence of high ground over the basement domes in Lesotho during the lower Karoo. Also, during the Beaufort, this pattern of high ground over basement domes may have existed. Dusar mentions that several basins and domes must have existed in Molteno times, resulting in thick Molteno deposits in the basins and thin layers over the domes.

This particular relationship between source area and deposition was disturbed by an important event in the sedimentary history of the Karoo Basin, namely the orogeny in the Cape, during which the sedimentary fill of a miogeosynclinal trough was severely folded and uplifted (Rust, 1975). The resultant fold range, that is the Cape Fold Belt, developed into a prominent southerly source of sediment. The dominantly north-south transportation was reversed, and this is reflected in the Stormberg Group of the Karoo sequence.

2.2 Dwyka Formation

The first sediments deposited in the Karoo Basin were Dwyka Tillites, a product of glacial erosion and transport (Figure 1.3). It can be inferred from those Tillites, from directional current structures, from geomorphological glaciation features and from palaeomagnetic data, that glaciation began when large continental parts of Gondwanaland moved into positions near the South Pole and vast areas of open water nearby provided the atmospheric moisture (Crowell and Frakes, 1970, 1972, 1975).

In the Karoo Basin, this glaciation of continental type waxed during the upper Carboniferous Period when the South Pole became situated over the Transvaal.

By the lower Permian Period, Gondwanaland had drifted approximately 10° farther north and its configuration had changed, causing waning glaciation (Anderson and Schwyzer, 1977; Crowell and Frakes, 1975). The Dwyka glaciation is, therefore, a climatic response to tectonic displacement of the continental plate (Rust, 1975).

Glacial sediment must have been shed from one or more continental ice sheets centered on northern Transvaal, eastern Botswana, Zimbabwe and Zambia, from where lobes extended peripherally (Crowell and Frakes, 1975). Although no definite conclusions about ice movements can yet be reached, ice carrying large amounts of debris must have entered the Karoo Basin from northerly and easterly positions (Figure 2.1).

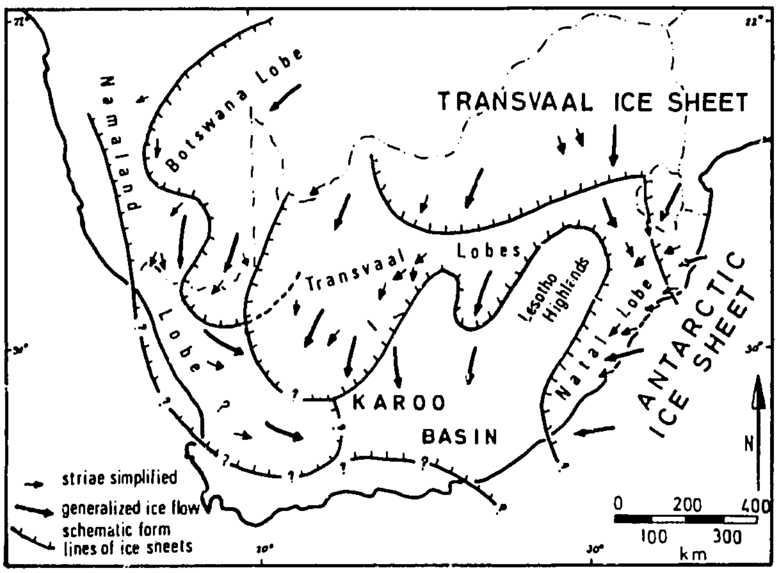

Figure 2.1: Palaeozoic glaciation of Southern Africa. (source: Crowell and Frakes, 1975).

In the northern part of the Basin, deposits were morainic and fluvioglacial, in the southern parts these deposits were subaquaous (Haughton, 1969).

The greatest thickness of the Dwyka Tillites was reached in the south of the Karoo Basin from where they thin out northwards. These Dwyka deposits rest unconformably upon the Basin floor.

An isopach map of the Dwyka Formation was made by Winter and Venter (1970) on the basis of information obtained from deep boreholes (Figure 2.2).

According to Stratten (1970 b), the northern part of Lesotho formed a mildly positive elevated area during the Dwyka Period, while the other parts of the country were part of a relatively neutral and stable cratonic shelf area.

The elevated area may have acted as a barrier to ice flow rather than as a source area shedding ice, although it may have acted as a minor source area. In the stable shelf areas, subsidence has been relatively slow resulting in only thin Tillite deposits. According to

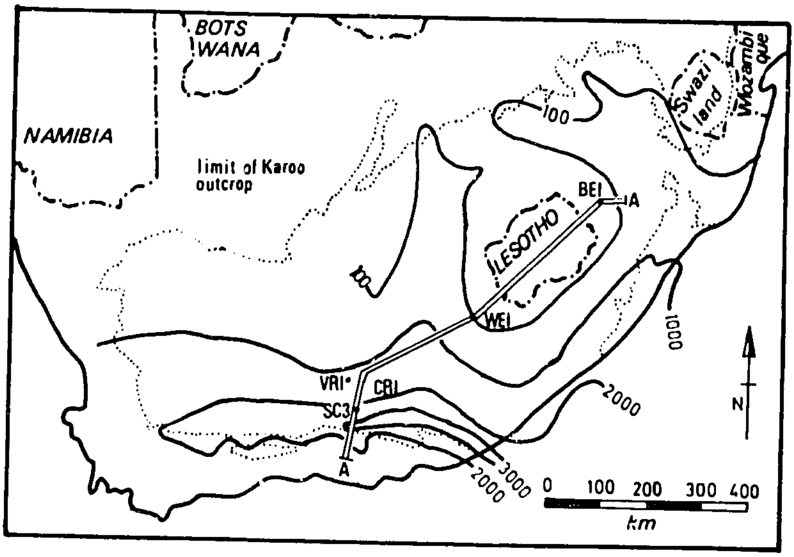

Figure 2.2: Isopach map of the Dwyka Formation with drill control points. AA = cross-section as shown in Figure 2.7. (source: Winter and Venter, 1970)

Dusar (1979) glacial deposits are probably not deposited over most of Lesotho because the glacial valleys descending from the northern highlands were diverted around the Lesotho Rise, an elevation of the basement (Crowell and Frakes, 1972) (Figures 2.1 and 2.2). In the northern area (Figure 2.2) the shelf zone is marked by an irregular isopach line which reflects an uneven floor, caused by glaciated valleys (Winter and Venter, 1970).

2.3 Ecca Group

After the melting of the ice cap in the lower Permian Period, the larger, northern depositional environment in Lesotho became lacustrine, swampy and deltaic, whereas, in the smaller southern part, Ecca sediments were deposited in a moderately deep inland sea (Rust, 1975) (Figure 1.3).

Ryan (1968) undertook detailed investigations of the Ecca outcrops, including directional structures, in the Karoo Basin and he was able to distinguish four separate facies within the Ecca Group (Figure 2.3).

Although the Ecca Group is only known from outcrops and drillings in surrounding South Africa, it may be expected to occur at depth in Lesotho.

The sediments of the northern facies consist of shales, coarse arkoses, conglomerates and coal seams. These northern sediments are composed of three units; the upper and lower units consist of shales, which were deposited in a relatively deep continental sea and the middle unit is composed of coal measures, coarse arkosic sandstones and conglomerates which were deposited in a series of deltas and fluvial channels which were built out over pro-delta muds.

The provenance of the northern facies was situated to the east and north-east of the present Natal coast and was mainly granitic in composition.

In the backswamps and lakes of the alluvial floodplains, dead vegetation could ac-

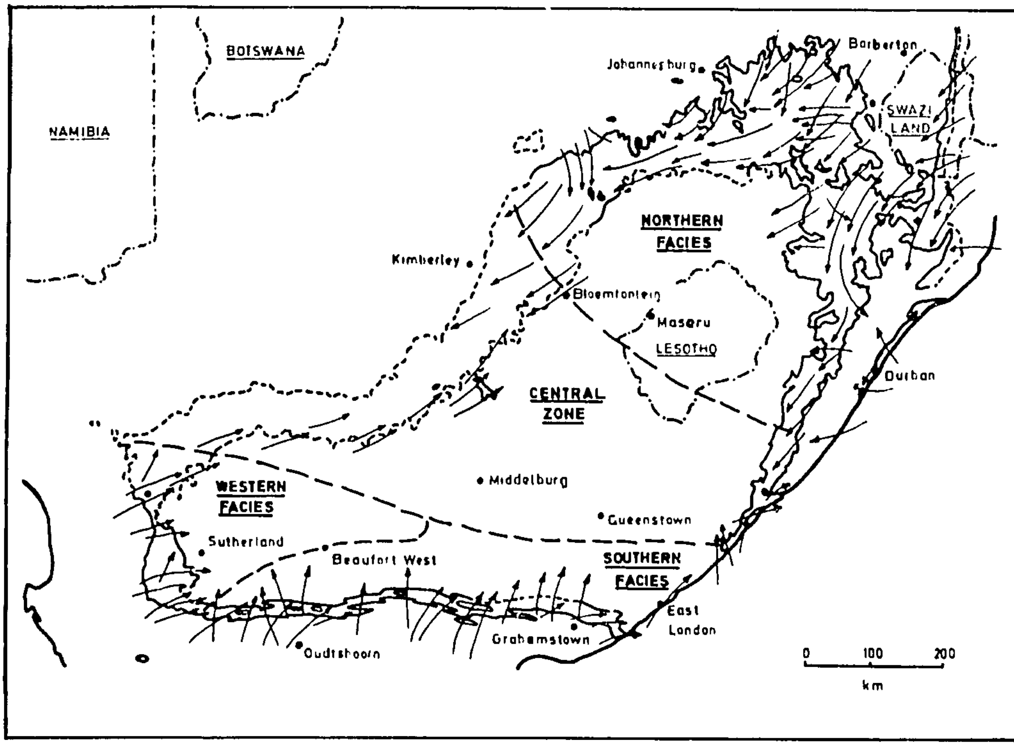

Figure 2.3: Facies and palaeocurrent directions for the Ecca Group (source: Ryan, 1968 and Truswell, 1977).

cumulate to form local coal measures, of which extensive deposits occur in the northern part of the Orange Free State, in the Transvaal, northern Natal and in Swaziland. In fact almost all of the coal so far produced in South Africa has been derived from the Ecca coal measures (Haughton, 1969). However, the coal measures fan out from the north-east in the direction of Lesotho and, during the middle Ecca the Lesotho Rise was apparently a controlling feature determining the gross shape of the original coal swamp (Rust, 1975).

Dusar (1979) mentions that limited coal deposits can probably be expected on and around the Lesotho Rise. The Lesotho Rise was probably composed of smaller basement domes and basins, the western high being the Clocolan Dome (Ryan, 1968) (Figure 1.4). The thickness of the Ecca and the Dwyka beds is reduced over the domes and both beds wedge out against their flanks.

The central Ecca facies, which may underlie the southern part of Lesotho (Figure 2.3), consist of extensive, moderately deep sea deposits, largely shales, from different source areas.

The total thickness of the Ecca Group decreases in Lesotho in north-westerly directions (Figure 2.4). The Ecca coal measures however form an exception to this as they have their thickest development in the north-east (Winter and Venter, 1970).

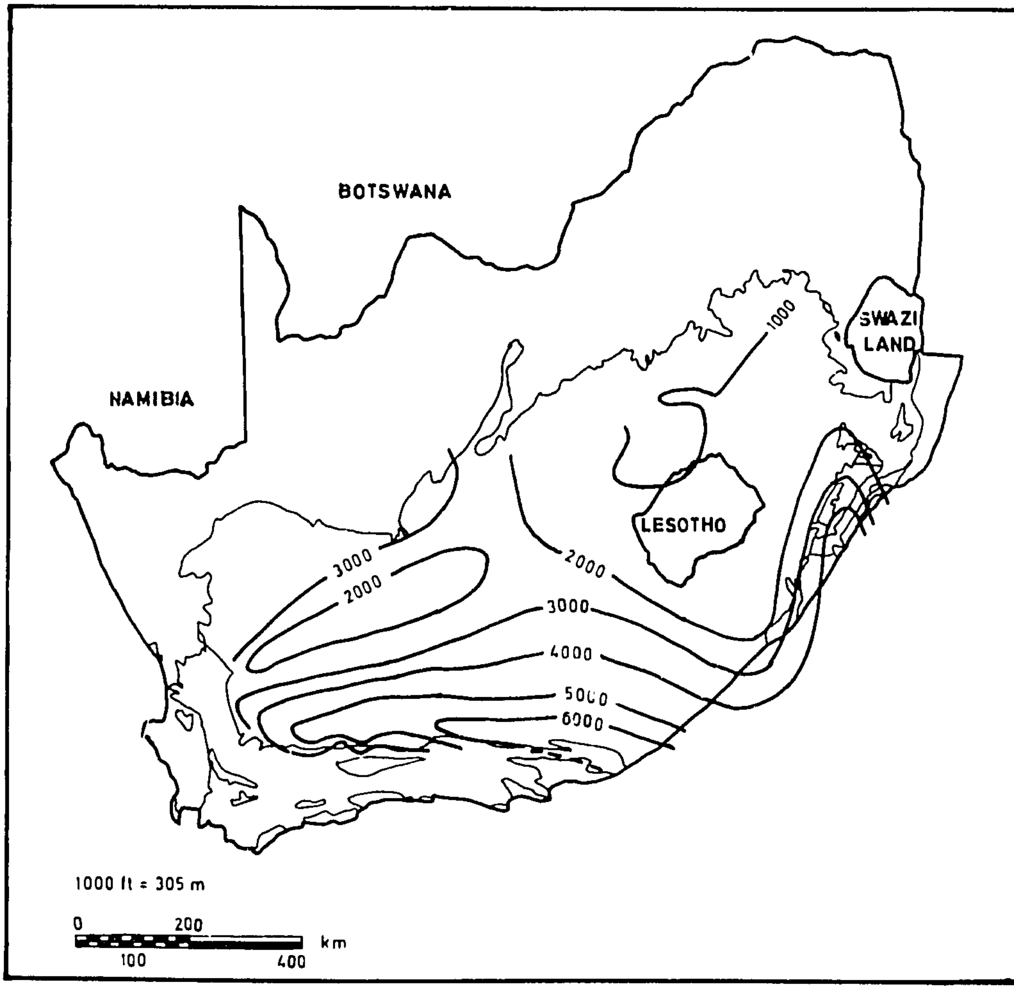

Figure 2.4: Isopach map of the Ecca Group (source: Winter and Venter, 1970).

2.4 Beaufort Group

After the Ecca sequence was deposited in a large body of water, during a time interval lasting from the middle Permian Period to the early Triassic Period (Scythian) the Karoo Basin became filled up further with thick and widespread, largely fluvial, accumulations: the Beaufort Group (Figure 1.3).

This drastic environmental change did not develop simultaneously through the whole basin. Instead, the Ecca – Beaufort boundary is considered to be diachronous (Kent, S.A.G.S., 1980; Ryan, 1967). The lower Beaufort units overlap northwards, indicating a northward regression of the Ecca basinal area and a simultaneous advance of the Beaufort sedimentary influence (Theron, 1975).

Generally the Beaufort Group can be distinguished by its homogeneous sequence of bright coloured, often reddish or purple, shales and sandstones. The total thickness of the

Beaufort deposits is approximately 6 000 metres in the southern trough of the Karoo Basin, but these sediments thin out rapidly to the north.

2.4.1 The Burgersdorp Formation. The Burgersdorp Formation is the highest unit of the Beaufort Group (Johnson et al, 1976; Kitching, 1977). In Lesotho it can be found outcropping in the western lowlands and it can be expected to underlie the whole country.* Outcrops in Lesotho consist of soft, polycoloured mudstones and siltstones with intercalations of more resistant fine and medium grained grey and buff coloured sandstones. Less commonly, concretionary ferruginous beds occur as do pebble conglomerates and minor intercalations of dark carboniferous shales and sometimes thin coal seams. Outcrops in Lesotho reach thicknesses of up to 250 metres. The Formation increases in thickness southward.

In Lesotho, the junction of the Formation with the overlying standstones and grits of the Molteno Formation is generally sharp. The contact is unconformably overlain and progressively overstepped northwards by Stormberg sediments (Dingle et al, 1983).

Theron (1975) made a detailed palaeocurrent analysis of the entire outcrop area of the Beaufort Group. Some of his conclusions, supported by heavy mineral analysis and particle size determinations, are incorporated here.

Rocks belonging to the Burgersdorp Formation were originally waterlain in a nonmarine environment. The mudstones represent low energy, alluvial flat, sediments, mostly deposited in larger bodies of standing water, but prone to dessication. The arenaceous sediments represent fluvial and deltaic sands. Considering the vertical variation in grain sizes, it is clear that the energy of the depositional medium changed periodically.

Theron (1975) inferred at least two sediment sources in the northern half of the Beaufort Basin: one along the south-eastern margin of the basin and one in its northern part. Dusar (1979) suggests that the nearby southern source may have been locally uplifted parts of the Lesotho Rise.

The part of the Beaufort Basin in which Lesotho is situated formed a relatively stable platform which subsided moderately by tilting slightly towards the south (Dingle et al, 1983) (Figure 2.5).

Near East London there is a large area of high vector strength with a strong radial pattern. The Katberg sandstone, forming a large alluvial delta, contains pebbles which indicate that a nearby landmass in the south-east underwent active denudation during the deposition of the sandstone, and the feldspatic content of the Katberg Sandstone proves that the source area for this sandstone was granitic/gneissic (Theron, 1967). Theron suggests that a large river which drained a southern landmass may have entered the Beaufort Basin near East London.

This landmass, composed mainly of Precambrian rocks and not far from the present coastline, was probably rapidly eroded in the late Permian and early Triassic Periods and may well have been the Falkland Plateau (Dingle et al, 1983).

Another dispersal system was active in the northern part of the Beaufort Basin, for a relatively short time during the sedimentation of the Beaufort. It resulted in the deposition of the Mooi River Formation. An area of low vector strength in the eastern and

*Except that rocks belonging to the Beaufort Group occuring to the NW of Butha Buthe may belong to the Smithfield Formation.

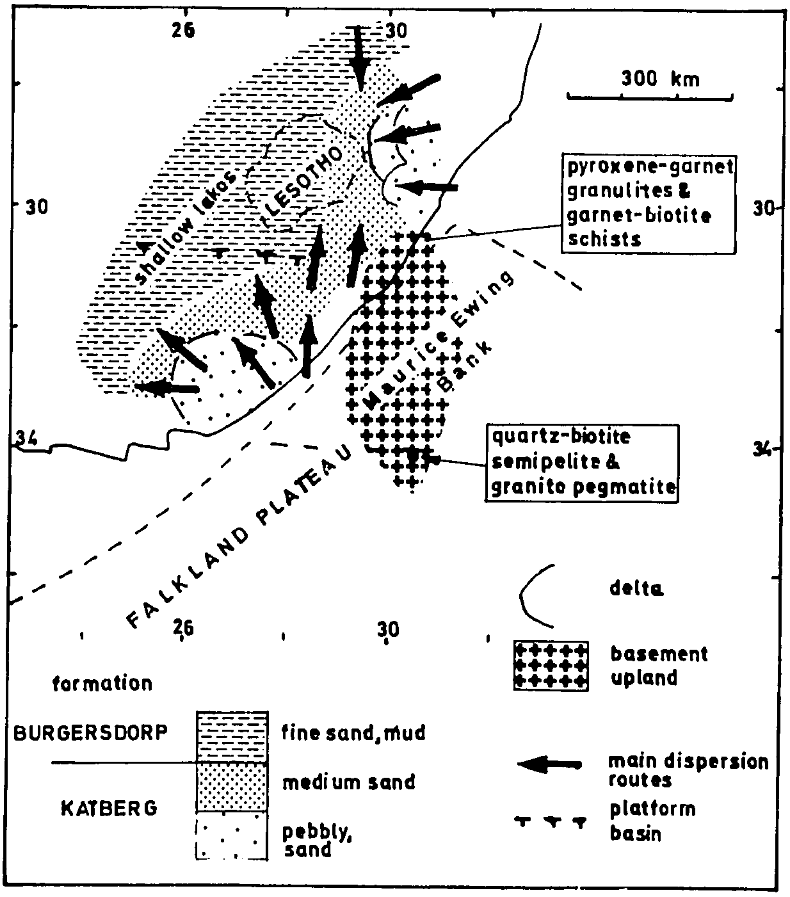

Figure 2.5: Palaeogeography of the main Karoo Basin in the Scythian Age (source: Dingle et al, 1983).

northern parts of the basin is thought to represent the position of the source area providing the sediments of the Mooi River Formation. The presence of large constituents in the Mooi River Formation may therefore reflect the composition of the floor of the Karoo Basin. As mentioned before, Dusar (1979) suggests that this nearby source may have been a locally uplifted part of the Lesotho Rise.

Figure 2.5 shows how during the Scythian age the whole of Lesotho formed part of a higher platform, largely covered by shallow lakes. The two sedimentary sources indicated provided the sandy and muddy material for deposition as lake, delta and alluvial sediments (Theron, 1975). In recent constructions of Gondwanaland (Francheteau and Le Pichon, 1972), the Falkland Plateau was placed adjacent to the southeast coast and it may, therefore, have functioned as a southern provenance area for sediments in Lesotho as well.

The Beaufort fauna shows a interesting record of vertebrate assemblages and, because the Beaufort lithology has a great deal of uniformity, attempts have been made to subdivide the unit on a palaeontological basis.

The latest developments have led to a biostratigraphical zonation of the Beaufort Group by Keyser and Smith (1979), of which two assemblage zones, as established for the Burgersdorp Formation, are of importance to Lesotho: the Lystrosaurus Zone and the Kannemeyeria Zone (or the Cynognathus Zone of Kitching (1970) and earlier workers). The distribution of the two Zones is shown in Figure 2.6. It can be seen that the Kannemeyeria Zone vertebrate assemblages occur in outcrops of the Burgersdorp Formation in the south-western part of the country.

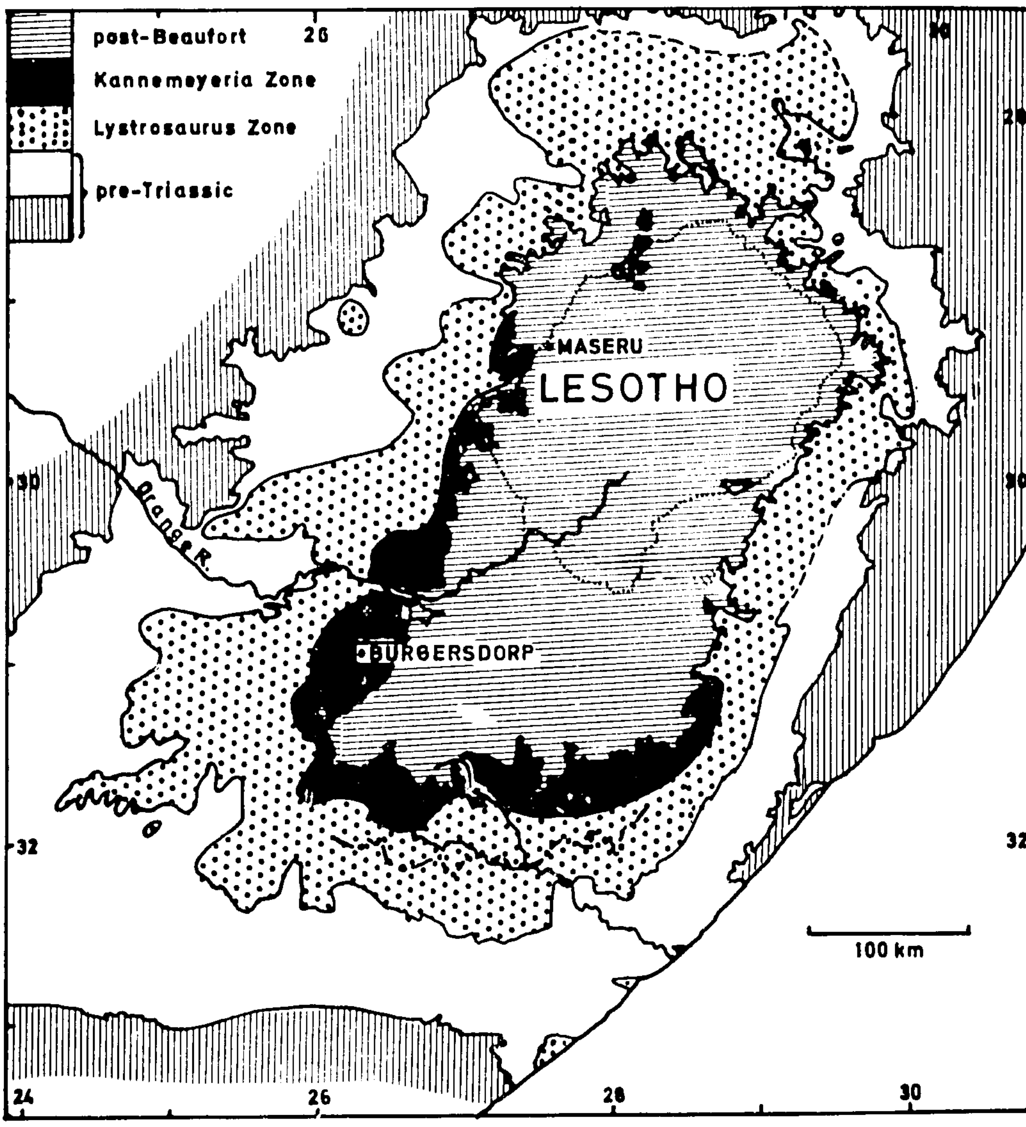

Figure 2.6: Distribution of strata of Lystrosaurus and Kannemeyeria Zones in the main Karoo Basin. (source: Kitching, 1977, Keyser and Smith, 1979, Dingle et al, 1983).

Lystrosaurus assemblages may occur in the Burgersdorp Formation in the north of Lesotho below the Stormberg Group, as the Kannemeyerian Zone is cut out northwards by an overstep of the Stormberg Group (Dingle et al, 1983).

In the southern Cape, the lower Beaufort Group, as well as the underlying Ecca Group and the Dwyka Formation were distributed by the Cape folding, which continued, probably spasmodically, at least until the time that the Molteno Formation was laid down (Haughton, 1970). At the Permian – Triassic boundary, compressional stresses led to the first phase of folding and uplift in the Cape Fold Belt. According to Johnson (1976) the earliest evidence for this folding is found in the Lystrosaurus Zone of the Beaufort Group. The main phase of uplift of the Cape Fold Belt possibly was in the Anisian – early Ladinian Ages (Dingle et al, 1983).

2.5 Stormberg Group

The uplift of the Cape Fold Belt constituted a major event in the sedimentary environmental history of Lesotho, as the Cape Fold Belt became the sole provenance area of the sedimentary Molteno and Elliot Formations, which together with the Clarens Formation made up the Stormberg Group (Figure 1.3).

The boundary between the Burgersdorp and Molteno Formations therefore marks a drastic change in environmental conditions, in basin configuration and in input directions in Lesotho.

Figure 2.7 shows the Stormberg remains in relation to their provenance area, the Cape Ranges, as based on the correlation of deep boreholes in the Karoo and Cape sequences (Crowel and Frakes, 1972).

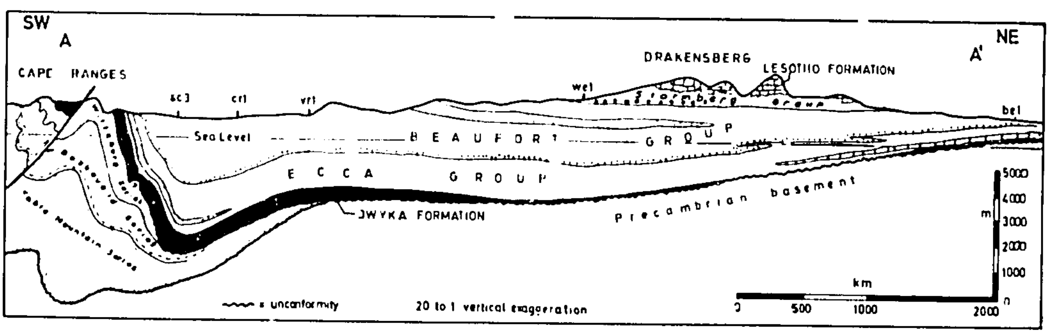

Figure 2.7: Cross section from the Cape Ranges through Lesotho to Natal (source: Winter and Venter, 1970; Crowel and Frakes, 1972. For the line of section see Figure 2.2).

Part of the Stormberg Group, from the base of the Molteno Formation to just below the top of the Elliot Formation, is considered to represent an upward fining megacycle. This part of the Stormberg Group has coarse-grained basal deposits mainly of braided streams, followed by fine-grained, sandy deposits of meandering streams and by largely argillaceous deposits of floodplain sedimentation (Turner, 1978; Visser and Botha, 1980) (Figure 2.8).

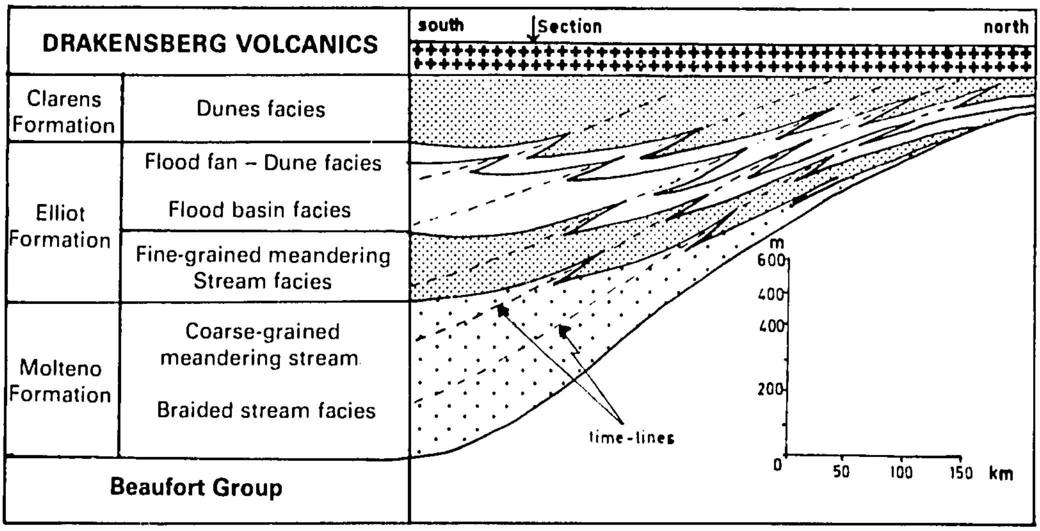

Figure 2.8: Schematic north-south section across the upper part of the main Karoo Basin, showing lateral facies changes (source: Visser and Botha, 1980).

This megacycle was caused by rapid tectonic uplift of the Cape Fold Belt, producing, initially, a coarse sediment fan and, by subsequent denudation in the source area, a gradually finer sequence of sediments.

The very top of the Elliot Formation is considered to represent a drastic climatic change, from cool temperate to warm arid, and the overlying Clarens Formation is supposed to have formed under arid conditions, with the exception of the very top, which represents a climatic change towards more humid conditions.

An isopach map of the Stormberg Group sediments (Figure 2.9A) shows a gradual northward decrease in thickness of the Stormberg sediments, away from the main contributor, the Cape Fold Belt, with maximum thicknesses of 800 metres in the south of Lesotho and values of 250 metres in the north.

The base of the Stormberg Group is generally defined by a discordance which represents an erosion surface. This sedimentary hiatus progressively increases northwards as the Molteno oversteps the upper Beaufort (Kannemeyerian Zone) in that direction to rest on the middle Beaufort (Lystrosaurus Zone) (Turner, 1969, 1972).

The South African Committee for Stratigraphy is of the opinion that there are no unifying lithologic features in the various units constituting the Stormberg Group which serve to distinguish them collectively from the Beaufort Group. The Committee therefore suggests that the use of Stormberg as a group designation in a formal lithostratigraphic scheme should be discontinued (Kent, 1980). Dingle et al (1983) however mention that the Stormberg Group of sediments form a distinct tectono-sedimentary sequence between the Beaufort Group and the Drakensberg Basalt Group as they were deposited to the north of the Cape Fold Belt and as a direct result of the sediment production by this Belt.

In Lesotho the name is still in use and therefore it appears in this text.

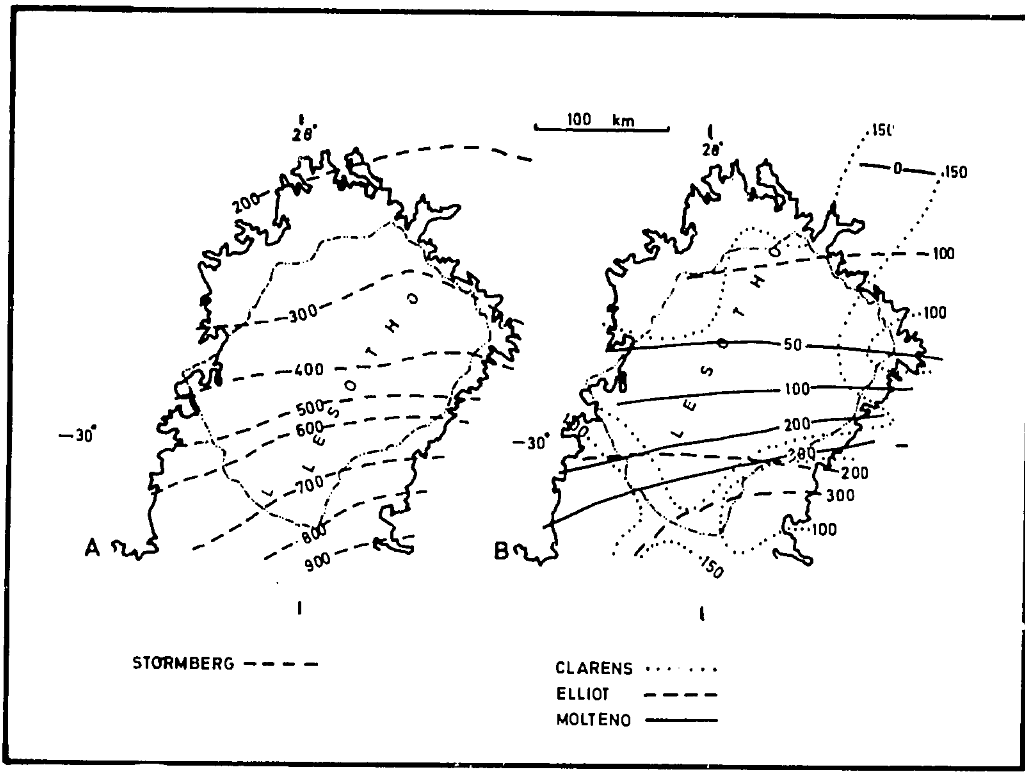

Figure 2.9: Isopachs of the Stormberg Group sediments and boundary of the Stormberg outcrop. A: total isopachs. B: isopachs of individual Formations (source: Dingle et al, 1983; Beukes, 1970).

2.5.1 Molteno Formation. The Molteno Formation as a whole forms a coarse intra-cratonic wedge, thinning out northwards, in the direction of sediment transport (Figure 2.9B), but underlying the whole of Lesotho, where it reaches thicknesses of between 150 metres in the southwest and 35 metres in the Butha- Buthe area.

Exposures in Lesotho consist of bench-forming and arkosic sandstones which range from coarse grained to gritty, and are buff and white coloured. These sandstones may contain small pebbles of vein quartz, quartzite and mud. The sandstones alternate with soft, often thinly bedded, green, buff or pale grey mudstones and siltstones and with fine-grained sandstones. Most sandstones sparkle in the sunlight. They have undergone a high degree of secondary silicification and the reflection is produced by the crystal faces of the cement.

At some places a lower horizon of gritty, ferruginous sandstones is exposed, and below this a conglomerate occurs and this latter rests upon a low relief erosion surface marking the base of the Molteno Formation and the contact with the Beaufort Group.

The basal conglomerate is often intensely ferruginised and iron concretions and plant remnants are common. This conglomerate consists mainly of quartzite pebbles and contains some quartzite boulders set in a matrix of coarse, gritty sandstone.

Intercalations of dark grey mudstones and shales with abundant carbonised plant remnants and incipiant coals do occur. Petrified wood can be found in the Molteno Formation.

Much research on this Formation has been undertaken by Turner (1969, 1971, 1975, 1977, 1978), and his published results are quoted below.

Cross-bedding patterns in the Molteno Formation are consistent with deposition by braided, low sinuosity streams that locally may have had a meandering character (Turner, 1977). Figure 2.10 shows the two major flow systems directed towards the north-west and north-east, combining to form a single northward route (Turner, 1977, 1978), leading to the floodplain, where Molteno sediments interfinger with those of the Beaufort Group and the Elliot Formation.

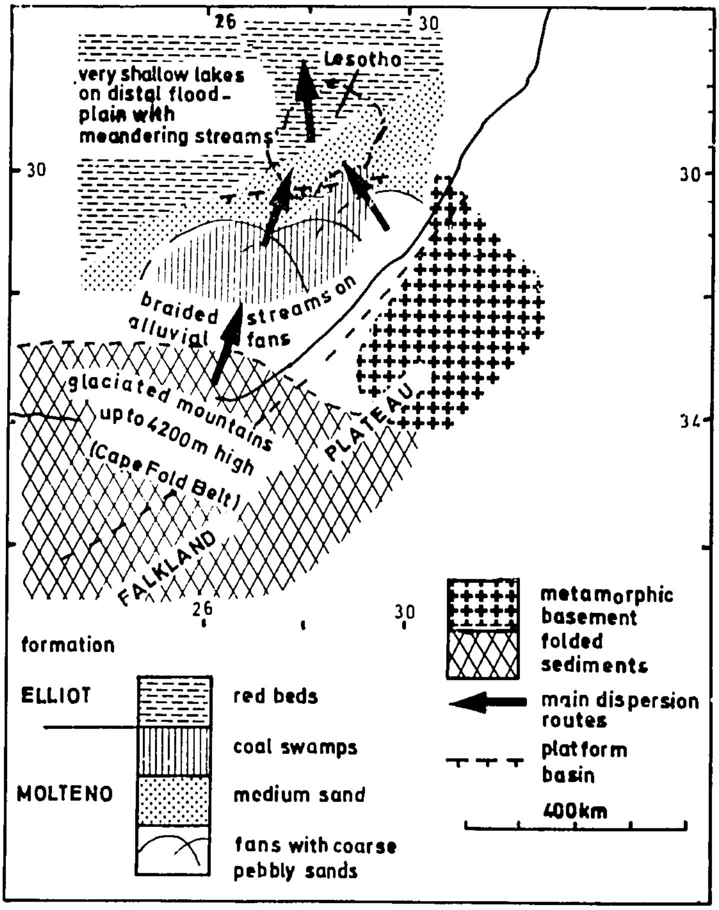

Figure 2.10: Palaeogeography of the main Karoo Basin in the Carnian Age (source: Turner, 1977, 1978; Dingle et al, 1983).

Rust (1959) mentions that the sedimentation of the Molteno Formation was a direct consequence of the second stage of the southern Cape orogeny. He also recognized sedimentary cycles in the Molteno succession, and interpreted them in terms of a series of discrete tectonic pulses. The frequency and intensity of these pulses are reflected in the stratigraphic distribution and the variation in the grain size of the sandstone horizons.

Turner (1972, 1975, 1977, 1978) subdivided the Molteno sequence into three members, each representing an increase in gradient and sediment input due to source area uplift, that is the rise of the Cape Fold Belt. Each member forms part of a sedimentological wedge thinning northwards and consisting of one or more upward-fining cycles. Each cycle shows a rough repetition of lithologies and represents a minor tectonic pulse (Table 2.1).

The pulsatic tectonic uplift in the mountainous source area may have resulted from a clockwise – counterclockwise wobble of eastern Gondwanaland (Australia – Antarctica) during the Triassic Period, which resulted in the repetitive onset and release of compressional stress against the southern tip of Africa (Anderson and Schwyzer, 1977).

Table 2.1: Members, Cycles and Lithofacies in the Molteno (source: Turner, 1970, 1978)
*present in Lesotho (?)

Member major phase of increase in gradient and sediment input from rising Cape Fold Belt	*Cycle* upward-fining sequence, representing minor tectonic pulses	*Lithofacies* rock record in relation to environment of deposition
Upper member*	Cycle F) Cycle E) cyclic nature Cycle D) less clear	
Middle member*	Cycle C	Molteno coal Indwe Sandstone Conglomerate
Lower member	Cycle B	Cuba Coal Conglomerate
	Cycle A	Indwe Coal and Shale Conglomerate

According to Turner (1970) the sequence of lithofacies within one cycle ideally consists of:

1. a basal facies, made up of pebble conglomerate which rests on an erosion surface of low relief. Poor sorting and the lower erosion surface implies deposition by turbulent currents of high intensity within the upper flow regime of the braided streams during times of intensive floods;

2. a sandstone facies, making up the greater part of the Molteno cycle, with sandstones of lenticular nature ranging in thickness from 20 to 50 metres; this facies representing point bar complexes of braided streams;

3. fine sandstone grading upwards into siltstone and silty shales. The facies represents sediment deposited almost exclusively from a suspension in a permanently inundated environment with slight current activity such as in the quiet parts of the channel or

in abandoned channels. The facies probably represent a fluvial channel sequence of dominantly in-channel sediments, deposited during times of low water;

4. shale and coal facies: the shales may represent fluvial overbank sediments, deposited from suspension in the quiet backswamp areas of the floodplain. The thin coal seams and many plant remains result from the growth of vegetation on the floodplain under shallow water conditions.

The lower member of the Molteno Formation, with cycles A and B, only occurs to the south of Lesotho, whereas the middle member overlaps the lower member and thins progressively northwards (Figure 2.11).

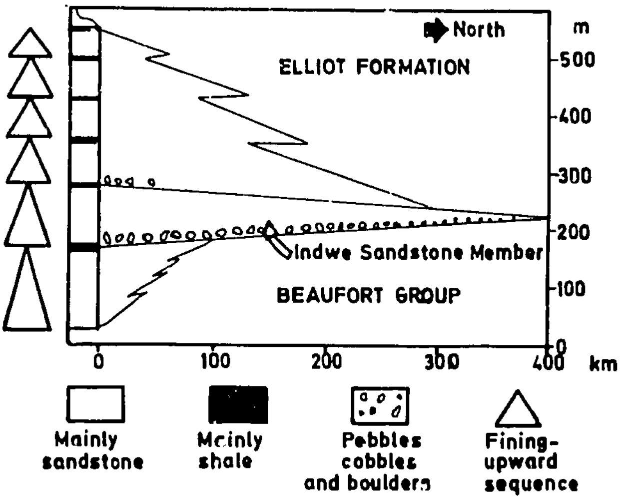

Figure 2.11: Generalised Molteno stratigraphic relations in the main Karoo Basin (source: Turner, 1978).

The middle member largely consists of the Indwe Sandstone facies, which is the most extensive deposit in the Molteno Formation (Figure 2.11), and represents a shortlived maximum of gradient, sediment input and tectonism (Turner, 1978).

In Lesotho basal conglomerate facies have so far been found in the following areas: the Hlotse Valley, south-east of Leribe; the valleys of Phuthiatsana and this river's side-branch, the Koro-Koro, near Mazenod; the Lerato Valley, near Morija; the valleys of the Tsoaing, the Motubatsana and Likhetla, near Kolo; the Montsoane Valley, near Mafeteng, and the Senqu Valley, west of Quthing.

This basal conglomerate marks the base of the Molteno Formation, as it rests on an erosion surface below which the Burgersdorp Formation can be found. Together with the overlying sandstone and the finer deposits, it may correlate with the Indwe Sandstone Member, although further research will have to prove this. Along the Tsoaing River Turner (1972) describes a site where the above mentioned cycle is capped by a grit and coarse sandstone of the succeeding, but incompletely developed cycle.

The upper member shows a progressive shift through time of each fining-upward sequence (Figure 2.11) and its cyclic nature is less clear (Table 2.1).

The conglomerate beds in Lesotho hold extrabasinal and intrabasinal material. The extrabasinal pebbles are quartzites of the Cape Super Group, of Karoo sandstones and of Cambrian basement rocks. Although the conglomerate components have largely been derived from the south, the Precambrian rocks could, according to Dusar (1979), only have come from the Transvaal craton in the north. He suggests that these Precambrian rocks were transported to Lesotho from the Transvaal Highlands during the Dwyka as fluvioglacial material, and then reworked on structural domes during the Beaufort. Later, during the Swartberg phase of the Cape orogeny, these rocks were eroded on the structural domes and deposited by Molteno rivers in depressions which, as will be shown later, are now overlain by Stormberg structural highs in Lesotho.

As fossils other than plants are scarce in the Molteno Formation, it is difficult to date it. An upper Triassic, Carnian age has however been suggested on the basis of palaeobotanical research (Anderson and Anderson, 1971; Turner, 1975; Anderson, 1976).

2.5.2 Elliot Formation. The Elliot Formation, formerly known as the "Red Beds", lies conformably on the Molteno Formation and was also formed in the Triassic. The Formation is characterised by the presence of red and purple mudstones and shales, together with red sandstones and thick beds of feldspatic sandstones, ranging in colour from buff to yellow and white. These latter sandstones are often coarse and gritty at the base and mostly very impersistent. Many of the sandstones are calcareous. The strong red or purplish colouration, as suggested in the original name of the Formation, differentiates the Formation from the Molteno Formation below and from the white and cream coloured Clarens Formation that overlies it. The transition from Molteno to Elliot is gradual, indicating that sedimentation was continuous. This makes it difficult sometimes to make a sharp division between the two formations. Their boundary is often taken at the first purple mudstone above the highest coarse, gritty sandstone. Red mudstones however do occur in the Molteno Formation and sandstones resembling the glittering Molteno sandstone do occur above the base of the Elliot Formation. Turner (1972) suggests that probably the most useful criteria for distinguishing the Elliot Formation from the Molteno Formation are: the abundance of reptile remains, and especially dinosaurs; the persistent presence, both laterally and vertically, of red mudstones and shales; the absence of carbonaceous shales and coal seams; and the lower sandstone/shale ratio. More detailed work needs to be done, however, to establish a general boundary (Botha, 1968).

Rocks belonging to the Elliot Formation underlie the whole of Lesotho and can be found outcropping in the lowlands, as far north as the northernmost point of the country, and in the Senqu Valley, as far upstream as Liqolabeng. These rocks predominantly consist of soft, red and green coloured, mudstone and siltstone beds, these latter alternating with fine to medium grained sandstone beds, which are more compact, commonly bench-forming, and grey or buff in colour.

Calcareous nodules and thin calcareous beds occur within the mudstones and sandstones throughout the succession. The sandstones may display cross bedding, ripple marks and scour and fill structures. They sometimes contain coarser channel lag deposits at their base. Towards the upper part of the Formation the siltstone-mudstone sequence is often increasingly red coloured and predominates over the sandstone. Coarse grained sandstone beds may occur in the lower part of the Elliot succession. Tuffaceous layers have been reported to occur in the sandstones in the Roma and Tša-Kholo area and south of Ha Motšoene, near Teyateyaneng.

The Elliot Formation thins rapidly northwards from a maximum of about 500 metres in the southern part of the Karoo Basin to 300 metres in the south-east of Lesotho and to 50 to 75 metres in the area between Moroeroe and Lenakaneng rivers (Figure 2.9).

Botha (1968) made a detailed study of the lithology and stratigraphy of the Elliot Formation in the type region near Elliot. A study of palaeocurrent directions in the sandstones in that area revealed that the sedimentary material was derived from two geographically different, but otherwise similar, source areas, one situated to the north and the other to the south of the area of deposition.

During the laying down of the Elliot Formation denudation considerably reduced the height of the Cape Fold mountains, resulting in a less steep palaeoslope north of the mountains towards Lesotho, and, therefore, in much finer deposits than those formed during the laying down of the Molteno Formation.

Visser and Botha (1980) studied the sandstone units in the Elliot Formation at Barkley Pass and concluded that the succession can be subdivided into three depo-facies representing different environments: a lower facies, representing meandering channel deposits and floodplain facies, a middle part representing a flood basin facies and an upper part representing flood fans overlain by dunes (Figure 2.8). The sequence suggests that depositional energy diminished through time and that aeolian conditions became dominant towards the end of Elliot deposition.

The top part of the Elliot Formation forms a transitional zone of alternating sandstone and shale beds with an increasing sandstone/shale ratio towards the top. Stockley (1947) therefore used the name Transition Beds for this part of the Formation. This transition zone indeed, seems to represent conditions of beginning aridity and spreading aeolian sands. The fauna content of the Elliot Formation also becomes sparser towards the top, which may confirm such a climatic change. There is also a change from heavy limbed fossils of dinosaurs in the lower strata to light built cursorial types in the upper strata (Haughton, 1924), which is considered evidence in favour of an increasing aridity in climatic conditions during the deposition of the Transition Beds (Haughton, 1969).

The gradual change in climate resulted in uneven contact between the Elliot Formation and the Clarens Formation and this is indicated by the presence of lenses of red mudstones in the Clarens Formation and of lenses of sandstones in the Elliot Formation. Aeolian sands gradually encroached upon the area and at one stage deposition of both formations took place at the same time.

The mudstones and the many thin lenses of sandstone and siltstone are generally brilliant red, especially in the upper part of the Elliot sequence. The red colour is due to the presence of haematite, which was either derived from preexisting soils or from red beds, and forms a coating around the grains. The red colour is generally considered as an indicative of an arid or semi-arid climate.

2.5.3 Clarens Sandstone Formation. The Clarens Sandstone Formation is the youngest sedimentary deposit in the Karoo Basin. The name, Clarens Sandstone Formation, was accepted by the SACS as proper terminology (SACS, 1980). The Formation was formerly called Cave Sandstone because of the many overhangs in the deposit and was subdivided by Van Eeden (1937) into the lower Transition Beds and the higher Massive Sandstone. This subdivision was followed by Stockley (1947) for Lesotho. In Lesotho, the name Clarens Formation is at present used, together with the names Cave Sandstone, for the highest massive sandstone in the Clarens Formation, and Transition Beds for that part of the Clarens Formation situated below the Cave Sandstone.

Du Toit (1918) was the first to suggest that the Clarens Sandstone Formation is of aeolian origin.

In Lesotho, the Transition Beds consist of a basal bed, which is compact, pale red to red or cream coloured fine-grained sandstone or siltstone whose facies resembles the overlying Cave Sandstone and which lies directly on the Elliot Formation. Above the basal bed are red, green or pink siltstones and mudstones, generally displaying mudstone-type cleavage.

The Cave Sandstone facies of the Clarens Formation consists of massive white to creamy brown coloured, fine to very fine grained sandstone and siltstone, frequently containing layered calcareous nodules and ferruginous nodules and rarely very thin chert beds. This upper sandstone is usually unbedded but is partly cross-bedded.

Beukes (1970) distinguished three mappable rock stratigraphical members in the Clarens Sandstone Formation:

Zone I is the basal zone and consists of massive, thick to very thick bedded, light brown and light red, very fine grained sandstone, silty sandstone and sandy siltstone. Irregular calcareous concretions and lenticular deposits with shallow water structures are abundant.

Zone II consists of alternating beds of massive and cross-bedded sandstone. Aeolian cross-bedding is almost solely restricted to Zone II.

Zone III is made up of massive to very thick bedded, very fine grained sandstone to massive silty sandstone, sandy siltstone and siltstone. Lenticular shallow water deposits are abundant throughout Zone III and especially conspicuous where there is contact with the overlying basalt.

On the basis of lithology and fossil content, Beukes (1970) came to the following conclusions on the depositional environment of the three Zones:

Zone I was deposited under semi-arid conditions. During the dry season the huge plateau, covered by sedimentary material of the Beaufort Group, was swept by winds, and fine-grained sediments started to accumulate in a shallow basin. After deposition, the sand dunes became saturated with water and this resulted in sand-flows and the destruction of the dune structures. Excess water resulted in temporary streams and playa lakes between the dunes. In these lakes, fresh water invertebrates flourished temporarily. The sand dunes were probably covered with scant vegetation and were roamed by light-limbed dinosaurs. Insects were present in the vicinity of the water. During deposition of Zone I, a gradual change towards still more arid conditions took place.

Zone II was deposited under arid conditions. Strong winds under dry climatic conditions caused the migration of dunes. Pans and playa lakes became filled up by migrating sands and underlying dune structures became protected by overlying sands. Plant and animal life were probably still present, although less abundantly.

Zone III was deposited during the period that the climate was changing from arid to semi-arid. Rain water and sandflows destroyed the primary dune structures. The climate became increasingly more humid during the deposition of Zone III, especially close to the first outpourings of basalt when plant and animal life flourished again, as is proved by the fossil remains of tree trunks and the dinosaur footprints in sandstone interbedded with basalt (Kingsley, 1964).

The base of the Clarens Sandstone Formation in Lesotho is taken as the contact between the pale to reddish or cream fine-grained sandstone or siltstone member of the Transition Beds and the underlying, often green or pink mudstones and siltstones (Figure 2.16). This contact is conformable and often gradual.

The top of the Clarens Sandstone Formation is overlain by lavas of the Lesotho Formation (Figure 6.7). Here, also, the contact is gradual in that interfingering occurs and lenses cf sandstone, often well bedded and associated with shale, are common in the lower basalts. Stockley (1947) mentions the occurrence of as many as six sandstone beds intercalating with the lowermost lave flows in the upper Quthing Valley, but in other parts of the country there are rarely more than three. They are mainly found in the basal part of the Lesotho Formation and their structure indicates deposition under shallow water conditions, probably playa lakes (Beukes, 1970), except in the cases of massive sandstone, which represent wind deposits.

An isopach map of the Clarens Sandstone Formation in Lesotho (Figure 2.12) shows thickness variations within the country from 90 to 200 metres.

The axis of the Clarens depocentre runs in a north-east-south-west direction through Lesotho. Beukes (1970) mentions that this may represent the final relic of the originally huge sedimentary basin of the Karoo. Dingle et al (1983) mention that this trough may be related to local tectonism which started before but also continued at the time of the Drakensberg volcanism. More local variations in thickness may be due to an irregular contact with the Elliot Formation and to an uneven surface onto which the lavas were poured. This uneven surface may or may not be due to differential regional commencement of volcanism.

The average palaeowind directions, as measured from aeolian cross-bedding, indicate that the source area of the Clarens Sandstone Formation was situated towards the west, north-west and south-west, and the good sorting of the Clarens may suggest primary aeolian deposition.

A trend map of the regional distribution of average grain size for the cross-bedded sandstone of Zone II is shown in Figure 2.13. The decrease in grain size towards the east corresponds with the palaeowind direction.

The mineralogical composition of the Clarens Sandstone Formation is given in Figure 2.14. Considering the fact that the untwinned feldspars have been grouped together with the quartz, the composition of the sandstone varies between quartzose and feldspatic sandstone for the cross-bedded sandstone, and between subgraywacke and graywacke for the massive- and silt-sandstones. The matrix is calcareous and contains, as the main component, illite, together with minor amounts of kaolinite, montmorillonite and chlorite.

The Clarens Sandstone Formation underlies the whole of Lesotho, with outcrops as plateau surfaces and as cliffs conspicuously marking the boundary between the lowlands and the foothills in the eastern part of the mohokare Basin (Figures 6.6 and 6.7), in the valley of the Senqu as far north as Sehonghong and in the Tsoelike Valley as far upstream as Sehlabathebe.

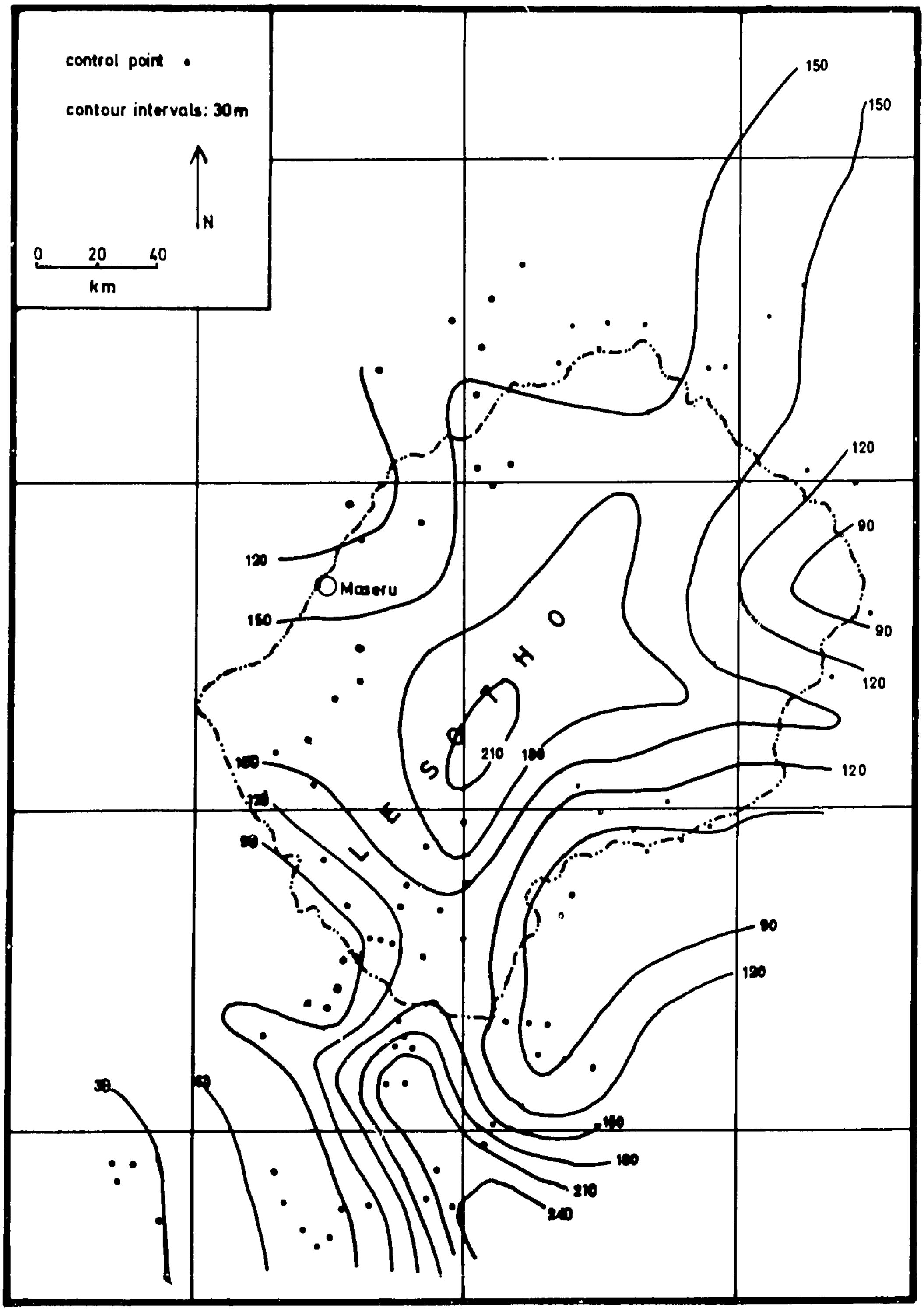

Figure 2.12: Thickness variations in the Clarens Sandstone Formation (source: Beukes, 1970).

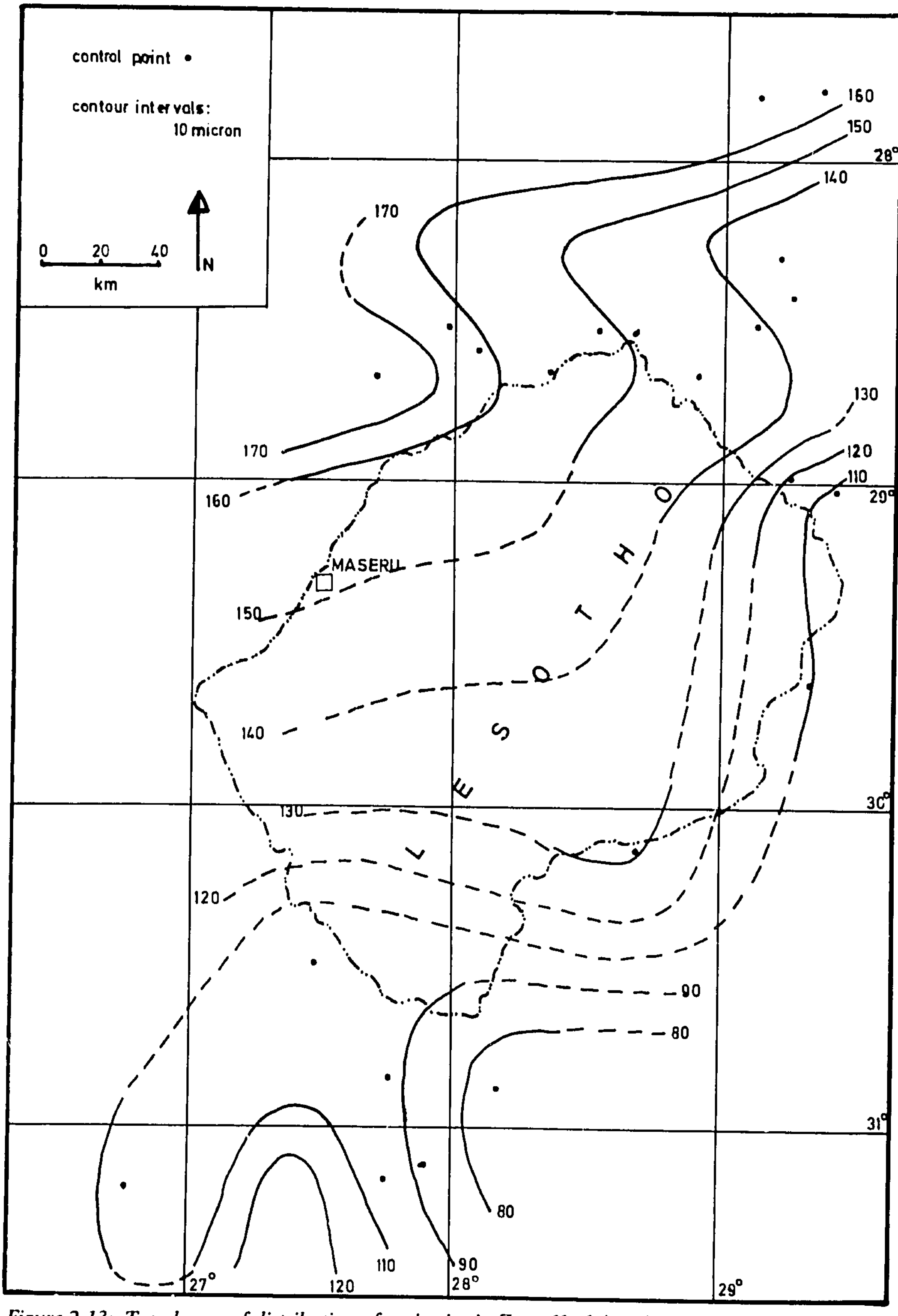

Figure 2.13: Trend map of distribution of grain size in Zone II of the Clarens Sandstone Formation (source: Beukes, 1970).

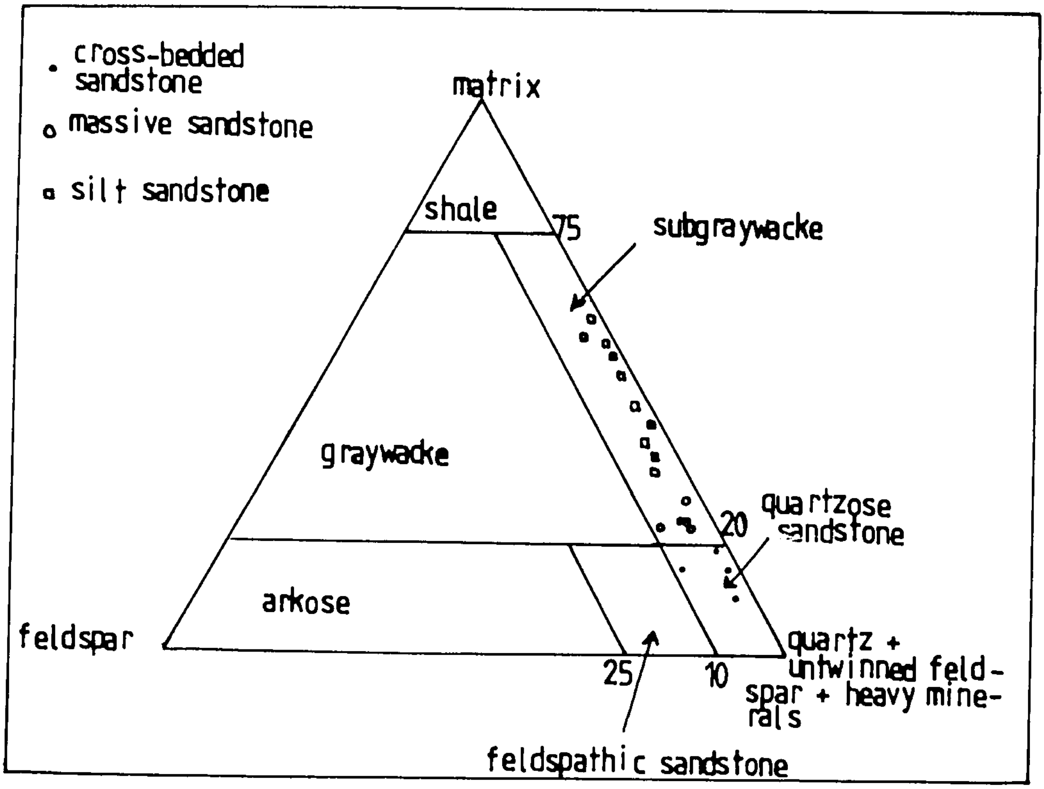

Figure 2.14: Mineralogical composition of sandstones of the Clarens Sandstone Formation (source: Beukes, 1970).

In Zone I, the calcareous content of the matrix may be high, and this makes the particular horizon susceptible to weathering. The many overhangs in Zone I could, therefore, be the result of differential weathering processes.

The fauna of the Clarens Sandstone Formation indicates a probably Rhaetian cum Hettangian age (Ellenberger, 1970; Cox, 1973).

Binnie and Partners (1971) mapped the elevation of the basalt/sandstone contact in Lesotho. On the basis of the field information obtained and by interpolation, a structural contour map was made (Figure 2.15).

From this map it can be seen that the elevation of the basalt/sandstone contact in Lesotho can vary from 1 480 metres at Tiama's Drift on the Senqu, to 2 510 metres, near Sehlabathebe. The authors of this map and later also Dusar (1979), concluded that these height differences cannot be due to the varying thickness of the Clarens Sandstone Formation, nor to the uneven surface over which the lava flowed, for example dunes and valleys, but must be the result of folding and faulting. They suggest that the doming was probably caused by the intrusion of sills into the underlying strata which may have occurred immediately before and during the outpourings of the first lavas. This is confirmed by the fact that the early lava flows are conformable with the sandstone, whereas the later flows are frequently horizontal.

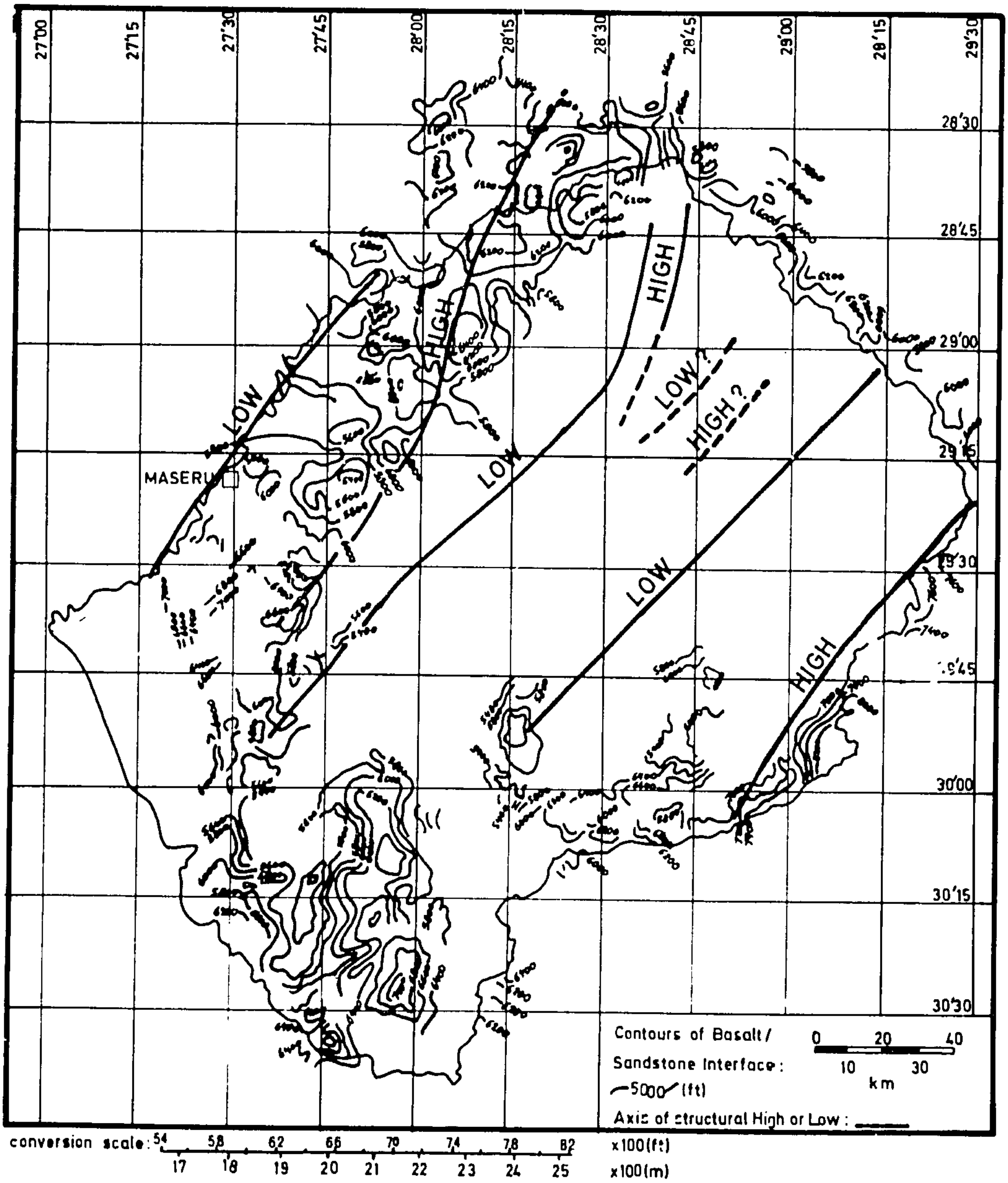

Figure 2.15: Structural contour map showing the elevation of the original basalt/sandstone interface (source: Binnie and Partners, 1971).

Figure 2.16: Sandstones of the Clarens Formation resting on mudstones and shales of the Elliot Formation near Maphotong.

Chapter Three

Magmatic and tectonic episodes

3.1 The Karoo volcanic episode

3.1.1 Early Phase. There are indications that, in Lesotho, the Karoo volcanic episode began as early as the time of the Elliot Formation, whereas in the Republic of South Africa findings indicate a beginning as early as that of the Dwyka Formation.

In Lesotho, Willan (1976) describes the occurrence of vitric tuff interbedded with Elliot strata between Maseru and Teyateyaneng. At Roma, on the University grounds, and in Maseru, near the Lesotho Sun Hotel, Montmorillonite clay has been found in the Elliot Formation (Reed, 1978). The presence of Montmorillonite clay in the Elliot is considered to be due to the alteration of acidic volcanic glass.

In the Tša-Kholo area, some sandstone beds of the Elliot Formation are reported to contain tuffaceous layers. Similar findings have been reported from areas to the south of Lesotho. Botha and Theron (1967) mention the occurrence of Bentonite in the Elliot beds near Jamestown. Bentonite is a clay, largely composed of the minerals montmorillonite and beidellite, and is considered to have been formed by the devitrification of glassy igneous material, usually tuff or volcanic ash, together with the latter's chemical alteration. The same authors mention the occurrence of volcanic agglomerates and breccias embedded in the Clarens Formation near Matatiele, Maclear and Elliot.

Occurrences like those described above are indications that explosive volcanic activity produced ejecta which descended on Lesotho, at least as early as the time of the Elliot Formation. It is not clear, however, where the centres of this volcanic activity were situated. Botha and Theron suggest that some of the volcanic necks in the southern part of Lesotho, and the adjacent areas in the Republic of South Africa, previously regarded as of post-Clarens age, erupted while sedimentation of the Elliot was still in progress. Bristow and Saggerson (1983) mention the possibility that a distant source, possibly Patagonia in a predrift position, produced much of the volcanic material in the Karoo sediments.

During the final stages of deposition of the Clarens Formation in Lesotho, explosive volcanic activity produced pyroclasts from many discrete centres. They were blown out and deposited as volcanic ashes, tuffs and agglomerates. So far 145 volcanic necks have been located in Lesotho. They represent perforations without cones and without associated lavas. Their distribution is shown in Figure 3.1.

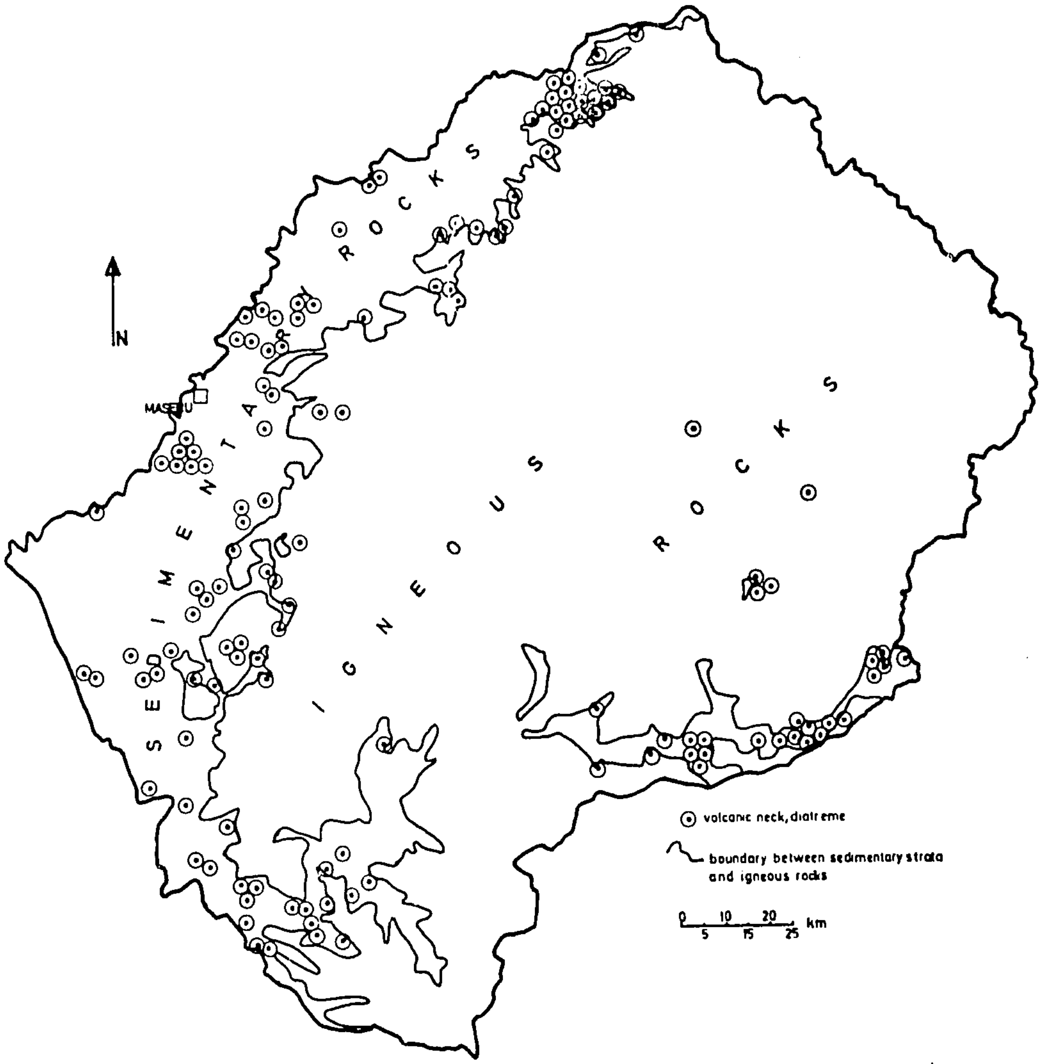

Figure 3.1: Distribution of volcanic necks in Lesotho (source: geological map of Lesotho, 1/250 000).

They can be found in the whole of Lesotho, including the lower Orange Valley. Binnie and Partners (1971) drilled a borehole near Taung which went through a volcanic plug, concealed below 124 metres of horizontal basaltic strata. It is most likely that more plugs are hidden below the Lesotho Formation. Most volcanic necks occur in the Clarens and in the Elliot beds, while only a few are found in Molteno. The upper stratigraphic limit of these necks falls within the basal part of the Lesotho Formation and their lower limit is near the Burgersdorp/Molteno boundary.

Gevers (1928) suggests that the volcanic explosions took place not far below the Molteno Formation and possibly within it. He also mentions that the stratigraphical horizons which make up the present surface, relate to the number and size of the volcanic necks, the nature of their rock fillings, including the abundance of dolerite, and the frequency of any one particular kind of intrusion. Considering the findings in Lesotho, this seems plausible. Figure 3.2, from Dingle et al (1983) illustrates how the distribution of vents and vent characteristics seems to be stratigraphically controlled.

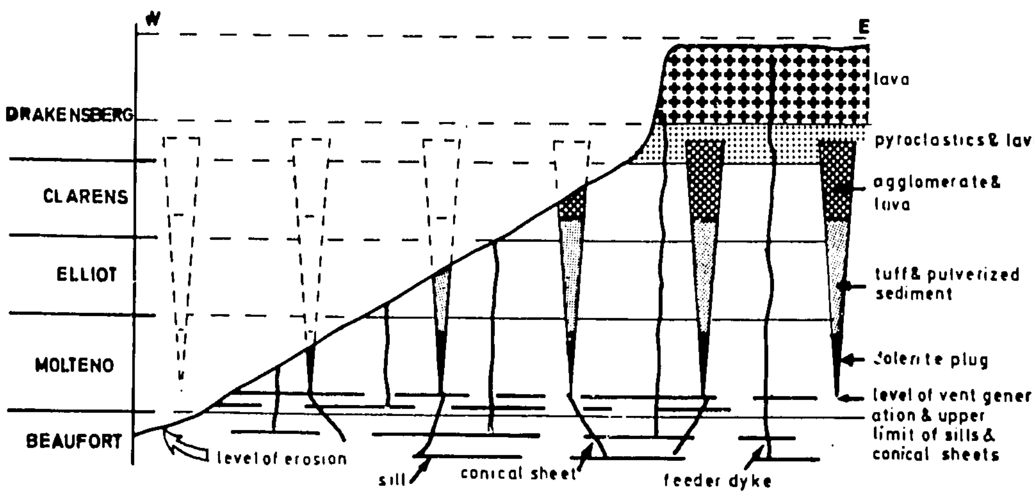

Figure 3.2: Idealised east-west section showing stratigraphic relationship of Drakensberg intrusive and extrusive volcanic rocks in the main Karoo Basin (source: Dingle et al, 1983).

The fact that most volcanic plugs do not penetrate the lower basaltic lava beds indicates that the explosive phase did no contribute to the formation of those beds.

There are no indications that the volcanic necks occur along pre-existing tectonic lines (Stockley, 1947). However, the necks may occur as individual volcanic centres or in clusters.

The diametre of the necks in Lesotho varies between 5 and 50 metres and it tends to increase with their height (Figure 3.2).

Generally, the country rock surrounding the plugs is only slightly deformed, except where the plug is wide. Country rock may then be found dipping into the vent. The vent fill, if it is exposed at the surface, depends upon the stratigraphic position in which the vent comes to the surface. In the lower situated vents it is likely to be dolerite, while in the higher positions it is likely to vary from tuff mixed with fine grained sediments, mainly from Elliot and Clarens beds, to agglomerates and basaltic lavas.

Volcanic tuff and agglomerate beds can be found in Lesotho. They occur largely in the south of Lesotho and usually they are found in a stratigraphic position between the Clarens sandstones and the basaltic lavas. Similar deposits occur within the lowest lava flows and a few can be found within the highest beds of the Clarens Formation (Figure 3.9).

These volcanic clastics, wedging out over short distances and clearly having a local appearance, relate to the many plugs and vents located in the southern part of Lesotho.

All the phenomena mentioned above indicate that, during the last phase of the Clarens Formation deposition, and until the onset of the flood basalts, explosive volcanic activity must have occurred, especially in the southern part of Lesotho. Discrete volcanic vents produced ash which was locally deposited and partly intermingled with the Clarens sands and the lower basaltic lava beds.

The local stratigraphy of individual vents and their related extravent pyroclastics have not been worked out yet in Lesotho. Lock et al (1974) undertook a survey of similar occurrences near Barkly East, these together being labelled as the Moshesh's Ford Formation.

Dingle et al (1983) mention that the main depocentre for the upper part of the Clarens Formation (Zone III) lies along a zone where the major volcanic centres are thought to have been situated. It is in this area that the large thickness variations in Zone III have been recorded and are thought to be due to rapid subsidence of the area.

3.1.2 Lesotho Formation. After the explosive phase, which occurred in the early Jurassic, magma of basic composition rose through long fissures, intruding the sedimentary strata and spreading over the sedimentary fill of the Karoo Basin (Figure 6.13).

A succession of mainly tholeiitic basaltic lava flows of varying thicknesses, known as the Lesotho Formation, was built up and reached a thickness of at least 1 600 metres at Mont-aux-Sources in the north of Lesotho. The Lesotho Formation originally covered the whole of Lesotho and large areas around it, but subsequent erosion of the volcanic plateau has removed an unknown thickness of the lava sequence.

Beds of tuff and ash are found intercalating with some of the lower flows of the lavas, and this indicates a coexistence of the explosive volcanoes and the early outpourings of lava.

The lower 300 metres of the lava succession has lenses of sandstone similar to the massive Cave Sandstone or to the well bedded sandstones associated with shales of the Clarens Formation. A combination of wind deposition and deposition in playa lakes may have resulted in the formation of these lenses (Beukes, 1970). At some places sandstones interdigitate with the lower lava beds. This indicates that the first lava flows did not completely cover the Clarens Formation. At the same time the aeolian sands continued to be deposited and reworked. During the volcanic interruptions, renewed incursions of Clarens sands and shales occurred over the first lava flows.

Neptunian dykes, made up of fine sandstone or siltstone and often being tuffaceous, occur within the lower lava flows and the Clarens Formation. Upward injection resulting from pressure on underlying unconsolidated sediments may have caused the formation of these dykes (Dempster and Richard, 1973).

The basaltic lava flows were probably very mobile as they have been found to extend for as much as several kilometres in almost parallel and horizontal strata (Stockley, 1947; Binnie and Partners, 1971). It also seems evident that each successive flow closely followed the chilling of the upper surface of its predecessor, as there are few signs of weathering or erosion between the flows. Flow structures can at some places still be observed at the surface of a lava flow (Figure 3.10).

Flows vary in thickness to a maximum of 50 metres. Each flow has a 10 to 20 millimetres thin basal zone of aphanitic basalt on which lies a zone of pipe amygdales. This zone was produced by the movement of bubbles of gas through the viscous, cooling material, the bubbles being generated at the chilled surface of the previous flow. The succeeding, central zone is of massive, weakly amygdaloidal basalt and finally there is an upper zone of strongly amygdaloidal basalt (Dempster and Richard, 1973). The thinner flows are usually amygdaloidal throughout.

The amygdales are filled with zeolite, quartz, agate, calcite, chalcedony and chlorite, which crystallised from solutions in the flows (Stockley, 1947; Bleakly and Workman, 1964).

The lavas are mainly basaltic and contain calcic labradorite, augite, opaque minerals and some olivine. Their average chemical composition is shown in Table 3.1.

Table 3.1: Average composition of Lesotho Formation basalt (source: Duncan et al, 1983).

	%		ppm
SiO_2	51.50	Cr	283
Al_2O_3	15.69	Sr	192
Fe_2O_3	10.96	Ba	177
CaO	10.69	Zr	94
MgO	7.01	Ni	94
Na_2O	2.17	Y	24
TiO_2	.95	Rb	12
K_2O	.70	Nb	14.9
MnO	.16		
P_2O_5	.16		

The texture of the lavas is microporphyritic, and in the succession these lavas gradually become less basic with height (Cox and Hornung, 1966).

Karoo volcanism is not everywhere of the same age. K-Ar age determinations of Drakensberg lavas and Karoo dolerite sills and dykes have shown that the Drakensberg volcanics in Lesotho began extruding 187 million years ago and continued intermittently until at least 155 million years ago (Fitch and Miller, 1969, 1971), that is from the early to the end of the middle Jurassic. Samples of basalt, taken at 6 metres and 400 metres above the base of the lava succession near Bushmen's Pass, show no essential age difference, and this indicates that there was little time between the formation of the successive lava flows (Fitch and Miller, 1969, 1971). This finding is confirmed because weathering profiles between the lava flows are not widespread.

The top of the lava sequence may represent subsidiary maxima in volcanic activity and within that sequence the following have been dated (Fitch and Miller, 1971):

million years ago
- 172 – the alteration of lavas at Bushmen's Pass
- 161 – the sill at Sebapala
- 161 – the Qalaheng dyke near Mohale's Hoek
- 155 – some dykes near Quthing and Bushmen's Pass

When volcanic activity terminated it left a lava plateau of great extent and probably of little relief.

An estimated 2 000 000 km^2 of southern Africa may have been covered or affected by dykes and sills which accompanied the eruption (Cox, 1970). At present the lavas are outcropping over 70 per cent of the surface of Lesotho, forming the mountain area and the higher foothills, whereas dykes and sills occur over the whole country, including the lower foothills and the lowlands.

3.1.3 Dykes and sills. The volcanic fissures, which are called dykes, have varying lengths of up to seven kilometres and a width which is normally between two and six metres, although much wider dykes do exist (Figure 3.11). If wider than 50 metres, these dykes contain mostly dolerite and gabbro; thinner dykes are usually doleritic or basaltic (Figure 3.12). The lavas and dolerites differ very little in composition and texture. The wider dykes usually contain coarse dolerite. Most dykes are near-vertical, but local variations may show dips as little as 60°.

Some of the dykes cut across all geological formations while others die out within the basalts. Some may therefore have been shortlived but others may have been active for a long time.

At least two swarms of dykes occur in all formations in Lesotho (Figure 3.3).

The main trends are north-west – south-east and north-east – south-west. The direction and the distribution of the dykes reflect stress patterns in the Karoo Basin at the time of igneous intrusions (Vail, 1970; Rust, 1975). Bonney (1975) mapped all the dykes in an area of 140 kilometres^2 around Roma and found a frequency of 1,2 km/km^2. In fact, dykes and sills are a very prominent feature in the whole of the Karoo Basin and are therefore referred to as "karoo dolerites".

The cover of basaltic lavas most probably had a much wider extent than at present, as dykes are found over the whole of Lesotho, including the lowlands and because their distribution also covers a large part of southern Africa.

Sills occur in the sedimentary strata, mainly in the lower beds in the southwest of Lesotho (Figure 3.13). The composition of these sills is similar to that of the lava flows and the dykes. They intrude along bedding planes, but may jump erratically from one bedding plane to another. In some cases, the sills grade into dykes. The vertical thickness of the sills varies from a few metres to a few hundred metres. There is only a slight assimilation of the adjacent sedimentary rocks (Du Toit, 1920) and it must be assumed, therefore, that while magma forced its way in between the strata, the thickness of the geological column increased by a distance equal to the sum of the thicknesses of the resulting sills (Haughton, 1969; Binnie and Partners, 1971). It must also be assumed that these intrusions modified the structure of the surrounding rocks by doming and/or faulting.

In Lesotho, the sills are usually restricted to the Burgersdorp Formation and the Molteno Formation. Only very thin sill offshoots of dykes have been found in the Clarens Formation. Sills are present in the basalts, but the former are not usually recognised as they have a chemical composition similar to the host rocks. On close examination, sills may be recognized by the presence of columnar jointing and by the absence of amygdales in the upper and lower margins.

Dykes, fissures and sills increase in number and thickness with pre-erosion depth. Information on subsurface amounts of dolerite present has been obtained from a deephole oil exploration programme, and although locally there may be strong variations, regional trends have been found to exist, as is to be seen from Figure 3.4, which shows that Lesotho has been situated in the centre of intrusive activities.

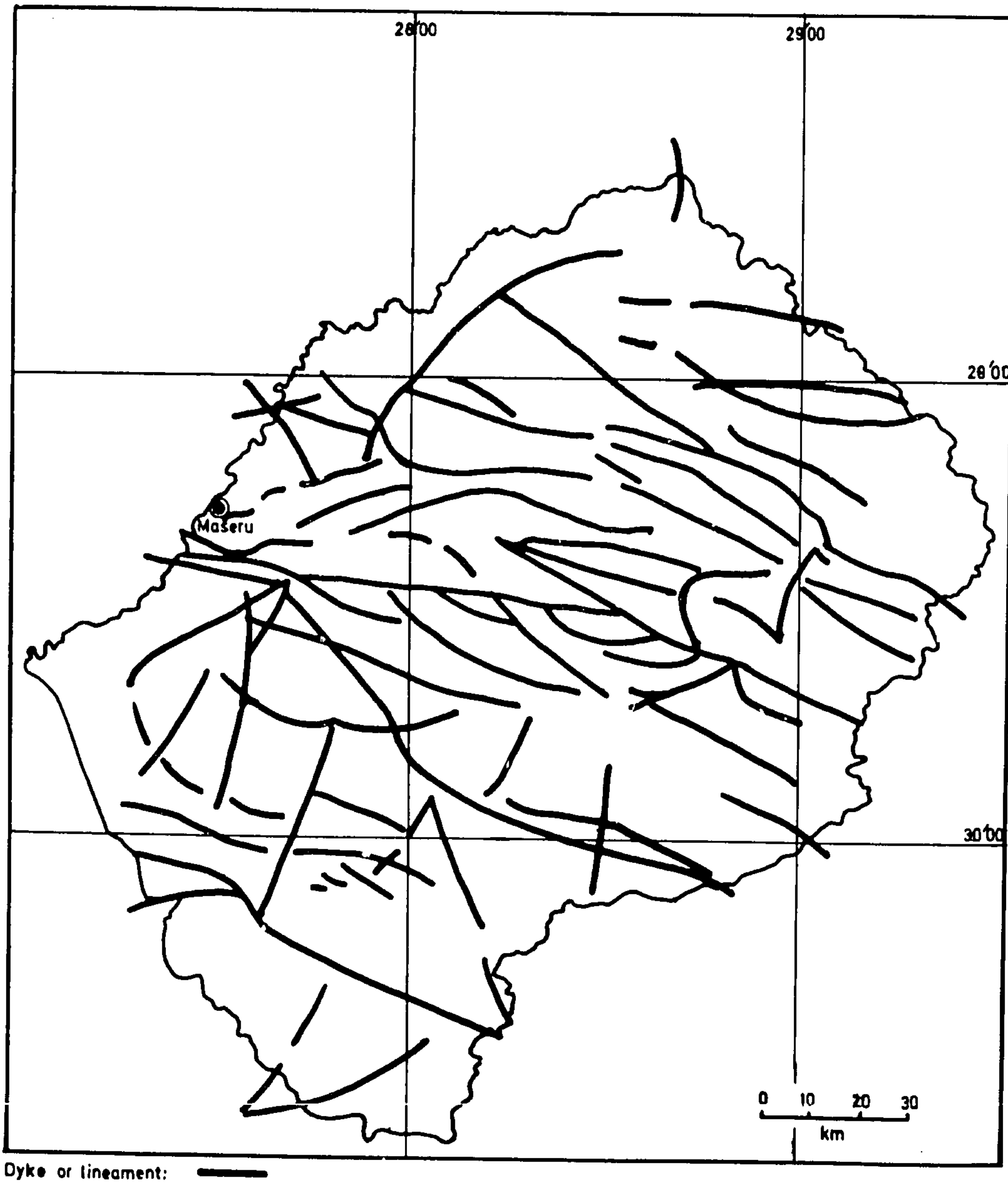

Figure 3.3: Major dyke or lineament trends in Lesotho. (source: Binnie and Partners, 1971).

3.1.4 Metamorphism. In immediate contact with the dyke and up to one dyke-width away, the country sandstones are fused to quartzites and the mudstones are baked to hornstones, both of these being the result of contact metamorphism (Figure 6.12 and 6.13). The quartzites may be fractured or massive, but the hornstones are usually fractured. Depending on the rock type, the width of the affected zone varies considerably, being least for quartzite and many times greater for hornstone. The extent of metamorphic effects also depends on the width of the dyke. Stockley (1947) found that the width of hornstone is almost directly proportional to the width of the dyke.

Beyond the zone of contact metamorphism, the country rock is affected by thermal metamorphism which discolours the rock but does not cause significant structural change.

The top of the sandstone of the Clarens Sandstone Formation is hard and has been metamorphosed to a shallow depth, that is from 0,5 metre to 1,5 metres, by the heat of the lava flows moving over it.

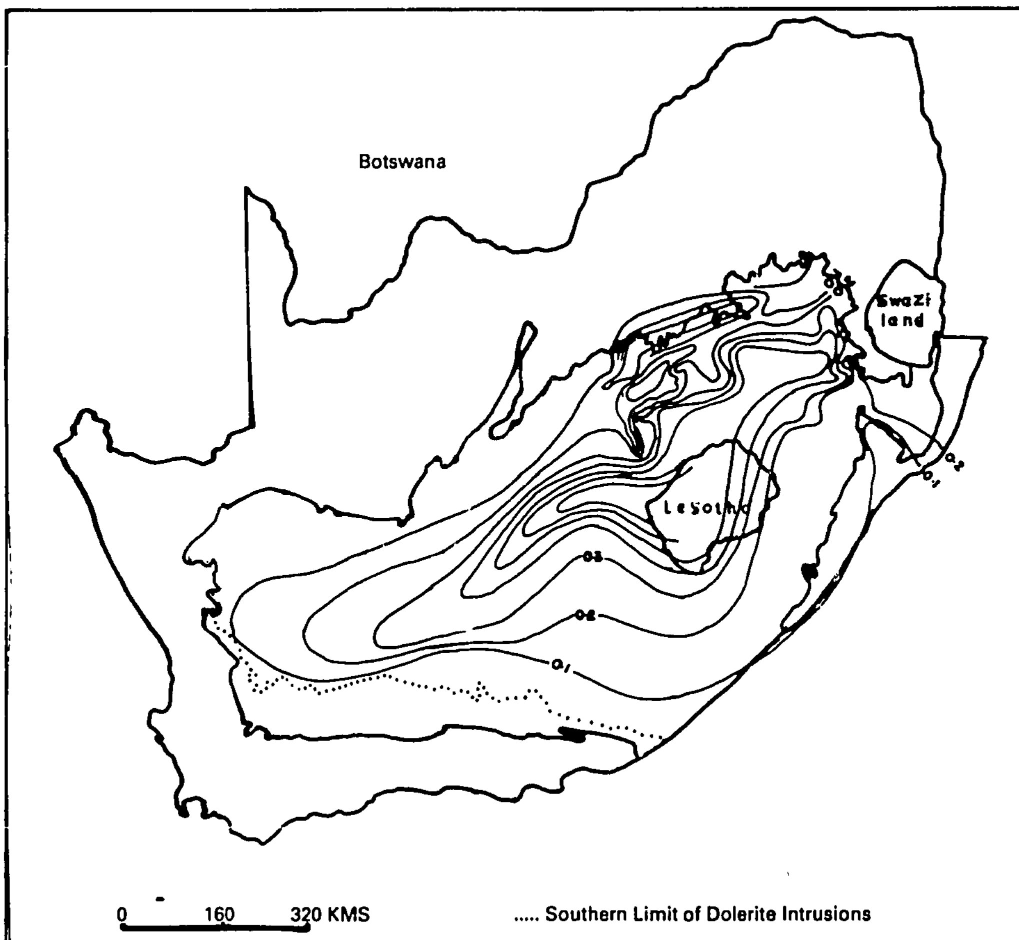

Figure 3.4: Dolerite – Sediment ratio map (source: Winter and Venter, 1970).

3.2 Intrusions and structural deformations

Du Toit (1904, 1933) and Van Eeden (1937) referred to the presence of small structural domes and basins within the Stormberg Group in South Africa, and, later, Stockley

(1947), Binnie and Partners (1971), Loxton Hunting and Associates (1973) and Dusar (1977, 1979) mention the occurrence of similar features in Lesotho.

Binnie and Partners (1971) mapped the elevation of the basalt/sandstone contact in Lesotho and Loxton Hunting and Associates (1973) undertook photogeological measurements of dips of bedding planes.

It was found that the early basalt flows, the massive sandstones and the underlying strata had been folded into a series of domes and basins approximately five to ten kilometres in diameter with dips of up to 6°, and that the elevation of the basalt/sandstone surface can vary from 1 480 metres at Tiama's Drift on the Senqu River, to 2 510 metres, near Sehlabathebe.

These domes and basins are revealed only in the areas where the sedimentary strata and the lower lavas are exposed, and in drill holes (Figure 2.15).

Binnie and Partners conclude that the doming was probably caused by the intrusion of sills into the underlying strata. This seems to be confirmed by the drilling results from two boreholes sunk on the top of structural domes, one between Kestell and Witsieshoek and one north of Ladybrand. In both cases, great thicknesses of dolerite sills have been found intruded into the sedimentary strata.

Stockley (1947) and Binnie and Partners (1971) also located several faults in Lesotho.

The exact age of the doming and faulting is not known but it may be immediately before and during the outpourings of the first lavas, as the basalt/sandstone contact and the earlier lava flows reflect the doming and faulting while the later flows are frequently horizontal.

Besides the above mentioned domes and basins of relatively small magnitude, from observations of structures around the Stormberg-Drakensberg contact (Dusar, 1977, 1979), a blockpattern of larger structural highs and lows, without a particular direction or geometric pattern, has been recognised in the near-surface Stormberg sediments.

Some of these larger structural units are known to coincide with the five basement provinces previously mentioned (Figure 1.5).

The structural highs are in periferal positions in Lesotho and have been named as follows:

Structural High	*Coinciding with*
Leribe – Butha Buthe	the Northern Plutonic Province;
Thaba Phechela – Mafeteng	
(northern part)	the Central Plutonic Province;
(southern part)	the Southern Plutonic Province;
Mount Moorosi	
Matatiele	
Qacha's Nek – Sehlabathebe	
Letšeng	

The structural lows coalesce in the central part of Lesotho and are named as follows:

Structural Low	*Coinciding with*
Teyateyaneng – Clocolan	the Basin and Range Province

Quthing – Makhaleng–
Malibamatšo
Senqu
Mokhotlong

Longitudinal plunging folds are present. They cause only minor elevation differences. They have two preferential directions: northeast – southwest to north-north-east – south-south-west, interrupted by west-north-west – east-south-east to east-west transversal trends (Figure 1.5).

The boundaries between the structural highs and the structural lows are either gradual, in extensive transitional zones, or sharply defined by faults or monoclinal flexures (Figure 1.5).

Some of the more noticeable faults are:

The Siepe Fault, which marks the transition from the Leribe-Butha Buthe High to the Malibamatšo Low.

The Helspoort Fault, which marks the transition from the Thaba Phechela – Maieteng High to the Quthing – Makhaleng Low.

The Sefako Fault, which marks the transition from the Letšeng High to the Malibamatšo Low.

The faults all have their downthrow on the side of the structural lows.

Cumulative dolerite intrusions were probably instrumental in the formation of the larger structural units, and therefore, in the monoclinal flexures and faults in between them (Dusar, 1979). Results obtained from two boreholes drilled in the Leribe – Butha-Buthe structural high seem to confirm this (Lerotholi and Reed, 1979). A hol at Mahobong reached a depth of 1 652 metres of which 256 metres (15,5%) was dolerite and one near Butha Buthe reached 1 475 metres of which 370 metres (25%) was dolerite.

The regional magnetic survey (Northway Survey Corporation, 1977) shows that the lower positions of the basement of Lesotho underlie the larger structural domes in the Karoo strata, whereas the higher positions of the basement underlie the larger structural basins in the same strata. In this connection, it is interesting to note that the supposed Port St. John's Arch (Figure 1.4) coincides with the Clocolan – Teyateyaneng Low, the Makhaleng Low and the Senqu Low.

Dusar's explanation (1977, 1979) for this inverse relationship between basement topography on the one hand, and the large structural basins and domes of the Karoo strata on the other, is that the sedimentary sequence in basement lows is thicker than elsewhere and therefore offers more space for sill intrusions than does the sedimentary sequence on basement highs. Upheaval by sill intrusion was, therefore, stronger above basement lows and less strong above basement highs, and this fact led to structural reversals (Figure 3.5).

Monoclinal flexuring, or even faulting, occurred, therefore, in the transitional zones between the structural domes, or the basement lows, and the structural basins, or the basement highs, where the dolerite sills taper out.

As faults and folds characterising the Drakensberg deformation affect the sedimentary beds and the lower lava flows, but taper out in the later lava flows, the Drakensberg deformation, as well as the larger dolerite dykes, and sheets, can be considered to be of late Clarens to early Lesotho Formation age, that is, simultaneous with the early Drakensberg volcanic phase.

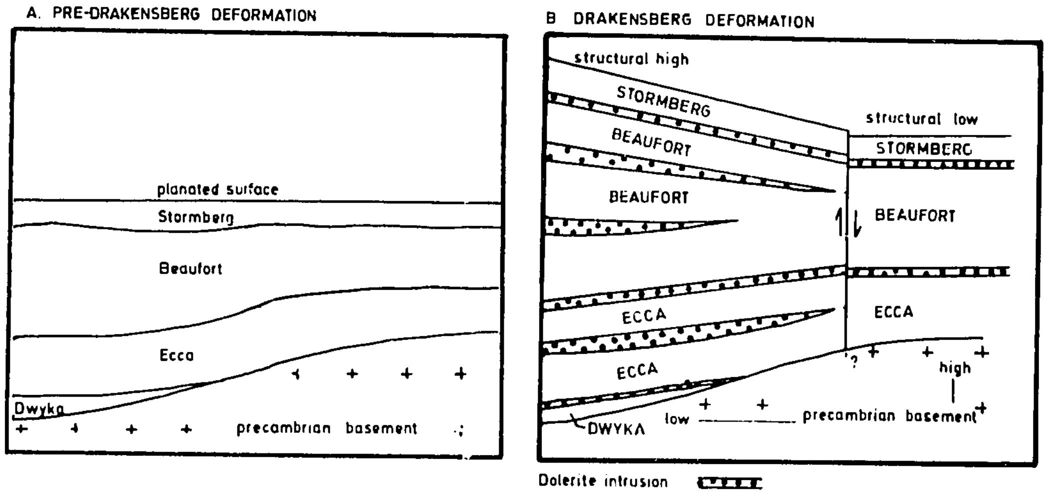

Figure 3.5: Diagramatic outline of structural reversal from Precambrian basement floor to Stormberg-Lesotho Formation contact. A: before intrusion; B: after intrusion (source: Dusar, 1979).

3.3 Kimberlite emplacements

Kimberlite is a very rare, potassic, ultrabasic, hybrid igneous rock that occurs in small diatremes, or in dykes or sills which have a limited extent (Dawson, 1971).

When, in the Cretaceous Period, Gondwanaland underwent its main fragmentation (Figure 1.2), Africa was involved in strong epeirogenic uplift accompanied by marginal downwarping and faulting and crustal extension, resulting from the deepening of the surrounding ocean basins (Dawson, 1970).

A large part of the inland plateau of Southern Africa, including Lesotho, underwent intrusions, mainly of kimberlite. Most kimberlite intrusions occurred into major fundamental fractures that cut cratonic areas and the circum-cratonic belts on a geometrical pattern (Dawson, 1970, 1971). In Lesotho, the Kaapvaal Craton as well as the Namaqualand-Natal Belt, both underlying the country, were affected by Kimberlite intrusions. However, diamondiferous kimberlites are confined to the older cratons, that is, in Lesotho the Kaapvaal Craton.

The fractures often form simple geometric patterns, sometimes intersecting to give areas of intense diatreme formation. The fractures and their geometric patterns result from large scale epeirogenic movements which may be connected with convection cells in the upper mantle (Dawson, 1970).

In Lesotho, kimberlite occurrences are found in clusters, in belts trending west-north-west – east-south-east, on the edges of basement lows (Dusar, 1979) (Figure 3.6). Emplacements have occurred at the intersection of two or three deepseated lineaments with directions of 50°, 110° to 130° and 160° to 170° (Barthelemy and Dempster, 1975).

There are, however, exceptions to this general pattern as, at several places along faults in the Karoo sediments, there is a concentration of kimberlites (Dusar, 1979), for example along the Siepe Fault and along the Helspoort Fault. Kimberlite dykes also strike west-north-west and are parallel to the dominant direction of Karoo dolerite dykes. This trend coincides with the main joint direction in the Karoo beds. Kimberlite pipes are the throats of structures that reached to the surface and were then eroded. In plan, they are roughly round with a diameter ranging from 15 metres to 1 600 metres. Dawson found that the shape of the kimberlite pipes in Lesotho is largely controlled by jointing in the country rocks. From mining experience and from the study of kimberlite features in deeply dissected areas, such as the mountains of Lesotho, it is known that pipes tend to taper downwards into dykes (Dawson, 1960, 1962) (Figure 3.7). The penetrating kimberlite was a hot fluid that came to within two to three kilometres off the surface before there was explosive breakthrough to the surface, with subsequent formation and infilling of the high level diatremes by a gas-solid fluidisation process.

A statistical study of the dimensions of kimberlites in Lesotho (Nixon, 1973) shows that kimberlites can be divided into the following groups:

Dimensions (in metres)	*Kimberlite groups*
0–8	dykes: more than two-thirds of all kimberlite dykes are less than 1 metre wide; their abundance being in inverse proportion to their width.
8–35	dyke enlargements or "blows".
70–200	satellite pipes of major intrusions and smaller discrete pipes with a true breccia or agglomeratic texture.
200–500	large pipes.

Kimberlite varies in appearance from fragmental tuffaceous or agglomeratic rock, through fragmented material cemented by magmatic kimberlite, to massive rock with magmatic textures.

The fragmental varieties predominate in the diatremes, whereas the massive rock is typical of sills, dykes and the deeper parts of the diatremes.

Near the surface, and to depths that may exceed 30 metres, the kimberlite is decomposed into soft yellowish, speckled clay. This material is known as "yellow ground". It passes downwards into "blue ground", below which lies unweathered kimberlite.

Kimberlite found in pipes is often a groundmass rich in serpentine and calcite, with some olivine, and occassionally other minerals. In kimberlite dykes, one often finds olivine, phlogopite mica, augite and other minerals. Amongst the other minerals found are red garnet, diopside, ilmenite, pyrite and diamond.

Xenoliths can be found in the kimberlites. In Lesotho they may be inclusions of Drakensberg lavas, Karoo sediments or of the basement complex and inclusions from the upper mantle. Xenoliths from the mantle are more abundant in dykes, though they are also found in the Matsoku pipe. Those xenoliths of the greatest depths are sheared and it is postulated that the movements of the African plate during the Cretaceous brought about these shearing effects, as well as the generation of the kimberlite as a partial melt derived from material at a depth of about 200 kilometres (Truswell, 1977).

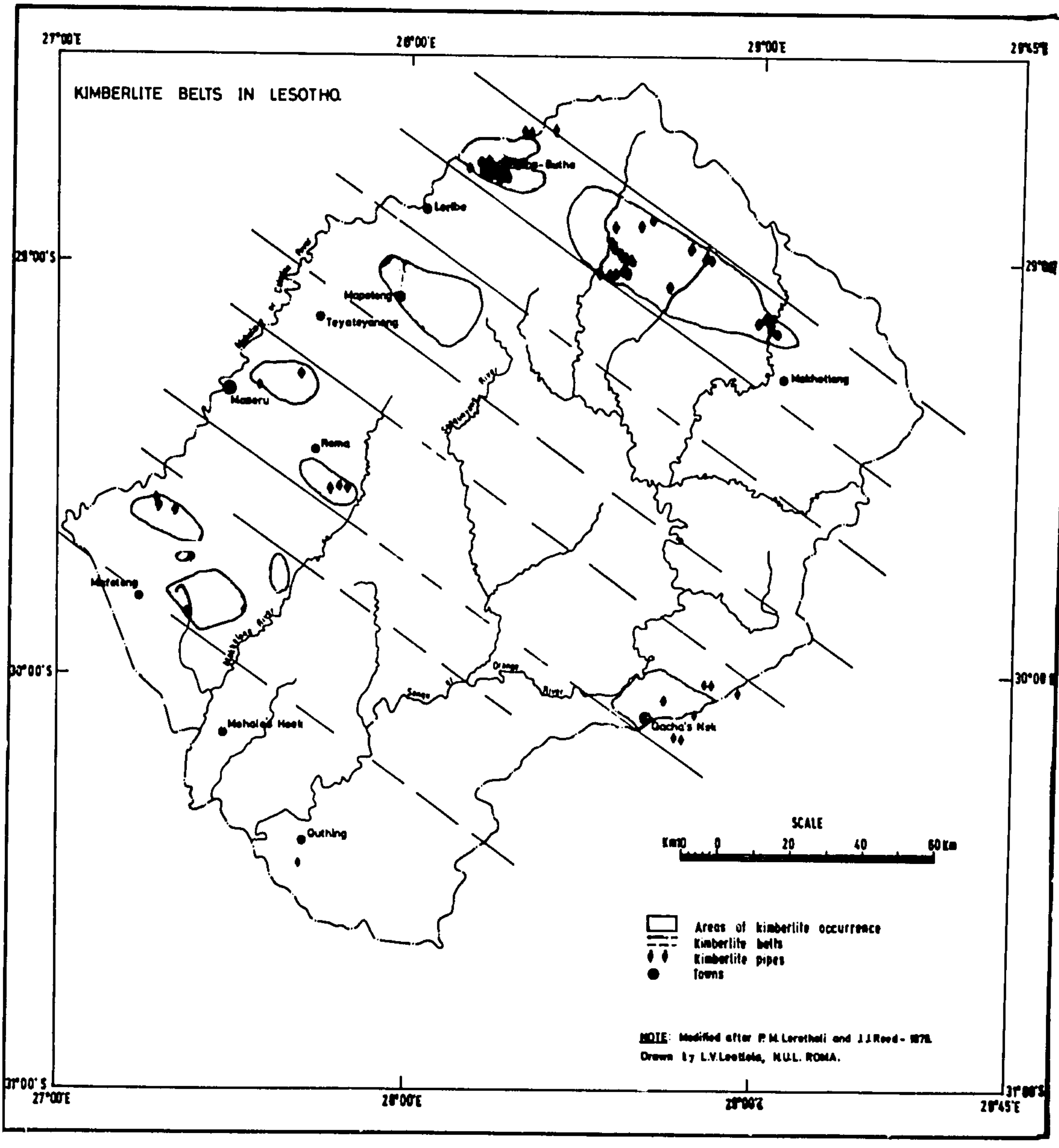

Figure 3.6: Kimberlite belts in Lesotho (source: Binnie and Partners, 1971).

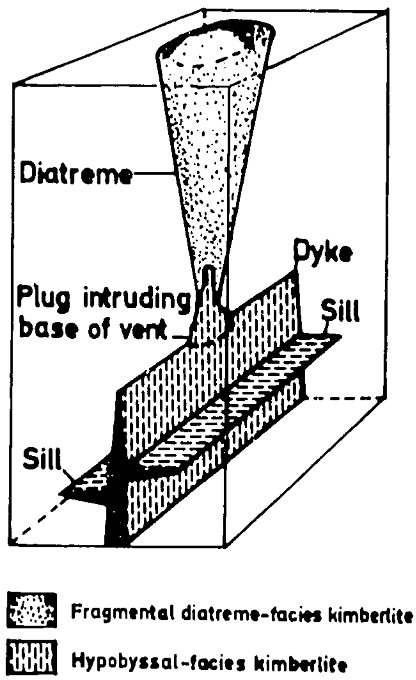

Figure 3.7: Schematic diagram showing the depth relationships between kimberlite dykes, sills, and diatremes, and between diatremes and diatremes facies kimberlite and hypabyssal facies kimberlite (source: Dawson, 1971).

3.4 Seismicity

The record of seismicity in Lesotho is short (Table 3.2) and the distribution patterns of earthquakes (Figure 3.8) does not show any clear correlation with the geology or with surface features.

The early information on earthquakes in Lesotho is descriptive. So, seismographically registered information about the approximate location of an earthquake's epicentre, magnitude and intensity can only be obtained for the more recent ones.

Generally, the location of earthquakes in southern Africa has an accuracy of 6′ of latitude or longitude.

The record shows that only minor earthquakes have occurred in Lesotho, and this can be explained because, being situated within the African plate, no strong but only sporadic seismicity, with shallow earthquakes can be expected.

In the wider southern African context, it is known that seismic activity manifests itself in the form of swarms of epicentres, for example, the Lesotho – Cape border in 1953, and these can be explained by the occurrence within the African plate of general tensional stresses. Earthquakes have occurred on cratons as well on mobile belts.

For the study of possible relationships between the seismic regime of Lesotho and its geology, such as tectonic processes and the emplacement of kimberlites, as well as seismic effects on geomorphological processes, such as landslides and rockfall on the debris slopes, a longer earthquake record is needed.

Table 3.2: Earthquake epicentres in and around Lesotho up to 1970. (Sources: Stockley, 1947; Binnie & Partners, 1971; Geol. Survey, 1979).

Date	*Lat.*	*Long.*	*Place*	*Magnitude (Richter)*	*Intensity (mod. Mercalli)*	*Source*
1882			Quthing			Stockley
1883	29°48′	27°24′	Mafeteng		III	SAGS
1928	30°24′	27°42′	Quthing		III	SAGS
1944	29°00′	27°42′	Ladybrand		V	SAGS
1951	29°00′	28°00′	Leribe	3,9		BP
1952	30°00′	28°18′	Ha Sekake	3,5	IV	SAGS
1952	30°00′	27°30′	Lifateng	3,4	III	SAGS
1952	29°00′	28°00′	Ha Sethophe	3,8	IV	SAGS
1952	29°48′	27°00′	Wepener	4,4		SAGS
1953	30°30′	27°30′	Sterkspruit	3,2–5,2	III–VI	SAGS
1953	30°30′	27°00′	Zastron	3,4	IV	SAGS
1953	30°18′	28°30′	Ongeluksnek	3,5	IV	SAGS
1953	30°00′	28°30′	Qacha's Nek	3,9	IV	SAGS
1953	30°30′	28°00′	Quthing	3,6	IV	SAGS
1953	30°30′	28°30′	Matatiele	3,0	III	SAGS
1957	30°30′	27°12′	Zastron	5,5	VII	SAGS
1957	30°18′	27°12′	Zastron	4,7	IV	SAGS
1958	29°18′	28°12′	Motikatiko	3,8	IV	SAGS
1966	29°00′	28°00′	Leribe	3,8	IV	SAGS
1966	29°18′	29°18′	Mokhotlong	5,0	VI	SAGS
1967	30°12′	27°36′	Mohale's Hoek	3,6	IV	SAGS
1968	29°48′	28°18′	Lesobeng	3,3	III	SAGS
1968	30°18′	28°30′	Ongeluksnek	3,9	IV	SAGS
1968	29°54′	28°18′	Masefabatho	3,2	III	SAGS
1969	30°24′	27°36′	Tele Bridge	3,2	III	SAGS
1970	28°18′	27°42′	O.F.S.	3,3	III	SAGS

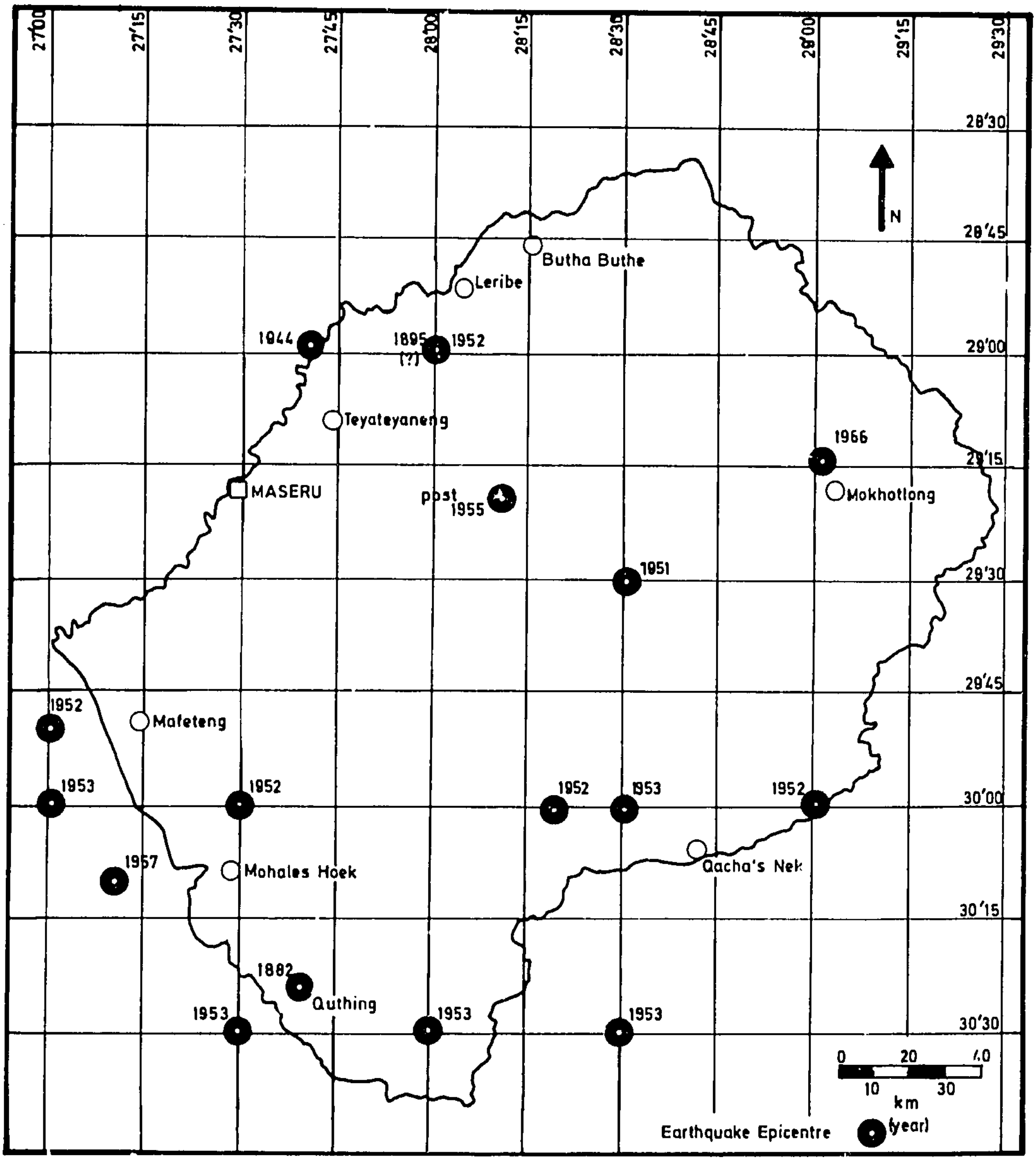

Figure 3.8: Earthquake epicentres in and around Lesotho up to 1970 (source: Stockley, 1947; Binnie and Partners, 1971; Fernandez and Guzman, 1979).

Figure 3.9: Volcanic tuff interbedded in Clarens sandstones near Ha Theko.

Figure 3.10: Flow Structure in a lava bed forming part of the early lava flows of the Lesotho Formation near Bushman's Pass.

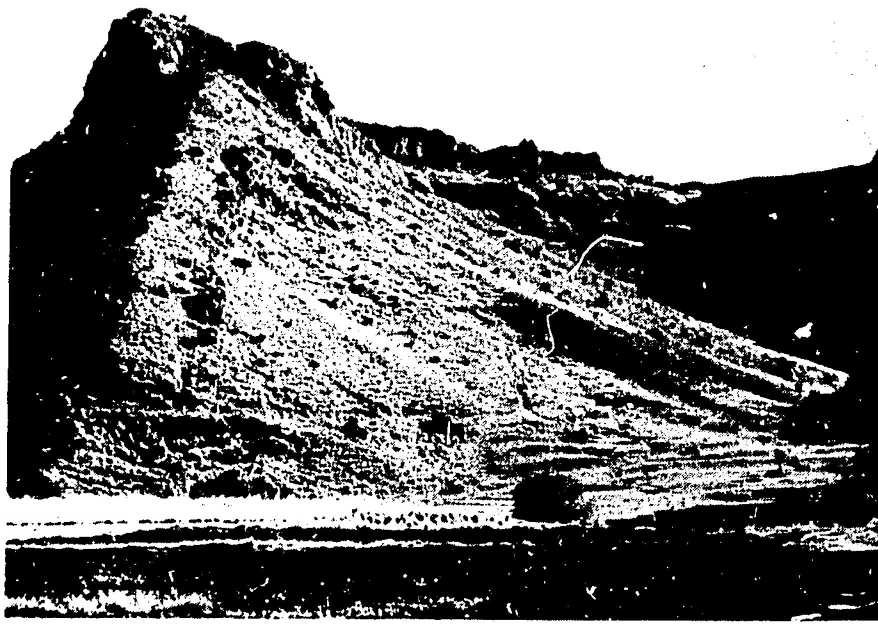

Figure 3.11: A dolerite dyke crossing the Elliot Formation and the higher Clarens Formation. The adjoining country rocks are metamorphosed. Notice the debris slope with linear piles of debris which partly derived from the dyke.

Figure 3.12: Dolerite outcrop in a dyke near Koro Koro. The longitudinal and cross fractures are due to cooling after the intrusion.

Figure 3.13: Outcrop of dolerite intrusion near Tša-Kholo.

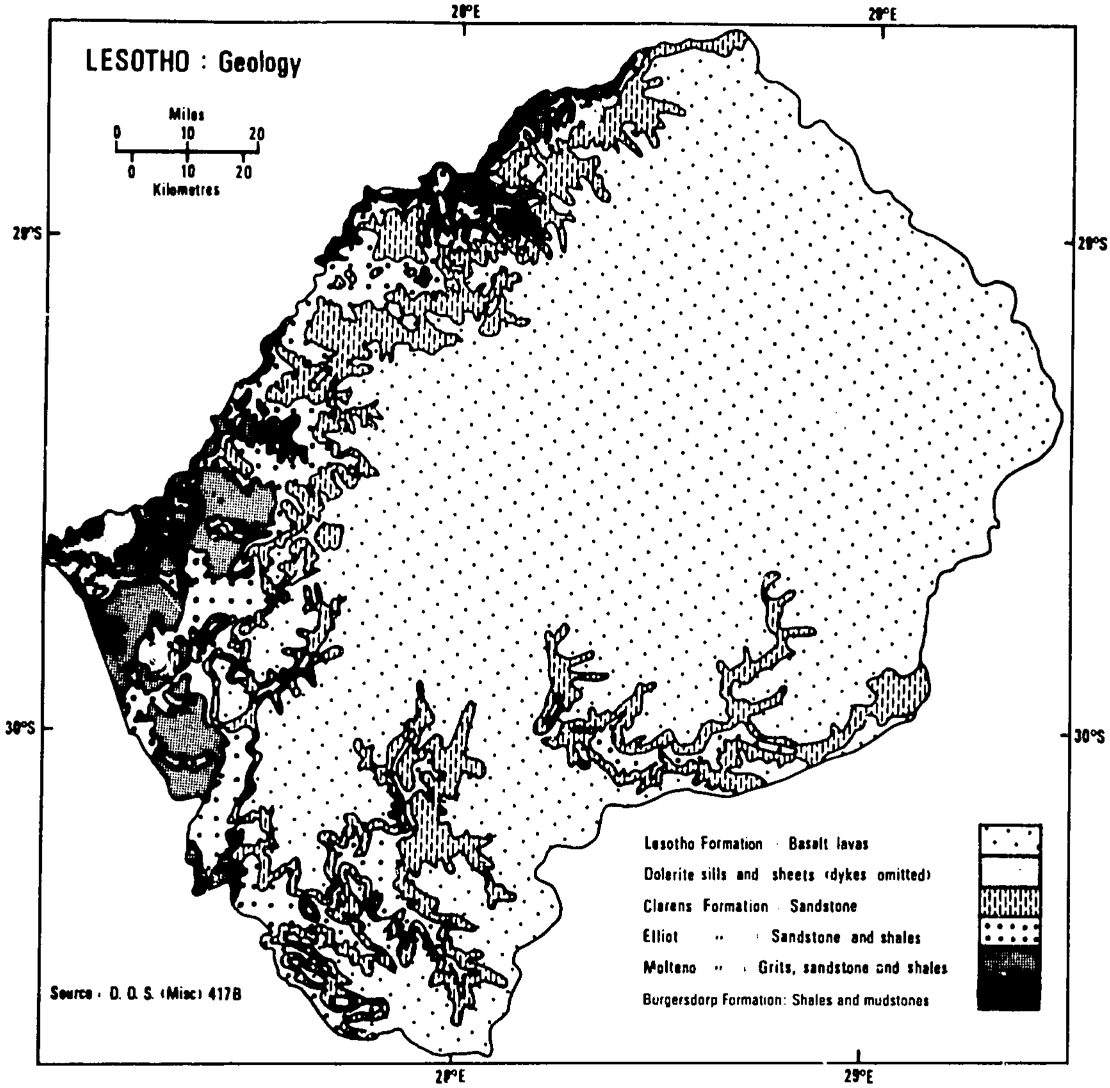

Figure 3.14: Geology of Lesotho (source: DOS, 1968).

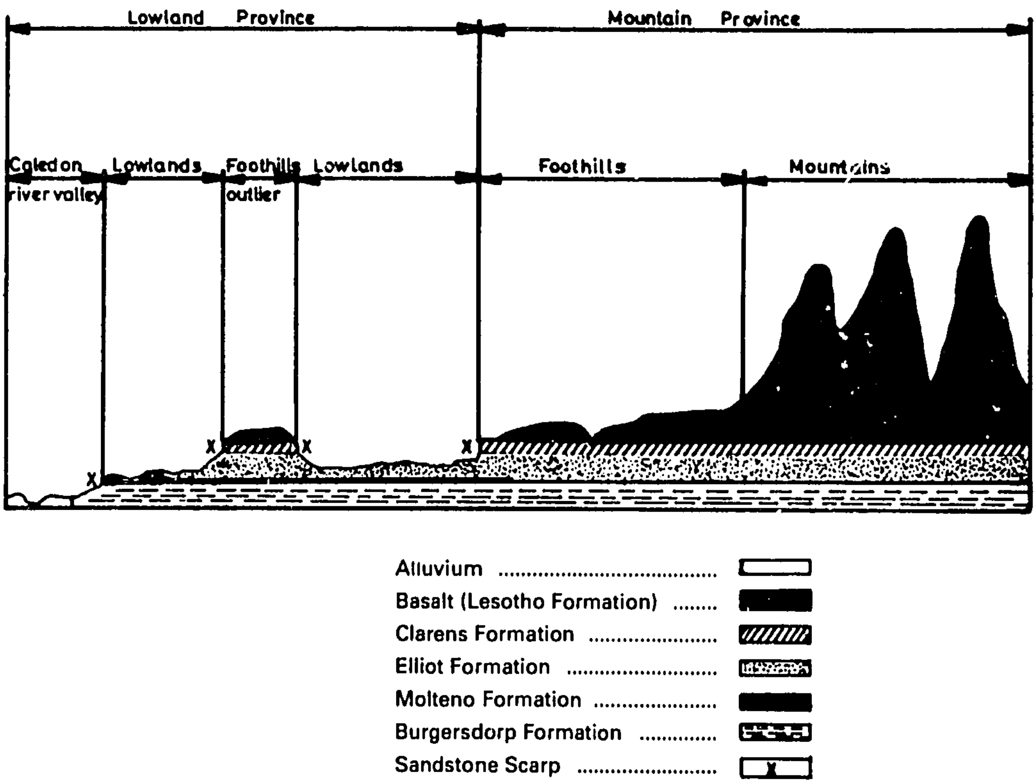

Figure 3.15: Simplified geological section of Lesotho (source: Binnie and Partners, 1972).

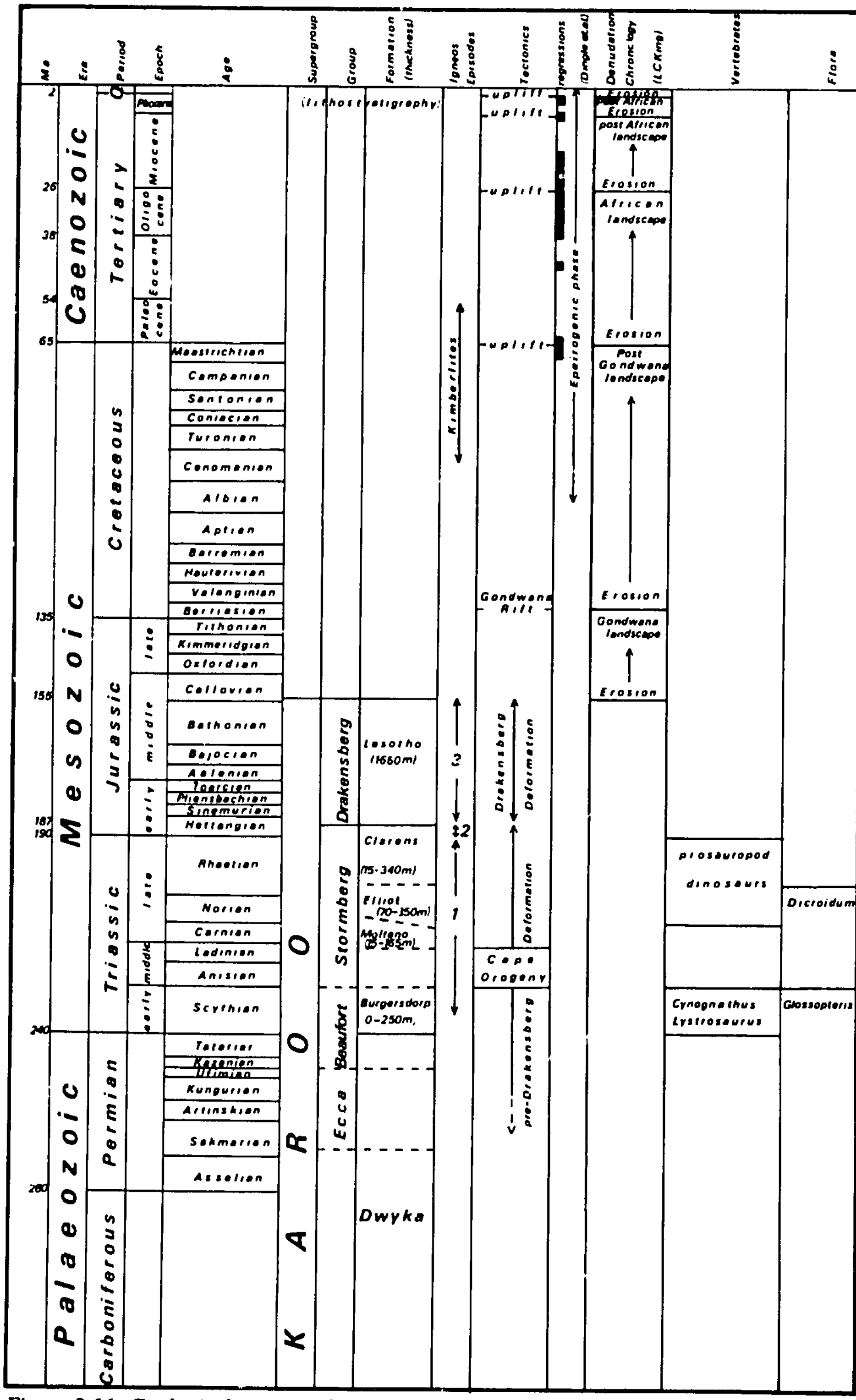

Figure 3.16: Geological Time Scale.

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Section Two

Geological Resources

Chapter Four

Groundwater Resources*

4.1 Groundwater occurrences

The storage and movement of groundwater depends to a large extent on the lithology of the area and on the latter's geological structure.

In dealing with the relationships between geology and groundwater in Lesotho, therefore, the various lithological units, which are also largely stratigraphical units, will be discussed and this will be followed by a look at the influence of structure on groundwater.

Springs, as outward expression of the relationship between groundwater and geology, will be discussed separately.

4.1.1 Dykes. Groundwater storage and movement is profoundly affected by the occurrence and characteristics of dykes.

The few dykes in Lesotho wider than 50 metres have a massive gabbro content below a depth of about 10 metres. They are normally impermeable and so they act as barriers to groundwater flow.

Many dykes in Lesotho are between two metres and 20 metres wide and contain basalt or dolerite. Some of these may be fractured to depths of 30 metres to 40 metres and therefore have a high permeability compared with surrounding strata. This quality enables the fractured dykes to act as aquifers. Other smaller dykes are massive and may again act as barriers to ground water movement.

The intrusion of the dolerite dykes has caused some induration and crushing of the surrounding country rock along the contact zones, depending on the temperature, thickness and dip of the dyke and on the nature of the country rock at the contact.

The metamorphosed zones accompanying the dykes on both sides are therefore often permeable. The widths of these zones vary with rock type, being mostly narrower in the quartzites and wider in the hornstones. These shattered zones may be as wide as the dyke itself. They act as aquifers, lying between low permeability country rock and the dyke. Groundwater flows through the less permeable surrounding strata towards the shattered metamorphosed zones and the dyke.

Boreholes drilled for the abstraction of groundwater in Lesotho are generally located along the dykes because the yield of dyke, or dykeside boreholes is about ten times that of holes in country rock. They are drilled to penetrate the contact zone of the dyke below the groundwater table.

*Much information on this chapter has been drawn from J. Bonney (1975d).

Although the aquifer is mostly narrow, and the greatest yields are obtained at the contact, boreholes selected within 50 centimetres of the contact of a vertical dyke will generally tap water from this zone. This conclusion is supported by the fact that yields of boreholes increase strongly with diminishing distance from the dyke body (Enslin, 1943).

Where dykes have vertical joints and fractures at depth and near their contacts, the contact zone within the dyke will yield large supplies of water. As it is often uncertain if such joints and fractures exist, boreholes are preferably sited to strike water in the metamorphic zone.

In the search for groundwater in Lesotho, the precise mapping of the dykes, their inclinations and their related metamorphic zones is an essential exercise. Still, the drilling for groundwater related to dykes is a speculative matter and one metre shift in the location of a borehole may make the difference between success or failure.

4.1.2 The Lesotho Formation. Lavas belonging to the Lesotho Formation are generally of low permeability. Binnie and Partners (1971) report that during drilling operations in the basalts, water losses were seldome observed, as massive rock was normally encountered. In the foothills, however, the lowest basalt pediments have patches of spheroidally weathered rock in which water might be found, and resistivity surveys have been suggested by Enslin and Kent (1943, 1962) to map those patches.

Bonney (1975) mentions that of 15 boreholes drilled into the Lesotho Formation, five penetrated through the Clarens sandstone which acts as an impermeable basement. In these cases, water deriving from the basalt aquifer entered at the lava/sandstone interface.

The yield of a borehole in the Lesotho Formation is in proportion to the area of catchment. Hilltop boreholes therefore are often dry. Six boreholes which did yield water, averaged 0,7 l/s, for a specific capacity, of one of them, of 0,04 l/sm.

4.1.3 The Clarens Formation. This Formation is not a good aquifer. Its porosity averages 2.5 per cent, and its grain size is fine.

Boreholes that have been drilled into this Formation, all have a low yield. Some are unreliable in the dry season.

4.1.4 The Elliot Formation. Of a total of 456 boreholes in Lesotho in 1975, 300 have been drilled into the Elliot Formation. This relatively large amount can be explained by its distribution and easy access in the lowlands. The Formation is not a particularly good aquifer. Many of the boreholes are randomly sited with respect to natural controls, and yield from 0,1 l/s to 0,2 l/s with a specific capacity of 0,05 l/sm after 60 minutes and 0,02 after 24 hours.

A critical factor appears to be the sandstone/shale ratio, which must be approaching unity for a good supply borehole.

4.1.5 The Molteno Formation. Boreholes in the Molteno beds, have yields varying from nil to 1,6 l/s, with a specific capacity of 1,9 l/sm after 24 hours. This large variation may be explained by variations in the degree of cementation and weathering.

4.1.6 The Beaufort Formation. Most of the boreholes drilled into this Formation are close to dolerite dykes or cut through them. The mean yield was 1,16 l/s with a mean specific capacity of 1,12 l/sm after 24 hours, with the influence of the dykes.

4.1.7 Superficial Deposits. Colluvial footslope deposits occur in most valleys and the larger valleys have an infill of alluvium. The deposits are silty and mostly form no suitable aquifer. So far only a few boreholes have been drilled into these deposits, one of which is known to yield 0,2 l/s.

Gravel beds of up to three metres thickness occur mainly at the base of the alluvial deposits. Their porosity is 0,25 and their permeability about 10 md. The specific yield is assumed to be 0,1%.

At Roma a borehole was struck through 42 metres of alluvial deposits of the middle stream terrace until bedrock was reached. No yield was obtained from the borehole.

4.2 Springs

Bonney (1975, GB 6) made an estimate of the number of springs in the various catchments of Lesotho on the basis of drainage net analysis, as developed by Strahler (1957). Strahler took a stream segment to be of first order if it had no side branches and of order n if it was generated by the confluence of two segments of the order (n-l). Bonney took the stream rises on the 1/50 000 topographical maps of Lesotho as being segments of first order. By plotting the number of stream segments against the stream order to which they belonged, estimates could be made of the number of stream segments of first order in an area, and therefore of the number of springs in a catchment area (Figure 4.1).

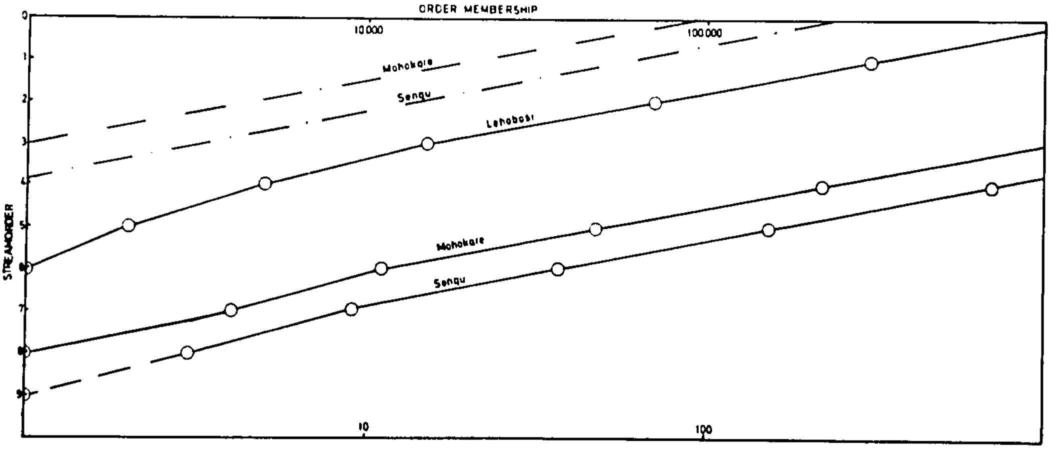


Figure 4.1: Estimated number of springs in the Senqu basin, the left Mohokare bank and the Lehobosi Basin (source: Bonney, 1975 GB 6).

The total number of springs in the Senqu Basin is estimated at 230 000, that is twelve springs per km^2. For the left bank of the Mohokare Basin, the estimated number is 90 000 springs, that is eight springs per km^2. The totals refer to wet season springs and are based on the consideration that the strong springs are collections of small springs.

The Hydrogeology Section of the Department of Mines and Geology has logged over a thousand springs in Lesotho.

The pattern of springs and spring lines closely relates to the lithology of the geological formations in Lesotho and to lithological boundaries and this close relationship will be discussed below.

4.2.1 The Molteno Formation. The base of the Molteno Formation forms a spring line, and within the Formation, stratified variations in permeability produce additional springs, some of which are strong. During the dry season, one kilometre of outcrop may discharge 0,5 l/s.

4.2.2 The Elliot Formation. Very few springs occur in this Formation and discharge is low. Wet season discharges may be 0,05 l/s. As in the Molteno Formation, stratified changes in permeability, caused by changes in the sandstone/mudstone proportion, seem to be the main cause of these springs.

4.2.3 The Clarens Formation. The contact between the Elliot and Clarens Formation forms a spring line. Although the sandstones of the Clarens Formation generally have a low permeability, in cliff zones water moves through cracks, and surfaces again in the contact zone with the even less permeable sandstones and shales of the Elliot Formation.

4.2.4 The Lesotho Formation. The metamorphosed top of the Clarens Formation forms an impermeable crust. Waters from the overlying basalts, or from the unconsolidated covers, surface when reaching the crust, to form a line of springs.

Pockets and layers of weathered basalt form aquifers, and springlines occur at all levels at the contact zones with unweathered basalts or dolerite sills.

4.2.5 Dykes. Many dykes produce strong perennial springs. As a spring is often the result of overflow, it can frequently be found near the dyke's lowest outcrop, that is, in a stream bed or near a stream bank. The catchment of a dyke-spring is usually large and, as much of its waters come from depth, the dissolved solids content is high, being as much as 350 mg/l. Discharges by dyke-springs of up to 0,7 l/s have been reported.

4.2.6 Faults and Fractures. In Lesotho, some springs can be found along faults and fractures. Bonney (1975) mentions a spring along the Helspoort Fault with a discharge of 0,5 l/s, and one near Roma, which is related to fractures and has a discharge of 0,4 l/s. If the fractures are singular, the spring yields are not much different from those of the surrounding geology. If clusters of fractures occur, good yields are common.

4.2.7 Bogs. On the high mountain plateau of Lesotho small bogs, also known as sponges, can be found and from these springs may discharge water. The bogs have diameters varying between 50 and 250 metres. They occupy surface depressions and therefore accumulate water where the underground is impermeable. Discharge occurs through a hole in the central part of the bog.

4.3 Groundwater estimates

Bonney (1975, GB 6) gives estimates of groundwater inflow and outflow in Lesotho (Table 4.1).

Table 4.1: Groundwater resources estimates for Lesotho (source: Bonney, 1975, GB 6).

	mm	in thousand cubic metres/day
precipitation	825	68 390
surface runoff	100	8 290
evaporation	690	57 200
groundwater inflow	35	2 900
groundwater runoff	25	2 070
groundwater evaporation	10	830
groundwater abstraction	0,1	9
groundwater outflow	35	2 900

Total groundwater resources are $2{,}9\times10^6$ m^3/day. Of these, 0.83×10^6 m^3/day evaporates. Of the roughly 2×10^6 m^3/day left, $1{,}5\times10^6$ m^3/day may be used for agriculture and for low flow maintenance. What is left for consumption is another $0{,}5\times10^6$ m^3/day.

These figures of water supply mean that the amount of groundwater available in Lesotho is adequate to meet the demand of the current various economic and social sectors.

Chapter Five

Mineral Resources

5.1 Diamonds

During the Cretaceous Period, the Kaapvaal Craton (Figure 1.1) was intruded by kimberlites, some of which are barren and some diamondiferous. During the same Period the Namaqualand-Natal Belt was intruded by kimberlites, which however are not diamondiferous.

It appears that the necessary conditions for diamond formation are an accumulation of volatiles under mantle conditions. The low heat-flux characteristics of the mantle under ancient cratons such as the Kaapvaal Craton, which are unlike those under more recent mobile belts, such as the Namaqualand-Natal Belt, may explain why some of the kimberlites underlain by the Kaapvaal Craton are diamondiferous and those underlain by mobile belts are not.

It is therefore important to know where the suture between the Kaapvaal Craton and the Namaqualand-Natal Belt is situated if one is exploring for diamonds in Lesotho (Chapter 3.3). Barthelemy and Dempster (1975) suggested that the Tugela Fault may continue underneath the Drakensberg lavas of Lesotho and link up with the Helspoort Fault. These two faults and their link may form the suture between the diamond bearing Kaapvaal Craton and the diamond barren Namaqualand-Natal Belt. Dusar (1979), however, stated that the boundary probably follows a more irregular and still unknown line and, for that reason, kimberlite exploration need not be restricted to the area suggested by Barthelemy and Dempster.

Bardet (1974) noted that in South Africa most kimberlites, especially those which are diamond bearing, are situated in some areas where the archean basement was less than 1500 metres below the surface at the time of the kimberlite emplacement. In Lesotho, however, the total thickness of the Karoo beds, that is, the depth of basement is more than 3 500 metres in the basement lows and more than 3 000 metres above the basement high. Thus, the emplacement of kimberlites in Lesotho did not favour the preservation of diamonds, certainly not in the basement lows.

5.2 Uranium

Uranium mineralisation has occurred in sediments of the Karoo Basin belonging to the Beaufort Group, the Molteno Formation and the Elliot Formation. The concentrations found so far are small and exploitation is not yet economically feasible, although exploration has been going on for more than ten years in South Africa and for nine years in Lesotho.

In South Africa Turner (1978) found significant uranium mineralisation in high sinuosity channel sandstones in the Beaufort Group. None of these uranium deposits, however, are economically exploitable.

Mineralisation is generally found in the thicker parts of channel sandstone lenses. The mineralised zones are separated by large areas of barren sandstones and range from small pods and lenses a few metres in extent to larger discontinuous bodies traceable for up to one kilometre (Kubler, 1977).

The sinuosity channel sandstones are often poorly sorted and contain carbonate cement, sulphides and volcanic fragments of predominantly acid character and are occasionally interbedded with cherts of tuffaceous origin and fossilised bones (Turner, 1978).

Individual mineralised zones vary in thickness from a few centimetres to a maximum of approximately seven metres and contain both, primary uranium minerals, uranite and coffinite, and secondary uranium minerals, metatorbernite, uranospinite and uranophane.

The distribution of the mineralised zones suggests that the environment has played a key role in their formation: lithology, local permeability differences, groundwater movements and presence of carbonaceous debris were major controls in mineralisation.

A volcanic source has been suggested for the uranium (Martini, 1974; Turner, 1975, 1978; Reed, 1978), as volcanic fragments and tuffaceous material occur in the host sandstones. The uranium was probably leached from the acid-rich volcanic source and transported by alkaline groundwaters. Interruption or delay of flow is essential to allow time for uranium to precipitate. The channel sandstones provide permeable pathways for uranium solutions, but also numerous permeability barriers. On encountering strong reductants, such as carbonaceous debris, in zones of differential permeability, fluid flow would be interrupted or delayed and the uranyl complexes in solution reduced and precipitated mainly as uranite and coffinite.

In Lesotho an airborne radiometric survey of the western lowlands was undertaken with ground follow-up. The main conclusions reached in the radiometric report were that on the whole the uranium responses throughout the survey area are very weak.

The Beaufort and Elliot beds contain by far the largest number of uranium anomalies. The Clarens beds, the basalts and dolerites are considered barren with respect to uranium. The highest uranium potential appears to be in the most western corner of Lesotho. Radioactive phosphatic horizons have so far been found at Lipeleng, north of Maseru, and also near Helspoort. The radioactivity is associated with washouts and phosphatic nodules and fossilised bone debris. All the radioactive horizons occur at the same stratigraphic horizon in the lower part of the Elliot Formation, approximately 30 metres to 50 metres above the Molteno/Elliot boundary (Reed, 1978). The horizon is usually at the second massive sandstone band above the boundary. It has, therefore, been recommended that prospecting be carried out in areas where this horizon may be expected to be present in order to find large washout channels (Reed, 1978).

Other radioactive occurrences have been found in the Burgersdorp Formation, in its ferruginous sandstones and carbonaceous shales, near Tšita's Nek and near Luka. These occurrences have also been found near Kolo Mountain, in a sequence of sandstones and siltstones which may belong to the Elliot Formation.

So far all occurrences found in Lesotho are limited in dimensions and exploration is not economically feasible.

In Lesotho, the source rock for the uranium is probably the acidic volcanic beds in the Karoo sedimentary sequence. The uranium is released into solution during the alteration of the volcanic glass to montmorillonite clay or to zeolite (Reed, 1978). The processes of leaching, transportation and precipitation probably took place shortly after the deposition of the host rock and before compaction and diagenesis had proceeded to completion (Turner, 1978).

5.3 Mercury

Lerotholi and Reed (1979) mention the finding of mercury mineralisation in the Drakensberg basalts of Lesotho.

The mineral cinnabar has been located in the south of Lesotho in the lower basalts of the Lesotho Formation (Rombouts, 1979). The mineral occurs in alteration zones which have red, purple and dark tints within a basically pale buff matrix. The authors recommend further exploration throughout the basal parts of the Lesotho Formation, including the sandstone lenses intercalated in the basalts.

5.4 Building stones

Sandstones and flagstones from one or other of the formations of the Karoo Supergroup have a considerable local use in the building industry.

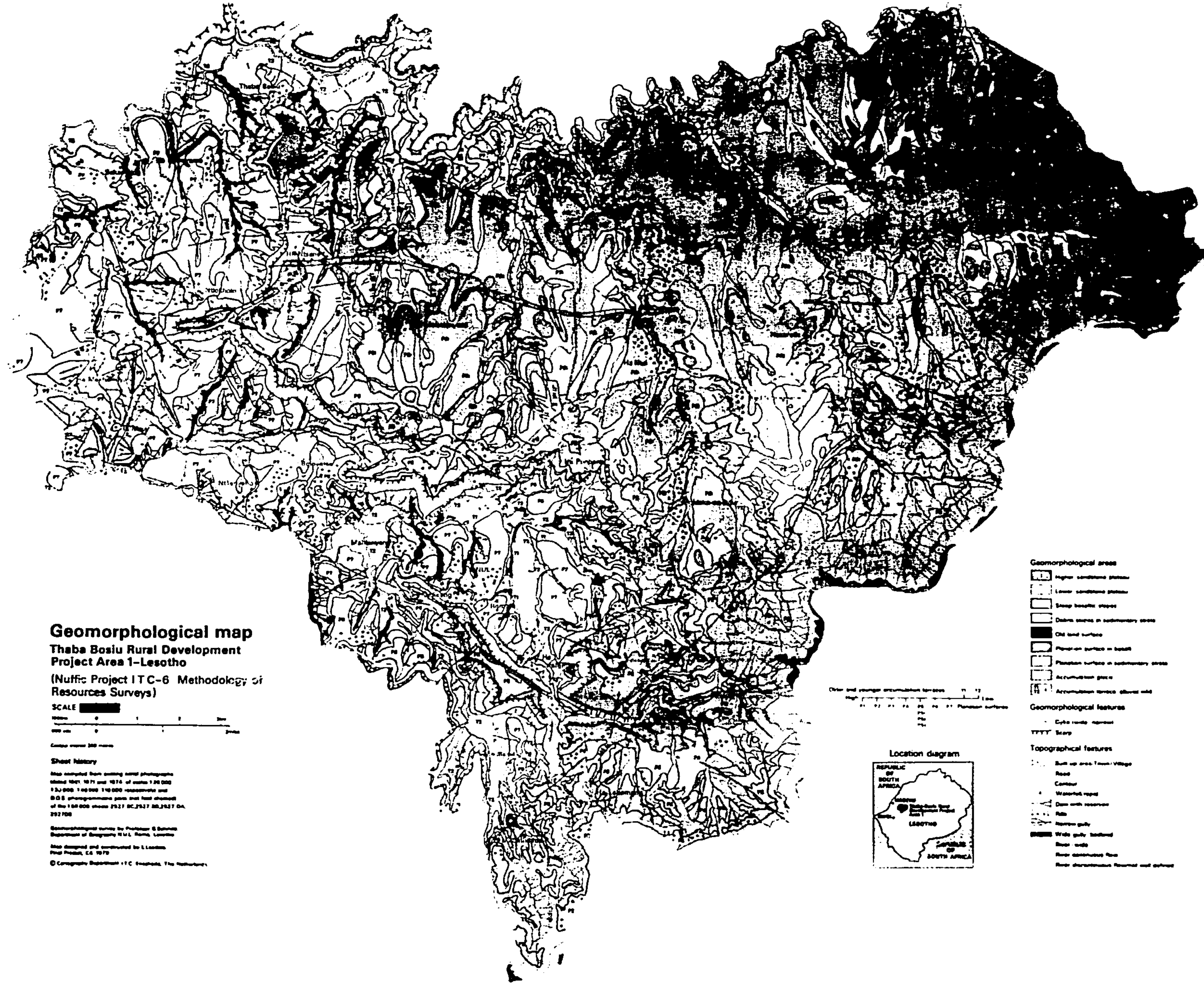
Karoo dolerites, under certain conditions, are used as foundation material in road construction and as a constituent of concrete aggregates.

5.5 Clay deposits

Adequate quantities of heavy clay have been located in the districts of Leribe, Mafeteng, Maseru, Mohale's Hoek and Qacha's Nek. In addition, high quality heavy clays in the Maseru area have been found to be suitable for a wide range of bricks which can be used widely from general purpose to facing and engineering class.

Section Three

Geomorphology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Thaba Bosiu Rural Development
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Geomorphological areas
Geomorphological features
Topographical features
Location diagram
REPUBLIC OF SOUTH AFRICA
LESOTHO

Chapter Six

Geomorphological Units

6.1 Definition and description

The broadest classification of the lands in Lesotho is the generally used division between the lowlands and the mountains, which is based upon geological structure, lithology and gross-topography.

The lowlands are the regions, mainly in the west, where sedimentary strata outcrop. They are situated below the scarp formed by the Clarens Formation.

The mountains include the eastern part of the country, which lies above the same scarp. They are formed mainly in the basalts of the Lesotho Formation.

A further subdivision into land regions with "similar climatic and geomorphological processes acting on similar rocks" was introduced by Bawden and Carroll (Figure 6.1 and Table 6.1).

Table 6.1: Land Provinces and Land Regions in Lesotho (source: Bawden and Carroll, 1968).

Land Province	*Land Region*
Mountains	Higher Mountains Lower Slopes Lower Mountain Flats Foothills
Lowlands	Lowlands Orange River

Within the land regions identified in Lesotho, a further, more detailed division into geomorphological units is possible and an attempt has been made by Schmitz (1979) for part of the Thaba Bosiu Project area as well as for the Roma Valley (see geomorphological map).

A geomorphological unit may be described as that part of the land surface which is homogeneous in terms of morphology and genesis. In Lesotho it often implies a uniform underlying geology as well and within each geomorphological unit a definite set of soils can usually be expected to occur, as well as particular processes of accelerated erosion, mass wasting and sedimentation.

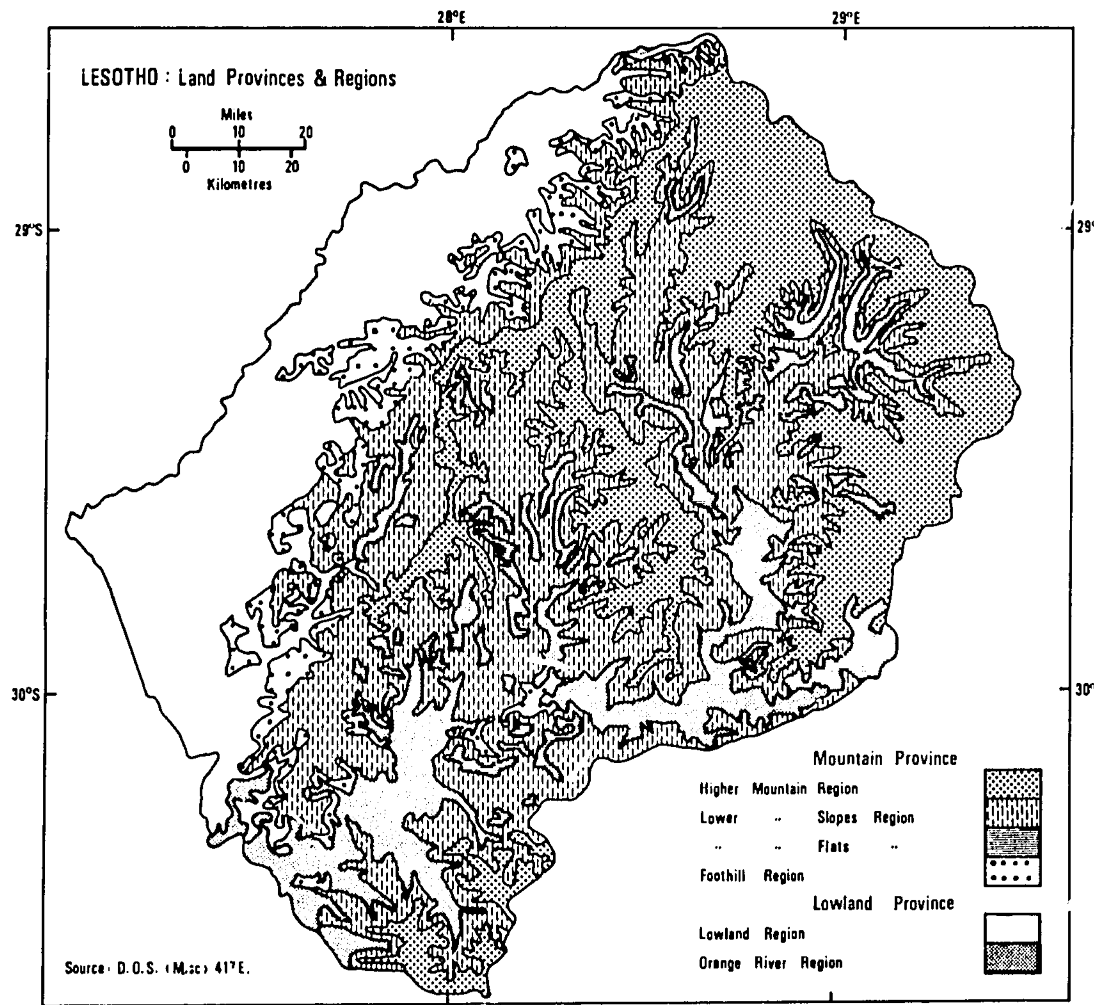


Figure 6.1: Lesotho, Land Provinces and Regions (source: D.O.S., 1968).

A list of the most widespread geomorphological units is presented below (Table 6.2; Figure 6.2).

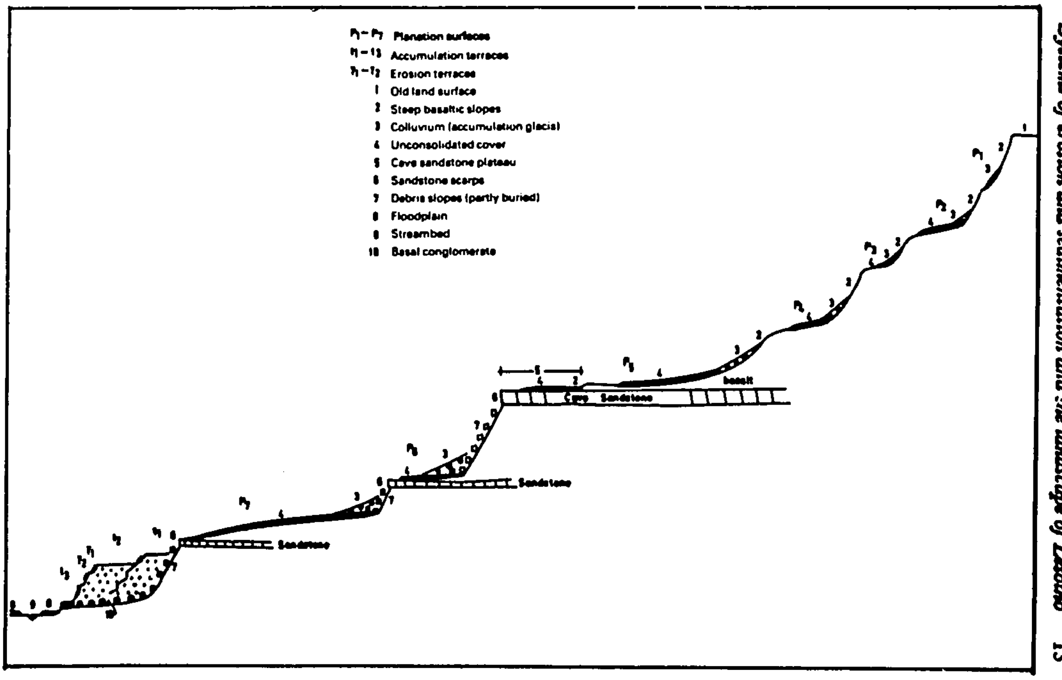


Figure 6.2: Schematic cross-section showing the different geomorphological units and their relative positions in the landscape of Lesotho.

Structural Clarens Plateaux are exhumed surfaces of sandstone layers, formerly covered by basalts. The plateaux are undulating, due partly to the original surface and partly to subsequent dissection. Deep, largely loamy to sandy sandstone residuum covers the plateau depressions, whereas hilltops, the steeper surfaces and the plateau rims have stony soils or form bare rock surfaces. Spring and seepage lines exist at the basalt/sandstone contact. Accelerated erosion is widespread and usually takes the form of rock stripping, a process described further in this text.

The margins of the Clarens Plateaux are formed by high sandstone scarps (Figure 6.7). Weathering and mass wasting led to their formation and to the retreat of the sandstone scarps in the Clarens Formation.

Low sandstone scarps are formed by sandstone layers in the Elliot and Molteno Formations. These low sandstone scarps usually make up the lower edges of planation surfaces. Some can be traced consistently throughout the area of outcrop of a sandstone layer.

Overhangs are numerous, especially in the Clarens Formation (Figure 6.8). The occurrence of overhangs as well as cliffs in the Clarens Formation mostly relate to the presence at the base of the sandstone layer of soft mudstones or clay-shales. Rapid weathering of the shales and mudstones leads to the undermining and collapse of the sandstones above (Figure 6.9).

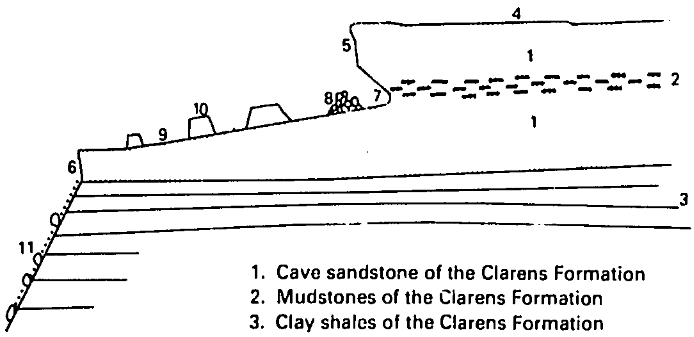
Sandstone overhangs in the Elliot and Molteno Formations occur mostly across the streambed. They seem to result mainly from basal sapping and from plungepool erosion.

The scarp faces are partially jointed, having one set of joints parallel to the scarp face (Figure 6.10). Most scarps are almost inactive at present.

Debris slopes can be found below the scarps. They are covered by the accumulated weathering products of the scarps and overhangs, which products have come down in rockfalls and avalanches (Figure 6.11). The debris is mostly dissected and partly covered by colluvium and by alluvial deposits near the foot of the slope.

The sandstone scarps of the Clarens Formation may be divided into an upper and a lower scarp, with an inclined rock shelf in between (Figure 6.3). The rock shelves are smooth, inclined rock surfaces, partly bare and partly covered with accumulations of sandy soils, as much as ten metres deep. Buried soil horizons may be found in the accumulations, and, if close to basalt outcrops, they contain basalt gravel. The accumulations are largely transported soils, derived from the higher plateau surface. The rock shelves, where covered, are normally severely gullied and rock stripping is frequent.

Where dykes occur in the lavas, they may form elongated sharp edged ridges, accompanied by debris slopes on both sides, or they may be recognized by the outcrop of dolerite and not have any further surface expression.



1. Cave sandstone of the Clarens Formation
2. Mudstones of the Clarens Formation
3. Clay shales of the Clarens Formation
4. Structural plateau
5. Upper cliff
6. Lower cliff
7. Overhang
8. Collapse Heap
9. Rock shelf
10. Soil relics
11. Debris slope

Figure 6.3: Rock shelves and their relationship to overhangs.

In the Clarens Formation, dykes usually form trenches with deeply weathered dolerite (Figure 6.12) and with parallel walls which form scarps in the adjoining metamorphosed sandstones. The dyke walls may, after a prolonged period of selective weathering, stand out as massive promontories, isolated from the main sandstone body (Figure 6.13).

In the Elliot Formation, dykes form spurs in the debris slopes (Figure 6.14), sometimes having a central trench. Lower in the landscape, they may form elongated sharp edged ridges or have only faint morphological expression. In streams dykes form waterfalls and rapids.

Steep basaltic slopes occur in the mountains and as lower edges of the basalt planation surfaces. The upper slopes consist mostly of bare rock surfaces. Further down, a veneer of rock fragments and stony soils appears, and at the foot of the slope fanlike screes occur. The regolith produced on the upper slopes is rapidly eroded, while further downslope, accumulation dominates, and this is reflected in the increasing thickness of the mollic epipedon of the soil sequence which has developed on these materials. Soil erosion takes the form principally, of rills and cattlesteps and the superficial soil cover is in many instances severely damaged.

Debris slopes with angles of 28°/34° occur in the Elliot Formation. Many large sandstone boulders derived from the Clarens Sandstone scarp above are embedded in a sandy matrix which covers the debris slopes. Where the slope is not topped by a sandstone cliff, its cover consists of fine fragments only. Where the lava front lies close to the top of the Clarens Sandstone scarp, the slope below has debris tongues of basaltic weathering residue up to two metres thick. Minor streams have cut into the debris cover and produced fans of fine materials on the footslope. Slope wash has produced recent forms of colluviation at the foot of the debris slopes.

Donga heads have partly oversteepened the lower debris slopes, and this has led to a sliding of the debris cover. Rills and minor gullies occur on the debris slopes.

Planation surfaces partly determined by outcrops and small cliffs a their base, are widespread in the basalts and in the sedimentary strata. These surfaces occur at several distinct elevations and slope towards the valley axes at angles of 1° to 4°, forming spurs which may be several kilometres long, although these spurs are sometimes reduced to ledges or are strongly denuded. In cross section the spurs are convex, with a maximum angle of 5°. These planed surfaces, cut in bedrock, are largely covered by unconsolidated materials, mostly loam, the depth of which varies from a few centimetres to several metres. Near the mountainside they are mostly covered by a mantle of colluvium, which rests on the loam and which was derived from the higher and steeper slope above. The rims of these surfaces are often bare rock or have thin soils with truncated profiles.

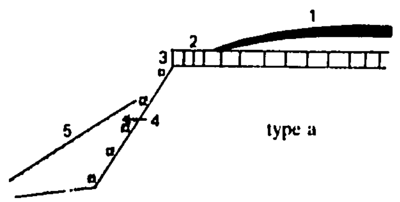
In the sedimentary strata, a sandstone scarp with a debris slope underneath often forms the lower edge of the planation surface (Figure 6.4, type a).

The lower part of this debris slope normally dips below a colluvial mantle, where it becomes concave and flattens out to grade either into a lower planation surface or into the valley floor.

Where a planation surface is not bound by a scarp, it passes into a convex-concave slope (Figure 6.4, type b). The convex part either has rock outcrops or a thin stony truncated soil cover, while the concave part is covered by a mantle of colluvium.

In basaltic strata, planation surfaces are either surrounded by a similar convex- concave slope or by a straight steep rocky slope.

Planation surfaces occur at least at seven distinct levels, from high to low indicated as p_1 to p_7. The upper five occur in basaltic strata, the lower two in sedimentary strata. P_5 occupies very large areas on the basaltic interfluves, and forms the major part of the foothills (Figure 6.15). Whereas the higher planation surfaces carry little or no soil cover, the p_5 has extensive unconsolidated covers of up to three metres thickness.



1. Unconsolidated cover
2. Bare rock surface or truncated soil profiles
3. Sandstone scarp
4. Dəbris slope (partially buried)
5. Accumulation glacis
6. Convex/Concave rock slope

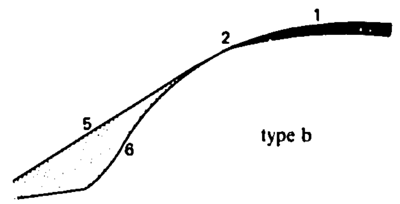


Figure 6.4: Lower edge of planation surface.

In the sedimentary formations there are two distinct planation surfaces, p_6 and p_7, the lower of which forms widespread areas on broad and long interfluves with slight undulations, but generally sloping towards the valley axes. Its upper parts are covered with dark, reddish brown sandloam to a maximum depth of two metres.

On the planation surfaces, sheet erosion is the dominant erosion process. It occurs during and immediately after intense summer storms. The lower edges of the planation surfaces are partly stripped of their superficial cover by this process. Accumulation glacis occur as slightly sloping surfaces, of from 4° to 8°, of stratified colluvium, also referred to as pedisediments. The accumulation glacis are a widespread feature which takes two different forms, namely, footslopes glacis and valley glacis.

Footslope glacis occupy the lower part of most debris slopes, as well as the lower edges of the planation surfaces. These lower slopes are covered with colluvium, which may take the form of cones, which have their apex in depressions on the debris slopes and their base resting on a lower geomorphological unit, normally a planation surface. Sometimes several cones coalesce, but more often, the whole footslope is covered by a continuous blanket of colluvium, which reaches its maximum thickness above the knickpoint between the debris slope and the lower unit.

Most of the footslope glacis are strongly dissected by discontinuous dongas with the donga heads at the upper boundary of the glacis and the donga mouths at the lower boundary. Most gullies are cut through the colluvial cover and their floor follows the underlying, reexposed debris slope of the planation surface (Figure 6.4). The footslope glacis are also covered with numerous rills that follow the main direction of the glacis slope.

Valley glacis are the surfaces of colluvium which fills the valley branches. The colluvium covers the original hard-rock topography and fills the rock-cut valley branches in layers up to 15 metres thick. Towards the valley axes this colluvium interfingers with fluvially reworked colluvium or with alluvial terrace deposits (Figure 6.5).

1. Planation surface
2. Sandstone scarp
3. Debris slopes (partly buried)
4. Valley glacis
5. Fluvially reworked colluvium

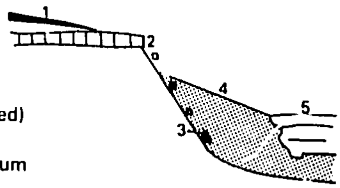


Figure 6.5: Valley Glacis.

Colluvial surfaces slope both towards the valley axes at angles of 2° to 4° and also downstream.

Valley glacis are extensively cut by strongly branched, deep gully systems, which normally cover the complete length of the valley and reach the bedrock or even in some cases some metres below the bedrock. Extreme dissection has led to badlands.

Of the fluvial terrace levels, three are accumulation terraces of different ages and two are erosional.

The highest accumulation terrace (t_1) consists of red coloured alluvial deposits which reach a maximum thickness of 45 metres. In some instances the original terrace surface is still intact. At other places only denudational humps are left, sometimes covered by more recent terrace deposits, sometimes protruding as small elevations above the younger terrace surfaces.

The surface of the highest accumulation terrace is little influenced by accelerated erosion, but its edges are severely attacked in places. Short, deep gullies form in them, leading to the retreat of those edges by headward erosion. Where the edges are oversteepened, slumping occurs.

The middle accumulation terrace (t_2) is the most extensive amongst the stream terraces in Lesotho. Its rock base is exposed in many places at 50 to 100 cm above stream level. The total fluvial accumulation reaches up to 15 metres. The terrace surface is flat and slopes at angles of 0,5° to 1° downstream.

The lowest accumulation terrace consists of deposits of from two to five metres thick. It is not extensive and its surface may still be flooded occasionally.

Erosion terraces have been carved out in the alluvial deposits of the middle accumulation terrace. Most of them have been formed by the lateral swing of a meander and appear to be local features.

The terrace surfaces have been little affected by forms of accelerated erosion. Rills, formed on geomorphological units above the terraces, discontinue where they reach the terraces and produce thin, fanlike deposite on the terrace surface. Dongas rarely occur in terraces, but where they do, their growth does not show the proliferation into badlands as is the case in the accumulation glacis. All the terrace edges, especially those of t_2, are subject to slumping and gullying. They are often naturally oversteepened by recent stream incision and lateral scour. The proximity of a low base level and basal sapping add to the process.

Floodplains are little developed in Lesotho. They occupy narrow stretches along the streambeds and have recent flood deposits of up to two metres thickness.

Most streambeds are cut in bedrock. In the lowlands channels are often choked by recent sedimentation.

6.2 Geomorphological units and associated soils

In plotting the boundaries of the geomorphological units in Lesotho, it was found that they normally correspond with those of soil series and that within each geomorphological unit only particular sets of soil series occur. Weston (1972), in classifying soils in the lowlands of Lesotho, also mentions that relationship of sets of soil to particular geomorphological features. McKee (1976) attempts to relate the development of some of the lowland soils to geomorphological development. Carroll et al (1979) refer to particular toposequences of soils in Lesotho.

On the basis of the findings of the above and the authors' own observations, the relationships between geomorphological setting and the main associated soil series have been tentatively worked out by Schmitz (1978, 1980, 1984). Correlations, partly modified again, are shown in Table 6.2.

Table 6.2: Geomorphological Units and Associated Soil Series

Geology	*Geomorphological unit*	*Main Associated Soil Series*
Lesotho Formation	*Steep and middle (complex) slopes*	
	gentle to steep upper mountain slopes, gentle to steep middle mountain slopes, rockland/rock outcrop escarpment.	Popa/Matšana
	Accumulation glacis	
	gentle to moderately steep plane or concave footslopes in mountains or foothills (footslope glacis).	Fusi
	gentle to moderately steep concave lower slopes (valley glacis), undissected slopes of the foothills, rising gently from a planed Clarens surface.	Thabana
	Planation surface (degraded or not)	
	undissected gently sloping to sloping crests and sideslopes of gentle land rise	Machache/ Nkau/ Sefikeng/Tumo
	very mildly dissected gentle to moderately steep hill crests and side slopes and broad slopes of foothills.	Matšaba/Seforong
	mildly dissected slopes of foothills rising gently from a planed Clarens surface.	Ralebese
	gentle sloping surfaces on sandstone lenses in basalt.	Matela
	Alluvial deposits	
	level or depressional sites, deep "pedisediment" of basaltic origin.	Phechela
	deep depressional alluvium and "pedisediments" of sedimentary origin capped with basaltic materials.	Maseru dark
	near level to gently sloping alluvial terraces.	Khabos
	Deep alluvium, recently deposited, primarily on flood plains, fans and terraces of rivers and small streams.	Sofonia
Clarens Formation	*Structural plateau*	
	associated with sandstone lenses in basalt and basaltic cover over sandstone.	Matela

	middle and lower slope positions.	Berea
	gentle to moderately steep slopes, often near the edge of the plateau.	Ntsi
	gentle slopes and gently sloping to sloping crests of low hills and gentle land rises.	Qalaheng
	gentle sloping to sloping footslope glacis; stabilized or active sand dunes.	Thoteng
	gently sloping to sloping side slopes on steep sided plateaux; drainageways; valley glacis.	Theko
	rockland; rock outcrop.	
	escarpment.	
	High structural plateau (above 2000 m. Sehlabathebe)	
	along ridge crests and steep sided plateaux.	Lekhalong
	gentle to steep footslope glacis, slightly concave basins	Tšenola
	nearly level to moderately sloping concave basins and drainageways that are subject to flooding; some seepage areas on the sloping uplands; valley glacis.	Sani
	rockland; rock outcrop.	
	escarpment.	
Burgersdorp, Molteno and Elliot Formations	*Debris slopes*	
	debris cover.	
	sandstone scarps/	
	rockland; rock outcrop	
	Accumulation glacis	
	gently sloping to sloping southern exposed slopes.	Maliele
	gently sloping to sloping, thick stratified colluvium, footslope glacis.	Bosiu
	nearly nevel to sloping interstream divides and gentle to moderately steep drainageways below sandstone scarps; underlain by duplex soils.	Majara
	plane and concave, middle and lower slope positions below pediment surface, footslope glacis.	Moshoeshoe
	nearly level to gently sloping valley bottoms of dissected pedisediments below and close to sandstone scarps.	Tsiki
	low, undulating to rolling terrain on gentle slopes below. pediment surface.	Sephula/Tšakholo
	nearly level to gently sloping valley floors of dissected fluvially reworked pedisediments; at middle valley position at some distance from the sandstone influence of the scarp.	Maseru
	Planation surface (intact or degraded)	
	convex crests of planation surfaces.	Leribe/ Matela
	gently sloping to moderately steep side slopes and crests of planation surfaces.	Qalo
	gently sloping to moderately steep side slopes and crests of planation surfaces.	Hololo (eroded variant of Qalo)

gently sloping gradients on undulating to rolling, generally sandstone controlled planation surfaces.	Rama
rockland; rock outcrop; scarps	
Alluvial deposits; high terrace	
ancient alluvium, below the Clarens escarpment, derived from higher lying basalt.	Matšaba/Seforong Ralebese
nearly level to sloping side slopes of river terraces and marginal uplands with ancient deposits of basaltic alluvium. Gravel mantled deposits of stratified silty alluvium.	Kubu
nearly level to gently sloping alluvial terraces, mostly along major streams of the western lowlands; deep, coarse to moderately fine, basaltic alluvium.	Khabos
Alluvial deposits: middle terrace	
see above	Khabos
see above	Kubu
nearly level to gentle sloping terrain; deep basaltic alluvium;	Bela
level or depressional sites.	Phechela
see above.	Maseru
on broad flats, on seepy side slopes of very gentle sloping land rises, or along gently sloping drainage basins.	Maseru dark
Alluvial deposits; low terrace and flood plain	
terraces and floodplains along major lowland streams.	Caledon
recent floodplain-, fan- and low terrace deposits.	Sofonia
recent floodplain-, low terrace- and depressional backwater deposits.	Kolonyama
see above	Phechela
Dolerite dykes and sills	
on or adjacent to outcrops of dykes and sills.	Ralebese

6.3 Geomorphology and land suitability classification

The geomorphological units as worked out by Schmitz (1978, 1980, 1984) have been extrapolated and expanded upon on a countrywide basis by Berding (1982) and later incorporated into a system for land suitability classification at the national and district level in Lesotho (Berding, 1984).

A geomorphological/landunits map has been produced in this context, at a scale of 1 : 500 000 of which a reduced version is published here (Figure 6.6).

For reasons of scale, the geomorphological units on this map have been grouped together into geomorphological associations.

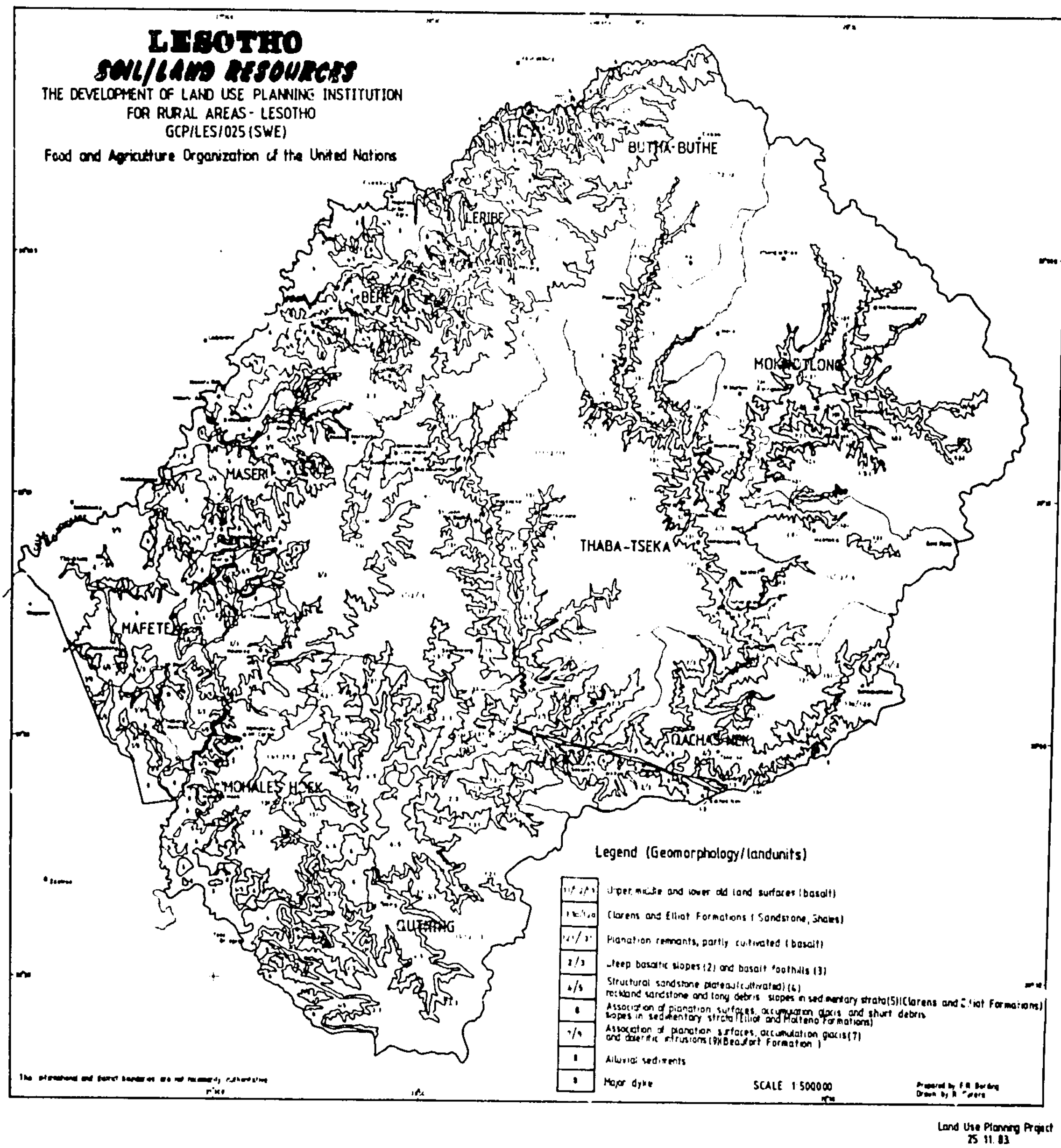


Figure 6.6: Geomorphology/Land Resources of Lesotho (source: FAO, LUP, MA, 1984).

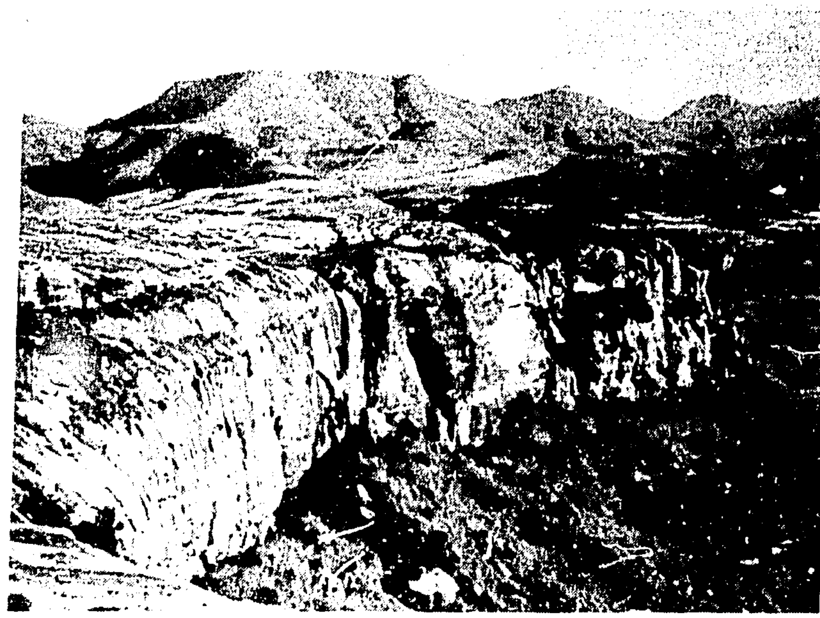


Figure 6.7: The mountains with the old land surface surrounded by steep basaltic slopes; the foothills with planation surfaces and steep basaltic slopes in between; the Clarens Sandstone Plateau bordered by the Clarens cliffs and the debris slopes below.

Figure 6.8: Clarens Sandstone covered by an early lava flow of the Lesotho Formation near Ha Theko. The Clarens outcrop consists of a cliff in massive sandstone, a line of ovehangs in soft mudstones and a lower rock shelf in massive sandstone. The surface on the early lava flow is part of planation surface p_5. In the distance are remnants of the higher planation surface p_2.

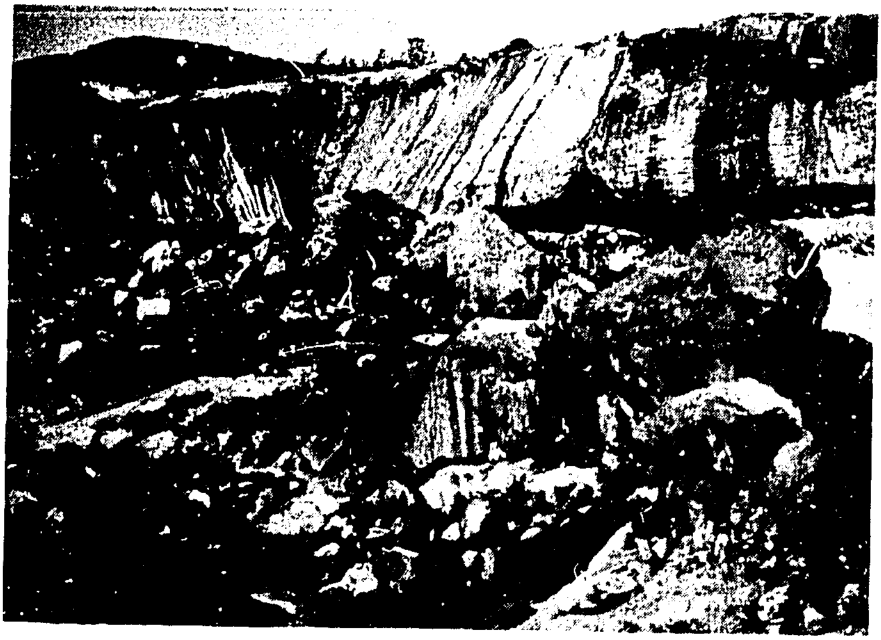


Figure 6.9: Rubble heap resulting from the collapse of a cave roof in Clarens sandstones near Tlouile.

Figure 6.10: Jointing of Clarens sandstone parallel to the cliff as a result of unloading, near Roma.

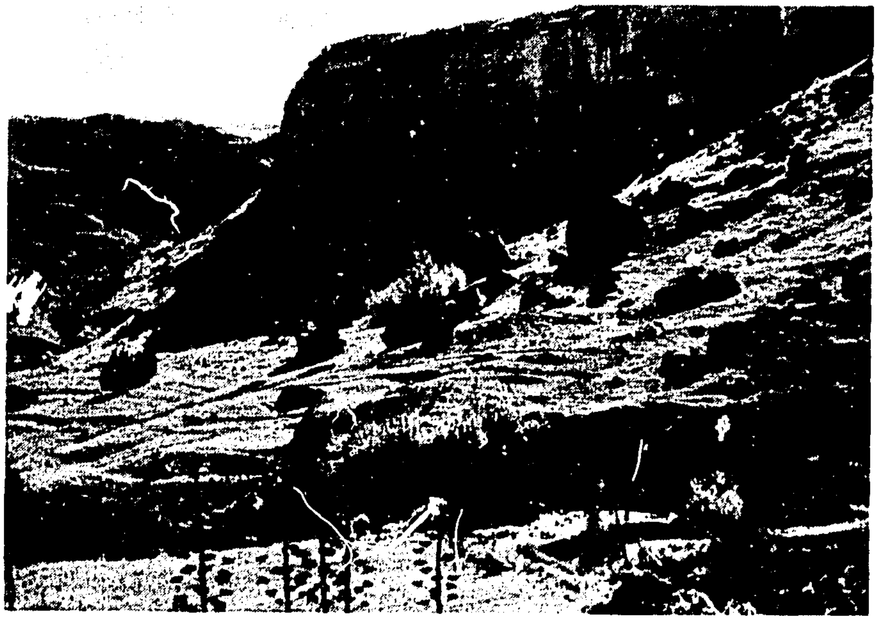


Figure 6.11: A debris slope on Elliot beds near Ha Mafefoane. The debris is supplied by the Elliot beds and by the overlying Clarens sandstones.

Figure 6.12: Spheroidal weathering of dolerites near Ha Khotso.

Figure 6.13: Remnants of a metamorphosed dyke wall in Clarens sandstones along the wide Lancer's Gap Dyke.

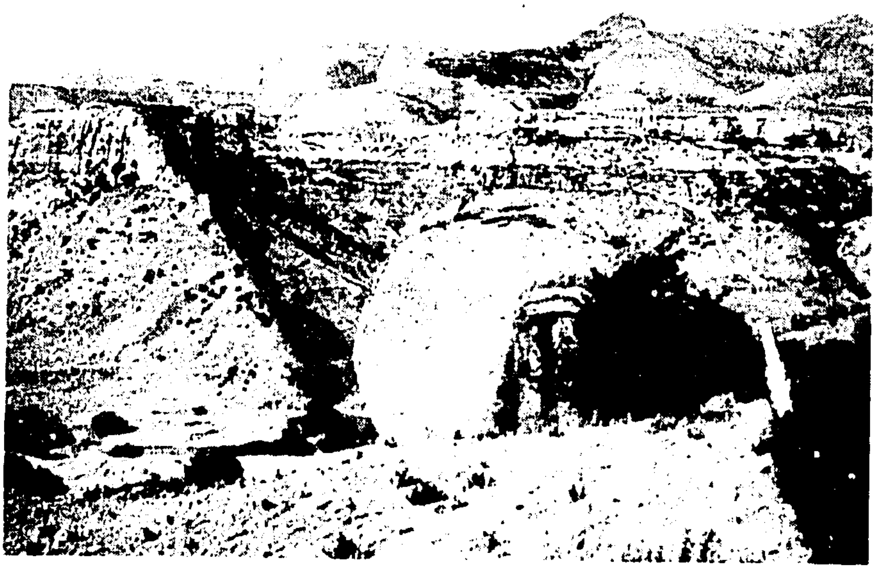


Figure 6.14: The mountains consisting of lavas of the Lesotho Formation; the plateau, the cliffs and the overhangs of the Clarens Sandstone Formation; the debris slopes of the Elliot Formation and a dolerite dyke bordered by metamorphic country rock.

Figure 6.15: Planation surface p_2 in the Lesotho Formation near Popa.

Chapter Seven

Geomorphological Evolution

Once the last floodbasalts of the Lesotho Formation were formed, about 155 million years ago (Geological Time Scale, Figure 3.15), the surface of Lesotho consisted of a lava plateau which extended far beyond its present borders and probably had little relief.

Since then the tectonic history of the area has been marked by the fragmentation of Gondwanaland in the early Cretaceous and by phases of epeirogenic and differential crustal movements since the middle Cretaceous.

The further geological history of Lesotho has been largely denudational. Two important trends have marked its geomorphological evolution: the formation of planation surfaces and the change from interior to coastal drainage.

7.1 The formation of planation surfaces

King (1951, 1967) describes the land surfaces of Lesotho, and Southern Africa, in terms of denudational landscapes at different levels, each resulting from tectonic movements and consequential upstream pediplanation. According to King the following landscapes can be recognized in Lesotho (Table 7.1):

King considers the summit level of the high mountain ridges between 3 300 m in the east and 2 400 m in the west of Lesotho as remnants of the Gondwana landsurface (Figure 7.1). The flat surface at 2 750 m at Sani Pass, the foothills, and the Clarens Sandstone structural plateau down to 1 770 m are regarded by him as belonging to the Post Gondwana, that is, early to late Cretaceous, landscapes. The larger part of the lowlands are considered to belong to the African, Eocene-Oligocene, landsurface, of which the lower parts have been affected by valley floor pediplanation at the end of the Oligocene and again at the end of the Miocene (King, 1967).

Although the concept of pediplanation may be correct and although in Lesotho definite levels of erosion can be recognised, some objections may be raised to a rigorous sub-division of Lesotho's planation surfaces according to King's scheme:

(a) As will be explained later, reorientation of Lesotho's drainage system and subsequent dissection seems to have gone so far, that no traces of the original Gondwana surface can be found anymore.

(b) Planation surfaces at different levels in Lesotho are all underlain by relatively resistant igneous or sedimentary layers. It seems therefore that structure has strongly influenced the geographic and altitudinal position of the planation surfaces.

Table 7.1: Important geomorphological events in Southern Africa (King, 1962).

Age	Tectonics	Denudation
Jurassic		GONDWANA LANDSCAPE of extreme planation
Early Cretaceous	Fragmentation of Gondwanaland and monoclinal flexing of eastern and western coast	
early to late Cretaceous		POST GONDWANA LANDSCAPES, usually in the vicinity of upwarps, incompletely planed
late Cretaceous	Continental uplift with outward flexing of eastern and western margins	
Eocene – Oligocene		AFRICAN LANDSCAPE of extreme planation forming the most perfectly planed surface, much dissected now by later cycles
Oligocene/ Miocene	Moderate epeirogenic uplift	
Miocene		BROAD VALLEY FLOOR PEDIPLAINS widespread into the African planation
Miocene/ Pliocene	Moderate epeirogenic uplift	
Pliocene		BROAD VALLEY FLOOR PEDIPLAINS widespread into the African planation
Pliocene/ Pleistocene	Powerful uplift and warping continuing possibly until present. Violent outward tilt of eastern and western margins	
Pleistocene		EROSION

(c) Local tectonic control may have influenced the formation of pediplains at different times and in different places.

It seems therefore that the planation surfaces in Lesotho are "structural pediplanation surfaces", formed by pediplanation associated with tectonic movements, but bound, in geographic position and altitude by resistant layers which served as local erosion bases.

The dating of the different landscapes has been done by King by extrapolating unconformities in the coastal plain stratigraphy on the eastern and western coastal margins into the interior of southern Africa. More research will have to be undertaken to verify the correctness of these extrapolations.

Also the dating, the intensity, and extent of the various tectonic events seem to be a matter which needs to be answered more precisely. On the basis of coastal sedimentation features in southern Africa, Dingle et al (1983) produce sea level curves showing Upper Cretaceous and Tertiary sea level movements from which a number of past regressions can be read:

- A late Cretaceous to lower Danian regression
- A brief middle Eocene regression
- A major mid-Tertiary regression
- A brief regression at the Miocene – Pliocene boundary
- A late Pliocene regression

These regressions may partly or wholly relate to eustatic sea level changes, but uplift, local or general, most probably has been the cause as well.

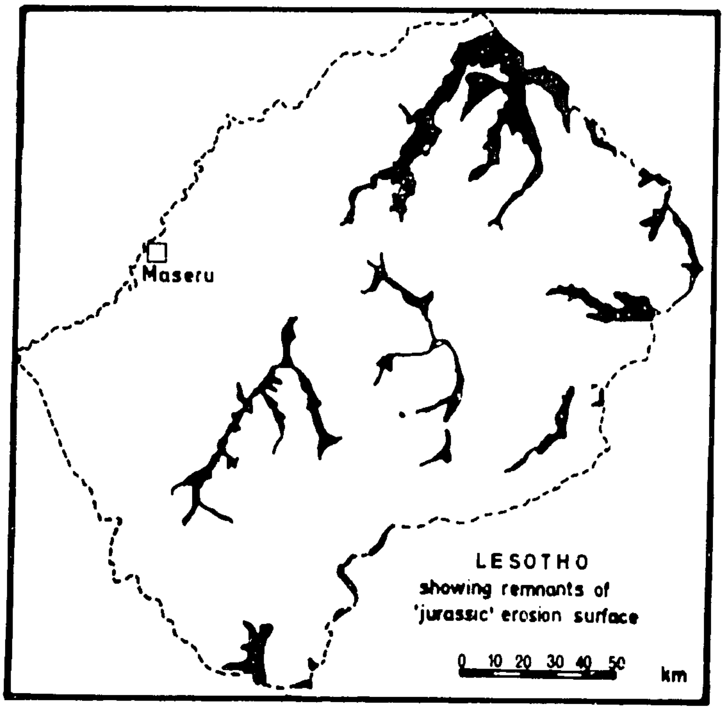


Figure 7.1: Lesotho, showing remnants of the Jurassic (Gondwana) summit level (source: King, 1962).

Dissection (Figure 7.6), which followed the final stage of the Drakensberg volcanics, was most likely related largely to the various phases of uplift, and the gross-morphology of Lesotho corresponds with the general picture of planation surfaces and erosional slopes as described by King (1967).

Superimposed on these tectonically controlled features are those ruled by lithology and the changes brought about by a changing climate. The processes of weathering, erosion, transportation and sedimentation that led to the formation of the present landforms in Lesotho all changed in character and in intensity through time under changing palaeoclimatic conditions which were often different from those of today.

Most geomorphological units in Lesotho can therefore be considered as remnants, which were once created under a particular climatic regime and under certain tectonic conditions and which were later, in a changing environment, modified and partly destroyed.

The oldest geomorphological unit in Lesotho is an old land surface, which forms the highest divides of the drainage areas (Figure 6.2(1)) and is considered to be a relic of an early, post-lava landscape of wide extent, which King (1967) dates as Jurassic (Figure 7.1). It consists of areas of subdued forms, where denudational processes presently seem little active (Table 7.1).

After the formation of this old land surface a phase of intense vertical erosion followed, which led to the almost total destruction of this surface, and to the creation of steep denudational slopes in the basalts (Figure 6.2(2)). Dissection was interrupted several times by the formation of planation surfaces (Figure 6.2 (P_1–P_5)). During those phases retreat of valley walls became dominant, leaving slightly inclined erosional surfaces which were then moulded by weathering and slope wash. Their altitudinal position seems largely determined by resistant rock layers, which formed local base levels.

Once the dissection reached the levels of the sedimentary strata a similar alternation of denudational slopes (debris slopes) with planation surfaces came into existance (Figure 6.2(7) (P_6, P_7).

It is not yet known when in time these planation surfaces were formed, but it is most likely that they were polycyclic. Etching for example could have occurred under savanna conditions in the Tertiary, whereas they could have functioned as transport surfaces, with surface wash as one of the dominant processes on them during the dry and warm interglacials. The red soil covering some of the lower planation surfaces in the basalts and in the sedimentary strata are most likely relics of a humid warm climate in the Tertiary.

The Cave Sandstones of the Clarens Formation seem to be particularly resistant to forms of erosion and weathering, while the overlying basalt formations were removed at a relatively fast rate, leaving structural sandstone plateau surfaces (Figure 6.2(5)), mesas and buttes in the landscape.

After the formation of the lowest planation surface (Figure 6.2(P_7)), another period of general dissection began, with the formation below that surface of deep, rock-cut valleys which became very wide in the lowlands. At the same time of their formation, some resistant basalt layers, the sandstone layers of the Clarens, Elliot and Molteno Formations underwent active scarp retreat (Figure 6.2(6)) and debris slopes were formed at their base (Figure 6.2(7)). The valley incisions progressed headwards through the retreat of waterfalls, which formed at sandstone outcrops and at resistant lava outcrops. The present scarps in basalt and in sandstones largely date back to this period, as do the debris slopes. It is known that such massive form of scarp retreat can take place under cold climatic conditions, whereby frost-shattering plays an important role. The above mentioned processes may have to be placed therefore in one of the early Pleistocene glacials. Butzer et al (1973) observed similar rock-cut features in the Vaal Basin, which he dated Pliocene to early Pleistocene.

In some heads of the deeply carved out valleys, very dark, heavy clay deposits of up to 3 m thick, resting on bedrock, can be found and thinner deposits of a similar clay exist further downstream in some valleys These clays were formed after the formation of rock-cut valleys had stopped, during a period of gentle runoff and extremely quiet deposition.

After that, intensive colluviation set in, and material was moved into the valleys and into depressions from headwaters as well as from the valley sides (Figure 6.4 and 6.5). Deeply weathered, pre-existing soils on the planation surfaces, on the plateaus, on the rock shelves and rock benches were transported down-slope to form pedisediments and (a) fill the deeply carved out valleys of the tributaries and the depressions; (b) form colluvial mantles at footslopes; and (c) provide the trunkstreams with source materials for intense fluvial accumulations. Most valleys became filled up to the brim with colluvium (Figure 6.5), and alluvial deposits (Figure 6.2(t_1–t_3)) and even the lower rims of the planation surfaces were partly covered. This accumulation phase ended with the formation of the highest accumulation terrace surface (Figure 6.2(t_1)). During this phase large amounts of soil were stripped off the various geomorphological units and deposited on lower adjoining units.

The t_1 accumulations are intensely red coloured by ferric oxides. These may have formed in situ under warm climatic conditions or have derived from the former but later transported soil covers of the planation surfaces.

A new phase of stream incision followed. This time the incision took place mainly in the t_1 accumulations (Figure 6.2) and in the colluvial and alluvial valley fill, although many local instances of super-imposition on underlying hard rock occurred. Ultimately streams reached a level partly below and partly above the base of the t_1 accumulation (Figure 6.2).

Then, a second period of colluviation began. Its magnitude was considerably less than the former one, but the same surfaces as before were once more partly or completely stripped of their soil cover and the already existing colluvial infills and mantles were covered by a second storey of pedisediments, commonly with thicknesses of 30 cm.

This colluviation must have initiated widespread fluvial accumulation, ultimately leading to the formation of the second accumulation terrace surface (Figure 6.2(t_2)). The t_2 accumulations consist of different dark coloured members, covered by buried palaeosols, which reflect a number of strong climatic oscillations and seem very similar to the various members of the Riverton Formation, which Van Zinderen Bakker and Butzer (1973) place in the Late Pleistocene and Holocene Epochs. They were formed by stream aggradation in the glacials, with cold and moist climates and stream dissection in the warm and dry interglacials.

Towards the end of the formation of this terrace surface a period of strong humification set in, leaving the top 30 cm of the terrace with black humified soil and, in some areas, peat deposits. The highest member of the t_2 accumulations, with its vertisol development, could be correlated with Riverton member V, which was formed in the early Late Holocene (ca 3 000 BP).

Streams have since cut into these accumulations. Prior to and during the incision, meandering of streams occurred and some local erosion terraces were formed in the t_2 accumulation (Figure 6.2 (t_1, t_2)), resulting from the lateral swing and subsequent truncation of meanders.

A final phase of stream accumulation led to the formation of the lowest terrace (Figure 6.2(t_3)) with young, poorly developed soils. After that, incision set in again and is continuing today. In most instances incisions have reached down to 50 cm below the base of former terrace accumulations, into the country rock (Figure 6.2(9)).

Processes that set in most recently in the area are those of accelerated erosion, marked by gullying, rilling, sheet wash, rock stripping, soil slip and slumping and those of accelerated sedimentation, featured by dam siltation, streambed choking and renewed colluviation. A discussion of those accelerated geomorphological processes follows in Chapter Eight.

A summary of geomorphological events in Lesotho is shown in Table 7.2.

Table 7.2: Summary of geomorphological events in Lesotho.

Formation of old land surface
Valley incision Shaping of major outlines of present valleys Formation of denudational slopes in basalt
Interruptions of the incision by periods of planation and valley widening by valley wall retreat. Formation of planation surfaces and denudational slopes in sedimentary strata.
Incision into the lowest planation surface. Formation of deep and wide, rock-cut valleys. Formation and headward retreat of waterfalls. Scarp retreat by rock fall and rock shattering. Formation of debris slopes.
Formation of deep soils under humid, warm conditions. Deposition of heavy clay layer on valley floors.
Widespread removal of soils by sheetwash from the planation surfaces and structural surfaces onto the adjacent lower lying units, mainly on footslopes, into valleys and depressions (pedisediments). Alluvial accumulation leading to the formation of the highest terrace (t_1) by often strong currents.
Incision into t_1 Renewed soil formation.
Removal by sheetwash of soils from the planation surfaces and structural surfaces onto adjacent lower lying units, mainly on footslopes, into valleys and depressions (pedisediments). Alluvial accumulation leading to the formation of the second terrace (t_2) with, towards the end, a period of humification. Formation of accumulation glacis.
Incision into t_2 and into pedisediments. Formation of erosion terraces.
Alluvial accumulation leading to the formation of the lowest terrace (t_3).
Incision into t_3. Accelerated erosion, with gullying, rilling, sheet wash, rock stripping, soil slip and slumping. Accelerated deposition as siltation, choking of channels, minor colluviation.

7.2 Reorientation from interior to coastal drainage

The first stream systems to have come into existence on the Lesotho Formation probably followed the natural gradient of the lava surface towards interior depressions. Schmitz (1968) concluded, on the basis of observed geomorphological features, that the primitive river systems in Lesotho had a northward orientation.

Along the offshore area of what is now the western continental margin of Africa, large taphrogenic structures developed in Jurassic-Lower Cretaceous times (Dingle et al., 1983), one of which formed the offshore Orange Basin, in which the earliest sedimentary infill, partly from a primitive Orange River, was formed. Continental separation between Africa and South America took place later, in the Valanginian, along the main north-south taphrogenic lineaments.

These two occurrences, the development of the oceanic Orange Basin off the present westcoast and the ultimate separation between Africa and South America, led to the establishment of a new base level and must therefore have given an impetus to the development and growth of the Orange River system, at the cost of pre-existing interior drainage systems.

Since the split up of Gondwanaland, Southern Africa has undergone phases of general uplift. The most widespread and intense occurred during the late Tertiary (Du Toit, 1954). Also these uplifts must have given a strong stimulus to the drainage extension of the Orange River System and therefore to morphological changes (Schmitz, 1968). In fact, drainage patterns as well as the geomorphology of the larger part of the Orange River system, including the whole of Lesotho, reflect a still ongoing evolution which is dominated by drainage reorientation.

The drainage features are:

- Barbed drainage patterns of many south flowing streams (Figure 7.2).
- Asymmetry of most east-west and west-east flowing streams (Figure 7.2).

The morphological features are:

- The presence, almost anywhere, of asymmetrical basins and divides (Figures 7.3 and 7.7).
- The occurrence of a large number of gaps on east-west stream divides, which are especially well conserved in the lowlands of Lesotho. Many of them indicate former stream crossings in northerly directions.
- Valley floor divides forming part of the northern divide of inversion basins with barbed drainage patterns.

The remodelling of the landscapes in the Orange River basin including Lesotho, seems to have proceeded along the following lines:

- A break through the original (mainly south-north) divides by newly developing streams.
- The capture of former (mainly south-north) streams.
- The rejuvenation of the captured streams and the development of asymmetric basins.
- The development of windgaps, deserted stream channels, interrupted stream channels, deserted valleys, choked streambeds and windblown deposits in the beheaded areas (and the development of pan-belts in the low-relief areas of the Orange-Vaal drainage basin).

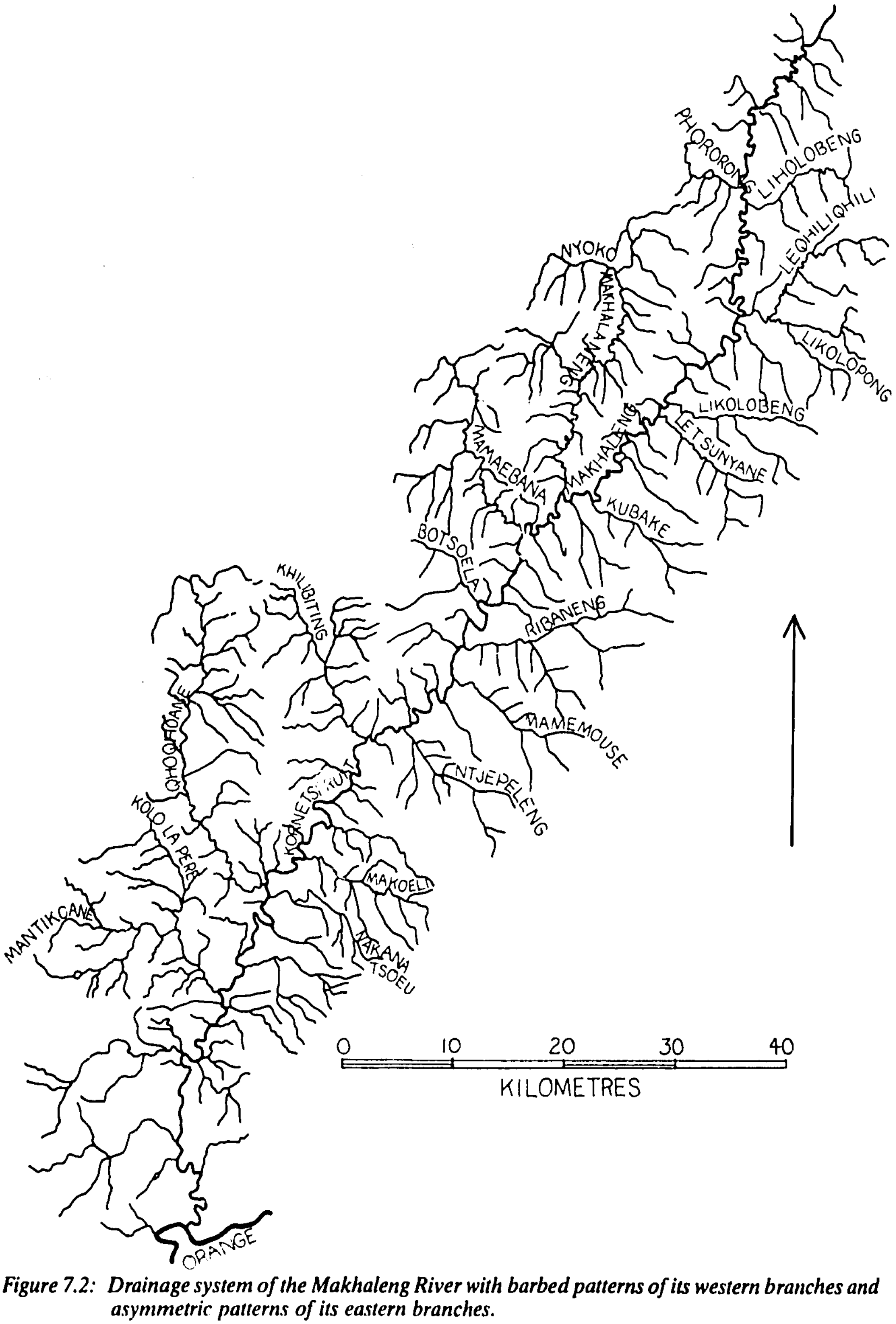


Figure 7.2: Drainage system of the Makhaleng River with barbed patterns of its western branches and asymmetric patterns of its eastern branches.

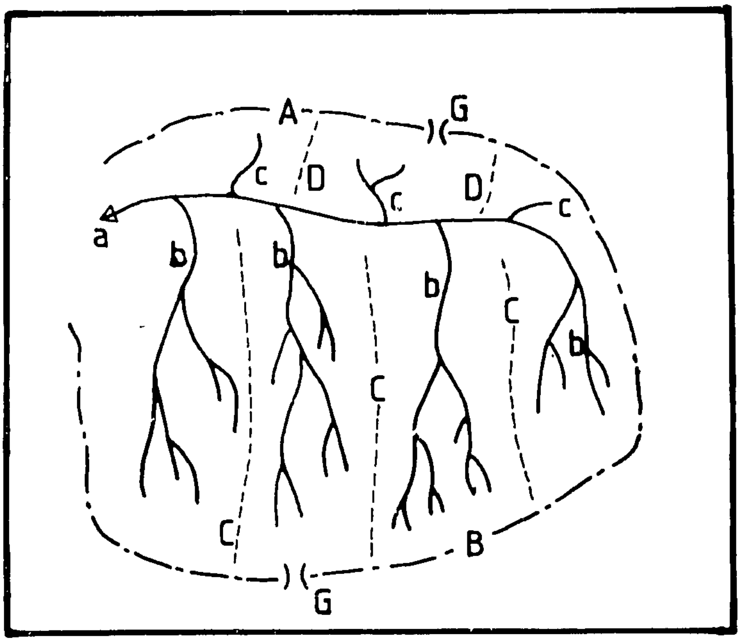


Figure 7.3: Outline of a typical asymmetric river basin in Lesotho: (a) trunk stream (capturer), (b) original (captured) drainage systems, (c) newly developing river branches, A, B: asymmetric northward shifting divides, C: original divides, D: newly developed secondary divides, G: windgaps or valley divides. Compare with figure 7.7.

- The migration of the newly formed asymmetric divides in the direction of the beheaded streams and the formation of valley-floor divides.
- The initiation and development, mainly by headward erosion, of south-flowing streams, with inversion patterns, and their valleys.

Within the territory once conquered by beheading, secondary adaptations took place and are still taking place, leading to the gradual breaking down of south-north stream directions and their replacement by streams that "match" the general orientation of the Orange River system.

Since the origin of the Orange River system, intrenchment has taken place to such an extent that the landscape which existed in pre-Orange times is now physically non-existent. What is left is a heritage of forms and directions. The processes of drainage reorientation and consequential remodelling of the landscape were controlled by two dominant factors: tectonic movements and lithology.

7.2.1 Tectonic Movements. Reorientation and remodelling seems to have taken place and to occur in waves, which, following tectonic movements like the split-up of Gondwanaland and epeirogenic uplift, spread upwards through the Orange River basin. This can be concluded from the fact that landscape relics reflecting more northerly orientations can especially be found at the levels of the planation surfaces and structural surfaces mentioned before.

The ultimate shape of the newly developed drainage basins seems to have been strongly controlled by differential epeirogenic movements (Du Toit, 1933, 1954) (Figure 7.4).

Binnie and Partners (1971) suggest that there is a tendency of the rivers of Lesotho to reflect the underlying structure. They mention the possibility of a post-Drakensberg tectonic movement, including gentle flexure, of the later basalts into a series of north-east/south-west trending ridges and furrows (Figure 2.15). They suggest that the first river systems might have developed in those furrows. To the authors however it seems that, as the whole Lesotho landscape reflects an early south-north flow, it is the later reorientation of stream systems that was strongly influenced by the post-Drakensberg flexures.

Barthelemy and Dempster (1975) mention that on the ERTS-1 satellite imagery north-south to northeast-southwest trending anticlines and synclines are discernable. Some can also be seen by mapping thick persistent lava beds in the field. All the axes correspond to the high and low axes postulated by Binnie and Partners.

The post-Drakensberg flexures represent very gentle dips in the basalt beds. The deformation was independent of the earlier Drakensberg structure and did not really modify it, with the possible exception of the uplifted anticlinal axes along the Drakensberg Escarpment (Dusar, 1979).

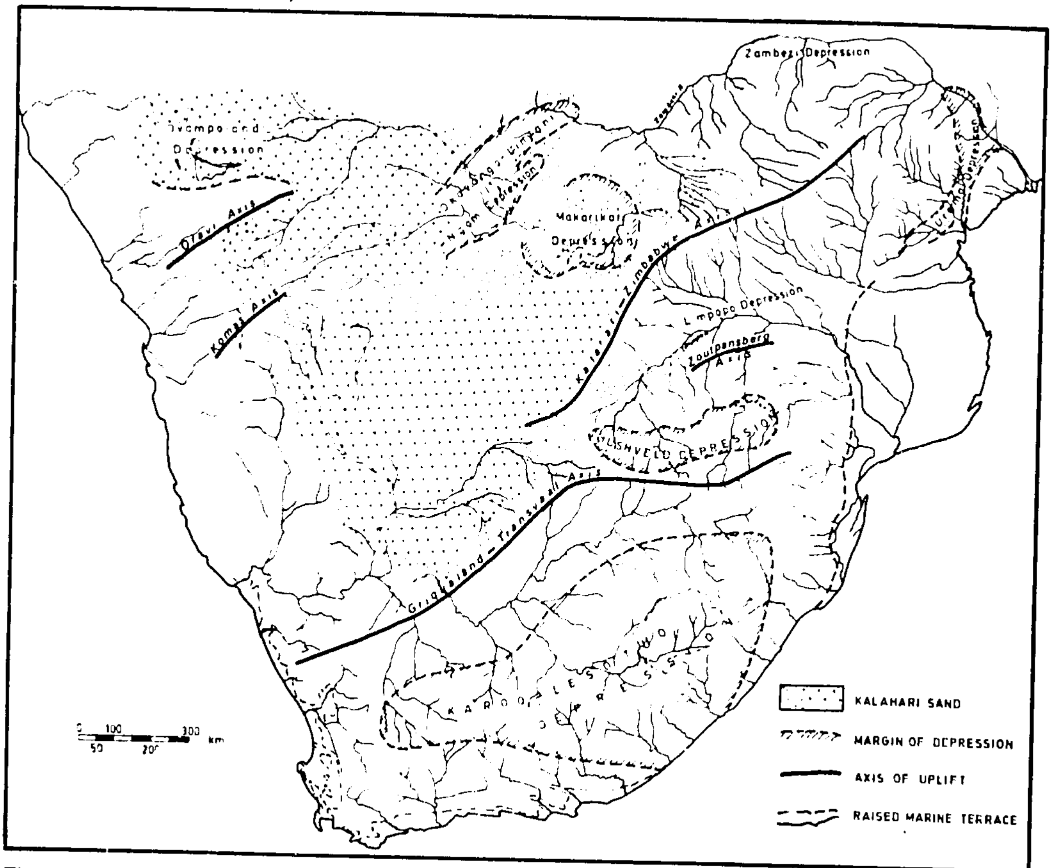


Figure 7.4: Axes of uplift and depressions resulting from Pliocene-Pleistocene deformations in Southern African (source: A.L. du Toit, 1954).

7.2.2 Lithology. The location of a specific drainage diversion can often be related to the occurrence of a lithological obstacle. For example, the location of new divides, formed after drainage diversion occurred, is often determined by the occurrence of a dolerite intrusion (Figure 7.7).

In general, drainage extension of the Orange River system and the consequential reorientation of drainage and morphology in Lesotho must have been initiated by the split up of Gondwanaland. They received their stimuli from repeated subcontinental uplifts, especially from the uplift in late Tertiary times, and were controlled strongly by differential epeirogenic movements and by the lithology of the Karoo sequence.

7.3 Nivation and glaciation hollows

Dyer and Marker (1979) plotted a total of 577 nivation/glaciation hollows in the highlands of Lesotho (Figure 7.5) and found that the highest hollow frequency occurs near the Drakensberg escarpment, that hollows have consistent dimensions, are restricted to areas above 3 000 m and have a dominantly northern aspect.

The northwest to southeast zones of hollows were distinguished:

A northeastern zone where high ground and high precipitation maximizes development. The zone has a high density of hollows covering the whole size and morphology spectrum.

A central zone, inland of the escarpment, where the conditions for the development of hollows was critical and variables of available area above 3 000 m and total precipitation are of increasing importance away from the escarpment.

A southwestern zone where hollows developed only where circumstances proved favourable, thus their location has a higher degree of chance.

An origin by nivation or by restricted glaciation during Pleistocene temperature depressions is suggested by the authors.

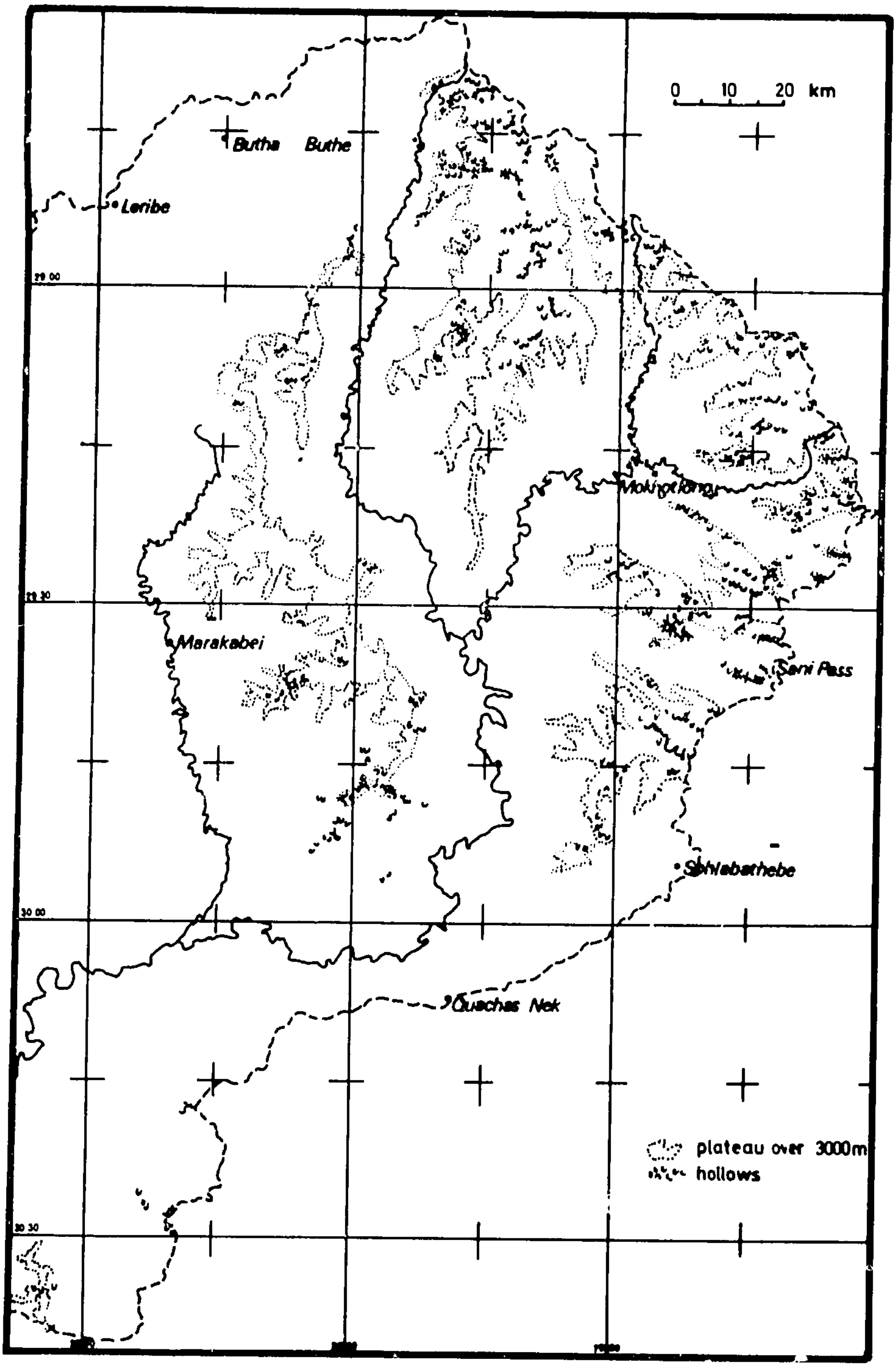


Figure 7.5: Nivation/Glaciation Hollows in the Highlands of Lesotho. (source: Dyer and Marker, 1979).

Figure 7.6: Intense dissection of the original lava plateau of the Lesotho Formation by the Orange River System.

Figure 7.7: Asymmetric drainage basins of some eastern branches of the Mohokare. Notice the dykes in the eas'-west divides. Compare with figure 7.3.

Chapter Eight

Accelerated erosion and sedimentation

8.1 Introduction

Reports show that 0,5 per cent of the total area of Lesotho has been irreparably damaged by erosion, and that six per cent of its soils, are highly vulnerable to water erosion (Flannery, 1977; Carroll et al, 1979; Rooyani, 1982). Of this six per cent, 20 per cent are soils in the lowlands.

In Lesotho, about 400 000 hectares of land are suitable for cultivation and all are used for that purpose. According to Flannery (1977), 25 per cent of that area is so badly eroded that it should not be being cultivated. Of the total arable land, 0,25 per cent is lost annually by erosion (Flannery, 1977; Rooyani, 1982) and in the lowlands the average annual soil loss on farmlands ranges from 30 to 100 metric tons per hectare.

The Conservation Division of the Ministry of Agriculture reports that the average soil loss from the farmlands of the country is 40 tons per hectare per annum (Masilo, Conservation Division, personal communication). This figure means a loss of 25 centimetres of topsoil in 100 years (assuming a bulk density of 1.6 g/cm^3) which is the total loss of the most fertile part of the soil over a century.

The level of soil loss in Lesotho is almost four times greater than the accepted level of loss from farmlands, which is 12 tons per hectare per annum.

The evidence of water erosion is widespread in Lesotho. Rain splash, sheet erosion and mass movement are quite common in the mountains. Donga (gully) erosion is quite extensive in the lowlands. In this chapter all these forms of erosion are defined and discussed within the context of Lesotho.

8.2 Erosion processes and forms

8.2.1 Rain splash. Rain splash causes soil particles to be detached and removed from their original position. The effectiveness of these processes depends on the size of the rain drops, their terminal velocity, the soil cover, and on the erodibility of the soil.

The splashed particles may seal off the pore spaces on the soil surface, thus reducing the infiltration rate and causing puddling. As a result, the runoff will increase and another form of erosion develops, namely the transportation of soil particles by runoff or sheet erosion.

8.2.2 Sheet erosion. SARCCUS (1981) defined sheet erosion as "the more or less uniform removal of soil from an area, caused by the detachment of soil particles through raindrop action and subsequent transport by runoff water. Water channels, if present, are very small and ill-defined and are not identifiable by air-photo interpretation".

During this process the most fertile part of the soil, the topsoil is removed, and, gradually and unnoticeably, the fertility and productivity of the soil is reduced.

Following rain splash erosion, the runoff carries the detached and splashed particles down the slope.

The erosivity of the runoff depends on the velocity of the water, which in turn depends on the steepness and length of the slope, on the amount of water, the level of turbulence of the water, and on the amount of abrasive material carried along.

During the process of sheet erosion, soil materials are transported in suspension, mainly clay and organic matter, in solution, mainly soluble soil constituents, and as surface creep of the larger particles.

Sheet erosion follows splash erosion and occurs on sloping lands. Since the boundary between splash and sheet erosion cannot be set precisely, the two together are often referred to as "surface wash".

8.2.3 Rill erosion. SARCUSS (1981) defines rill erosion as follows: "The removal of soil through the concentration of overland flow into numerous small, but conspicuous, channels or rivulets."

As runoff concentrates on bare land or in surficial depressions such as footpath, cattle tracks, plough furrows up and down the slope, and field boundaries, sufficient soil may be removed to form a small rill.

Rills are small enough to be ploughed in or to be crossed by farm implements. However if unchecked, they may become wider and deeper and eventually form a donga.

The combination of surface wash and rill erosion is the most destructive erosional process in Lesotho. These processes are responsible for the removal of the most fertile constituents of soil in solution or suspension.

8.2.4 Donga erosion. The name donga is used in Southern Africa for a gully, that is a channel cut by running water and which is so large and deep that it cannot be crossed or smoothed out by farm implements. This distinguishes the donga from the rill, although the division between the two remains subjective.

Dongas are the result of severe erosion and have been described as "characteristic symptom of erosion" by Hudson (1979).

After heavy storms, the concentration of runoff and its flow over unprotected, deep and erodible soils will lead to the formation of rills and narrow, shallow channels which are a threat to agricultural land.

Most dongas in Lesotho are either U-shaped or V-shaped. The U-shaped dongas occur where the subsoil is deep, erodible, and subjected to repeated cutting by channel flow and subsurface flow. The vertical walls are due to the undermining and collapse of the banks.

The V-shaped dongas occur in soils with erosion resistant subsoils, or with subsoils that are not easily undercut. They have steep banks and heads.

Some dongas are partly U-shaped and partly V-shaped or have intermediate shapes. They occur on lands with variations in subsoil characteristics.

Dongas may be continuous or discontinuous. Continuous dongas form a network of streams and are linked up with a river system. They normally increase in depth downstream. Discontinuous dongas form where there is a sharp change of gradient in the landscape, for example between a hillside and the lower valley or plain. They decrease in depth downstream. Several discontinuous dongas may be incorporated into a continuous system.

Dongas normally come into existence in unconsolidated earth materials, but may, when they grow deeper and longer, cut into the underlying bedrock as well. This can especially be observed in the relatively soft sandyshales of the Elliot Formation.

In Lesotho, most dongas, including the largest amongst them, occupy old drainage lines, these being rock-cut valleys filled with sediment. Within the boundaries of the sedimentary fill the dongas have proliferated by headward extension and by forming sidebranches, thus gradually consuming the original valley glacis (Table 8.5).

Another group of dongas has developed, seemingly independently of the pre-existing drainage systems, on unconsolidated materials covering different geomorphological units, especially the footslope glacis, in which they are often discontinuous (Table 8.5).

Donga density is much greater in the lowlands than in the foothills and mountains. Also the size of the dongas, in length, depth, width and branching, is much greater in the lowlands. This can be observed on the geomorphological map of the Thaba Bosiu area (Figure 8.13), which can be considered as representative for a larger part of Lesotho. The difference is due to the fact that most factors, including human factors, which govern the extent and growth of dongas are more prevalent in the lowlands.

Population density, density of road and track networks, urbanisation and agricultural activities are some of the human factors that may promote donga development.

Sediment filled valleys, Duplex Soils and footslope deposits are some of the natural features prone to donga erosion, and these land units are larger and more widespread in the lowlands.

About 15 000 hectares, or 0.5 per cent of Lesotho's land area, has been classified as gullied land, that is land which has already been lost through donga action (Carroll et al., 1979). In addition, Flannery (1977) estimates that there are about 25 000 dongas in Lesotho, of which 90 per cent are active and that seven per cent of the arable land in the country has been lost to gullies.

8.2.4.1 Donga growth. Donga growth may occur in different ways. It may occur through headcut advance or lengthening. This form of growth happens mainly through the processes of tunnelling and plungepool erosion.

The widening of dongas, or the erosion of the sidewalls, occurs by multiple headcutting sideways and by basal sapping and by lateral scour, followed by soil fall and slumping and by the subsequent removal of the sediments, mainly by runoff during flood.

Stromquist et al (1984) found in some small catchment areas in Lesotho that sidewall erosion occurs particularly in areas with intense rill and wash erosion.

Lateral scour can be found mainly in the lower reaches of a donga, especially where bedrock forms the donga floor.

Heads are often formed in the sidewalls of a donga, leaving sidewall spurs which are gradually reduced. The widening of the donga by this combined process of head retreat and spur reduction is a regular feature.

Stepwise upstream deepening can be observed in many dongas in Lesotho. The steps relate to discontinuity surfaces, such as the discontinuity between the upper and lower storey in the Duplex Soils, and the unconsolidated materials resting on bedrock. In such cases, subsurface flow, and plungepool erosion contribute to the headcutting of the steps. The deepening of the dongas slows down when the rockfloor is reached.

Another form of donga growth in Lesotho is the development of tributary dongas. These are often caused by the concentration of surface and subsurface flow along cattle tracks, footpaths, field boundaries and broken conservation structures. Sequential aerial photography shows that the speed of donga growth is relatively high along such features.

The development of new dongas can be observed especially where recent changes in the landscape have been brought about by man, for example where new roads, have been constructed, and where there are newly ploughed fields or where fields are left bare.

The areas most prone to the development of new dongas are the footslope glacis, especially if situated below a steep slope, examples of which are debris slopes and steep basaltic slopes, especially where both are concave in plan.

Deepening of existing dongas can be limited by underlying bedrock, and lengthening and widening by rocky escarpments. Reduction in drainage area may also reduce or stop expansion.

Stromquist et al (1984) found, in their study of erosion and sedimentation in small catchments in Lesotho, that the expansion of dongas seems to vary in space and time and that there are certain threshold values which need to be exceeded to promote rapid donga development.

In comparing erosion by gullies with erosion by surface wash and rills, they found that the relationship between the two varies from period to period, and that, when the threshold for donga erosion has been passed, dongas may temporarily be the most important sediment source in a catchment area, whereas, otherwise, it may be the surface wash and rill erosion.

The growth rate for dongas with active headcutting is of the order of one to ten metres per year (Chakela, 1981). Table 8.1 shows the growth rates of dongas in some selected catchment areas in the Khomokhoana catchment.

8.2.5 Piping as a mode of donga formation and extension. Piping has been found to be an important mode of formation and extension of dongas in Lesotho (Schmitz, 1978, 1984; Chakela, 1981; Faber and Imeson, 1982; Rooyani, 1985). All these authors have reported on the evidences of piping in Duplex Soils. A discussion on Duplex Soils and their properties influencing piping has been presented in Section 8.5.2 in this chapter.

Table 8.1: Gully erosion in some selected catchment areas in Khomokhoana catchment, between 1951 and 1977. (source: Chakela, 1981).

Area	*Gully growth in metres between 1951 and 1977*							
	0-5	*5-10*	*10-20*	*20-30*	*30-40*	*40-50*	*50*	*Total*
1	6	2	2	2	2	0	2	16
2	21	3	5	1	0	0	0	30
3	11	2	2	1	0	0	3	19
4	21	3	2	3	1	0	0	30
	59	10	11	7	3	0	5	95

8.2.6 Mass movements. Mass movement, whether it is the slow or rapid downslope movement of soil, regolith or solid rock, can also be accelerated, and some of these accelerated forms exist in Lesotho.

A very serious and widespread form of accelerated mass movement is the occurrence of terracettes on the basaltic slopes. These terracettes result from soil slip under water saturation and are caused by trampling by cattle, overgrazing and road construction. The ultimate result of this form of mass movement is exposure of bare rock surfaces on slopes which once had a complete soil cover.

Soil fall, that is the direct fall of a mass of soil, and slumping, which is the sudden downward movement of a coherent block of earth along a sliding plane, are both features that can be observed in donga walls and along the steep, unconsolidated banks of rivers, especially in outward bends (Figure 8.6). With the general spread of erosion and gullying, soil fall and slumping also are on the increase. Lateral scour and subsurface flow are the main contributors to these processes, which intensify with the onset of drenching rainfall. Fresh dumps of soil can be observed during early summer on donga floors and floodplains. These dumps are then being removed by subsequent floods.

8.2.7 Rock stripping. Rock stripping, that is the removal of a soil cover from a bedrock surface, is a widespread form of erosion on sandstone and basalt surfaces, like plateaux, rock shelves, rock benches and the lower rims of planation surfaces (Figure 8.7).

Seepage water from the basalt/sandstone interface or otherwise infiltrates the soil covering those units, and, via lateral flow, oozes out again where the soil/sandstone or the soil/basalt contact is exposed (Figures 8.1 and 8.7). There, a miniature soil scarp is formed by the undermining activity of the oozing water, and miniature collapse occurs. The collapsed soil is removed and the soil scarp migrates upwards, leaving the sandstone of basalt surface bare.

On any one geomorphological unit the process may operate on many fronts, thus reducing the soil cover to isolated patches, surrounded by bare rock (Figure 8.1). In Lesotho, this type of accelerated erosion is active seasonally, mainly in the summer and continues for the duration of the seepage, which normally stops in autumn. Large parts of the sandstone surfaces have already been denuded in this way.

As the process is concentrated in headwaters, and as it leads to a drastic change in surface characteristics, from vegetated soil cover to bare, smooth rock surface, it has a severe impact on the surface hydrology and on suspended load in the lower reaches.

In the advanced stages of rock stripping, overland flow increases so much in the stripped areas, that the lands below, especially if they are accumulation glacis, may become severely gullied.

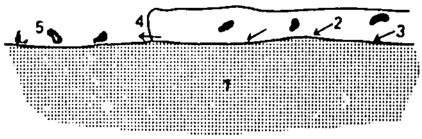


Figure 8.1: Rock stripping.
1. Sandstone, 2. Sandy soil with foreign pebbles, 3. Water movement, 4. Soil scarp, 5. Foreign pebbles left after removal of soil cover.

8.2.8 Wind erosion. Dust storms are a regular feature in the spring. They come from the west and northwest and become particularly strong after a dry winter, during which vegetation growth has been minimal.

Not much is known about the source areas of the dust, about the amounts and types transported nor about the depositional areas.

Generally speaking, given the rugged terrain and the few places where clear indications of wind erosion and wind deposition can be found, water erosion and deposition seems more devastating than wind erosion and deposition.

8.3 Sediment transport and deposition

8.3.1 Colluviation. Important source areas for sediments in Lesotho are those where sheet wash is an important erosional process. As mentioned before, these are the debris slopes, the planation surfaces and the accumulation glacis. It is therefore on the footslopes and in the depressions below those geomorphological units where wedges of colluvial deposits form.

In general it can be said that colluviation wedges can be found at the junction of a higher and a lower geomorphological unit. Recent accumulations of up to 30 centimetres exist.

8.3.2 Donga fans. Another form of recent accumulation exists in conjunction with discontinuous dongas (Figure 8.2). The discontinuous donga is erosive in its upper sections, but it produces a depositional fan at its lower end (Figure 8.8). The fan grows during the wet season and its apex moves up the donga floor. The lower end of the donga fills gradually with silt.

8.3.3. Siltation. High sediment concentrations can be observed in streams during the wet season. Chakela (1975) confirmed this by measuring sediment loads at four dam inflows in the Roma Valley and at bridges across the Lehobosi and Phuthiatsana Rivers. Siltation rates in the dams are also found to be high. Streams generally build up banks in their present courses and floodplains receive fresh sediment during annual floodings (Figure 8.9).

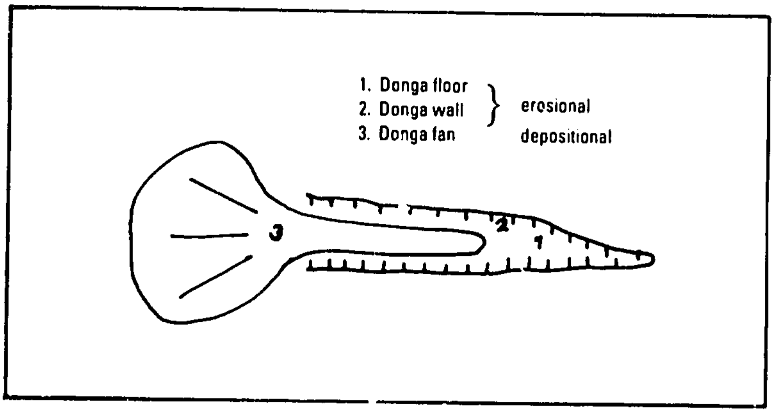


Figure 8.2: Discontinuous Donga.

8.4 Climatic factors

The impact of falling raindrops and hail pellets on soil, leading to the detachment and removal of soil particles, is an important form of erosion in Lesotho.

How much damage results from splash erosion depends on the amounts and intensities of the precipitation and on how sensitive the soils are to this type of erosion. Also important is the amount and type of vegetation cover, which serves as protection for the soil against raindrop impact.

Hudson (1979) states that "The factor which most influences soil erosion by water is the mean annual rainfall." Areas with a low annual rainfall have only little erosion by rain, whereas regions with a very high annual rainfall mostly have dense vegetation, which serves as a protective cover for the soils. With natural vegetation undisturbed, the most severe erosion by water is associated with an annual precipitation of between 500 and 1 000 millimetres, values which are prevalent in Lesotho. When the natural vegetation is removed, erosion by water generally increases with the annual amounts of precipitation.

8.4.1 Seasonality. The precipitation pattern in Lesotho is seasonal, with the rainy season normally starting in October and ending in April. Water erosion in the country shows a strong seasonal pattern too, which results mainly from the combination of a dry season, during which the soils dry out and the protective plant cover deteriorates, and a subsequent wet season with high intensity storms. In summer, the time of strongest water erosion, precipitation is largely of the convectional type. An example of rainfall intensities is given in Table 8.2.

During the wet season there may be regular periods of greater or less erosion, depending on rainfall intensities and on land management. Flannery (1977) makes mention of three maximum erosion seasons in Lesotho and of the lands maximally affected:

(a) high intensity storms of the late spring months on land fallowed for summer crops or on burned pasture and range;

(b) the low to moderate intensity rains of late summer or early autumn on saturated soil under fallow for winter crops, or on late summer crops whose growth is not well

Table 8.2: Estimated Maximum Rainfall Amounts for Maseru (source: Wilken, 1978).

Return Period (years)	*15 min.*	*30 min.*	*45 min.*	*60 min.*	*24 hours*
2	17 mm	26 mm	28 mm	33 mm	56 mm
5	24	35	40	45	74
10	27	—	44	52	85
20	31	45	49	58	95
50	36	52	58	68	112
100	39	58	64	74	126

enough matured to provide adequate soil protection;

(c) low intensity rains of mid-autumn on land ready for planting or already planted to winter crops.

8.4.2 Threshold values of intensity. As Hudson (1979) states: "there is a threshold value of intensity at which rain starts to become erosive." At low precipitation intensities there is little or no erosion. The raindrop impact itself is small and the resultant runoff may be non-existent or too small to have much erosive effect. Results of experiments (Hudson 1979) show that for Africa rain falling at intensities larger than 25 millimetres per hour become erosive, while Rydgren (1985) found, in the Maphutseng Soil Conservation A ea, that the threshold for erosion was 3 millimetres per hour to create surface runoff on hardpan and trampled ground and 15 millimetres per hour to create surface runoff on cultivated land. He claims that "it is the havy thunderstorms with a relatively long return period that are responsible for the bulk of the soil detachment leading to transport and erosion." However, more threshold values of intensity at which rain becomes erosive and at which surface wash and rill erosion occur have yet to be established for Lesotho.

8.4.3 Dry and wet periods. In addition to the seasonal precipitation pattern, the annual amounts can vary considerably. Tyson (1981) mentions the quasi recurrence in drought periods for Southern Africa. A number of years with a relatively low rainfall, followed by years with a high rainfall, may lead to much erosion during the wet years. During the dry years, overgrazing and overcropping will further reduce the protective plant cover and prepare the land for strong erosion during the next wet years.

Stromquist et al (1984) found in a small drainage basin in southwest Lesotho that active and rapid gully erosion occurred during the 1951 to 1961 period, which was three times as high as the gully erosion in the next twenty years. They give as a possible explanation the fact that the 1951 to 1961 period was characterised by high annual rainfall rates, with the annual rainfall then being about 100 millimetres more than normal. The previous years were characterised by a dry spell, the most noticeable of which was the period from 1944 to 1953 (Tyson, 1981), during which there was little growth of dongas.

Kulander (1984) made similar observations in a small catchment in the Roma Valley. According to her, rapid development and expansion of dongas may occur after a threshold has been reached, which seems to have happened in the period 1951 to 1961. She also mentions that during such a period of rapid expansion, the dongas may temporarily be more important as sediment sources than the wash- and rill erosion are.

8.5 Soil factors

8.5.1 Soil erodibility. An important characteristic in determining the soil loss by water erosion is the erodibility of soils in Lesotho. Amongst those factors determining the erodibility of soils are the physical soil properties, like the infiltration capacity, the resistance to detachment and transport of soil particles by the rain and by runoff, represented by the K-factor. This matter will be discussed in more detail under paragraph 8.8.2.

8.5.2 Duplex Soils. Duplex Soils appear to be the natural setting for the formation of U-shaped dongas.

Table 8.3 indicates the most extensive Duplex Soils in Lesotho. They all are found in the lowlands and have similar characteristics. Table 8.4 summarizes such characteristics. It seems that the combined influences of such properties has made these soils prone to donga erosion. Rooyani (1985) has found the following as common characteristics of the Duplex Soils in Lesotho:

- there is an abrupt textural change between the A-horizon and the B-horizon. The two layers are separated by a bleached layer, the E-horizon. The texture of the A- and E horizons is sandyloam to loam, overlying a clayloam to clay B horizon;
- the E-horizons are massive, that is, structureless, or have a weak blocky structure. The E-horizon is rather compacted with closely packed sand grains. The E-horizon overlays a strongly prismatic B horizon. The prisms are skeletal and round on top with a tendency towards columnar structure. Cracks are found along the vertical and horizontal axis of the exterior faces of the prisms;
- the exchangeable sodium percentage, the ESP, is high at the top of the B-horizons. The ratio of (Na^{+} $+Mg^{++}$)/$Ca^{++}$is highest at the boundary zone between E-and B-horizons. The value of the sodium absorption ratio, the SAR, which is a better indication of the activity of sodium than is the ESP, is also highest at that boundary zone.
- in most Duplex Soils, illite, with or without kaolinite, is the major clay mineral of the E-horizons, whereas the upper part of the B-horizons has a more expandable clay mineral. It is either a mixed layer of Illite and smectite or poorly crystalline and relatively expandable illite and smectite.
- the underlying material, that is the lower B-horizon or the C-horizon, is either shale, mudstone or clayey pedisediment.

Based on the common characteristics of Duplex Soils, a simplified model has been developed explaining the formation of pipes and the development of dongas in these soils. The following sequence of events probably constitutes the mechanism of piping as a mode of donga formation and extension in the Duplex Soils (Rooyani, 1982, 1985):

The textural difference between the two storeys of the Duplex Soils causes uneven infiltration of water through the soil profile. Water from rain and runoff infiltrates rapidly through the upper storey, but low permeability of the lower storey prevents penetration of water through the soil profile. Thus a capillary fringe is formed at the boundary between the E-and B-horizons and that zone rapidly becomes saturated with water.

Table 8.3: Taxonomic name and coverage of the major Duplex Soils in Lesotho (source: Carroll et al, 1979).

Soil Series	*Taxonomic name*	*Total coverage (ha)*	*Percentage of the lowlands**	*Percentage of the country*
Maseru	Typic Albaqualfs	20,482	2.25	0.67
Patsa	Typic Natraqualfs	29,960	3.30	0.98
Tšakholo	Glossic Natraqualfs	80,097	8.81	2.62
Sephula	Aeric Albaqualfs/Albaquic Hapludalfs	42,188	4.64	1.38
Tsiki	Typic Albaqualfs	2,751	0.30	0.09
	Total	175,478	19.30	5.74

*The area of the lowlands covers 30% of the area of the country.

Table 8.4: Differences between certain properties of upper-storey and lower-storey of four Duplex Soils (source: Rooyani, 1985).

Taxonomic name	*Horizon*	*Depth (Cm)*	*Structure*	*Clay Content (%)*	*SAR*	*$(Mg^{++} + Na^{+})/Ca^{++}$* (meq/l)*	*Clay Mineralogy*
Typic Natraqualf	E	22-35	Massive	8.5	1.41	2.74	Illite
	Btg	35-70	Columnar on top	34.1	6.04	8.14	Illite + Smectite
Aeric Albaqualf	E	22-55	Massive	9.6	0.47	0.97	Illite
	Btg	55-80	Prismatic (Skeletal on top)	28.6	2.65	5.36	Poorly chrys, Illite + traces of Smectite
Typic Albaqualf	E	15-40	Week. SA Blocky	8.0	0.63	1.73	Illite + Kaolinite
	Btg	40-75	Prismatic (Skeletal on top)	42.5	1.55	2.71	Poorly chrys, Illite + Smectite
Aeric Albaqualf	E	20-70	Massive	11.1	0.36	0.78	Illite
	Btg	70-125	Prismatic (Skeletal)	23.3	1.22	2.06	Smectite

Presence of water in the saturated zone promotes chemical reactions. Sodium is activated and disperses clay particles and enhances a lower permeability at the B-horizon.

It has been found that in most Duplex Soils, both sodic and non-sodic, the maximum SAR, or the combined activity of soluble sodium, magnesium and calcium, occurs at the top of the B-horizon. It was also found that the ratio (sodium + magnesium)/calcium becomes higher in this zone. Because of high exchangeable sodium, SAR and $(Na^{+} + Mg^{++})/Ca$, the clay dispersion at the top of the B-horizon enhances, which results in poor permeability in this zone and facilitates the lateral movement of water.

A water saturated zone, activated sodium and dispersed clay particles in a clayey medium, the B-horizon, impede the vertical movement of water. The existing cracks then become the only spaces in which water can move. The cracks are formed due to the presence of a more expandable clay mineral at the B-horizon and due to a climatic regime with an alternating wetting and drying season. Once the water is concentrated in the cracks, the formation of openings due to the collapse of the dispersed particles along the walls of the cracks becomes inevitable. Openings become larger and due to the lateral movement of water, small pipes are formed along the direction of the lateral movement of water. The slope and aspect of slope dictate the general direction of lateral flow.

The materials detached and transported by subsurface flow are usually the clay particles, which are carried in suspension, and the soluble soil constituents carried in solution.

Lateral flow makes its way under the ground, along the slope, until it drains off the soil profile as seepage. With the continuation of the process, the pipes, or tunnels, develop to such an extent that the roofspan, which consists of A- and E-horizons, becomes unstable and collapses under its own weight. Thus a donga is formed and new erosion processes in an open channel start their cycle.

The small dongas, formed by the opening of the tunnels develop rapidly in width and depth due to high erodibility of the B-horizon and the underlaying materials, which may be unconsolidated pedisediments or bedrock. The pedisediments are as erodible as the B-horizons of the Duplex Soils.

At this stage, a similar process of piping may start at the boundary between the soil and the underlying bedrock. The source of water to initiate this process is channel flow and not the percolating water.

Clay analysis of samples of Elliot shales and mudstones, overlain by Duplex Soils, revealed that the clay content of the rocks exceeds 50 per cent, and montmorillonite was found to be the dominant clay type. The combination of these two makes the shale and mudstone extremely vulnerable to erosion when and where a source of water is available. Differences in permeability, in texture, and in clay mineralogy seem to be the factors involved in undercutting at this level.

Undermining of the banks by scour during floods with results slumping of the donga walls seems to be facilitated at this level, leading to the widening of the dongas. Secondary heads can also form through slumping and tunnel formation.

The requirement for the above mechanisms to happen is concentration of water and an adequate water supply. Reduction of the vegetation cover may lead to the local concentration of runoff. Mis-use of the land, like overcultivation, overgrazing and the lack of maintenance of conservation structures, is therefore a key factor in donga formation through piping in the Duplex Soils of Lesotho.

8.6 Terrain factors

In Lesotho, there exist a close relationship between the type of erosion or sedimentation and its resultant features on the one hand, and the geomorphological unit on which they predominate on the other (Schmitz, 1984b). Table 8.5 shows this relationship and reference is being made to it in this chapter and in chapter six.

Another important terrain factor, the topographic factor, is discussed under 8.8.3.

8.7 Human factors

8.7.1 Removal of vegetation. The removal of the vegetation cover, or the reduction of its density, poor cultivation practices, overgrazing, bush burning or urbanisation activity, are important factors in the acceleration of erosion of erosion susceptible soil.

Table 8.5: Geomorphological Units in Lesotho with Dominant Processes and Forms of Accelerated Erosion and Sedimentation. (source: Schmitz, 1986).

Geomorphological Unit	*Dominant Process (erosive)*	*Resultant Features*
basaltic slopes	soil slip rilling rock stripping	cattle steps, terracettes rills bare rock surfaces
plateaux, rock shelves rock benches	rock stripping	bare rock surfaces
debris slopes	sheet wash rilling headward erosion	truncated soils rills donga heads
planation surfaces	sheet wash rock stripping	truncated soils bare rock surfaces (on rims)
footslope glacis	sheet wash piping gullying rilling	truncated soils tunnels, collapse holes strongly branched dongas (first generation) rills
valley glacis	sheet wash piping gullying rilling	truncated soils tunnels, collapse holes strongly branched dongas (second generation) badlands rills
alluvial terraces (edges mainly)	headward erosion slumping	donga heads stepped, hummocky slopes
streambanks	bank caving	slump heaps
	Dominant Process (accumulative)	
footslopes, depressions	colluviation	colluvial wedges, burried soil profiles
floodplains	stream deposition	alluvial deposits
stream channels	stream deposition	gravel and sand bars
dams	siltation	infill

The effect of the vegetation cover is mainly the physical protection against raindrop impact and scour by running water, and in reducing the velocity of overland flow. Bare patches of land are the collectors of runoff, and there the runoff increases at the expense of the infiltration, and will concentrate where the slope allows for it.

Removal of vegetation will therefore lead to an acceleration of surface wash, rill erosion and donga erosion.

8.7.2 Continuous single cropping. Most of the soils listed in Table 8.3 and similar soils have a low pH range of 5 to 6, a low base saturation, of around 60 per cent and a low organic matter content, of about 1 per cent at the top.

These figures, extracted from Carroll et al (1979), indicate a poor fertility status for the named soils.

Under the inherited poor fertility condition, continuous cropping of row crops, mainly maize, has increased the soil infertility, and grazing of crop residues after harvest prevents the maintenance of organic matter.

These agricultural practices on soils of inherited poor fertility in Lesotho, not only cause a gradual decrease in crop yield, but also increase the instability of the soil and leave it with little protection against rain action and surface wash.

8.7.3 Overgrazing. Overgrazing occurs when and where the number of livestock grazing on a unit of land exceeds the production capacity of the unit. Excluding the influence of man, the production capacity of any unit of land is determined by a combined influence of soil, plant, and climatic factors. Overgrazing depletes the soils, removes the productive ground cover and leaves the exhausted soil exposed to rain splash. Overgrazed patches of land and livestock tracks, particularly around the villages, become the centres for concentrated runoff with subsequent surface wash, rill and donga erosion. Accelerated erosion as a result of overgrazing occurs throughout Lesotho. As the larger part of the mountains is rangeland, overgrazing is a dominant cause of accelerated erosion in that area.

The lowlands have a distinct dry season, which makes a year round grazing system impossible. Soils of the lowlands and of the foothills, are mostly poor in fertility and are therefore not able to produce enough to satisfy the needs of the increasing number of livestock.

8.7.4 Lack of maintenance. The practice of contour farming and buffer strip cropping is rather common in Lesotho, with a significant proportion of the farmlands having been provided with contour banks, the construction of which dates back to the 1930s.

It seems that in constructing these terraces and contour banks, the slope rather than the soil was the major criterion. While terracing is generally an effective conservation measure on erosion resistant soils, on erosion susceptible soils, such as Duplex Soils, it may increase soil instability and at places where water concentrates, cause more subsurface drainage and subsurface erosion.

The key to an effective terracing system is the frequent repairing and maintenance of both, the channels and the ridges of the terraces. In Lesotho it is common to find broken contour banks which are not maintained (Figure 8.12). The main cause of the failures is the use of these structures for footpaths by both humans and cattle.

A single broken contour bank is sufficient to destroy the entire terracing system of a farmland. The rills formed along the slope as a result of broken contour banks are the most suitable sites for the concentration of runoff and eventually for the formation of dongas. Many of the dongas formed in Lesotho follow the points of failure of the contour banks.

8.7.5 Roads and tracks. Until recently not much attention had been paid to the environmental damage caused by road construction. Apart from certain sections of the highway Leribe-Maseru-Mafeteng, little attempts were made to align the road correctly or to put culverts in place during road construction in the country.

On paved roads the major problem is the culverts. Usually, road engineers are mainly concerned with removing the runoff from the road surface, not necessarily from the adjacent areas.

Culverts installed at certain intervals along the road collect the runoff from the road surface and rarely release it into stable waterways, but mainly onto lower farmland and rangeland. A rapid development of rills, and consequently of dongas, occurs where the culverts release concentrated runoff.

The situation is worse along dirt roads and tracks, including livestock tracks (Figure 8.11) and field boundaries (Figure 8.12). In Lesotho, many of them are not properly placed and maintained and they therefore constitute stretches of bare soil and are collectors of runoff from adjacent farms and grazing land. Field observations reveal that concentration of runoff on dirt roads and tracks, due to poor or complete absence of the installation of culverts, is one of the major factors responsible for rapid rill and gully formation.

8.7.6 Tillage practices. When the soil is always ploughed to the same depth, or when it is ploughed too wet, a plough pan may develop which is dense and has low permeability. Rapid saturation of the layer above leads to increased runoff and erosion.

8.8 Estimation of soil loss and the Universal Soil Loss Equation

The most commonly used method to estimate the soil loss caused by runoff in farmlands is the application of the Universal Soil Loss Equation (USLE), as developed by Wischmeier and Smith (1965).

The equation has been successfully applied in predicting soil loss from croplands, but doubts exist about its validity for predicting soil loss from rangeland (Schuster, 1984).

The equation states:

A = RKLSCP, Where
A = The estimated soil loss in tons per hectare per year
R = Rain erosivity factor
K = Soil erodibility factor
LS = A factor showing the combined influence of slope steepness and slope length
C = Crop management factor
P = Conservation practice factor

In this chapter, the above factors will be discussed within the Lesotho context.

8.8.1 Rain erosivity: R-factor. The erosivity of rainfall depends on the level of kinetic energy carried by it. The kinetic energy of rain depends to a large extent on rainfall intensity.

The rain erosivity is calculated as:

E = (210+89 log I), where
E = The energy of rain
I = The rainfall intensity measured in 30 minutes.

Attempts have been made to compute the R-factor for Southern Africa and for Lesotho (Scherer, 1978; Smithen and Schultze, 1982; McPhee and Smithen, 1984) and Figure 8.3 shows the R-factor for Southern Africa. According to this map, the values of R are 200 for the lowlands and 150 for the foothills of Lesotho.

Because of lack of long term rainfall intensity data in the mountains of Lesotho, no attempt has been undertaken to compute the R-factor for the mountains.

8.8.2 Soil erodibility: K-factor. The soil erodibility factor predicts soil loss of tilled, continuous fallow soil. To obtain the K-factor value of a particular soil one can use a nomograph and have the following information about its topsoil (Wischmeier et al, 1971):

percentage of silt and very fine sand;
percentage of sand, excluding the very fine sand;
percentage of organic matter;
type and size of soil structure;
permeability.

The values of the K-factor for the most important soil series of Lesotho have been evaluated by using the erodibility nomograph. Table 8.6 shows the K-factor for the most important soil series of Lesotho. Ranges of K values have been arbitrarily set to reflect the relative erodibility.

Table 8.6: Calculated K-factor values for the most important soil series of Lesotho (source: Carroll et al, 1979; Cauley et al, in press).

Soil Series	*K-Value*	*Soil Series*	*K-Value*
Bela	0.42	Patsa	0.60
Berea	0.32	Phechela	0.45
Bosiu	0.55	Popa	0.28
Caledon	0.18	Qalaheng	0.42
Fusi	0.28	Qalo	0.27
Hololo	0.27	Ralebese	0.40
Khabos	0.35	Roma	0.43
Kolonyama	0.41	Sani	0.18
Kuba	0.23	Sefikeng	0.18
Lekhalong	0.22	Seforong	0.30
Leribe	0.28	Sephula	0.58
Machache	0.28	Sofonia	0.18
Majara	0.55	Thabana	0 22
Maliele	0.22	Theko	0 40
Maseru	0.60	Thoteng	0.49
Matela	0.25	Tšakholo	0.39
Matšaba	0.30	Tšenola	0.18
Matšana	0.21	Tsiki	0.56
Moshoeshoe	0.36	Tumo	0.35
Nkau	0.27		
Ntsi	0.42		

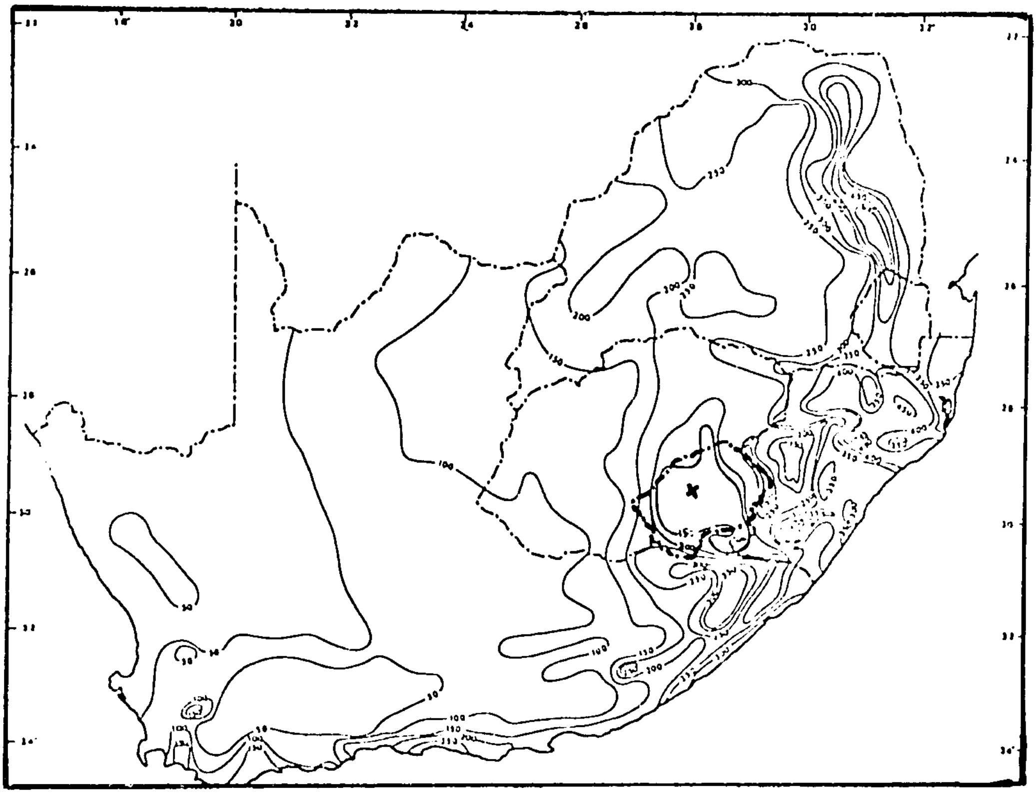


Figure 8.3: Rainfall erosivity in Southern Africa (source: McPhee and Smithen, 1984).

8.8.3 Topographic factor: LS-factor. This factor represents the combined influence of the slope length and slope steepness on soil loss. Runoff increases proportionally, and thus more surface wash can be expected, as steepness of slope and length of slope increases. Values for Lesotho can be obtained from Figure 8.4.

8.8.4 Crop management factor: C-factor. The crop management factor takes into consideration the combined influence of type of crop, crop residue, cropping management, rotational or continuous tillage practices, and crop stage periods, such as rough fallow, seedling, establishment, maturity and residue.

The C-factor is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding loss from tilled, continuous fallow (Wischmeier and Smith, 1965). Computation of the C-factor requires many years of plot experiments. Its value varies considerably from locality to locality.

A first attempt to provide some basic information on the C-factor in Lesotho was carried out by Scherer (1978). Table 8.7 shows estimates of the C-factors for a complete crop cycle under different cropping management for Lesotho. However, as yet no information is available on the C-factor for specific growth stages.

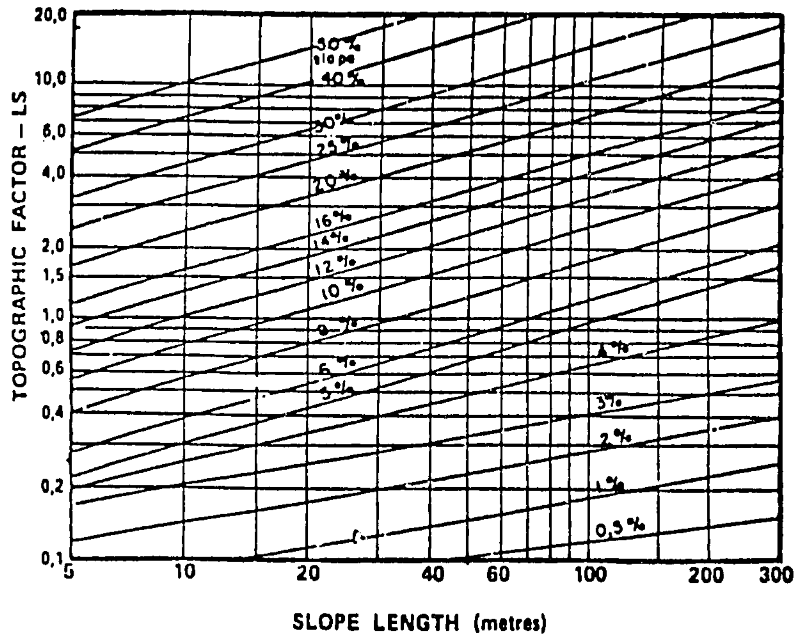


Figure 8.4: The combined slope-length factor.

Table 8.7: C-factor values estimated for Lesotho (source: Scherer, 1978).

Rotation	*Low Yield*	*Medium Yield*	*High Yield*
1. Maize or sorghum – clean – continuous	0.64	0.54	0.47
2. Maize or sorghum – weedy – continuous	0.50	0.45	0.38
3. Maize or sorghum – weeds – maize or sorg. – weeds	0.31	0.29	0.23
4. Maize or sorghum/beans–semi-weedy – continuous	0.57	0.50	0.43
5. Maize/beans-Maize/beans (clean)	0.67	0.56	0.50
6. Maize or sorghum with beans (4 Years)-Fodder (4 years)	0.26	0.23	0.20
7. Beans clean continuous	0.69	0.59	0.52
8. Beans weedy continuous	0.57	0.52	0.45
9. Beans – Fodder – four year rotation (clean)	0.17	0.13	0.08
10. Wheat continuous	0.24	0.23	0.20
11. Wheat-Fodder-Wheat-Fodder	0.05	0.45	0.04
12. Wheat/Beans (1 Year) – Continuous	0.45	0.38	0.31
13. Wheat (4 Years) – Fodder (Perennial) (4 Years)	0.16	0.14	0.12
14. Potatoes-Maize-Beans-Wheat-Fodder	0.34	0.26	0.23
15. Potatoes-Wheat-Beans-Fodder-Fodder	0.27	0.24	0.14
16. Potatoes-Maize-Beans-Wheat (Clean)	0.41	0.35	0.20
17. Wheat/Peas-Maize-Potatoes-Fodder (4 Years)	0.27	0.25	0.23
18. Lucerne (4 Years)-Maize-Pot-Sunf-Wh-Fod-Maize-Soy-Wh-Fod (Phuthiatsana)	–	–	0.17

8.8.5 Conservation practice factor: P-factor. The P-factor reflects the influence of soil conservation, like contour farming and terracing, on soil loss, and has been based on the ratio between the soil loss under a specific conservation practice and soil loss from a clean, that is with weeds removed, up and down hill ploughed farm.

If no conservation practice is implemented, the P-factor will be equal to one, and if contour farming is implemented, the P-factor is determined, using Table 8.8.

Table 8.8: P-factor values for contour farming (source: Wischmeier and Smith, 1965).

Land slope (percentage)	*P-value*
1.1– 2	0.40
2.1– 7	0.50
7.1–12	0.60
12.1–18	0.80
18.1–24	0.90

8.9 The Soil Loss Estimation Model for Southern Africa. Although some conservationists claim that the USLE can be made to work satisfactorily in other parts of the world, it has been stated by others that the equation will not work outside its tested range; that is outside the eastern part of the United States (M. Stocking, 1981).

In 1976, the Southern African Regional Commission for the Conservation and Utilization of the Soil (SARCCUS), set up a multidisciplinary team to design a soil loss estimation model suitable for conditions in Southern Africa (SLEMSA).

SLEMSA is a framework for soil loss estimation, to be used as a guide to regional models.

Currently one regional model, the Highveld Model, has been fully developed using the SLEMSA approach, and several more, including a model for Lesotho, are in various stages of development.

Within the SLEMSA framework, three phases of model development are distinguished, from a qualitative model initially, to a semi-quantitative model in the second, and a fully quantitative model in the final phase.

Once the final model is developed for Lesotho, it is hoped that soil loss rates can be specified for any given field situation in the country.

8.10 Suspended sediment yield. Suspended sediment yield measurements over the 1976–1982 period, undertaken in the Senqu and Mohokare River Systems (Makhoalibe, 1984) show that annual suspended yields range from 3 to 500 tons km^{-2} in the Senqu System and from 460 to 2050 tons km^{-2} in the Mohokare System.

Differences in the erodibility of igneous rocks and their soils, on the one hand, and sedimentary rocks and their soils on the other, become clear if one considers that suspended sediment measurements, above the point where sedimentary strata outcrop within the Senqu System, that is above Koma-Koma, show an annual sediment yield of between 3 and 80 tons km^{-2}, and below Koma-Koma of between 110 and 500 tons km^{-2}. The Mohokare System, with its high sediment yield, is almost entirely situated in sedimentary strata.

A further explanation for the differences in sediment production in the different areas of Lesotho is that the densely populated areas and the areas with extensive cultivation have the highest sediment yield figures. The highest values in Lesotho are found at Mapoteng, in the Northern Phuthiatsana Catchment, with a yield of 2 050 tons $km^{-2}yr^{-1}$, and at Masianokeng in the Southern Phuthiatsana Catchment, with a yield of 1380 tons $km^{-2}yr^{-1}$.

8.11 Reservoir sedimentation. Reservoirs can provide valuable information on the rate of accretion of deposited sediment, which reflects erosion rates in the related catchment areas. In order to obtain reliable data, measurements have to be long term. Ideally, the original bed level immediately after the construction of the dam should be known. Dam sections can be surveyed periodically to provide information on sedimentation rates. Chakela (1981) published some preliminary short term rates of erosion and sedimentation in the Roma Valley and in the Maliele catchment (Table 8.9).

Table 8.9: Sedimentation yields in Roma Valley and in the Maliele Catchment (source: Chakela, 1981).

Catchment	*Relief Ratio m/km*	*Catchment Area km^2*	*Sedimentation yield per km^2 per Year*
Roma Valley Area 1			340
Roma Valley Area 2	200/0.8	0.5	1,700-1,870
Roma Valley Area 4	310/2.6	2.2	825
Maliele Area 1	210/1.4	0.6	220
Maliele Area 2	325/4.2	6.3	350

Figure 8.5: An active donga system in the Mohlakeng Valley. The trunk below the confluence is situated in the accumulation terrace t_2, the upper network developed in valley glacis. Notice the parallelness between the main road and one donga branch. The other branches are strongly fed by a distant overgrazed debris slope.

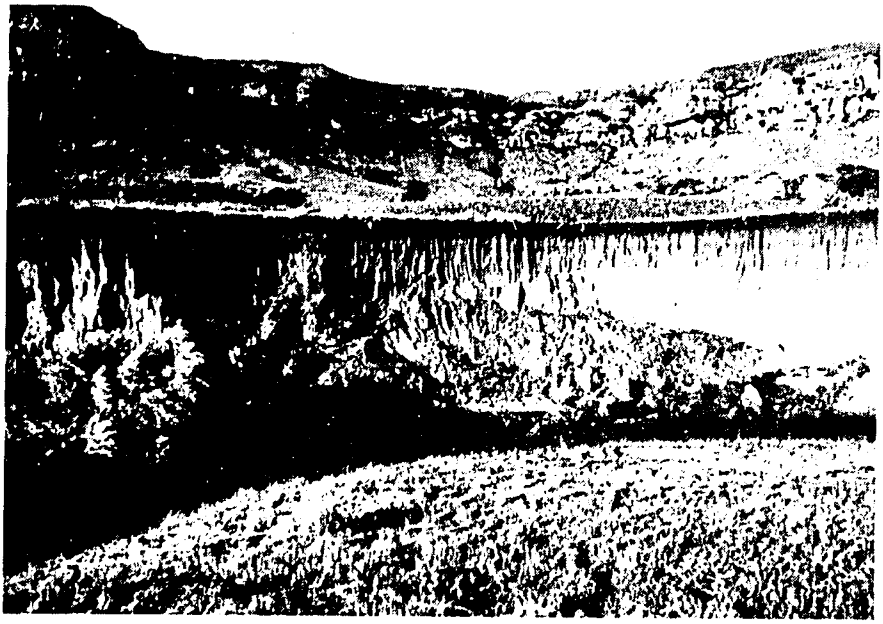


Figure 8.6: The undermining and collapse of an unstable wall in the accumulation terrace t_2, in a bend of the Liphiring River near Ha Mokhitli.

Figure 8.7: Rock stripping on a sandstone outcrop of the Elliot Sandstone Formation near Moeling in the Liphiring Catchment. The dark layer on top consists of basaltic lavas of the Lesotho Formation.

Figure 8.8: A donga fan near St. Michael's. Sediments are deposited seasonally in this field near the outlet of a discontinuous donga.

Figure 8.9: Accelerated sedimentation in the bed of the Liphiring River near Lesekele.

Figure 8.10: The upward progression of a donga head, parallel to and on the upslope side of a terrace bench. The terrace bench was built in the 1930s. Concentrated overflow resulted in the break through of the donga.

Figure 8.11: Rill development on livestock tracks in basaltic soils in the mountains of Lesotho near Mantšonyane.

Figure 8.12: Donga development along original field boundaries on a valley glacis near Ha Mokhitli in the Liphiring Catchment.

Section Four

Soils

Chapter Nine

Soil Materials

Excluding the areas of higher elevation, that is, areas close to or above 3 000 metres, most of Lesotho's soils are mineral soils. Mineral soils consist, principally, of minerals with a small fraction of the usually well decomposed organic material being present. On a volume basis, the remainder of the mineral soil system is occupied by air and water which fill the pore spaces. The two important components of soils in Lesotho, the organic and mineral components, will be discussed in this chapter. The discussion on the organic component is limited to amount and distribution of organic matter in soils of Lesotho and not on the composition. Unfortunately no recorded information is available on the composition of organic matter in soils of the country.

9.1 Organic component

The main source of a soil's organic constituents is plant residues, but the remains of animals and of soil microorganisms are others, though their contribution is normally small.

The build up of organic matter in soils depends on many factors: for example, climate, relief, time and supply and the type of plant residues available. Where an abundant supply of plant residues is available, and climate prohibits the rapid decay of the residues, an organic soil may develop (Figure 9.1).

At higher elevations in Lesotho, where low temperatures persist for most of the year, areas of organic soils have been identified (Mack, 1981). These soils, classified as Borosaprists, have formed under dense grass cover, where there is a mean annual temperature of less than 8°C, and where drainage is impeded.* The organic component of these soils is commonly well decomposed, with few identifiable fibres.

Excluding such elevated areas, the soils of the country are mineral soils with an organic matter content ranging from less than one per cent to ten per cent. Soils occurring at elevations below 3 000 meters in the mountains have developed in temperate climatic conditions and under a natural, tall grass vegetation of a dominantly Themeda-Festuca veld type. These soils have a higher level of organic matter than most soils of the foothills and the lowlands. Soils such as Popa and Fusi formed in the mountains in basalt controlled terrain, have a significant quantity of organic matter throughout their pedons (Figure 9.2).

*See Appendix One for information about Soil Taxonomy.

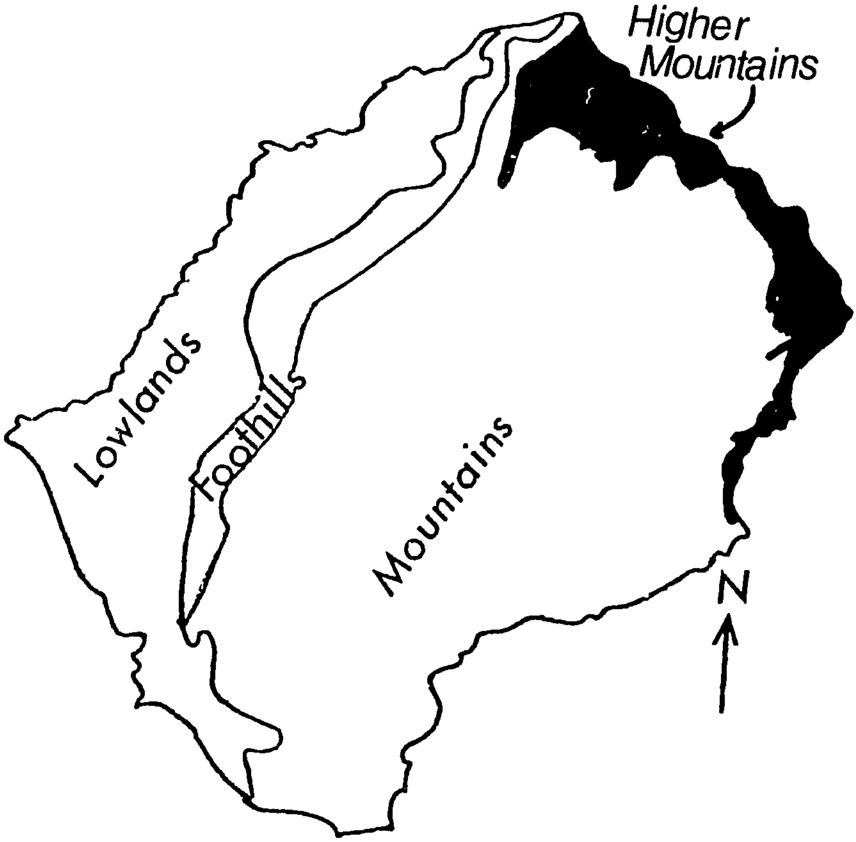


Figure 9.1: (Top) Higher elevations of Lesotho (above 3000m) where organic soils are found. (Below) An organic pedon is examined by a Soil Survey crew of Lesotho (Molumong).

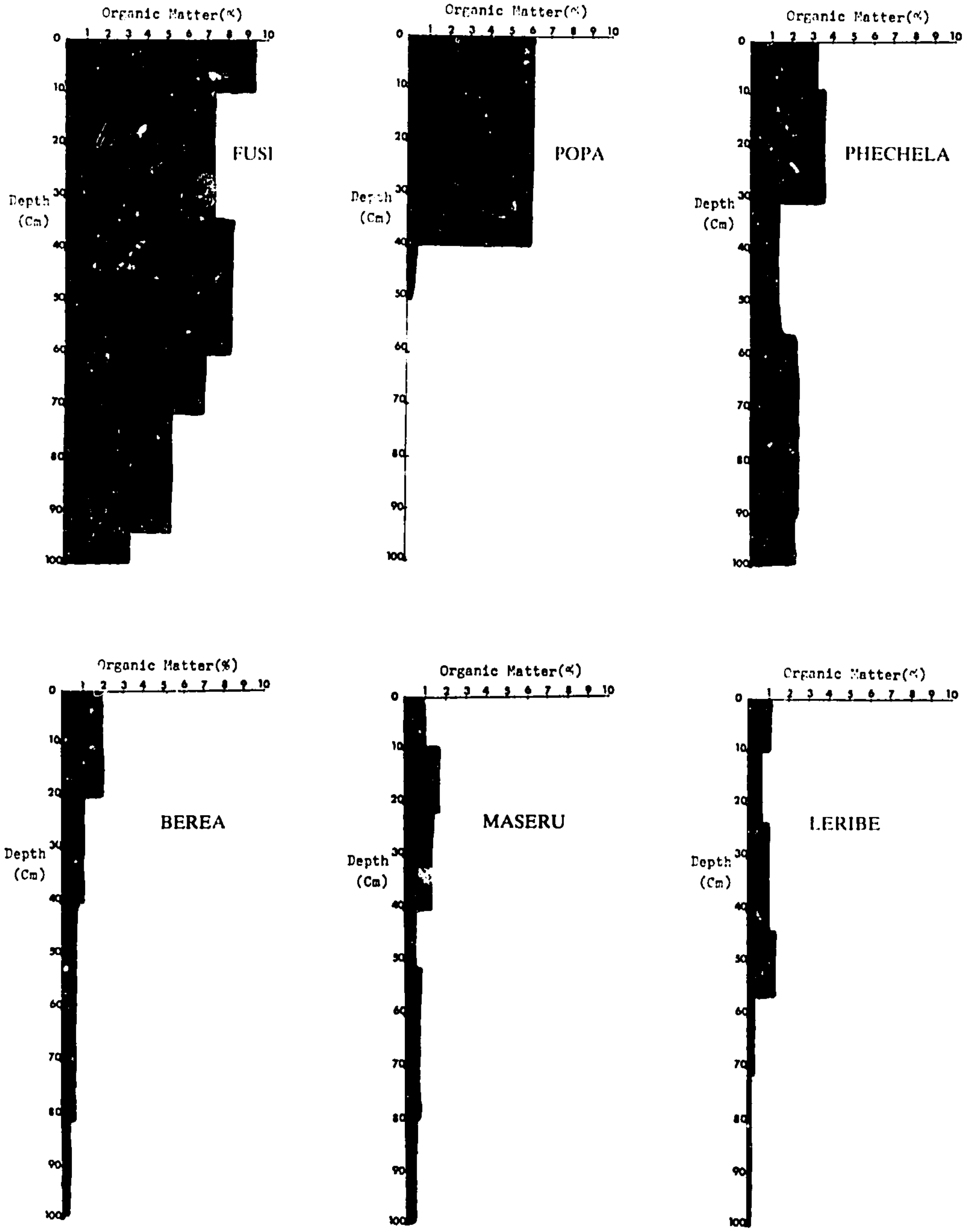


Figure 9.2: The distribution of organic matter in the profile of selected soils of the mountains and the lowlands of Lesotho. (Rooyani and Badamchian, 1984. Source of data; Carrol et al, 1979).

In contrast to the mountain soils, the soils of the lowlands, which are used extensively for crop production, such as Leribe, Berea and Duplex Soils have less than two per cent organic matter in the top layer (Figure 9.2).*

The higher level of organic matter in the soils of the mountains compared wih the soils of the foothills and the lowlands may be attributed to several factors: first, the lower temperatures in the mountains; second, the higher level of moisture in the mountains because evaporation is less, particularly on southern slopes; third, the dominance of a tall grass vegetation cover; and, finally, the presence of basaltic parent material, which has helped the build up of organic matter in the mountain soils. In this case the basic cations released from basaltic saprolite help the growth of the grass and formation of a dense cover.

In addition, certain soils of the mountains, which are associated with concave slopes, depression type of landforms and poor drainage, built up a greater quantity of organic matter. Under poor drainage conditions, the activities of the oxidizing microorganisms are limited, which leads to slow decay of organic residues. Soils such as Fusi, formed in depressions and on concave slopes, have more organic matter than Popa soils, formed on convex slopes within the same bioclimatic environment and on similar geologic material.

Black clay soils, such as Thabana and Phechela, derived from basaltic colluvium and alluvium in the mountain valleys, have three to seven per cent organic matter in the top layer. The very dark colour of these soils is not necessarily due to a high level of organic matter, but may also be attributed to the black complex of divalent cations, which are released during the weathering of basalt, and the humus produced upon decomposition of the grass residues (Van der Merwe, 1940).

Although soil forming factors are responsible for the diversity in the organic matter content of the soils of Lesotho, how the soils are managed and used may well influence the accumulation or loss of the organic matter in the topsoil. For example, most of the soils in the lowlands are naturally poor in organic matter. Continuous monocropping of maize and sorghum, practised for the last one hundred years in the lowlands, has contributed to an increasing loss of organic matter from the cultivated fields. In addition to the fact that there are favourable bioclimatic conditions in the lowlands and the foothills for rather rapid decomposition of organic matter, heavy tillage, overgrazing, grazing of the crop residues, burning of the bush and cow dung for fuel, and sheet erosion because of poor farming practices, all have contributed to the present low level of organic matter in most topsoils of the lowlands and the foothills.

9.2 Mineral component

The sources of material for the mineral component of the soils in Lesotho, as elsewhere, are the rocks or materials derived from rocks.

The results of a semiquantitative spectrographic analysis of four soils from the lowlands of Lesotho have shown that silicon is by far the most abundant metallic element among the elements analyzed, followed by aluminium and iron (Table 9.1). The abundance of elements in Table 9.1 is similar to the sequence of abundance of elements forming the lithosphere (Paton, 1978).

*More information about the named soil series has been presented in the following chapters.

Table 9.1: Semiquantitative analysis of elemental composition of selected soils in the lowlands of Lesotho (Rooyani, 1982).

	Elements (%)										
Soil Series	*Na*	*K*	*Ca*	*Mg*	*Ti*	*Si*	*Al*	*Fe*	*Mn*	*Ba*	*Zr*
Tšakholo Topsoil	1.0	.5	.07	.02	.7	30	1.0	1.5	.05	.02	.03
Tšakholo Subsoil	1.0	.5	.10	.10	.7	30	2.0	1.5	.15	.03	.03
Sephula Topsoil	.7	.5	.07	.07	.7	30	2.0	1.0	.07	.01	.05
Sephula Subsoil	1.0	.5	.07	.10	.5	30	3.0	1.5	.01	.01	.03
Maseru Topsoil	.5	.5	.05	.02	.5	30	1.0	1.0	.01	.01	.03
Maseru Subsoil	.2	.5	.10	.15	.5	30	3.0	2.0	.05	.02	.02
Sephula Topsoil	.3	.5	.05	.02	.5	30	1.0	1.0	.01	.01	.05
Sephula Subsoil	1.0	.5	.20	.07	.5	30	2.0	1.0	.07	.02	.01

*Oxygen was not measured
*Other elements were present in quantities less than 0.01%.

As has been pointed out in the previous chapters, the most common rocks and unconsolidated geologic materials underlying the soils of the country are igneous in the mountains and sedimentary in the lowlands. In addition, the dolerite dykes and sills, igneous in origin, have been intruded mostly into the horizontal sedimentary strata of the lowlands.

Basalt of the Lesotho Formation and, to a lesser extent, dolerite and gabbro are the dominant bedrocks for the shallow to moderately deep soils of the steep and middle slopes of the mountains. Basaltic colluvium and alluvium are the geologic material for the deep soils of the mountain valleys and accumulation glacis. Basalt of the Lesotho Formation is dark and fine textured. The dominant mineralogy of basalt in Lesotho is plagioclase, a sodium/calcium aluminosilicate. Pyroxene, which is dominantly iron/magnesium silicate, and olivine, a magnesium/iron silicate are next in abundance (Binnie and Partners, 1971). Also, tuffaceous materials and, to a lesser extent, seals of calcite have been identified in the Lesotho Formation (Stockley, 1947, Carroll and Bascomb, 1967 and Binnie and Partners, 1971). Zeolite, agate and quartz are present in basalts of Lesotho, but, these minerals have formed as secondary minerals through precipitation, filling the pores of the original lava (Figure 9.3).

Shale and sandstone of the sedimentary formations Clarens, Elliot and Molteno, form the geologic material for most of the soils of the foothills and the lowlands. The main exceptions are the soils developed on dolerite sills and dykes and the soils formed on basaltic alluvium in the lowlands. The mineralogy of the sedimentary deposits in Lesotho varies considerably from one place to another. Mica, potassium feldspar and illite are probably the dominant minerals in the finer particles of the shale deposits of the sedimentary formations of Lesotho. Montmorillonite and kaolinite may be present in shale depending on the fineness of the particles and the degree of weathering. Figure 9.4 shows the mineralogy of two size fractions of samples from red and purple coloured shales of the Elliot Formation. Illite and Kaolinite are dominant in the clay fraction and quartz and sodium/potassium/feldspar in the sand fraction.

The dominant mineralogy of sandstone is quartz. Sandstones belonging to the different sedimentary formations of Lesotho have a wide range of different properties, for example, texture, colour and binding materials. Clay minerals are the most important cementing material in older sandstones of the country. Binnie and Partners (1971) have reported that carbonates are the cementing agents for the Clarens Formation. Illite and kaolinite are the important clay minerals found in sandstone of the Clarens Formation.

The mineral components of the soils of Lesotho, therefore, have originated from the igneous and sedimentary geologic material discussed here. The mineral soils of the mountains, formed in basalt controlled terrain, are commonly dark brown to black and fine textured. Generally they exhibit the presence of a high level of basic cations such as calcium and magnesium. The clay mineralogy of these soils is typified by the expandable clay mineral montmorillonite or interstratified montmorillonite and illite with or without vermiculite.

Some of the soil properties mentioned above can be directly related to the properties of the basaltic geologic material from which they have developed. However such generalisation is impossible in case of the soils formed on sedimentary formations in the lowlands and the foothills. The geologic material of these two zones is not uniform. Mixing, remixing, sorting, erosion, soil creep, deposition and weathering processes have caused a great deal of diversity in the surficial geology of the lowlands and the foothills, to the extent that generalisation, in relating the soil properties directly to the underlying geologic material, may be misleading.

Table 9.2 concludes this discussion of the mineral component of the soils of Lesotho. In this table the mineralogy of the clay fraction of a number of soils of Lesotho and their geomorphologic occurrence are presented. According to Table 9.2, montmorillonite is the dominant clay mineral in the two soils formed on basalt. Kaolinite and illite seem to be the dominant clay minerals in the lowlands and the foothills. Further discussion of the formation of different types of clay in different geomorphological zones of Lesotho is presented in the following chapters.

Table 9.2: Semiquantitative XRD analysis of the clay fraction of selected pedons in Lesotho. (source: Carroll et al, 1979).

Geomorphologic Unit	*Soil*	*Montmorillonite*	*Illite*	*Vermiculite*	*Chlorite*	*Kaolinite*	*Quartz*
Lesotho Formation							
Accumulation Glacis	Fusi (subsoil)	4	0	2	0	1	3
Alluvial Deposits	Phechela	5	1	0	0	3	1
Clarence Formation							
Structural Plateau	Berea (topsoil)	2	3	0	2	4	3
	Berea	0	2	0	2	4	2
Molteno and Elliot Formation							
Accumulation Glacis	Maseru (topsoil)	0	3	1	0	2	3
	Sephula (topsoil)	1	3	0	2	2	3
Planation Surface	Qalo (subsoil)	1	4	2	0	2	2

5 – Dominant; 4 – Large Amount; 3 – Medium Amount; 4 – Small Amount; – 1 Trace

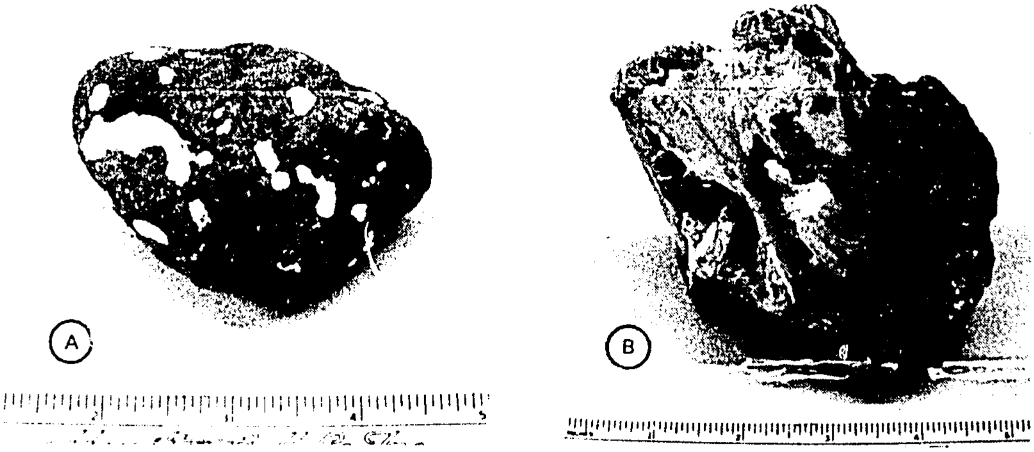


Figure 9.3 (A): Amygdaloidal basalt rich in plagioclase (road to Thaba Tseka, near Mantšonyane); (B): Amygdaloidal basalt infilled by zeolite (Senqu Valley). (Rooyani, 1982).

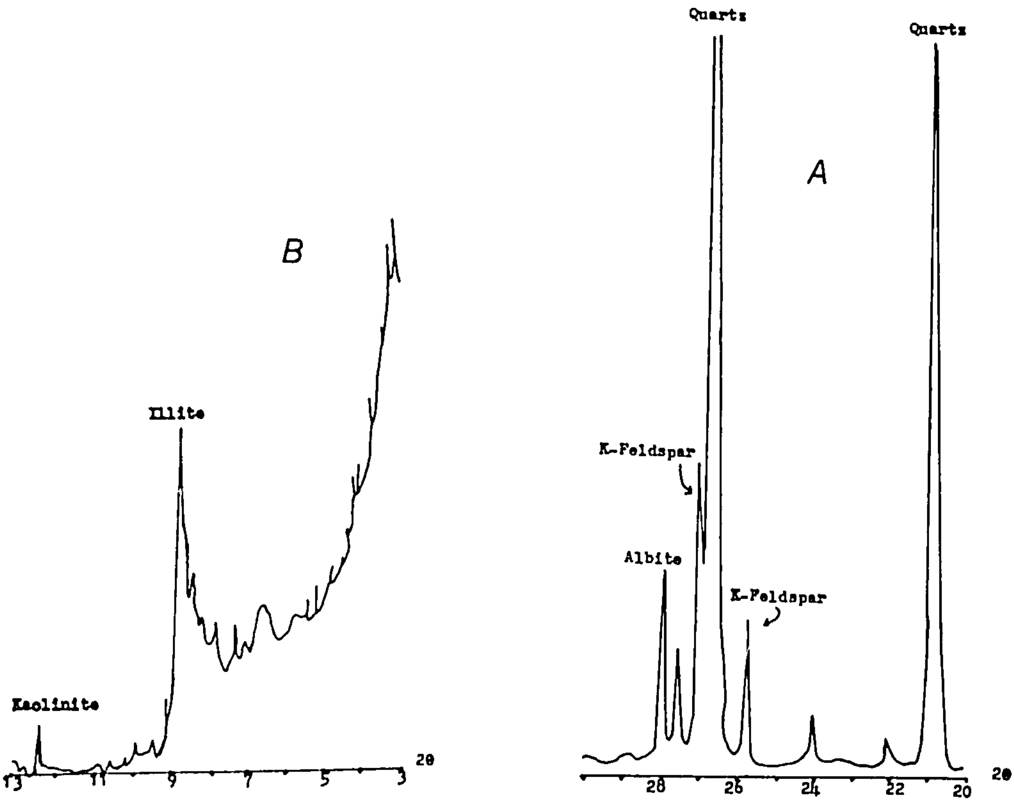


Figure 9.4: (A): XRD analysis of fine sand fraction of red shale (Elliot Formation), and (B): of clay fraction, Berea District. (Rooyani, 1982).

Chapter Ten

Soil Formation

As has been mentioned, not all the soils of Lesotho reflect the mineralogy of the geologic material underlying them. The rocks exposed to the atmosphere undergo weathering. Depending on bioclimatic factors, such as precipitation, temperature, vegetation and biological activities, some of the constituents of the original material may be released during the process of weathering. The released constituents may be removed from the system by the vertical or lateral flow of water, that is, by leaching, or they may be translocated within the system, that is, by illuviation. The minerals of the original geologic material may alter chemically to form new material, principally clay minerals, during soil formation. Alteration and resynthesis may take place in situ or, in the case of eroded and removed material, somewhere else. Also during the course of erosion, some components of the exposed geologic material may be removed from their original setting and transported by water in the form of solids, suspension or solution. During transportation the eroded materials are mixed and sorted and are gradually deposited.

In Lesotho, soil formation processes such as weathering, leaching, eluviation and illuviation, erosion and deposition have, to a large extent, caused the alteration, removal, transportation, addition and formation of new material. In brief, such processes have caused modifications which have led to the present diversity and complexity among the soils of the country. The complexity is highly pronounced in the contact zone between the Lesotho Formation and the sedimentary formations.

10.1 Weathering and formation of new material

The stability of the structure of the minerals, that is, the strength of atomic bonds, the climatic factors, the stability of the landforms against erosion, the time and the pH and Eh of the system are among the factors controlling the rate of weathering of the mineral component of the rocks and what happens to the products of weathering. Recognising the weathering sequence of the primary and secondary minerals, which has been documented by Goldich (1938) and Jackson (1968), one would expect that in the mountains of Lesotho the olivine and pyroxene components of basalt would undergo weathering first, followed by plagioclase. The products from the breakdown of the structure of such minerals by weathering are: silica, basic cations, mainly calcium and magnesium, and iron and aluminium in the form of oxides or hydroxides. Given sufficient time, the products which would result from weathering may be secondary minerals, such as montmorillonite or kaolinite.

If leaching of basic cations and the removal of silica become limited, under the prevailing alkaline condition, montmorillonite will be formed. On the other hand, rapid removal of basic cations and silica will lead to the formation of kaolinite clay, and sesquioxides. A typical example of the latter situation exists in the mountains of Lesotho and neighbouring South Africa. MacVicar (1978) and Mack (1981) have reported on the occurrence of red clay and black clay soils adjacent to each other, both forming on basic igneous rocks in the Drakensberg. Bawden and Carroll (1968) have reported on the occurrence of contrasting black Vertisols adjacent to Eutrophic, low base content, red brown soils in Lesotho. These two soils have been named Thabana, the black, and Machache, the red by Carroll et al (1979). MacVicar (1978) has attributed the difference between the two soils mainly to difference in drainage. Thabana has formed on valley glacis and Machache on planation surfaces, both in basalt controlled terrain and presumably under the same climatic condition. The well drained saprolite in Machache site has allowed greater leaching of basic cations and silica which leads to the formation of kaolinite and sesquioxides. In Thabana site, due to the poor drainage of the underlying saprolite, the removal of basic cations and silica was limited, and so the alkaline condition persisted and montmorillonite was formed and stabilized. Machache and Thabana Soils occurring adjacent to each other have contrasting properties because of the different rates of influence of the soil forming process. The morphology and mineralogy of Machache Soil reflect a more advanced weathering process than does that of the Thabana soil.

In general, the present bioclimatic condition in the mountains of Lesotho does not permit intensive weathering of basalt saprolite. Thus montmorillonite becomes the dominant clay mineral where leaching is not rapid. In the Senqu Valley, the presence of carbonates in the form of concretions or of calcic and petrocalcic horizons* within the soil profile is an indication of limited removal of basic cations and of a slow rate of weathering.

In the foothills and the lowlands, soils derived from shale commonly show the dominance of illite alone or of illite and kaolinite. Illite is the dominant product of the weathering of mica and orthoclase, both of which are components of shale. Theoretically, what happens to illite depends on the soil pH and on the level of leaching. Where there is poor drainage, it may alter to montmorillonite, but in a well drained system with a low pH, it may alter to vermiculite. In time and after intensive leaching, it may alter to kaolinite. However, with Lesotho's present climate, the occurrence of kaolinite in the surficial layers of shale derived soils, cannot be explained in terms of weathering. It is therefore possible that the kaolinite component of such soils may simply be inherited from the coarse texture, wind blown or water laid, overburden, originated from Clarens and Elliot sandstones. The phenomenon described here is characteristic of many soils in the lowlands and is elaborated upon later in this text.

The well drained red soils of planation surfaces and of plateaux, generally show the clay mineralogy of kaolinite or sesquioxide, thus indicating a stronger weathering. Soils such as Leribe, Qalo, and Rama have formed on Elliot Formation outcrops. They have been less affected by erosion and deposition processes and have been more influenced by weathering. This is probably the reason for the presence of more weathered minerals,

*See the diagnostic horizons in Appendix One.

such as kaolinite and sesquioxides in these soils. Also the influence on the weathering process of a warmer and more moist climate which prevailed in the region cannot be ignored.

10.2 Erosion and deposition processes

Erosion and deposition processes have significantly influenced the soil formation in Lesotho. In mountainous terrains, such as Lesotho, water is the dominant agent of erosion and deposition. The detachment or dissolution, the transportation and the deposition of soil and geological material by water, influence soil formation. Soil and geological material are transported by water, either in the form of a solution which contains, for example, soluble monovalent and divalent salts, free ions, or a suspension, that is, clay and humus, or a solid, such as silt and sand. The amount of soil removed depends on the steepness and length of the slope, the erosivity of rain, and the erodibility of the soil and the vegetation cover (Wischmeier and Smith, 1965). Figure 10.1 demonstrates the relationship between the position of soil in the landscape and the erosion and deposition processes.

In Lesotho, because of the complex and rugged topography of the country, the influence of erosion and deposition processes is quite significant. The complexity is more pronounced at the contact zone between the different geomorphological surfaces. As will be explained later, during the recent geological time, processes such as soil creep and sedimentation have played an important role in forming the present morphology of the soils in the lowlands. De Villiers (1965) has reported on the importance of cyclic erosion, introduced by climatice changes since the Tertiary, in forming the soils in tropical and subtropical Africa. Bawden and Carroll (1968) have reported on large scale creep and sedimentation during the Quaternary, that is, during the pluvial stage of an interglacial period, which led to the deposition of what they termed pedisediments on top of the older sedimentary formations of Lesotho and to the burial of the drainage channels. De Villiers (1965), Roberts (1964), and Carroll and Bascomb (1967) have reported that most of the Duplex Soils of Natal and the lowlands of Lesotho have formed on such pedisediments and not on the underlying shale or sandy shale of the sedimentary formations. Further, they have mentioned that the topsoil of these soils was developed from deposits laid down by soil creep in a more recent time.

The overthickened A-horizon of the soil Maseru Dark, that is the dark variant of the Maseru Series, and the Phechela Series, has been developed due to addition of the topsoil material from adjacent slopes. Overthickening is usually associated with bottomland positions, or with the zone of deposition. The zone of stonelines occurs in midslope. In Figure 10.2 the changes in soil drainage at different slope positions should be noted, as should be the dominance of light coloured topsoil, ochric epipedon, in midslope, the zone of erosion.

Figure 10.2 shows the influence of erosion and deposition on the formation of soils within a hydrotoposequence in Lesotho. Although this figure is based on hypothetical assumptions, it is valid enough to show our point. Here the influence of erosion and of deposition on the development of the topsoil, the structural subsoil, and on the occurrence of stonelines, gravel sized petroferric nodules, are shown.

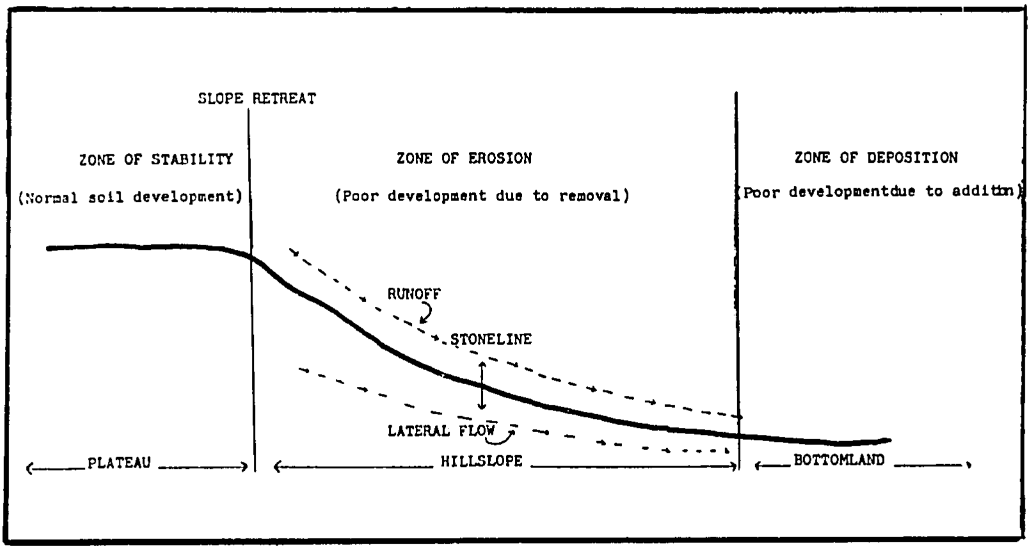


Figure 10,1: The relationship between erosion and deposition processes and the position of soils on a slope.

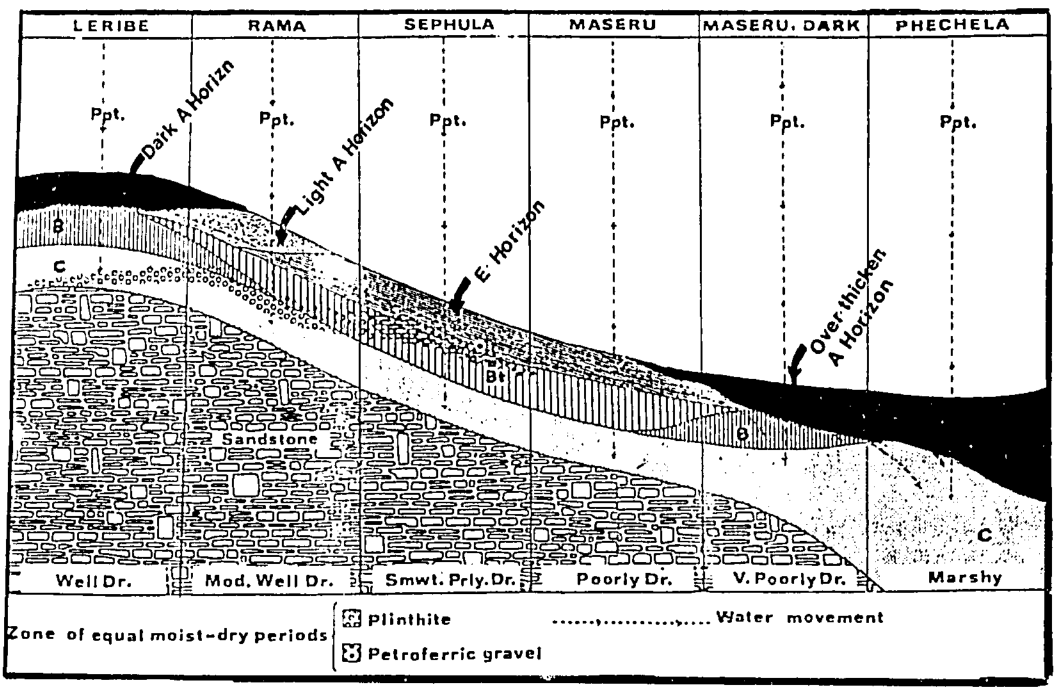


Figure 10.2: Hypothetical illustration of hydrotoposequence of certain soils in Lesotho (Modified from Carroll et al, 1979).

10.3 Eluviation and illuviation

Evidence of eluviation and illuviation has been reported in soils of both the mountains and the lowlands of Lesotho (Carroll and Bascomb, 1967; Carroll et al, 1979; Mack, 1981; Rooyani, 1982). Evidence of illuviation of clay, a higher clay content in the subsoil, a higher ratio of fine clay to total clay and the presence of clay films, have been reported on soils such as Machache, Nkau, Khabos and certain Duplex Soils of the lowlands. MacVicar (1962) reported on the influence of vertical and lateral illuviation of clay on the formation of Duplex Soils of Natal.

According to Carroll et al (1979), Duplex Soils of the lowlands are the best examples of the influence of eluviation and illuviation. The presence of a contrasting albic horizon, a bleached layer underlain by an argillic horizon, a clay accumulation zone, in soils such as the Maseru, Sephula and Tšakholo Series, suggests translocation of fine clay material from the topsoil and its accumulation in the subsoil (Figure 10.3).

The argillic horizons in the soils of the higher mountain zone of Lesotho are believed to be the relics of a warmer climate (Mack, 1981). Whereas the argillic horizons of the lowlands, foothills and Senqu Valley soils probably have been formed during recent geological time. The higher temperatures, cyclic dry periods and moist summers of the present climate condition in the lowlands and the Senqu Valley seem to favour the illuviation of clay, where a source of clay is available. The characteristics of certain soils in the Senqu Valley, for example, Nkau, and some of the Duplex Soils, for example, Tšakholo, suggest that illuviation must have occurred when the removal of carbonates, the flocculating agent, from the upper part of the subsoil was completed. Carbonate concretions in Nkau Soils and the iron and manganese nodules coated with carbonates in Tšakholo soils, occur immediately below the argillic or natric horizons.

Carroll et al (1979) further suggest that lateral movement of fine clay, montmorillonitic in mineralogy, from midslope soils and its accumulation in the soils of bottomlands, such as Phechela, is responsible for the present characteristics of Phechela Soils. These soils are clayey throughout the pedon, have montmorillonite clay mineralogy and have the tendency towards Vertisols.*

The combined influence of soil forming processes in the development of the present soils of the country has been shown in Table 10.1 and Figure 10.5. In order to illustrate the point, three soils with contrasting characteristics in morphology, extent of weathering, drainage, and clay mineralogy have been selected. Table 10.1 shows the recent analytical data on the three soils. Based on the percentage of clay, organic matter and CEC, the dominant type of clay has been estimated for each soil. Figure 10.5 has been constructed using the data in Table 10.1. This figure shows the important properties of the soils in question.

The information provided here shows that the black clay soils of the accumulation glacis and the alluvial deposits such as Thabana, and associated black clay soils, Phechela and Khabos, are clayey, have neutral or close to neutral pH, are high in CEC and basic cations and are predominantly montmorillonitic in mineralogy. These soils are associated wih poor drainage.

The red soils of planation surfaces and plateaux, such as Leribe, Rama, Hololo and

*See Appendix One for the definition of soil orders.

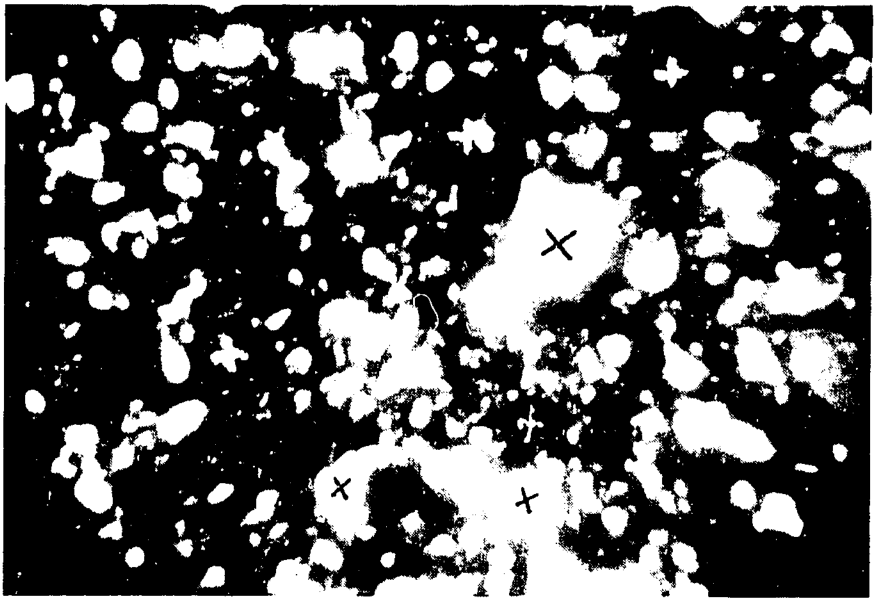


Figure 10.3: Thin section from the E-horizon (albic) of the Tšakholo Soils in the lowlands of Lesotho showing vesicles and vughs (marked with white+) and loosely cemented quartz skeleton grains (marked with black+). Diameter of the largest grain is 0.125 mm. Crossed polarizer. (Rooyani, 1982).

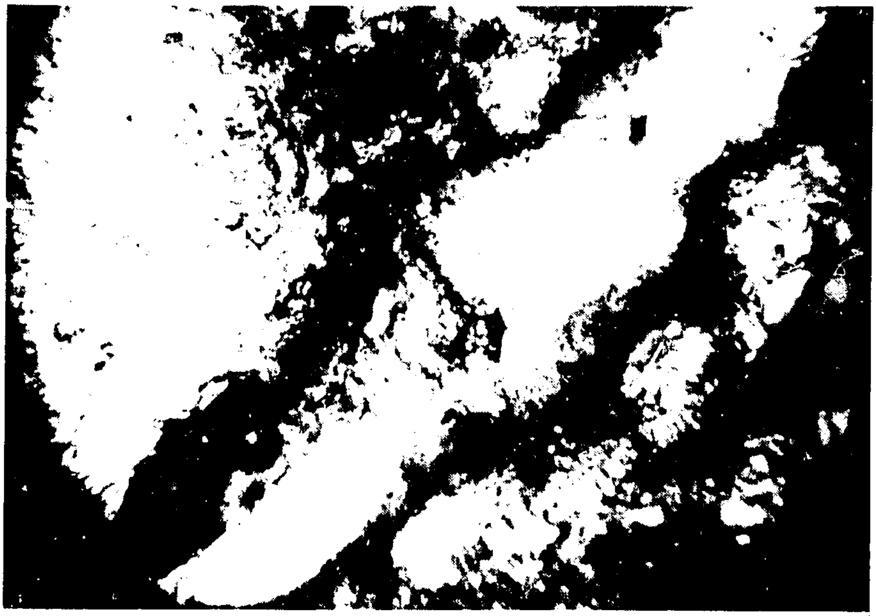


Figure 10.4: Thin section from the subsoil (natric horizon) of Tšakholo Soils showing argillans around a channel (indication of clay illuviation). Length of the channel is 0.15 mm. (Rooyani, 1982).

Qalo, are medium textured throughout the pedon, are moderately acidic to strongly acidic. They are well drained and low activity clays such as kaolinite and sesquioxides are dominant.

The Duplex Soils of the lowlands have intermediate properties, unlike the two groups of soils described above. Whether they are formed on binary parent materials or on one, they are two storey systems.

Table 10.1: Some important characteristics of three selected soils in Lesotho. (source: Cauley et al, in press).

Soil Series		*Clay %*	*Organic matter %*	*CEC*	*CEC (calculated)*	*pH*
Leribe	Topsoil	18.4	1.13	5.3	16	4.5
	Subsoil	25.5	1.37	6.6	15	5.4
Maseru	Topsoil	13.9	1.09	6.3	31	5.7
	Subsoil	45.2	0.54	20.3	43	7.4
Thabana	Topsoil	50.8	7.36	60.0	89	6.1
	Subsoil	60.2	3.16	57.3	85	6.7

Calculated CEC represents the CEC of hundred per cent clay expressed in meq per hundred grams of clay. It is calculated as: CEC (calculated) = (CEC – Organic Matter × 2)/Clay % × 100. The CEC of the soils is expressed in meq per hundred grams of soil.

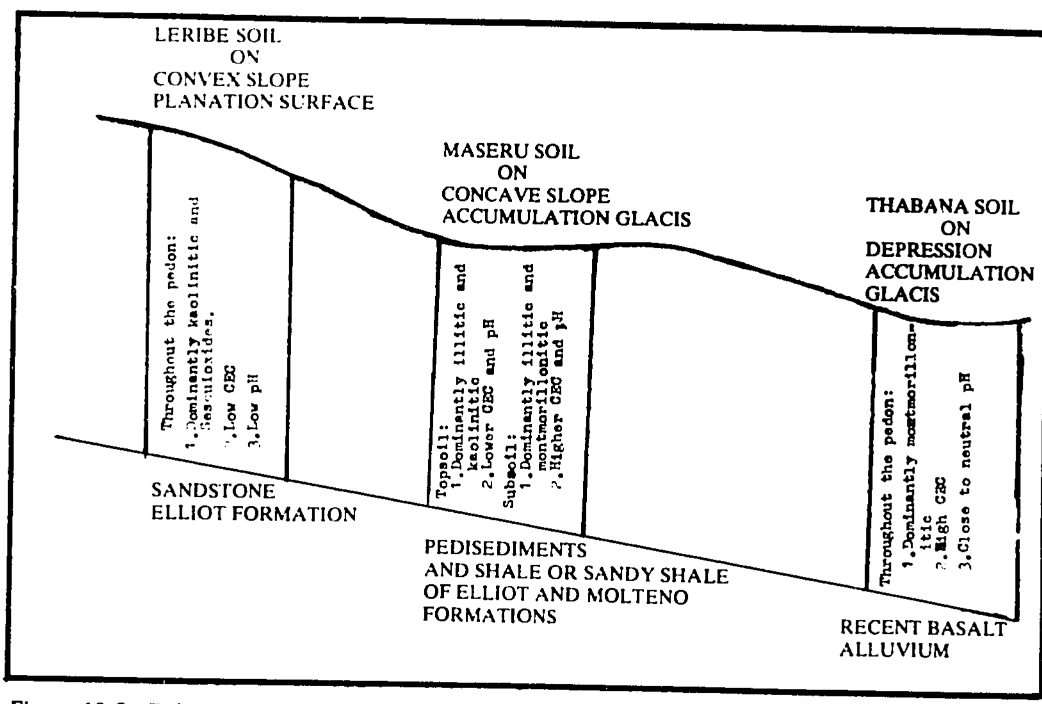


Figure 10.5: Relationship between important soil properties, parent materials and slope.

The topsoil and subsoils of these soils have contrasting properties. The two are separated from each other across an abrupt boundary. The topsoil of the Duplex Soils is coarse in texture, light coloured, and slightly to moderately acidic. The subsoil is fine textured, darker in colour than the topsoil, and is neutral to alkaline in pH. The mineralogy of the Duplex Soils changes with depth. The upper storey has a less expandable clay type of dominantly illite whereas the lower storey is dominantly more expandable of montmorillonite or interstratified illite and montmorillonite. The dominance of illite in Duplex Soils in Lesotho is Probably due to weathering of micaceous underlying material being pedisediments or reworked shale of the Molteno or Elliot Formations. The more expandable clay in the subsoil of Duplex Soils probably has formed due to the weathering of illite at a later stage.

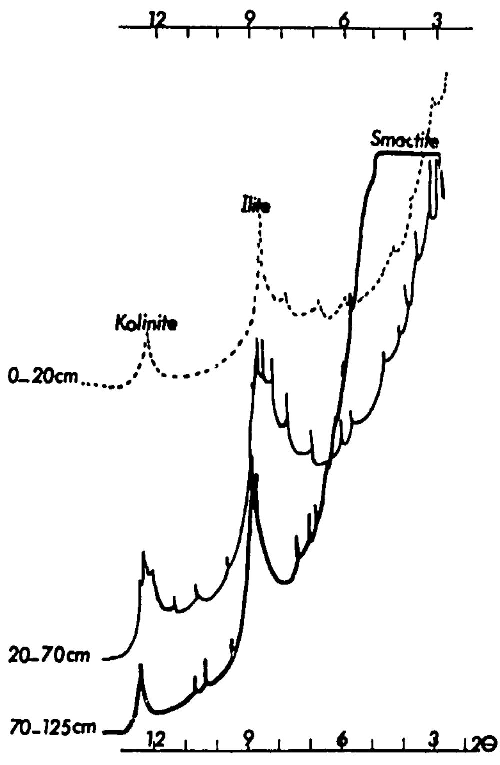


Figure 10.6: Changes in mineralogy of fine clay fraction of Tšakholo Soils with depth. Samples are glycolated and heated for 60°C. Berea District (Rooyani, 1982).

Chapter Eleven

Soil Forming Factors

Soils, as natural bodies, are formed because of the interaction of soil forming factors. These soil forming factors are: climate (C), vegetation (V), relief (R), parent material (P), and time (T). In this section we have been discussing the processes influencing the formation of soils. A review of the last two chapters will show that there certainly are factors which control those processes and so control the formation of those soils. Jenny (1941) presented a mathematical expression for soil formation implying that no soil is formed in the absence of any one of the soil forming factors, and suggested the following formula:

$$\text{Soil} = f(C,V,R,P,T)$$

In the early stage of development of soil genesis theories, much stress was placed on individual soil forming factors. The prevailing concept of soil genesis emphasizes the interaction of all the soil forming factors. That is, the operation of physical, chemical, and biological processes and the balance among the processes in any combination. According to the current concept the soil forming factors are the potential contributors to the development of every soil, but their rates differ dependent on the different climatic, biotic, topographic, and geological conditions (Simonson, 1959; Cline, 1961; SSS, 1975).

A detailed discussion on soil forming factors has been presented by Buol et al (1973). Also, De Villiers (1965) and McVicar (1978) have addressed the principle concepts of soil forming factors in tropical and subtropical Africa and in Southern Africa respectively. Carroll et al (1979) presented a summary of soil forming factors in Lesotho. The soil forming factors within the context of Lesotho will now be elaborated on.

11.1 Climate

Precipitation and temperature are two important climatic factors which directly influence the soil formation. These two factors influence soil moisture and soil temperature, and so influence the weathering of soil minerals, the translocation of soil constituents within the pedon, leaching, the decomposition of organic matter, and the activities of soil fauna and flora.

The climate of Lesotho is characterised by warm moist summers, from November to March, and cold dry winters, from May to September. Lesotho's climate can thus be categorized as semiarid to subhumid and continental. The Southern lowland and Senqu

Valley are warmer and drier than the Northern lowlands and mountains. Higher elevations, above 3 000 metres, receive enough snow during the winter to cover the ground for several months.

Precipitation ranges from 540 mm in the Southern lowland to more than 1 400 mm at higher elevations. The mean annual temperature ranges from 5.7°C at the higher elevations to above 16°C in the southern lowlands (Table 11.1).

The soils of Lesotho reflect the influence of two types of climates, the present day climate and a previous climate which was more humid and warmer. The presence of strongly weathered subsoils in the red soils of the foothills, the dominance of a low activity clay type, that is of kaolinite and sesquioxides, in certain red soils such as Tumo and Machache, and the presence of a well defined argillic horizon in certain soils of the mountains such as Soloja, Thamathu, and Nkau, suggest a climate which had created a more favourable condition for weathering, leaching and illuviation. Similarly, the presence of well defined argillic horizons in certain soils of the lowlands reflects strong illuviation of fine clay and indicates that, previously, a more moist climate was prevalent in the region.

Table 11.1: Summary of climatological data from selected stations in Lesotho (Binnie and Partners, 1972).

Physiographic Zone	*Elevation (m MSL)*	*Mean Annual Rainfall (mm)*	*Annual Potential Evaporation (mm)*	*Mean Annual Temperature (°C)*
Lowland				
Butha-Buthe	1770	781	2010	14.2
Maseru	1530	682	2130	15.3
Quthing	1740	730	2040	14.8
Mountains				
Thaba-Tseka	2160	560	1970	12.1
Oxbow	2600	1420	1560	7.4

Van Wanbeke (1982), using climatological data, attempted to estimate the moisture and temperature regimes of the soils in Africa (Table 11.2). Acording to this study, a Udic soil moisture regime* has been established for Lesotho excluding the southern lowlands and Senqu Valley. For these two zones a Ustic moisture regime was proposed. Thermic and mesic temperature regimes were established for the soils of the lowlands and the mountains respectively.

*See Appendix for the definitions of soil moisture and temperature regimes.

Table 11.2: Soil moisture and temperature regimes for the lowlands of Lesotho (Van Wanbeke, 1982).*

*Location***	*Station*	*Mean Soil Temperature (C°)*			*Soil Temperature Regime*	*Maximum Consecutive Days that Moisture Control Section is Moist in Some parts in one year*	*Soil Moisture Regime*
		Annual	*Summer*	*Winter*			
Northern Lowland	Butha-Buthe	16.8	20.1	12.4	Thermic	360	Udic
Central Lowland	Maseru	17.2	21.0	12.5	Thermic	360	Udic
S/W Lowland ***	Wepner (RSA)	17.9	21.8	13.2	Thermic	253	Ustic

*These data are based on computerized interpretation of climatological data and not direct measurement from soil profile.

**No data interpretation was carried out on stations in the mountains, probably, because of lack of long-term data.

***The data from Wepener Station in the RSA has been projected to southwestern lowlands of Lesotho.

Cauley et al (in press) has reported that the soils of the lowlands have a ustic moisture regime and the soils of the mountains a udic one. Mack (1985) recognizes a cryic temperature regime for the mountain soils above 3000 m.

Generally, it is believed that the upper mountains have a udic moisture regime and a cryic temperature regime. The lower mountains and the foothills have a udic moisture regime and a mesic temperature regime. The lowlands have a ustic moisture regime and a thermic temperature regime. Excluded from this generalized interpretation are soils of depressions and soils with claypans which may have an aquic moisture regime.

It seems that the influence of the present day climate in Lesotho which causes variability among soils has been pronounced only in certain localities. For example, the presence of carbonates in the form of concretions, of calcic and petrocalcic horizons, is more pronounced in soils of the Senqu Valley. These soils are experiencing a condition of limited leaching compared to their counterparts in the higher elevations.

11.2 Vegetation

Lesotho is, predominantly, a climatic climax grassland. Shrubs co-dominate at higher elevations and in localized, cool and moist sites in the foothills and mountains. Six climax vegetation types have been identified in Lesotho (Table 11.3).

Cymbopogen-Themeda Sourveld (Seboku Sourveld) is dominant in the lowlands and the lower foothills, including the lower elevations of the Senqu Valley. Highland Sourveld is found at elevations higher than those areas where Seboku is predominant. Scrub forest predominates in the undisturbed or less-disturbed sites in the Highland Sourveld zone.

Mixed Sourveld of Themeda Triandra and Festuca Caprina are predominant in the upper foothills and mountain valleys. The climax of the Subalpine zone is mixed Sourveld and Letsiri Sourveld, dominated by Themeda Triandra, and the Alpine Zone has a climax of Erica Helichrysum heath.

Table 11.3: Ecological zones and climax vegetation types of Lesotho (Jacot Guillarmod, 1971; M. Schmitz, 1984; Limbach, 1985).

Ecological Zone	*Elevation Range (m)*	*Climax Vegetation Type*
Lowland	1500–1800	Seboku Sourveld
Senqu River Valley	1500–2000	Mixed Sourveld
Foothill	1800–2300	Mixed Scrub forest/Sourveld
Mountain Valley	2000–2500	Mixed Scrub forest/Sourveld
Subalpine	2300–2900	Letsiri Sourveld
Alpine	2900–3500	Mixed Heath/Letsiri Sourveld

The influence of predominantly tall grass is apparent in the formation of a well defined mollic epipedon in most of the soils of the mountains. The epipedon of steep slope soils, such as Moroke, Popa and Matšana and valley soils such as Fusi and Thabana, reflect the greater influence of a dense natural grass vegetation. These epipedons are dark to black in colour, have an organic matter content of three to ten per cent, a granular structure, and a high level of base saturation. In the lowlands, evidence of a buried mollic epipedon can be found in some of the soils on alluvial terraces, indicating the predominance of grasses at the time of their formation.

11.3: Parent material

Generally, basaltic bedrock, alluvium and colluvium are the main parent materials of the mountain soils. In the lowlands, shale, sandstone, mixed alluvium or colluvium of sedimentary and basaltic origin, and dolerite are the important parent materials.

The properties of the black soils of the mountain slopes and of the mountain valleys, reflect the influence of basaltic parent material. Such characteristics as neutral reaction, high base status, dominance of smectite clay mineralogy and presence of calcium carbonate (Senqu Valley), all show the greater influence of a basic bedrock or saprolite such as basalt. The soils in the mountains of Lesotho do not reflect the influence of either a preweathered or a strongly mixed, reworked and altered geological material.

In contrast, the characteristics of most soils in the lowlands and lower foothills cannot easily be correlated to the characteristics of the consolidated or unconsolidated materials underlying them. De Villiers (1965) describing the influence of parent material in soil formation in Southern Africa stated that "preweathering and soil creep, with implied mixing of materials of different provenance, can give rise to a high degree of non-genetic variability in the initial state of the system. As a consequence, there may be many more kinds of parent material than there are lithological rock types." Although this statement, in its full context, cannot be applied to the mountainous soils of Lesotho, it is definitely valid for most of the soils in the lowlands and the foothills.

Most of the red soils of the lowlands and the foothills, including those, presumably, formed on basalt, for example Machache and Tumo, reflect a preweathering process of the parent material, as is indicated by the dominance of sesquioxides and low activity clay types throughout the pedon.

Carroll and Bascomb (1967) have stated that the soil formation in the lowlands of Lesotho "is only indirectly related to the underlying bedrock." They have added that the slope crests and pediments of this zone are covered by mantles of colluvially reworked material. Further they have stated that "during the Quaternary era, Africa had its own palaeoclimatic sequence and it is likely that the thick mantles covering pediment slopes today were formed by long periods of intense erosion during a pluvial stage of an interglacial period, followed by gentle colluviation and accretion. Sediments of this kind, termed pedisediments by South African pedologists, cover large areas of the lowlands to depths of over 20 metres. The material is well stratified and is mainly composed of a greyish calcareous clay. It is usually overlain by more recent sandy sheetwash or creep deposits."

Thus, in the lowlands, preweathered geological material and erosion and deposition cycles, to a large extent, have contributed to the non-genetic variability in the formation of most soils in the lowlands. The influence of the deposition of pedisediments in the lowlands seems to be mainly limited to depression-type landforms, footslopes and drainageways. The red and yellowish soils of the rolling slopes of the lowlands have been less influenced by the deposition of the pedisediments and more affected by the influence of a preweathered geological material. The presence of a coarse texture overburden is characteristic of many soils in the lowlands and foothills. It is found on soils formed on more recent alluvium as well as on red soils of the other types of landform.

11.4 Topography

Lesotho has mountainous to steep rolling topography, with the altitude ranging from 1500 m to almost 4000 m. Because of such variations in slope and altitude, topography has played an important role in the formation of the soils of Lesotho. The principal role of topography is its direct controlling influence on the erosion and deposition processes, both of which are active in Lesotho. As has been suggested by De Villiers (1965), the soil formation in this part of the world "should be considered in terms of cyclic rather than steady-state concept."

On steep slopes in the mountains, soil development is impaired because of the greater influence of erosion and low temperature which lead to the formation of immature skeletal soils, like Moroke and Popa Soils. In the foothills, where volcanic materials meet the sedimentary formations, colluvial activities have caused a great deal of variation in the geological material through mixing and reworking of sedimentary and volcanic materials. In the lowlands the hydromorphic soils have developed in depressions and bottomlands, where they receive a lateral flow of water which contains dissolved materials and suspended fine clay from soils on the surrounding slopes.

Carroll et al (1979), illustratively, presented models of the relationship between topography and soil formation in Lesotho. Although these models are hypothetical, they illustrate the toposequence concept of soil series in Lesotho. Figure 11.1 shows such a toposequence in the mountains and upper foothills and Figure 11.2 represents the toposequence of the important soil series in the lower foothills and lowlands.

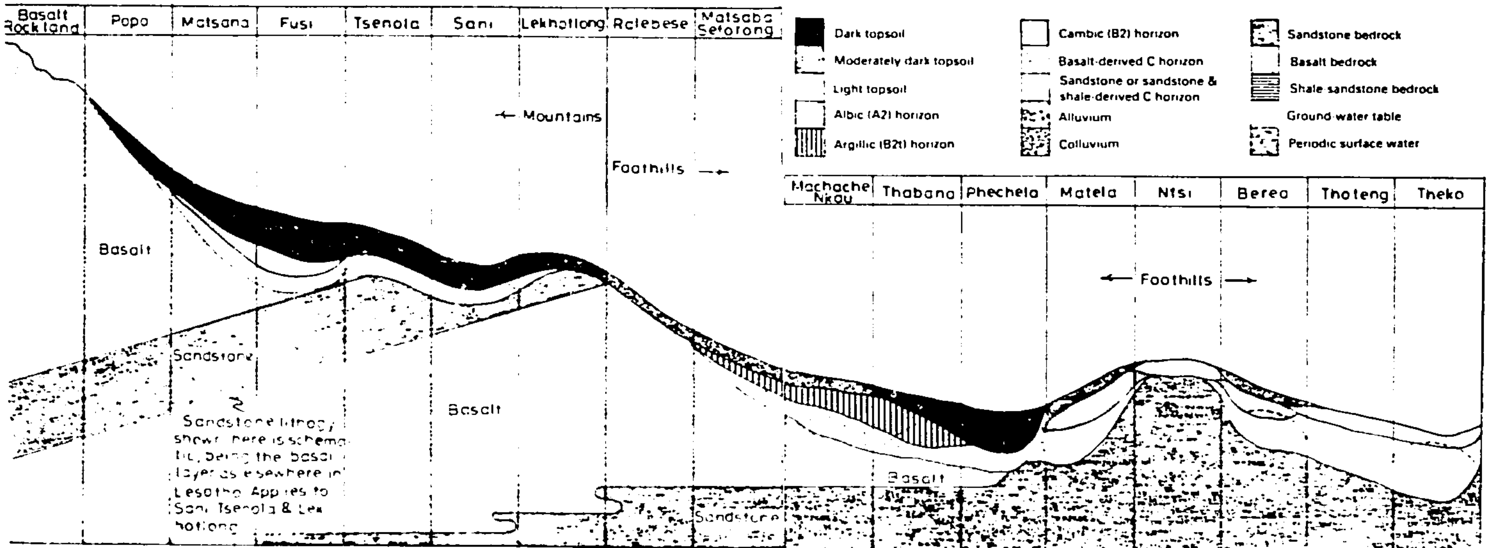


Figure 11.1: Toposequence of important soil series of the mountains (A) and upper foothills (B) of Lesotho: (source: Carroll et al, 1979).

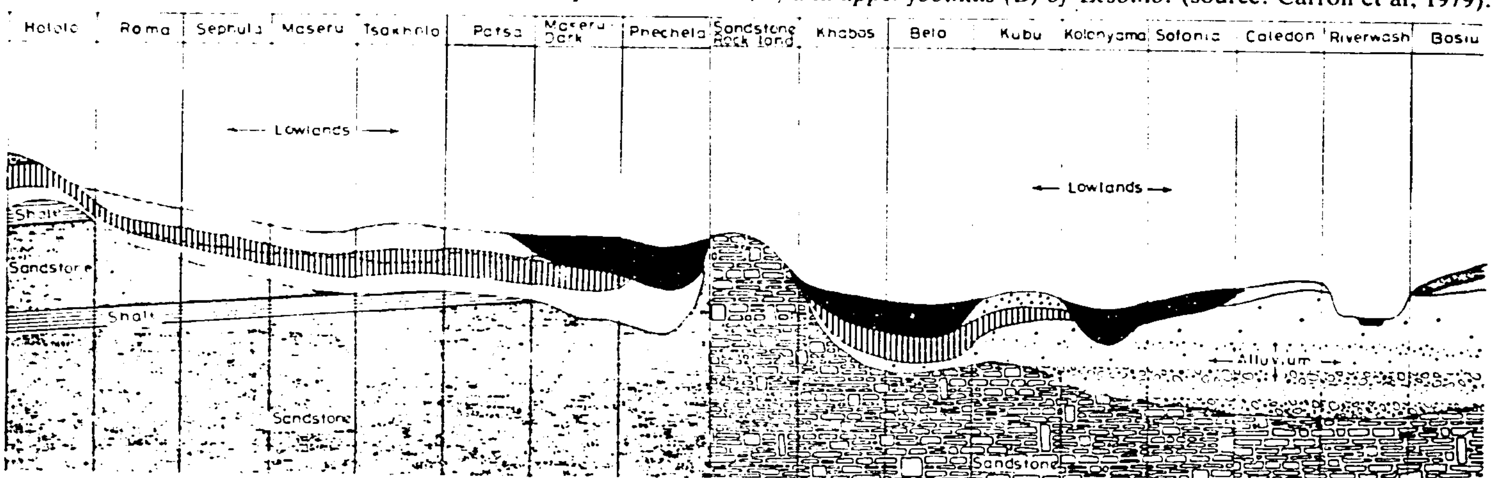


Figure 11.2: Toposequence of important soil series of the lower foothills (A) and the lowlands (B) of Lesotho. (source: Carroll et al, 1979).

11.5 Genesis and classification of soils in Lesotho

Very few studies have been done on the genesis of soils in Lesotho. Reports which consider this subject are more or less qualitative (Carroll and Bascomb, 1967; Binnie and Partners, 1972; Carroll et al, 1979). As mentioned earlier, it seems that the soils of the foothills and lowlands of Lesotho have been influenced by topography, by palaeoclimatic conditions and by the assemblage of original or reworked geological materials, that is, sandstone, shale, mudstone, dolerite and basalt. The soils of the mountains generally reflect a strong influence of grassland vegetation and of basaltic parent material.

Table 11.4 presents a brief account of the genesis of the major soil groups of Lesotho. This table is based on generalized concepts, and includes the opinions of those who have worked on the genesis of the soils of the country.

The first soil map of Lesotho was prepared by Carroll and Bascomb in 1967. Carroll et al (1979) made a more detailed soil map on a scale of 1 : 250 000, showing the geographic distribution of the soil series associations in the country (Figure 11.3). More detailed maps of certain areas, particularly of the lowlands, are available at the Office of Soil Survey on 1 : 10 000 scale at series level.

Recently a more detailed study was carried out on selected soil series of Lesotho. These series are considered the benchmark soils of the country because of their coverage and their importance to agricultural production in the country. Eleven soil series: Fusi, Khabos, Leribe, Machache, Tumo, Sefikeng, Rama, Qalaheng, Sephula, Thabana and Matela have been identified as benchmark soils of the country. Detailed information in relation to characteristics, use, and management of the named soils is available in the publication "Benchmark Soils of Lesotho" (Cauley et al, in press).

Table 11.4: Simplified and generalized concepts of the genesis of broad groups of soils in Lesotho.

Broad Group of Soils	*Examples of Soil Series*	*Genesis*
Entisols		
Stratified	Caledon	Very young soils, formed under present climatic conditions, recent alluvium of the Caledon River or other main rivers in the lowlands. The alluvium is remixed and sorted sandstone and basalt derived material.
	Majara	Buried Mollisols formed on basaltic alluvium under grassland vegetation, later covered by recent alluvium.
Nonstratified	Thoteng	Young soils, formed on remnants of old sand dunes, derived from sandstones of the Clarens Formation.
	Ntsi	Young, shallow soils, formed on the sandstone escarpments of the Clarens Formation, under present climatic conditions.

Inceptisols	Berea/Qalaheng	Young soils, formed on gentle slopes of the Clarens Formation and on less permeable saprolite than Ntsi.
	Matela	Young soils, formed on a saprolite mixture of sandstone and basalt, under present climatic conditions and in grassland vegetation.
Vertisols	Thabana	Clayey soils, formed on basalt saprolite with poor permeability, under grass and under present climatic conditions.
	Phechela	Clayey soils, formed on basalt colluvium in bottomland areas, where inflush of fine clay from surrounding slopes in common. They have formed under a heavy grass cover and under present climatic conditions.
Mollisols		
Shallow	Moroke/Popa	On steep basaltic slopes, under a dense grass cover and under present climatic conditions.
Overthickened epipedons	Fusi	On basaltic alluvium in the mountain valleys, under a dense grass cover. Buried by washed topsoil from the surrounding slopes.
Carbonate accumulation	Nkau/Seforong	On basaltic saprolite and under a grass cover. Have experienced limited leaching. Reflect dry climatic conditions of the southern lowlands.
Clay accumulation	Soloja/ Thamathu	On more stable landforms, on basalts in the mountains. Reflect palaeoclimatic conditions favouring clay illuviation. Have formed under a grass cover.
Alluvial	Sofonia/ Kolonyama	Young soils which have formed on basaltic alluvium, on river terraces and under a grass cover.
Alfisols		
Red Soils of the lowlands	Leribe/Qalo/ Rama	On preweathered sandstones of the Elliot Formation. May represent a lithological discontinuity between the preweathered material, that is the subsoil, and the more recent sandstone-derived material introduced by soil creep, that is the topsoil.
Red Soils of the upper foothills	Machache	On preweathered permeable basaltic saprolite, under a grass cover.
Duplex Soils	Maseru/Sephula	On reworked and remixed pedisediments of shale and sandstone on concave slopes, under humid palaeoclimatic conditions. May show a lithological discontinuity between the pedisediment-derived material, and overlain coarse texture overburden, added by soil creep.

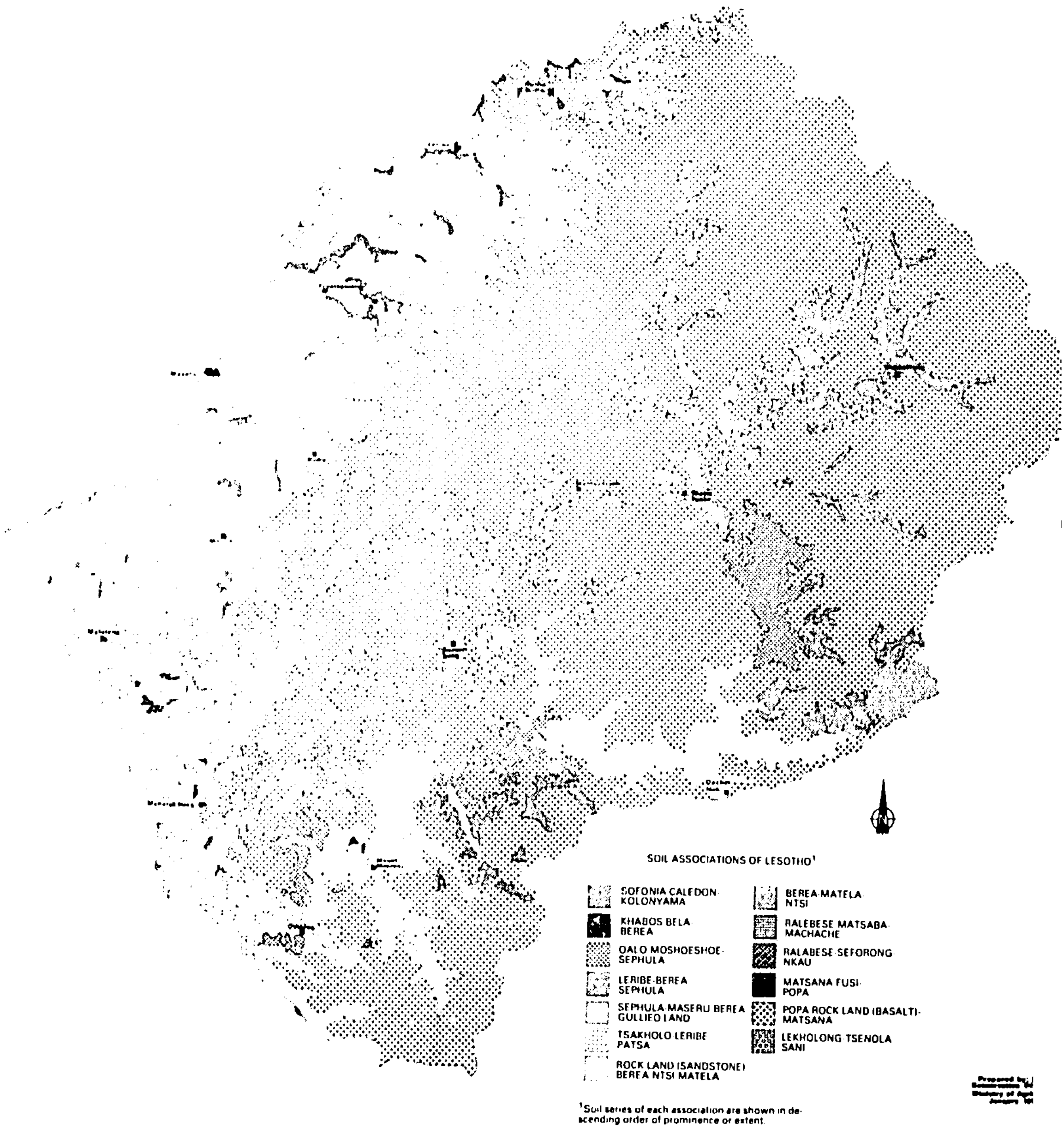


Figure 11.3: Soil association map of Lesotho (Source: Carroll et al, 1979).

Chapter Twelve

Important Soil Groups of Lesotho

I. Mollisols

Among the soil orders so far identified in Lesotho, Mollisols and Alfisols are the most extensive orders. They cover almost all the mountains slopes and mountain valleys, and most of the foothills and the lowlands.

This chapter is a summary discussion of important soil series belonging to the Mollisols in Lesotho while the following chapters are devoted to Alfisols and the other orders identified in Lesotho.

Most of the dark coloured soils, formed from basaltic parent material under the tall grass natural vegetation in the mountains of Lesotho, are Mollisols. They are dark soils with a rather thick topsoil, and a base saturation of more than 50 per cent. This dark topsoil has characteristics which meet the requirements for mollic epipedon. They form in a wide range of climatic regimes provided that the moisture available is sufficient to support the growth of perennial grasses (SSS, 1975). Mollisols have a dark coloured topsoil, but they do not have the characteristics of black Vertisols which crack and have a high shrink swell potential.

Mollisols of Lesotho form the backbone of agricultural production covering almost all the mountain slopes and mountain valleys. Excluded are the patches of organic soils, Histisols, and limited areas covered by Vertisols. Mollisols are also found in the foothills, the lowlands, and Senqu Valley.

In Lesotho, Mollisols cover approximately 1.5 million hectares, that is almost half of the country.

Table 12.1 shows the taxonomic classification of the more important soil series belonging to Mollisol order. Figure 12.1 presents a simplified flowchart differentiating soil series of Mollisol order in Lesotho.

Table 12.1: Taxonomic classification of the most extensive Mollisols in Lesotho (Modified from Carroll et al, 1979 and Cauley et al, in press).

Soil Series	*Taxonomic Classification (Subgroup)*
	Mollisols with Aquic Moisture Regime
Bela	Typic Argiaquolls
Maseru Dark	Cumulic Haplaquolls
Sani	Typic Natraqualfs
Tšakholo	Cumulic Haplaquolls
	Mollisols with Cryic Temperature Regimes
Moroke	Lithic Cryoborolls
	Mollisols with Ustic Moisture Regime
Bosiu	Fluventic Haplustolls
Kolonyama	Fluventic Haplustolls
Kubu	Fluventic Haplustolls
Sofonia	Fluventic Haplustolls
Khabos	Pachic Argiustolls
Nkau	Pachic Argiustolls
Seforong	Pachic Argiustolls
	Mollisols with Udic Moisture Regime
Lekhalong	Lithic Hapludolls
Popa	Lithic Hapludolls
Ralebese	Typic/Lithic Hapludolls
Matšana	Typic Hapludolls
Fusi	Cumulic Hapludolls
Maliele	Cumulic Hapludolls
Tšenola	Cumulic Hapludolls
Soloja	Typic Argiudolls
Thamathu	Typic Argiudolls

12.1 Mollisols with an aquic moisture regime

12.1.1 Bela Series. This is a very poorly drained, deep, and medium texture soil. Its topsoil is a very dark grayish brown loamysand to clayloam, resting over a black to very dark brown clayloam to clay buried alluvial soil. The lower part of the solum is characterized by mottles.

Bela Soil has formed on ancient terraces above the perennial flooding of streams in the lowlands and the foothills. Commonly it is associated with black clay soils, Vertisols. Its parent material consists predominantly of basaltic alluvium

Coverage of Bela Soil in Lesotho is about 2,700 hectares. It is used mostly for cropping. However, this soil has severe limitations for crop production, namely, it is saturated with water for most part of the year; it has poor drainage and aeration; it has differential hydraulic conductivity due to the significant increase in clay content at the subsoil level. The best use for Bela Soil is pasture.

12.1.2 Maseru Dark Series. This is a poorly drained, deep and medium to fine texture soil. It has a black to dark brown and loamy to silty clayloam topsoil overlying a grayish brown (sandy) silty clayloam subsoil. Morphologically, it is similar to Bela Soil except for

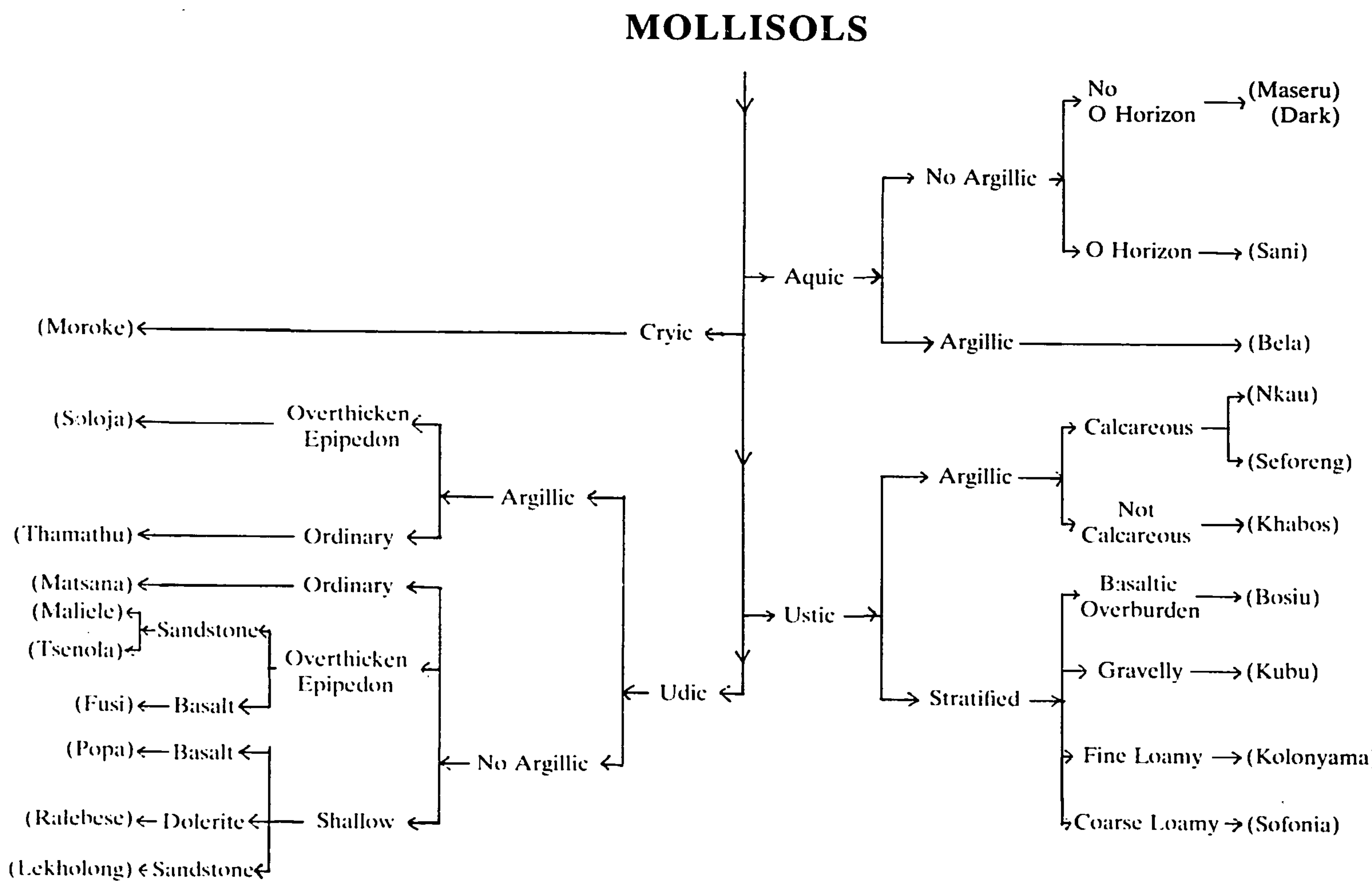


Figure 12.1: Simplified flow chart showing how soil series belonging to Mollisols have been differentiated.

a lighter colour and coarser texture in the subsoil. This soil has formed from pedisediments on concave slopes in the lowlands. The topsoil is probably accumulated basalt-derived material.

Coverage of this soil in Lesotho is about 4 000 hectares. It is used for cropping. Basically, it has the same limitations as mentioned for Bela Soil, but they are less severe. The best use for Maseru Dark Soil is improved pasture

12.1.3 Sani Series. This is a poorly drained, moderately deep, and coarse to medium textured soil, formed under a dense grass cover on nearly level to concave basins in the upper foothills. The epipedon is a thick, black, loam to clayloam. The subsoil is a grayish, mottled, loam grading to yellowish brown sandyloam to loam sandstone saprolite. The distinguishable characteristic of Sani Soil is the presence of a thin organic mat, the O horizon.

Coverage of Sani Soil is about 2 700 hectares. It has limitations similar to those of Bela Soil. It is best suited for rainfed cropping or, preferably, improved pasture.

12.2 Mollisols with a cryic temperature regime

12.2.1 Moroke Series. This is a well drained, shallow, medium texture soil. It is characterized by a dark brown to black mollic epipedon underlain by basalt. The thickness of the soil ranges from 20 to 50 centimeters. Moroke Soil is found in the mountains at elevations about 2 750 metres, where the mean annual temperature is below 8°C and summers are cold.

The Moroke Series has only been established recently and its coverage is not known (Cauley et al., in press). This soil is best suited for native grass because of its severe limitations, related to low temperature and shallowness.

12.3 Mollisols with a ustic moisture regime

12.3.1 Bosiu Series. This is a well to moderately well drained, very deep and medium texture soil. Its topsoil is characterized by a very dark brown sandyloam to sandy clayloam underlain by a dark brown or reddish brown loam to clayloam subsoil. The solum rests on a stratified sedimentary-derived alluvium. Bosiu Soil has formed on gentle to moderately steep slopes in sandstone/shale controlled terrain.

Coverage of Bosiu Soil in Lesotho is limited to approximately 300 hectares. In most cases it occupies the slopes between sandstone escarpments and the toeslope drainageways. The major limitations of the soil are slope, for the steeper slope phases and, to a certain extent, overflow, yet it may be used for intensive cropping under good management.

12.3.2 Kolonyama Series. This is a moderately well to somewhat poorly drained, deep, medium texture soil. Its topsoil is a very dark brown to black loam underlain by black clayloam. It is stratified soil forming on deep recent floodplain deposits and lower terraces. It may have high chroma mottles in the upper part of the subsoil (Figure 12.2).

Coverage of Kolonyama Soil is about 4 000 hectares. It is principally found in the lower terraces of the Caledon River and other rivers of the northern and central lowlands. Kolonyama is a fertile soil. It may be used successfully for rainfed cropping. Overflow and drainage of the soil may be considered limitations for irrigated cropping. If used under irrigation, care should be taken that there is proper irrigation scheduling and, if needed, drainage should be improved.

12.3.3 Kubu Series. This is a well drained, moderately deep, gravelly medium texture soil. Its topsoil is a (very) dark brown, gravelly sandyloam to clayloam, underlain by gravelly sandyloam grading to gravelly siltloam. Kubu Soil is stratified and is found on higher terraces in nearly level to sloping sideslopes. It has formed on older alluvium. Kubu Soil is similar to Bosiu Soil, but lacks the basaltic overburden.

Coverage of Kubu Soil is about 2 000 hectares. It generally occupies the old terraces in the central lowlands. Gravelliness is the main limitation of this soil for cropping use.

12.3.4 Sofonia Series. This is a well drained to moderately well drained, very deep, medium texture soil. The topsoil is a very dark brown sandyloam underlain by dark brown to yellowish brown, stratified, sandyloam to sandy clayloam subsoil. The stratified subsoil may contain a thin buried mollic epipedon. This soil is formed on fans, flood plains, and levees of the major rivers in the western lowlands. It is, usually, associated with Kolonyama and Khabos Series. The former is found in lower positions and has a finer texture; the latter is formed on older alluvium and higher terraces and has a clayey subsoil.

Coverage of Sofonia Series is approximately 6 000 hectares. Sofonia Soil is fertile, deep, and has favourable texture and drainage. Apart from its limitation due to overflow, this soil has no major limitation for irrigated cropping. It is one of the most fertile and productive soils of the country (Figure 12.3).

12.3.5 Khabos Series. This is a moderately well drained, very deep, medium to fine texture soil. It has a very dark brown to black loam to clayloam topsoil underlain by dark yellowish brown clayloam to clay subsoil. It is similar to Bela Soil except for having a better drainage. Khabos Soil has formed on level to gently sloping higher alluvial terraces from basalt-derived alluvium. The C horizon of the soil may contain calcareous nodules.

Coverage of Khabos Soil in Lesotho is approximately 12 000 hectares. This includes the thin variant of Khabos. Khabos Series are mostly found in the western lowlands. It is a highly productive soil. With good management, it may be used for intensive cropping.

12.3.6 Nkau Series. This is a well drained, very deep, and medium texture soil. Its topsoil is characterized by a dark reddish brown loam to clayloam material underlain by a dark reddish brown clayloam to clay. It grades into soft and loamy basaltic saprolite. The lower part of the solum is characterized by carbonate concretions. Included in this series are soils with calcic and petrocalcic horizons. These two horizons occur below one meter of the soils depth. Nkau Soil is formed on gentle to moderately steep slopes in basalt controlled terrain in the Senqu Valley and other central and southern mountain valley (Figure 12.4).

Coverage of Nkau Soil is approximately 9 500 hectares in Lesotho. This soil is highly productive. It may be used for rainfed cropping and, if water is available, for irrigated cropping.

Figure 12.2: Profile of Kolonyama Soil (Road to Ha Qaba, South of Morija.)

Figure 12.3: Profile of Sofonia Soil (LAC Farm, Maseru).

12.2.7 Seforong Series. This is a well drained, moderately deep, medium to fine texture soil whose coverage in Lesotho is approximately 17 000 hectares. It is very similar to Nkau Soil and often occurs in the same geomorphological units as Nkau. However, Seforong is thinner and contains less carbonates in the lower part of its solum than the Nkau Series.

12.4 Mollisols with a udic moisture regime

12.4.1 Lekhalong Series. This is a moderately well drained, shallow and coarse to medium texture soil. Its topsoil is a very dark brown to black, sandy loam or finer texture underlain by sandstone or sandy shale. This soil is similar to Ntsi Soil, both being shallow and underlain by sandstone. Lekhalong Soil has a mollic epipedon and Ntsi Soil has an ochric epipedon.

Coverage of Lekhalong Series is approximately 6 500 hectares in Lesotho. It is principally found on higher sandstone plateaux. This soil has severe limitations for cropping, shallowness being the most important one. It is most suitable for native grass.

12.4.2 Popa Series. This is a well drained, shallow, medium texture soil. The epipedon is a very dark brown to black loam or sandyloam underlain by basalt. It is a residual soil formed on mountain slopes in basalt controlled terrain. It is similar to Moroke, except for the temperature regime (Figure 12.5), the latter existing only at low temperatures.

In Lesotho, Popa is the most extensive soil, the coverage of the Popa and of the Moroke Series (undifferentiated) being approximately 950 000 hectares, or about 30 per cent of the area of Lesotho. Popa Soil, and its cool counterpart, Moroke Soil, are fertile soils. The organic matter content may reach six per cent. They have a high base saturation and a reaction close to neutral. Although they have limitations which preclude their use for cropping, they can successfully support native grasses. Their main limitations for cropping include shallowness, slope, and low temperature. Popa Soil, because of its coverage and its favourable characteristics for grassland production, is one of the most important natural resources of Lesotho.

12.4.3 Ralebese Series. This is a well drained, shallow to moderately deep, and medium texture soil. The dark reddish brown and gravelly loam mollic epipedon rests on paralithic basalt/dolerite saprolite (Figure 12.6). This soil occupies moderately steep to steep slopes of dolerite dykes in the lowland, the foothills, and the mountains. It can be as shallow as 20 centimeters or it may have a thick saprolite. The most suitable taxonomic name for this soil would have been Paralithic Hapludolls, but such a subgroup has not been recognized in Soil Taxonomy (SSS, 1975).

Ralebese Soil covers about 71 000 hectares of different physiographic zones of the country. Limitations due to shallowness restrict the use of this soil primarily to pasture although where saprolite is thick enough, it may be used for woodlot.

12.4.4 Matšana Series. This is a well drained, moderately deep, gravelly, medium texture soil. its topsoil is characterized by (very) dark brown and gravelly loam material. Its subsoil is brown and gravelly loam to gravelly clayloam. The solum rests on basalt saprolite. Commonly, this soil is associated with Popa Soil, both covering most of the moderately steep to steep slopes of the mountains (Figure 12.7).

Coverage of Matšana Soil in Lesotho is not known. This Series has recently been divided into three separate Series. In addition to the Matšana Series, there are now the Soloja Series and Thamathu Series (Cauley, personal communication). The total coverage of these three soils (undifferentiated) is estimated to be around 370 000 hectares. Matšana Soil, if found on gentle slopes in lower altitudes, can be used for cropping. The steep slope and cool phase of Matšana Soil are exluded from cropping. They are best suited for native grassland.

12.4.5 Fusi Series. This is a well drained, very deep, medium texture soil. Its topsoil is characterized by a thick, very dark to black and (gravelly) loam material, underlain by a dark brown gravelly loam. The solum rests on basalt saprolite. The central concept for Fusi Soil includes the presence of an overthickened dark mollic epipedon, gravelliness, medium texture, and having a substantial depth. Fusi Soil is found on gentle sloping to moderately steep slopes in concave sideslopes of mountain valleys. The landscape of Fusi Soil is predominantly basaltic.

Coverage of Fusi Series in Lesotho is approximately 69 000 hectares. Fusi Soil is a fertile soil. It has a high level of organic matter and of base saturation. At lower altitudes and on northern slopes, Fusi Soil has only minor limitations for cropping, but at higher altitudes, this soil has limitations due to the low temperature. The Fusi Soil at higher temperatures and on gentle slopes may be used for intensive cropping.

12.4.6 Maliele Series. This is a well to moderately well drained, very deep, medium texture soil. It has a topsoil of dark brown to black, sandyloam to clayloam, underlain by a dark brown (sandy) clayloam subsoil. This soil occupies the gentle slopes in the foothills. It has been formed on sandstone colluvium below the toeslope of sandstone escarpments. In morphology this soil is similar to Fusi Soil. The main difference between the two is the stronger influence of basaltic parent material in Fusi and of sandstone in Maliele Series.

Coverage of Maliele Soil in Lesotho is about 8 000 hectares. This soil, if found, on gentle slopes has no major limitation for intensive cropping. The steeper slope phases may be used for rainfed cropping or improved pasture.

12.4.7 Tšenola Series. This is a moderately well drained to somewhat poorly drained, deep, coarse to medium texture soil. Its topsoil is a very dark brown to black sandyloam, underlain by a dark grayish brown sandyloam or loam. The solum rests on sandstone saprolite. This soil has intermediate properties between the Sani Series and Maliele Series. The former is wetter and the latter deeper than Tšenola Soil. This soil occupies fans and toeslopes in the upper foothills.

12.4.8 Soloja and Thamathu Series. These soils are well drained, moderately deep, fine texture soils. Both soils are similar to the Matšana Series but are finer in texture. Soloja Soil is lighter in colour and shallower than Thamathu Soil, while the latter has a thicker mollic epipedon. Both of them have been established recently and not much laboratory data is available.

Figure 12.4: Profile of Nkau Soil (Senqu Valley). Photo by C. Mack (1981).

Figure 12.5: Profile of Popa Soil (Mokhotlong). Photo by C. Mack (1981).

Figure 12.6:

Profile of Ralebese Soil (Road to Roma Valley).

Figure 12.7:

Profile of Matšana Soil (Molimo Nthuse).

Chapter Thirteen

Important Soil Groups of Lesotho

II. Alfisols

Alfisols are soils which have developed a more distinct horizonation than Entisols and Inceptisols. Mostly, the former have an ochric epipedon resting on an argillic or natric horizon. Light coloured epipedon, evidence of significant illuviation of clay in the subsoil, and a high base saturation, more than 35 per cent, make up the central concept for Alfisols.

Most of the Alfisols of Lesotho have formed in the lowlands and the foothills. Generally they fall into two broad groups, the duplex soils and the reddish soils. Duplex is a general term applied to those Alfisols of Lesotho which have a significant change in texture between the upper storey, the epipedon, and the lower storey, the endopedon. The epipedon, which includes the bleached albic horizon, has a coarse texture while the endopedon, the argillic or natric horizon, is of a fine texture. The two storeys meet at an abrupt and smooth boundary.

These soils have received considerable attention, primarily, because they are highly vulnerable to gully erosion (see Chapter Eight). The reddish Alfisols of Lesotho are intensively used for cropping. They, generally, reflect a more weathered and leached solum, low base saturation, and predominance of low activity clay.

Coverage of Alfisols in Lesotho is approximately 300 000 hectares. So far about 14 soil series in Lesotho have been identified and classified as Alfisols. Table 13.1 and Figure 13.1 provide additional information about these 14 soil series.

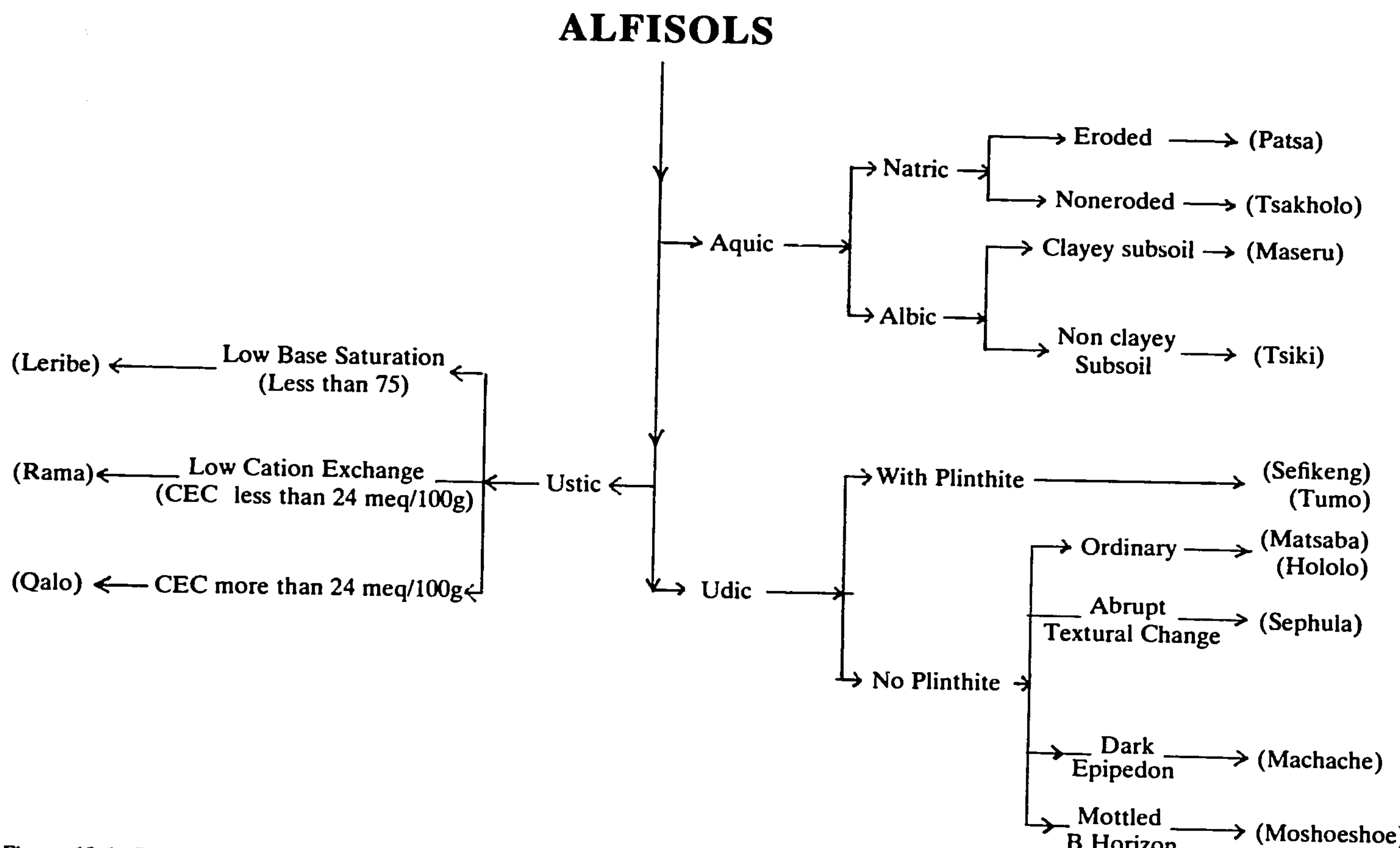


Figure 13.1: Simplified flowchart to differentiate soil series belonging to Alfisols.

Table 13.1: Taxonomic classification of the most extensive soil series of Alfisols in Lesotho (modified from Carroll et al, 1979, and Cauley et al, in press).

Soils Series	*Taxonomic Classification (Subgroup)*
	Alfisols with Aquic Moisture Regime (Duplex Property)
Maseru	Typic Albaqualfs
Tsiki	Typic Albaqualfs
Patsa	Typic Natraqualfs
Tšakholo	Typic Natraqualfs
	Alfisols with Udic Moisture Regime Bordering on Aquic (Duplex Property)
Sephula	Albaquic Hapludalfs
Moshoeshoe	Aquic Hapludalfs
	Alfisols with Udic Moisture Regime
Hololo	Typic Hapludalfs
Matšaba	Typic Hapludalfs
Machache	Mollic Hapludalfs
Sefikeng	Mollic Paleudalfs
Tumo	Mollic Paleudalfs
	Alfisols with Ustic Moisture Regime
Leribe	Ultic Paleustalfs
Qalo	Typic Paleustalfs
Rama	Oxic Paleustalfs

13.1 Alfisols with an Aquic Moisture Regime

13.1.1 Maseru Series. This is a poorly drained, moderately deep to deep, duplex soil. The upper storey consists of a (dark greyish) brown and (sandy) loam ochric epipedon, and a greyish or light brown grey loamy albic horizon. The upper storey rests abruptly on a grey brown, mottled, clay argillic horizon. In this layer, organic matter stains are common on all faces of peds. The solum is underlain by shale and sandstone derived pedisediments (Figures 13.2 and 13.3). Commonly, the subsoil has few manganese and iron nodules. The presence of a rather thick albic horizon, the lack of many nodules in the subsoil, the low chroma in the upper part of the argillic horizon, and a nonsodic subsoil make up the central concept of Maseru Soil.

Maseru Soil is found exclusively in the lowlands. It occupies lower concave slopes, footslopes, and depressions. This soil is extensive in Lesotho (20 000 hectares) and is mostly used for rainfed crop production. Maseru soil has severe limitations for crop production: it is highly erodable and formation of gullies becomes imminent if it is used improperly. Also, Maseru soil is poor in fertility. The safest use for this soil is improved pasture.

13.1.2 Tsiki Series. This is a poorly drained, moderately deep, duplex soil. The ochric epipedon consists of a dark greyish brown, fine sandyloam layer, and a greyish brown (sandy) loam albic horizon. The epipedon rests on a greyish brown, gravelly sandy clayloam argillic horizon. The faces of peds in this horizon are stained with organic matter. The solum is underlain by variegated (grey), light olive brown, fine sandyloam pedisediment. Tsiki soil occupies nearly level to gently sloping valleys. It has formed at the base of sandstone scarps. Sandy residuum from sandstone scarps is, probably, the parent material for the soil.

Coverage of Tsiki soil is approximately 2 700 hectares. Similar to other duplex soils, this soil is highly erodable and is susceptible to gully erosion. The main difference between this soil and other duplex soils is that Tsiki soil has a lower level of clay in its argillic horizon. The safest land use for this soil is improved pasture or native grassland.

13.1.3 Patsa Series. This is a poorly drained, moderately deep duplex soil. The epipedon consists of an eroded thin layer of dark greyish brown loam, and a rather thick albic horizon of (light) greyish brown loam to (sandy) clayloam material. The epipedon rests on a yellowish brown or olive brown, mottled, clay horizon. The solum is underlain by saprolite of shale of the Molteno Formation. The peds in the subsoil are prismatic with their top being skeletal. The exchangeable sodium of the subsoil may exceed 15 per cent. This soil occupies undulating to nearly level concave slopes in the central and southern lowlands.

Coverage of Patsa soil is approximately 30 000 hectares. This soil has severe limitations for crop production, for example, it has the general limitation of being duplex and so having high erodibility. In addition, it also has the problems associated with high exchangeable sodium. This soil is very vulnerable to gully erosion and piping.

13.1.4 Tšakholo Series. This is a poorly drained, moderately deep to deep, duplex soil. The ochric epipedon is a (dark greyish) brown sandyloam underlain by a pale brown sandyloam or loam albic horizon. The topsoil rests on a variegated, dark greyish brown, mottled, gravelly clay natric horizon. The solum grades into pedisediments, and the shale and sandy shale of the Molteno Formation. Nodules of iron and manganese are common in the upper part of the solum. The nodules are coated with carbonates in the lower part of the solum. In some varients of Tšakholo soil, the albic horizon tongues into the natric horizon (Figure 13.4). The central concept of this soil consists of duplex property, presence of a natric horizon, presence of many iron and manganese nodules in the upper part of the natric horizon, and calcareous coatings of the nodules in the lower part of the soil. Tšakholo soil occupies the concave sideslopes of gently sloping terrains, mainly, in the central and southern lowlands.

Coverage of Tšakholo Soil in Lesotho is approximately 80 000 hectares. This soil is used for rainfed maize and sorghum. Tšakholo soil has the similar severe limitation for cropping as does Patsa Soil, namely high erodibility and, particularly, its vulnerability to piping (Figure 13.5). The safest use for this soil is as native grassland.

13.2 Alfisols with a udic moisture regime bordering on aquic

13.2.1 Sephula Series. This is a moderately well to somewhat poorly drained, deep duplex soil. Its topsoil is a (dark greyish) brown sandyloam or loam, underlain by a pale brown, sandyloam or loam albic horizon. The epipedon rests on a brown to yellowish

Figure 13.2 Profile of a Maseru Soil (LAC Farm).

Figure 13.3 A close up of the boundary between the epipedon and endopedon in Maseru Soil (Mafeteng).

brown, mottled, gravelly sandy clayloam to clay argillic horizon. The gravels are mostly in the form of ironstone nodules. The solum grades into shale saprolite (Figure 13.6). The central concept for Sephula Soil is duplex property, presence of many iron and manganese nodules in the upper part of the argillic horizon, and a better drainage than that of Maseru Soil. This soil is not sodic. The Sephula Series occupy undulating to gently rolling and mostly concave slopes in the northern and central lowlands. It has, probably, formed on the purplish shale residuum of the Elliot and Molteno Formations.

Coverage of Sephula Soil is approximately 42 000 hectares. It is mostly used for rainfed cropping. Although this soil is better drained than Maseru Soil and, unlike Tšakholo and Patsa Soils, is not sodic, it still has moderate to severe limitations for cropping. The safest use for this is as improved pasture. The more gentle slopes may be used for rainfed cropping if proper management practices are implemented.

13.2.2 Moshoeshoe Series. This is a moderately well drained, moderately deep, duplex soil. Its topsoil is a brown, loamy fine sand to loam underlain by a (dark) yellowish brown and gravelly (sandy) clayloam subsoil. The solum rests on variegated clay grading into purple-greenish saprolite of Elliot and Molteno shale. This soil occupies gentle to moderately steep slopes in the lowlands, occurring principally on plane and concave midslopes.

Coverage of Moshoeshoe Soil is approximately 6 000 hectares. As with other duplex soils, this soil has severe limitations for cropping. The safest use for this soil is improved pasture or rainfed cropping if proper management practices are implemented.

13.3 Alfisols with a udic moisture regime

13.3.1 Hololo Series. This is a well to moderately well drained, moderately deep, medium texture soil. The topsoil is a (dark) reddish brown to yellowish red or strong brown clayloam. Its subsoil is a reddish brown to yellowish red clayloam. The rather uniform solum rests on Elliot Formation shale and sandstone. This soil is residual. It is found on moderately steep slopes and on the crests of rolling upland areas of the lowlands. Carroll et al (1977) identified this soil as an eroded variant of the Qalo Series.

Hololo Soil is not an extensive soil. Its coverage in Lesotho is limited to approximately 600 hectares. Poor fertility, low pH, and steepness of slope are the major limitations of this soil for cropping, although if the steep slope phases are excluded, this soil can be used for cropping. Its productivity can be increased by the addition of high intensity fertilizers, organic matter and soil amendments.

13.3.2 Matšaba Series. This is a well drained, moderately deep to deep, medium texture soil. Its topsoil is characterized by a dark reddish brown loam to clayloam material underlain by a dark reddish brown to red clayloam or clay argillic horizon. The solum is yellowish red siltloam to clayloam, grading into basalt saprolite. This soil occupies the crests of gentle to steep slope land rises, mainly, at the boundary zone between the Lesotho Formation and the Clarens Formation.

Coverage of Matšaba Soil in Lesotho is approximately 33 000 hectares. It is a fertile soil and, excluding the steep slope phases, this soil has very few limitations for intensive cropping.

Figure 13.4: Profile of Tšakholo Soil (LAC Farm).

Figure 13.5: Formation of pipe at the top of the natric horizon in a Tšakholo Soil (Mazenod).

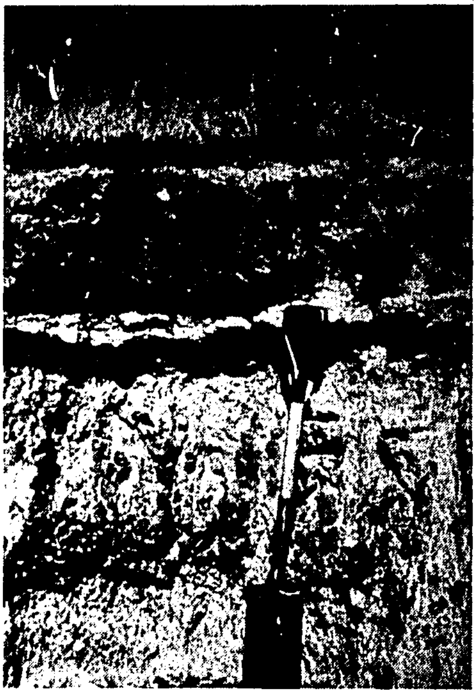


Figure 13.6: Profile of Sephula Soil.

13.3.3 Machache Series. This is a well drained, very deep, fine texture soil. Its topsoil is a dark reddish brown silty clayloam to clay, underlain by a dark red silty clayloam to clay argillic horizon. The solum rests on a dark yellowish brown sandyloam basaltic saprolite. The topsoil meets the requirements of a mollic epipedon, except for its base saturation, which is slightly less than 50 per cent (Cauley et al, in press). This soil occupies gently sloping to sloping crests and sideslopes of low land rises in the upper foothills, where the terrain is controlled by basalts of the Lesotho Formation. It may be found in close association with its black counterpart, Thabana Soil, in the foothills.

Although Machache Soil is one of Lesotho's best agricultural soils, it does have certain limitations which must be borne in mind when land use recommendations are made. It has a low base saturation of 45 to 60 per cent. It is characterized by the dominance of low activity clay. The CEC of the soil is from 14 to 17 milliequivalent per hundred grams of soil where clay content in the solum is around 50 per cent. Under a good management system the gentle slope phases of this soil can be used for intensive cropping. Improving the fertility level of the soil is the key to successful cropping on a Machache Soil.

The Machache Series was first identified by Carroll and Bascomb (1962). It was characterized in more detail by Carroll et al (1979). Recently this soil has been divided into three series (Cauley et al, in press). The other two series are the Tumo and Sefikeng Series. The coverage of the three soils in Lesotho is approximately 25 000 hectares.

13.3.4 Sefikeng and Tumo Series. These are well drained, very deep, medium to fine texture soils. The topsoil of both soils is a dark reddish brown, underlain by a yellowish or red subsoil. The texture of Sefikeng Soil is siltloam in the topsoil and heavy siltloam to silty clayloam in the subsoil. Tumo Soil has more clay in the solum. Both soils have formed on convex slopes of uplands in basalt controlled terrain.

In addition to differences in texture, it has been reported that the dominant clay mineralogy for Sefikeng Soil is kaolinite and for Tumo Soil is halloysite (Cauley et al, in press).

13.4 Alfisols with ustic moisture regime

13.4.1 Leribe Series. This is a well drained, (very) deep, medium texture soil. The topsoil is a (dark) reddish brown loam to fine sandyloam. The subsoil is a dark reddish brown or dark red (sandy) clayloam to silty clay. The solum rests on a buried reddish clayloam to clay argillic horizon. The lower part of the soil may have dark mottles or aggregates of iron and manganese. Leribe soil is found mainly in sandstone controlled terrain, in the northern and central lowlands and foothills. It occupies gentle to moderately steep slopes, commonly, the crests of land rises. This soil has probably formed on a residuum of the Elliot Formation. It is characterized by the lithological discontinuity at the lower part of the B horizon.

Leribe Soil is similar to the Qalo and Rama Series in many of its morphological features. Rama Soil has less organic matter in the topsoil and has more clay in the lower part of the B horizon than does Leribe Soil. Qalo Soil has a finer texture throughout the pedon and has black manganese nodules in the upper part of the argillic horizon.

Coverage of Leribe Soil is around 48 000 hecares. This soil is used, intensively, for maize and wheat production. However, it has significant limitations for cropping, including a very low pH, which may reach to a level as low as 4.5 in the topsoil, a low base saturation, from 50 to 70 per cent, and a low CEC, approximately 5 to 7 milliequivalent per 100 grams of soil. There is also the possibility of aluminium toxicity. It can be used successfully for intensive cropping if the fertility status of the soil is improved.

13.4.2 Qalo Series. This is a well to moderately well drained (very) deep, fine texture soil. It has a topsoil of a dark reddish brown sandyloam to clayloam. The subsoil is a variegated reddish brown to yellowish brown clayloam. Few to many black manganese concretions and stains are found in the argillic horizon. This soil is found on convex sideslopes and crests of the gentle to moderately steep slopes of shale and sandstone terrains in the central lowland.

Qalo Soil is acidic, but the limited data available shows that it has a higher base saturation and CEC than do the Rama and Leribe Soils (Carroll et al, 1979).

Coverage of this soil is around 4 200 hectares. Excluding the steep slope phases, this soil can be used for intensive cropping if its fertility is improved.

13.4.3 Rama Series. This is a well to moderately well drained, (moderately) deep, medium to fine texture soil. The topsoil is characterized by a dark brown loam to yellowish red clayloam. The solum rests on a gravelly clayloam to clay residuum of shale and sandstone. Petroferric gravels, hardened plinthite, may be present in the argillic horizon. This soil occupies the middle slopes of gentle to moderately steep slopes of undulating to rolling terrains in the lowlands and foothills. It normally occupies lower positions than Leribe Soil.

Similar to Leribe Soil, the Rama Series has a low pH of 5 to 5.5, a low base saturation, a low CEC, and low activity clay. It is lighter in colour than is the Leribe Soil, has more clay in the argillic horizon and less organic matter in the topsoil. It may have a weakly developed albic horizon.

Coverage of Rama Soil in Lesotho is about 4 500 hectares. This soil has the same type of limitations as Leribe Soil. In addition, it may have the limitation associated with wetness during the growing periods. Rama Soil can be used successfully for cropping if the fertility status of the soil is improved.

Chapter Fourteen

Important Soil Groups of Lesotho III. Entisols, Inceptisols, Vertisols

In addition to Mollisols and Alfisols, other orders have been identified in Lesotho. Their coverage is smaller than that of Mollisols and Alfisols. Among them are Entisols, Inceptisols and Vertisols which can be found in all three of Lesotho's physiographic zones, (Table 14.1). In addition to the soil orders previously mentioned, patches of Histisols, the organic soils, can be found in higher elevations in the mountains. In Lesotho, Histisols do not occur extensively and, other than observation types of reports (Mack, 1981) no detailed information about their characteristics is available.

Table 14.1: The taxonomic classification of the most extensive Entisols, Inceptisols, and Vertisols in Lesotho (modified from Carroll et al, 1979, and Cauley et al, in press).

Soil Series	*Taxonomic Classification (Subgroup Level)*
	Entisols
Caledon	Typic Udifluvents
Majara	Typic Udifluvents
Ntsi	Lithic Udorthents
Theko	Typic Haplaquents
Thoteng	Typic Udipsamments
	Inceptisols
Berea	Aquic Dystrochrepts[1]
Qalaheng	Aquic Dystrochrepts[2]
Matela	Dystic Eutrochrepts[3]
	Vertisols
Phechela	Typic Pelluderts
Thabana	Typic Pelluderts

[1,2] Proposed by Cauley et al (in press) as Oxic Haplustalfs.
[3] Proposed by Cauley et al (in press) as Oxic Eutrochrepts and by Carroll et al (1979) as Paleudalfs.

14.1 Entisols

Entisols are young soils. In Lesotho, they lack diagnostic horizons except for the ochric epipedon. Entisols are either young soils or, if formed on old landscapes, their pedogenetic development has been interrupted by erosion or by deposition of new material. Also, they may stay young due to the dominance of minerals, such as quartz, which are strongly resistant to weathering. Soil Taxonomy (SSS, 1975) allows the presence of buried diagnostic horizons in Entisols, provided that they occur below a level of 50 centimetres of soil.

In Lesotho, soil series belonging to Entisols occupy approximately 128 000 hectares, almost four per cent of the total area of the country (Carroll et al, 1979). Lesotho Entisols have formed either on steep slopes, subjected to sheet erosion, on colluvium at the foot of slopes, or on alluvial deposits, subjected to overflow and deposition of recent material (Figure 14.1).

The soil series belonging to Entisols of Lesotho are the Caledon, Majara, Ntsi, Theko and Thoteng Series. Table 14.1 presents the taxonomic names of the soil series.

14.1.1 Caledon Series. This is a well drained, deep and coarse texture soil. It has been formed on alluvial deposits along Lesotho's major rivers and is well stratified, reflecting its alluvial origin. The topsoil is dark brown to yellowish brown and loamysand to sandyloam, underlain by lighter coloured and coarser textured alluvium. The organic matter content of the soil decreases irregularly with depth. It lacks mottling (Figure 14.2).

Coverage of Caledon Soil in Lesotho is approximately 1 800 hectares, occurring primarily along the Caledon River in the northern and central lowlands. Although it is used for cropping, it has limitation due to its coarse texture and because it is subjected to overflow. The fertility status of this soil is poor because of intensive leaching and low capacity for holding nutrients and water. It dries easily and becomes problematic during dry periods.

14.1.2 Majara Series. This is a moderately well drained, deep, coarse texture soil. The upper solum of the soil is a dark brown to yellowish brown loamysand. This stratified overburden is underlain by dark clay and buried duplex soil. The presence of this buried soil below the stratified overburden is the central concept of Majara Soil. This soil has been formed along drainageways and interstream divides on level to gentle slopes below the sandstone scarps. Carroll et al (1979) have classified Majara Soil as Udifluvents but Berding (1984) has proposed the Albaqualfs due to the presence of the buried clay zone.

Majara soil covers 3 600 hectares in Lesotho. It has two major limitations for cropping. The presence of a clay accumulation zone, resulting in differential hydraulic conductivity between the coarse textured upper layer and the clay zone and, the other being overflow. This soil is suitable for rainfed cropping. Given careful water management and subsoiling, Majara Soil can be brought under irrigation.

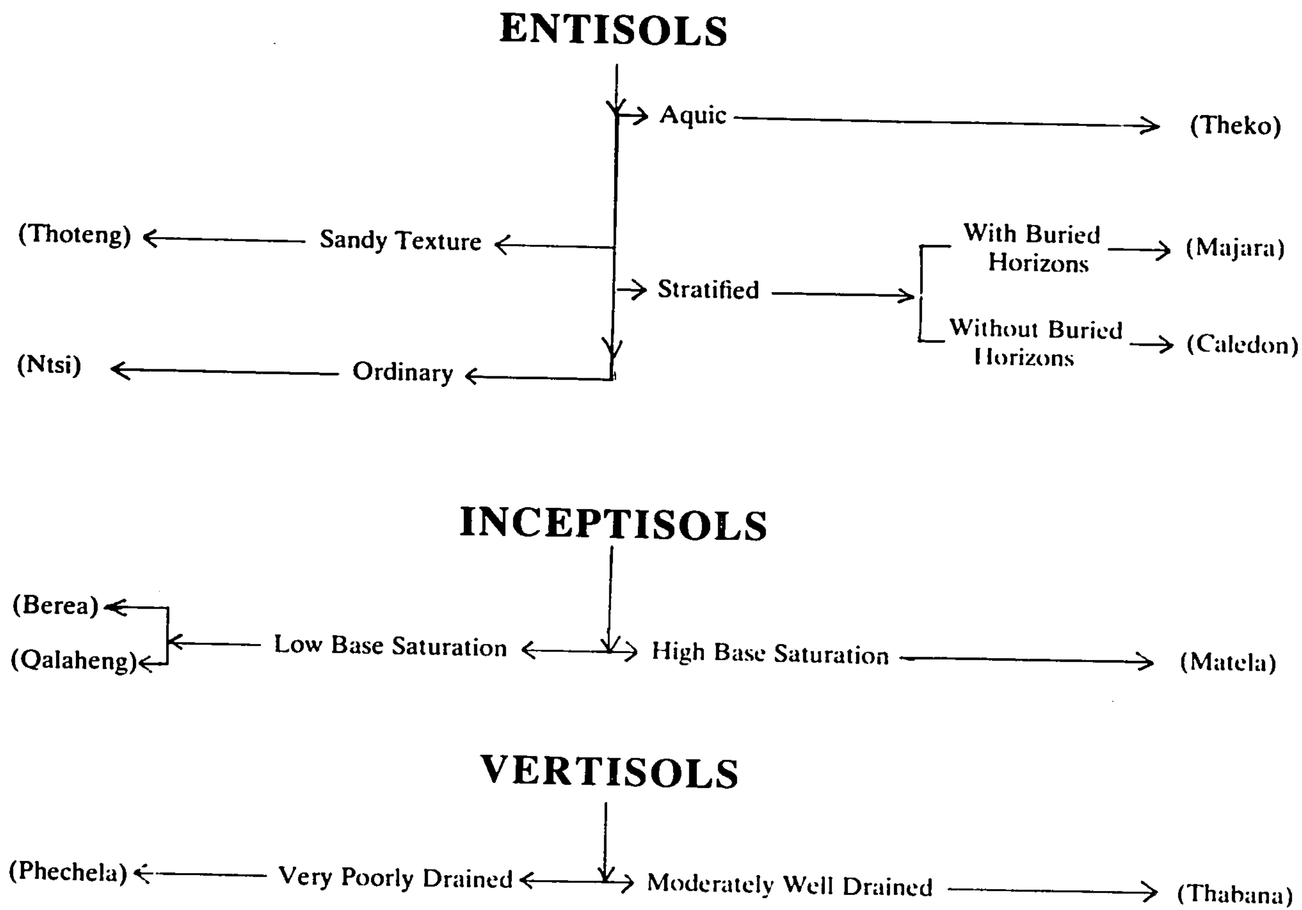


Figure 14.1: A simplified flow chart showing the main criteria to separate the soil series in Entisols, Inceptisols, and Vertisols orders.

14.1.3 Ntsi Series. This is a well drained, shallow, coarse to medium texture soil. The thickness of the solum ranges from 20 to 50 centimetres. The grayish to yellowish brown ochric epipedon of the soil is underlain by a lithic contact, sandstone. The central concept of Ntsi Soil is, therefore, shallowness, the presence of an ochric epipedon and of a sandstone contact within 50 centimetres of the soil's depth. Ntsi is a residual soil formed on sandstone on the crest or sides of Clarens sandstone outcrops in the lowlands and the foothills.

The coverage of Ntsi Soil in Lesotho is about 120 000 hectares. This soil is not suitable for crop production because of the limitations of depth and, in most cases, slope. It may support the native grasses and, where the sandstone saprolite is thick, it may be used as a woodlot site.

14.1.4 Theko Series. This is a poorly drained, moderately deep to deep coarse texture soil. The upper solum is a very dark grey loamysand or sandyloam, and the subsoil is dark yellowish brown, mottled and fine sandy. The epipedon is dark but it is poor in organic matter and is acidic. The central concept for Theko Soil is that the soil is saturated with water most of the year. This is evident by the presence of prominent mottles, sometimes occuring close to the surface, and of a rather dark chroma.

The coverage of Theko Soil is only about 600 hectares. Its limitations of excessive wetness and coarse texture make it unsuitable for cropping although it may be used successfully for improved pasture or native grass.

14.1.5 Thoteng Series. This is a well drained to excessively well drained, very deep, (very) coarse texture soil. The upper solum is a very dark grey to dark brown sand or sandyloam, underlain by reddish or yellowish brown and, sometimes, mottled sand. This soil has been formed from sandstone colluvium, mainly along the sides of sandstone escarpments, in the lowlands and foothills. The central concept of the soil consists of a sandy texture, a deep and mostly mottle free solum and absence of a lithic contact.

Thoteng Soil covers about 600 hectares. The major limitation of this soil for agricultural uses is coarse texture. Due to excessive leaching, it has a poor fertility and is acidic. This soil cannot hold water and nutrients. Native grass and woodlot are the best uses for this soil.

14.2 Inceptisols

Inceptisols are soils in an early stage of pedogenic development. They are young but the time involved in their development has been sufficient to allow some, but not strong, horizon development. They normally have a B-horizon which shows some alteration when it is compared with overlying and underlying horizons. Such differences may be the development of a redder colour, the formation of structure, and some illuviation of clay, organic matter and iron from the epipedon. Formation of such a B-horizon, called cambic, is the central concept for Inceptisols.

Among the six suborders established for Inceptisols (SSS, 1975) so far, only one suborder, Ochrepts, has been reported to be present in Lesotho. Ochrepts are Inceptisols having an ochric epipedon and cambic endopedon. A mollic epipedon is allowed, if it is less than 25 centimetres thick. The Inceptisols of Lesotho are acidic and, commonly, are associated with wetness at the lower part of their solum.

Carroll et al (1979) recognized in Lesotho two soil series belonging to the Inceptisols order although Cauley et al (in press) have recognized only one. The former established the Berea and Qalaheng Series as Inceptisols but the latter recognize neither of them as Inceptisols and instead propose the Matela Series to be an Inceptisol. In this text, all the three soil series suggested as belonging to the Inceptisols have been covered. Future work will determine exactly what soil series belong to this order (Table 14.1 and Figure 14.1).

Assuming that Matela, Qalaheng and Berea Series are Inceptisols, the total coverage of these soils in Lesotho is approximately 185 000 hectares or six per cent of the area of Lesotho.

14.2.1 Berea and Qalaheng Series (Undifferentiated). These are moderately well to somewhat poorly drained deep soils. They are yellowish brown to dark yellowish brown, have a fine sandyloam to loam and have an acidic topsoil, underlain by a yellowish brown to dark yellowish brown loam to clayloam, acidic and mottled subsoil. The parent material, presumably derived from sandstone, is characterized by a continuous phase of petroferric hardpan (Figure 14.3). These soils are residual soils formed on sandstones of the Clarens Formation in the lowlands and the foothills. They occupy the gentle to moderately steep slopes.

These soils have moderate to severe limitations for crop production. They are subjected, periodically, to wetness, are acidic, have a low base saturation, normally below 50 per cent, and have low activity clay which is indicated by a low CEC of about three to five milliequivalent per 100 grams of soil; neither should the possibility of toxicity, mainly iron, be overlooked. However, these soils may be used for cropping if some of the limitations due to their poor fertility and acidic nature are corrected.

14.2.2 Matela Series. This is a well to moderately well drained deep soil. The topsoil is dark reddish brown, sandyloam to loam and acidic, overlying a yellowish red, sandyloam to clayloam and acidic subsoil. The lower part of the solum has distinct mottles of dark reddish brown and soft plinthite nodules. This soil has formed on mixed basaltic/ sandstone saprolite and occupies gently sloping landscapes, mostly at the contact zone between basalt or sandstone in the foothills, and between dolerite and sandstone in the lowland.

Matela Soil has a coverage of about 60 000 hectares in Lesotho but has certain limitations for crop production, including a strong acidity, low fertility and low CEC. In possessing such characteristics, it is similar to the Berea and Qalaheng Series. The advantages of Matela Soil over the other two soils is that it is better drained and has a slightly higher base saturation.

Given the fact that field identification of a cambic horizon, the central concept for Inceptisols, is often difficult, it is possible that in future other great groups of Inceptisols will be found in Lesotho. Particular reference is made to soils, observed by the authors, forming on northern slopes of the Western Maluti Mountains in the Mapoteng area. It seems that

Figure 14.2: Profile of A Caledon Soil (LAC Farm, close to the bank of the Caledon River).

Figure 14.3: Profile of a Berea Soil (Leshoboro Woodlot).

these soils have formed on tuffaceous material. They are characterized by a dark red mollic epipedon underlain by rather thin, somewhat developed structure, and a reddish layer. The solum is 60 to 70 centimetres thick, resting on tuffaceous material. The extension of this Andepts-like soil is not known.

14.3 Vertisols

Vertisols are deep soils having a considerable amount (30 per cent or more) of clay throughout their pedons, often cracking during the dry periods. They have formed mostly in depressions and drainageways, and on concave and flat to gentle slopes. All Vertisols in Lesotho have been ploughed, removing the evidences of gilgi.

The coverage of Vertisols in Lesotho is about 70 000 hectares. They have formed on basaltic alluvium and colluvium in the lowlands, foothills and mountains.

Carroll et al (1979) recognized only the Phechela Series as Vertisols in Lesotho. Recent investigations however, have shown that the Thabana Series is also a Vertisol (Cauley et al, in press). See Table 14.1 for the taxonomic names of the two soils and Figure 14.1 for the main differentiating criteria between the two.

14.3.1 Phechela Series. This is a very poorly drained, deep soil, which, throughout the solum, is black clay. The clay content of the soil ranges from 50 to 70 per cent. Phechela Soil is primarily formed on concave and closed basin landforms where accumulation of fine clay particles through lateral flow and seepage water is possible.

The central concept of Phechela includes a heavy clay texture pedon, the presence of a thick black epipedon resting on yellowish brown basalt saprolite, the formation of cracks, and very poor drainage.

Coverage of Phechela Soil is about 25 000 hectares and although it is used primarily for cropping, it has severe limitations for this, including very poor drainage (wetness), poor permeability, and high shrink-swell potential. However, it is better suited for pasture than for other uses.

14.3.2 Thabana Series. This soil is moderately well to somewhat poorly drained, deep, and clayey. The topsoil is a dark brown to black clayloam to clay, with a granular structure, underlain by dark brown to red textural clay. The solum rests on basalt saprolite (Figures 14.4 and 14.5). Thabana Soil is found on level, gentle to moderately steep slopes, particularly in the upper foothill zone.

The coverage of Thabana Soil is about 45 000 hectares. It is used principally for rainfed crop production as it is fertile, has a high level of organic matter, of CEC, and of base saturation while the main limitation of the soil for cropping is its texture. This soil is not recommended for irrigation. However, under good management, it may be successfully used for rainfed cropping. The most suitable use for this soil is fodder production.

Figure 14.4: Profile of a Thabana Soil (Matelile, north of Mafeteng).

Figure 14.5: Landscape of Thabana Soil (Matelile, north of Mafeteng).

Appendix

Brief Definitions of Diagnostic Horizons in Soils and Categories of Soil Taxonomy

Diagnostic horizons

Diagnostic horizons are the keys to the Soil Taxonomy, classification of soils.Those horizons are the products of the interaction of the soil forming factors and the rate of their influence. Diagnostic horizons reflect the pedogenesis processes that a particular pedon has gone through. Diagnostic horizons either form at the soil surface, the epipedons, or they are formed in the subsoil, the subsurface or endopedons. Here, the requirements for those diagnostic horizons that have been identified in Lesotho, or which possibly occur in Lesotho, are discussed. Note that diagnostic horizons are layers of one or more horizons and not a soil as a whole.

Epipedons

MOLLIC is a dark surface horizon. The requirements include:

1. minimum depth ≥ 17.5cm;
2. organic matter content ≥ 1%;
3. base saturation ≥ 50%;
4. moist colour value ≤ 3.5 and dry colour value ≤ 5.5;
5. moist colour chroma ≤ 3.5;

The structure is usually granular or fine blocky but it cannot have a massive structure. Mollic epipedon is the dominant epipedon in the mountain soils of Lesotho.

UMBRIC is similar to mollic epipedon except that the base saturation in umbric is less than 50%. It forms the epipedon of very acidic soils. It is not dominant in Lesotho but may occur in certain soils of the lowlands.

OCHRIC is a light coloured epipedon. It is too light in colour, or it may be too thin in thickness, or too low in organic matter to be either mollic or umbric. Ochric is quite common in the lowlands of Lesotho. The greyish epipedon of most Duplex Soils in Lesotho is ochric.

PLAGGEN and ANTHROPIC are epipedons which reflect the strong influence of the human being.

PACHIC AND CUMULIC are two terms applied to those mollic epipedons with a thickness of more than 50cm.

Endopedons

There are a number of subsurface diagnostic horizons identified in soils. The following list is only of those diagnostic subsurface horizons that are either found in Lesotho or are of great importance in Soil Taxonomy.

ARGILLIC is an illuvial layer in soil and is the zone of clay accumulation. An argillic horizon is formed because of the movement of fine clay particles from the upper layer. Conventionally it is a B horizon that accommodates the leached outs of the A horizon.

The formation of an argillic endopedon normally takes several thousand years. Adequate moisture and proper temperature are necessary for the formation of an argillic endopedon.

An argillic horizon is identified in the field by clay accumulation and clay films on the ped surfaces. The requirements for an argillic endopedon are:

1. if the eluvial horizon (the top layer) has <15 per cent clay then the B horizon must have 3 per cent more clay to be argillic;
2. if the eluvial horizon has 15 to 40 per cent clay, then the B horizon must have at least 1.2 times as much clay
3. if the eluvial horizon has >40 per cent clay then B horizon must have at least 8 per cent more clay to be argillic.

In addition, an argillic horizon must be at least 1/10 as thick as the overlying horizons or must be more than 15cm thick.

Argillic endopedons have been identified in a number of soils of Lesotho, both in the lowlands and the foothills.

NATRIC is an endopedon which meets the requirements of an argillic horizon and in addition has > 15 per cent exchangeable sodium. Certain soils of the lowland zone of Lesotho have a natric endopedon.

CAMBIC is a relatively young B horizon, which shows some indications of structural development, removal of certain materials, a small increase in clay, but not enough to meet the requirements for argillic, or in iron and humus, and sometimes a reddening of the matrix colour. It may also indicate changes caused by wetness, such as mottling. All or some of these alterations and changes are enough to separate the cambic horizon from the underlying or overlying horizons.

A cambic endopedon has been identified in some of the soils in the lowlands and lower foothills of Lesotho.

SPODIC is a zone of accumulation of organic matter and amorphous Al and Fe oxides, illuviated from the upper horizons. This horizon has not been found in soils in Lesotho.

OXIC is a highly weathered subsurface horizon. Kaolinite clays, Fe-Al oxides and quartz are the major contituents of this horizon. It is normally acidic with a low CEC. So far the presence of this horizon has not been identified in the soils of Lesotho. However, there is a strong possibility that in future, with more accurate data available, the presence of an oxic endopedon in Lesotho will be confirmed.

CALCIC is a horizon showing an accumulation of Ca and Mg carbonates leaching from the upper layers. It may form in the B or upper C horizons. A subsurface horizon to be calcic must be at least 15 cm thick, must contain >15 per cent calcium carbonate and must have 5 per cent more carbonates than the underlying horizon. The presence of this endopedon has been reported in some soils of the Senqu Valley in Lesotho.

PETROCALCIC is an indurated or hardened calcic horizon. The dry fragments do not slake in water. It has been found in certain soils of the Senqu Valley.

ALBIC is a bleached horizon occurring above a B-horizon. It is a horizon with a light colour due to the leaching of organic matter, clay and iron oxides. The albic endopedon is a common feature of some of the Duplex Soils of Lesotho.

PLINTHITE is an iron-rich endopedon formed usually in the lower B-horizon. Upon alternate wetting and drying, it hardens irreversibly to ironstone.

LITHIC CONTACT is the boundary between soil and continuous coherent underlying material that has a hardness of more than 3 Mohs. An example is the boundary between Popa Soils in the mountains of Lesotho and the underlying coherent basaltic rock. The lithic contact becomes diagnostic in Soil Taxonomy where it occurs within the top 50cm depth of the soil.

PARALITHIC CONTACT is similar to lithic contact except for its hardness which is less than 3 Mohs. A paralithic contact can be dug with a spade when it is moist.

ARENIC is a horizon of loamy fine sand or of coarser texture above an argillic horizon. It must be at least 50cm thick. If the thickness is more than 100cm, it is called GROSSARENIC.

Soil moisture regimes

In addition to diagnostic horizons, the soil moisture regimes have to be established before attempting to classify the soils. The soil moisture regime is determined by measuring soil moisture mainly at the zone (depth) of maximum plant root activity or it is established by using the relevant climatological data. The depth where the soil moisture measurement is conducted is the Soil Moisture Control Section. This depth varies and is based on the soil texture. The Soil Moisture Control Section is defined as follows:

Sandy	30–90cm depth
Coarse loamy	20–60cm depth
Finer than coarse loamy (including all the particle size classes finer than coarse loamy)	10–30cm depth

Five classes of soil moisture regimes have been identified:

AQUIC – It is a soil moisture regime indicating a reducing regime and seasonal lack of oxygen. Soils with an aquic moisture regime are saturated during most of the year. The source of water for saturation is either ground water, or the accumulation of water due to the presence of a claypan or other hardpans with very low permeability. Continuous seepage from a nearby river, stream or spring may also provide adequate water to saturate the control section depth. Lateral movement of water from the soils of higher slopes may also be considered as a source of water for soils located in depressions or at the foot of the slopes. An aquic moisture regime is usually associated with mottles and low chroma.

Some of the soils in Lesotho, mainly the Duplex Soils and semi-Duplex Soils of the lowlands have an aquic moisture regime.

ARIDIC (TORRIC) are soil moisture regimes indicating long continuous dry condition. They are normally associated with arid and semi-arid climates and are not applicable to soils in Lesotho.

XERIC is a moisture regime that is associated with the Mediterranean type of climate where winters are cold and moist and summers are warm and dry. This regime is not applicable to soils of Lesotho.

UDIC is a soil moisture regime in which in most years the soil moisture control section is not dry in any part for as long as 90 days. Under udic moisture regime soil normally is moist during the growing season.

The moisture for most soils of Lesotho is established as udic. Exceptions are the soils with an aquic moisture regime and those occurring in the central and southern lowlands, and in the Senqu Valley.

USTIC is a soil moisture regime intermediate between aridic and udic. The concept is one of limited moisture, but moisture is present at a time when conditions are suitable for plant growth.

A ustic moisture regime has been established for the soils of the central and southern lowlands of Lesotho including the Senqu Valley.

Soil taxonomic classes

Soil taxonomy similar to plant taxonomy is a system consisting of different classes each reflecting a certain category within the system. The system of soil taxonomy consists of orders, suborders, great groups, subgroups, families and series, from the highest category to the lowest.

Soil taxonomy, similar to plant taxonomy, uses Latin, Greek or Roman terminology. The name of the soils is derived from the formative elements of each class (order, suborder, etc.). For example, a soil name at subgroup level may be:

Lithic Hapludolls in which

Lithic is the subgroup

Hapl	is the formative element for great group (for minimum horizonation)
Ud	is the formative element for suborder (from Udic moisture regime)
Oll	is the formative element for order (from Mollisols)

Tables 1, 2, 3 and 4 show the formative elements used at different categories. In these tables only those formative elements which are relevant to the soils of Lesotho have been presented.

Soil orders. Ten soil orders have been established to cover the soils of the world. The criteria used to separate soil orders are mainly based on the presence of diagnostic horizons. The ten soil orders are: Entisols, Inceptisols, Mollisols, Aridisols, Ultisols, Oxisols, Vertisols, Spodosols, and Histisols (see Table 1 for the formative elements of each order).

Soil suborders. Orders are divided into suborders. The criteria for separating the suborder are: the dominant soil moisture regime or other factors important to the genesis or plant growth. So far 47 suborders have been established (See Table 2).

Table 1: Soil orders and their formative elements.

Order	*General Features***	*Formative Elements*
Entisols*	Young soils mostly with no diagnostic horizon but ochric	ent
Inceptisols*	Are in early stage of development but are older than Entisols, mostly have a cambic horizon	
Mollisols*	Soils with mollic epipedon but no cambic, spodic and oxic horizons	oll
Aridisols	Soils with aridic moisture regime	id
Vertisols*	Clayey soils, with high shrinkage/swelling potential, crack during dry periods	ert
Spodosols	Soil with spodic horizon	od
Ultisols	Soils low in base saturation with ochric and argillic horizons	ult
Alfisols*	Soils high in base saturation with ochric and argillic horizons	alf
Oxisols	Soils with oxic horizon	ox
Histosols	Organic soils (have histic epipedon)	ist

NOTE: *Are the only orders that have been identified in Lesotho (CDS, 1979).
**The general features mentioned here, have been extremely generalized. For a detailed description of requirements for each order refer to SSS, 1975.

Great groups. About 185 great groups are subdivisions of the suborders. The criteria to separate great groups are: moisture regime, if not used at suborder level, or temperature regime, which will be discussed later, or the presence or absence of diagnostic horizons (Table 3).

Subgroups. Great groups are divided into subgroups. More than 970 subgroups have been established. The criteria used to arrange the great groups into subgroups are as follows:

1. Subgroups representing the central concept of the great group are called TYPIC;
2. subgroups showing transitional forms to other orders, suborders or great groups in the taxonomic system. They are recognized Intergrade subgroups.
3. Subgroups showing the presence of other horizons are Extragrades (Table 4).

Table 2: Some formative elements of soil suborder (applicable to Lesotho).

Formative element	*Meaning*
alb	Presence of albic horizon (bleached, eluvial horizon)
aqu	Aquic moisture regime
bor	Cool temperature (usually applied to certain mountain soils)
ferr	Presence of a high amount of iron oxide
fluv	Indication of a flood plain landform
ochr	Presence of an ochric epipedon
orth	The common ones
psamm	Very coarse texture
ud	Udic moisture regime
umbr	Umbric epipedon
ust	Ustic moisture regime

Table 3: Some formative elements of soil great group (applicable to Lesotho).

Formative element	*Meaning*
acr	Extreme weathering
alb	Albic horizon
aqu	Aquic moisture regime
calc	Calcic horizon
camb	Cambic horizon
dystr	Low base saturation
eutr	High base saturation
gloss	Tongued
halp	Minimum horizonation
moll	Mollic epipedon
natr	Natric horizon
ochr	Ochric epipedon
pale	Old
pell	Low chroma
plinth	Plinthite
ud	Udic moisture regime
umbr	Umbric epipedon
ust	Ustic moisture regime
argi	Argillic horizon

Table 4: Some formative elements of extragrade subgroups (applicable to Lesotho).

Formative Element	*Meaning*
Abruptic	Sharp difference in texture between clayplan and the horizon above
Aeric	Browner and better aerated than typic (higher chroma)
Arenic	Sandy eluvial horizon between 50 and 100cm thick
Cumulic	Overthickened mollic epipedon
Glossic	Tongued eluvial and illuvial horizons
Lithic	Hardrock within 50cm of the surface
Petrocalic	Presence of Petrocalcic horizon
Pachic	Thick mollic epipedon
Plinthic	Presence of plinthite

Examples of nomenclature

The taxonomic name of a soil to subgroup level is composed of the formative elements of each class. For example, a Mollisol with an argillic horizon and ustic moisture regime is named at great group as:

Argiudolls where: *oll* is the formative element for Mollisols
ud is the formative element for Udic moisture regime
Argi is the formative element for argillic horizon

If the soil meets the requirements of the central concept of the great group it is named at subgroup level as:

Typic Argiudoll

Soil temperature regimes

The soil temperature regime is measured at 50cm depth. Depending on the soil mean annual temperature (MAT) and on the difference between the soil mean summer and mean winter temperature, the soil temperature regime is established using the following guide:

Temperature Regime	*Mean Annual Temperature* (C°)
Pergelic	<0°
Cryic	0–8° (cold summers)
Frigid	<8° (warm summers)
Mesic	8–15°
Thermic	15–22°
Hyperthemic	>22°

The term Iso will be prefixed to the above listed names if the difference between mean summer and mean winter temperature is less than 5°C. In Lesotho, the soils located above 3000m MSL have frigid (or cryic) temperature regimes. The soil temperature regime for the rest of the country has been established to be mesic and/or thermic.

Glossary of Geological, Geomorphological, and Soils Terms Applicable to Lesotho

Accelerated Erosion	An accelerated, man-induced, form of erosion.
Accumulation terrace	A river terrace made up entirely of alluvial deposits.
Acid rock	Obsolete term for igneous rock containing at least 66 percent silica.
Aeolian deposits	Deposits laid down by wind.
Aggradation	Raising a surface by deposition.
Alluvium	Detrital material which has been transported and deposited by a river and consists mainly of gravel, sand and clay.
Amygdale	A cavity in lava, caused by seeping gas bubbles, which has become filled by a mineral, for example, zeolite and quartz.
Aphanitic texture	Having such a small grain size that individual crystals are invisible to the naked eye.
Aquifer	A rock yielding significant quantities of water.
Arkose	A variety of sandstone containing at least 25 per cent of feldspars.
Augite	A mineral belonging to the Pyroxene Group of the silicates. It is characteristic of dark igneous rocks such as basalt, gabbro and peridotite.
Axis (basin)	A line connecting the lowest points in the basin.
Banded ironstone	A sedimentary rock made up of predominantly siliceous layers alternating with mainly ferruginous bands.
Banded structure	A term used for a rock having distinct layers of different physical/chemical composition.
Barbed drainage pattern	A drainage pattern with tributaries running in a direction opposite to that of the trunk stream.
Basal conglomerate	A conglomerate which forms the lowest stratum of a sedimentary succession.
Basalt	A fine-grained igneous rock, composed mainly of calcic plagioclase and pyroxene and which is the extrusive equivalent of the intrusive gabbro and the hypabyssal dolerite.
Base level	The level below which a river cannot erode. Sea level can be considered as a general base level, but local, temporary base levels are formed by, for example, resistant outcrops and lake levels.
Basement (complex)	A complex of Precambrian, or early-Palaeozoic igneous and metamorphic rocks which underlies the sedimentary formations.
Basic rock	An igneous rock which contains minerals rich in iron and magnesium and relatively low in silica.
Basin	A large depression of tectonic or erosional origin, in which sediments derived from surrounding highlands may be deposited.
Bentonite	A clay formed from the decomposition of volcanic ash.
Braided stream	A stream of which the channel is choked with sand and gravel deposits, causing it to split up and then recombine in many smaller, continuously shifting channels.
Breccia	A clastic rock whose components are coarse and angular.
Buried soil	A soil whose profile is covered by a younger deposit.
Calcite, $CaCO_3$	A mineral belonging to the group of carbonates. It occurs abundantly and has many varieties.

Catchment area	The surface area contributing water to a river system.
Cation Exchange Capacity (CEC)	The total amount of exchangeable cations a soil can adsorb. Expressed in milliequivalents per 100 grams of soil.
Chalcedony, SiO_2	A general term for a number of fine-grained varieties of quartz, for example, agate, onyx, jasper, flint, chert and silicified wood.
Channel lag deposit	A coarse stream deposit formed in the channel by sorting action during stream flow.
Chert	An amorphous or cryptocrystalline variety of silica.
Chlorite	A general term for a group of green coloured hydrous iron-magnesium aluminium silicates.
Cinnabar, HgS	A vermillion-red mineral which usually occurs in fine granular masses, or is disseminated through a rock, and is used for mercury extraction.
Clastic	A descriptive term for a rock consisting of mineral, or organic fragments.
Coal	Metamorphosed accumulations of plant remains, which, after burial and compaction, underwent a relative enrichment of carbon compounds.
Coal measures	Strata containing coal beds.
Colluvium	The unconsolidated sedimentary product of slope wash, mostly occurring at the foot of a slope, in depressions and valley heads and often interfingering with the alluvial accumulations to be found there.
Concretions	Discrete bodies identifiable from surrounding material in strength, composition, or internal organization and which are strong and distinct enough to be removed from the soil.
Conformable succession	A succession of strata which has been deposited without interruption by erosion.
Conglomerate	A clastic sedimentary rock containing rounded pebbles and boulders which are cemented together.
Contact metamorphism	the mineralogical and textural changes brought about in rocks which were in close contact with an intrusion, heating having been the main changing factor.
Continental glacier	A sheet of ice covering a large part of a continent.
Craton	A large part of a continent which has been stable since Precambrian or early Palaeozoic times.
Cratonic shelf	A surface between higher and lower parts of a craton.
Cratonisation	The welding of sedimentary and volcanic rocks to a craton.
Cross-bedding	Inclined laminations in sedimentary strata which relate to the direction of current and the angle of repose at the time of deposition.
Crystal	A regular form of a mineral species bounded by smooth faces, reflecting a regular internal arrangement of atoms.
Debris slope	A slope covered by unconsolidated earth or debris which fell onto it from a vertical or overhanging cliff, the angle of the slope being determined by the angle of repose of the coarser material.
Degradation	The lowering of a land surface by erosion.
Denudation	The general lowering of the lands by geomorphological processes.
Depocentre	Area of maximal deposition.
Deposition	The chemical or mechanical process of laying down rock-forming material

Detritus	Mineral or rock particles produced by weathering or erosion of country rock.
Diachronous	The expression is used if one particular facies did not develop everywhere at the same time.
Diamond, C	A mineral of pure carbon composition and of the greatest hardness amongst the minerals; its crystals are usually octahedrous, and it possesses a high luster and is mostly pale yellow, colourless or black.
Diatreme	A volcanic vent, perforated through country rock by a gas-charged magma.
Dinosaurs	Reptiles which became the dominant land animals during the Mesozoic.
Diopside, $CaMgSi_20_6$	A mineral belonging to the Pyroxene group of the silicates which is characteristic of some metamorphic rocks and present in some gabbros and peridotites.
Diorite	A coarse-grained plutonic rock essentially consisting of plagioclase feldspar and some ferromagnesia minerals.
Discharge	The rate of flow in terms of volume per unit of time, for example, in litres per second.
Discordant	A term used to describe an igneous contact cutting across the bedding or foliation of adjacent rocks.
Dolerite	A medium-grained intrusive igneous rock which normally occurs in dykes and sills. Mineralogically and chemically it has the same composition as basalt and gabbro.
Dome	Circular upwarp with strata dipping equally in all directions.
Donga	A gully or ravine produced by accelerated erosion, which is so deep that it cannot be crossed by farm equipment.
Duplex soil	A conventional term applied to the two storey soil system: the upper storey is of a coarse texture while the lower storey has a fine texture, the two layers being separated across an abrupt boundary.
Dwyka	The name for a particular stratigraphic formation.
Dyke	A plate-like body of intrusive igneous rock that cuts across the structure of pre-existing surrounding rocks.
Earthquake	The violent shaking of the ground resulting from the passage of waves caused by the sudden displacement of rocks along faults.
Eh	Oxidation – reduction potential.
Eluviation	Movement of soil material out of a portion of a soil profile.
Epeirogeny	Dominantly vertical, fairly even, movements of a large part of the earth's crust.
Epicentre	The point on the earth's surface which is situated directly above the focus of an earthquake.
Erosion	The detachment and removal of a rock- or mineral particle by agents, of which running water, wind and moving ice are examples.
Erodibility	The vulnerability of the soil to erosion.
Erosion terrace	The stream-cut surface which has been abandoned as a result of the lowering of the stream bed.
Erosivity	The potential ability of rain to cause erosion.
Explosive volcanism	Volcanic eruptions with a high percentage of pyroclastic ejecta.
Extrusive rock	An igneous rock which derived from the extrusion of magma at the surface of the earth.

Facies	The set of characteristics of a sedimentary rock which reflect the environmental conditions under which it was formed.
Fault	A fracture plane in the earth's crust along which differential movements took place.
Feldspar	A collective name for the most common aluminosilicates.
Felsic	Pertaining to light coloured silicate minerals: feldspars and quartz.
Fissure volcanism	The emission or ejection of volcanic materials at the earth's surface from a fissure.
Floodplain	A flat stretch of land alongside a riverbed which is frequently flooded and forms an alluvial accumulation surface.
Fluvial	Pertaining to rivers or produced by river action.
Fluvioglacial	Pertaining to the combined action of glaciers and their meltwaters.
Fold	A flexure in rock strata.
Formation	The smallest unit in stratigraphic mapping: it embraces materials or a succession of strata with some characteristic lithological appearance.
Gabbro	A coarse-grained igneous rock, composed mainly of calcic plagioclase and pyroxene. The intrusive equivalent of the extrusive basalt and the hypabyssal dolerite.
Garnet	A silicate mineral belonging to the Pyroxene group. Its name covers a group of several subspecies with similar crystal habits.
Geology	The science which studies the earth, its composition and structure, its dynamics, and its evolution.
Geomorphology	The study of landforms and surficial materials and of the processes which caused them both.
Geosyncline	A very large elongated trough of subsidence and simultaneous sedimentation: the ultimate thickness of the sediments may reach several thousands of metres and ultimately the sediments may rise and be folded into a mountain chain (progenesis).
Gilgi	Small mounds formed on the surface of not-cultivated Vertisols because of shrinking and swelling of the soil mass.
Glacial	A geological time interval during which climatic conditions favoured the development of large continental glaciers.
Glaciation hollow	A hollow at the earth's surface resulting from erosion by local ice movements.
Glacier	A large accumulation of ice, resulting from the compaction of snow and within which flow occurs resulting from pressure by overburden and gravitational pull.
Glacis	A gentle sloping surface at an angle between 1° and 9°, at the foot of a higher area and descending to a local base level, the surface may be the result of erosion (erosion glacis) or of accumulation (accumulation glacis).
Gneiss	A coarse-grained metamorphic rock with bands of granular minerals alternating with aligned schistose minerals, and which results from regional metamorphism.
Gondwanaland	The name given to a supercontinent which supposedly existed in the southern hemisphere, and which consisted of present-day Africa, South America, Australia, Antarctica and India, and which fragmented and drifted apart in post-Carboniferous time.
Graded bedding	Occurs when the particles of each bed or stratum are sorted in such a way that their grain size diminishes upwards.

Granite	A coarse-grained intrusive igneous rock composed of quartz, feldspar and mica which is the intrusive equivalent of the extrusive rhyolite.
Greenstones	Greenstones in the context of this book are metamorphosed mafic igneous rocks belonging to the Swaziland sequence, which form part of the Kaapvaal craton, in which green minerals, chlorite, hornblende and epidote, for example, developed.
Ground water	The mass of subsurface water which saturates the total pore space in the rock and moves in response to gravitation.
Gully	An erosion channel or ravine which is so deep that it cannot be eliminated by ploughing (see Donga).
Hornstone	An argillaceous rock, of clay, shale or mudstone, which has been baked in contact with hot magma or lava.
Hypabyssal	A term relating to igneous intrusions under conditions intermediate between plutonic and extrusive, such as the intrusion of dykes and sills, producing crystalline rock with medium-sized grain.
Igneous rock	A rock which has resulted from the cooling and solidification of a melt, usually cooling sufficiently slowly to become crystalline, although some became noncrystalline after rapid cooling.
Illuviation	Movement of soil material into a portion of soil profile.
Illite	A secondary mineral, aluminosilicate clay.
Ilmenite, $FeTiO_3$	A mineral which occurs in igneous and in matamorphic rocks.
Interglacial	A geological time interval in between two glacials, during which climatic conditions led to the retreat of continental glaciers (see glacial).
Intrusion	The body of igneous rocks which penetrated into country rock when molten.
Ironstone	A deposit of siderite, $FeCO_3$, and the commonly associated iron silicates.
Joint	A fracture in rock.
Kimberlite	A peridotite containing olivine and garnet which is found in volcanic pipes and in dykes and which may contain diamonds.
Labradorite	A mineral belonging to the group of plagioclase feldspars, consisting of 30% to 50% $NaAlSi_3O_8$, with $CaAl_2Si_2O_8$ making up the other 70 to 50%.
Lapilli	Fragmental volcanic ejecta varying in size between 4 and 32mm.
Lava	Magma which has reached the earth's surface and flows over it.
Leaching	The removal from the soil of soluble elements by percolating water.
Lithology	The physical characteristics, mineral composition and texture of a rock.
Lithosphere	The solid portion of the earth's crust, rather than the atmosphere and the hydrosphere.
Mafic	Pertaining to dark coloured silicate minerals, rich in iron and magnesium.
Magma	Molten rock below the earth's surface, from which igneous rocks originate after cooling.
Magnetic anomaly	Any deviation from the normal earth's magnetic field.
Mantle	The earth layer composed of mafic silicates, from 40km to 2900 km deep and situated between the crust and the core.
Marine	Pertaining to the sea.

Meander	The loop of a river which has resulted from progressive stream deposition along the convex bank and stream erosion of the concave bank of a river curve.
Metamorphic rock	Rock, of sedimentary, igneous or metamorphic origin, which has been subjected to high temperature and/or high pressure and/or has been in contact with chemically active fluids, resulting in essential changes in the rock's mineralogy, texture and composition.
Metasediment	Sedimentary rock which is partly metamorphosed.
Metatorbernite	Torbernite.
Mica	A group of complex aluminium silicate minerals with potassium and hydroxyl, which have a perfect cleavage and whose individual sheets are elastic.
Mineral	A naturally occurring inorganic substance of a definite chemical composition, with a characteristic atomic structure and having particular physical properties.
Miogeosyncline	A geosyncline adjoining a craton and receiving chemical and well-sorted clastic sediments from it.
Monocline	A single downward flexure of strata.
Montmorillonite	An aluminosilicate clay mineral with an expanding crystal lattice, characterised by swelling in water.
Moraine	A glacial deposit, formed after transportation by the glacier, either below it or near its margins.
Mudstone	A fine-grained clastic sedimentary rock containing a mixture of silt and clay and a little sand.
Neptunean dyke	A more or less vertical sheet of sediment cross-cutting a contrasting rock type.
Nivation	Frost weathering and downslope movement of rock debris beneath and adjoining a snow patch.
Nivation hollow	A hollow at the earth's surface resulting from nivation.
Olivine $(Mg, Fe)_2SiO_4$	A common mineral found normally in dark-coloured igneous rocks.
Organic soil	Soil which is saturated with water for long periods and excluding the live roots, has a proportional content of organic carbon between 12 to 18 per cent if clay is between zero to 60%.
Orogeny	The process of mountain building by deformation and deep level metamorphism and granite emplacement and by ultimate uplift, usually on the site of a geocyncline.
Outcrop	Bedrock appearing at the surface of the earth.
Palaeocurrent	A natural current of water, wind or ice as carrier of sediment in the geological past.
Palaeogeography	The natural geographical environment at some time in the geological past.
Palaeomagnetism	The study of the properties of the earth's magnetic field at times in the geological past.
Palaeontology	The study of life forms and their evolution in the geological past.
Palaeosol	An ancient soil which was formed under environmental conditions that differ from those of today.
Pediment	A slightly inclined, planed erosion surface, between mountain front and valley axis, covered by a veneer of gravel or soil; the surface resulted from water transport between the retreating mountain-front and the valley floor.
Pediplanation	The formation of slightly inclined land surfaces (pediments) resulting from headward river incision, followed by scarp retreat.

Pedon	A three dimensional soil body, the depth of which includes the whole soil profile, and the area ranges from one to ten square metres. It is the smallest soil unit for sampling and analysis.
Peridotite	A coarse-grained igneous rock with olivine and pyroxene as the main constituents.
Permeability	The capacity of a rock or soil to transmit a fluid.
pH	A measure of soil acidity, defined as the negative logarithm of the hydrogen ion concentration.
Phlogopite mica	A mineral belonging to the group of micas
Phyllite	An argillaceous metamorphic rock, intermediate between slate and schist, with micas and chlorites grown parallel to the cleavage planes, producing a lustrous sheen.
Pillow lava	Lava, mostly basic, structured like a set of pillows.
Plagioclase	A group of feldspar minerals which forms a solid solution series between 100 and 0% of $NaAlSi_3O_8$, with $CaAl_2Si_3O_8$ making up the other 0% to 100%.
Planation surfaces	A general term for any natural planar erosion or any accumulation surface.
Plate	A segment of the lithosphere which is internally rigid and moves independently over the earth's surface.
Plateau	A level or slightly undulating area at altitudes higher than its surrounding area.
Plateau basalt	Basaltic lavas which resulted from fissure eruptions and, by spreading out over vast areas and building thick accumulations, formed an extensive plateau area.
Playa	A relatively flat basin area of internal drainage in arid regions, sometimes occupied by a central lake, called a playa lake.
Pluton	A deepseated igneous intrusion of great dimensions.
Plutonic	Deepseated igneous activity; or, the description of a body of igneous rocks of deepseated origin.
Point bar	A stream deposit which forms mostly in the inner curve of a stream channel.
Porosity	The percentage of the total volume of a rock that is pore space, or voids.
Porphyry	An igneous rock consisting of large crystals in a finer groundmass.
Pyrite, FeS_2	A mineral which may form under a wide range of conditions.
Pyroclastic	Pertaining to fragments ejected during a volcanic eruption.
Pyroxene	A complex group of silicate minerals of Ca, Mg and Fe.
Quartz, SiO_2	A common mineral, especially characteristic in granites, sandstones and quartz veins.
Quartzite	A metamorphic rock composed of crystalline quartz, or a sandstone cemented by silica.
Regression	A withdrawal of the sea from an area of land.
Rejuvenation	The renewed entrenchment of a stream after its base level has been lowered.
Rill	A small channel of only several centimetres in depth, resulting from accelerated erosion, mainly on recently cultivated soils.
Ripple marks	Surface undulations in sediment caused by water or wind flowing over it with the marks possibly being conserved after burial and consolidation of the sediment.
River capture	The abstraction of the head-waters of a river or river system by another more actively eroding stream.
Rock	A solid assemblage of minerals of one or of different species.
Rock stripping	The removal by erosion of soil from a rock surface, entailing

	the upslope retreat of a soil scarp because of the undermining by seepage waters and the repeated collapse of the scarp.
Sandstone	A coarse-grained clastic sedimentary rock containing sand grains bound together by cement or by a matrix of clay minerals.
Saprolite	The upper portion of the consolidated rock,which has been slightly to moderately weathered.
Schist	A medium to coarse-grained metamorphic rock with a sub-parallel arrangement of planer and linear crystals, resulting from regional metamorphism.
Secondary Mineral	A mineral resulting from the weathering of preexisting (primary) mineral(s).
Sedimentary rock	A rock formed by the deposition of mineral matter after having been transported by water, wind or ice; or by the accumulation of organic matter; or by chemical or organic precipitation.
Sedimentation	The process of deposition of mineral particles or organic matter or organic or chemical precipitates by water, wind or ice.
Seismicity	The distribution and characteristics of earthquakes in time and space in a region.
Serpentine	A common and widely distributed mineral belonging to the Zeolite family and formed by the alteration of olivine, pyroxene or amphibole.
Sesquioxides	Compounds of iron and aluminum, mainly oxides and hydroxides.
Shale	A very fine-grained sedimentary rock which has resulted from the consolidation of clay and silt and shows fissility along bedding planes.
Sheet erosion	The erosion of a layer of soil resulting from runoff.
Shield	A large portion of a continent, composed mainly of Pre-cambrian rocks, which has been stable for a long time.
Sill	A plate-like body of intrusive igneous rocks which have forced their way in between preexisting strata or structural planes in a concordant fashion.
Siltstone	A fine-grained sedimentary rock which derived from the consolidation of mainly silt particles.
Slumping	The detachment and downslope movement of one or more units of a mass of rock or earth along a sliding plane.
Soil slip	The downslope movement of parcels of soil because of trampling by animals.
Specific Capacity	The rate of discharge of a water well per unit of drawdown, expressed in litres per second per metre.
Spring	A place at the earth's surface where groundwater surfaces.
Springline	A line of springs following a geological boundary.
Stratification	The layering of sedimentary rocks.
Stratigraphic Time Scale	The geological time scale based on the succession of strata and their fossil contents.
Stratigraphy	The description, classification and correlation of rock strata and the study of their sequence and of their depositional environments.
Stratum	A rock layer with a particular set of characteristics which distinguishes it from adjoining layers.
Stream order	Stream segments are numbered according to their hierarchical position within the stream system: a first order stream has no tributaries; an n-th order stream is initiated by the confluence of two streams of order n-1.

Structural plateau	An elevated, comparatively flat surface, formed by a rock layer which is relatively resistant to denudation.
Superimposition	The imposition of a stream or stream system onto a buried landsurface.
Taphrogenesis	Broad vertical movements with high-angle faulting, which cause rift valleys by tension.
Tectonics	The study of the static, as well as the dynamic, aspects of the geological build of an area.
Terrace (River)	The original floodplain of a river which has been abandoned as a result of the lowering of the riverbed.
Terrestrial	Originating on, or being part of, the land.
Texture	The grain sizes and grain size distribution as well as the grain shapes and orientations within a rock.
Thermal metamorphism	Rock changes mainly brought about by the action of heat.
Tholeiitic basalt	Basalt which is poor in olivine and contains basic plagioclase and pigeonite, a pyroxene, with a ground mass which is commonly glassy or contains quartz and alkali feldspar.
Till	Sediment deposited by a glacier.
Torbernite-Metatorbernite	A green, radioactive tetragonal mineral; $Cu\,(UO_2)_2\,(PO_4)_2 . nH_2O$
Transgression	An extension of the sea over an area of land.
Type region	The region in which a formation shows its typical characteristics and after which it is named.
Unconformity	A discontinuity in a sedimentary sequence.
Uranite, UO_2	A mineral which is essentially composed of UO_2 and UO_3 and is the chief ore of uranium.
Uranophane	A secondary uranium mineral.
Valley-floor divide	A divide which crosses a valley, separating it into two parts which then drain into different river basins.
Volcanic agglomerate	A pyroclastic rock composed of fragments with a diameter larger than 32mm.
Volcanic ash	Dust which settled from a volcanic eruption cloud.
Volcanic breccia	A consolidated assemblage of rock fragments which were ejected from a volcano.
Volcanic cone	A cone-like mountain produced by the accumulation of volcanic products around a central eruption vent.
Volcanic glass	Amorphous volcanic rock which resulted from sudden cooling during the extrusion process.
Volcanic pipe	The chimney through which volcanic eruptions took place.
Volcanic plug	The solidified igneous content of the pipe of a volcano.
Volcanic tuff	Igneous rock composed of consolidated volcanic ashes and pyroclastics.
Volcanic vent	A hole in the earth's crust through which magma has been expulsed to the earth's surface.
Volcano	The assemblage of volcanic vent, crater and the surrounding deposits which derived from the vent.
Weathering	The disintegration and decomposition of rock by physical and chemicals processes, under the influence of the weather.
Xenolith	An inclusion of foreign rock in a mass of igneous rock.
Zeolite	The name for a group of hydrous aluminium silicate minerals.

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Abbreviations

DEP	Diamond Exploration Project
DMG	Department of Mines and Geology
EM	Exploration of Minerals Project
LNDC	Lesotho National Development Corporation
MA	Ministry of Agriculture, Cooperatives and Marketing
MWEM	Ministry of Water, Energy and Mining
UNDP	United Nations Development Programme

Index

ERRATA

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The sixth line should read :

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Page 8 . second paragraph

Read : Port St.John's Arch

Page 132. 10.2. second paragraph

Read : climatic changes

Page 148. table 12.1

In the Soil Series column, delete : Tsakholo.

In the column on Taxonomic Classification, delete: Typic Natraqualfs.

Read :

Bela	Typic Argiaquolls
Maseru Dark	Cumulic Haplaquolls
Sani	Cumulic Haplaquolls