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DP/UN/LES-71-503/8
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LESOTHO

UNITED NATIONS

EXPLORATION FOR DIAMONDS
(Phase I)
EXPLORATION FOR MINERALS
(Phase II)

Technical report

GEOLOGY AND MINERAL RESOURCES OF LESOTHO

DP/UN/LES-71-503/8
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UNITED NATIONS
UNITED NATIONS DEVELOPMENT PROGRAMME

EXPLORATION FOR DIAMONDS (Phase I)
EXPLORATION FOR MINERALS (Phase II)

LESOTHO

Technical report

Geology and mineral resources of Lesotho

Prepared for the Government of Lesotho
by the United Nations
acting as executing agency for the
United Nations Development Programme

New York, 1984

NOTES

The designations employed and the presentation of material in this report do not imply the expression of any opinion whatsoever on the part of The Secretariat of the United Nations concerning the legal status of any country, territory, city or of its authorities, or concerning the delimination of its frontiers or boundaries.

The monetary unit in Lesotho is the Maloti (M). The value of the Maloti in relation to the United States dollar, as of January 1984, was $US = M 1.22.

The SI, or metric system, is used except where conversion of the source data might imply unwarranted certainty ore precision. Accordingly, both the tonne (SI) of 1,000 kilograms and the long ton (English) of 2,240 pounds are used.

Abbreviations used

CIDA	-	Canadian International Development Agency
cm	-	centimetre
ERTS	-	Earth Resources Technology Satellite (Landsat)
g/t	-	grams per tonne
ha	-	hectare(s)
kb	-	kilobar(s)
km	-	kilometre(s)
Landsat	-	See ERTS
Ltd	-	Limited
m	-	metre
MeV	-	million electron volts
mGal	-	milligal(s)
mm	-	millimetre(s)
m.y.	-	million years
N/mm^2	-	newtons per square millimetre
ppb	-	parts per billion
ppm	-	parts per million
pty	-	Propriety
RTL	-	Rio Tinto Zinc Corporation
wt.%	-	in per cent by weight

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FOREWORD

This volume embodies the results of two major mineral surveys undertaken by the United Nations Development Programme and the Lesotho Government between 1971 and 1981. The surveys were the project Exploration for Diamonds (LES-71-503) between April 1971 and March 1974, and the project Exploration for Minerals (LES-73-021) between April 1974 and December 1981. The executing agency for UNDP was the United Nations and the Department of Mines and Geology was the Government implementing agency. Significant bilateral aid was provided by the Canadian International Development Agency (CIDA) and several European donors so that the overall programme was a splendid example of international co-operation. All these thorough surveys as well as other work have been considered in the compilation of this authoritative account of the geology and mineral resources of Lesotho which has been prepared by Dr. D.D. Reed, Project Manager/Chief Technical Adviser, assisted by Mr. H.R. Robison, Economic Geologist (Diamonds), and Mr. R. Voets, Map Geologist/Stratigrapher, all of the project Exploration for Minerals. This volume should preferably be read in conjunction with the 28 geological maps compiled by the project Exploration for Minerals, especially the general geological map of Lesotho at a scale of 1:250,000. All the maps have been printed for the Lesotho Government by the Directorate of Overseas Surveys, United Kingdom, and copies may be obtained from the Department of Mines and Geology, P.O. Box 750, Maseru 100, Lesotho.

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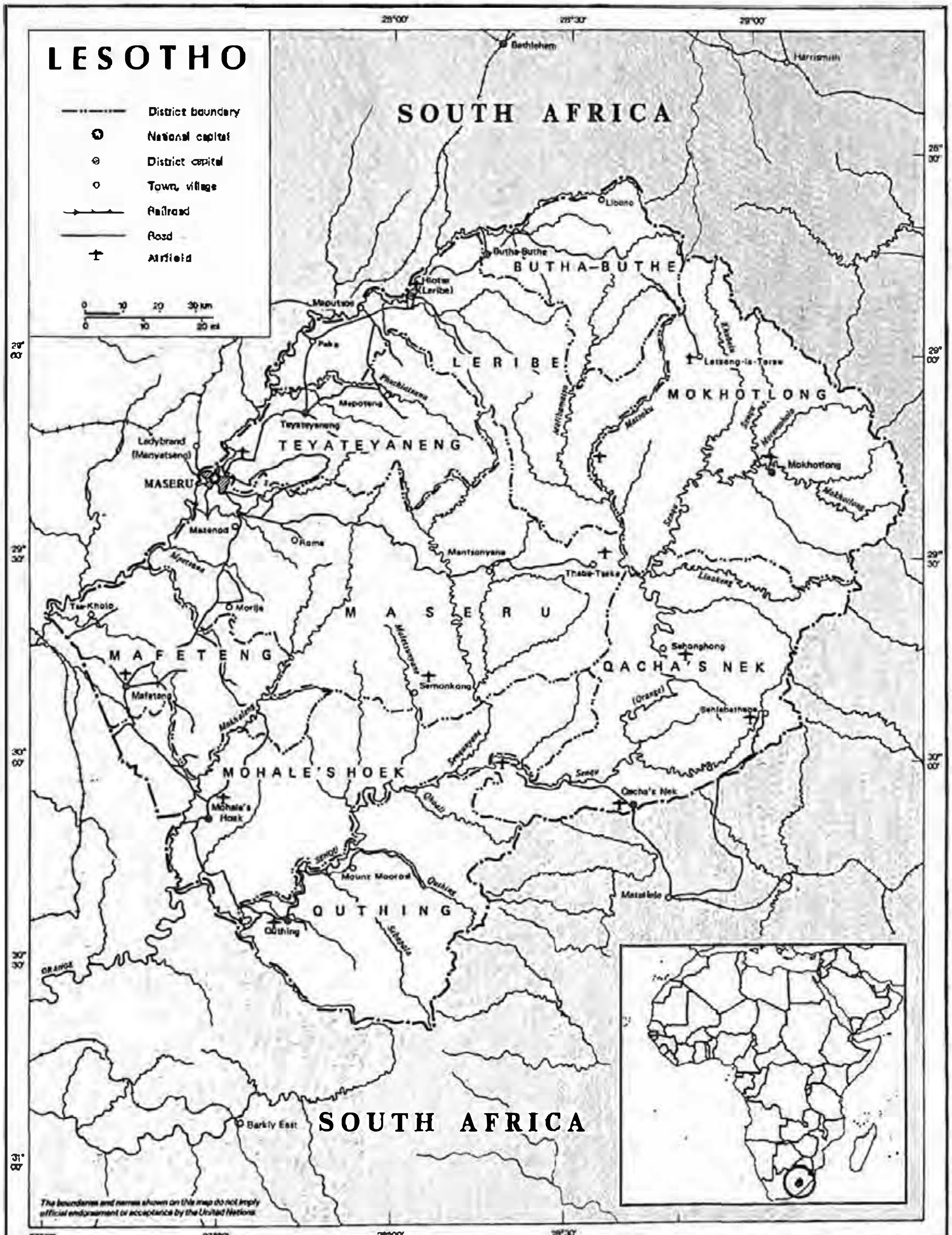
General

The Kingdom of Lesotho covers approximately 30,310 km^2, lies between south latitudes 28°35' and 30°40' and east longitudes 27°00' and 29°30', and is totally enclosed by the Republic of South Africa (figure 1). It is the country of the Basotho people who were brought together under the leadership of Moshoeshoe I in the early part of the nineteenth century. In response to a request from Moshoeshoe the country in 1868 came under British protection and this protectorate of Basutoland became the independent state of Lesotho in 1966. The population is approximately 1,262,000 (1978-1979 estimate) and the capital is Maseru. The country rises from a plain at an altitude of about 1,520 m in the west to mountains over 3,350 m in the east. The climate in the lowlands is cold and dry in the winter and hot in summer with occasional rain; in the mountains the winters are colder and longer and the summers cooler.

Involvement of United Nations

The United Nations Development Programme (UNDP) in co-operation with the Lesotho Government undertook systematic mineral exploration in Lesotho in the period April 1971 to December 1981. The executing agency for UNDP was the United Nations and the Government implementing agency was the Department of Mines and Geology. Two projects were involved, Exploration for Diamonds (LES-71-503) from April 1971 to March 1974 which prospected an area of 4,660 km^2 in the north-

Figure 1. Map of Lesotho showing main centres, roads and airstrips.



MAP NO. 3120 Rev.3 UNITED NATIONS
AUGUST 1984

eastern part of Lesotho (figure 2) and Exploration for Minerals (LES-73-021) which from April 1974 to December 1981 explored the remaining 25,650 km^2. The first project was involved primarily in the search for kimberlite and diamonds but the scope of the second project was widened to cover all minerals with the exception of oil. Systematic regional reconnaissance geological surveys consisting of heavy mineral sampling and geological traversing were undertaken over the whole country and the geological information acquired, in conjunction with photogeological interpretation, led to the compilation of geological maps for all 1:50,000 mapsheet districts which were printed as 15 maps at a scale of 1:50,000 covering the sedimentary formations in the lowlands and 12 maps at a scale of 1:100,000 covering the volcanic lavas in the highlands (figure 3). In addition a general geological map of the whole of Lesotho was compiled at a scale of 1:250,000 (two sheets). A photogeological fracture trace analysis study was carried out over 7,500 km^2 of the basalt covered central part of Lesotho (figure 2) and other experimental techniques tried out were airborne thermal infrared scanning, airborne false-colour, infra-red photography, airborne multispectral photography and ERTS-1 satellite imagery. Drilling and bulk sampling were undertaken where warranted. Institution-strengthening included re-equipping of the mineralogical and chemical laboratories of the Department of Mines and Geology, and training of staff, although the latter effort was handicapped by the paucity of counterpart personnel.

Related United Nations projects were a photogeological project from 1974 to 1976 (Project 72-046), a UNIDO heavy-clay survey from 1974-1978 (Project LES-74-023) and consultancies on a sandstone block industry (LES-75-025), coal exploration (1981) and energy resources (1981).

Figure 2. Map of Lesotho showing the 1:50,000 mapsheet districts, the phase I and phase II United Nations exploration areas, the CIDA airborne geophysical survey area and the photogeological fracture trace analysis contract area.

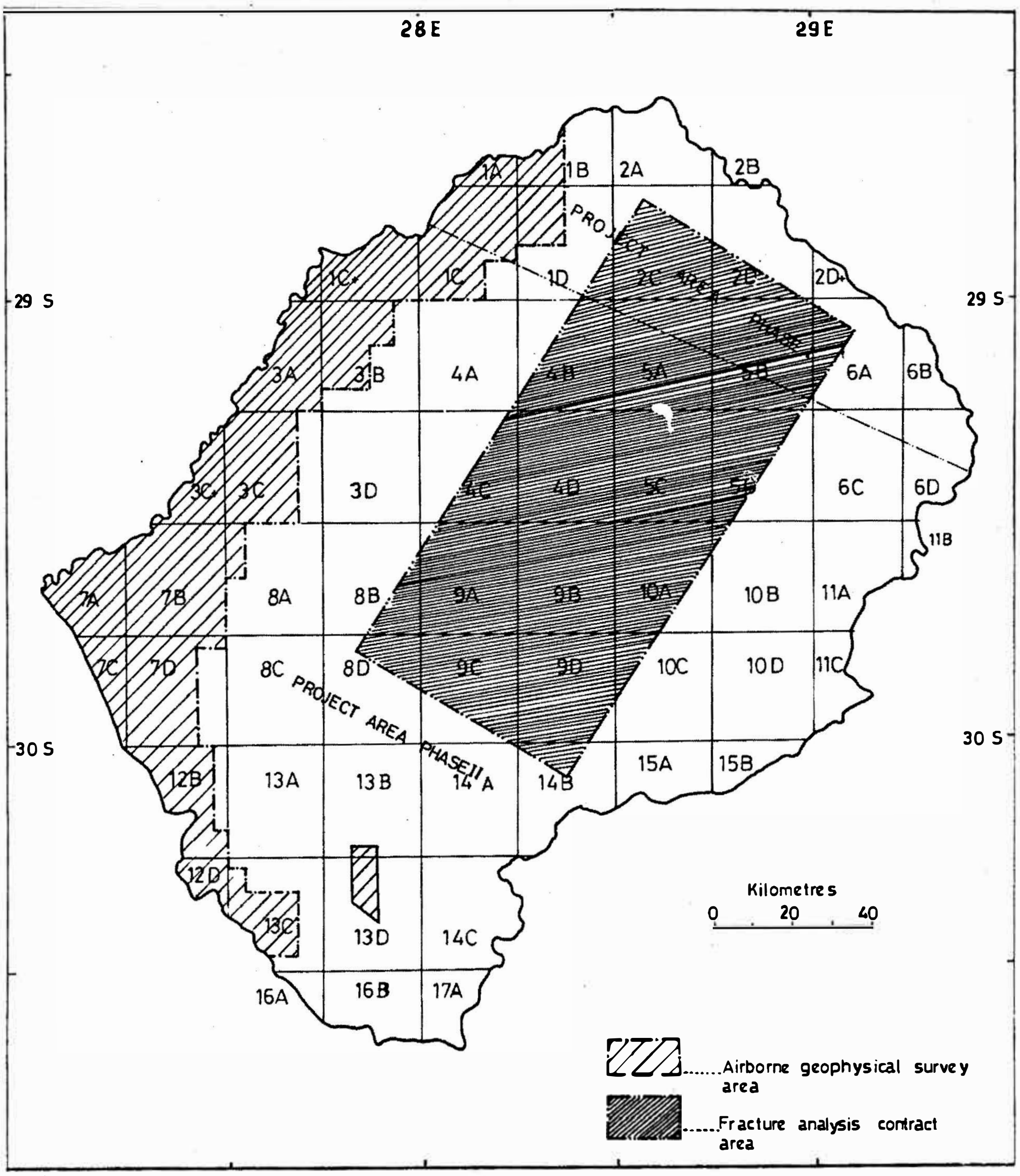


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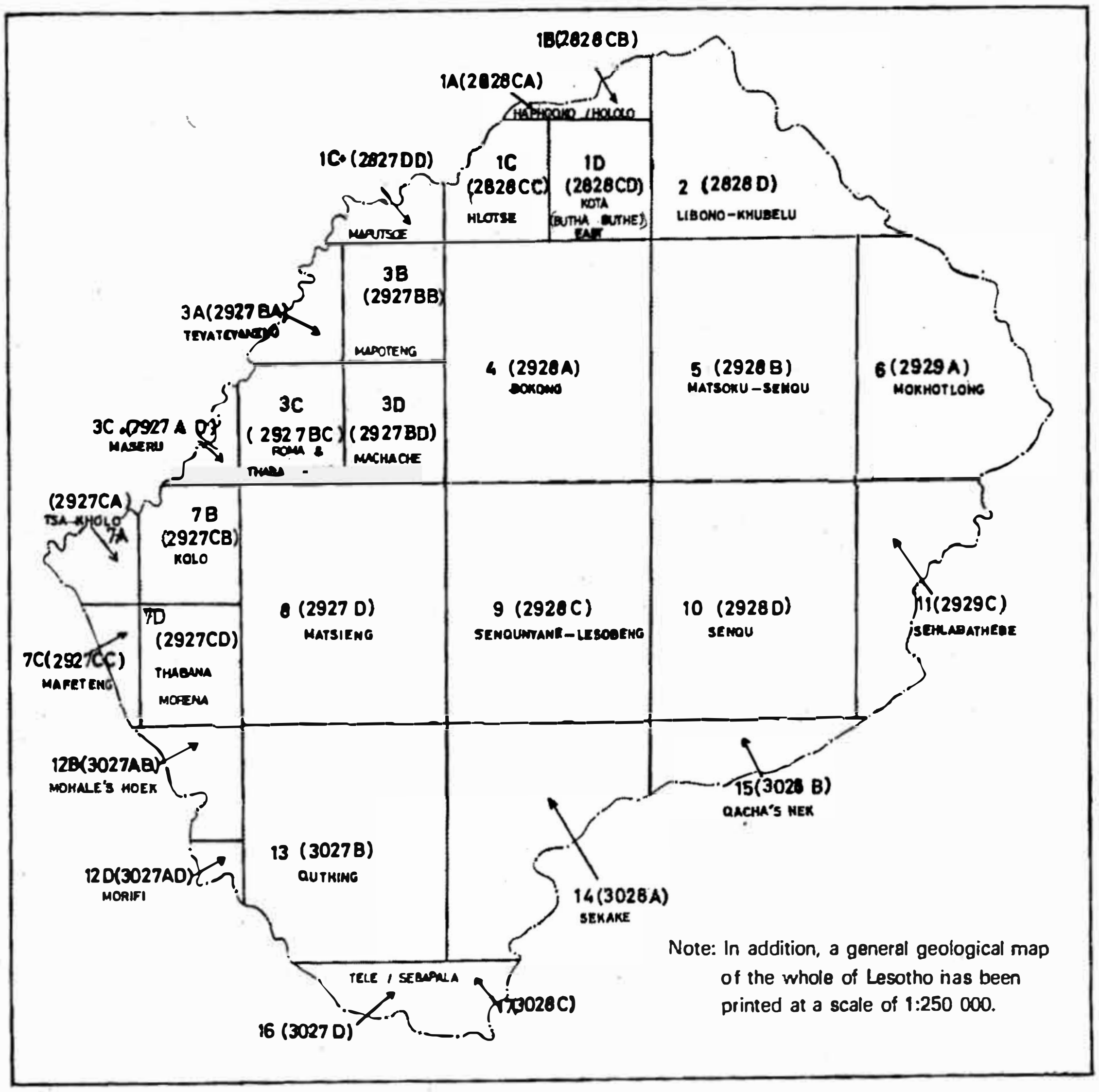
Figure 3. Index to geological maps of Lesotho compiled by the project Exploration for Minerals and printed by the U.K. Directorate of Overseas Surveys.



Note: In addition, a general geological map of the whole of Lesotho has been printed at a scale of 1:250 000.

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Bilateral assistance

A major bilateral contribution was made by the Canadian International Development Agency (CIDA) with an airborne magnetic and radiometric survey of 4,800 km^2 of the western lowlands followed by ground follow-up of the magnetic anomalies (figure 2). CIDA also undertook training of nationals in Canada. A particularly valuable contribution was the assignment through UNDP of associate experts (field geologists, map geologists, geophysicist) by the Governments of Belgium, The Netherlands, Denmark and Sweden; these associate experts, along with United Nations volunteer field geologists, overcame the problem created by the lack of national field staff. A gravity survey of the whole of Lesotho was carried out in 1979 by the U.K. Institute of Geological Sciences, and the U.K. Directorate of Overseas Surveys undertook to publish the 28 geological maps compiled by the project. Close liaison was also maintained with separate CIDA coal drilling and diamond diggers projects.

Altogether the mineral exploration projects were fine examples of multi-donor co-operation and it is considered that the sum of the co-operative input has been considerably greater and more effective than if it had been provided separately and piecemeal (Reed, 1979).

Previous work

A missionary belonging to the French Protestant mission made the first geological study of Lesotho (Dornan, 1908) and this was followed about thirty years later by a comprehensive survey of Stockley (1940, 1947) who produced a geological map at a scale of 6 miles to the inch (1:390,160). There have since been general descriptions by Bleackley and Workman (1964), Binnie and Partners (1971), Dempster and Richard (1973), Loxton (1973) and Lerotholi and Reed (1979). All this previous work and specialized studies such as Lesotho Kimberlites (Nixon, 1973a) have been drawn on in the compilation of this volume.

Acknowledgements

Mr. K.T. Whitelock, Manager, De Beers Lesotho Mining Pty Ltd., kindly provided photographs of Letseng-la-Terae diamond mine and details of the history of diamond prospecting and mining in Lesotho; also the reference to the 1980 PhD thesis on Letseng-la-Terae Kimberlites by Dr. N. Lock. Dr. H.M. Anderson gave permission for the inclusion of photos of fossil plants from Lesotho. Unless otherwise stated, the photographs were taken by Dr. J.J. Reed. The figures were mainly drawn by the drafting section of the Lesotho Department of Mines and Geology.

I. GEOMORPHOLOGY

A. Major land divisions

The landscape of Lesotho is divided into two major land divisions - lowland and highland (mountains) and these are directly related to the underlying geology (figure 4). Thus the lowlands, found primarily in a narrow western part of Lesotho and ranging in elevation from about 1,400 m to 1,750 m, are composed of sedimentary formations (figure 5) and minor igneous intrusions whereas the highlands, comprising about 70 per cent of the country, consist of a dissected basaltic plateau (figure 6) with a maximum height of 3,482 m at Thabana-Ntlenyane, the highest peak in southern Africa. The transition from lowland to highland is shown by small plateaus formed on both sandstone and basalt which rise eastward on long spurs towards the steeper mountain slopes (Dempster and Richard, 1973; Richardson, 1976b); this transition zone, generally known as the "foothills", lies between about 1,750 m and 2,000 m. The spectacular steep Drakensberg Escarpment characterizes the eastern and north-eastern boundary with Natal (figure 1).

B. Erosion cycles

Erosion cycles in Lesotho were clearly outlined by De Swardt and Bennett (1974) following a photogeological study of the north-eastern and south-eastern border areas. The dominant geomorphic features observed are wide U-shaped valleys which descend fairly abruptly down-stream and which are being

Figure 4. Map of Lesotho showing the major geological divisions, the sedimentary formations in the lowlands and the volcanic lavas in the highlands.

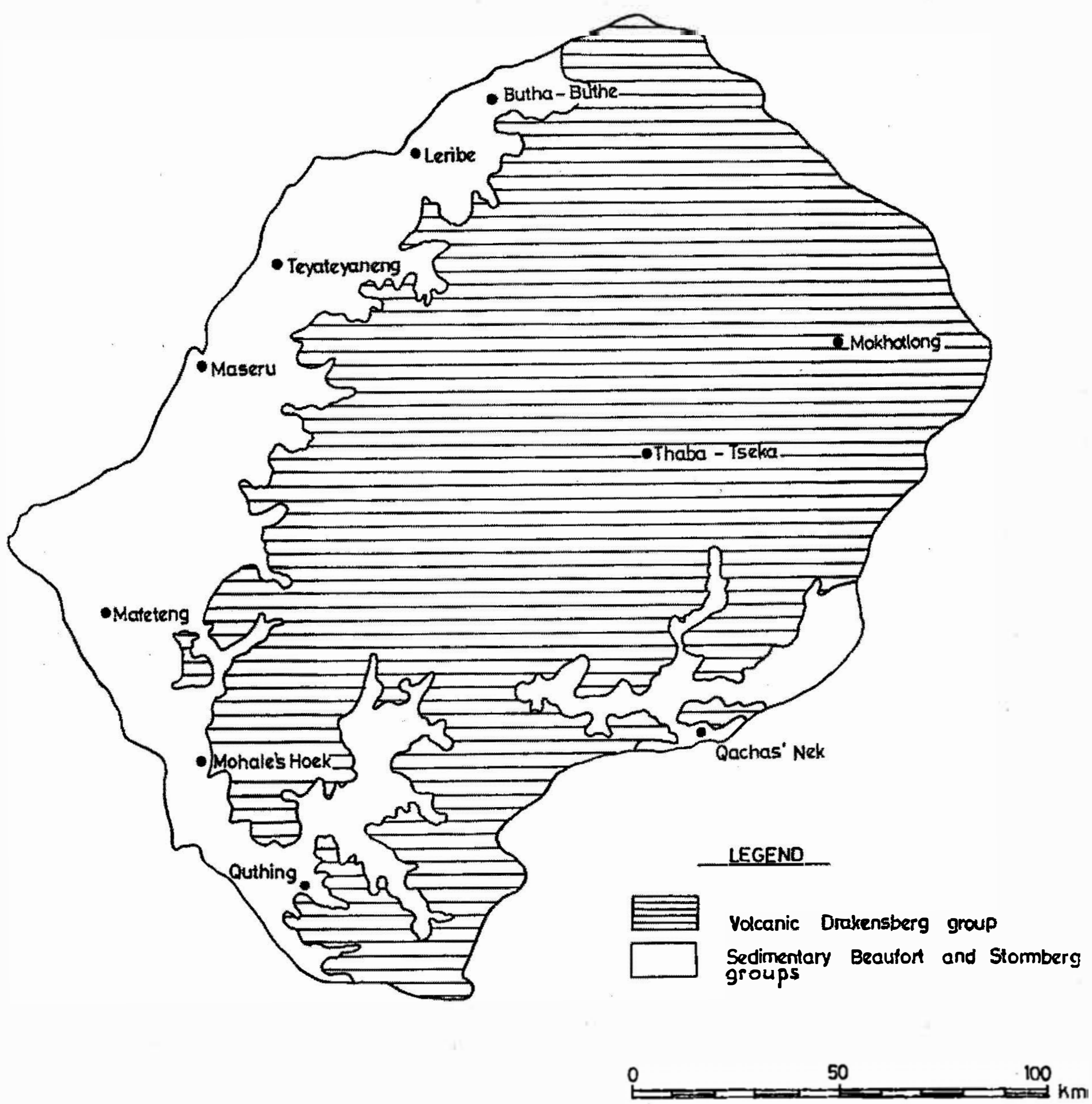

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Figure 5. Horizontal sedimentary formations in the lowlands near Ha Jonathane with characteristic cliff-forming Clarens sandstone capping the sequence

Figure 6. Dissected basalt plateau in the highlands on way to Letseng-la-Terae

encroached upon upstream by an active erosion cycle which is producing a much more rugged topography. The steepened valleys are in turn being invaded by an even later cycle which is carving V-shaped valleys that truncate the lateral spurs along the major valleys; this cycle is responsible for the deeply entrenched meanders in the region of the bend in the upper Senqu River. Similar observations were made during the United Nations regional surveys. Thus on sheet 90 the two major rivers (Mantsonyane and Senqunyane) show a mature U-shaped profile whereas the smaller rivers have young V-shaped valleys (Leroy and Vandichel, 1981). On sheet 100 the Senqu, Tsoelike and the lower courses of the Matebeng and Melikane have developed U-shaped valleys but the middle and upper courses of the Matebeng and Melikane have V-shaped valleys (Leroy and Vandichel, 1980). On sheet 108 the westward flowing rivers display three typical regimes (a) the upper reaches flow directly over basalt with practically no alluvium, (b) a middle stretch (2,133 - 2,285 m), commonly with waterfalls, where the rivers cut steep canyons, and (c) the lower reaches with wider valleys and abundant alluvium (van Rooijen, 1976). On sheet 98, Willan (1976c) also noted three different levels of river erosion: at a high level (or 2,590-2,742 m above) the stream flows directly over basalt or a thin cover of disintegrated basalt; at a medium level (2285-2,590 m) the stream is found in a steep gorge commonly marked by the outcrop of a prominent flow of basalt; at a low level (1,980-1,828 m or below) the river meanders on a flat-bottomed, steep-sided gorge with extensive deposits of gravel and alluvium.

During late Tertiary and Quaternary times strongly eroding conditions in the mountains resulted in the widespread accumulation in the lowlands of several metres of fluviatile cobble beds overlain and intercalated by pediment and aeolian gravel, silt and clay (Dempster and Richard, 1973). An active erosion cycle in the lowlands is presently removing this material giving rise to narrow steep sided ravines locally known as dongas (figure 7). The massive development of these dongas has been accelerated by the deterioration of the soil and vegetation cover through soil erosion; thus many dongas have formed along the traces of footpatns or cattle tracks. The active erosion cycle in the lowlands is dramatically shown in Landsat satellite photos where the denuded sedimentary formations and the Lesotho border itself are clearly outlined (Jackson and Nixon, 1974).

C. Structural erosion levels and peneplains

Level areas of land, separated by steep slopes, are characteristic of the topography of Lesotho but their origin and time of formation have been the subject of much controversy extending up to the present (King, 1976; De Swardt and Bennett, 1974, 1976). Three well-defined levels in Lesotho were recognized by Stockley (1947), four by Bleackley and Workman (1964), and five by Dempster and Richard (1973) who noted that none occur at the same altitude throughout but each, where present, occurs in the same position relative to the others. The most prominent and highest level is shown by the summits of the rolling high basaltic plateau of the highlands (figure 8) and is generally found at an elevation between 3,000 and 3,300 m near the Drakensberg escarpment and at lower levels away from the escarpment. Reference to this level was made many times by geologists undertaking the United Nations regional field surveys (e.g., Willan, 1976a,b,c; Grohmann, 1976; Rombouts, 1979b; Noel and Robison, 1980; Leroy and Vandichel, 1980; van Vreumingen and Robison, 1980).

The second prominent level is at an elevation of 2,750 m at Sani Pass and drops gradually to 2,000 m. On sheet 4A, Willan (1976a) noted the surface at an elevation of 2,437 m and on sheet 9B between 2,194 and 2,163 m. On sheet 8D the

Figure 7. Active erosion of Quaternary sediments near Teyateyaneng leading to the formation of steeply sided ravines locally known as dongas

Figure 8. Prominent basalt erosion level in highlands near Letseng-la-Terae

plateau occurs between 1,950 and 2,250 m and is responsible for the location of all the major waterfalls of the sheet -- Ketane, Qoasing and Ribaneng (Noel, 1980b). On sheet 9C the high tableland is at 2,130-2,165 m and at this level is the most spectacular topographic feature, the Maletsunyane (Lebihan) Falls with a drop of 192 m; the actual location of the falls is caused by a fracture at right angles to the Maletsunyane River (van Vreumingen and Robison, 1980). The third prominent level, between 1,890 m and 1,770 m, corresponds closely with the sandstone-basalt contact and is represented by the flat tops of the Clarens sandstone plateau studding the lowland tract and can be recognised on the foothills spurs; Stockley (1947) in particular drew attention to this well defined "peneplain". The lowlands themselves between 1,830 m and 1,520 m also form a prominent level (Bleackley and Workman, 1964) with an even lower level along the lower reaches of the Senqu and Mohokare rivers (Bleackley and Workman, 1964; Bawden and Carroll, 1968; Dempster and Richard, 1973).

The levels have been interpreted as cyclic peneplains ("erosion surfaces") to which dates have been ascribed ranging from the end of the Jurassic ("Gondwana") for the highest level, Cretaceous ("post-Gondwana") for the second prominent level and Tertiary ("African") for the lower levels (Stockley, 1947; Bleackley and Workman, 1964; L.C. King, 1962, 1976). The major problem is that it is difficult to prove the existence of peneplains unless the erosion surface clearly cuts across stratification, but this is not the case in Lesotho. Moreover, continuous erosion of flat-lying beds of differing hardness, as found in Lesotho, would result in the production of similar prominent levels which thus would be structurally controlled. That structural control played a major role is suggested by observations made during the United Nations regional surveys. Thus Dempster and Richard (1973) noted that the conspicuous bench flanking the Mokotlong and Senqu rivers near Mokhotlong township descends gradually from an altitude of 2,560 m at Mateanong in the east to 2,410 m near Motubeng in the west, a distance of 35 km, but is underlain throughout by a massive prismatically jointed basalt layer in places 40 m thick. It is thus obvious that although the level may relate to the "post-Gondwana" cycle, it owes its existence in this area to the presence of a resistant layer which it nowhere transgresses. Massive basalt layers also give ruse to several other benches at different heights in the Mokhotlong area. On sheet 10A the essentially horizontal flows of basalt form extensive structurally controlled terraces, the best example being that extending from Thaba Tseka to Mohlanapeng (Richardson, 1976a). A zone of massive basalt flows on sheet 9C form a pronounced guide horizon which can be followed in the field over long distances (van Vreumigen and Robison, 1980). In lowland sheet 7B, van Rooijen (1975b) noted remnants of several lithologically controlled erosion surfaces. From oldest to youngest the component beds on which the surfaces were developed are (a) competent ferruginized sandstones of the highest part of the Beaufort Formation (b) the mostly ferruginized basal Molteno conglomerates - a conspicuous bench - and (c) gritty or fine conglomeratic basal Elliot sandstone.

The strongest criticism of the ancient peneplain concept has been made by De Swardt and Bennett (1974, 1976) who considered that there is no evidence in the Lesotho highlands for the existence of a Jurassic peneplain or, for that matter, for any high peneplain. The correlation of the present landscape forms in Lesotho with Mesozoic unconformities at the Natal coast 240 km away was regarded as arbitrary and without supporting evidence. It was considered inconceivable that a land surface reputedly dating back to the Late Jurassic would not have been significantly lowered over a period of more than 130 million years in an area where erosional processes are now extremely active and were presumably so over much of the time since the Jurassic. Attention was drawn for example to the evidence for vigorous periglacial action (Harper, 1969; Morgan, 1970). If cyclic status is assigned to structurally controlled erosion features, then there is virtually no limit to the number of geomorphic reconstructions that can be made. No grounds existed for relating the wide U-shaped valleys of the highlands to any surface or event elsewhere. The valleys could represent a phase of the present erosion cycle of the Orange basin west of Lesotho stranded as a result of local uplift or climatic change. There is also the distinct possibility that they owe their form to periglacial action during the Pleistocene and survival to the protective action of colluvial deposits (Harper, 1969; Morgan, 1970). In reply to comments by L.C. King (1976), De Swardt and Bennett (1976) repeated that the highest interfluves in the Lesotho highlands are sharply crested and that the wide valleys are floored by cryogenic deposits, neither of which have the attributes of ancient erosion surfaces. Accordance of summit levels in uneven country is a common phenomenon on rocks of uniform lithology, especially igneous ones and in the Lesotho case the most that can be construed is the possible earlier existence of a relatively flat erosion surface at a higher level. In this connection it appears probable that the higher points in the Lesotho mountains, such as Thabana Ntlenyane (3,490 m) and Makheka (3,465 m), represent horizon close to the original surface of the last volcanic outpouring (Stockley, 1947; Dempster and Richard, 1973). Support for this view is provided by the present erosion levels of the Letseng-la-Terae kimberlite pipes; these levels are close to the transition from diatreme to crater facies in the model of a kimberlite pipe (see figure 41) and indicate that the original surfaces were 400-500 m higher (N.P. Lock, 1980).

D. Asymmetric valleys

Another typical feature in Lesotho is the striking asymmetry of valleys which has been noted by Schmitz (1968, Dempster and Richard (1973), Richardson (1976a, b), Willan (1976c), Rombouts (1978b), van Vreumigen and Robison (1980), and Leroy and Vandichel (1981). Thus east or west flowing rivers have fewer and shorter north-bank affluents and the northern slopes are much steeper than southern slopes. In other words, the northward flowing rivers are relatively long and gentle whereas the southward flowing rivers are short and steep. This feature was ascribed (Schmitz, 1968) to reversal of drainage flow from an early northerly direction to present-day southerly direction, but the general concensus is that the asymmetry in Lesotho is simply the end results of differential solar heating, snow accumulation, weathering and solifluction between north and south slopes. Once initiated, the tendency to asymmetry is progressively enhanced with overgrazing by animals seeking the warmer slopes accelerating the process. In the long term this asymmetry could easily dominate the topography as the prevalent horizontal layering does not introduce any other kind of asymmetry.

E. Erosional features in Sehlabathebe National Park

The Sehlabathebe National Park in south-east Lesotho (Sheet 11C) is characterized by unusual landforms (figure 9) and their origin has been discussed by Rombouts and Robison (1980). The park consists of a plain formed by the Clarens Formation - Drakensberg basalt contact and also by pediplanation in the Clarens and upper Elliot formations. The spectacular erosion features seen in the park are caused by the present erosion level having reached the irregular sandstone bodies close to the Elliot-Clarens contact. Unusual features such as arches and overhangs are accentuated by wind erosion.

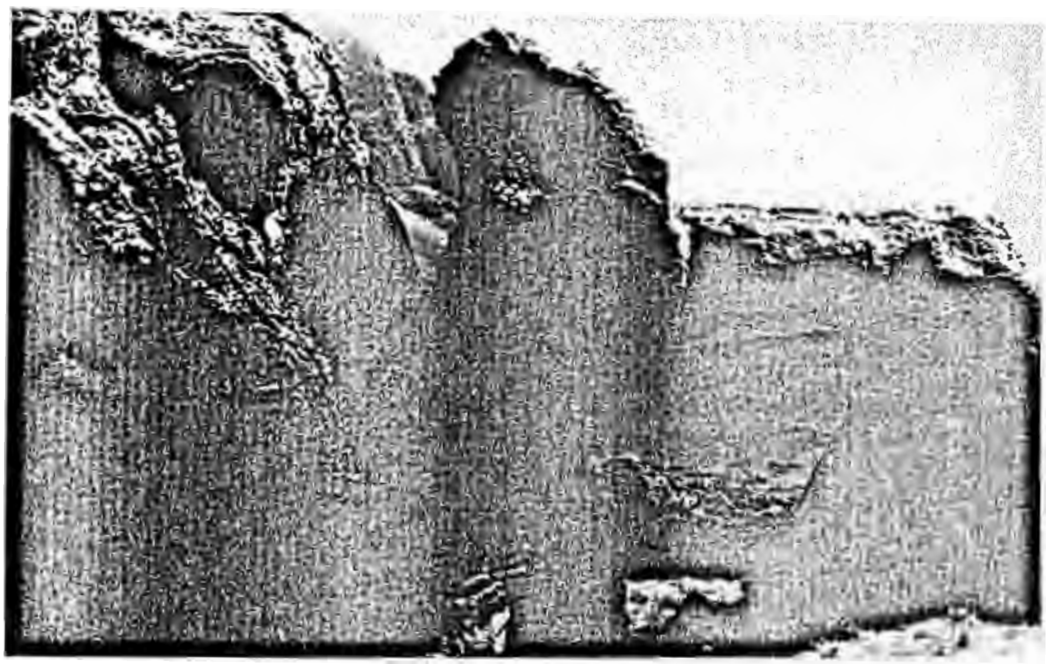


Figure 9. Unusual landforms in Sehlabathebe National Park (Photo by Lesotho Ministry of Information and Broadcasting)

II. STRATIGRAPHY AND HISTORICAL GEOLOGY

A. Outline of succession and structure

The rocks exposed in Lesotho consist of a single major division of sedimentary formations and basaltic lavas, two different types of igneous intrusions, and younger unconsolidated sediments (table 1). The major division which underlies most of Lesotho is the Triassic-Jurassic Karoo Supergroup which comprises an older conformable terrestrial sedimentary sequence, found principally in the lowlands, and younger basalt flows forming thick piles overlying the sedimentary formations in the highlands (figure 4). Closely associated with the lavas are volcanic vents and dolerite dykes and sills. Kimberlite pipes, dykes and blows (dyke enlargements), presumably of Cretaceous age, are a separate younger intrusive type. Late Tertiary to Recent unconsolidated sediments (clay, gravel, silt, etc) are found mainly in the lowlands where the material is presently being removed by streams giving rise to narrow steep-sided ravines locally called dongas (figure 7).

The Karoo Supergroup is divided on lithological grounds into the sedimentary Beaufort and Stormberg groups and the volcanic Drakensberg Group. Formational units that are recognised are the Burgersdorp Formation in the Beaufort Group, the Molteno, Elliot and Clarens formations in the Stormberg Group and the Lesotho Formation in the Drakensberg Group (table 1). Only the upper part of the Beaufort Group is exposed in Lesotho but drilling at Mahobong and near Butha Buthe has penetrated into the underlying Ecca Group of the Karoo Supergroup (figure 10). There is no direct evidence of the nature of the

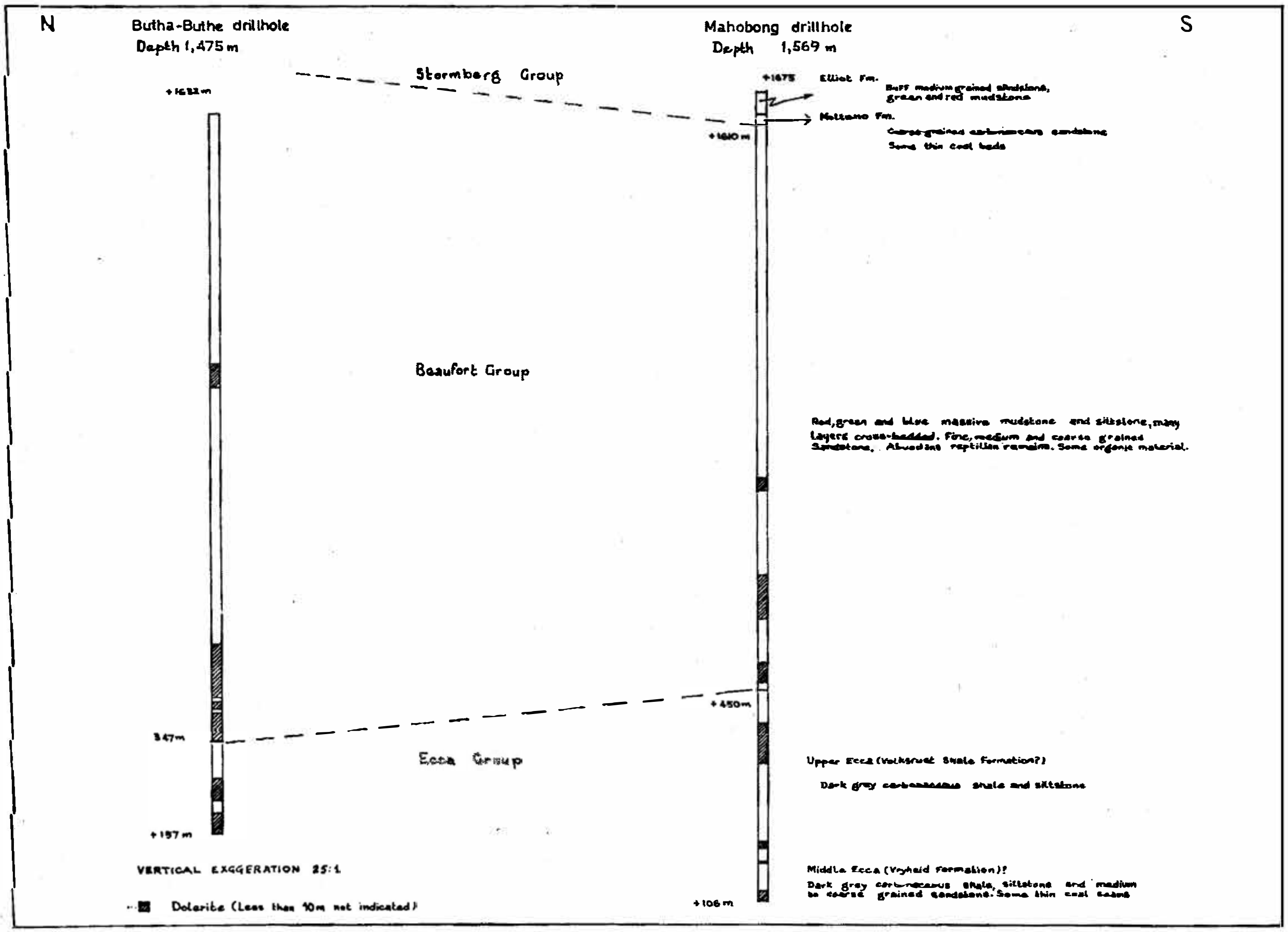
Table 1. Lithostratigraphic subdivisions in Lesotho

Age	Supergroup	Group	Formation, thickness (in meters)	Lithology
Quaternary and late Tertiary			0-20	Fluviatile, pediment and aeolian gravel, silt and clay
		DRAKENSBERG	LESOTHO 1,650	Compact and amygdaloidal basalt with several sandstone bands and pillow lavas in lower part. Ashy or agglomerate beds near the base.
		STORMBERG	CLARENS 15-250	Numerous small explosive vents preceded basalt outpouring. Massive cream-coloured fine-grained sandstone to siltstone with occasional laminated beds; plant remains and thin coal seams near top (upper facies)
Lower Jurassic				Red, fine-grained sandstone to siltstone and compact siltstone with nodular cleavage; shaly beds in lower part (lower facies)
	KAROO		ELLIOT 70-250	Fine- and medium-granied sandstone becoming red coloured upwards, with occasional coarse beds, alternating with buff and red mudstones and siltstones; phosphatic nodules towards base, occasional acidic ash beds
Upper Triassic			MOLTENO 15-300	White grit and sandstone with occasional coaly streaks and plant remains, alternating with buff and grey mudstone and siltstone; occasional conglometate bed at base
		BEAUFORT	BURGERSDORP 0-240	Grey sandstone alternating with buff, green and purple mudstone, with occasional carbonaceous shale with thin coal seams; some ferruginous concretion beds

Intrusives

Upper Cretaceous?	Kimberlite pipes, blows and dykes
Lower Jurassic	Dolerite dykes and sills

Figure 10. Logs of Mahobeng and Butha-Buthe drillholes.



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pre-Karoo basement in Lesotho although indirect evidence has been obtained from drilling outside the borders of Lesotho (figure 11, table 2), from xenoliths in kimberlite pipes, and from gravity and airborne magnetic surveys.

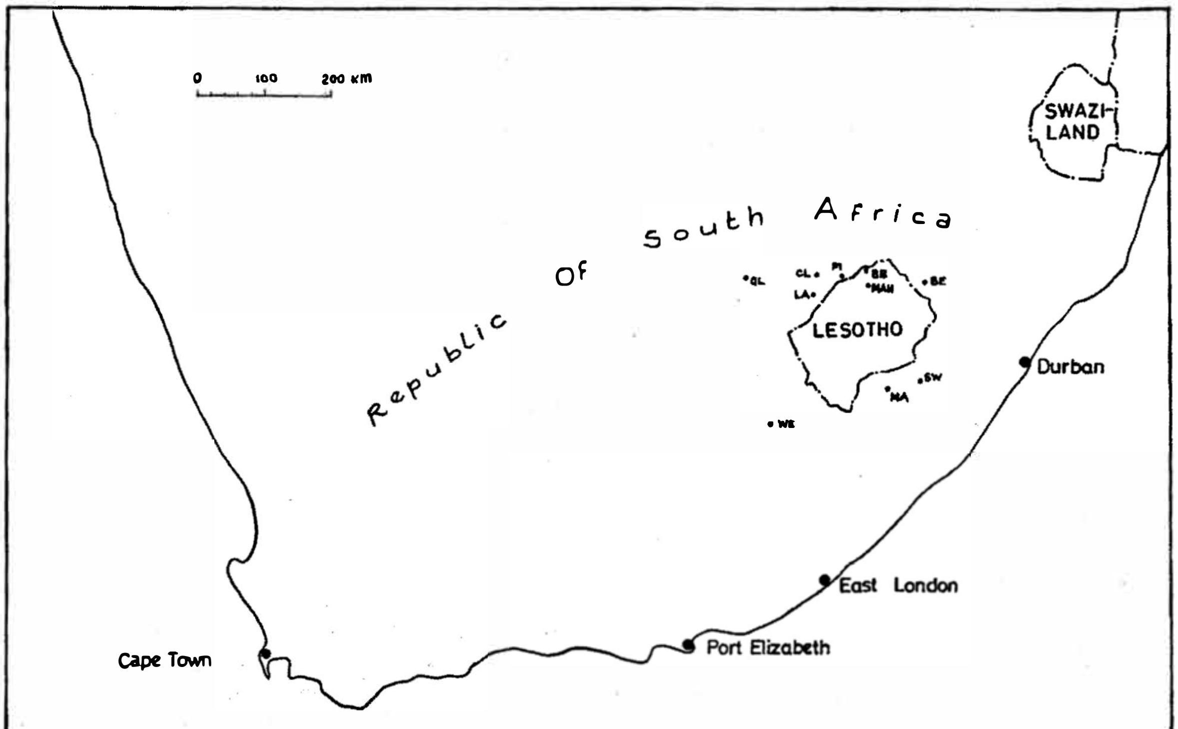
Both acidic and basic volvanism has been recognised in Lesotho but the earlier acidic volcanism is represented only by vitric tuff layers and altered glass shards in the sedimentary formations, especially the Elliot Formation. The later basic volcanism was in two distinct phases, an earlier explosive phase resulting in numerous volcanic vents and a later quieter phase of lava outpouring through well defined fissures now shown by congealed dolerite dykes and sills. The basic volcanism has been dated by radiogenic methods as beginning about 187 million years ago and continuing intermittently until about 155 million years ago.

More than 400 kimberlite intrusions have been discovered and they form distinct belts or zones, with the largest and most diamondiferous pipes being found in the Lemphane-Robert belt in north-west Lesotho (see figure 38).

The most significant fact about the geological succession in Lesotho is its virtual restriction to the upper part of the Karoo Supergroup with the relatively young geological age range from about 210 million years to the present. This restriction of the geological succession had significant influence on the mineral resources of Lesotho and it should also be noted that this restriction does not apply to neighbouring Swaziland, Botswana, Zimbabwe and the Republic of South Africa where pre-Karoo rocks are exposed at the surface (figure 12). Another controlling factor is that all the sedimentary formations were deposited in a terrestrial environment which was favourable for uranium deposition but the absence of marine deposits mean that no limestone is present.

In the absence of marine fossils in the Lesotho Karoo

Figure 11. Location of deep boreholes in Lesotho and adjacent areas.



LESOTHO : BB – Butha-Buthe borehole CL 78/1/1A; MAH – Mahobong borehole of Westrans.

ADJACENT AREAS : LA – Ladybrand LA 1/68; FI – Ficksburg FI 1/72; CL – Clocolan CL 4/68; GL – Glen GL 1/67; BE – Bergville BE 1/67; SW – Swarteberg SW 1/67; MA – Matatiele MA 1/69; WE – Aliwal North WE 1/66.

3300.5x

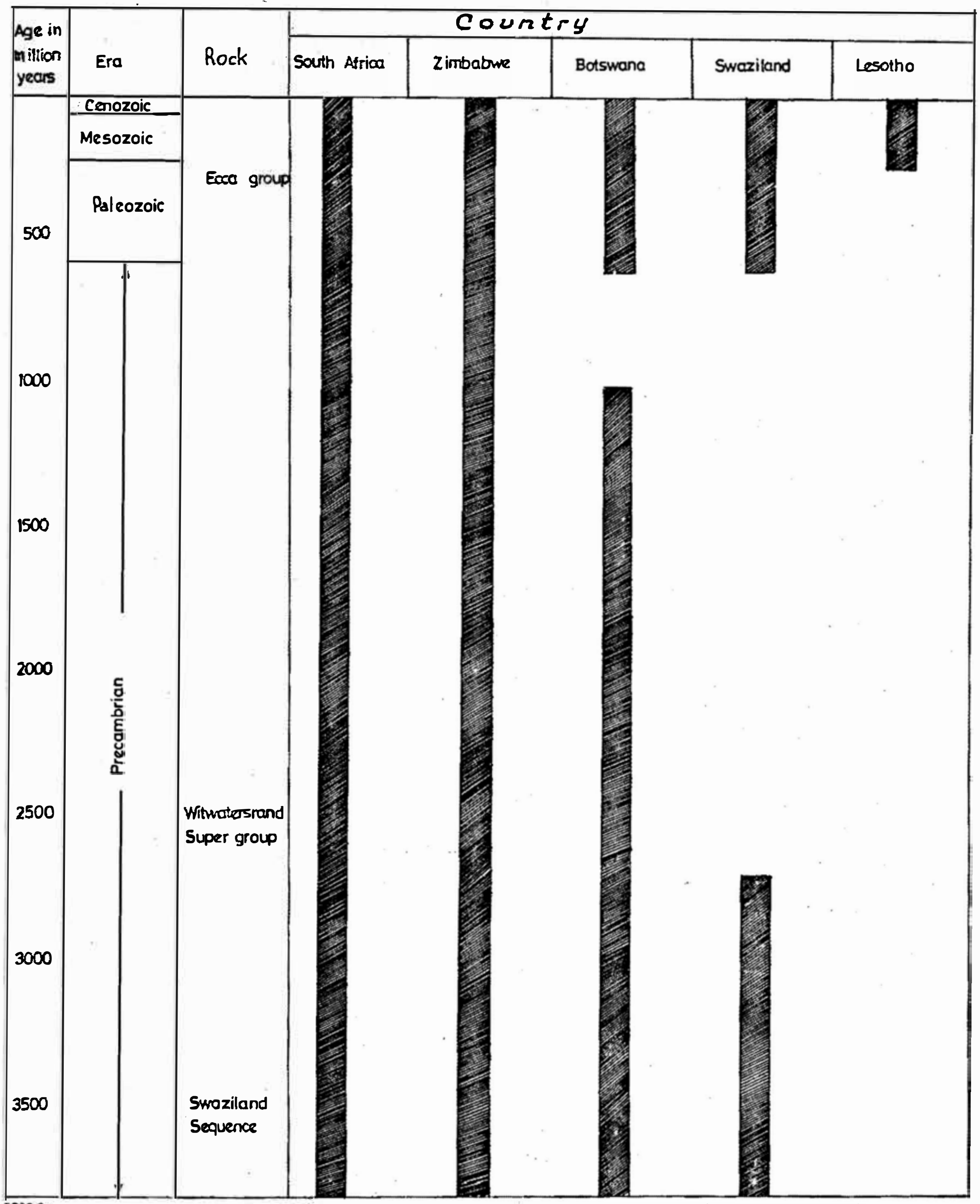
Table 2. Deep boreholes in Lesotho and adjacent areas

Borehole	Locality	Top of upper Ecca (m)	Top of lower Ecca (m)	Depth of basement (m)	Total depth with formation (m)
			A. Lesotho		
Westrans	Mahobong		NR	NR	1,653 in Ecca
CL 78/1/1A	Butha Buthe	920	NR	NR	1,475 in Ecca
			B. Adjacent areas		
LA 1/68	Ladybrand	ca 1,270	ca 1,617	1,700	2,000 in granite ?
FI 1/72	Ficksburg	ca 1,085	ca 1,588	1,870	?
CL 4/68	Clocolan	NR	NR	NR	897 in Lower Beaufort
GL 1/67	Glen	21	681	772	2,945 in Granite
BE 1/67	Bergville	314	858	1,050	1,177 in Greenstone
SW 1/67	Swartberg	1,147	NR	NR	1,420 in Ecca
MA 1/69	Matatiele	1,532	NR	NR	1,981 in Ecca
WE 1/66	Aliwal North	2,428	?	3,731	3,745 in Biotite Gneiss

NR - Not Reached

Data on adjacent areas from Winter and Venter (1970) and Rowsell and De Swardt (1976)

Figure 12. Stratigraphic column of southern Africa showing strata exposed.

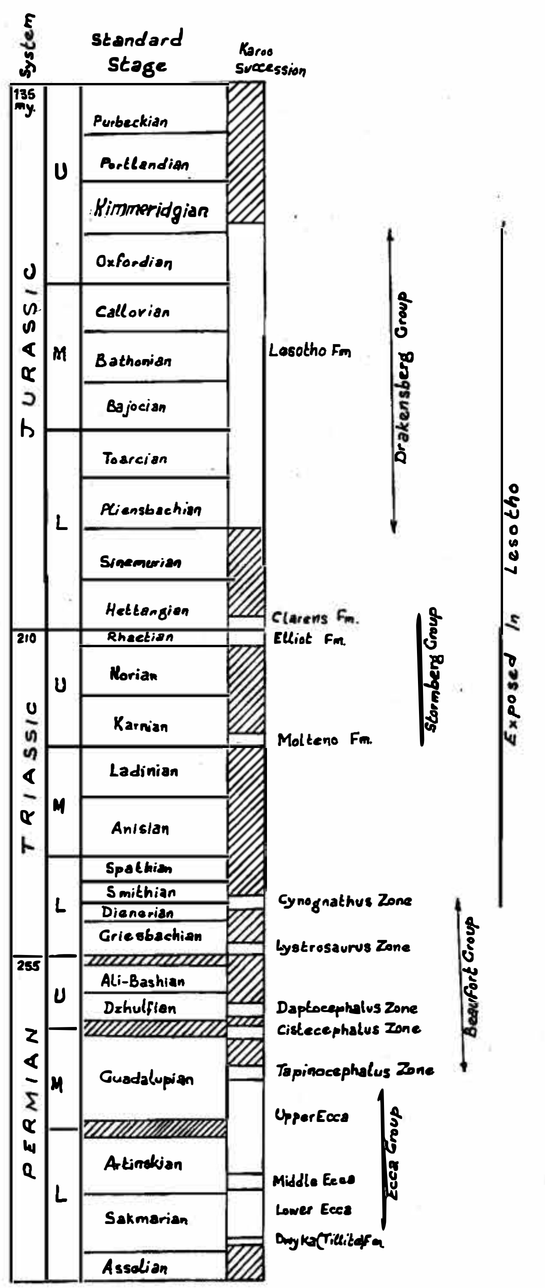


Source: Simplified after Coetzee, 1976

formations the only fossils which can be used for biostratigraphic correlation are vertebrates and plants. A reptile biozonation has been established for the Beaufort Group and the upper Burgersdorp part of the Group exposed in Lesotho has been assigned to the Cynognathus zone (Kitching 1970; Ellenberger, 1970). The Molteno Formation is characterized by a scarcity of reptile remains (Turner, 1972) and an abundance of plant fossils, especially the genus Dicroidium (Anderson, 1974). For the Lesotho Stormberg Group, Ellenberger (1970) distinguished two phases on paleontologic, paleobotanic and lithologic evidence, a warm humid lower Stormberg, which was subdivided into 7 zones, and a warm arid upper Stormberg, also subdivided into 7 zones. This detailed zonation, however, is not readily applicable as fossils are rare and their time range is insufficiently established. Most chronostratigraphic boundaries are established in type sections for which, generally, no absolute age dating is available and the correlations are then based on the biozonation of guide fossils. Correlation of the Lesotho Karoo sequence with the standard Permo-Jurassic stratigraphic stages, which were established primarily in the Northern Hemisphere, is made difficult by the paucity of the fossil evidence and the restriction of the absolute age dating to basalts and dolerites, but a tentative correlation is indicated in figure 13. In line with international lithostratigraphic usage the terms "Supergroups", "Group" and "Formation" replace the formerly used "System", "Series" and Stage" respectively. Similarly "Elliot Formation" replaces "Red Beds" and "Clarens Formation" replaces "Cave Sandstone" (Dusar, 1977b; South African Committee for Stratigraphy, 1980). The term "Transition Beds" was sometimes applied to indicate a transitional facies between the "Red Beds" and the "Cave Sandstone" but these transitional strata are now incorporated in the "Clarens Formation".

As Lesotho is located in the centre of the large Karoo tectonosedimentary basin (figure 14) the overall structural

Figure 13. Tentative correlation of Lesotho Karoo sequences with the standard Permo-Jurassic stratigraphic stages.



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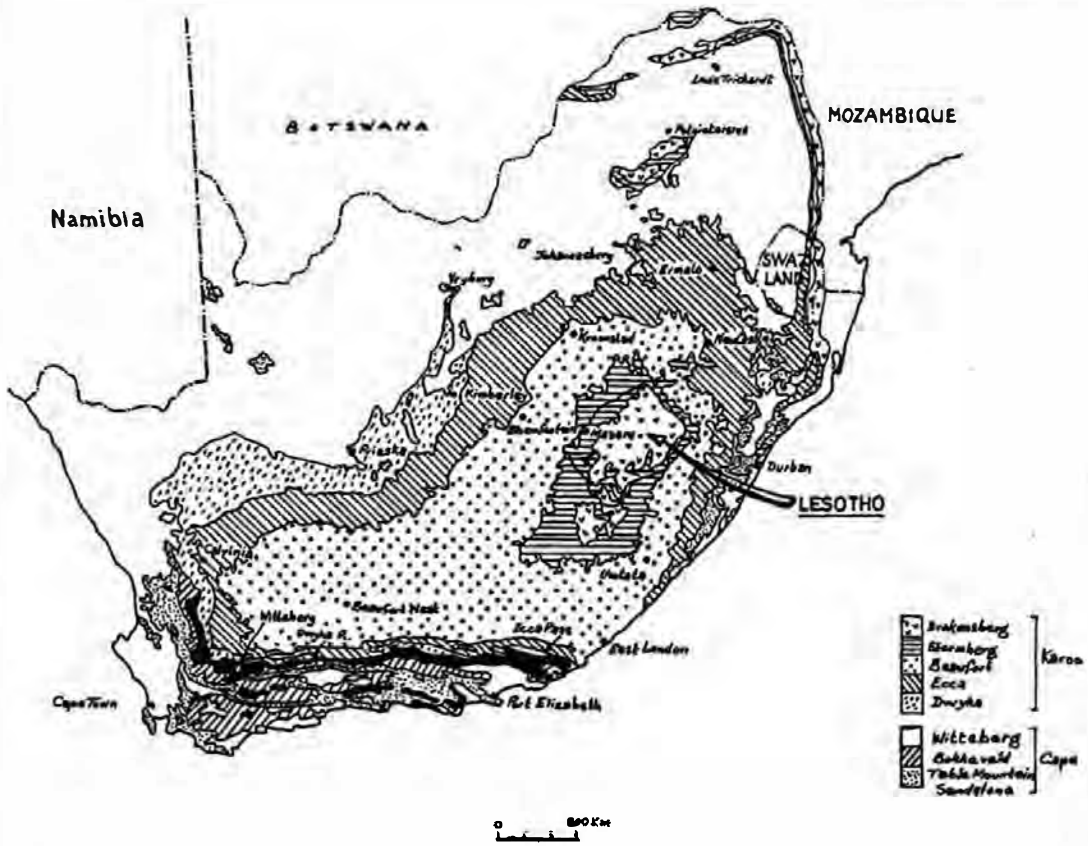
Source: Modified after Anderson and Schwyzer,1977

Figure 14. Location of Lesotho within the central part of the Karoo basin.



Source: After Truswell, 1977

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pattern is synclinal with the consequence that the sedimentary rocks buried beneath Lesotho are exposed in the areas surrounding Lesotho. Within this overall major structural framework, however, it has proved possible to establish three periods of tectonic deformation - pre-Drakensberg, Drakensberg and post-Drakensberg (Dusar, 1979). The pre-Drakensberg deformation is based on basement composition and structures and has influenced the sedimentation of the Karoo beds. The Drakensberg deformation at the onset of volcanic activity has produced most tectonic efforts and is indicated particularly by the changes in elevation of the Stormberg-Drakensberg basalt contact. The post-Drakensberg deformation significantly influenced the location of the primitive river system and thus the present hydrography and geomorphology.

B. Burgersdorp Formation of Beaufort Group

1. General characteristics and boundaries

The Beaufort Group spans the Paleozoic-Mesozoic boundary ranging in age from Middle Permian to Lower Triassic. The sedimentary beds thin abruptly northwards from a maximum of almost 6,000 m in the central Karoo basin and generally consist of a sequence of polycoloured shale and mudstone with interbedded fine- to medium grained yellowish sandstone. The Beaufort beds are rich in reptilian remains and useful biozonation (figure 13) has been established (Kitching, 1970). Only the upper Burgersdorp Formation of the Beaufort Group is exposed in Lesotho and this belongs to the *Cynognathus* zone (Kitching, 1970; Ellenberger, 1970). The base of the Burgersdorp Formation is not seen in Lesotho. The top is taken at the base of the first coarse-grained arkosic sandstone unit. In some areas, this sandstone unit contains a basal conglomerate (see Molteno Formation.)

2. Detailed lithology

The Burgersdorp Formation in Lesotho consists of soft, polycoloured but commonly red mudstone and siltstone, alternating with more competent fine- and medium grained grey and buff lenticular sandstone. The thicker sandstone commonly contains lenses of mud-clast conglomerate or siltstone in their lower part. The base of individual sandstone beds is generally slightly erosional. Abundant calcareous nodules and layers are found in the finer-grained beds. Caliche or carbonate nodules considered to be of pedogenic origin are found at several levels in the Burgersdorp Formation. They may occur as laterally continuous beds up to 0.5 m thick. Ferruginous beds or layers with ferruginous concretions are regularly found towards the top of the formation in the Mafeteng area; these beds generally form prominent topographic benches. The extensive outcrops of Burgersdorp strata in western Lesotho yield numerous reptilian remains and some reptile footprints. Many sandstone beds assigned to this formation contain fragmented or carbonized plant remnants. It is not uncommon that these Burgersdorp beds yield a typical Molteno fossil plant association (Neocalamites, Dicroidium, Baiera, Podozamites). According to Dusar (1978b) these strata are probably the time-equivalent of the lowermost Molteno beds towards the south of Lesotho. They may also yield many fossil insects, mainly cockroaches (Anderson, 1978).

Because only the uppermost part of the Beaufort Group is exposed in Lesotho, little is known of the regional lateral changes in thickness or lithology. Its maximum exposed thickness of between 200 m and 250 m is found in the Mohokare (Caledon) River valley in extreme western Lesotho.

3. Stratigraphic sections (figure 15)

(a) Herman Mission (figure 16)

The thick mudstone units are predominantly red with zones of green mottling. Purple mudstone occur towards the base whereas the arenaceous facies becomes more important and feldspathic towards the top. The lower part is very calcareous. Reptile bones are found on top of the first calcareous siltstone beds while a fine-grained sandstone about 115 m above the base of the section yields numerous non-coalified plant remains. The sandstones are commonly cross-bedded and some display ripple-marks. The base of the overlying Molteno Formation is not disclosed. The exposed thickness of the Burgersdorp beds is 225 m which represents approximately the maximum for this formation in Lesotho.

(b) Rantja (figure 16)

The whole sequence consists of brown and green fine- to medium-grained sediments. No maroon beds were found. Many of the mud clasts, which commonly concentrate along erosion surfaces at the base of the sandstones, are ferruginous. The top of the formation is taken at the base of coarse feldspathic sandstone bed with abundant carbonized Calamites remnants.

(c) Liphofung (figure 19)

The Burgersdorp sequence consists of a basal fine-grained arenaceous facies and an upper polycoloured argilaceous facies with a combined exposed thickness of 75 m.

4. Environment of deposition

The Burgersdorp Formation was deposited in a fluvial environment, marked by low energy conditions. The complete

Figure 15. Location of stratigraphic sections shown in figures 16, 19-23.

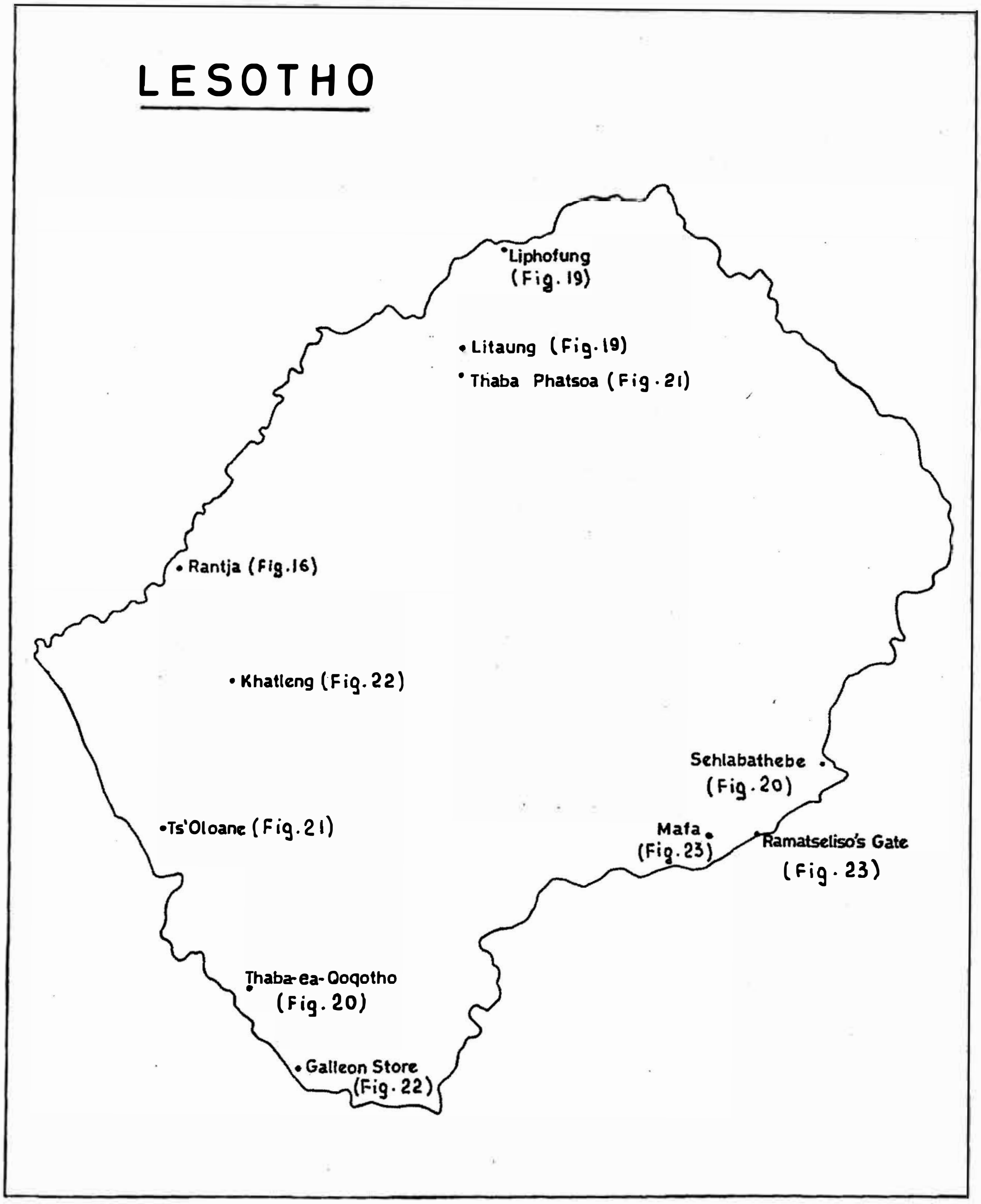

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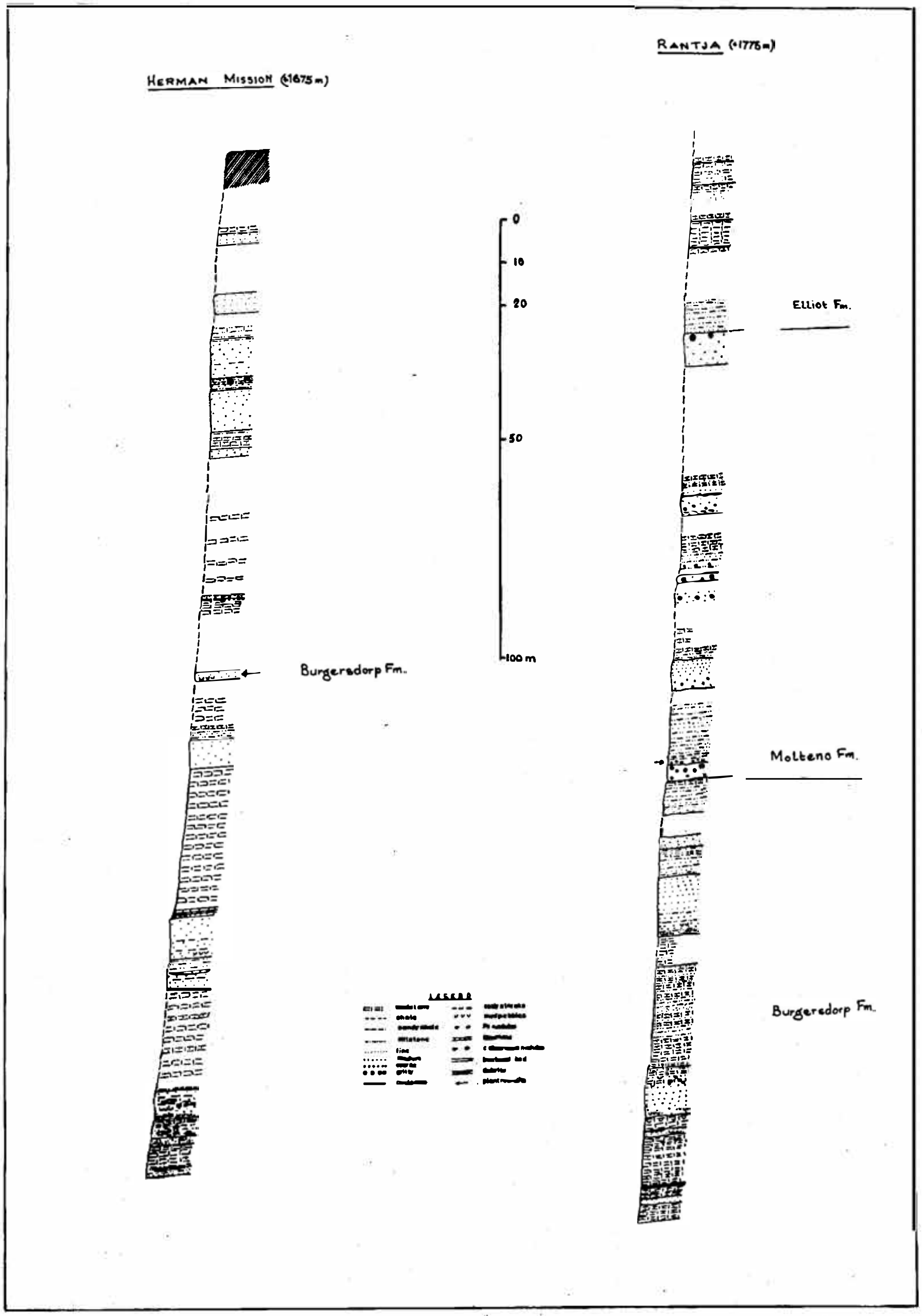
Figure 16. Stratigraphic sections at Herman Mission and Rantja.



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faunal and floral assemblage suggests a swamp with much deposition from mainly meandering rivers (Rust, 1975). This gives rise to a highly dispersed paleocurrent pattern. It is suggested that the upper Beaufort (Burgersdorp Formation) may represent sediment stripped from lower and middle Beaufort outcrops in the steadily rising southern source area.

C. Molteno Formation of Stormberg Group

1. General characteristics and boundaries

The Molteno Formation forms a northward-thinning intracratonic clastic wedge that was deposited following uplift, and pulsating source area diastrophism during Late Triassic times (Rust, 1959; Truswell, 1978; Turner, 1977). The general lithology is a succession of predominantly coarse sandstone beds with subordinate fine-granied sandstone, siltstone, mudstone and shale and occasional thin lenticular seams of coal. A study by Turner (1977) revealed that the sedimentary sequence shows a major cyclic repetition composed of many smaller incomplete cycles. Seven major upward fining cycles were recognized in the type area of the north-eastern Cape Province, Republic of South Africa. An unconformity exists between the first cycle - named the "Bamboesberg Member" - and the remainder of the formation. As this member is not developed as far north as Lesotho, the unconformity in Lesotho occurs between the Beaufort Group and the Molteno Formation which then begins with the second major sedimentary cycle. The unconformity, however, is not easy to observe in the field.

Much of the base of the Molteno Formation is marked by a basal conglomerate facies overlying a low-relief erosion surface. Other conglomerate facies occur at the base of new major sedimentary cycles. Although the presence of the conglomerate makes recognition of the base of the Molteno Formation easier, correlations with areas where no conglomerate has been observed are still reliable because of the greater lateral persistence of the overlying gritty sandstone which forms the most prominent element in the Molteno cyclic sedimentation. The base of the Molteno Formation is then fixed at the base of the first coarse-grained arkosic sandstone - with or without a basal conglomerate - overlying the polycoloured sandstone and fine-grained arenaceous beds of the Beaufort Group (Burgersdorp Formation). The top of the formation, and hence the boundary with the overlying Elliot Formation, is taken at the base of the first thick red continuous mudstone unit. Thus, intercalations of red mudstone may occur in the upper part of the Molteno Formation; they are, however, laterally restricted and subordinate to the Molteno sandstones whereas the mudstones of the Elliot Formation are dominant over sandstones (see Elliot Formation).

2. Detailed lithology

The cycle pattern of sedimentation observed in the Molteno Formation has been divided into four major facies according to lithology, grain size and sedimentary structure (Turner, 1977). Ideally, a conglomerate facies deposited on an erosion surface is overlain by a coarse-grained sandstone facies which becomes progressively finer grained upwards. Fine-grained sandstone, siltstone and silty shale complete the cycle which finishes with a thin shale-coal facies. The sandstone facies is volumetrically the most important.

The Molteno conglomerate facies in Lesotho consists of well-rounded pebbles, cobbles and boulders, generally set in a coarse to gritty sandstone matrix. They are predominantly quartzitic in composition and light grey in colour. Clasts of the underlying mudstone together with carbonized plant fragments are associated with the conglomerate. According to Dusar (1978b) the basal Molteno conglomerates are concentrated in four areas (Litaung, Mphoto, Kolo, Mafsteng) while a fifth pebble bed occurs at a higher level in the Molteno Formation south of Mohale's Hoek. This level represents presumable the base of a new major sedimentary cycle (the second known in Lesotho).

In the southern part of the country, some geographically and stratigraphically dispersed quartzite cobbles can be expected either in isolated occurrences or in lenticular beds. They are everywhere associated with coarse-grained sandstone beds. These coarse-grained to gritty sandstones form the major part of the Molteno Formation in most areas. They are yellowish and grade upwards into medium- and fine-grained sandstone. They typically contain vein quartz pebbles and concentrations of mud-pebble conglomerate, the latter especially along their base. Secondary silicification gives them a typical glittering appearance. Cross-bedding is the dominant type of sedimentary structure in these sandstones. Honeycomb weathering (figure 17) is typical of the Molteno sandstones although it is also shown by some sandstones of the Elliot Formation. Mostly greyish-blue and buff massive siltstone and fine-grained rippled sandstone occur as inter-beds together with discontinuous carbonaceous shale, carbonaceous shaly siltstone or coaly paper shale. Thin intercalated coal seams occur as a result of the compression and coalification of plant stems. Layers of iron concretions are not uncommon in the medium-grained sandstone underlying the finer-grained sedimentary beds and micaceous beds are common.

Within the Molteno Formation (and its lateral time equivalents) an abundant and diverse flora is preserved. The fossils consist of carbonized stems, leaves, fertile structures and microflora (spores, pollen and acritarchs) assigned to the Dicroidium (former Thinnfeldia) flora (figure 18). They

Figure 17. Typical honeycomb weathering of Molteno sandstone near Phoqoance

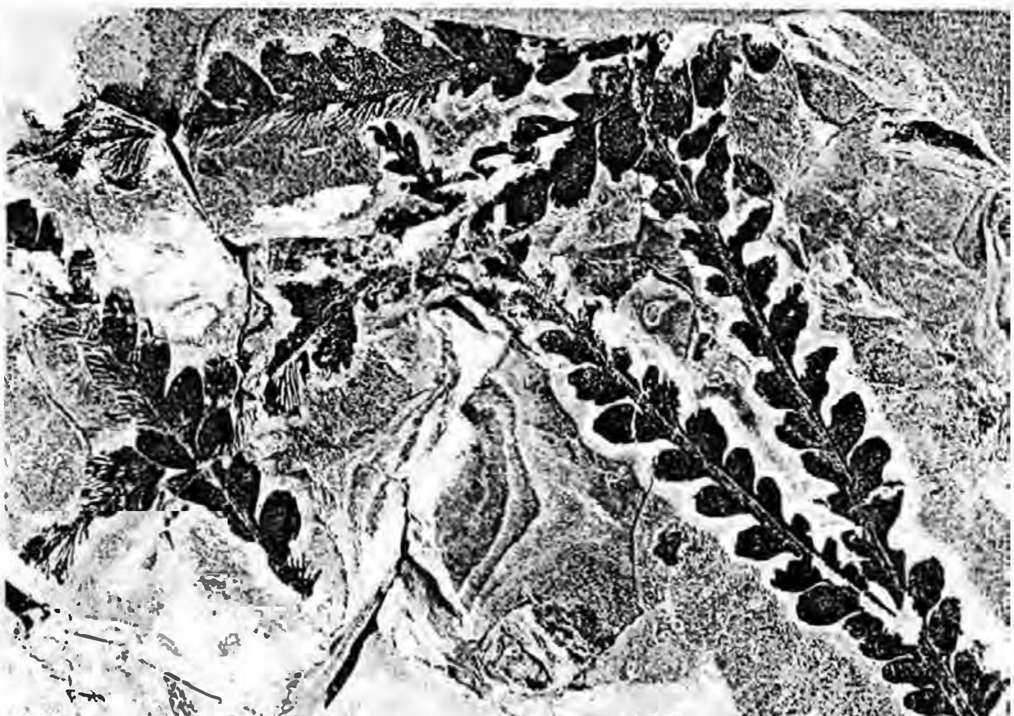


Figure 18. Fossil plants, <u>Dicroidium sp.</u>, in shale at Lechesa near Mazenod (Photo by Dr. H.M. Anderson)

are described (Stockley, 1947; Anderson, 1978) from carbonaceous shaly intercalations in coarse-grained sandstone at the base of the succession or from non-coalified Molteno sandstone. Petrified wood assigned to Dadoxylon and Rhexoxylon (Stockley, 1947) are found occasionally throughout the Molteno Formation. In addition, some of the Molteno beds yield ostracods, molluscs, insects and fish remnants but reptile (cynodont) remnants are particularly scarce compared to the underlying Burgersdorp and overlying Elliot formations. One reptile bone breccia was reported from the Molteno Formation at Morobong (Dusar, 1978b) where it occurs below the uppermost sandstone. Reptile footprints are known from the same area (Ellenberger, 1970) and reptile bones were also found in a silty mudstone sequence from the lower part of the Molteno Formation along the Tsoaing River (Stockley, 1947). These are the only evidence of vertebrate life during Molteno times in Lesotho.

The Molteno Formation has a maximum thickness of between 250 m and 300 m in the south (these values have only been obtained from the south-east as towards the west the base of the formation is not exposed) and thins abruptly towards the north, reaching a thickness of 40-50 m on the northern Lesotho border.

3. Stratigraphic sections (figure 15)

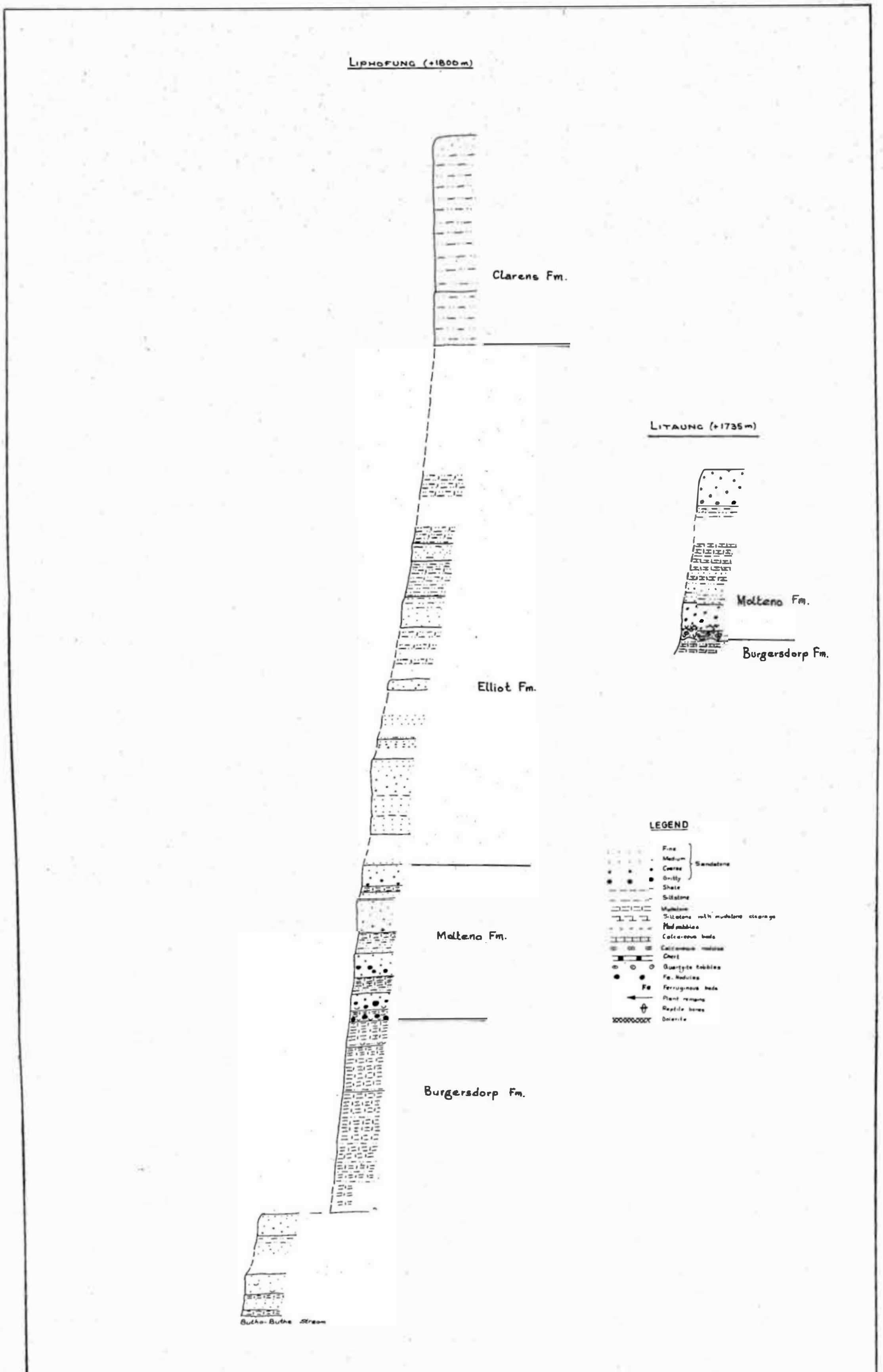
(a) Liphofung and Litaung (figure 19)

Both sections show several coarse-grained to gritty sandstone beds containing vein quartz pebbles, siltstone clasts and mud pebbles. They grade into medium- to fine-grained sandstone and subordinate shaly siltstone and silty mudstone. The entire Molteno sequence is 40 m.

(b) Rantja (figure 16)

The softer beds are not well exposed, especially towards

Figure 19. Stratigraphic sections at Liphofung and Litaung.



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the top of the formation, but they generally consist of bluish-grey and brown siltstone and silty mudstone. The coarse- and very coarse grained sandstones contain the typical vein quartz pebbles. A black shaly layer with macerated plant remains and coaly Calamites stems occurs on top of the first gritty sandstone bed. The uppermost coarse-grained Molteno sandstone bed is overlain by a thick succession of red and grey siltstone and mudstone. The entire Molteno sequence is approximately 100 m thick.

(c) Sehlabathebe Escarpment (figure 20)

The Molteno facies can be divided into two parts. The lower half consists almost entirely of coarse grained and gritty feldspathic buff to whitish sandstone rarely passing into medium- or fine-grained sandstone with thin interbeds of mudstone. In the upper part, the meidum- to fine-grained sandstone becomes more important together with mudstone and siltstone which are generally greyish-blue or green. However, the coarse sandstones still characterize the sequence which ends with a 20 m-thick coarse sandstone bed below a continuous (partly unexposed) red mudstone unit. Sedimentary structures include cross-bedding of the coarse sandstone and ripple marks in the medium- to fine-grained sandstone. Several coarser sandstones are reddish stained. Some of the gritty arenaceous beds in the middle part of the succession yield carbonaceous streaks, non-carbonized plant stems and iron concretions.

(d) Ts'Oloane (figure 21)

In the section south of Ts'Oloane, the coarse-grained Molteno sandstones are buff coloured and mostly feldspathic with numerous vein quartz pebbles and mud-pebble conglomerate. Two of these sandstone beds yield coal patches with one seam occurring 25 cm above the base of the first gritty bed.

Figure 21. Stratigraphic sections at Thaba Phatsoa and Ts'Oloane.

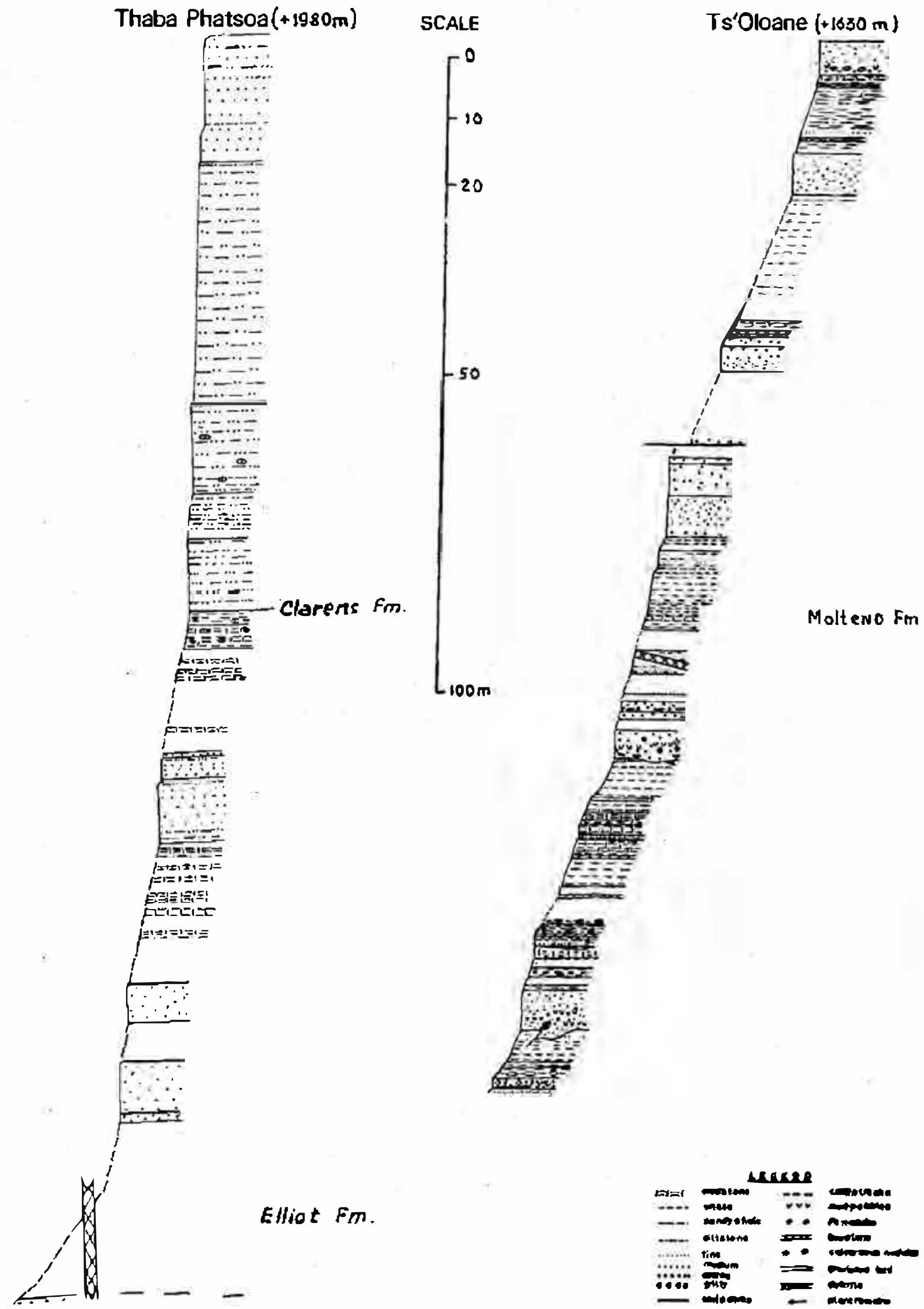

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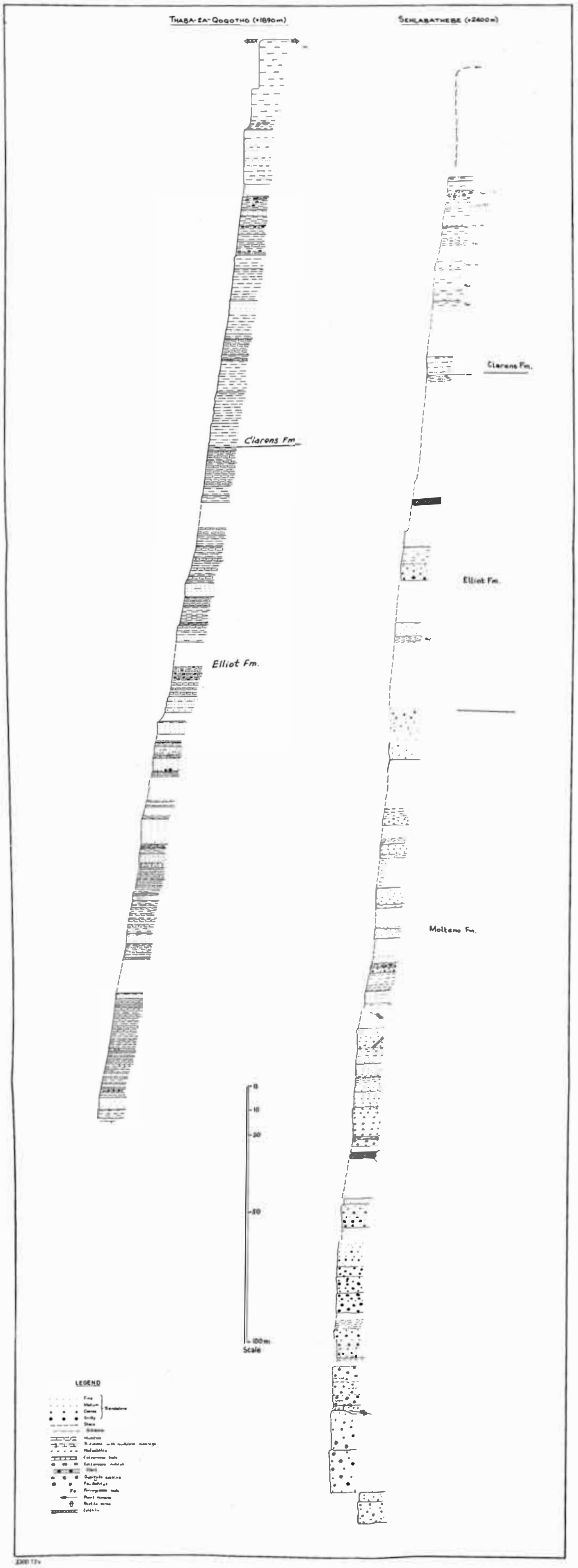
Figure 20. Stratigraphic sections at Thaba-ea-Qoqotho and Sehlabathebe Escarpment.



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Interbeds consist of blue-grey, green and purple shale and mudstone and green and brown siltstone. Unusual for the Molteno Formation is the interval with calcareous nodules and thin even calcareous shales associated with some red shales. A grey siltstone higher up yields numerous carbonized plant remains.

(e) Galleon Store (figure 22)

Green, brown and bluish-grey mudstone and siltstone to together with fine-grained sandstone alternate with buff, medium- to coarse-grained and gritty, sandstone. The sandstone is commonly feldspathic with abundant vein quartz pebbles and mud pebbles in the coarser beds. No coal fragments or quartzite conglomerate have been found. Some thin lenses of red mudstone or shale and grey-red siltstone occur in the upper part of the succession which ends with approximately 30 m of coarse-grained sandstone with abundant vein quartz pebbles underlying a sequence of red mudstone and siltstone (the base of the Elliot Formation). It should be noted that in many sections, the lower part of the Elliot Formation is poorly exposed as owing to differential weathering, there is generally a break in slope, which is then covered by vegetation.

(f) Mafa and Ramatseliso's Gate (figure 23)

The coarse-grained sandstones which constitutes almost the entire lower half of each section (Molteno part) are off-white and characterized by large amounts of vein quartz pebbles up to 2.5 cm. Noteworthy is the relative absence of mud pebbles in this interval but they are more abundant in the sandstone of the upper part as more mudstone interbeds occur. At about 20 m above the base of the section at Mafe, a trough occurs filled with mud-clast breccia (with the individual clasts up to 50 cm) accompanied by quartzite boulders and vein quartz pebbles. The trough is approximately 5 m deep.

A little unusual for the Molteno Formation is the thick shaly sequence on top of the first coarse sandstone succession at Mafa. The exposure, however, is poor. The top of the Molteno succession at Mafa then consists of a coarse sequence with abundant vein quartz pebbles and mud pebbles followed by a (first) red mudstone unit which represents the base of the Elliot Formation.

The clastic dykes shown on the section consist of silty mudstone full of angular mud pebbles. They pass into a funnel-shaped volcanic vent filled mostly with green mudstone, but where it becomes wider, it is filled with calcareous and phosphatic nodules, some reptile bones, baked sandstone, ropy lava, vesicular lava and lava bombs.

Most of the coarse-grained sandstone in both sections is cross-bedded, and some is stained red. The lower half of the Ramatseliso's Gate section also consists entirely of coarse- and coarse-grained cross-bedded sandstone with some interbedded bluish-grey and brown shale. The blank spots represent areas of no outcrop. Towards the top, brown medium-grained sandstone and brown and grey shale become more important. The basal Molteno conglomerate was found at approximately 25 m below the base of the section at Ramatseliso's Gate (on the other side of the border).

4. Environment of deposition

The Molteno sediments form river-bed deposits of erosion products transported by different (low sinuosity) braided streams that locally may have been meandering in character.

Paleocurrent direction measurements from cross-bedded sandstone reveal the presence of two major flow systems directed towards the north-west and north-north-east respectively and converging somewhere in the centre of Lesotho.

Figure 22. Stratigraphic sections at Khatleng and Galleon Store.

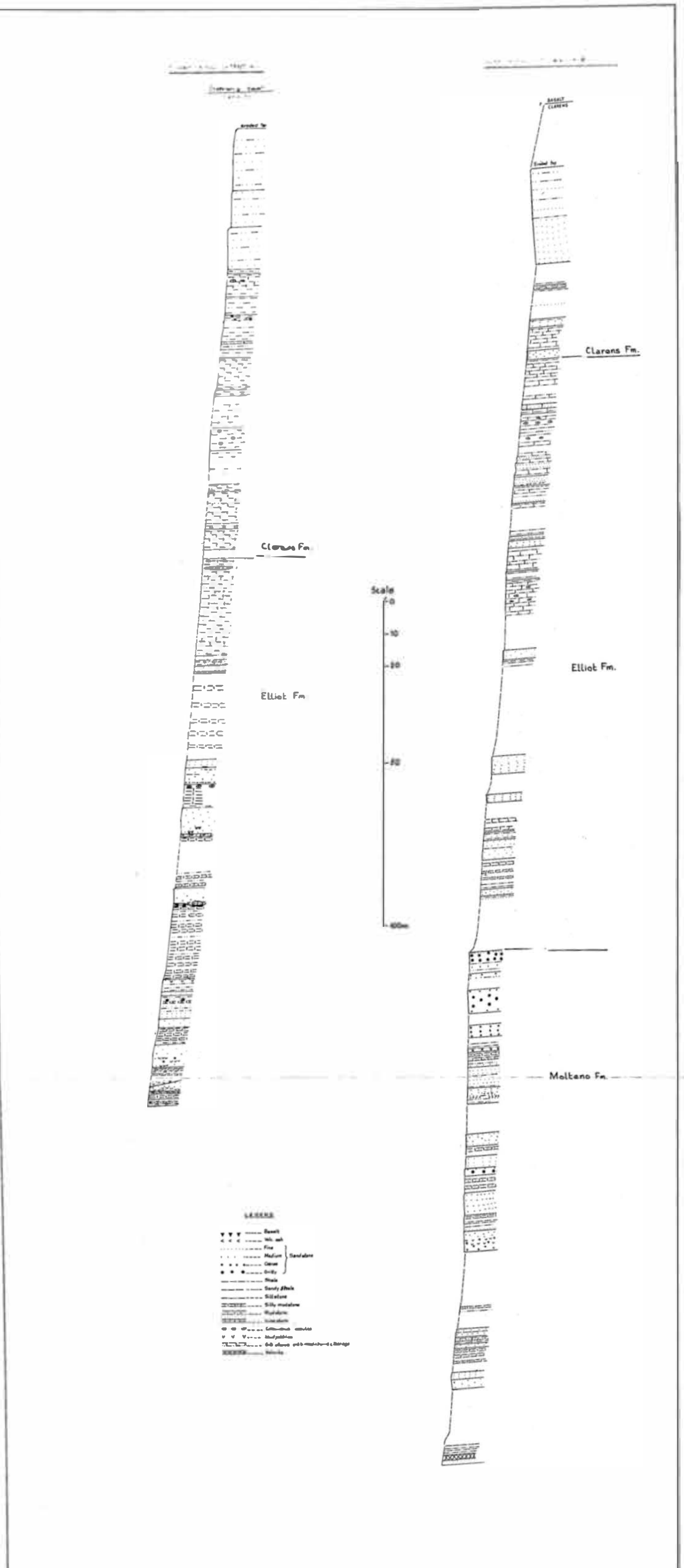

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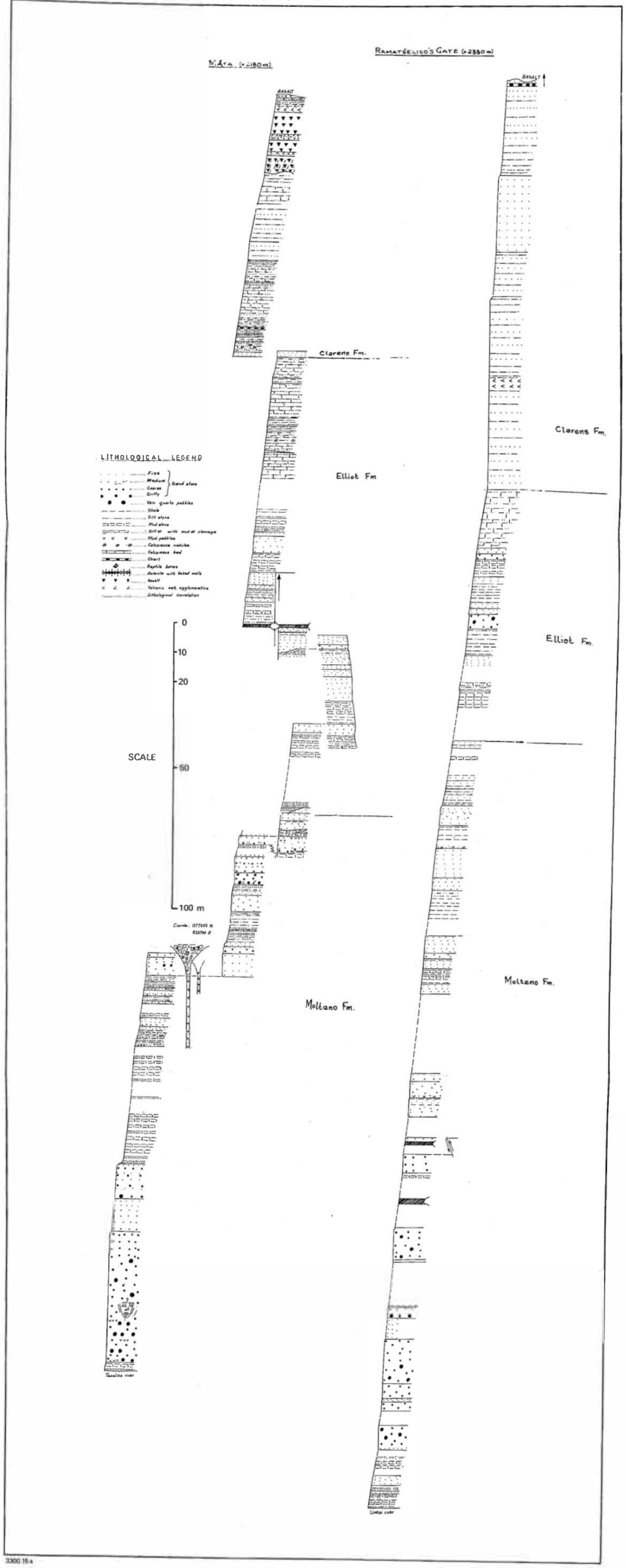
Figure 23. Stratigraphic sections at Mafa and Ramatseliso's Gate.



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A detailed outline of the paleogeography and transport directions of this formation is given by Betha and Theron (1967b) and Turner (1970, 1975b, 1977).

5. Discussion

There is apparently a difference in facies of the Molteno Formation between the south-east (Sehlabathebe, Ramatseliso's Gate and Mafa) and the south-west, as in the south-east coarse to gritty sandstone beds are particularly dominant in the lower part of the succession with almost no finer-grained interbeds. This may be related to the two different transport directions (SE and SSW) proposed by Turner (1977). Towards the north, the sections become too thin to compare, but generally the sediments become finer grained in that direction. At least part of the Elliot Formation in the north was deposited contemporaneously with the upper part of the Molteno Formation in the south.

D. Stormberg Group of Elliot Formation

1. General characteristics and boundaries

The Elliot beds conformably overlie the Molteno beds and thin abruptly northwards from a maximum thickness between 500 and 600 m in the vicinity of Elliot (about 90 km south of the Lesotho border). The sediments consist of predominantly red and polycoloured mudstone and shale alternating with subordinate buff or reddish fine- to medium-grained, commonly felds-pathic, lenticular sandstone and siltstone. The sediments are thus characteristically fine grained but occasional coarse sandstone beds occur, some even with small quartzite pebbles. Visser and Botha (1980) recognized four sandstone models in the Elliot Formation based on texture, sedimentary structures, geometry and depositional environment.

The boundary with the underlying Molteno Formation is taken at the base of the first thick and continuous red mudstone, where mudstone becomes predominant over sandstone. Although some red mudstone interbeds may occur in the upper part of the Molteno Formation, they are restricted in both lateral and vertical extent. Additional criteria which can be used in distinguishing these two formations are the generally finer grain size of the Elliot Formation (mudstone becomes predominant over sandstone) together with its abundance in reptilian remains which are rare in the Molteno Formation. Furthermore, there is the absence of coal and an almost total lack of Dicroidium flora which are both so typical for the Molteno Formation. Noteworthy also is the abundance of calcareous nodules in the Elliot Formation.

The upper contact with the Clarens Formation is gradational due to a gradual change in climatic conditions from humid (Molteno) to arid (Clarens), with the consequence that the upper limit of the Elliot Formation and hence the base of the Clarens Formation is fixed arbitrarily. As beds with distinct Elliot characteristics, such as red and polycoloured mudstone, occur abundantly (in certain locations) in the lower part of the Clarens Formation, the top of the Elliot Formation is fixed at the base of the first continuous fine-grained sandstone or siltstone having distinct aeolian characteristics. As the upper part of the Elliot Formation is predominantly argillaceous and the sandstone interbeds typically lens-shaped, this continuous layer generally constitutes a distinct marker bed.

2. Detailed lithology

Beds of red and polycoloured mudstone form the bulk of the Elliot sediments in Lesotho. Many of the mudstone beds are poorly exposed due to differential weathering compared to the sandstone and, hence, gaps in the observable stratigraphic sections are unavoidable. Fine- to medium-grained cross-bedded feldspathic sandstone generally lies upon erosion surfaces on the mudstone and some beds display coarse-grained channel lag deposits at their base, with even some rare but small quartzite pebbles. They contain abundant mud pebbles which are especially concentrated towards their base. The sandstone beds are characteristically lens-shaped and many show vertical and lateral transitions to siltstone. Many of the latter are micaceous. In some locations these sandstone lenses are relatively thick but argillaceous rocks everywhere prevail. The mudstones can be very silt-rich and as observations were made in the field, the distinction between a silt-rich mudstone and an argillaceous siltstone is not everywhere obvious. This may obscure the general picture of a stratigraphic section. In some outcrop areas, a distinction can be made between a lower Elliot facies containing relatively thick lenses of fine- to medium-grained sandstone and an upper Elliot facies, where arenaceous beds are restricted to thin, fine-grained, and subordinate feldspathic medium-grained sandstone occurring in a thick sequence of predominantly red mudstone.

Calcareous concretions, patches and thin calcareous beds or breccia layers occur throughtout the succession. Phosphatic nodules are generally present in association with reptile bones. Iron concretions concentrate along some erosion surfaces at the base of sandstone beds. Some sandstone layers in parts of the Elliot succession contain tuffaceous layers or chert beds. These presumably indicate an early volcanic phase in the Drakensberg Group.

In the central-western part of Lesotho, the transition with the underlying Molteno Formation is commonly characterized by several dark brown (manganese ?) stained, compact silty mudstone or siltstone beds. Through cross-bedding is the dominant sedimentary structure in the sandstone. Horizontal lamination and ripple markes are common and bioturbation is a general feature, especially in the mudstone.

Broken and rounded reptile bones and calcareous nodules containing bone fragments or ceprolites are common throughout the formation. Petrified wood is widely found in the Elliot beds. Animal tracks associated with ripple marks and mud-cracks occur in thinly cleaving fine-grained sandstone beds. The Elliot Formation is especially known for its reptile foot-print locations (figure 24).

The Elliot Formation attains its maximum development in the central-south of the country with a thickness of approximately 250 m and diminishes towards the east (less than 150 m in Qacha's Nek), towards the west (less than 150 m west of Mafeteng - Mohale's Hoek) and towards the north (about 100 m in the Leribe - Butha-Buthe area).

3. Stratigraphic sections (figure 15)

(a) Thaba Phatsoa (figure 21)

Elliot beds are exposed over a thickness of 105 m and consist of red, green and buff mudstone and rather thick, fine- to medium-grained sandstone. Calcareous nodules occur towards the top.

(b) Khatleng (figure 22)

The top of the Molteno Formation is located 20 m below the base of the section. Red mudstone, becoming more silty towards the top, dominates the Elliot succession. The fine- to medium-grained feldspathic buff coloured sandstone beds occur in the lower half with at least one of them showing a clear erosion surface, along which calcareous and phosphatic nodules, together with mud pebbles, concentrate. A coarse channel-lag deposit occurs on top of a red mudstone containing large cal-careous nodules. The latter occur throughout the formation with one continuous layer in the upper part. Washout channels containing phosphatic nodules and reptile bones occur in a fine-grained sandstone 15 m above the base of the section. Many of the upper siltstone beds are micaceous.

(c) Sehlabathebe Escarpment (figure 20)

The section is poorly exposed but gives a good idea of the thickness (about 150 m) of the Elliot Formation in this area. The coarse-grained bed probably represents a channel lag deposit. Most of the unexposed parts are probably underlain by red mudstone and siltstone.

(d) Thaba-ea-Qoqotho (figure 20)

Maroon, green and grey mudstone and silty mudstone constitute the bulk of the formation. The sandstones are fine- to medium-grained, feldspathic and characteristically lenticular. Some sandstone lenses show an irregular lower contact with concentrations of iron concretions and mud pebbles, whereas others display thin grit layers above a more regular base. The most prominent is a metre thick and consists of coarse-grained cross-bedded layers in a shaly matrix. It grades upwards through fine-grained sandstone to siltstone. Thin chert layers were found in the basal part of this section. As in all Elliot sections, calcareous concretions and irregular calcareous lenses are abundant. The first sandstone below the base of the section is the top of the Molteno Formation. This gives the Elliot Formation a thickness of approximately 250 m.

(e) Galleon Store (figure 22)

This is a typical Elliot sequence starting with thick red mudstone overlying the last gritty Molteno sandstone. The lithology corresponds well with the detailed description given for this formation. Its thickness is 180 m.

(f) Mafa and Ramatseliso's Gate (figure 23)

Both sections are relatively arenaceous with unusual amounts of fine- to medium-grained sandstone. The mudstone is generally silty and almost entirely red. Carbonaceous concretions were not found at Ramatseliso's Gate. This section yields several coarse grained beds with occasional grit layers which, however, grade abruptly into fine-grained sandstone or siltstone. The Elliot Formation is reduced to 90 m at Ramatseliso's Gate. The Mafa section shows 150 m of Elliot sediments with the sandstone lenses generally found in the lower half. No gritty layers occur but some calcareous concretions were found at one level.

4. Environment of deposition

The sediments of the Elliot Formation are fluviatile in origin and mainly deposited by low gradient meandering streams although some coarse channel lag deposits may indicate high-energy fluctuations. Paleocurrent analyses based on sedimentary structures observed and measured in the Elliot sandstones, indicate a general transport direction from the south-east towards the north-west with a north-easterly component in Natal (NE of Lesotho) (Le Roux, 1974).

5. Discussion

At least part of the Elliot Formation in the north was deposited contemporaneously with the upper part of the Molteno Formation in the south.

E. Clarens Formation of Stormberg Group

1. General characteristics and boundaries

With the Jurassic Clarens Formation the Stormberg sedimentary cycle ends. Rocks belonging to this formation consist predominantly of cream-coloured and reddish fine-grained sandstone and siltstone with subordinate mudstone and shale. The lower contact with the Elliot Formation is taken at the base of the first continuous siltstone or fine-grained sandstone having distinct aeolian characteristics. The lateral continuity of this bed distinguishes it immediately from the underlying lenticular sandstones of the Elliot Formation. The sandstone of the bed is generally well sorted with no gradual transitions to finer or coarser material. The upper limit of the Clarens Formation is taken at the base of the first lava flow (see Lesotho Formation).

2. Detailed lithology

The Clarens Formation in Lesotho commonly consist of a lower facies formerly named the "Transition Beds" (Stockley, 1947) and an upper facies formerly known as the "Cave Sandstone". The lower facies shows waterlaid intercalations of red and polycoloured mudstone and shale interbedded between beds of fine- and medium-grained sandstone and siltstone. Some of these lenses show lateral transitions to aeolian sandstone indicating that they may have been deposited in playa lakes. They typically show mudcracks and evidence of bioturbation is common. Some trough cross-bedded sandstone beds show scour and fill structures and poor sorting, indicating that at least part of the arenaceous beds of this facies were waterlaid. Mud clasts are not uncommon at the base of these sandstone beds. In the upper facies, the sandstone is predominantly aeolian with large-scale cross-stratification and few subaqeous intercalations. This facies forms the cream-coloured cliffs which characterize the Clarens Formation (figure 25). Horizontally bedded silty sandstone occurs as interdune deposits. Waterlaid deposits become more abundant again near the contact with the underlying Lesotho Formation. Calcareous nodules occur

Figure 24. Five-toed reptile footprints in Elliot siltstone near Leribe; the reptiles roamed Lesotho over 200 million years ago

Figure 25. Cliff-forming Clarens Formation near Ntlo-Kholo on road to Thaba-Bosiu

abundantly throughout the formation but are generally confined to interdune facies. The fine-grained aeolian sandstones commonly have calcareous cement.

The Clarens beds yield numerous clearly preserved reptile footprints. Reptile, and possibly also mammal, bones occur, but are generally poorly preserved. Argillaceous intercalations contain conchostracans, ostracods, molluscs, fish remains and carbonized plant fossils. Silicified or carbonized tree trunks occur at the top of the Clarens Formation, covered by the first lava flow.

3. Stratigraphic sections (figure 15)

(a) Thaba Phatsoa (figure 21)

The Clarens Formation consists only of the upper facies with a preserved thickness of 90 m. No distinct waterlaid intercalations were recognized.

(b) Khatlang (figure 22)

A massive reddish bed of fine-grained sandstone constituting the base of the formation underlies a sequence of red siltstone with a mudstone cleavage showing abundant bioturbation structures. The harder siltstone bed in the middle contains mudclasts.

A thick, more massive red siltstone separates this sequence from a similar facies which represents the upper part of the lower Clarens Formation. It is in turn overlain by the cream-coloured, cross-bedded, fine-grained sandstone of the upper facies. The thickness of the Clarens Formation is 130 m.

(c) Schlabathebe Escarpment (figure 20)

The Clarens Formation is not well exposed but waterlaid deposits occur abundantly as grey-red fine-grained sandstone with mud pebbles and as red mudstones. Together with the overlying cliff-forming aeolian sandstone the thickness is 120 m.

(d) Thaba-ea-Qoqothe (figure 21)

The Clarens sedimentation begins with a thick sequence of reddish and purple siltstone overlain by red silty mudstone. On top of this occurs a typical lake (varved type) deposit of bright green finely laminated siltstone. The overlying aeolian sandstone and green mottled red siltstone are followed by predominantly red siltstone-mudstone sequence containing abundant calcareous, iron-rich nodules. These beds are in turn overlain by the typical aeolian sandstone cliff of the upper facies. The exposed thickness of the Clarens Formation is 15 m.

(e) Galleon Store (figure 22)

Red silty mudstones and siltstones overlie the first sandstone of the Clarens Formation at Galleon Store. The fine-grained sandstone cliff of the upper Clarens facies contains abundant pyritic nodules. The total thickness of the Clarens Formation is 80 m.

(f) Mafa and Ramatseliso's Gate (figure 23)

The section at Ramatseliso's Gate yields no lower facies and hence the Clarens Formation consists of a 140 m high cliff of predominantly aeolian sandstone. A 5 m thick volcanic ash and agglomerate layer is interbedded between the sandstone approximately 35 m above the base of the Clarens Formation.

The lower facies at Mafa consists predominantly of red argillaceous siltstone with shale intercalations and a chert layer occurring 10 m above its base. Calcareous nodules occur in the lower part. The upper facies shows occasional blue horizons. The thickness of the entire formation at Mafa is 65 m.

4. Environment of deposition

The upper facies of large-scale cross-bedded strata is considered to have formed as wind-deposited dunes. The lower facies apparently represents a mixture of aeolian sandstone and both fluvial and lacustrine type (interdune ?) deposits in a semi-arid to arid environment. It could represent a dune-extradune system (McKee, ed., 1979).

5. Discussion

The waterlain deposits in the Clarens Formation are generally reduced in the north of Lesotho where the aeolian facies becomes predominant. This is thought to reflect a transition from a periodically wet desert environment (with ephemeral streams and playa lakes) in the south to a completely dry desert environment dominated by migrating dunes in the north.

F. Drakensberg Group

1. Introduction

Karoo volcanism included in the Drakensberg Group is of two different compositions and ages: an earlier acidic period, the evidence for which comes from the sedimentary formations themselves, and a later distinct major basic Lesotho Formation which comprises an early explosive phase now shown by the widespread occurrence of minor volcanic vents and plugs and a subsequent massive but quieter phase when lava welled up through numerous well-defined fissures, the infilling of which formed dolerite dykes and sills. The basaltic lavas of the Lesotho Formation are the dominant feature of Lesotho geology as they form the highlands in sequences up to 1,600 m thick and cover about 70 per cent of the country (figure 4).

2. Acidic volcanism

Acidic activity during the deposition of the Karoo sediments in Lesotho is most clearly demonstrated by the occurrence of a vitric tuff interbedded with the Elliot Formation on sheet 3A between Maseru and Teyateyaneng (Willan, 1976b). The tuff outcrops for 30 m in a north-trending donga near Ha Motsoene and the maximum thickness is 1.3 m (figure 26). The tuff dips at about 3° to the east and is underlain by about 2 m of compact medium- to fine-grained quartzitic sandstone. The tuff is siliceous, fine grained and occurs in grey and pink layers with small 1-2 mm devitrification white spots. The bedding is well developed at intervals of 1-10 cm and the bedding planes are stained with black manganese dendrites. The tuff has been exposed only because of the fortuitous development of the donga. A similar vitric tuff has been reported from the Elliot Formation on sheet 13D (Rombouts, 1978c) where it is underlain by an acidic volcanic breccia; the occurrence is close to the Khatoane volcanic plug. Another possible vitric tuff was noted at the base of the Clarens sandstone on sheet 11C near Ngangoana gate (Rombouts and Robison, 1980).

Further evidence of acidic volcanism is provided by the presence of swelling montmorillonite clay which has been encountered during building construction in the Maseru region. Thus the Danish contractors who built the Africa Hall at the University of Lesotho, Roma, encountered 1.5 m of red and green clay which tests in Copenhagen indicated had high swelling properties due to the presence of montmorillonite. Undoubtedly the cracking of walls in many Maseru houses is caused by montmorillonite clay below the houses. The montmorillonite in these Elliot beds is almost certainly due to the alteration of acidic volcanic glass, a conclusion reached by Botha and Theron (1967a) for the presence of montmorillonite in Elliot beds between Jamestown and Dordrecht. There are many other references to the widespread occurrence of acidic volcanism in the Karoo sequence in the Republic of South Africa. Possibly the most comprehensive paper is that by Martini (1974) who described tuff layers and greywacke rich in volcanic fragments from the uppermost part of the Dwyka Group, the Ecca Group and the lower part of the Beaufort Group in the southern part of the Karoo basin. Ash beds were found throughout the entire succession and are generally completely recrystallised with glass shards visible in only a few examples. Some of the tuff bands were originally described as "chert". The volcanic contribution to the greywacke was considered to be rather more acidic than mafic. Comparison was made with similar rocks in the Beacon Supergroup of Antartica. Other papers comparing acidic volcanism in Antartica with that in the Karoo are those by Elliot and Watts (1974) and Lock and Wilson (1975) who recorded glass shards in green and yellow mudstone of the lowest part of the Ecca Group. A crystal tuff from the Ecca Group has also been noted by Lock and Johnson (1974). Other evidence of widespread acidic volcanism is the abundance of zeolotes in the Beaufort and Stormberg Groups (Fuller, 1970) which were formed by alteration of volcanic material. The discovery of these zeolites was made by X-ray diffraction techniques during a petrographic investigation of the Elliot Formation to determine the origin of their coloration and the proportion of zeolite was up to 50 per cent.

The source of the acidic volcanism is not clear although the presence of vitric tuff and glass shards suggests that it must have been nearby. Attention is drawn to the fact that potassium-argon age dating (Fitch and Miller, 1971) indicate that the Lesotho Drakensberg flood-basalt outpourings to the north (191-194 million years). As these acidic volcanics include ignimbrites it is reasonable to assume that the acidic material in the Lesotho sedimentary formation was provided from these rocks or their southern equivalents (table 7). It is also pertinent to note that Stockley (1947) reported trachyte rocks from the base of the Drakensberg sequence at Thaba Tseou near Mafeteng, pointing to acidic precursors of the basalt.

It is considered probable that detailed petrographic and mineralogical studies of the Lesotho Karoo sedimentary formations will reveal additional evidence of contemporaneous acidic volcanic activity.

3. Lesotho Formation

(a) Contact with Clarens Formation

The boundary between the Clarens and Lesotho formations is drawn at the base of the first lava flow which means that some sandstone and ash beds are included in the lower part of the Drakensberg Group. Stockley (1947) noted that the contact ranged in height from 1,967 to 2,315 m with the highest elevation occurring at Sehlabathebe. These height variations were confirmed by Binnie and Partners (1971) and during the United Nations regional surveys (e.g., Rombouts and Robison, 1980; Grohmann, 1977a; Willan, 1976a; Grant, 1976). Data is not available to determine whether the thickness of the lavas correlated with contact elevation but at Sehlabathebe the thickness is only 799-900 m whereas near Mokotlong, as shown by recent drilling, the thickness is 1,600 m. Stockley considered that the variations in contact elevation were due in large measure to the varied thickness of the Clarens Formation, the geological structure and the uneven surface of the Clarens sandstone over which the first lavas flowed. As will be discussed later under "Structural Deformation (III, B)", Dusar (1979) proposed that the basalt-Clarens contact be classified into a block-pattern series of structural "highs" and "lows" resulting from the Drakensberg deformation occurring at the onset of volcanism and characterized by small scale (5-20 km) doming, faulting and downwarping (Binnie and Partners, 1971).

The contact junction was examined in many exposures and drill cores by Binnie and Partners (1971) who found that the transition was abrupt, sound tight and unweathered. The top of the Clarens sandstone is hard as it has been metamorphosed to a shallow depth (0.5-1.5 m) by the heat from the lava flows. Similar observations were made on sheet 4A (Willan, 1976a) and 9C (van Vreumingen and Robison, 1980).

(b) Explosive vents

A notable feature of the Lesotho Formation is the large number of explosive vents which preceded the outpourings of the flood basalts. These vents were completely buried under the later basalt sheets and were exposed only by erosion of the periphery of the cover in the lowlands. The vents are generally perforations of minor local extent only and individual occurrences have been described in detail by Stockley (1947) and Bleackley and Workman (1964). Stockley recognised 72 vents and diatremes; later work has increased this number to 213 (table 3). That there must be numerous vents concealed below the basalt cover was demonstrated at Taung on sheet 10B where a volcanic plug was intersected below 124 m of horizontal basalt flows (Lesotho Highlands Water Project, 1979). Most of the vents are circular to elliptical with diatremes ranging from 7 m to 40 m and an accessible example is exposed near the Mokotakoti River on the main road between Peka and Maputsoe (figure 27). They occur either singly, in pairs, or as clusters rather than being aligned along planes of weakness. The vents are in various stages of preservation. At Rathebane in the middle Tsoelike valley, Stockley has described a magnificent example which forms a conical hill largely filled with agglomerate and ash. A fine example of a partly obscured crater is in the Ribaneng valley on sheet 8D; the tuffaceous sediments infilling the crater dip inwards to the west and to the east respectively at angles of 30^{o} and 10^{o}. Three main types of infilling can be distinguished:

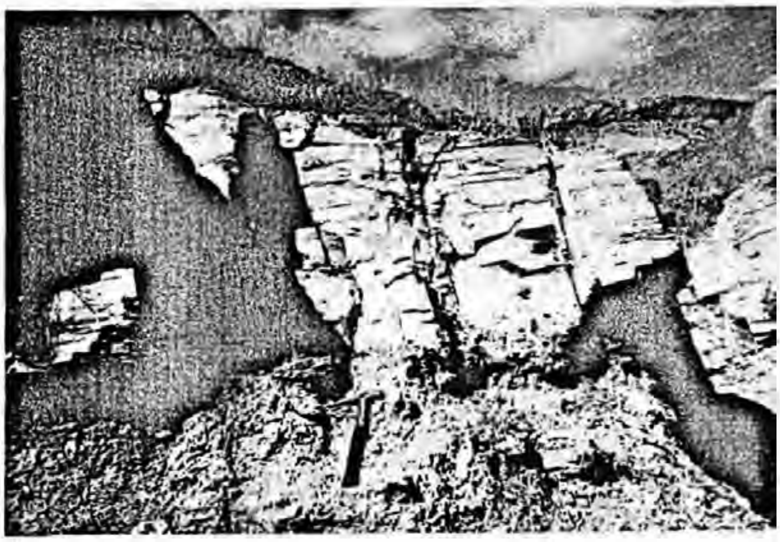

Figure 26. Acidic vitric tuff intercalated within the Elliot Formation in a donga near Ha Motsoene

Figure 27. Volcanic vent exposed near the Mokotskoti River on the main road between Peka and Maputsoe

(a) Dolerite and basalt fragments, commonly vesicular, amygdaloidal or brecciated, accompanied by varied amounts of baked sediment breccia broken off the enclosing walls, encompassed in fine sand, silt, tuff or amygdaloidal basalt,

(b) Massive vesicular dolerite or basalt with xenoliths of sandstone, tuff, basalt or baked sediment, and

(c) Finely divided sedimentary material which can be distinguished from the Clarens Formation only by the presence of basalt, sandstone and shale xenoliths.

These different types are not restricted to one vent but can occur together in the same vent. In the neighbourhood of some vents are tuffaceous layers containing blocks of basalt and lapilli of vesicular basalt and sandstone. The host rocks are in many cases effected by the eruptions, and Stockley (1947) recorded blocks of the Clarens Formation dipping at 55^{o}. Elsewhere, Grohman (1977b) has suggested that some examples of vents may really be collapse structures. On sheet 3A Willan (1976b) observed a neck with sandstone flow lines parallel to the contact and also around a block protruding from the vent. Other features noted are circular concentric jointing of the country rocks around plugs or necks and metamorphic baking of the sediments at the contacts.

Sixty-six plug-like features in the higher members of the Drakensberg lavas have been described and illustrated by Dempster and Richard (1973). They are restricted to a roughly circular area 22 km in diameter with centres 12 km west of Letseng-la-Terae and occur singly or in clusters of up to six in which two or three may be contiguous. The features are restricted to only a few flows with a stratigraphic vertical range as little as 150 m. They consist of circular shallow depressions in the basalt up to 150 m in diameter made up of brecciated lava with a platey or flakey rim which is continuous with the country rock lava. This flakiness extends only a few metres from the rim and dips inward towards a central circular plug of petrographically similar but slightly coarser basalt. Evidence from trenching near Mothae suggests that the depressions are floored at shallow depth by the same basalt that forms the rim and core although altered to a certain extent. Consequently they may not represent plugs but concordant discs or tori (doughnut-shaped) perhaps owing their origin to localized gas expansion within individual flows and thus representing incipient vents.

The distribution of the vents according to the geological formations is indicated in table 3 and figure 28 and it will be seen that over 78 per cent occur within the Elliot and Clarens formations, 94 per cent if the Lesotho Formation is included. Less than 6 per cent are found in the Molteno and Beaufort formations. This evidence supports the view expressed by Gevers (1928) and Stockley (1947) that the volcanoes originated at shallow depths not far below the Molteno Formation, possibly within it; this explosive phase drilled innumerable perforations through the crust and blew off the uppermost portion of the sand cover. Gevers also draw attention to the connection between the vents and dolerite sheets which are generally limited to the upper Beaufort Group or base of the Molteno Formation. As noted by Stockley (1947) this view is supported in Lesotho where extensive sheets of dolerite occur at the upper Beaufort-Molteno contact, a convincing example being the area north and north-west of Mafeteng. There is also a progressive thinning and decreasing occurrence of dolerite sheets from the base of the Molteno to the base of the Clarens Formation. Even thin sheets of dolerite are rare in the Carens Formation.

(c) Basalt lavas

Massive outpouring of basaltic lava followed the explosive vent phase of basic volcanism. These lavas of the Lesotho

Figure 28. Distribution of volcanic vents in the different formations.

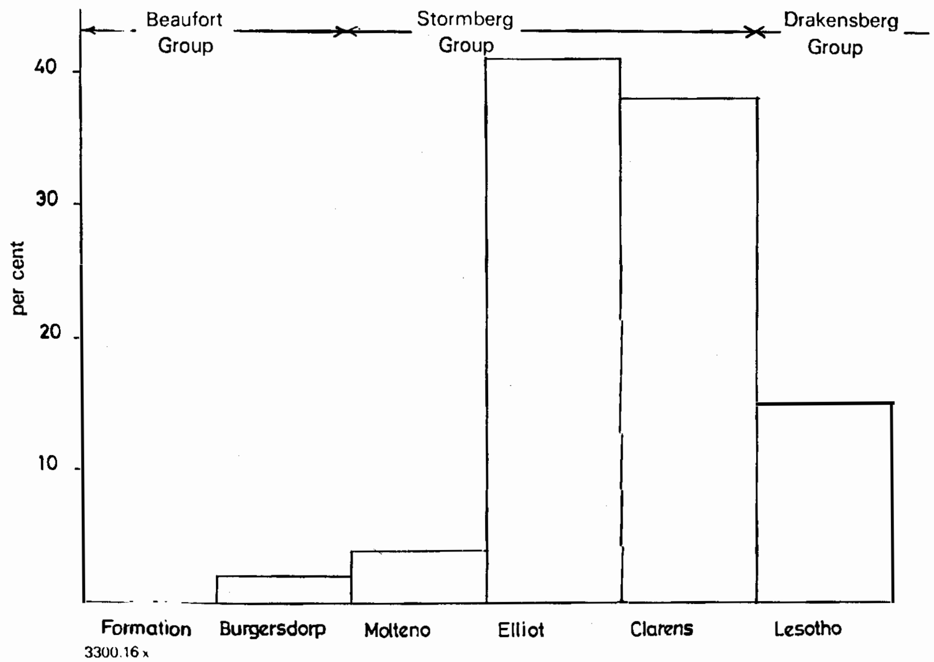

Table 3. Distribution of volcanic vents in Lesotho

Map sheet	BEAUFORT	STORMBERG (GROUP)			DRAKENSBERG	Totals	References
	Formation						
	Burgersdorp	Molteno	Elliot	Clarens	Lesotho		
1B				9	2	11	3 4 12 14 19
1C			5	3	1	9	4 10 12 14 19
1C +			2	1		3	6 19
1D			3	16	5	24	3 4 12 14 19
2A					2	2	5
3A			10	2		12	12 19 26
3B			4	2		6	12 15 19
3C				2		2	9
3C +			9			9	2 12 23
3D					3	3	2 12
4A		1	2	6	2	11	2 12 25
7A	1					1	12
7B		2	2			4	19 21
7C	2					2	22
7D			9			9	1 12 19
8A	1	1	3	2	7	14	2 12 19
8C			4	1	4	9	2 7 12 19
8D				1		1	19
9C					1	1	19
9D			1			1	11
10B				4	1	5	19 24
11C				12		12	19
12B		3	2			5	2 3 19
12D			1	2		3	12
13A			1			1	2 3 18 19
13B			1	8	2	11	2 13 19
13C			7	5		12	12 16 19 20
13D			6	2		8	12 17 19
14B			1		1	2	19
15A		1	10		1	12	2 3 8 12 19
15B			3	4	2	9	2 3 8 12 19
Totals	4	8	86	81	34	213	

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17. Rombouts, 1978b
18. Rombouts, 1979a
19. Stockley, 1947
20. van Middelaar, 1981 (personal communication)
21. van Rooijen, 1975b
22. van Rooijen, 1975d
23. van Rooijen, 1975e
24. van Rooijen, 1976
25. Willan, 1976a
26. Willan, 1976b

Formation (Drakensberg Group) are mainly a uniform series of flows which attain a maximum thickness of 1,650 m along the Great Escarpment in northern Lesotho (Dempster and Richard, 1973; Nöel and Robison, 1980). There is a general increase in thickness from west to east, from 30 m for example on sheet 3A in the lowlands to intermediate thickness in the central area, but there are exceptions such as the Sehlabathebe area where the thickness is only 700-900 m, a reflection probably of the high elevation of the Lesotho-Clarens contact.

The colour of the lavas ranges from moderate to dark grey, greenish grey or purplish when fresh, to red or rusty brown when weathered (van Vreumingen and Robison, 1980; Jaggie, 1981a; Niemi, 1978; Willan, 1976b). The lavas are generally horizontal and range from amygdaloidal, easily weathered varieties with a rubbly appearance to hard, fine-grained, resistant types. The more massive flows are usually characterized by prismatic jointing which does not transgress flow boundaries (Niemi, 1978), and many commonly form impressive cliffs or marker units (Rombouts, 1978b; 1978c; Longerstaey, 1979b; Grant, 1976). The flows are normally evenly superimposed one on another and range in thickness from 20 cm to about 30 m, the larger individual flows covering hundreds of square kilometres. Although individual flows may be remarkably constant in thickness there can be considerable differences in the thickness of successive flows. On sheets 4D and 5C the general individual thickness ranges from 2 to 10 m but north of Khomolihane on sheet 5C four different flows were distinguished in a thickness of 1 m (Jaggie, 1981a). Van Vreumingen and Robison (1980) noted that owing to the uniformity of composition of the basalt the recognition of individual flows is not always easy and depends on the preservation of original surface features of the lower basalt flow, the occurrence of a baked earth zone, an abrupt change in the number and form of amygdales and abrupt changes in petrography. Bleackley and Workman (1964) have provided some representative sections of individual flows exposed at Sani Pass and Letele Pass while Binnie and Partners (1971) have provided logs and descriptions of lava flows ranging in thickness from a few centimetres to possibly 30 m in 14 boreholes drilled for the Oxbow investigations.

Zoning of flows has commonly been observed. Binnie and Partners (1971) noted a thin basal zone (150-300 mm) of pipe amygdales containing agate and chalcedony whereas spherical amygdales containing quartz, agate and zeolites are found at or near the tops of flows in zones up to 5 m thick. These observations were supported by Niemi (1978) on sheet 4B where pipe amygdales 1-5 cm long and 2 mm to 1 cm in diameter are generally found in a narrow (10-20 cm) zone at the base of the flows with spherical amygdales 3 mm to 15 cm in diameter tending to be concentrated near the top of flows but can be found throughout. The central portions of flows over 3 m are amygdale-poor with the number and size of amygdales increasing towards the top and bottom. Four zones were distinguished in individual flows by Bleackley and Workman (1964) and Dempster and Richard (1973), a thin (10-20 mm) basal zone of aphanatic basalt followed by one of pipe amygdales, a central zone of weakly vesicular basalt and an uppermost zone of strongly vesicular basalt. Experience by Jaggie (1981a, b) on sheets 4D and 5C however indicated that the narrow basal zone of aphanatic basalt is often difficult to establish. A thorough study was made of sheet 9C by van Vreumingen and Robison (1980) who observed that most basalts regardless of level contain many mineralized gas cavities which occur in two forms - as pipes 5-15 cm in length and 1-2 mm in diameter or as globular gas bubbles 3 mm to 15 cm in diameter. The gas bubbles can occur throughout a flow but tend to be concentrated near the top of flows and in general the number and diameter of globular cavities tends to increase from the bottom to the top of an individual flow.

On sheet 10B, van Rooijen (1976) noted conspicuous differences between the upper and lower basalts (arbitrary elevation limit 2,135-2,285 m) as follows:-

Lower basalts	Upper basalts
Thin flows prevailing (0.5-3 m)	Thicker flows (20-30 m)
Basalt very amygdaloidal	Basalt less amygdaloidal
Quartz and calcite in amygdales and geodes	Zeolite filling in amygdales and geodes
Rich in geodes and chert veins/ lenses	Geodes and chert veins rare

No significant correlation of flow thickness with height was seen on sheet 9B (Willan, 1976c); thus thick flows of 10 m were seen at 2,102 m and thin flows at 2,803 m and vice cersa. On sheet 10A, Richardson (1976a) did not find that amygdaloidal basalts were less common in the higher elevations but the mineral composition of the fillings of the amygdales changed from a calcite-zeolite predominance in the lower basalts to a quartz predominance in the higher basalts. Lava flows particularly rich in zeolites were found in two places and heavy mineral gravitations in the region are white with zeolites. The weathered surfaces of the rocks themselves have the appearance of a quartz conglomerate. On sheet 4B about 80-90 per cent of the amygdales are filled with white zeolites and 10-20 per cent with quartz agate or chalcedony although no agate or chalcedony was noted above 2,430 m (Niemi, 1978). On sheets 5D, 6C, 6D, 11A and 11B, Noel and Robison (1980) found that zeolite amygdales were present throughout and to altitudes greater than 3,300 m whereas quartz-filled amygdales and geodes rare. On sheet 4D and 5C Jaggie (1981a) found that most amygdales are filled with zeolites and, to a lesser extent, quartz with both mineral types occurring at all levels. Richardson (1975) noted on sheet 9A that in addition to zeolites, quartz and chalcedony, chlorite is present which can be mistaken for copper mineralization. Calcite and chlorite are found in amygdales on sheet 4A (Willan, 1976a) and sheets 16A and 16B (Rombouts, 1979b) but on sheet 4B amygdaloidal calcite is quite rare and its occurrence within the basalt is clearly sporadic (Niemi, 1978). As stated earlier by Bleackley and Workman (1964) no overall pattern of compositional change can be detected in the distribution of the amygdale minerals which points to numerous local differences of the volatile phase within the flows, also repeated changes in the nature of the volatiles and dissolved components throughout the period of the eruption.

The lower 30 m of the basalts are more varied than these higher in the sequence owing largely to the presence of pillow lavas, sediment intercalations, ash beds and neptunian dykes. Pillow lavas have been recorded on many sheets in Lesotho (4B, 8A, 8B, 8C, 9C, 10B and 14A) and have also been described from a basalt flow in the Drakensberg volcanics in the Ndedema valley of Natal (McCarthy, 1970). On sheet 4B a thin Clarens green siltstone is overlaid by 1-2 m of pillow lavas followed by about 25 m of massive basalts (Niemi, 1978). Such pillow "zones", formed when the basalt flowed into streams or small lakes, are usually confined to 20 m or less along strikes of one or more successive flows, clearly suggesting localized formation. The pillows are generally less than 40 cm in diameter and exhibit exfoliation-type weathering with up to 5 mm-thick layers commonly spalling off. Pillow lavas were noted as low as 2,134 m and one as high as 2,804 m. On sheet 8A autobrecciated pillow lavas were noted along the Kena and Raleqheka road north of Popa-Popanyane (Richardson, 1975). At Thabana-li-mele and Ramabanta on sheet 8B pillow lavas are found near the base of the lava succession and generally have been broken up by autobrecciation to a distinctive cream-coloured rubble but perfect pillows, probably the finest in Lesotho, are exposed in the Hlatsing River near Ramabanta (Grohmann, 1976). On sheet 9C pillow lavas about 30 m thick separate persistent sandstone lenses from the top of the Clarens Formation. Pillow lavas were found on sheet 9C in the Ntsupe valley where a silt sedimentary intercalation is covered by a chaotic mixture of sediment and pillow lava forming a zone 8 m thick (figure 29). Probably the basalt flowed into a lake having unconsolidated sediments in the bottom (van Vreumingen and Robison, 1980). Pillow lavas in the lower basalt flows have also been recognised on sheet 10B (van Rooijen, 1976) and on sheet 14A (Longerstaey, 1979b).

Sedimentary inclusions are abundant in the lower basalt flows and frequently can be traced over long distances. On sheet 3B sandstone lenses are 0.5-2 m thick and one near Ramothane has been traced for nearly 1 km (Richardson, 1976b). Sandstone and fine-grained ashy-looking beds 40-60 cm thick are present in the lower 90 m of lavas on sheet 4A (Willan, 1976a). On sheet 8A sandstone 1-2 m thick are common but generally are of limited extent although one bed near the junction of the Makhaleng and Makhaleneng rivers can be traced for a few kilometres (Richardson, 1975). A few metres to tens of metres above the Clarens contact on sheet 8D lenticular inclusions of sandstone were observed, especially in the Ribaneng valley (Noel, 1980b); these inclusions are 2-3 m thick, have a length of 10-20 m and are intensely baked. Sandstone intercalations and ash beds in the lowest 180 m of lavas have been described in detail on sheet 9C (van Vreumingen and Robison, 1980). In the lower Maletsunyane and Ntsupe valleys one thick intercalation and 4 or 5 levels with thin irregular sand lenses were distinguished. The thickness of the main intercalation which is exposed continuously about 120 m above the Clarens contact, increases from 5 m in the north to 20-30 m between Motlotla and Ntja (figure 30). The sediments forming the intercalation are varied laterally. Thus near Motlotla the lowest 1.5 m consists of sandstone overlaid by 10 m of green volcanic breccia with 10-15 m of mudstone, siltstone and sandstone above; the common occurrence of mudcracks, ripple marks and small-scale

Figure 29. Pillow lava and deformed sediments in the Ntsupe valley.

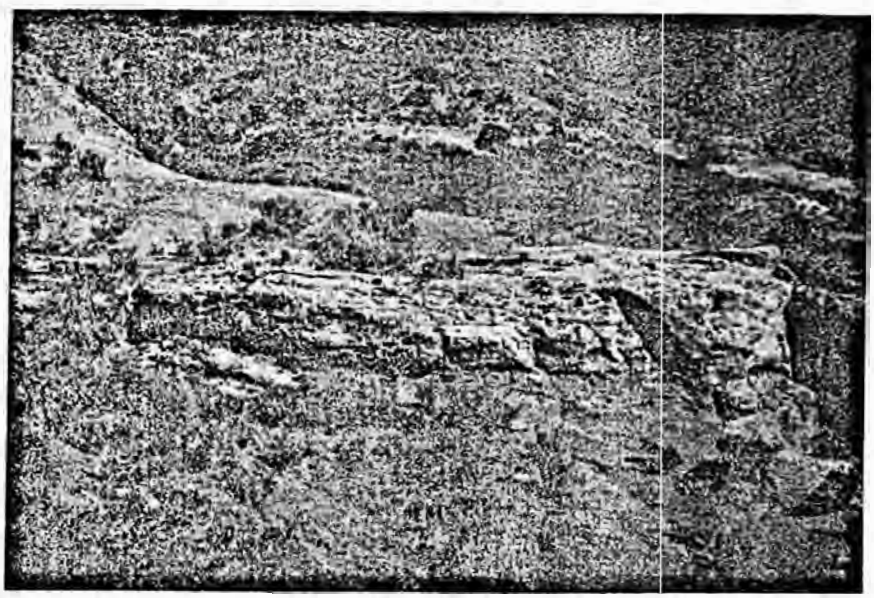


Figure 30. Sandstone lens in lower basalts near Motlotla, lower Maletsunyane valley.

cross-bedding suggests deposition in playa lakes. South of Motlotla near Ntja the green volcanic breccia becomes predominant, attaining a thickness of 30 m. At Ntja two lower and four higher levels containing irregular sandstone lenses (1-3 m) were observed. Near Motlotla lenses of cross-bedded sandstone can be found at three levels above the main intercalation; a few metres below a sediment layer (0.5 m thick) contained 3 cm of coal. In the Ntsupa valley the base of the main intercalation is about 20 m above the Clarens contact. The intervening basalts, however, become thinner in a south-easterly direction and at the Ntsupe-Senqunyane confluence the green breccias forming the major part of the intercalation were deposited directly on the Clarens sandstone. Probably the similar sedimentary intercalations near Motlotla, Ntja and the Ntsupe valley correspond to the same period of time during which a major standstill of lava eruption occurred and the sediments accumulated in a small basin, but fossils are lacking to prove or disprove the hypothesis. It is of interest to note that sandstone intercalations near Tolonyane on sheet 13D contain coal (Rombouts, 1978c). On sheet 10D an intercalation in the Selobatho catchment had a circular outline indicating a basin-shaped structure and demonstrating deposition in a shallow pool (Leroy and Vandichel, 1980). As described by van Vreumingen and Robison (1980) above, tuff beds are commonly associated with the sandstone intercalations. Sections covering the tuff beds in the southern areas of Lesotho are given in some detail by Stockley (1947) who noted that palagonite glass fragments are present.

At many places on sheet 9C ropy lavas were seen, with the thickness of the ropes ranging from 2 cm to 10 cm (figure 31) but block lava was observed only at one locality where the Maletsunyane River had exposed the surface of a flow. Perfect examples of ropy lavas were also seen on sheet 4C (Jaggie, 1981b) and on sheets 4D and 5C (Jaggie, 1981a). On sheet 9B the apparent movement of the ropy lavas, and the recording of the tilt of sloping pipe amygdales, were used to determine the source directions of the lavas (Willan, 1976c); the main direction is south to south-west (30%) followed by flows to the north-west and north (12%). Overall the preferred direction is westward rather than eastward. Similar criteria were used on sheet 9C (van Vreumingen and Robison, 1980) but the small number of measurements made gave an almost isotropic result. it was noted that a large number of measurements would be required because local flow directions could deviate from the main direction owing to topographic irregularities and where a number of sources were not erupting synchronously, vertical as well as horizontal variations would occur. The topographic position of the lavas was combined with tilt of pipe amygdales to determine flow directions on sheet 10B (Van Rooijen, 1976). The nearly thin lavas flows of local extent had many sources scattered over the sheet although a preference for southerly directions existed. For the higher lavas, north-west flow directions prevailed.

Amygdaloidal xenoliths forming amygdale-rich inclusions in amygdale poor lavas were observed on sheet 9c and in general they are circular with a dimater of 10-15 cm. In other localities the xenoliths were larger (30-35 cm) or cigar shaped. Probably the xenoliths were formed by autobrecciation of congealing but still mobile flows. Their edges are diffuse suggesting partial remelting by the incorporating lava flow. Autobrecciation of lavas was also noted on sheet 4C (Jaggie, 1981b), 5C (Jaggie, 1981a) and 5D (Noel and Robison, 1980). A phenomenon observed on sheet 9C (van Vreumingen and Robison, 1980) is the occurrence of vesicular dykes which have a thickness of 10-25 cm and contain many mineral-filled gas cavities. These were probably formed by still fluid lava of the interior of the flow intruding cracks in the already congealed surface. The amygdaloidal fillings consist in most cases of zeolite and quartz with less common calcite.

G. Dolerite intrusions

1. Occurrence

Dolerite intrusions are ubiquitous in Lesotho, as is the case in other areas of the upper Karoo Supergroup in southern Africa and are in two forms, horizontal or inclined sills and vertical or subvertical dykes. Stockley (1947) recorded more than 1,000 dykes and sills and the numbers were markedly increased during the United Nations regional surveys as indicated on the geological maps. As mentioned earlier a sympathetic relationship exists between the occurrence of doleritic sills and sheets in the Burgersdorp and Molteno formations and the occurrence of volcanic vents in the higher Elliot and Clarens formations; the sills and sheets decrease both in thickness and number from the Beaufort to the Clarens Formation. The dykes and sills were the feeder fissures along which the Drakensberg lava flowed to be poured out on the surface.

2. Dykes

The mapping of the larger dykes is facilitated by their topographic expressions. Thus where they cut sandstone they characteristically give rise to gullies or channels whereas in the softer mudstone and siltstone they have a tendency to stand out as low ridges or chains of hillocks (figure 32). Both negative and positive relief may be shown by the larger dykes such as Lancers Gap (Dusar and Grohmann, 1978) while the conspicuous parallel dykes near Mohale's Hoek form prominent geomorphological features. The dolerite channels traversing the cream-coloured Clarens sandstone may be observed extending across the countryside for several kilometres in both directions. The metamorphic effects produced by the dykes can be striking. Sandstone can be converted into quartzite in which strong prismatic jointing arranged at right angles to the length of the dykes may be developed (figure 33). The quartzite resists

Figure 31. Ropy lava in Lesotho Formation north-east of Motlotla

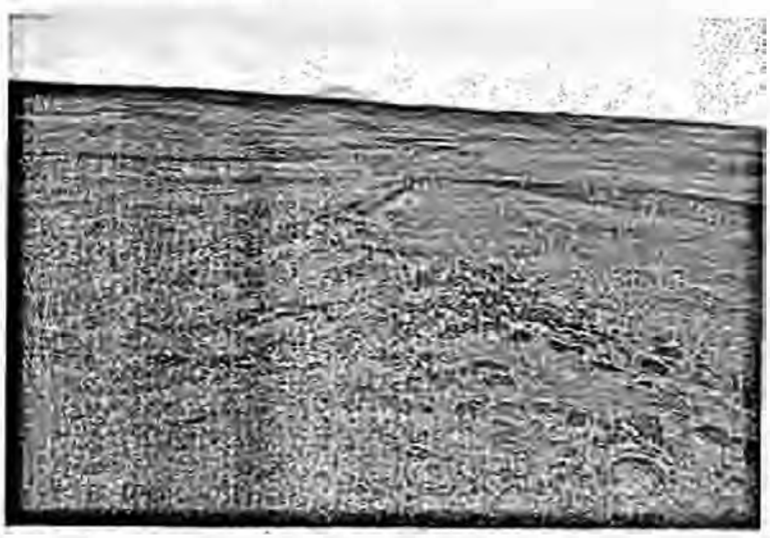


Figure 32. Dolerite dyke cutting Beaufort Formation near Ha Mpalami

erosion so that the presence of a dyke is often indicated by these remaining quartzite walls as is the case at Lancers Gap (figure 34).

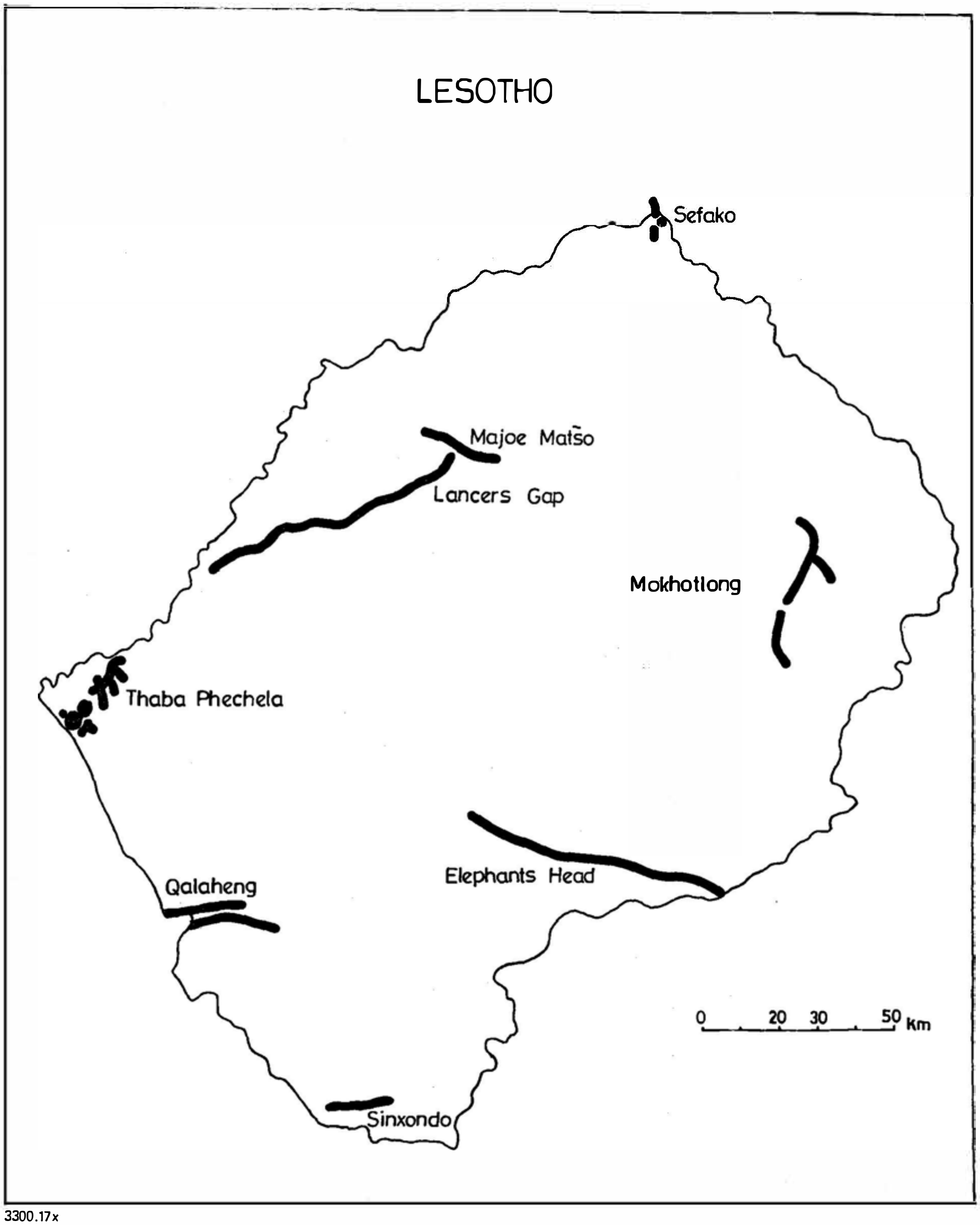
Another example is the main entrance to the Thaba-Bosiu fortress of Moshoeshoe I where the steep ascent is along a weathered dolerite dyke with the formidable final portal formed by metamorphosed Clarens sandstone (figure 36). With the softer mudstone and shale the rock is either completely bleached or black or dark-bluish hornfels is produced. The extent of the metamorphic effect is roughly proportional to the width of the dyke. Crushing, shattering and slickensides due to the thrusting aside of the country rock during intrusion are seen especially where the dykes have been quarried for road metal.

The dykes differ greatly in length and thickness. The Lancers Gap dyke has been traced for 70 km (figure 35) and ranges in thickness from 3 m to 300 m, the average being 100 m (Dusar and Grohmann, 1978). On sheet 4A the Majoe dyke is 23 km long and up to 300 m thick whereas the Mapoteng dyke is 6.5 km long and up to 200 m thick (Willan, 1976a). Large dykes intruded into basalt are the Elephants Head dyke 50 km long and up to 600 m thick and the Mokhotlong dyke 20 km long and averaging 100 m thick (Dempster and Richard, 1973). The Lesobang dyke on sheet 9B is 20 km long and up to 150 m thick although the average is probably 2-5 m (Willan, 1976c). Numerous dykes cutting the basalt on sheets 4D and 5C have are generally between 0.6 and 10 m thick but some are over 100 m thick (Jaggie, 1981a). The larger dykes can be traced for more than 20 km especially in the south part of sheet 5C where a major zone of intrusions trends north-east in the south-east veering to easterly in the south-west. The larger dykes are uniformly doleritic in texture and mineralogy but the smaller dykes are less uniform with those between 0.5 and 50 cm being black, aphanitic and massive.

Figure 33. Prismatic jointing in metamorphosed sandstone at the contact with the Lancers Gap dolerite; the Clarens sandstone caps the hill in the background

Figure 34. Langers Gap near Maseru formed by metamorphosed Clarens sandstone walls after the removal of a dolerite dyke through erosion; partly weathered dolerite (foreground) is quarried for road metal

Figure 35. Major dolerite intrusions in Lesotho.



Probably the most closely mapped dyke is the Lancers Gap which follows a twisted course in a direction varying between ESE and NNE. It changes from an average dolerite dyke 3 m thick to about 200 m at Lancers Gap and 300 m at its thickest on the southside of the Phuthiatsana River where 19 boreholes were drilled in the dolerite and surrounding baked Elliot Formation as part of the investigations for the Phuthiatsana irrigation scheme (Dusar and Grohmann, 1978). The structure is reminiscent of a lopolith, i.e., a sill-like enlargement above and downwards gradually turning into a dyke. North of the Phuthiatsana River the enlarged dyke abruptly narrows and disappears below the first basalt flow although it probably continues at depth and joins the Majoe dyke. The Lancers Gap dyke thus probably represents an early phase of magmatic activity. Grain-size differentiation between the finer-grained walls and the coarser-grained centre of the dyke was regularly observed. The dolerite is ophitic in texture but commonly olivine-rich and there more serpentinized. Serpentinized gliding planes are common in the boreholes where fresh rock is encountered. Leucocratic coarse-grained segregations are common. Segregations and schlieren consisting of ilmenite or magnetite and fine-grained pyrite and bornite have been recorded (Dusar and Grohmann, 1978). Serpentinization of olivine-rich dolerite, originally thought to be peridotitic, was observed in drill cores from the Ha Sebako area south of Maseru (Smirnoff, 1980).

The dolerite directions are summarized in table 4 where it will be seen that the directions can be quite diverse. In northern Lesotho it was found that almost 70 per cent are in a west-north-west trend which is that of the kimberlite intrusions. This direction is considered to be the youngest one with other dolerite directions, north, east, north-north-west and north-north-east being older directions (Dempster and Richard, 1973). On sheet 9C some of the large dykes strike 190°-218°, almost at right angles to the prevailing direction of 90°-120° (van Vreumingen and Robison, 1980).

Table 4. Direction of dolerite dykes

Area on mapsheet	Trend	Source
Northern Lesotho (Phase I)	$80^{o}-140^{o}$ (69%)	Richard, 1972
1C+	$96^{o}-116^{o}$, $117^{o}-136^{o}$ $137^{o}-156^{o}$, $177^{o}-196^{o}$	Etoile, 1980
3A	$110^{o}-119^{o}$ (main) $80^{o}-90^{o}$	Willan, 1976b
4A	$81^{o}-100^{o}$ (19%) $111^{o}-130^{o}$ (24%) $171^{o}-180^{o}$ (8%)	Willan, 1976a
4D	$90^{o}-135^{o}$	Jaggie, 1981a
5C	$105^{o}-130^{o}$	Jaggie, 1981a
9B	ESE	Willan, 1976c
9C	$90^{o}-120^{o}$	van Vreumingen and Robison, 1980
9D	WNW NE	Leroy and Vandichel, 1980
10C	WNW	Jaggie, 1981c
10D	WNW (main) NE (secondary)	Leroy and Vandichel, 1980
11C	WNW	Rombouts and Robison, 1980
12AB	E-NW	Grohmann, 1977b
12D	Random	Michel and Dusar, 1977
14B	WNW	Longerstaay, 1979a
15AB	ESE-WNW	Grant, 1976

Bleackley and Workman (1964) described the continuity of a dolerite dyke with a lava flow demonstrating that the dolerite dykes are feeder fissures for the lavas. A similar occurrence has been observed in the Tsoelike River on sheet 10D (Leroy and Vandichel, 1980). A dyke changing into a sill has been described and illustrated by Dempster and Richard (1973); it is a vertical dyke 10 m wide penetrating Clarens sandstone but on reaching the overlying lavas turned into a sill which follows the sandstone-basalt boundary. On sheet 9B sedimentary xenoliths were noted in three dolerite dykes at heights more than 55 m above the unexposed Clarens sandstone surface (Willan, 1976c).

3. Sills

As noted by Stockley (1947) dolerite sills are more common in the Burgersdorp and Molteno formations as can be seen by their abundance on sheet 7A near Mafeteng where van Rooijen (1975c) estimated that about 22 per cent of the sheet was occupied by dolerite sills or sheets, primarily in the Beaufort Group. The largest sill is at Thaba Pechela where the thickness may be 150 m. As a rule the sills are not uniform in thickness over long distances but intrude the sediments irregularly, jump from one level to another and can pinch out abruptly. Sills may form ridges which have the appearance of solid dolerite whereas they may be merely thin veneers. This was clearly shown by drilling undertaken as part of aggregate investigations in the Maseru region (Dusar and Reed, 1977). Thus drilling of a dolerite ridge near the Sekamaneng River north of Maseru revealed that the sill forms a thin blanket only 3-10 m thick. The pre-erosional shape of this folded dyke was probably lens-like with a doming upper boundary similar to the quarried Foso sill which is approximately at the same elevation 1 km to the south-east. Another example of a folded sill ridge was near Thetsane where bulldozing indicated a thickness of only 1 m.

A complex dolerite sill occurs on both sides of the Little

Caledon River south of Likotsi Hill where it has intruded sandstone and mudstone of the Beaufort Group (Dusar and Reed, 1977). The sill dips 12°N and the maximum thickness is about 25 m decreasing gradually to the east. The western edge is more irregular and becomes inter-layered with the host rocks.

Detailed investigations at Mokunutlung Hill in connection with the proposed construction of an international airport revealed that a dolerite sill forms the cap of the hill and is joined on the eastern side by a large dolerite dyke (Dusar and Reed, 1977). The dolerite sill is extensively developed on top of the northern part of the hill and overlies sediments, mostly red mudstone, of the Elliot Formation. At the contact, chilled dolerite and baked sediments form hard fine-grained quartzitic hornstones. Many smaller, more weathered, dolerite sills occur below the main sill. Feeder dykes run in several directions from the main sill and the occurrence illustrates the interconnecting network of dykes and sills to which Dempster and Richard (1973) have drawn attention.

Stockley (1947) noted that many dolerite sheets display columnar structure, examples being in Dilly Dilly stream in the Quthing district and to the west of Morije below Masite Hill. Some of the more massive members of the Lesotho Formation are considered by Dempster and Richard (1973) to be, in fact, sills or gently inclined semi-concordant sheets most less than 10 m thick; they may be recognized by the presence of columnar jointing and the absence of vesicles in the upper and lower margin, e.g., at Oxbow at the lower Motete road crossing and at Muella. An unusually thick layer of basalt at Mokhotlong may also be a sill.

Although many sills and dykes display coarser differentiated fractions, the Sinxondo gabbroic still discovered by the United Nations Exploration for Minerals project in the remote mountainous region of sheet 16B in southern Lesotho

(Rombouts, 1979b) is of a different dimension and may be compared with the Insizwa differentiated sill in nearby Transkei. In contrast to many sills which are intruded into the Beaufort or Molteno formations the Sinxondo sill is about 210 m above the base of the basalt flows of the Lesotho Formation. The basal zone above the top of a compact columnar basalt layer is a coarse-grained hornblende gabbro about 20 m thick. This zone is topped by a pyroxene-rich gabbro about 40 m thick. The pyroxene gabbro shows banding of two types, one having an equal alteration 2 cm thick of 'laminae' containing different amounts of white plegioclase crystals, the other showing a rhythmic display 15-20 cm thick in a zone containing large green pyroxene crystals forming a star-like texture. It was inferred that the hornblende gabbro originally covered an area of about 72 km^2 and the pyroxene gabbro an area of 15 km^2 but that subsequent erosion removed about two thirds of each. The sill now covers the valley heads of the southern tributaries of the Sinxondo River. A possible feeder for the sheet-like intrusion could be a dolerite dyke running parallel to the Sinxondo River. A volcanic agglomerate crops out between the dyke and the intrusion and is well developed in the Mamakeli valley around the Clarens-Lesotho formational contact. To the east the agglomerate thins out, both in area and thickness, and dips towards the west reaching the level of the upper Elliot Formation in the Nkutu valley.

The Sinxondo sill warrants further study although this will be difficult owing to the mountainous nature of the country with vertical cliffs hampering access to the base of the intrusion.

H. Comparison of basalts and dolerites

1. Petrography

The petrography of the Lesotho basalts has been studied by Stockley (1947), Bleackley and Workman (1964), Cox and Hurnung (1966) and Binnie and Partners (1971). Of 53 samples examined by Stockley, 39 were ordinary basalts, 10 olivine basalts, 2 andesites and 2 trachytes, but the non-basaltic lavas were all found close to the base of the succession in western and south-western Lesotho. In contrast, all the rocks examined by the other investigations were true basalts and the majority were found by Bleackley and Workman to contain a small percentage of altered or replaced olivine phenocrysts. Petrographically the lavas were the same from bottom of the succession to the top. A variety of textures was observed. Commonly the rock consists of a uniform groundmass of subhedral crystals with or without phenocrysts. Where pyroxene occurs in large grains the texture is markedly ophitic. Fine-grained densely coloured brown or grey materials is everywhere present interstitially and is dominant in some cases. No flow textures were observed and in most of the basalts there is little or no glass. Again, observed variations bear no relationship to the sequence of flows, coarse- or fine-grained, granular and ophitic types occurring in all parts of the succession. The rocks observed all possess plagioclase feldspar, clinopyroxene and opaque grains with or without olivine as the primary mineral assemblage. In addition they contain products of the alteration of the primary constituents, notably minerals of the serpentine and chlorite groups. Binnie and Partners found that the basalts could also be described as dolerites on account of the frequency of the occurrence of ophitic texture. The rocks showed signs of considerable alteration as evidenced by the presence of many microcrystalline alteration products. This alteration could be the result of hydrothermal solutions or of volatile components released during the final stage of consolidation of the magna from which the rock crystallised.

Cox and Hornung (1966) studied in detail a 1,500-m east-west succession between Leribe, Letele Pass, Kao and Thaba

Bosiu in northern Lesotho. The succession was sampled on the average every 21 vertical metres, the average thickness of the flows being estimated at about 10 m. Twenty-four rocks were analysed, each collected from the massive central portion of a flow. The uniformity of the basalts in the field is little less striking in thin sections. The rocks are typically tholeiitic in appearance, containing little olivine and substantial amounts of interstitial glass. Although few of the rocks appear porphyritic in the field, microphenocrysts of plagioclase and altered olivine are present in nearly all the chilled basalt from flow bases. The central massive portions of flows are generally rather coarse, tabular groundmass plagioclase crystals, many reaching 1 mm across, with the result that the microporphyritic texture is somewhat obscured. Clinopyroxene generally has an ophitic to sub-ophitic relation to the plagioclase in the coarser rocks which consequently have a doleritic appearance in thin section. Fine-grained specimens have typical microporphyritic basaltic textures. In the majority of basalts examined, small pseudomorphs after olivine make up 1-2 per cent of the rock but it is occasionally difficult to distinguish altered olivine from altered glass and the original presence of olivine cannot always be substantiated. No fresh olivine was found in any of the normal basalts but a few olivine-rich flows were found at the base of the succession of the Letele track and these contained up to 12 per cent olivine, some of which is still unaltered. A similar olivine-rich flow was found about 290 m above the base of the succession on the Sani-Pass road. Augite is the dominant pyroxene and is accompanied in many rocks by pigeonite; both appear as nearly colourless anhedral crystals. Plagioclase is the most abundant mineral in the rocks and includes sparse microphenocrysts which may be up to 2 mm across, not uncommonly arranged in a glomeroporphyritic fashion. Glass is relatively abundant in most of the rocks and may reach 25 per cent by volume. It is mainly dark brown and crowded with minute granules or ore. In many of the rocks examined much of the glass is altered to a variety of radiating micaceous mineraloids ranging from a clear bright orange to an almost opaque dull green appearance. Zeolites are widely present in amygdales with natrolite, heulandite, phillipsite and apophyllite recognized by Cox and Hornung (1966); scolecite, analcite, thomsonite, mesolite, and heulandite by Stockley (1947); epistilbite, clinoptilolite by Bleakley and Workman (1964); and scolecite, stilbite heulandite, phillipsite and laumontite-leonhardite by Jaggie (1981a). Clinoptilclite was found by Bleakley and Workman to occur over a vertical range between 390 m and 1,240 m. Two core samples containing some dark brown soft mineral from depths of 235 m and 421 m respectively were studied by Binnie and Partners using X-ray diffraction (XRD) and electron scanning microscope and these indicated the presence of swelling material which may form up to 20 per cent of the sample. Optical microscopy suggested a form of altered glass (chlorophaeite) but the XRD and scanning electron microscopy suggested a montmorillonite-vermiculite mixture.

No detailed study of the Lesotho dolerites comparable to the study by Cox and Hornung has yet been undertaken but it probably is unlikely to differ materially from the general study of the Karoo dolerite made by Walker and Poldervaart (1949).

2. Petrochemistry

When the average Lesotho basalt, calculated from 21 analyses (Cox and Hornung, 1966), is compared with the average Karoo dolerite a close similarity is observed and this verifies the field evidence that the two rock types represent the same series of magmas (table 5).

Within the southern African Karoo province, the Lesotho

Table 5. Average Composition of Lesotho basalts and Karoo dolerites

Major element	Basalts (in per cent)	Dolerites	True element	Basalts	Dolerites
SiO_2	51.8	52.7	Ba	256	200
TiO_2	1.13	1.16	Be	3	-
Al_2O_3	14.8	15.4	Co	34	38
Fe_2O_3	3.92	1.38	Cr	317	293
FeO	7.26	9.35	Ga	16	24
MnO	0.17	0.22	Li	10	9
MgO	7.1	6.6	Mo	3	-
CaO	10.57	9.96	Ni	73	70
Na_2O	2.40	2.22	Pb	10	10
K_2O	0.74	0.87	Rb	50	17
H_2O+	-	-	Sc	34	38
P_2O_5	0.13	0.16	Sr	190	168
			V	300	225
			Y	23	22
			Zr	85	88

Source: Cox and Hornung (1966).

lavas of the central Karoo basin are lower in Ti, Fe, Na, K and P and higher in Si, Al and Mg relative to those of the basin margins (Rhodes and Krohn, 1972); these geochemical variations are apparently related to regional tectonics of

Karoo age and are unrelated to pre-existing trends in the Precambrian basement complex.

3. Potassium-argon dating

Whole-rock potassium-argon age dating of Karoo basalts and dolerites were undertaken by Fitch and Miller (1971) and the results are given in table 6. It is concluded that Karoo volcanism began in Lesotho about 187 million years ago and that intrusive activity continued intermittently until at least 155 million years ago. The lava flows must have been poured out in rapid succession as there is no significant time difference between the lowermost lavas and those 400 m higher at Bushman's Pass (figure 37) even though a paleomagnetic reversal occurred at this time (Fitch and Miller, 1971). Possible subsidiary maxima of activity occurred around 173 million years (alteration of lavas at Bushman's Pass), 161 million years (sill at Sebapala; Qalahang dyke near Mohale's Hoek) and 155 million years (dykes near Quthing and at Bushman's Pass). Activity thus terminated in the Late Jurassic.

The relationship of the Lesotho volcanism to the overall Karoo volcanic cycle of southern Africa is indicated in table 7. The acidic volcanism in Lesotho can be correlated with the Nuanetsi and Lebombo rhyolites which pre-date the Drakensberg lavas.

I. Kimberlite intrusions

1. Occurrences

The ultrabasic rock kimberlite, the only primary terrestrial source of diamond, occurs as dykes, blows (dyke enlargements), pipes (diatremes) and less commonly as sills. Although sills have been reported from South Africa, Zimbabwe, Tanzania, Greenland (Dawson and Hawthorne, 1973) and Australia (Stracks

Table 6. Whole-rock potassium-argon age dates of basalts and dolerites (after Fitch and Miller, 1971)

Description	Average apparent age & error (million years)
Dolerite sill, roadside 5 km W of Sabapala	137 ± 3
Dolerite sill, roadside 5 km W of Sabapala	160 ± 9
Basalt lava 6 m above Clarens Formation on hill immediately S of Cutting Camp	186 ± 7
Dolerite dyke same locality as above	157 ± 27
Dolerite sill, in river 2.5 km N.E. of Quthing	187 ± 7
Dolerite dyke, 2230 m Bushman's Pass, E. of Maseru	154 ± 6
Basalt lava, 2225 m Bushman's Pass section	189 ± 7
Basalt lava, 2225 m Bushman's Pass section	160 ± 16
Basalt lava, 2205 m Bushman's Pass section	169 ± 7
Basalt lava, 2180 m Bushman's Pass section	176 ± 5
Basalt lava, 2175 m Bushman's Pass section	173 ± 5
Dolerite dyke, 2165 m Bushman's Pass section	155 ± 15
Basalt lava, 2165 m Bushman's Pass section	179 ± 6
Dolerite dyke, 2025 m Bushman's Pass section	148 ± 16
Basalt lava, 1930 m 6 m above base of lavas	165 ± 7
Dolerite dyke, 2.5 km N. of Mohale's Hoek	162 ± 5

<u>Summary</u>

155 ± 6 m.y.	Average apparent age of 3 fine-grained intrusive rocks.
161 ± 7 m.y.	Average apparent age of 3 coarse-graines intrusive rocks
171 ± 8 m.y.	Average apparent age of 5 subsequently altered lava rocks (i.e. approximate age of metasomatism).
187 ± 9 m.y.	Average apparent age of the fresh top and bottom lavas of the first 400 m of the lava succession along Bushman's Pass Road.
186 ± 7 m.y.	Apparent age of the basal lava at Cutting Camp, Quthing district.
187 ± 7 m.y	Apparent age of associated intrusive rocks in Quthing district

Figure 36. Steep ascent to the main entrance of the Thaba Bosiu fortress of Moshoeshoe I along a weathered dolerite dyke with the formidable final portal formed by metamorphosed Clarens sandstone

Figure 37. Lavas at Bushmans Pass near Maseru which have been dated by K/Ar methods as being 187 million years old

Table 7. Relationship of Lesotho volcanic activity to overall Karoo volcanic cycle (after Fitch and Miller, 1971)

Stage of cycle	Age dating	Lesotho activity	Activity elsewhere
Waning phase			
Subcycles	105-115 ∓ 10 m.y.	-	Lupata alkali basalts
	ca 155 m.y., 161 m.y.	Subsidiary maxima of dolerite magmatism and metasomatism	-
	166 ∓ 10 m.y.	-	Lupata rhyolites
	167 ∓ 7 m.y.	-	Granites of Mateke Hills
	ca 172 m.y.	Subsidiary maxima of dolerite magmatism and metasomatism	-
Culminating phase			
Subcycles	ca 187 ∓ 7 m.y.	Drakensberg basalts	Flood basalts of Central Southern Africa
	190-194 ∓ 12 m.y.	Acidic volcanism	Nuanetse and Lebombo rhyolites
Waxing phase			
Subcycles	-	Explosive vents	Lower alkaline and tholeiitie basalts of Nuanetsi and Lebombo districts
	ca 195 m.y.	-	Marangudzi igneous complex
	ca 197 m.y.	-	Shawa igneous complex

et al, 1979), only two minor sill-like bodies, occurring as apophyses to a dyke (Dempster and Tucker, 1973) and a pipe (Robison, 1980d), are known in Lesotho, and accordingly this mode of occurrence will not be considered further. A total of 405 kimberlite bodies have been recorded in Lesotho, of which 39 are pipes, 23 blows and 343 dykes (Robison, 1981). Their distribution is shown in figure 38. The largest kimberlite intrusion is the Kao Pipe, which with dimensions of 730 m by 720 m and a surface area of 19.8 ha, is one of the larger pipes in the world. The size and shape of some major pipes in Lesotho is given in figure 39. Pipe sizes range down to about 30 m by 24 m (Pipe 300, Ha Lenonyane), with dimensions of all known pipes and blows shown in figure 40. Kimberlite pipes are typically subcircular and of conical form, contracting with depth to less regular cross-sections and ultimately to irregular and dyke-like root zones (figure 41), and their surface expression is, at least in part, a function of the level of erosion. Thus the level of Letseng-la-Terae is just below the crater facies whereas the level of Koalabata in the lowlands is well down the original pipe. The tapering shape is evident at Kao (Rolfe, 1973) and Letseng-la-Terae (Bloomer and Nixon, 1973) where surface contacts dip inwards at 80°-85° and 83° respectively, and drilling has shown a reduction in cross-sectional area with depth. Extrapolation of the dips of the pipe walls suggests an origin for both pipes at about 1,300 metres above sea level, close to the assumed base of the Drakensberg Basalts, and these diatremes may have exploded at this stratigraphic break. Nixon (1973c) cites the restriction of the larger pipes to the high mountain areas as further indirect evidence for the downward tapering shaper of pipes, and this is borne out by the data presented in figure 42 which plots the length-to-width ratio against altitude. The preponderance of low ratios at higher elevations shows that the highland kimberlites (those of the Lemphane-Robert group) tend to be equidimensional, probably

Figure 38. Distribution of kimberlite in Lesotho.

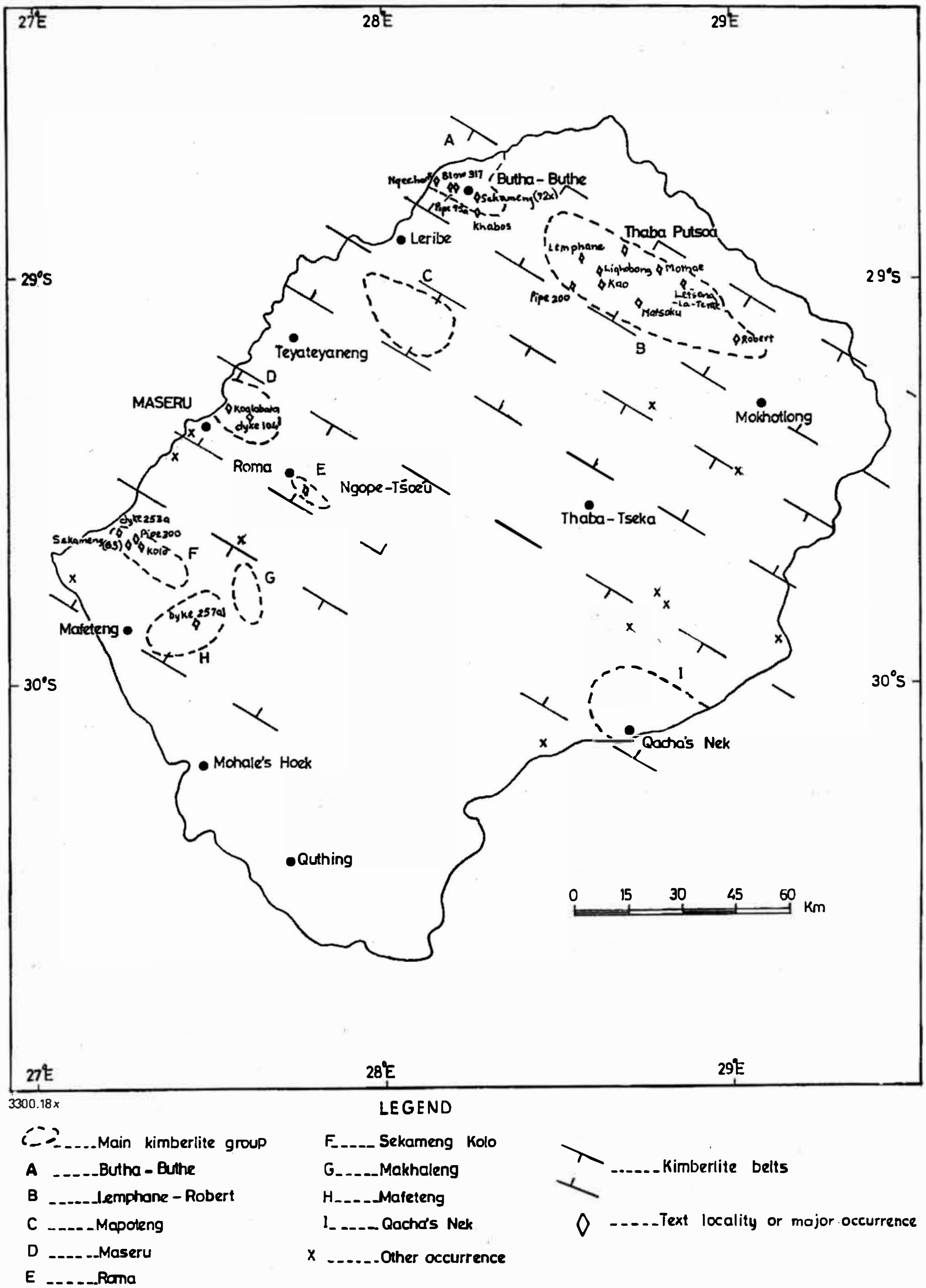


Figure 39. Size and shape of some major kimberlite pipes in Lesotho.

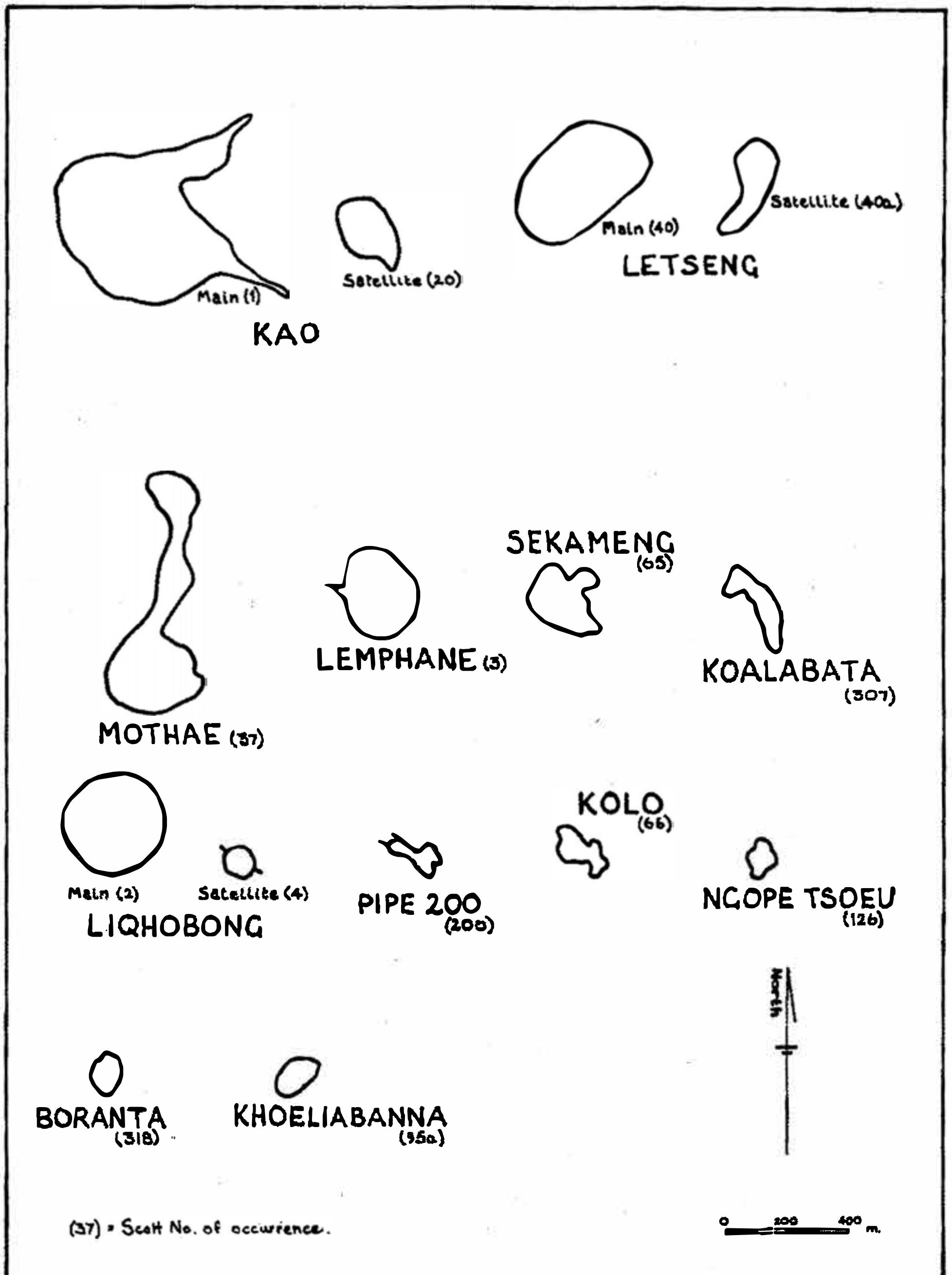


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Figure 40. Size of kimberlite pipes and blows in Lesotho.

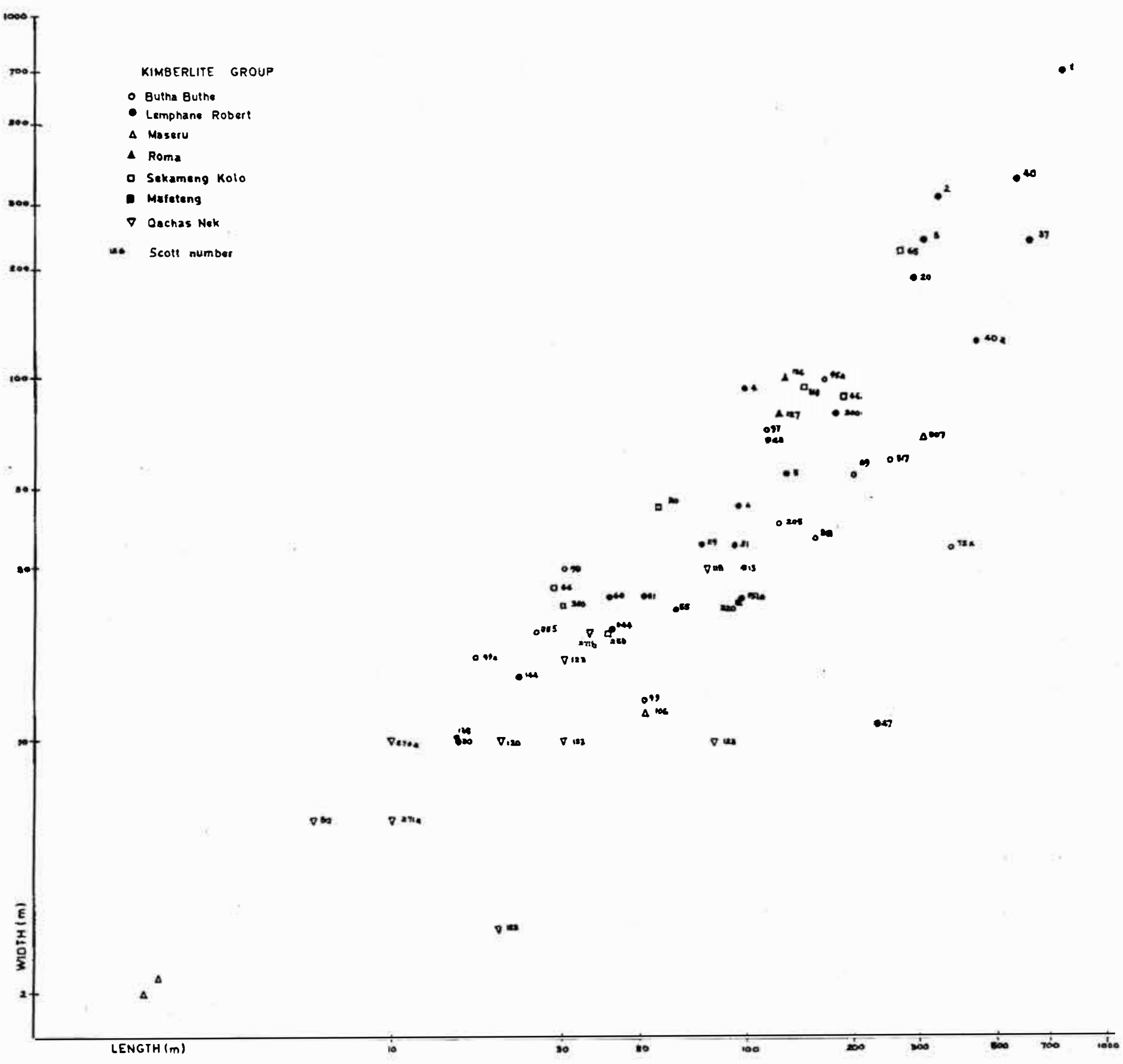

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Figure 41. Model of a kimberlite pipe with Lesotho stratigraphy.

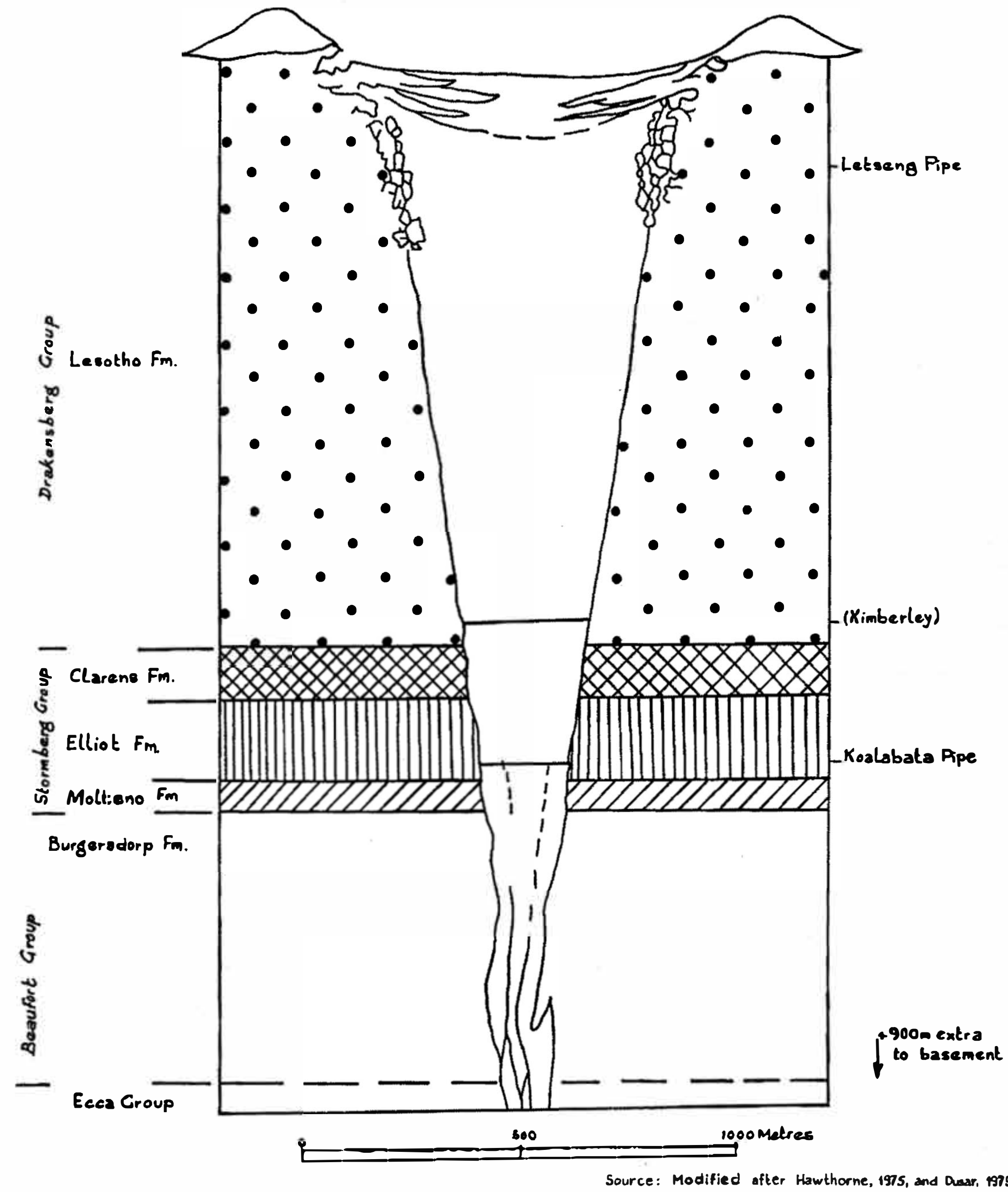

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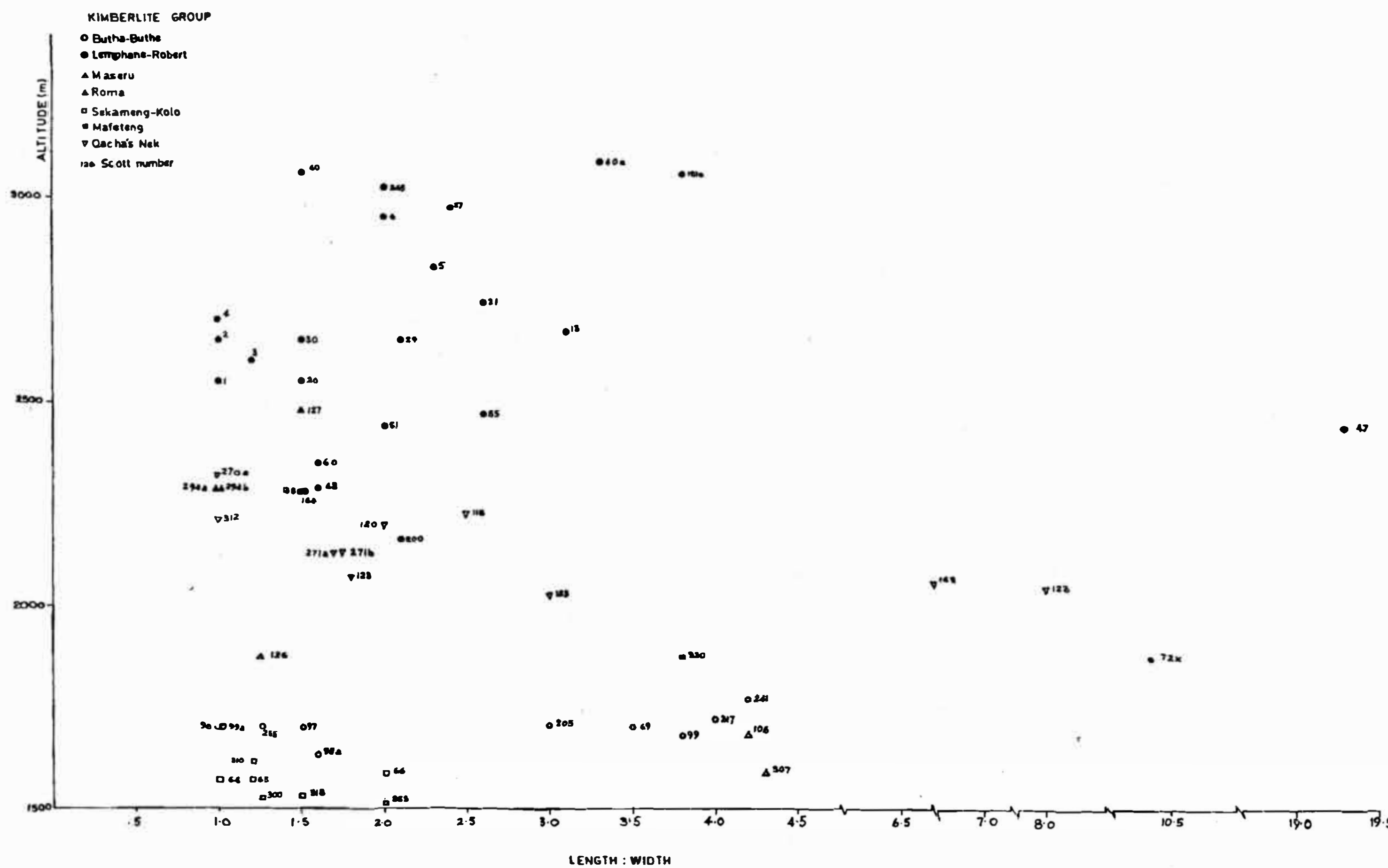
Figure 42. Relation between altitude and the length-to-width ratio of blows and pipes in Lesotho.



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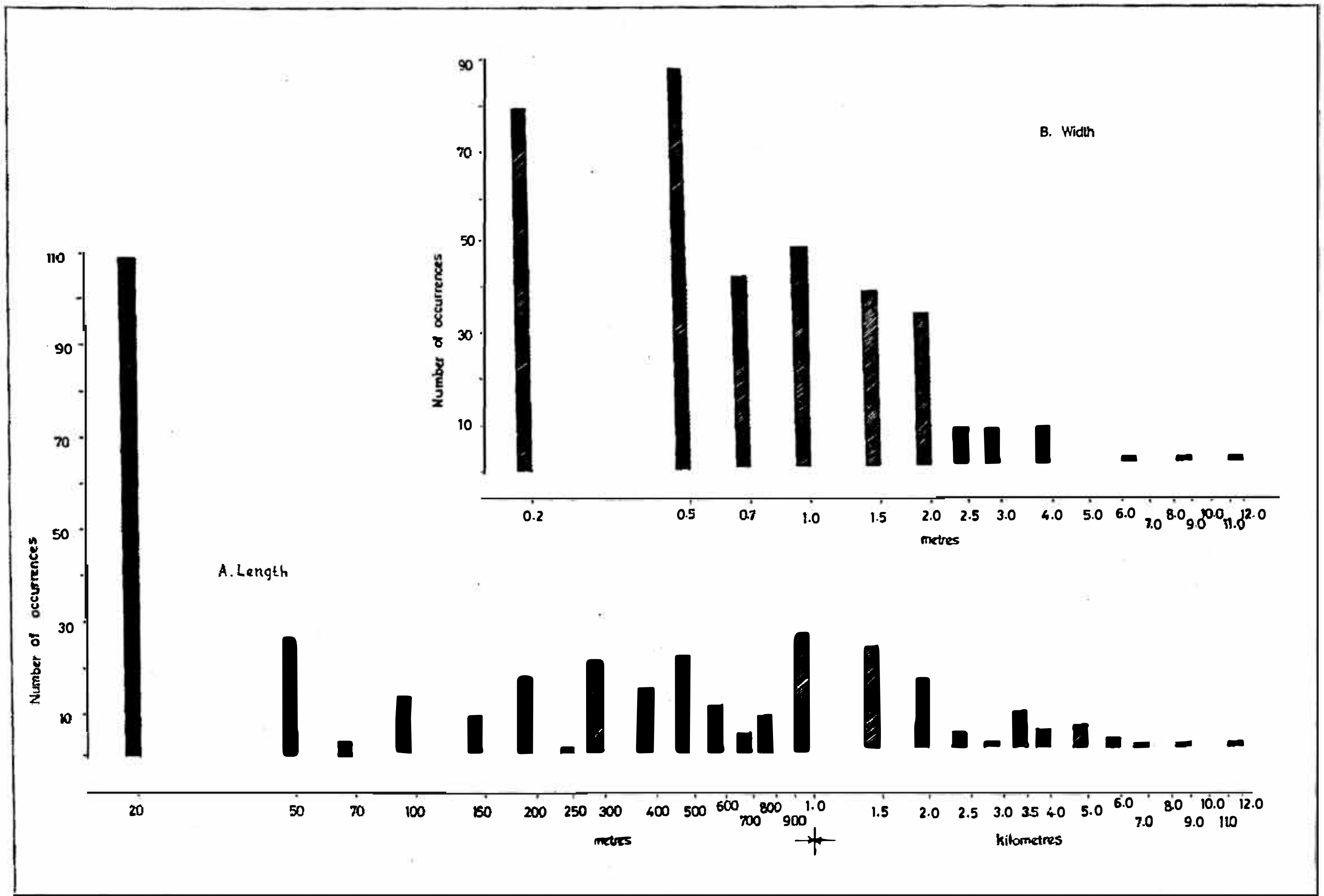
representing the higher, more regular levels of the diatreme. The wide spread of ratios for lowland kimberlites indicates a far greater variation in shape, showing more cross-sections of the typically irregular lower zones of the pipes. The blows range in size up to 240 m by 60 m (Blow 317, Kuenaneng), but most have dimensions in the 10 m-to-30 m range and several have a length and/or width of less than 10 m. They occur where weaknesses in the wall rock permit local widening, and are characterized by high length-to-breadth ratios and are elongated on or close to the strike directions of the dykes with which they are associated. There is a natural progression from the smallest blows to dyke swellings, although some blows are petrologically distinct from their associated dykes.

The dykes occupy vertical or subvertical closely spaced parallel fractures forming zones up to 25 m wide. Where fracture zones are narrow, a single kimberlite dyke is normally present, but where the zone of fracture widens the dyke may split into two or more principal dykes, some accompanied by a number of anastomosing stringers. Many of the dykes pinch and swell, both horizontally and vertically and may occur _en echelon_ in the wider fracture zones. Some dykes are abruptly reduced at the contact between the Clarens Formation and the Drakensberg basalt (Dempster and Tucker, 1973) and become either stringers or simply fractures dying out with increasing height in the basalt; dykes capped by sediment are also known. Kimberlite dykes in Lesotho reach a thickness of 12 m, but are most commonly less than 1 m thin (figure 43). Lengths range up to 12 km, although the majority of dykes are less than 1 km long (figure 43A) and the longer dykes are only intermittently exposed and may consist of discontinuous kimberlite at the surface linked by fracture zones or other linear features. There is some evidence to suggest that a small number of dykes are composite (Dempster and Tucker, 1973), but most result from a single phase of intrusion, as do the majority of blows. In contrast,

Figure 43. Length and width of kimberlite dykes in Lesotho.



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many pipes are multiple intrusions; four main kimberlite types were identified at Kolo (United Nations, 1981b), and eight varieties in the main pipe at Letseng-la-Terae (Bloomer and Nixon, 1973). Additional earlier kimberlite types, not seen at surface, are represented by inclusions within some of the surface types.

The contacts between country rock and kimberlite are everywhere sharp and may be slickensided. Deformation of adjacent sedimentary beds is sometimes observed, as at Kolo Pipe (United Nations, 1981b), Pipe 95a (Nixon and Kresten, 1973a) and dyke 254, but this is the exception rather than the rule, and the enclosing strata are normally undisturbed. There has been strong movement, however, within the kimberlite itself especially in pipes, where xenoliths of mantle material have ascended more than 100 km and blocks of country rock detached from the walls have descended at least 700 m (Nixon and Kresten, 1973a). A characteristic brecciated sandstone was mapped at the contact of Koalabata Pipe 307 (Reed, 1978a) and was observed as surface float on Boranta pipe 318 (Robison, 1979a). Contact metamorphism is slight. A few dykes show narrow (2-3 cm) baked selvages, but other metamorphic-me asomatic effects appear limited to the redistribution of silica (Nixon and Kresten, 1973a) and partial fenitization of wallrock (Ferguson et al., 1973a).

2. Surface expression

Kimberlite is easily weathered and altered, with the primary silicate assemblage being replaced primarily by soft serpentine and clay minerals, and as a result it is rarely seen in natural exposure, except in watercourses, and is normally covered by a vegetated layer of clayey weathering products. Because of the hygroscopic nature of some of the secondary minerals in the weathered overburden, and perhaps also owing to trace element concentrations, a healthier vegetation cover may be present over kimberlite, and hence some bodies may be traced by a brighter green and more luxurient growth of grass at some times of the year. Although some pipes such as Nqechane (Bleackley and Workman, 1964) and Kolo (United Nations, 1981c) may form slight topographic highs, the ease of weathering and the mode of kimberlite emplacement, resulting in the formation of a shallow crater (Hawthorne, 1975), generally lead to a slight depression or no topographic expression at all. Dykes may assume positive or negative relief, which may vary along the length of a single body, but most weather out to form slot-like features bounded by distinctive closely spaced, parallel features. The highly coloured mudstone and siltstone of the Beaufort, Molteno and Elliot formations, are not uncommonly bleached in association with kimberlite emplacement, and this may form a useful prospecting guide. Many of the kimberlites appear on aerial photographs as tonal differences related to variations in rock, soil and vegetation type, whereas others, particularly to the lowland sedimentary environment, produce recognizable magnetic anomalies from ground (United Nations, 1981a) and airborne surveys (Northway Survey Corp., 1977b). A radiometric response may be observed for larger bodies (Paterson, 1976) and trial surveys conducted by Burley and Greenwood (1972) over pipes in Lesotho have shown that at least some occurrence have expressions as resistivity, electromagnetic and gravity anomalies. As elsewhere in the world, Lesotho kimberlites also produce distinctive heavy mineral dispersion trains and haloes (United Nations, 1981a).

3. Distribution and orientation

Kimberlites in Lesotho show an irregular distribution, characterized by their concentration into a number of discrete groups, outside of which only a few scattered and isolated occurrences are known. Large areas in central and southern Lesotho are barren. On a local scale, the clustering of pipes, blows and dykes may lead to local concentrations within the main groups, as at Letseng-la-Terae (United Nations, 1961a), wheras disposition of the groups appears to indicate the location of subparallel belts of kimberlite emplacement (figure 38). Table 8 summarizes the distribution of kimberlite within the groups and highlights the extremely high concentration in the northern, Butha-Buthe - Lemphane-Robert kimberlite belt where 218 occurrences are present, about one per 21 square kilometres. It is unlikely that this density, over a comparable area, is surpassed elsewhere in the world.

Table 8. Distribution of kimberlite within the kimberlite groups of Lesotho

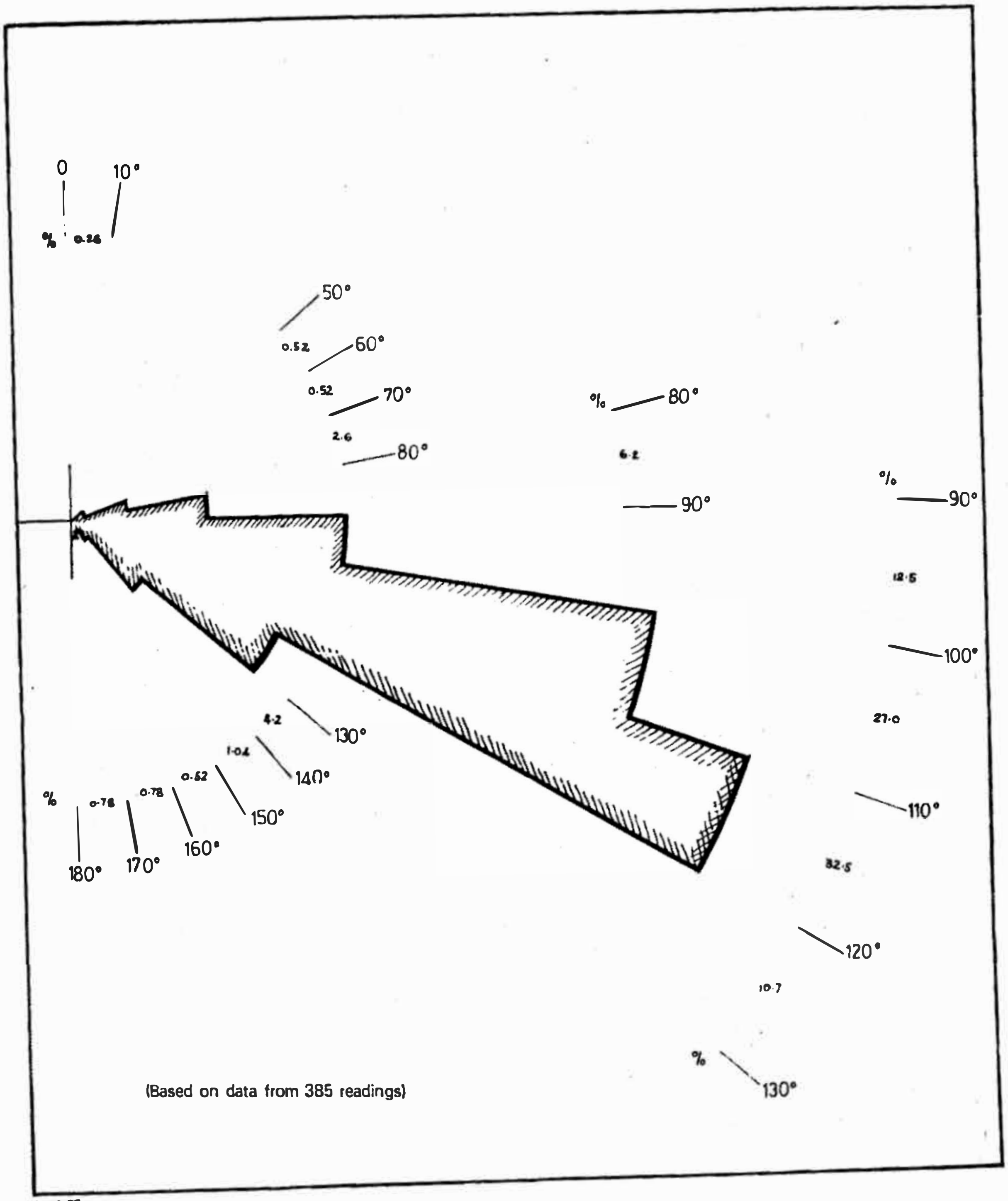
Group	Pipes	Blows	Dykes	Totals
Butha-Buthe	8	3	59	70
Lemphane-Robert	17	7		148
Mapoteng	-	-	16	16
Maseru	1	1	26	28
Roma	2	4	13	19
Sekamang-Kolo	6	1	11	18
Makhaleng	-	-	4	4
Qacha's Nek	5	5	49	59
Other occurrences	-	-	17	17
Total	39	23	343	405

A striking preferred orientation may be observed on all scales. Individual dykelets and dykes, dyke zones, the long axes of asymmetric bodies, "chains" of pipes and blows, the long dimension of elongate kimberlite groups and the kimberlite belts all tend to be oriented approximately west-north-west. A statistical analysis of 385 strike observations from kimberlites throughout Lesotho shows that 93.1 per cent of the readings lie between 80° and 140°, whilst 82.7 per cent fall in the 90°-130° sector (table 9, figure 44). These results confirm an earlier study based on northern Lesotho, which showed a similar preferred orientation for all linear features (Dempster and Richard, 1973). However, some dykes, notably in the Mapoteng, Makhaleng and Mafeteng groups occur on quite atypical strikes, perhaps because of major faulting in these areas (Robison, 1979b).

Table 9. Frequency distribution of kimberlite dyke orientation

Orientation (in degrees)	Individual Number	Individual per cent	Cummulative Number	Cummulative per cent		
0 - 10	1	0.26	1	0.26		
11 - 20	-		1	0.26		
21 - 30	-		1	0.26		
31 - 40	-		1	0.26		
41 - 50	-		1	0.26		
51 - 60	2	0.52	3	0.78		
61 - 70	2	0.52	5	1.3		
71 - 80	10	2.6	15	3.9		
81 - 90	24	6.2	39	10.1		
91 - 100	48	12.5	87	22.6	82.7%	93.1%
101 - 110	104	27.0	191	49.6		
111 - 120	125	32.5	316	82.1		
121 - 130	41	10.7	357	92.8		
131 - 140	16	4.2	373	97.0		
141 - 150	4	1.04	377	98.04		
151 - 160	2	0.52	379	98.56		
161 - 170	3	0.78	382	99.34		
171 - 180	3	0.78	385	100.12		

Figure 44. Orientation of kimberlite dykes in Lesotho.



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4. Petrography

The kimberlites range from relatively fresh porphyritic types more common in dykes, to soft, highly altered, tuff-breccias largely restricted in occurrence to pipes. Some varieties are conspicuously micaceous. A wide variation in colour is seen, but shades of grey, blue, green and brown are most common. Olivine is the most abundant primary mineral, occurring in two generations, i.e., as phenocrysts which may reach 1 cm or more, and as tiny grains in the groundmass. Olivine is also present as a result of the breakdown of peridotite and pyroxene nodules (Nixon and Boyd, 1973c). Most of the olivine is typically partially or completely replaced by pseudomorphs of serpentine, or by serpentine-magnetite, serpentine-chlorite or serpentine-carbonate intergrowths. The pseudomorphs are composed of antigorite and chrysotile, which may have serpophite cores, and some are rimmed by small phlogopite crystals or a thin black rind of magnetite. In addition to undergoing serpentinization, olivine may also be altered to talc. Unaltered olivine, where present, is optically positive indicating a forsterite end-member content greater than 90 per cent (Dawson, 1962). The calcium olivine, monticellite, has been recorded from some localities (e.g., Skinner abd Clement, 1979). Other minerals occurring as phenocrysts include pyroxene, mica, garnet, ilmenite, chromite and, occasionally, zircon. Both ortho pyroxenes and clinopyroxenes occur, the former as enstatite and bronzite, the latter as dipside and chrome dipside. The partial thermal history of two clinopyroxenes from the Thaba Putsoa pipe has been presented by McCallister _et al._ (1979). Greenish-brown and bronze phlogopitic mica is present as aggregates and books which may reach a size of 1.5 cm. Zircon is a common accessory mineral in most kimberlites and is known from a large number of the Lesotho occurrences in which it occurs as short, rounded, normally colourless prisms and irregular grains up to about 7 mm in size. Euhedral crystals are absent or rare.

A chalky coating of admixed monoclinic (baddeleyite) and tetragonal zirconia is common. Although inclusions within zircon are most uncommon, both magnesian ilmenite and phlogopite are reported, suggesting that zircon should be regarded as belonging to the deep-seated discrete nodule suite. It has been suggested that kimberlitic zircons have characteristic properties which may enable them to be used as an aid to exploration (Kresten et al., 1975). The unusual minerals zirconim-armalcolite and zirconolite have been reported from Mothae pipe (Raber and Hagerty, 1979).

The groundmass comprises fine-grained serpentine pseudomorphs, occasional relicts of fresh second-generation olivine, a second generation of fine phlogopite, which may be abundant but is often only detected under the microscope (Dawson, 1962; Smirnoff, 1980), pyroxene, tremolite-actinolite, chlorite, vermiculite, hydromica, magnetite, chrome-spinel, calcite, apatite, iddingsite, saponite, talc, hematite, epidote and rutile, not all of which are necessarily of primary origin. Many of the kimberlites are carbonated particularly in dyke occurrences (Smirnoff, 1980). The stable isotope compositions for carbonates in some Lesotho kimberlites are given by Kobelski, Gold and Deines (1979).

The complex nature of kimberlite petrography and mineralogy is compounded by the occurrence of monomineralic nodules, minerals derived from the disaggregation of country rock, crustal and mantle xenoliths, and the development of a large suite of secondary minerals. The latter are derived both from weathering in the near-surface environment and from a pervasive autometasomatism which is quite independent of weathering. This autometasomatism results in the breakdown of the primary rock-forming silicates, and their replacement by secondary minerals perhaps typified by serpentine-chlorite-talc-carbonate-iron oxide/hydroxide assemblages. According to Kresten (1973a) the alteration sequence progresses through 'serpentine' and 'vermiculite' stages to a most highly altered 'saponite' stage, and many kimberlites do not contain appreciable amounts of carbonate or serpentine, but are characterized by the development of highly hydrated magnesium silicates. As previously noted, most kimberlites are easily weathered and their surface zones are therefore normally represented by predominantly clayey layers beneath the soil cover. The weathered zone may range in thickness from about 0.5 m, below which recognizable, although still weathered, kimberlite occurs. In bodies studied by Smirnoff (1960) montmorillonite is the dominant mineral present in the surface weathered zone. Chlorite, calcite, serpentine and hydromica may also be present in significant amounts. Quartz, feldspar, vermiculite, dolomite and iron hydroxides normally occur only in minor quantities. Although the processes of weathering may destroy the primary mineralogy and characteristic texture of the kimberlite, the presence of resistant minerals within the weathered zone may be diagnostic. The percentage of components in concentrates from Lesotho kimberlites is given in table 10.

5. Inclusions

Many pipes, and to a lesser extent blows, are characterized by a high inclusion content, enhancing their brecciated appearance. Xenoliths of country rock, up to 6 m in size predominate and include sandstone, siltstone, mudstone and shale from the Karoo sediments, dolerite and basalt. The basement complex is represented by inclusions of gneiss, schist, amphibolite, banded ironstone, quartzite, phyllite, granulite and marble. Rare ultrabasic nodules (to 30 cm) and inclusions of earlier kimberlite phases (to 1 m) also occur, as do rare fragments of eclogite and crystalline basement rocks (Dawson, 1962). Microxenoliths, comprising mega- and xeno-crysts and mineral aggregates may be present (Smirnoff, 1980). Nearly spherical kimberlite autoliths up to 7 cm in diameter consisting of mantle and crustal derived

Table 10. Percentage of components in concentrates from Lesotho kimberlites

Component	Pipe 205	Pipe 99a	Pipe 255	Blow 317	Pipe 95a	Pipe 307 SE.	Pipe 307 Rest.	Pipe 307 Ave.	Pipe 65	Pipe 310	Pipe 318
Dolerite fragments	4.7	5.3	3.4	3.8	21.6	12.6	28.5	25.7	9.4	5.7	60.3
Sediment fragments	5.6	3.3	1.7	0.6	12.6	2.0	16.0	13.5	4.6	16.8	12.2
Kimberlite fragments	0.3	1.2	0.7	1.5	16.5	21.4	9.4	11.5	0.8	14.0	1.9
Carbonate fragments	–	0.1	–	–	1.2	5.1	1.0	1.8	3.1	–	1.8
Ultrabasic fragments	0.2	1.0	1.0	–	0.1	–	–	–	0.1	–	–
Serpentine pseudomorphs	1.6	1.3	0.5	8.3	1.2	53.5	2.5	11.4	1.5	48.9	0.7
Olivine	–	–	–	0.9	–	–	–	–	0.4	–	0.1
Picroilmenite	63.6	73.6	71.2	47.2	35.2	4.3	34.1	28.9	75.5	0.4	14.9
Garnet	21.4	12.3	20.1	31.9	3.9	0.3	6.8	5.6	4.3	2.1	3.9
Pyroxene	2.1	1.6	0.9	1.0	2.6	0.7	1.2	1.2	0.2	0.5	1.4
Chromite	0.2	0.1	0.2	4.6	4.9	–	–	–	0.1	1.1	2.7
Zircon	0.3	0.2	–	–	–	–	–	–	–	–	–
Apatite	–	–	–	–	–	–	–	–	–	–	–
Mica	–	–	0.2	–	–	–	0.1	–	–	–	–
Hornblende	–	–	–	–	–	–	–	–	–	–	0.1
Magnetite	–	–	–	–	–	–	0.1	0.1	–	–	–
Iron hydroxides	–	–	0.1	0.1	0.2	0.1	0.3	0.3		0.5	–

Data from Smirnoff, 1980.

mineral or rock fragment nucleii surrounded by fine-grained equigranular kimberlite are relatively common in pipes but have not been recorded from dykes (Ferguson et al., 1973b). Kimberlite pellets, interpreted as volcanic lapilli, have been recognized in the Kao Pipe (Clement, 1973), and here too is an occurrence of friable stratified grit equated with water-laid sediments found in the original kimberlite volcanic crater and probably preserved by down faulting at the pipe margin (Rolfe, 1973). Inclusions in dyke kimberlite are generally rare and small, but there are some exceptions such as the Khabos dyke (Nixon and Kresten, 1973a).

Ultrabasic nodules and inclusions are generally rounded or ellipsoidal and may reach 30 cm in size. They are present in most pipes, but are generally rare except in one or two exceptional cases, for example the well-documented Matsoku Pipe where they comprise some 20-30 per cent of the total rock volume (Cox, Gurney and Harte, 1973) but in some instances the primary mineralogy is totally destroyed (Robison, 1980a). Ultrabasic xenoliths from Pipe 72X, Sekameng (Butha-Buthe) are intensively carbonated (Nixon and Boyd, 1973a; Smirnoff, 1980) but this is not reported elsewhere. The ultramafic nodules from pipe 200 have been described by Carswell et al. (1979) and those in the Kao pipe by McGregor (1979).

Deep-seated nodules including spinel-olivinite, harzburgite, spinel-harzburgite, micaceous harzburgite, lherzolite, garnet-lherzolite and micaceous lherzolite have been recorded. The dominant olivine in these rocks occurs in irregular colourless to pale yellowish-green grains of 0.3-4 mm with serpentinized margins. Orthopyroxene is present as yellowish-green to brownish, slightly coarser, prismatic to irregular grains, and bright green clinopyroxene occurs as small (to 2 mm) grains distributed throughout. Phlogopite, if present, occurs as scattered or aggregated brownish crystals of up to 8 mm. Garnets reach 7 mm in diameter and are normally a violet-red pyrope surrounded by kelyphitic rims and commonly fissured and replaced. Chrome-spinel occurs in minor amounts as scattered small irregular grains of up to 3 mm, which occasionally occur in clusters to form pockets or streaks (Smirnoff, 1980).

The presence of "micro-xenoliths" (mineral aggregates) of peridotite and pyroxenite has been reported (Smirnoff, 1980), whilst eclogitic types occur in Pipe 307, Koalabata and in dyke 257a, where kyanite- and corundum-bearing varieties are present (Sobolev et al., 1978). Violet-red garnets from micro-xenoliths from Koalabata pipe were micro-probed and showed a uniformly high MgO content, but only 3 grains had sufficient Cr_2O_3 for a knorringite component to be present. The highest chrome-component recorded from associated chrome-spinel was 71 per cent.

Other xenolith types recorded include pyroxenite, garnetiferous amphibole/pyroxene gneiss, and various types of granulite and eclogite. The lower crustal granulite and eclogite from 10 pipes in north-east Lesotho have been described in great detail by Griffin et al. (1979) who considered that the results indicated kimberlite intrusion on or outside the edge of the Kaapvaal craton as pipes within the craton apparently lack granulite nodules. An interesting assemblage of sheared nodules with flaser or submylonitic textures occur in the Thaba Putsoa and Mothae Pipes (Nixon and Boyd, 1973b). Ilmenite-silicate intergrowths, and ilmenite with silicate inclusions are reported from Mothae, Kao, Thaba Putsoa, Marsoku, Solane and Pipe 200 (Boyd and Nixon, 1973). Monomineralic nodules or xenocrysts of pyrope, dipside, enstatite, bronzite, olivine, chromite, ilmenite and perovskite are also known, the latter occasionally showing banding which may result from magmatic sedimentation (Nixon, 1973c; Kresten and Dempster, 1973).

6. Mineralogy

(a) Garnet

Pyrope garnets occur as two main varieties, lilac and orange-red, although there are many shades of colour represented in these classes (Smirnoff, 1980). Garnets with a greenish tinge may be found occasionally, as at Letseng-la-Terae (Bloomer and Nixon, 1973), where large fractured brown garnets have also been noted. The garnets, which may reach a diamteter of 15 mm, are typically rounded, fissured and replaced, and surrounded by kelphitic rims which differ in colour according to their composition; their surfaces show a characteristic shallow pitting (United Nations, 1981c). Lilac varieties are distinguished from the orange-red by higher Cr_2O_3 and MgO and lower FeO (tables 11, 12). The orange-red garnets display considerable variations in the Mg and Fe values and have relatively low CaO contents. Both the lilac and orange-red garnets have very low TiO_2 values. Especially significant are the relative variations in Cr_2O_3 and the CaO contents, which determine the favourable knorringite component, as a direct relationship between high-chrome - low-calcium garnets and the presence of diamond has been established for Yakutian kimberlites (Smirnoff, 1980) and for the Finsch pipe in South Africa (Gurney and Switzer, 1973). Analyses of Lesotho garnets (table 13) indicate, however, that few show development of the knorringite component as increase in Cr_2O_3 is accompanied by higher CaO and this leads to increase in the uvarovite component which does not require high pressure in its formation; moreover, 95 per cent of the garnets fall within the compositional field of the diamond-barren bi-pyroxene lherzolites instead of the diamond-bearing wehrlites or harzburgite-dunites (Smirnoff, 1980).

Garnets from Lesotho kimberlites appear to be characterized by a low refractive index. Dawson (1962) cites values in the range 1.740 to 1.746, and measurements on 1,500 garnets from

Table 11. Chemical composition of violet-red (lilac) garnets from Lesotho

Pipe	Koalabata	310	310				Koalabata					310
Analysis No	1	2	3	4	5	6	7	8	9	10	11	12
Sample No	JCM-110a	GS-99B	GS-99a	LS-9/10	LS-9/11	LS-9/7	LS-9/9	JCM-79a	LS-9/2	LS-9/17	LS-9/4	GS-99c
SiO_2	41.63	41.21	40.99	42.79	42.08	42.35	43.11	41.92	42.57	43.19	42.22	41.85
TiO_2	0.07	0.42	0.03	–	0.18	0.67	0.02	0.03	–	0.01	0.18	0.45
Al_2O_3	19.56	19.15	20.90	21.55	20.89	21.00	22.24	22.49	21.36	22.45	22.41	21.83
Cr_2O_3	6.67	5.63	5.02	4.32	4.07	3.37	3.05	2.94	2.75	2.54	2.08	1.99
Fe_2O_3	–	0.96	1.52	1.34	0.60	1.74	0.84	1.64	1.40	0.61	1.90	0.63
FeO	7.03	5.75	4.52	4.03	6.71	5.06	4.97	5.85	5.16	5.11	5.30	6.90
MnO	0.40	0.25	0.23	0.26	0.36	0.33	0.22	0.37	0.29	0.21	0.37	0.24
NiO	0.01	0.03	0.03	–	–	–	–	0.01	0.02	0.03	–	0.03
M_9O	19.59	20.32	20.80	24.28	20.68	21.66	24.66	20.95	22.34	23.66	22.33	21.06
CaO	6.67	5.80	5.58	2.84	5.16	5.07	1.49	5.04	4.47	3.34	3.97	4.60
Na_2O	0.01	0.03	0.03	0.01	0.01	0.19	0.11	0.02	–	–	–	0.03
K_2O	0.01	0.03	0.03	0.03	–	0.01	0.02	–	–	0.01	0.02	0.03
Totals	101.67 x)	99.58	99.40	101.45	100.74	101.41	100.73	101.28 x)	100.36	101.16	100.78	99.55

x) 0,02 percent of V_2O_3 included in the total of analyses 1 and 8

Analyses: Nos 1,8 U.K. Institute of Geological Sciences; Nos 2,3,12 De Beers Geological Laboratory; Nos 4-7, 9-11 Geosciences Department, Purdue University

Source: Smirnoff, 1980

Table 12. Chemical composition of orange-red garnets from Lesotho

Pipe	Koalabata	310	310	Koalabata								
Analysis No	1	2	3	4	5	6	7	8	9	10	11	12
Sample No	JCM-110a	GS-99B	GS-99a	LS-9/10	LS-9/11	LS-9/7	LS-9/9	JCM-79a	LS-9/2	LS-9/17	LS-9/4	GS-99c
SiO_2	41.92	41.76	41.28	42.28	42.77	43.11	40.31	41.39	40.53	42.15	40.15	41.30
TiO_2	0.20	0.34	1.04	0.20	0.03	0.04	0.14	0.16	0.19	0.25	0.16	0.18
Al_2O_3	21.76	22.80	21.97	23.84	23.93	24.11	23.63	23.00	22.32	23.63	22.46	23.25
Cr_2O_3	2.06	1.47	1.05	0.72	0.62	0.36	0.36	0.18	0.14	0.13	0.07	0.04
Fe_2O_3	1.68	1.28	1.41	0.99	0.88	0.65	-	0.33	0.72	1.51	0.14	0.44
FeO	8.63	6.11	7.63	4.99	6.39	5.44	11.86	16.73	18.58	8.94	20.35	15.15
MnO	0.36	0.23	0.18	0.25	0.15	0.14	0.32	0.34	0.38	0.42	0.40	0.48
NiO	-	0.03	0.03	-	-	-	-	-	-	-	-	-
MgO	19.69	21.45	20.67	22.84	20.91	20.80	18.02	15.89	14.13	20.35	12.59	16.69
CaO	4.71	4.41	4.36	3.95	5.69	7.00	4.65	3.38	3.30	3.89	3.76	3.22
Na_2O	0.05	0.03	0.03	-	-	-	0.05	-	0.07	-	0.05	0.02
K_2O	-	0.03	0.03	0.01	0.02	-	0.01	-	0.02	0.01	0.02	0.02
Total	101.06	99.85	99.68	100.27	101.39	101.65	99.36 x)	101.40	100.38	101.28	100.15	100.79

x) 0.01 percent V_2O_3 included in the total

Analyses:- Nos 1,4-6,9-12 Geoscience Department, Purdue University
Nos 2,3 De Beers Geological laboratory
No 7 U.K. Institute of Geological Sciences

Source: Smirnoff, 1980

Table 13. Average contents of Cr_2O_3, FeO and CaO in garnets from Lesotho kimberlites

Kimberlite	Number of analyses	Cr_2O_3			FeO			CaO		
		$\bar{x}$	S	range	$\bar{x}$	S	range	$\bar{x}$	S	range
Dyke 104A	340	2.67	1.59	0.00-9.26	8.48	1.43	5.21-13.5	4.73	1.04	2.99-9.04
Dyke 257A	328	4.02	1.38	0.00-8.00	7.27	2.64	0.57-15.9	5.28	0.49	3.50-6.36
Pipe 126	166	2.91	1.16	9.18-6.36	7.74	1.44	5.64-13.3	4.75	0.35	3.91-5.77
Dyke 253A	155	3.63	1.88	0.02-9.89	7.68	0.82	6.28-10.6	4.92	1.49	2.76-10.6
Pipe 300	244	2.78	1.95	0.17-11.1	7.88	1.47	5.33-13.6	4.71	1.71	1.67-11.3

Analyses: Institute of Geology and Geophysics, Siberian Branch, USSR, Academy of Sciences, Novosibirsk

$\bar{x}$ = mean value S = standard deviation

Source: Smirnoff, 1980

Pipes 126 (Ngope Tseou) and 300, and dykes 104, 253a and 257a show a spread from 1.724 to 1.780 (Smirnoff, 1980). However most values for Pipe 126 and dyke 104 are in the range 1.736 to to 1.744, and those for Pipe 300 and dyke 257a lie in the range 1.740 - 1.748, so that a rather restricted range of low values may generally be inferred. Violet-red garnets from dyke 253a have a noticeably higher refraction index, with nearly half greater than 1.752. This latter group show a slightly higher potential for the presence of high-chrome garnet, but the results in general suggest the majority of the garnets recently examined should be referred to high MgO, low Cr_2O_3, types (Smirnoff, 1980). The low refractive index garnets appear to fall within the 'payable kimberlite' class established by Snyman (1974) for South African kimberlites, but it should be noted that the values obtained also show great similarity to garnets from the North Yakutian kimberlites, which are barren or only weakly diamondiferous (Smirnoff, 1980).

(b) Ilmenite

Ilmenite shows a wide size range from less than 1 mm up to several centimetres probably because ilmenite of more than one origin is present. At Liqhobong, for example, there is a clear distinction between large discrete ilmenite nodules (xenocrysts), and smaller grains of "ground-mass" (magmatic ?) ilmenite (Boctor and Boyd, 1980). This distinction has also been noted elsewhere, including Kao and Thaba Putsoa (Dawson, 1962). The ilmenites lack crystal form whereas larger nodules may show striations, pluck marks and other abrasions inflicted during intrusion; narrow tubules, possibly of gaseous origin, may be present (Nixon, et al., 1963). Simple, polysynthetic and lattice twining are rare, but optical heterogeneity shown by micro-block extinction is characteristic. Rutile inclusions may be present and reaction rims and mantles with rutile, brookite and perovskite are present in almost all, commonly forming a white skin (Smirnoff, The reaction mantles on ilmenite nodules at Liqhobong comprises irregular zones of perovskite, secondary ilmenite and spinels of unusual composition which reflect changes in late-stage redox conditions (Haggerty, 1973). These nodules also show an enrichment, perhaps metasomatic, in MgO in a narrow zone at their margins (15-21 wt. % MgO) relative to their cores (11-13 wt. % MgO) (Boctor and Boyd, 1980).

Ilmenite appears less common in autolithic kimberlite than in other varieties, but may nevertheless form nucleii which are enriched in iron relative to ilmenites in the autolithic bodies (Ferguson et al., 1973b). Highly magnetic ilmenite, comprising magnetite with exsolved ilmenite and hematite is reported from Pipe 200, where high concentrations of ilmenite occur at the contacts between the various kimberlite types (Kresten and Dempster, 1973). Similar highly magnetic kimberlite is also found at Koalabata (United Nations, 1981c).

Kimberlite ilmenites from Lesotho, as elsewhere, are high in magnesia and ferric oxide (table 14). They have also been shown to be rich in rare elements (Nb, Ta, Zr, Hf) relative to ilmenite from basic rocks (Mitchell et al., 1973) and to have a considerable range in Cr and Ni content which may reflect a depth zonation or an igneous fractionation sequence (Nixon and Kresten, 1973b).

(c) Chrome-spinellids

The chrome spinellids are represented mainly by chromites and are found in nearly all the kimberlites, generally as sporadic crystals 0.1-2 mm in size. Many of the crystals are distorted and differentially absorbed, forming isometrically orbicular-ovate shapes with partially or completely corroded faces. Table 15 shows the chemical compositions of 19 chrome-spinelids from pipes 307 Koalabata and 310, 18 of which are chromites with the 19th from pipe 310 a spinel. The Cr_2O_3 contents range from 36.42 to 61.59 per cent, the Cr-component from

Table 14. Chemical composition of ilmenites from Lesotho kimberlites

	Ilmenite samples (see notes below)											
Element	1	2	3	4	5	6	7	8	9	10	11	12
TiO_2	54.43	53.06	52.01	48.26	49.35	55.95	52.32	52.12	45.55	51.74	47.05	49.59
SiO_2	0.05	n.d.	n.d.	n.d.	-	0.01	0.01	0.01	n.d.	n.d.	0.14	0.07
Al_2O_3	0.44	0.35	0.30	n.d.	0.33	0.26	0.30	0.34	0.27	0.45	0.76	0.55
Cr_2O_3	1.45	1.68	0.44	-	-	1.64	1.54	2.55	0.64	0.45	0.05	0.53
Fe_2O_3	4.06	0.16	6.10	17.10	13.71	7.85	7.27	11.24	44.67+	34.37+	15.30	12.77
FeO	22.33	23.95	26.82	27.12	27.57	14.68	26.62	15.91			26.44	29.90
MnO	0.30	0.14	0.08	0.26	0.05	0.70	0.68	0.66	0.30	0.20	0.23	0.25
MgO	14.15	13.21	11.71	8.65	8.65	19.59	11.07	16.99	6.63	11.11	8.80	8.11
CaO	-	n.d.	n.d.	-	0.20	0.01	0.01	0.01	n.d.	n.d.	0.05	0.05
Totals	98.31	100.59	98.28	100.39	99.86	100.67	99.81	99.81	98.06	98.32	98.84	101.32

Ilmenite samples:

1. Koalabata; 2. Pipe 64; 3. Kolo; Smirnoff, 1980
4. Thaba Putsoa; Dawson, 1962
5. Kao; Nixon *et al.*, 1963
6. Nodule rim; 7. nodule core; 8. groundmass ilmenite, Liqhobong; Boctor and Boyd, 1980
9. Autolith nucleus; 10. autolith body, Pipe 200; Ferguson *et al.*, 1973
11. Lamellar intergrowth with clinopyroxene, Pipe 200; 12. discrete nodule with silicate inclusions, Solane; Boyd and Nixon, 1973

n.d. not determined   + Total Fe as FeO

Table 15. Chemical composition of Chromespinellids from Lesotho

Pipe	307	307	310	310	307	307	310	310	310	307
Analysis No	1	2	3	4	5	6	7	8	9	10
Sample No	LS-14/2b	LS-14/2a	GS-90b	GS-90a	JCM-79e	LS-14/4	GS-90d	GS-90e	GS-90c	LS-14
SiO_2	0.51	0.49	0.03	0.03	0.11	0.02	0.03	0.03	0.03	0.02
TiO_2	0.07	0.05	0.32	1.16	1.35	1.84	1.54	1.98	3.30	0.65
Al_2O_3	6.11	5.89	9.39	8.86	8.48	8.39	9.36	9.55	7.89	9.45
Cr_2O_3	61.59	61.53	56.90	56.48	56.31	55.79	54.97	54.29	53.99	53.90
Fe_2O_3	7.22	5.68	6.12	6.13	3.64	5.72	6.29	5.98	5.61	5.96
FeO	8.97	10.30	13.35	13.87	17.85	12.80	13.97	14.02	14.34	16.98
MnO	0.25	0.25	0.25	0.26	0.36	0.32	0.25	0.25	0.24	0.36
NiO	0.13	0.14	0.16	0.16	0.15	0.13	0.19	0.21	0.24	0.04
MgO	14.84	14.89	13.16	13.23	10.39	13.28	13.26	13.58	13.57	10.20
CaO	-	-	0.03	0.03	-	0.01	0.03	0.03	0.03	-
Na_2O	0.42	-	0.03	0.03	0.01	0.23	0.03	0.03	0.03	0.05
K_2O	-	-	0.03	0.03	-	-	0.03	0.03	0.03	-
Totals	100.11	99.22	99.85	100.15	98.65	98.53	99.83	99.86	99.68	97.60

Table 15. (Continued)

Pipe	307	307	307	307	307	307	307	307	310
Analysis No	11	12	13	14	15	16	17	18	19
Sample No	LS-14/9	LS-14/1	LS-14/3b	LS-14/3a	LS-14/7	LS-14/8	LS-14/6	LS-14/10	GS-93
SiO_2	0.50	0.45	0.57	0.42	0.43	0.48	0.49	0.52	9.13
TiO_2	0.20	0.86	0.89	0.97	0.32	0.60	3.56	0.44	0.13
Al_2O_3	11.79	8.68	8.91	9.05	11.34	14.09	11.03	9.36	10.67
Cr_2O_3	52.87	52.32	50.19	49.97	49.76	46.93	46.02	43.16	36.42
Fe_2O_3	6.92	10.25	11.13	11.63	11.30	9.49	9.29	18.80	29.19
FeO	10.52	12.03	12.48	12.65	9.62	11.13	12.36	12.91	7.29
MnO	0.24	0.28	0.27	0.28	0.21	0.23	0.30	0.22	0.31
NiO	0.11	0.04	0.06	0.07	0.16	0.15	0.16	0.10	0.35
MgO	14.89	13.87	13.55	13.95	14.98	15 09	15.50	13.43	17.19
CaO	-	-	-	-	-	-	-	0.02	0.03
Na_2O	0.12	0.20	0.18	0.05	0.30	0.02	0.18	-	0.03
K_2O	-	-	-	-	-	-	-	-	0.03
Totals	96.14	98.96	98.24	99.00	98.43	98.20	98.90	98.24	101.67

Analyses: 1,2,6,10-18 Dept. Geosciences, Purdue University;
4,5,6-10,19 De Beers Geological Laboratory;
5 UK Institute of Geological Sciences

Soucre: Smirnoff, 1980

45.2 to 80.6 per cent and Al-component from 11.4 to 24.5 per cent. It has been noted by Sobolev that chromites associated with diamonds have Cr_2O_3 contents greater than 62 per cent, Cr-components more than 80 per cent and Al_2O_3 contents less than 7 per cent but the only Lesotho chromite which approaches these criteria is the inner zone of a crystal from pipe 307 (Smirnoff, 1980).

(d) Diamond

Diamond is fairly widespread in kimberlite in Lesotho, with diamondiferous occurrences found in the Butha-Buthe, Lemphane-Robert, Maseru, Roma, Sekameng-Kolo and Qacha's Nek groups. In contrast, kimberlites with significant quantities of diamond are limited, with the single exception of the Kolo Pipe (United Nations, 1981b), to the Lemphane-Robert group (United Nations, 1981a). The only pipe from which large numbers of diamonds have been studied, and for which statistically acceptable data are therefore available, are the occurrences at Letseng-la-Terae and Kao. Lesser numbers of stones from Liqhobong, Lemphane and Kolo have been examined, as have a few stones from other localities.

At Letseng-la-Terae (Harris, 1973; Harris et al., 1979) the most distinctive morphological feature of diamonds from the main pipe is the low octahedra content, coupled with an unusually low proportion of macles. The satellite pipe has even fewer octahedra and macles, but contains more dodecahedra. Browns and faint yellows predominate in the main pipe, whereas a greater absence of colour is noted for the satellite. An absence of transparent green-coated diamonds appears characteristic. Both pipes are notable for the relatively high content of large stones.

The diamonds from Kao (Whitelock, 1973) show a progression from well-formed octahedra through transitional rounded forms to rhombic dodecahedra, with the proportion of octahedra decreasing with diminishing stone size. The size distribution varies with kimberlite type, as does colour. A sympathetic variation between the octahedra/dodecahedra ratio and the irregular/regular form ratio was also noted. From the observations made it was proposed that diamonds were formed initially as octahedra, from which transitional rounded forms and, ultimately, rhombic dodecahedra were derived by progressive resorption.

More than 90 per cent of the diamonds from the Liqhobong main pipe are broken and formless; they are predominantly yellow and have a high proportion of black inclusions. Dodecahedra predominate among those stones which have a crystal form. In contrast, the satellite pipe produces a high proportion of clean yellow stones with good crystal shapes, although dodecahedra and transitional forms are again prevalent (Nixon and Boyd, 1973c). At Lemphane, about 80 per cent of the diamonds, which are mostly pale yellow, are broken and formless. Octahedra and transitional forms are subordinate to rounded dodecahedra amongst stones with crystalline shape (Kresten, 1973b). Almost all the diamonds recovered from Kolo Pipe are badly shaped chips with corroded surfaces, and crystal faces are rarely seen (Hall, 1976). Ninety-three typical diamonds in the 1.5-3.5 mm size range from Loqhobong, Lemphane and Kolo were subsequently studied by Smirnoff (1978) and Kvasnitsa <u>et al.</u> (1978) using goniometric, photogoniometric and photoluminescence techniques. Rounded crystals are prevalent at Liqhobong and Lemphane whereas at Kolo there are more octahedral types, more transitional crystals and more stones filled with graphite. There are more yellow and brown diamonds at Liqhobong and Lemphane than at Kolo. Hollows are especially typical of these Lesotho diamonds. Overall the sharp prevalence of rounded rhombic dodecahedra was noted and this was taken, as at Kao and elsewhere (Whitelock, 1973), to be indicative of resorption. It was concluded that there were considerable differences in the conditions of formation and subsequent dissolution of the diamonds from these three pipes. The isotopic carbon composition was determined for six diamonds (Smirnoff et al., 1979; Smirnoff, 1980) and three (two from Kolo and one from Liqhobong) were found to be characterized by a light isotopic ratio, a discovery which appears to have genetic significance as diamonds of this isotopic composition have not been encountered elsewhere in Africa or Yakutia. The crystalline structures of the six diamonds were studied by infrared absorption spectra, X-ray diffraction, fluorescence, and paramagnetic resonance and it was possible to correlate some physical peculiarities with the abnormal isotope compositions and this supports the inference that special genetic conditions are involved.

Only a few diamonds have been recovered and described from other sources. In general they tend to be irregular or rounded in form, and many are fissured and contain inclusions. Stones from Sakameng (Pipe 72X, Butha-Buthe District) are predominantly octahedra or fragments thereof, suggesting rapid explosive ascent with mechanical breaking of diamonds but minimal resorption. However at most other occurrences, as at Pipe 200, dodecahedral forms outnumber octahedra reflecting a degree of resorption perhaps resulting from postemplacement changes in temperature and pressure (Dempster, 1974). In general, conditions for the preservation of diamond do not appear to have been met.

7. Petrochemistry

A number of new chemical analyses of Lesotho kimberlites have recently become available (table 16). Dykes 66a, 70a and 252 are all low in silica, whilst dykes 70a and 252 are also high in carbonates, low in MgO and high in MnO_2; dykes 661 and 270b are high in Fe; and Pipes 200 and 307 (Koalabata) are low in MgO and high in alumina. These variations might reflect differences in magma composition, but may also result from variation in the quantity and type of xenoliths present. No systematic variation between pipes and dykes, the various

Table 16. Chemical composition of Lésotho kimberlites

Scott No.	Type of Body	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	Fe_2O_3	FeO	MgO	NiO	CoO	MgO	CaO	Na_2O	K_2O	H_2O	H_2O^-	CO_2	P_2O_5	S	Group
310[1]	pipe	31.92	0.97	2.10	n.d.	3.36	3.82	0.14	n.d.	n.d.	33.22	7.07	0.09	0.48	9.26	–	6.63	0.71	0.02	(S-K)
257a	dyke	31.64	1.04	1.38	0.23	3.61	4.01	0.11	0.17	0.01	35.78	7.00	0.05	0.37	6.41	0.66	5.46	0.58	0.16	Maf.
277a	dyke	29.75	1.04	1.77	0.28	4.88	4.07	0.12	0.15	0.01	33.78	8.22	0.05	0.43	6.73	0.67	6.53	0.66	0.16	Maf.
276	dyke	30.56	1.14	1.70	0.28	4.82	5.40	0.13	0.15	0.01	34.26	7.39	0.07	0.48	5.96	0.63	5.46	0.85	0.25	Maf.
65	pipe	32.60	2.13	4.10	n.d.	3.91	4.94	0.16	n.d.	n.d.	29.72	7.46	0.25	1.05	8.44	–	4.55	0.69	0.04	S-K
66[2]	pipe	30.26	2.01	3.11	n.d.	5.48	3.18	0.17	n.d.	n.d.	28.04	9.30	0.24	1.08	9.78	–	6.01	1.13	0.02	S-K
265[2]	dyke	30.40	1.92	2.55	0.19	4.71	4.20	0.15	0.12	tr	28.66	8.43	0.07	0.70	9.19	0.98	7.39	0.46	0.14	Mak.
300	pipe	28.75	1.71	2.37	0.25	3.77	5.74	0.12	0.12	0.01	27.97	10.37	0.14	1.18	4.38	0.73	11.15	0.64	0.28	S-K
100	dyke	32.60	2.80	2.10	n.d.	5.70	5.17	0.19	n.d.	n.d.	33.15	7.99	0.22	0.84	6.58	–	2.35	0.92	0.10	Mas
253	blow	29.76	3.07	2.92	0.18	5.81	6.11	0.14	0.11	0.01	29.90	9.36	0.05	1.06	5.97	0.47	3.34	0.95	0.32	S-K
172	dyke	26.40	2.25	3.00	n.d.	2.49	9.10	0.20	n.d.	n.d.	29.83	8.40	0.15	0.84	3.76	–	12.03	0.59	0.05	B-B
250	dyke	31.20	2.25	3.00	n.d.	4.47	6.24	0.18	n.d.	n.d.	26.91	10.30	0.25	1.07	6.86	–	7.57	0.65	0.04	(S-K)
154	dyke	30.00	2.50	2.50	n.d.	5.62	5.38	0.19	n.d.	n.d.	26.91	8.94	0.10	0.84	11.40	–	6.13	0.72	0.02	L-R
271	blow	32.60	3.30	4.30	n.d.	11.17	2.37	0.13	n.d.	n.d.	28.18	4.88	0.30	0.15	11.68	–	0.89	0.95	0.02	QN
104[3]	dyke	29.80	2.50	2.96	n.d.	6.90	5.00	0.34	n.d.	n.d.	25.11	10.29	0.12	1.27	7.33	–	7.86	1.19	0.02	Mas.
307[4]	pipe	37.67	1.99	7.14	n.d.	4.87	4.50	0.16	n.d.	n.d.	19.35	11.41	0.44	1.50	5.82	–	3.88	0.69	0.02	Mas.
263a[3]	dyke	29.15	3.24	3.10	o.14	7.06	5.98	0.16	0.08	tr.	25.78	8.31	0.10	1.31	8.39	0.90	5.16	0.69	0.10	L-R
99	blow	26.70	2.30	5.20	n.d.	5.67	5.16	0.19	n.d.	n.d.	20.86	13.28	0.20	1.87	7.08	–	8.98	1.00	0.02	B-B
293	dyke	33.20	4.00	4.80	n.d.	8.00	3.87	0.25	n.d.	n.d.	22.03	8.67	0.20	1.98	0.34	–	3.40	0.73	0.03	O
282	dyke	33.20	3.83	4.60	n.d.	9.50	4.59	0.17	n.d.	n.d.	23.69	7.86	0.35	0.09	9.96	–	1.73	1.70	0.02	Q-N
200[3]	pipe	34.80	1.58	7.91	n.d.	2.04	6.23	0.16	n.d.	n.d.	16.77	14.36	1.15	1.59	6.00	–	6.63	0.85	0.13	L-R
270	dyke	28.06	3.07	3.38	0.16	13.65	5.67	0.21	0.11	0.11	28.18	2.44	0.22	–	11.93	1.04	0.62	1.30	0.24	QN
70a	dyke	15.40	2.50	4.90	n.d.	4.40	3.15	0.45	n.d.	n.d.	8.58	30.89	0.20	0.79	5.10	–	22.33	0.81	0.03	B-B
66a	dyke	11.34	9.65	5.96	0.31	11.64	0.26	0.31	0.05	0.01	27.97	10.37	0.14	1.18	4.38	0.73	11.15	0.64	0.28	S-K
252	dyke	9.35	1.51	1.87	0.15	3.71	0.36	0.90	0.06	tr.	4.70	39.57	0.10	0.05	2.91	1.41	31.40	1.34	0.11	S-K

Notes:
1. Average of 5 analyses
2. Average of 10 analyses
3. Average of 2 analyses
4. Average of 6 analyses

n.d. = not determined
tr = trace

Kimberlite Groups:
B-B Butha-Buthe
L-R Lemphane-Robert
Mas. Maseru
QN Qacha's Nek

( ) = marginal
S-K Sekameng-Kolo
Mak Makhaleng
Maf. Mafeteng
O Other

Data from Smirnoff, 1980

kimberlite groups represented or diamondiferous and barren occurrences is apparent. The average of the new analyses is compared with kimberlites predominantly from the Lesotho highlands and from elsewhere in the world in table 17. The abundance of palladium, iridium and gold in kimberlites from Thaba Putsoa, Kolo and Ramatseliso and in nodules from Thaba Putsoa, Liqhobong, Matsoku and Kao are given by Paul, Crocket and Nixon (1979). New data on 23 xenoliths is provided by Smirnoff (1980) for a spinel olivinite, harzburgite, spinel harzburgite (6), micaceous harzburgite, lherzolite, garnet lherzolite (6), spinel lherzolite (5) and micaceous lherzolite (2). In addition data are given for a dolerite xenolith from pipe 200, a garnetiferous schist xenolith from pipe 273, and for olivine, clinopyroxene and spinel from a spinel lherzolite xenolith from blow 99. For garnetiferous microxenoliths from pipe 307 (Koalabata) data comprise 12 garnet analyses, 9 pyroxene analyses, and 8 chrome spinel analyses and for ferruginous eclogite microxenoliths 2 garnet analyses, 5 clinopyroxene analyses and a rutile analysis. For garnet-free harzburgite, lherzolite and peridotite microxenoliths are 5 olivine analyses, 4 orthopyroxene analyses, 3 clinopyroxene analyses, 3 spinel analyses and a plagioclase analysis.

8. Date of intrusion and structural relations

There is little data available on the age of Lesotho kimberlites, and they are therefore taken, by analogy with occurrences from all over southern Africa, to have been emplaced near the close of the Cretaceous period. This contention is supported by a Pb/U date of 87.1 million years for a zircon from Mothae Pipe (Davis et al., 1976). By contrast, the Letseng-la-Terae kimberlites yielded mica ages of 380 m.y., 580 m.y. and 660 m.y. but this probably reflects basement mica (Allsopp and Kramers, 1977). A cretaceous age would mean that the emplacement of kimberlite could be related to the final break up of Gondwanaland, but on a more local scale the precise relationship

Table 17. Average kimberlite compositions

	Lesotho[1.]	Lesotho[2.]	Kimberlite Basaltic[2.]	Micaceous[2.]	Yakutia[2.]	South Africa[2.]
SiO_2	30.44	33.21	35.2	31.1	27.64	36.36
TiO_2	2.31	1.97	2.32	2.03	1.65	0.90
Al_2O_3	3.84	4.45	4.4	4.9	3.17	5.13
Cr_2O_3	0.21*	0.17	-	-	0.14	0.22
Fe_2	5.41	6.78	9.8^+	10.5^+	5.40	7.71^+
FeO	4.59	3.43			2.75	
MnO	0.20	0.17	0.11	0.10	0.13	0.16
NiO	0.10*	-	-	-	-	-
CoO	0.02*	-	-	-	-	-
Mgo	26.23	22.70	27.9	23.9	24.31	17.43
CaO	10.51	9.36	7.6	10.6	14.13	11.16
Na_2O	0.25	0.19	0.32	0.31	0.23	0.42
K_2O	1.00	0.79	0.98	2.1	0.79	1.52
H_2O ·	8.03	8.04	7.4	5.9	7.89	-
H_2O^-	0.78*	2.66	-	-	-	-
CO_2	6.06	4.58	3.3	7.1	10.84	-
P_2O_5	0.89	0.65	0.72	0.66	0.55	0.55
S	0.07	0.28	-	-	0.24	-

1. Data based on Smirnoff, 1980, average of 46 analyses except *, average of 11 analyses
2. Gurney and Ebrahim, 1973

\+ Total Fe as FeO

between the kimberlite occurrences and structure of Lesotho is imperfectly understood. The location of the kimberlite belts at regular intervals seems independent of any other structure, and the occurrences or absence of kimberlite within these belts still awaits a satisfactory explanation (Dusar, 1979). According to Barthelemy and Dempster (1975), the 110^{o}-130^{O} trend is a very ancient one which has controlled kimberlite dyke emplacements almost exclusively whereas pipe emplacement may be influenced by the inter-relationship of this and trends at 50^{o} and 160^{o}-170^{o}. They also note an apparent relationship between kimberlite occurrence and synclinal basement structures. Some empirical relationships may be remarked on between kimberlite distribution and Dusar's more recent structural interpretations (Dusar, 1979) which, as noted in a later chapter, are based on the Stormberg beds and include a hypothesis of structural reversal such that Stormberg 'highs' correspond to basement 'lows'. The Butha-Buthe, Lemphane-Robert and Qacha's Nek kimberlite groups all appear to occur on, or close to, the flanks of Dusar's structural highs and hence, according to the reversal hypothesis, of basement lows. These correspond with Bartholemy and Dempster's basement synclinal structures. Moreover, the break in the northern kimberlite belt, between the Butha-Buthe and Lemphane-Robert groups appears to correspond to an unfavourable basement high. The relationship between the other kimberlite groups and Dusar's structural elements are less certain. However a special relationship between the Helspoort and Siepe faults and the Mafeteng, Makhaleng, Roma and Mapoteng groups may be observed. The central area of country, for which little structural detail is available is considered by Dusar to be generally a Stormberg low, i.e., a basement high. If this is the case it may explain the absence of kimberlite.

Examination of the results of the gravity survey of Lesotho (Burley et al., 1981) suggests a possible relationship between basement domes and kimberlites (figure 48, 49). The

Sekameng-Kolo, Maseru, Mapoteng and possibly Butha-Buthe groups all occupy peripheral locations with respect to a gravity high corresponding to the Maseru-Clocolan Dome. On the other side of the country, the Qacha's Nek group also lies on the flank of of what might be a similar structure which creates a comparable gravity anomaly. However, the gravity data does not offer an obvious explanation for the location of the Lemphane-Robert group, which economically is the most interesting.

J. Quaternary deposits

Strongly eroding conditions in the Pleistocene resulted in the widespread accumulation in the lowland valleys of several metres of fluviable cobble, beds overlain and intercalated by pediment and aolian gravel, silt and clay filling and levelling the previous drainage channels (Dempster and Richard, 1973). This material which is up to 10 m thick (J. King, 1978) is at present being removed by active streams giving rise to narrow steep-sided ravines or dongas (figure 45). The donge pediment deposits probably accumulated during a pluvial stage of the Quaternary, possibly an interglacial period as evidence of three successive glacial periods during Pleistocene times in Lesotho have been described by Alexandre (1962) and Harper (1969). Some indications exist from the Lemphane gravels (Scott, 1973) that pre-Quaternary deposits may exist but their extent is unknown.

The typical donga succession in the Maseru region has been described (Spurek, 1975a) as consisting of a surface layer of soil and rock debris a few centimetres to a metre in thickness followed downward by a layer 0.3-1 m thick of dark grey to black carbonaceous clay; this in turn grades into a layer of dark brown to brownish-grey clay 1-2 m thick which passes into a buff-coloured mottled layer of silty clay and silt usually 2-3 m thick. The silty unit in most places rests on sandstone, siltstone or shale bedrock although elsewhere a basal gravel and gravel or sand lenses are present (van Rooijen, 1975a; King, 1978).

The terrace gravels along the Sanqu River have been described by Rombouts (1979c, 1978c) and those along the Mohokare (Caledon) River by Etoile (1980). Recent sands, silts and gravels are generally of limited extent except along the major rivers. An interesting phenomenon is the presence of active sand dunes at Thaba-Sosiu near Maseru and east of Makhoma's Pass (Stockley, 1947).

Figure 45. Erosion of Quaternary sediments near Matsaba giving rise to dongas. Molteno sandstone at middle distance right; in left background, white Clarens sandstone capped by basalt of the Lesotho Formation

III. GEOPHYSICS AND STRUCTURAL GEOLOGY

A. Surveys and studies

1. Airborne magnetic

An airborne magnetic survey covering 4,800 km^2 of the western Lesotho lowlands (figure 2) was carried out in 1975 under a bilateral co-operative agreement between CIDA and the Lesotho Government. Both the survey and the interpretation were undertaken by Northway Survey Corporation Ltd (1977a, 1977b). The survey was drape flown using a fixed-wing Britten-Norman Islander aircraft with the mean terrain clearance being 150 m and the mean airspeed 150 km/hr. Lines were flown at a nominal spacing of 275 m and were oriented north-south, whilst east-west control lines were at a nominal-15 km spacing. Visual navigation was aided by the use of airphoto strips at 1:25,000 scale. Variations of the magnetic field were measured by a Gulf Mk III-D digital, total field magnetometer with output recorded in both digital and analog forms. Diurnal variation was recorded by a Geometrics 806 magnetometer located near the operations base. A 35 mm continuous strip camera was used to provide photographic positioning information for flight path recovery, and a Honeywell HG9050 precision radar altimeter recorded terrain clearance. All data acquired was compiled and reduced by computer processing.

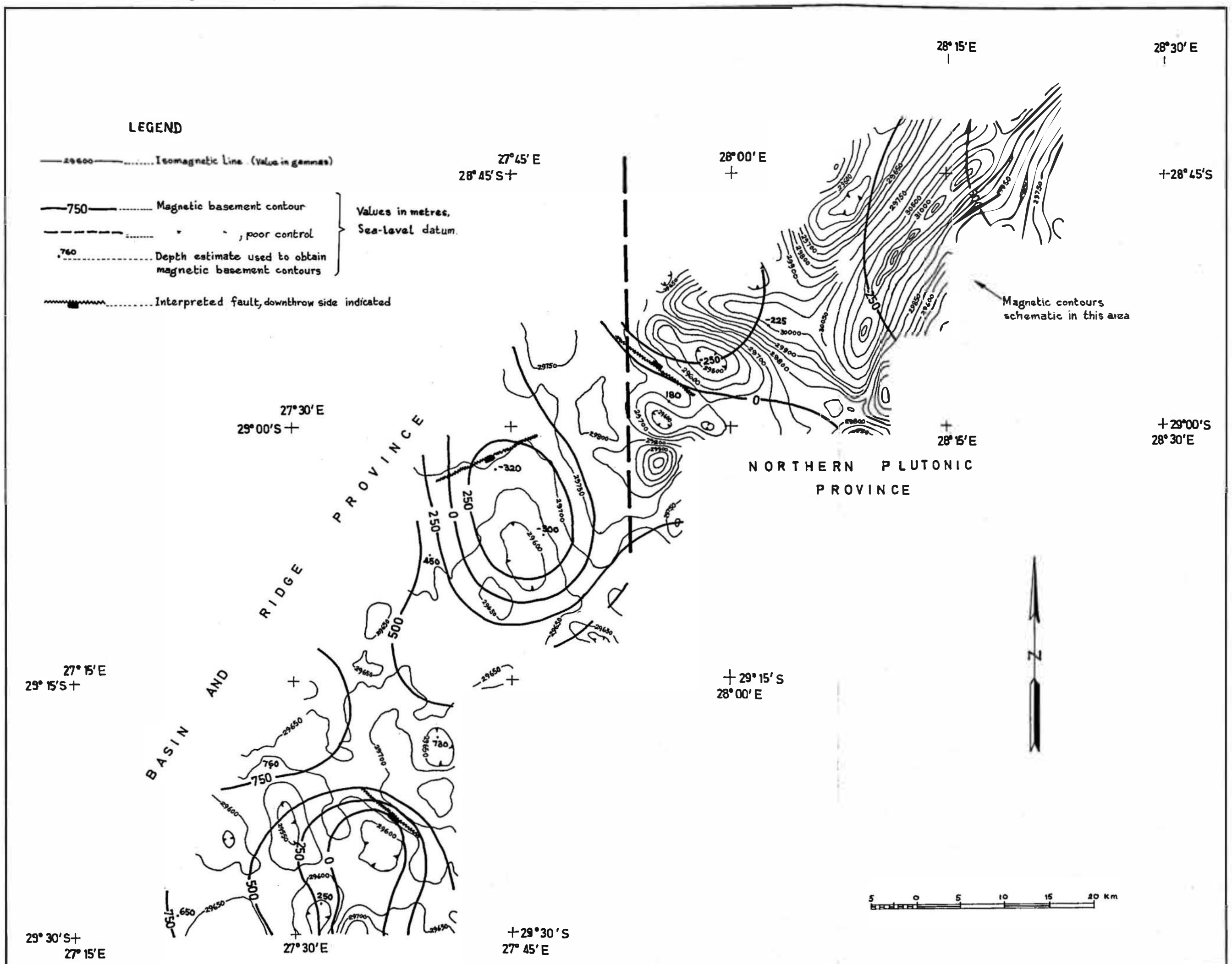
Regional interpretation of the data shows that the depth to basement in the survey area increases from south to north and from west to east. Basement faulting is restricted to two directions 45^{o}-55^{o} and 120^{o}-130^{o}, two of the primary directions identified from satellite imagery, the latter corresponding closely to the principal kimberlite trend (Barthelemy and Dempster, 1975). The survey area can be divided into 5 provinces (figure 46, 47) with differing magnetic characteristics, of which the "Northern Plutonic Province" has the greatest interpreted depth to basement. It is characterized by many large, intense, magnetic anomalies, probably the result of large intrusive bodies emplaced in a gneissic terrain, and dominated by one large north-east trending linear anomaly. This is interpreted to result from a 2.3-3.5-km-wide body at a depth of about 2 km, which may be a large ultramafic intrusion or a large belt of thin iron formation. The "Basin and Ridge Province" is typified by moderate magnetic activity, perhaps corresponding to granitic basement. Two basins and three ridges, all trending at about 170^{o} are present. The boundary between this and the adjacent central province is fault controlled, with an apparent uplift to the south. The "Central Province" is characterized by short wavelength magnetic activity, resulting in shallow depth estimates, although the interpretation may be blurred by the response of numerous and extensive near-surface dolerite sills (Dusar, 1979), and the area may have been a highland in Molteno times. Substantial faulting, considered to be basement controlled, is present on 45^{o}-55^{o} and 110^{o}-130^{o} trends. The "Southern Plutonic Province" is similar in nature to the Northern Plutonic Province and is bounded on the south by the Helspoort Fault, across which a 400-gamma fall in magnetic level from north to south demonstrates a major change in basement lithology. Some difficulty was experienced in obtaining reliable depth estimates, but the area, with reservation, is interpreted to be shallow. The "Southern Province" includes 3 mapsheets for which the data was not computer processed, and interpretation is thereby hindered. The most striking magnetic feature is the narrow linear anomaly trending east-northwest across mapsheet 12B. The substantially lower susceptibility of basement indicated by the 400-gamma lower magnetic level in this province leads to the conclusion that the basement complex probably consists of greenschist facies metasediments.

2. Airborne radiometric

An airborne radiometric survey was undertaken simultaneously with the magnetic survey (figure 2) and the instrument used was an Exploranium 3001, 4-channel differential gamma-ray spectrometer. This instrument measured, at a 1 second sampling rate, the count rate signals of potassium-40, bismuth-214 (uranium daughter isotope), thallium-208 (thorium daughter isotope) and total count. Input to the spectrometer was provided by two Hershaw hexagonal crystals with a total volume of 14,514 cm^3. A caesium-137 mono-energetic isotope with a single gamma line at 0.662 MeV was used for spectrum stabilization and a "stripping function" processed the analog output of the spectrometer to remove the effects of Compton scatter (Northway Survey Corporation Ltd, 1977a).

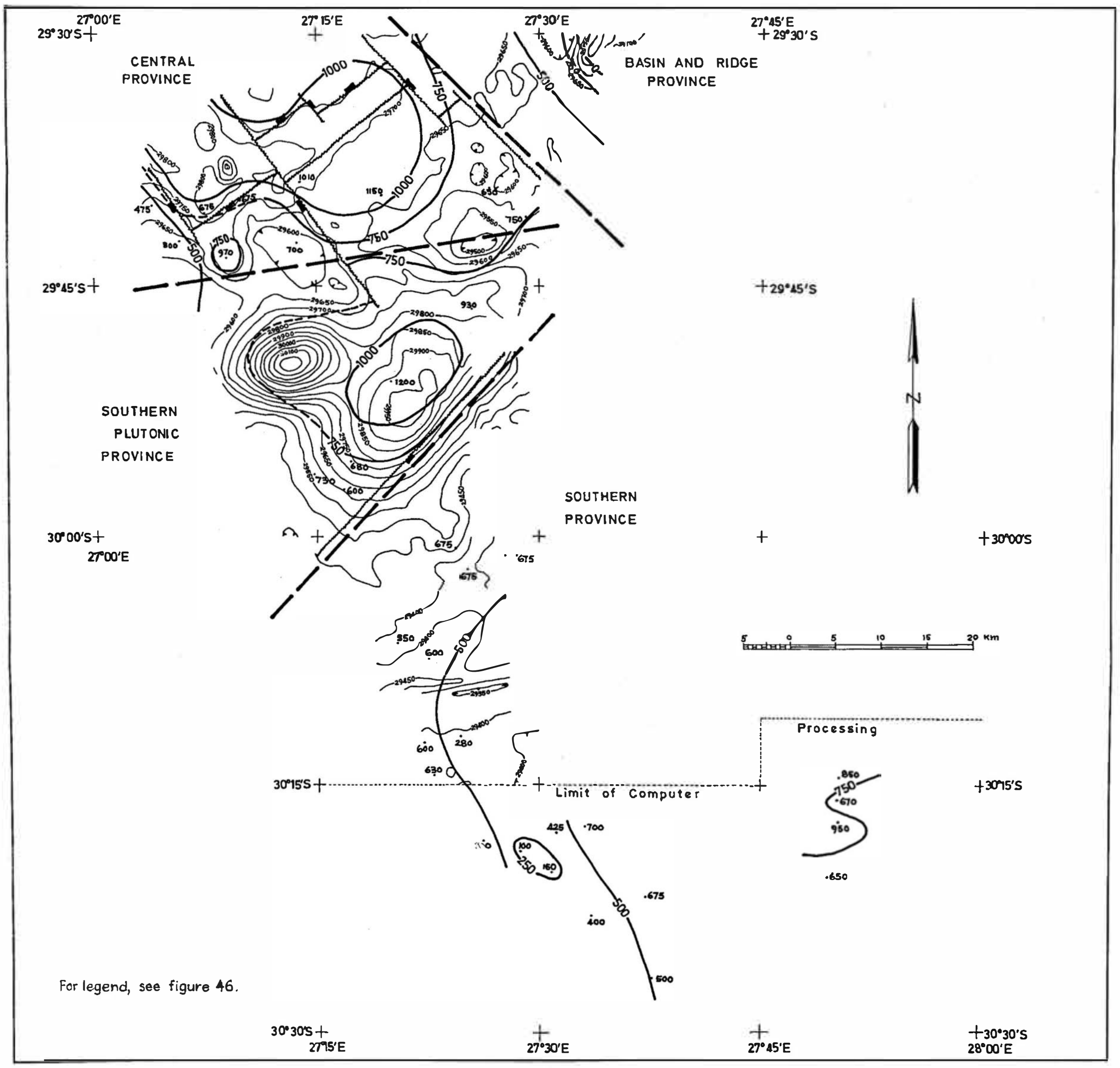
The main conclusion reached in the interpretation report (Northway Survey Corporation Ltd, 1977b) was that uranium response on the whole was weak throughout the survey area. The Beaufort Group and the Elliot Formation contained by far the largest number of uranium anomalies whereas the Clarens Formation, basalts and dolerites were barren. In assessing the effectiveness of the airborne radiometric survey, it must be borne in mind that the survey was an adjunct to the airborne magnetic survey which primarily governed the choice of flight height, line spacing and type of aircraft employed. The main factor limiting the usefulness of the survey was the terrain flown over -- steeply rising hills and mountains with intervening low-lying ground with thick colluvial cover. Despite these limitations, however, the airborne gamma ray spectrometer survey proved a useful guide for exploration (United Nations, 1981f).

Figure 46. Regional magnetic interpretation, north sheet.



3300.26x

Figure 47. Regional magnetic interpretation, south sheet.



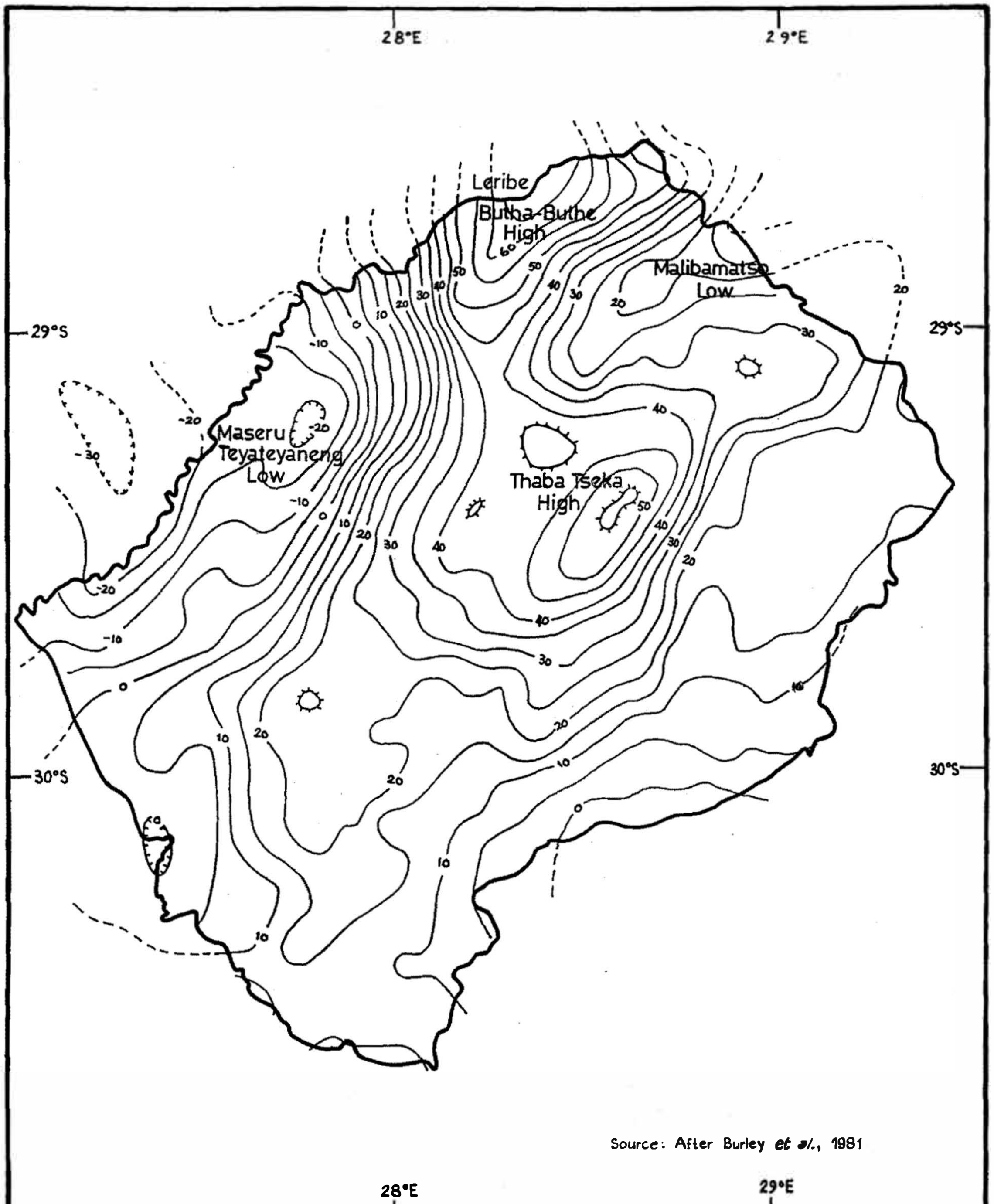
3300.27x

3. Gravity

A gravity survey of the whole of Lesotho was conducted in 1979 by personnel of the Applied Physics Unit of the U.K. Institute of Geological Sciences assisted by the geophysicist from the Exploration for Minerals project. The country was divided into eight areas, in each of which a gravity base was established, and gravity measurements were taken with a Lacoste and Romberg gravity meter at 767 gravity stations with an average spacing of 6.3 km. To provide reasonably uniform coverage, an Aluette-III helicopter was used to occupy 689 of the stations. As many stations as possible were at locations of pre-determined altitude, such as trigonometric points and benchmarks, whilst unknown station heights were measured by a set of three Wallace and Tiernan altimeters, using the pre-determined heights for control. The gravity data were processed to produce values for the Bouger and isostatic gravity anomalies at each station and initial station plots and contour maps were prepared on an IBM 360/195 computer (Burley et al., 1981).

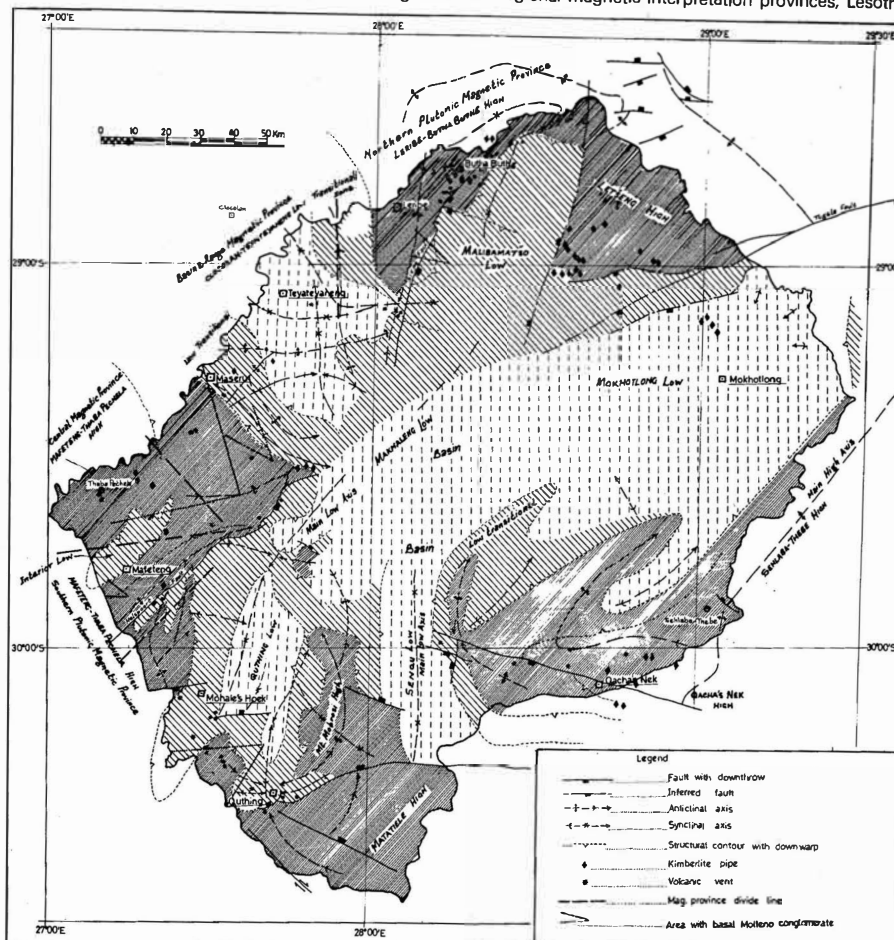
The dominant feature shown by the gravity data is a large positive anomaly extending over much of the basalt-covered central and eastern parts of the country (figure 48). The peak amplitude is more than 55 mGal, and the anomaly is bounded on two sides by parallel features trending roughly north-east, echoing the major structural trend. By analogy with anomalies of similar scale in South Africa, the most likely cause is a substantial thickness (4-5 km ?) of basic, chiefly gabbroic, material. The Thaba Tseka gravity high is a local north-east-oriented closure superimposed on the dominant positive anomaly, and its probable explanation is that the intrusion responsible for the major feature is domed (i.e., shallower) in this area (Burley et al., 1981). Several smaller-scale features are also present, including the Leribe - Butha-Buthe gravity high which appears to be an extension of the Bethlehem high in the Republic of South Africa and may have a similar cause to that

Figure 48. Gravity survey, isostatic anomaly map.



3300.1x48

Figure 49. Structural interpretation of Stormberg beds and regional magnetic interpretation provinces, Lesotho.



3300.29x

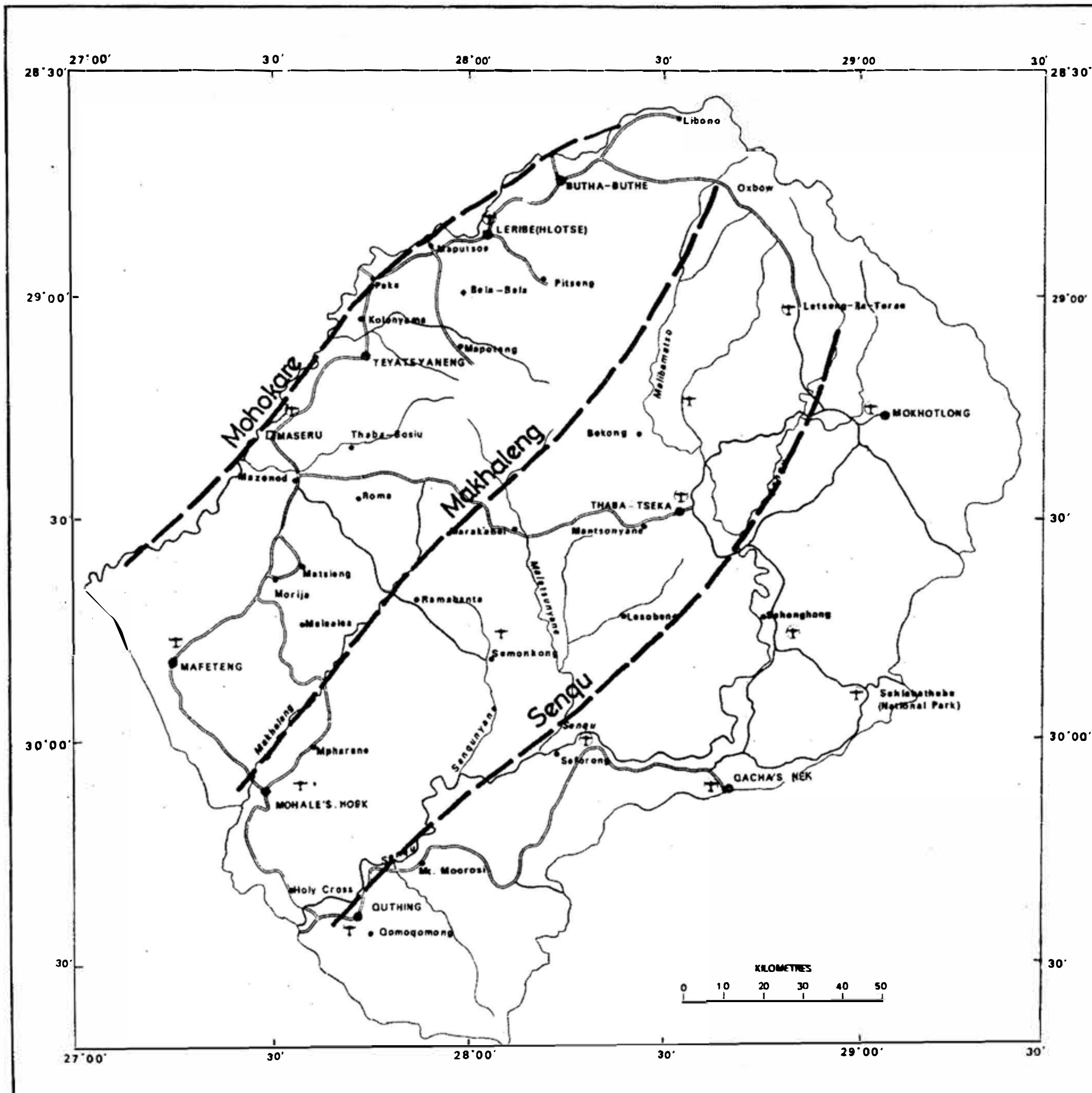
of the dominant large positive anomaly, of which it could be considered a part. The Maseru-Tayateyaneng gravity low probably shows an extension of the granite dome known to exist north of Maseru, whilst the Malibamatso gravity low may represent deep basement if the basement in the surrounding area is basic and the overlying sediments contain a low proportion of dolerite. This feature might also represent a ridge of granitic basement, although this is not compatible with Dusar's (1979) hypothesis of structural reversal.

Perhaps the most striking feature of the gravity survey is that there is little evidence of any trends of typical "kimberlitic" orientation (ESE), which had been supposed to relate to deep and fundamental basement structures. Otherwise the data affords corroboration of the structural highs and lows and magnetic provinces (figures 46, 47, 49), the dominant northeast trending post-Drakensberg deformation (figure 50) and a possible partial explanation for the kimberlite distribution (see previous section on kimberlite structural relations).

4. Experimental

A multisensor serial survey was carried out in 1971 over an area of 2,590 km^2 in the northern phase I area of the United Nations Exploration for Diamonds project by the Space Division of the North American Rockwell Corporation with Hunting Geology and Geophysics Ltd as sub-contractor (United Nations, 1972). North American Rockwell provided the management and most of the instrumentation and scientific analyses and Hunting provided the aircraft, flight crew and basic navigation and photographic equipment. Flights were first made over known kimberlite bodies using a range of available sensors and the data evaluated to determine the optimum combination of sensors and wavebands for use in the survey proper which involved the collection of thermal infrared imagery, true colour and infrared false-colour photography and four-band multispectral

Figure 50. Possible location of primitive river system, Lesotho.



3300.30x

photography. Interpretation of the data was done by manual and advanced automatic imagery enhancement methods with the dual aims of determining the most effective and economic methods of searching for kimberlite bodies and actually locating unknown kimberlite diatremes. Localities propitious for kimberlite exploration were listed but ground follow-up did not lead to a discovery. The general conclusion was that the experimental techniques were ineffective in reconnaissance exploration (United Nations, 1975b).

5. Photogeological fracture trace analysis

As a result of a recommendation made by the Exploration for Diamonds project (United Nations, 1975b) a photogeological fracture trace analysis study was carried out for the project by Hunting Geology and Geophysics Ltd over 7,500 km^2 of central Lesotho (figure 2) in the period February to December 1975. (Hunting Geology and Geophysics Ltd, 1976; Norman, Price and Peters, 1977). The primary object of the study was to determine whether a specific fracture pattern was associated with kimberlite intrusion, thereby assisting in the discovery of additional kimberlites. The work programme comprised annotation of fractures, colour-coded according to type, on overlays to 1:30,000-scale aerial photographs, followed by compilation onto maps at 1:50,000 scale. The fracture traces were then digitised and analysed statistically by computer. The final stage involved interpretation and listing of fracture trace anomalies. Field work was undertaken at the annotation stage to ground check the fracture-trace date, and a brief visit was also made to Lesotho during the computer analysis. During the study, 896 black and white prints of the aerial photographs were used, with each stereo-pair systematically examined and more than 30,000 fracture traces recorded. The annotated fracture data was subsequently transferred onto the 1:50,000-scale topographic sheets with the aid of a low-order stereo-plotter and the co-ordinates of each fracture trace and its classification were punched onto cards for computer analysis using a D-Mac digital plotter. Short lines were identified by their end points, whilst intermediate points were also digitised for long and curved lines. All data was subjected to statistical analysis carried out on a CDC 6400 computer, with the data for each quarter-degree mapsheet processed individually. Data was computed in terms of 1-km^2 cells with a subsequent output related to cells of approximately 25 km^2. Graphical output was either onto a Kingmat flat-bed plotter or microfilm plotter whilst other data was recorded as lineprinter output. The results of the fracture-trace study were presented as an explanation and interpretation of: a total field of fracture map; a fracture density map; rose diagrams (angular frequency analysis); an angular atypicality map (angular residual analysis); co-ordinated unique peaks (radial pattern analysis); interpretation map; sub-surface sills interpreted from fracture traces; interpretation of angular atypicality map; and length frequency histograms. A listing of primary and secondary prospecting targets based on the study accompanied the report.

The fracture traces annotated on the photographs agreed in density and direction with those observed on the ground, and showed good agreement with fracture patterns extracted from Landsat imagery (Barthelemy and Dempster, 1975). Interpretation of the fracture map suggested that the basalts of the study area have been intruded by small, medium and large sills at various depths. Larger unfractured sills may have acted as barriers to the later episode of kimberlite intrusion. It was apparent that no unique fracture pattern formed around kimberlite pipes at the time of their intrusion, but stress interpretation pointed to kimberlites utilising existing fractures a and the intersections of fractures trending between 100° and 130° were considered to be the best sites to investigate for kimberlite.

Subsequent ground checking of fracture analysis targets by United Nations field geologists failed to locate a single instance in which a target corresponded to an unknown kimberlite. Moreover, an examination of the known kimberlites within the study area and the targets listed showed only a relatively low degree of correlation. The importance of lineaments in the 100^{o}-130^{o} sector had previously been highlighted (Dempster and Richard, 1973) and intrusion of dolerite sills accompanying the extensive dykes and basalts of the Lesotho Formation was not entirely unexpected. It was concluded that the study had provided little new information, and that it had little practical application in the search for kimberlite in Lesotho. In view of the disappointing results, and in particular the absence of a unique fracture 'signature' for kimberlite, the decision was taken not to extend the area of study (United Nations, 1981a).

B. Structural deformation

1. General

As Lesotho is located in the centre of the large Karoo tectonosedimentary basin (figure 14) the overall structural pattern is synclinal (Stockley, 1947) with the important consequence that the sedimentary rocks buried beneath Lesotho are exposed in the areas surrounding Lesotho. Within this overall major structural framework, however, it has proved possible to establish three periods of tectonic deformation - pre-Drakensberg, Drakensberg, and post-Drakensberg (Dusar, 1979). The pre-Drakensberg deformation is based on basement composition and structures and has influenced the sedimentation of the Karoo beds. The Drakensberg deformation at the onset of volcanic activity produced the most striking tectonic effects and is indicated particularly by the changes in elevation of the Stormberg-Drakensberg basalt contact. The post-Drakensberg deformation significantly influenced the location of the primitive river system and thus the present hydrography and geomorphology.

2. Pre-Drakensberg deformation

The pre-Drakensberg deformation includes structures confined to the basement and to those pertaining upwards into the Karoo beds. No direct evidence of the nature and structure of the Precambrian basement in Lesotho is available but drillhole data round Lesotho indicates that rocks with granitic and gneissic affinities are the most widespread except in the north-western Natal and the north-eastern part of the Orange Free State where metamorphic volcanic and sedimentary rocks of the Swaziland system are known (Stratten, 1970a). These beds form the oldest sedimentary sequence on the Kaapvaal craton (figure 12). Rocks belonging to the Swaziland system probably also underlie the northern part of Lesotho as inclusions of baked shale, phyllite, ferruginuous quartzite and bonded ironstone in kimberlite pipe 241 near Butha-Buthe were assigned to the Figtree Series of the Swaziland system (United Nations, 1975a). Possibly a strong deep-seated north-north-east-trending magnetic anomaly in the Butha-Buthe area results from the presence of a banded ironstone zone in the basement (Northway Survey Corporation Ltd, 1977b). The boundary between the northern 2,500 m.y. Kaapvaal craton shield and the southern Namaqualand-Natal circumcratonic belt which suffered orogenic deformation during the 1,100 m.y. Kibaran orogeny (Clifford, 1970) possibly crosses Lesotho (Truswell, 1977), although its exact position is not certain. In Natal the Tugala Fault marks the contact between the two basement units and its western continuation in Lesotho has been considered to link up with the Helspoort Fault (Barthelemy and Dempster, 1975; Barthelemy, 1976) but this hypothesis is not supported by Dusar (1979) who points out that there is no known evidence of extensive east-west fracture zones in the sedimentary rocks underlying the undisturbed basalt despite the fact that the Tugela Fault displayed recurrent activity as late as 200-100 m.y. (van Eeden, 1972), i.e., the time of the Drakensberg volcanic outpourings and the kimberlite emplacement. Further, there is certainly no inportant fault zone displacing the Stormberg-basalt contact south of Letseng as recent drilling has indicated that the contact dips away from an altitude of 2,075 m on the anticlinal axis north of the Drakensberg Escarpment to 1,635 m at Letseng to 1,560 m at Tlokoeng near Mokhotlong. An extension of the Tugela Fault into Lesotho is also not apparent from the results of a gravity survey (figure 48). Based on this evidence it appears that the contact between the Archean Kaapvaal craton and the younger circum-cratonic mobile belt is not necessarily fault controlled and may have a more irregular and as yet unknown outline in Lesotho (Dusar, 1979).

The presence of an uneven basement floor is inferred from a regional magnetic survey of the western lowlands (Northway Survey Corporation Ltd, 1977b), from the paleogeographic reconstruction of the Molteno (Dusar, 1978b), and from borehole evidence in the surrounding areas of South Africa (Ryan, 1967; Winter and Venter, 1970). From the Permian to Early Jurassic, Lesotho was situated in the centre of the Karoo Basin, a marginal cratonic shelf which merged southwards into a tectonically much more active miogeosynclinal trough which was severely folded and uplifted in upper Beaufort-Molteno times. The resultant fold range - the Cape Fold Belt - developed into a prominent southerly source of sediment whereas the main sediment source before was the epeirogenically elevated Kaapvaal craton. On the shelf area the "Lesotho Rise" was for a long time a fairly strong positive element (Rust, 1975). Dwyke glacial deposits were probably not deposited over most of Lesotho as the glacial valleys descending from the northern highlands were diverted around the "Lesotho Rise" which was an elevation of the basement (Crowel and Frakes, 1972). Coal and sandstone deposited in a swampy and deltaic environment are abundant in the northern facies of the Middle Ecca in contrast to shales deposited in a deep-lake or even marine environment in the central part of the Karoo basin west of Lesotho. Apparently the location of the "Lesotho Rise" was a controlling feature determining the gross shape of the original coal swamp (Rust, 1975) and probably only limited Ecca coal deposits can be expected on and around the "Lesotho Rise" (Dusar, 1978b). In the northern half of the Beaufort basin Theron (1967, 1975) inferred at least two sediment sources, one apparently from the south-east and the other a nearby granitic source which produced the coarse-grained arkoses in the Middle Beaufort; this nearby source may have been a locally uplifted part of the "Lesotho Rise". The Stormberg sedimentation was restricted initially to a rather small basin and represented the syntectonic sedimentary response to renewed tectonic movements along the southern margin of the Karoo tectono-sedimentary sequence (Swartberg phase of the Cape progeny). Except for this southern margin, tectonic activity was restricted to small vertical movements and local uplift. During Molteno times at least the dispersal of the sediments was originated by a pulsatic tectonic uplift in the mountainous source are leading to a cyclic sedimentation in the basin area (Turner, 1970). One of the most significant features is that the subsidence leading to the accumulation of the Stormberg sediments was concentrated on or around the "Lesotho Rise" (Rust, 1975; Dusar, 1979). In the Mt. Moorosi region, for example up to 1,000 m of Stormberg sediments were accumulated in a deep sedimentary trough, the gradual subsidence of which kept pace with the sediment input as there is no noticeable facies difference in the sedimentary succession between the trough area and the surrounding region. In contrast a small structural dome of pre-Drakensberg age found near Mafa in the

Qacha's Nek district is characterized by a much thinner Elliot and Clarens beds (Dusar, 1978a). Other structural domes probably underneath the basalt in the central part of Lesotho may have been uplifted and subsequently eroded during Beaufort-Molteno times and supplied the basement pebbles which were deposited in the Molteno conglomerates (Dusar, 1978b).

3. Drakensberg deformation

The Drakensberg deformation is characterized by faults and folds which effect the sedimentary formations and the lower lava flows but taper out in the later flows. Hence it is only in areas where the basalt cover has been stripped off by erosion that Drakensberg tectonic structures are revealed. Besides small 5-10 km-wide structural domes and basins (Binnie and Partners, 1971; Loxton, 1973) a block pattern of larger structural highs and lows has been recognized (Dusar, 1977a, 1979). These highs and lows have no particular direction or geometric pattern for the highs (Leribe - Butha-Buthe, Thaba Pechela-Mafeteng, Mount Moorosi, Qacha's Nek-Sehlabathebe, Letseng) generally occupy peripheral positions in Lesotho whereas the structural lows (Teyateyaneng-Clocclan, Quthing-Makhaleng-Malibamatso, Senqu, Mokhotlong) coalesce in the central part of Lesotho (figure 49). The boundaries are either gradual in extensive transitional zones or sharply defined by faults or downwarps (monoclinal flexures). Thus the Leribe - Butha-Buthe High is separated by the Siepe Fault from the Malibamatso Low on the east and grades into the Clocolan-Teyateyaneng Low to the south-west. The Thaba Pechela-Mafeteng High also grades to the north-west into the Clocolan-Teyateyaneng Low and is separated by the Helspoort Fault and an intermediate basin and ridge zone from the Quthing-Makhaleng Low to the south-west. The Mount Moorosi high forms a northern extension of the Matatiele High across a downwarping axis and is wedged between the Quthing-Makhaleng Low in the west and the Senqu Low in the east. The Qacha's

Nek High lies north of the Matatiale Upwarping and interfingers in a northward direction with the Central Basin. The Sehlabathebe High on the Drakensberg Escarpment forms a north-western extension of the Qacha's Nek High and is interrupted to the north by the Mokhotlong Low. The Letseng High dips away from an upwarping axis situated to the north of the north-western Drakensberg Escarpment and is separated by the Sefako Fault and downwarp zone from the Malibamatso Low to the West. The transition to the Makhotlong Low in the south is probably gradual as there is no evidence for a westward extension of the Tugela Fault zone.

An airborne magnetic survey carried out over the western Lesotho lowlands has led to the recognition of five basement provinces (Northway Survey Corporation Ltd, 1977b) which are closely co-incident with the larger structural highs and lows (figure 49). The data clearly indicated an uneven basement floor and especially significant is that the provinces where the deepest depth to basement were postulated underlie the structural highs (the Northern Plutonic Province below the Leribe - Butha-Buthe High and the southern Plutonic Province below the Thaba Pechela-Mafeteng High). A granite dome is known near Clocolan (Ryan, 1967) and this probably extends into Lesotho underneath the Clocolan-Teyateyaneng Low. As already outlined above paleogeographic evidence points to the existence of high ground on top of basement highs in Lesotho during the Lower Karoo (Ryan, 1967; Rust, 1975) and probably during the Beaufort (Theron, 1975). For the Molteno, Dusar (1978b) has inferred the presence of several basins and domes, the latter with an attenuated Karoo sequence. The Molteno basal conglomerates themselves were deposited in river basins, now all on structural highs and apparently derived from uplift areas now structural lows (figure 49). The Mount Moorosi High coincides with a deep sedimentary trough in which up to 1,000 m of Stormberg sediments were accumulated.

The gravity survey of Lesotho (figure 48) has provided additional evidence that the geological structural units and magnetic provinces are distinct structural entities and it is instructive to list the main similarities and differences. The Leribe - Butha-Buthe High coincides with both the Leribe - Butha-Buthe gravity High and the Northern Plutonic Magnetic Province. The eastern boundary with the Malibamatso Low is marked by the Siepe Fault and the steep magnetic and gravity gradients would also suggest a fault contact. On the west the high was considered by Dusar to grade into the Clocolan-Teyateyaneng Low whereas the gravity and magnetic gradients point to a fault-controlled boundary. The Clocolan-Teyateyaneng Low coincided with the Maseru-Teyateyaneng Gravity Low and with the northern part of the Basin and Ridge Magnetic Province. All three interpretations suggest granitic basement extending southwards from the Clocolan Dome in the Republic of South Africa. Both the magnetic and gravity data suggest that the unit extends farther to the south-west. The Mafeteng-Thaba Pechela High includes both the Central and Southern Magnetic Province but there is no particular gravity feature. Although, overall, the unit was considered by Dusar to be a single one, the southern part of the High is an "interior low" and this may coincide with the Southern Plutonic Magnetic Province. The gravity results do not support the presence of two structural units over the area of the Basin and Ridge and Central Magnetic Provinces; perhaps the magnetic response of the Central Province may be a function of the numerous near-surface dolerites and in this case the Central Province would be more appropriately included in the Basin and Ridge Province. The southern boundary of Dusar's Mafeteng-Thaba Pechela High is the Helspoort Fault and this is supported by both the magnetic and gravity gradients. The Mount Moorosi High may coincide in part with relatively high gravity indicated by a lobe in the 15-mGal contour but there is no specific gravity feature associated with the Qacha's Nek High.

The Sehlabatheba High parallels the gravity contours. The Letseng High coincides with the Malibamatso-Letseng gravity Low.

It is generally agreed that the small-scale Drakensberg doming resulted from intrusion of dolerite sills (Binnie and Partners, 1971; Loxton, 1973) and cumulative dolerite intrusions were probably also instrumental in the formation of the larger units (Dusar, 1979). A greater sediment thickness will mean more confining pressure from the weight of the overlying strata and more bedding planes along which the dolerite could intrude and so more sills. The intensity of uplift inferred from the variation in height of the Stormberg-basalt contact provides a measure of the cumulative thickness of dolerite sills which depends in turn on the thickness of the sedimentary beds. No drillholes have reached basement in Lesotho but some data is provided by two holes drilled in the Leribe - Butha-Buthe Structural High (figure 10). A hole at Mahobong reached a depth of 1,652 m of which 256 m of 15.5 per cent was dolerite and near Butha-Buthe 370 m or 25 per cent was dolerite out of a total depth of 1,475 m.

The most important fault in Lesotho is the Helspoort Fault which has been traced over 70 km until it disappears in basalt and which marks the southern boundary of the Thaba Pechela-Mafeteng High with the Southern Plutonic magnetic basement province (figure 47). The fault has been linked with the Tugela Fault in Natal which separates the ancient Kaapvaal craton with the Namaqualand-Natal circum-cratonic belt (Barthelemy and Dempster, 1975; Barthelemy, 1976) but more likely, as discussed earlier, the Helspoort Fault joins below the basalt with the Siepe Fault which marks the eastern boundary of the Leribe - Butha-Buthe High. The fault is considered by Dusar (1977a, 1979) to merely concentrate the regional dip from a structural high to a structural low and does not necessarily extend into the basement (figure 51). In contrast, the 400-gamma fall in magnetic level across the fault implies at least a change in basement composition. Again the main gravity north-east trend parallels the fault and this could indicate a line of structural weakness in the basement. It appears certain, however, that the faults and downwarps in Lesotho are not comparable to large-scale structures such as the Natal Monocline or Lesotho downwarps which are important continental margin features or else related to the break-up of Gondwanaland.

4. Post-Drakensberg deformation

The main geomorphologic feature that has been used as evidence for post-Drakensberg Deformation is the north-east trend of the major river system which is considered to result from north-east trending flexures cut along the north-eastern Drakensberg Escarpment by a NW-SE axis of uplift (Binnie and Partners, 1971). Thus the primitive drainage system established after the basalts had been deposited consisted of three major rivers - the Caledon, the Makhaleng and the Senqu, and modifications to this system were mainly caused by river capture (figure 50). The postulated flexuring correlates with anticlinal and synclinal axes discernible on Landsat photos (Barthelemy and Dempster, 1975). Even more significant, however, is the fact that the primitive drainage system follows the major north-east gravity trends suggesting renewal of ancient basement lineaments.

5. Hypothesis of structural reversal

The hypothesis of structural reversal was postulated by Dusar (1977a, 1979) and is based on comparison of two surfaces, first, the contact between the Stormberg sediments (Clarens Formation) and the Drakensberg basalts and, second, the Precambrian basement floor on which the Karoo sediments were deposited. As already noted the Stormberg-Drakensberg contact reveals a series of structural highs and lows which appear to correlate with basement lows and highs (figure 19). Dusar's explanation of the correlation is that more Karoo sediments will be accumulated on basement lows, less on basement highs. The intensity of uplift inferred from the variation in height of the sediment-basement contact is assumed to result primarily from the cumulative thickness of dolerite sills which depends in turn on the thickness of the sedimentary beds. In this way structural highs observed with Stormberg beds will directly overlie basement lows as on these places the Karoo sediments attained a greater thickness and hence a higher incidence of delerite sills. Monoclinal flexuring will occur above the transition from basement highs to basement lows where part of the dolerite sills taper out. Faults will accentuate the flexuring in places where the transition is too steep. These faults are not necessarily connected with basement faults although they could be located in weakness zones or on lithologic contacts in the basement. A diagramatic illustration of the hypothesis is given in figure 51.

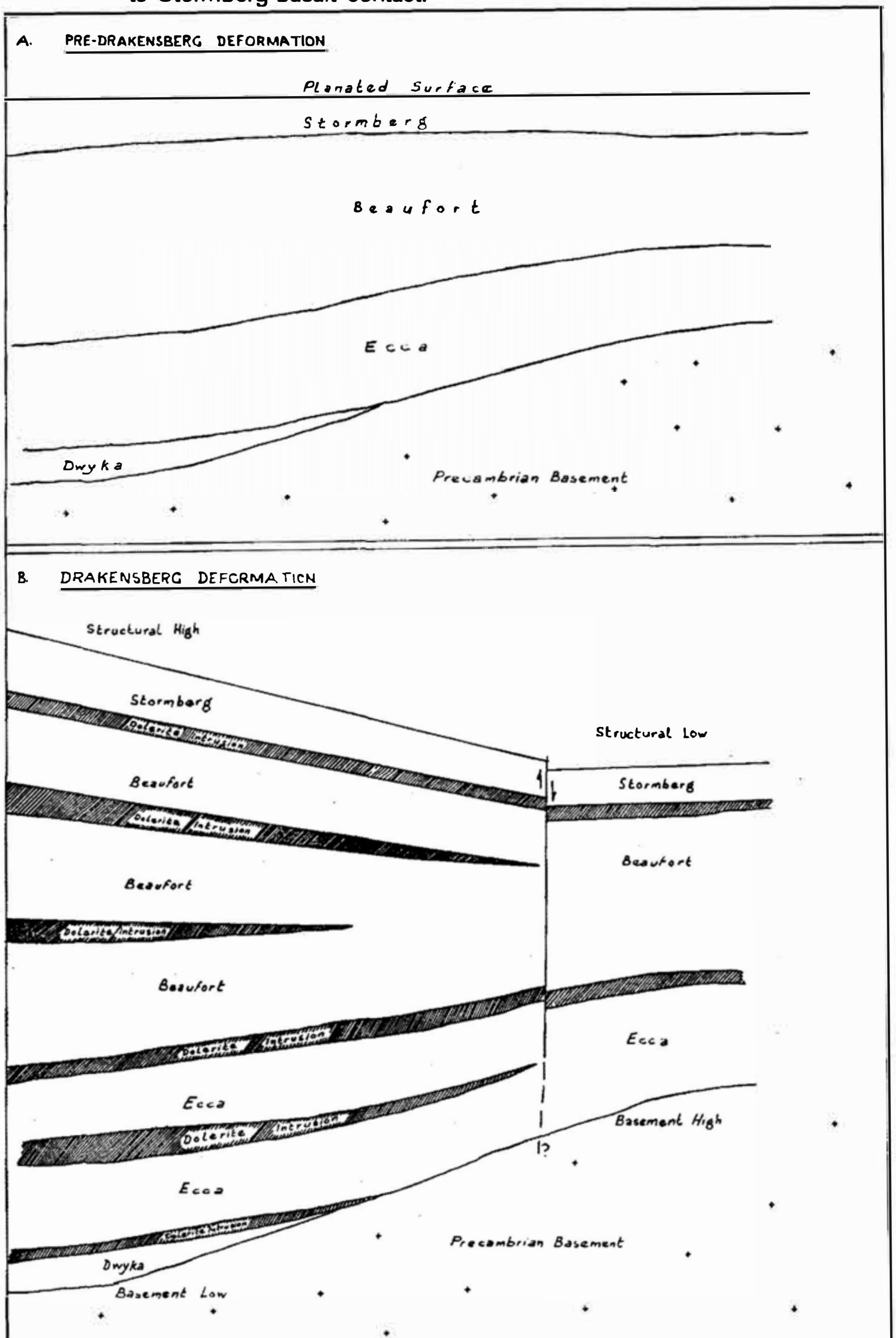
C. Sedimentation, volcanism, kimberlite intrusion and Gondwanaland

Some features linking sedimentation, volcanism and kimberlite intrusion in Lesotho with the formation and break-up of Gondwanaland as a whole can be briefly outlined.

1. Sedimentation

One of the important factors influencing sedimentation in Lesotho was the Triassic Cape Orogeny which was apparently induced by compressional forces produced by the collision of East Gondwana (Australia-Antartica) with southern Africa. This orogeny was probably responsible for a reversal of the sediment source from the north during Dwyka and Ecca times to the south

Figure 51. Diagrammatic outline of structural reversal from Precambrian basement floor to Stormberg-basalt contact.



Source: Modified after Dusar, 1979

3300.31x

for the bulk of the Beaufort Group. Theron (1975) in fact has postulated that the main Beaufort provenance area lay to the south-east of southern Africa. The major effect of the Cape Orogeny is seen, however, in the cyclic nature of the Molteno sedimentation for which repetitive uplift and denudation of the Cape Fold Belt is considered the cause (Turner, 1970). These cycles have been related to a clockwise - counter-clockwise wobble of Eastern Gondwana which led to repetitive onset and release of compressional stress against the tip of Africa (Anderson and Schwyzer, 1977).

2. Volcanism

At the Triassic-Durassic boundary a 20^{o} north-west drift of Eastern relative to Western Gondwanaland brought about the final union of the supercontinent and the assembly at this stage persisted throughout the Jurassic (Anderson and Schwyer, 1977). Possibly this episode of major relative movement followed by unification and stability had a bearing on the Jurassic Drakensberg lavas and dolerites but the relationship is not clear. The distribution of the dolerite dykes, which were the conduits for the sheet lavas, indicates the tensional structures in the Karoo Basin and this reflects the stress pattern in the crust at the time of igneous intrusion (Vail, 1970; Rust, 1975). Attention is drawn particularly to the highly significant fact that the "Lesotho Rise" which was a strong positive element during early Karoo times (Dwyka, Ecca, Lower Beaufort) had become a strong negative element by late Beaufort times, with the cumulative downwarp during the Triassic being estimated at 2,000 m (Rust, 1975). This localized tectonic reversal points to a major localization of crustal instability and weakness which would favour the development of tensional fractures followed by dolerite intrusion and basalt outpourings. Farther south, compressive stresses associated with the Cape Orogeny provided a limit to dolerite intrusion (Truswell, 1977).

3. Kimberlite intrusion

Dawson (1970) postulated that the final break-up of Gondwanaland during the Cretaceous involved the uplift of the continent, marginal downwarping and the deepening of the ocean basins with convection cells rising beneath the continent and descending at its margins. The rising convection cells were accompanied by melting in the upper mantle, kimberlite being one of the products. Fundamental fractures resulted from dilation caused by subcrustal flow (Cox, 1970; Bardet, 1973) and these are apparently related to the three directions which controlled kimberlite emplacement in Lesotho, namely, 50°, 110°-130° and 160°-170° (Barthelemy and Dempster, 1975). The most important of the directions is 110°-130° (Robison, 1979b).

IV. ECONOMIC GEOLOGY

A. Outline of mineral resources

The major mineral resource of Lesotho is diamond which is found in kimberlite and alluvial gravels. Large-scale mining is presently being undertaken by De Beers Lesotho Pty Ltd on the two pipes at Letseng-la-Terae and diggers co-operatives are operating at Lemphane and Liqhobong. Production particularly from Letseng-la-Terae has had a major effect on the economy as indicated in figure 59 and tables 17 and 28. The Letseng, Liqhobong and Lemphane pipes along with the previously worked Mothae and Kao pipes form part of the major Lemphane-Robert belt in northeastern Lesotho; this belt is by far the most important and most diamondiferous. With the exception of one kimberlite type in Kolo pipe none of the other kimberlite bodies appear to contain economic quantities of diamond. There are also no important alluvial diamond deposits, although minor deposits are associated with the major pipes in the Lemphane-Robert belt.

Uranium mineralization is widespread in the lowland areas and appears similar to that found elsewhere in the Karoo sequences of southern Africa where the uranium grades tend to be of low tenor, the deposits ill defined and difficult to delineate and evaluate. Their nature is such that it may take a number of smaller deposits to constitute a viable unit. Another recent discovery has been mercury (cinnabar) mineralization associated with the lower Drakensberg basalts; occurrences have been found in various parts of Lesotho with the most important being near Qoane village in southern Lesotho but none appear to be of an economic size and grade. Geological surveys supported by shallow and deep drilling have pointed to the paucity of coal in the Karoo sedimentary formations in Lesotho and the possibilities of economic finds of oil and gas are remote. Hydro-electricity constitutes the only available large-scale source of energy. The terrestrial paleogeologic environment was not favourable for the development of limestone so that the only possibility in Lesotho is the discovery of carbonate lenses of sufficient size and grade to have local development potential.

The base metal potential has been assessed by a Lesotho-wide geochemical stream sampling programme but the results are not encouraging. Minerals with development potential comprise raw materials such as clay, dimension stone and aggregate for the building and construction industries.

A major factor influencing the mineral resources of Lesotho is the restriction of the rock formations virtually to the relatively young Karoo Supergroup which forms only a small fraction of the total world column (figure 12). Moreover, two thirds of the country is covered by basaltic lavas more than 1,300 m thick which prevents exploration of the rocks beneath (figure 4). Conspicuously absent are Precambrian rocks with which many major mineral deposits elsewhere are associated and in this respect Lesotho differs from neighbouring Botswana, Swaziland, Zimbabwe and the Republic of South Africa. The Witwatersrand gold-bearing beds are estimated to be about 2,500 million years old and even the major Witbank coal field of South Africa are found in rocks sequences about 100 million years older than any exposed in Lesotho. This does not mean that these rock formations cannot be found in Lesotho but rather that if they do occur they will be at great depth, a fact which can only be established by drilling. The Witbank horizon was approached in a barren oil well drilled to a depth of 1,652 m near Mahobong but only traces of coal were found. The only other deep hole in Lesotho was drilled near Butha-Buthe to a depth of 1,475 m but was stopped by thick dolerite sills from reaching the main inferred coal horizon but no sign of coal was noted. It should be emphasized that no borehole in Lesotho has penetrated the pre-Karoo basement.

Any realistic appraisal of the mineral resources of Lesotho must take cognisance of the geological limitations.

B. Diamonds

1. History of prospection

Although Stockley (1947) recorded and examined five kimberlite pipes and one dyke in the lowlands without finding diamonds, prospection in Lesotho really started in 1955 when Colonel J. Scott obtained a concession from Paramount Chieftainess Mantsebo to explore the whole country, and investigated occurrences at Kao, Hololo, Liqhobong, Kolo, Lemphane, Ngopetsceu and Matsoku. These initial operations ceased in November 1959 when Scott formed a new company, Basutoland Diamonds Ltd, with participation rights by De Beers Consolidated Mines Ltd, and with geologists recruited by the Anglo-American Corporation. A reconnaissance programme of the whole country was initiated in November 1959, initially with three field parties headed by a geologist, 4 field assistants and 30 labourers. The first stage was completed by February 1961 when follow-up work was undertaken by six parties. By March 1962 this stage was virtually complete and for the next 18 months operations were confined largely to sampling the Kao and Liqhobong pipes and their overlying stream gravels (Meaton, 1966). Final reports indicated the existence of 33 pipes and 140 fissures of which only 24 contained diamonds.

Following this major survey from 1955 to 1969 smaller evaluation and prospection surveys on selected kimberlites and alluvials were made by Bleackley and Workman (1964) and Meaton (1966). In April 1971, a United Nations project undertook renewed exploration in the northern 4,660 km^2 of Lesotho (figure 2) and this was followed in April 1974 by a Phase II project which surveyed the remaining 25,650 km^2, with field work being completed by March 1981. The major pipes at Letseng, Mothae, Kao, Liqhobong and Lemphane were excluded from the United Nations projects.

The discovery of kimberlite in Lesotho is summarized in table 18, and it will be seen that the total of 405 is made up of 39 pipes, 23 blows, 231 dykes and 112 "offset" dykes.

One of the most obvious features of their distribution (table 8) is the extremely high concentration in the phase 1 area (figure 2) which, although occupying only some 15 per cent of the area of Lesotho, contains 54 per cent of the known kimberlite bodies. The 218 kimberlite bodies here, about one per 21 km^2 have a density probably unequalled elsewhere in the world. Attention has already been drawn to the marked tendency for the kimberlite bodies to occur in groups (figure 38) with the five largest pipes located in the Lemphane-Robert belt in the northern part of the country.

Table 18. Discovery of kimberlite bodies in Lesotho.

	Pipes	Blows	Dykes	Offset Dykes	Totals
Pre-1971	30	12	104	45	191
United Nations Exploration Project, Phase I, 1971-4	4	2	66	34	105
United Nations Exploration Project, Phase II, 1974-81	5	9	61	33	108
Totals	39	23	231	112	405

2. Methods of prospection

All the surveys used the standard technique of examining heavy mineral concentrates in regional drainage samples for such kimberlitic indicator minerals as pyrope garnet, picro-ilmenite and chrome diopside. This was supplemented in the later stages of the United Nations mineral exploration project (LES-73-021) by the direct search for micro-diamonds in heavy mineral samples (United Nations, 1981a). The regional sampling by the United Nations projects at a density of about one sample per square kilometre of drainage represents an exceptionally thorough programme. The standard drainage surveys were supplemented by airborne and ground magnetic surveys, photogeological interpretation, geological traversing, geochemical sampling, pitting and drilling, radiometric spectrometer surveys and such experimental techniques as fracture trace study, airborne, multi-spectral photography, thermal infrared scanning, airborne false colour infrared photography, and ERTS-I satellite imagery. The effectiveness of these methods has been discussed in two United Nations technical reports (United Nations, 1975b and 1981a). In general, the experimental techniques were ineffective as was geochemical stream sampling. Heavy mineral sampling, photogeology, magnetometry and geological traversing in selected areas were the most successful methods but the advantages of an integrated programme combining several techniques cannot be overemphasized.

3. Distribution and size of kimberlite bodies

The distribution of kimberlite bodies in Lesotho has been discussed earlier, with the distribution shown on figure 36 and the size in figures 39 and 40. The blows and pipes range in size from small plugs of 2 m by 2 m up to the Kao pipe which, with dimensions of 730 m by 720 m, is one of the larger pipes in the world. With the single exception of Sekameng (Kolo) pipes belong to the Lemphane-Robert group found in the mountains of north-eastern Lesotho. The mountain kimberlites tend to be equidimensional representing the higher, more regular levels, of the diatreme whereas the lowland kimberlites show a far greater variation in shape as would be expected in cross sections approaching the typically irregular root zones of the bodies. The kimberlite dykes range in width from one or two centimetres to about 12 m; 63 per cent are less than 1 m and 87 per cent are less than 2 m wide (figure 43). Dyke length reaches a maximum of 12 km in dyke 257a in the Mafeteng group but most dykes are considerably shorter with 51 per cent being less than 30 m and 17 per cent less than 10 m long.

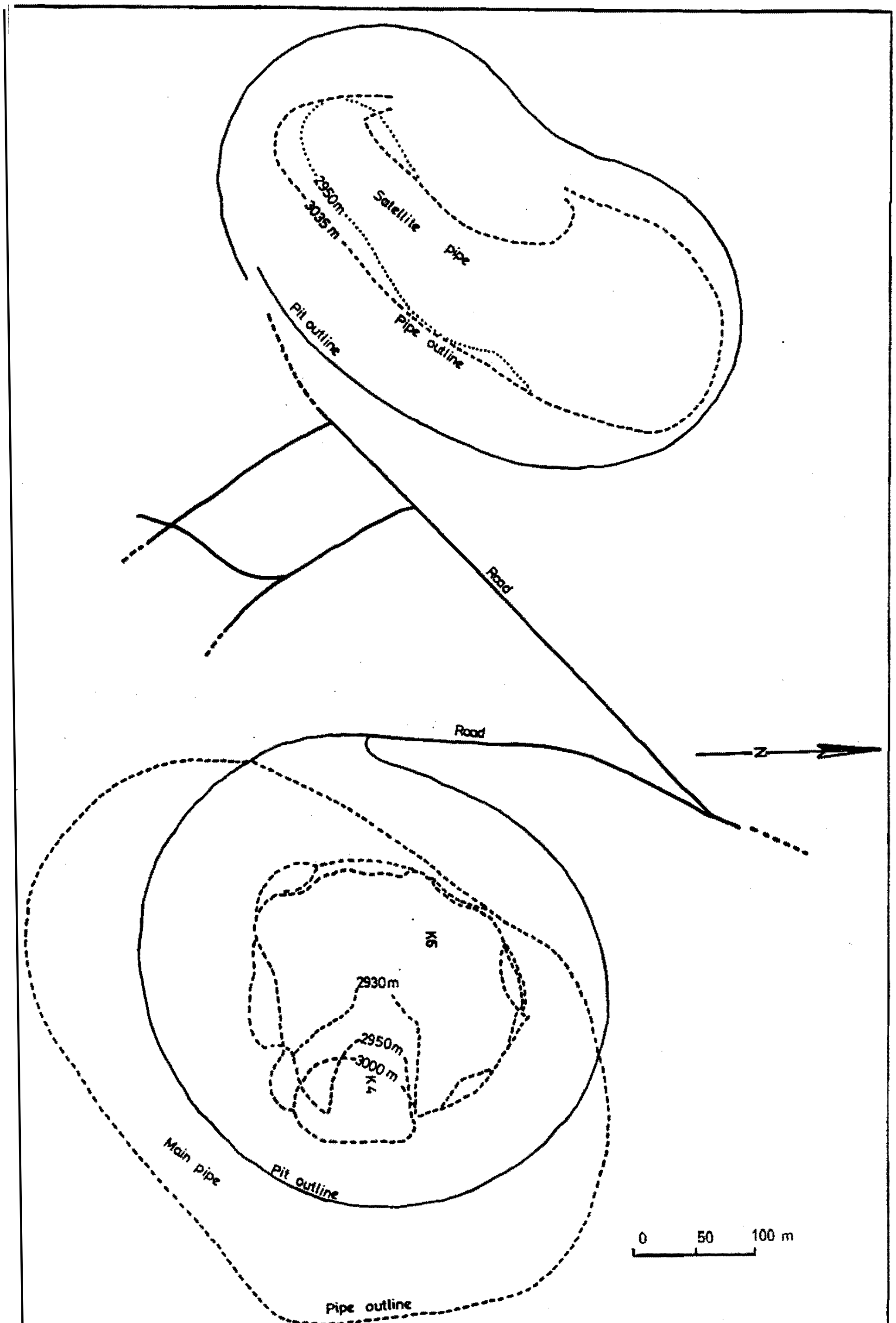
Descriptions of the main kimberlite bodies are given in the following sections which include discussions on bulk sampling and/or mining.

4. Letseng-la-Terae pipes

The most important kimberlite pipes in Lesotho and the only ones currently being mined on a large scale (figure 53) are the Letseng-la-Terae pipes situated at an altitude of 3,100 m in the northern Lesotho mountains about 37 km from Mokhotlong (figure 1) and forming part of the Lemphane-Robert kimberlite belt (figure 38). Both pipes are elliptical with the main pipe measuring 540 m by 365 m and covering a surface area of 15.9 ha while the satellite pipe, 400 m to the west, measures 425 m by 130 m and has an area of 4.7 ha (figure 52). That the satellite pipe is elliptical was proved once a large surface basalt "floater" had been penetrated.

The main pipe was discovered in 1957 by P.H. Nixon who found a weathered outcrop in the stream draining the north-east corner of the pipe. The pipe was declared a Government digging in 1960, and 1,200 Basotho diggers were reported on the site in 1960 and 6,000 by 1966-1967. Large stones of exceptional quality were recovered, earning fortunes for their finders. A 527-carat diamond was found in 1965 followed in

Figure 52. Letseng-la-Terae diamond mine, main and satellite pipes.



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1967 by a record 601.25-carat stone, the Lesotho Brown. But as the gravels diminished and the diggers encountered problems such as water and the fowling of claims by tailings from adjacent diggings, production, which peaked in 1967, began to decline. In 1968, the Rio Tinto Zinc Corporation (RTZ) commenced an evaluation of the pipes and the remaining diggers were relocated at Kao pipe. In order to determine the area and shape of the Letseng pipes, 23 boreholes totalling 2,100 m were drilled between 1967 and 1972. Underground sampling of the main pipe began in October 1969 by means of a 3 m by 2.7 m drive at 60-m depth laid out on a 122-m grid. Surface sampling along trenches was carried out in 1971-1972. A total of more than 80,000 tons of kimberlite was treated, and 2,635 of diamonds recovered. The exceptionally low diamond grade of the pipe was verified but so was the presence of larger stones of exceptional value. More than 90 per cent of the value of the diamonds was accounted for by less than 10 per cent of the stones, a ratio which made it extremely difficult to forecast production revenues. This consideration and the tremendous logistic problems involved in establishing a full-scale mine in so isolated a central plateau site proved too discouraging and RTZ withdrew in 1972. In 1973 De Beers secured an option and completed a drilling programme and associated investigations by December 1973. The results were sufficiently encouraging for De Beers to enter negotiations with the Government to mine by open-cast methods the higher-grade central core of the main pipe. Agreement was reached in March 1975 and the mine, which is operated by the De Beers Lesotho Mining Corporation of Lesotho, was officially opened by the Prime Minister of Lesotho on 9 November 1977, at a capital cost of R 36 million (Whitelock, 1979). Letseng mine, with an output of less than 3.5 carats per 100 tonnes of kimberlite processed has the lowest diamond grade of any mine in the De Beers Group (table 19). The profitability of the mine, however, lies in the occasional large beautiful diamonds which it yields (figure 54). Since mining began in the middle of 1977,

Table 19. Comparison of diamond grade of Letseng-la-Terae mines with others in the De Beers group

Location	Grade (Carats per 100 tonnes) 1979	1980
Letseng-la-Terae	3.09	2.82
Kimberley Pool	25.07	26.04
Finsch	73.42	75.21
Koffiefontein	11.24	11.84
Namaqualand	25.52	18.42
Premier	27.62	26.84
COM (Namibia)	10.31	9.27
Orape (Botswana)	66.64	64.12
Letlhakane (Botswana)	23.22	19.00

Source: Annual Report 1980, De Beers Consolidated Mines Ltd

Figure 53. Open pit of main pipe, Letseng-la-Terae

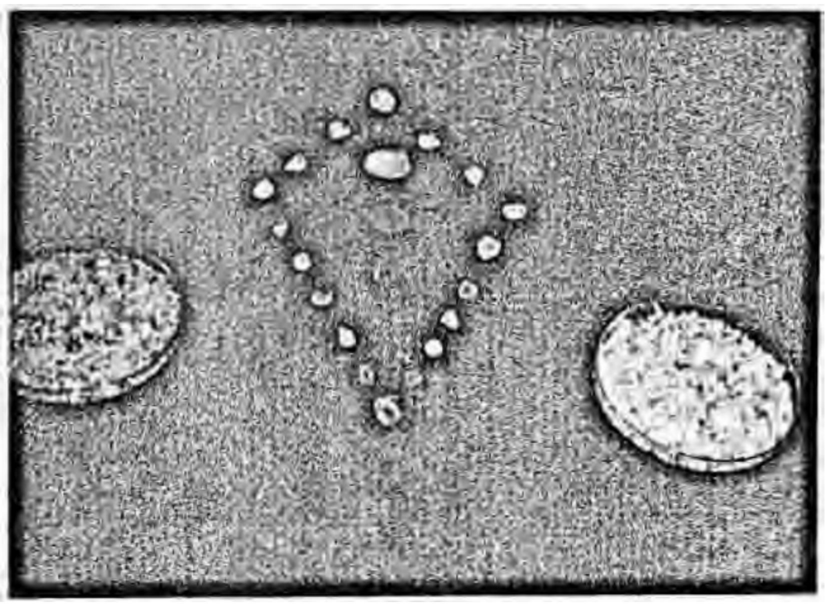


Figure 54. Two weeks output at Letseng-la-Terae mine; the lar-gest stone is 178 carats with a brown of 73 carats, a white of 65 carats and a cape of 65 carats

more than 330 diamonds in excess of 20 carats have been produced to mid-1981, the largest being 290 carats.

The geology of the pipes has been outlined by Bloomer and Nixon (1973). The typical succession of superficial deposits over both pipes is:-

Succession	Thickness
Organic layer	less than 1 m
Leached gravel	widespread
Brown basaltic gravel	maximum 5 m
Oxidized kimberlite (yellow ground)	less than 1 m
Soft kimberlite (blue ground)	greater than 20 m

The poor development of yellow ground is attributed to the lack of chemical weathering at high altitude. The brown basaltic gravel represents surface wash. The leached white gravel contains kimberlite heavy minerals in the vicinity of the pipe. The organic layer of "black cotton" soil originally formed a swamp or sponge over the main pipe.

Because of their great elevation the pipes are thought to penetrate about 1,500 m of the Drakensberg lavas. The contact with the lavas in the main pipe, determined by drilling, dips inward at a fairly uniform 83°. If the pipe continues to taper with depth at the same rate the origin would be at approximately 1,350 m, close to the assumed depth of the base of the lavas, and it is thus possible that the diatreme exploded at this stratigraphic break. This inference is borne out by the paucity of sedimentary xenoliths from below the lavas. The relative abundance of inclusions of Karoo sediments in the satellite pipe may imply, however, that the pipe structure is well developed below the base of the Drakensberg lavas (N.P. Lock, 1980). The contact between the kimberlite and the lava is normally sharp, although shatter zones are present in the lavas particularly on the western margin of the main pipe and the southern margin of the satellite pipe. There is, however, no indication of upfolding or pronounced chemical alteration of the country rock. The kimberlite within about 1.3 m of the contact is highly sheared with mylonitic zones, mud seams and abundant calcite veining and this zone is invariably sharply demarcated from the adjacent relatively undisturbed kimberlite. Eight different types of kimberlite (K1-K8) were originally recognized (Bloomer and Nixon, 1973) but later mapping by N.P. Lock (1980) indicates that the K1, K2, K3, K7 and K8 types can be grouped as the autolithic kimberlite (the non-K6 of the De Beers geologists) and the key diamondiferous K6 type as the garnetiferous kimberlite. The use of the term autolothic follows Ferguson et al. (1973b). The K4 and K5 kimberlites are both distinctive micaceous types and for descriptive purposes can be continued to be referred to by their original symbols. Autolithic kimberlite forms the bulk of the pipe and is considered the oldest type exposed, with inclusions of apiclastic and pyroclastic kimberlite of the crater facies suggesting that the pipe structure was well established before intrusion of the kimberlite which is generally a moderately hard blue-grey or grey tuffisitic kimberlite breccia in the classification of Skinner and Clement (1979). It is characterized by a well developed autolithic texture and by the virtual absence of pyrope garnet; only pink, orange-brown or red-brown almandine garnets occur. Autoliths, recognizable by eye, are common throughout and locally constitute up to 10 per cent of the rock. The autoliths have cores of altered olivine or rock fragments as nuclei and many show concentric growth which distinguishes them from kimberlite xenoliths of angular habit and different texture. Accidental inclusions of the Drakensberg lavas, Karoo sediments, basement gneisses and granulites and various peeidotites form less than 20 per cent of the rock. Most of the inclusions are angular, less than 1 m in size and highly altered. The remainder of the rock is composed of a fine-grained matrix of serpentine and other minerals. The generally harder, more compact, nature of the rock is shown by the contrast with the other kimberlite types. Thus the garnetiferous and other kimberlites crumble rapidly on exposure to the air whereas the autolithic kimberlite often maintains its tough character for a considerable time. Another feature only observed in this kimberlite is the flow structure which was seen at several widely scattered localities.

The economically important diamondiferous and garnetiferous kimberlite is a soft grey-green tuffisitic kimberlite breccia characterized by abundant pyrope garnet, large phlogopite xenocrysts and virtual absence of recognisable macroscopic autoliths. The garnet xenocrysts and megacrysts average 4 mm in size but range up to 2 cm. Their colour varies from orange to pink, red and lilac. Many have kelyphitic rims with red garnets having a thin black kelyphitic rim in contrast to the considerably thicker grey-brown rims seen in the lilac garnets. Red garnets commonly have a rough cubic shape and are larger than the rounded lilac garnets. Dark brown to bronze phlogopite xenocrysts and megacrysts attain a size up to 5 cm although the average is about 2 mm. Olivine xenocrysts and phenocrysts are entirely altered to serpentine and clay minerals; they compose 15-20 per cent of the rock but are slightly smaller on average than in the autolithic kimberlite. A characteristic feature of the garnetiferous kimberlite is the zonation resulting from the increasing abundance or size of the characteristic xenoliths and megacrysts towards the centre of the kimberlite. In particular, garnet and basalt xenoliths are more abundant and larger towards the centre of the body; in fact the kimberlite is clearly demarcated by the 2 mm-size contour of orange-red and lilac garnets whereas the almandine garnets in the autolithic kimberlite show a uniformly smaller grain size. The suite of accidental inclusions in the garnetiferous kimberlite is similar to that in the autolithic kimberlite except that Karoo sediments are virtually absent. There are fewer basement xenolithis but their size is considerably larger. The basalt inclusions are also considerably larger (up to 3 m or more), fresher and more abundant (up to 40 per cent of the rock). Similarly, ultramafic xenoliths are larger and more abundant. Contacts between the garnetiferous and autolithic kimberlites are rarely sharp and usually are transitional over a distance of 2-3 m. Thus, although the form of the intrusion tends to indicate a younger age for the garnetiferous kimberlite the time separation of the two intrusions may have been small since the autolithic kimberlite was probably not fully consolidated at the time. The K4 kimberlite shows some sharp contact and cross-cutting relation to the autolithic and garnetiferous types and is interpreted as being younger. It is a fine-grained mottled green kimberlite with a distinctive weathering appearance resulting from flaky exfoliation. The K5 kimberlite is probably younger than the K4 kimberlite and is characterized by fresh olivine phenocrysts and xenocrysts up to 4 mm in size.

Nine varieties of kimberlite were originally mapped in the satellite pipe but re-mapping of the surface exposures and mapping in the new underground workings has shown that the kimberlite throughout the pipe is dominantly autolithic (N.P. Lock, 1980). The pipe is now considered to contain only one major kimberlite intrusion - the satellite pipe kimberlite - which is classified as a tuffisitic kimberlite breccia. A well developed autolithic texture is characteristic with the autolithic contact in places as high as 30 per cent. The autoliths are set in a serpentinuous matrix containing serpentinized olivine pseudomorphs and accidental inclusions in a texture similar to the main-pipe autolithic kimberlite. As already pointed out Karoo sedimentary inclusions are more abundant than in the main pipe, and together with Drakensberg lava xenoliths constitute up to 25 per cent of the rock. Peridotite nodules are even rarer than in the main pipe. The autoliths from the satellite pipe display a remarkably constant composition in contrast to those from the main pipe which range notably in SiO_2, MgO, CaO, Na_2O, K_2O, P_2O_5 and CO_2. The satellite pipe autoliths differ from the main pipe autoliths in lower SiO_2, FeO, Na_2O, and K_2O but higher TiO_2, Al_2O_3, Fe_2O_3, CO_2, and H_2O. A rather surprising result of the investigations by N.P. Lock (1980) was the almost complete lack of overlap in the upper mantle rocks sampled by the kimberlites of the main and satellite pipes; this was most unexpected in view of their proximity. The satellite pipe xenoliths derive from the two extremes of the temperature range, 800°C and 1,260°-1,285°C, whereas the main pipe specimens were derived from the intermediate range 620°-1,250°C with the main group between 930° and 1,000°C. It was concluded that the kimberlites of the two pipes have divergent origins, an inference supported by the chemical differences in the autoliths described above and by the apparent differences in the diamond populations in the two pipes (Harris et al., 1979). The abundance of xenoliths and the greater range in temperatures observed in the main pipe samples suggests that the main pipe kimberlites were intruded earlier than the satellite pipe kimberlite which followed up the opened passage without further sampling of the conduit wall. The evidence of the peridotite xenoliths suggests that the separate source regions were tapped by magma originating at some depth in excess of 150 km.

5. Kao pipe

The Kao pipe forms part of the Lemphane-Robert belt in north-eastern Lesotho at an elevation of 2,500 m (figure 36). The main pipe is an irregular oval with NE and SE dyke-like appendages, the whole covering 19.8 ha. It is thus the largest pipe in Lesotho. The satellite pipe about 400 m north-west of the main pipe is pear-shaped and elongated NW-SE and has an area of 3.2 ha. It has no obvious connection with the main pipe although both lie on the line of a west-north-west narrow-trending dyke.

Between 1955 and 1959 the pipe was prospected by Scott, from 1959 to 1962 by Basutoland Diamonds, and from 1962 to 1967 by Basutoland Factory Estates Development. The operation met with only limited success and the pipe was opened to licenced diggers in 1969. In September 1971 the Maluti Diamond Corporation entered into a prospecting agreement with the Government covering the Kao pipes. Shareholders of Maluti Diamond Corporation were Newmont Mining Corporation in association with Lonrho which was later replaced by U.S. Steel. Resistivity and magnetometric surveys helped to delimit the kimberlite types and boundaries which were firmly established by drilling in both the satellite (7 holes totalling 739 m) and main pipe (26 holes totalling 2,593 m) and by a series of pits (each 6 m diameter and averaging 20 m deep) on a 120-m grid. Sampling operations continued to January 1973 when the company withdrew as the grade was considered insufficient for a large-scale mining operation.

The geology of the pipe has been described by Rolfe (1973). Superficial sediments are thickest along the three north-flowing streams on the main pipe where coarse ill-sorted basaltic gravels are up to 10 m thick. They are overlain by less than 1 m of brown soil, a stony horizon and a topmost peaty soil layer. As at Lemphane and Liqhobong a layer of kimberlite 2 m thick, possibly representing a slumped or mud-flow horizon is locally interlayered with gravel in the central area of the pipe. It dips and tongues out to the north. Perched on the northern wall of the quarry area is a patch of friable stratified grits consisting of round, altered basaltic pebbles loosely cemented by abundant calcite and yellow-green serpentine. At the base and immediately overlying a coarse breccia is a bed rich in ilmenite nodules. This grit is considered to be water-laid sediment found in the original kimberlite volcanic crater and constitutes the sole example found in the Cretaceous kimberlite of southern Africa. Its preservation is probably due to down faulting at the pipe margin.

Both pipes taper slightly but there appears to be a steepening of the walls with depth. The measured area of the main pipe at 240 m is approximately 17.5 ha, greater than would be the case by extrapolation of observed surface contacts of 80^{o}-85^{o}. On the basis of decrease in cross section of the main pipe the origin cannot be higher than 1,300 m above sea level which is comparable to that calculated for Letseng-la-Terae main pipe. Six kimberlite types have been recognized (Rolfe, 1973) and their probable order of intrusion was quarry, lower quarry, gritty, fragmental, transitional and fine fragmental. The quarry kimberlite is gray with serpentinized olivine and pyroxene phenocrysts and 20-50 per cent of rounded altered basalt xenoliths. The lower quarry kimberlite is comparatively fresh with less serpentinized olivine and pyroxene and much is khaki green. The gritty type is aquigranular (2-20 mm) with a brown friable matrix in which mica occurs. Basement and ultrabasic mantle inclusions are relatively common. The blue green, less homogeneous fragmental kimberlite appears to contain more zircons than the other types. In the peripheral fine fragmental type, the groundmass xenoliths are more rounded. The transitional type was produced by the partial assimilation of the gritty type by the fragmental type. Economically the most important type is the quarry kimberlite which is characterized by the relative abundance of ilmenite and diamond (table 34 in Rolfe, 1973). The quarry kimberlite is notably richer in Fe, Ca, Ti, Zr, U and Cu but depleted in Si, Cr and Ni compared with the other kimberlites.

As quoted by Rolfe (1973) the grade of the quarry kimberlite is 18 carats per 100 tonnes compared with 3-9 carats per 100 tonnes for the remainder of the pipe and an overall grade of 6 carats per 100 tonnes. It is possible that the quarry area contains over 5 million tonnes of a higher grade kimberlite (Lesotho Department of Mines and Geology, 1973), and thus could form the basis of a small mining operation. The grade of

6. Liqhobong pipes

Diamond-bearing gravels have been known at Liqhobong for many years and currently provide employment for diggers through the Liqhobong Diamond Diggers Cooperative. Pitting and mapping has indicated the presence of two kimberlite pipes, a near circular large main pipe (330 m diameter) joined by a dyke to a circular satellite pipe (95 m diameter) 300 m upslope to the WNW (figure 39). The main pipe lies near the head of the Liqhobong valley at an altitude of 2,650 m and both pipes fall within the major Lemphane-Robert kimberlite belt (figure 38). The pipes were pitted, evaluated, and subsequently worked by Basutoland Diamonds on behalf of the Basutoland Factory Estates Development Corporation until mid-1967 (Lesotho, Department of Mines and Geology, 1968). Since that time the gravels and soft kimberlite have been worked by diggers who in late 1977 formed the Liqhobong Diamond Diggers Cooperative with technical assistance provided by the Department of Mines and Geology and by CIDA.

The geology of the pipes has been described by Bleackley and Workman (1964) and by Nixon and Boyd (1973b). Both pipes are covered by gravel and soil and their thickness is given in table 20 which is based on unpublished reports of Basutoland Diamonds Ltd quoted by Nixon and Boyd.

Black cotton soil overlies brown colluvial gravel of angular to rounded basalt boulders in a clay matrix. In the centre and south of the main pipe former streams have laid down current-bedded silt and boulder beds with blue (younger) and brown (older) matrices and basalt-rich gravels. Slumped kimberlite, overlying soil-covered kimberlite in situ, is seen in the south and north-east and can be compared with a similar occurrences at Kao and Lemphane. Prior to the deposition of the gravel, erosion had removed all but thin discontinuous strips of weathered yallow ground. This and the underlying soft greyish blue kimberlite show sharp contacts with soft zeolite- and calcite-impregnated basalt country rock. Apart from blue

Table 20. Thickness and grades of gravels and kimberlite at Liqhobong pipes

Main succession	Main pipe: Thickness (m)	Main pipe: Grade (carats per 100 tonnes)	Satellite pipe: Thickness (m)	Satellite pipe: Grade (carats per 200 tonnes)
Black cotton soil	0.7	3.4	3 - 3.5	21
Brown gravels	3			
Basaltic gravels				
Boulder beds	0.5	63	-	-
Turquoise silt band				
Weathered kimberlite (yellow ground)	0.1	21	0 - 0.6	-
Soft kimberlite	-	15	-	33

Source: Nixon and Boyd, 1973, and unpublished reports of Basutoland Diamonds Ltd, 1962 hardebank in the south-east part of the main pipe there appears to be little or no variation in kimberlite types other than can be ascribed to weathering. Soft blue kimberlite from the main pipe contains 20 per cent weathered green subrounded basalt fragments and abundant rounded, altered, pale-brown olivine. The groundmass consists of comminuted basalt fragments, dark brown euhedral serpentinized olivine, phlogopite and minor perovskite, magnetite and zircon. The heavy mineral wash is characterized by abundant ilmenite. The satellite pipe lacks a thick alluvial cover, and the thin oxidized kimberlite gives way to a central area of blue-grey brecciated kimberlite surrounded by a light-green, fine-grained variety richer in basalt inclusions.

The grades of the gravels and kimberlite are given in table 20. At a future date when the gravels and soft kimberlite are exhausted, or depths get prohibitive, consideration will need to be given to mining the harder kimberlite.

7. Lemphane pipe

The Lemphane kimberlite pipes consist of a main oval pipe (figure 39) measuring 250 m by 300 m (5.7 ha) with a small adjoining satellite pipe (12 m by 17 m) and they lie at one end of the Lemphane-Robert kimberlite belt at an elevation of 2,650 m about 10 km north-north-west of Kao pipe (figure 38). Prospecting was undertaken by Scott between 1955 and 1959 and by Meaton in 1965-1966 (Meaton, 1966) and the overall grade was about 1-2 carats per 100 tonnes with locally enriched oxidized kimberlite and gravel (Kresten, 1973a). In September 1971, 380 licensed diggers at Kao pipe were relocated at Lemphane when Kao pipe was taken over by Maluti Diamond Corporation Ltd (Lesotho, Dept. of Mines and Geology, 1971). In late 1977 the Lemphane Diggers co-operative was formed with technical assistance provided by the Department of Mines and Geology and by CIDA, and this cooperative is currently operating (1980) at the pipes.

The kimberlite of the satellite pipe is exposed but on the main pipe overburden ranges from 1 to 10 m in thickness. A general succession is as follows (after Kresten, 1973a):-

Organic layer
Grey gravel
Grey soil
Brown oxidized gravel
Reworked kimberlite enriched in ilmenite
Yellow oxidized kimberlite
Blue ground (not exposed)

Local intercalations are oxidized kimberlite between the grey gravel and soil, and grey clayey layers and brown to reddish brown boulder gravel between the brown oxidized gravel and the reworked kimberlite. Kresten (1973a) has shown that the local intercalations of kimberlite ranging from 0.1 to 1.8 m in thickness are due to slumping from the topographically higher kimberlite near the contact with the more deeply eroded central parts.

The contacts between the main pipe and the Drakensberg lavas are vertical or nearly vertical, and sharp, although the basalt is shattered at the contact. Effectively there is only one kimberlite type which is green with abundant phenocrysts of olivine in a fine serpentinized matrix. The lavas near the satellite pipe are shattered but to a less extent than with the main pipe. The pipe is also composed of only one kimberlite type which is greyish green and has more ilmenite and garnet phenocrysts than the main pipe.

When the gravels and soft kimberlite have been exhausted consideration may need be given to as to whether the harder kimberlite could be mined.

8. Mothae pipe

Mothae pipe which has an area of 8.8 ha (figure 39) is 6.5 km north-west of Letseng-la-Terae in the headwaters of a tributary of the Mothae stream at an altitude of 2,900 m (figure 38). There are no natural exposures and the pipe is covered by extensive gravel and peat, forming a typical swamp or sponge. The pipe was found in 1961 by Basutoland Diamonds Ltd, when a heavy wash of garnets and ilmenites was found downstream. Subsequently gravel immediately below the pipe was worked for diamonds by local diggers. Prospecting by Scott, and by Lonrho Ltd who between 1969 and 1971 sank 12 pits of 6-m diameter to 24 depth, proved the pipe to be uneconomic having an overall grade of 2.28 carats per 100 tonnes (Meaton, 1966; Nixon, 1973b).

A generalized geological section, adapted from Meaton (1966) and Nixon (1973b) is:

Mean thickness (m)	Succession	Local intercalation
1.20	Peaty soil	
2.40		grey clay and terrace gravel
2.45	Brown clay and gravel	
1.50		blue gravel
0.60	oxidized kimberlite soft blue kimberlite hard kimberlite	

The oxidized kimberlite forms a thin, weathered, diamond-enriched zone which in the central area of the main pipe is replaced by blue gravels which in turn, from their similar diamond content, represent slumped or reworked kimberlite. The overlying brown gravel is crudely stratified with large rounded basalt boulders near the top. It is a colluvial deposit, formed by gravitational creep of debris from the surrounding slopes but nevertheless contains kimberlitic heavy minerals including diamond near the base (Meaton, 1966). The overlying black soil has a similar but diluted suite of minerals.

The pipe is in two main parts which were originally regarded as separate but which are joined by an irregular dyke which in part is concealed beneath 7 m of basalt lavas (Nixon, 1973b). The long axis is over 600 m long and the width is 150 m (north pipe) and 250 m (south pipe). There is no marked diminution in the area of the main pipe down to 190 m depth. Four main types of kimberlite have been recognized, each found in three pits in different sectors of the intrusion. The south-eastern part of the main pipe is the richest in diamonds and consists of a green kimberlite having a chunky fracture. Elsewhere the kimberlite is a drab blue or khaki green commonly with a platey fracture. The kimberlite increases in hardness with depth but true hardebank was noted only in the bottom of one pit and elsewhere as cobbles within the soft kimberlite.

9. Kolo pipe

Kolo pipe is located in the lowlands of Lesotho about 38 km south-west of the capital Maseru (figure 38) and is an irregularly shaped body of about 180 m by 90 m and an area of about 1.1 ha (figure 39). The pipe is intruded into a Beaufort sandstone and shale sequence and a dolerite sill forming a low ridge running out from the feet of Kolo mountain. The pipe is thus unusual in that it forms a positive topographic feature (figure 55).

There is no record of the actual discovery of Kolo pipe and it is thought that this is one of the occurrences that has been known to the local people for many years. Indeed Stockley (1947) refers to the "Kolo mountain occurrences". The first major prospecting of the pipe was undertaken by Scott in 1961 although probably some work had been done prior to this. Scott excavated 14 pits on a 30-m grid, treated about 85 m^3 of kimberlite and recovered 208 diamonds having an aggregate weight of 13.11 carats. He concluded that the pipe was uneconomic. Between 1961 and about 1964 a small syndicate worked the pipe but little data is available. In 1975 the United Nations

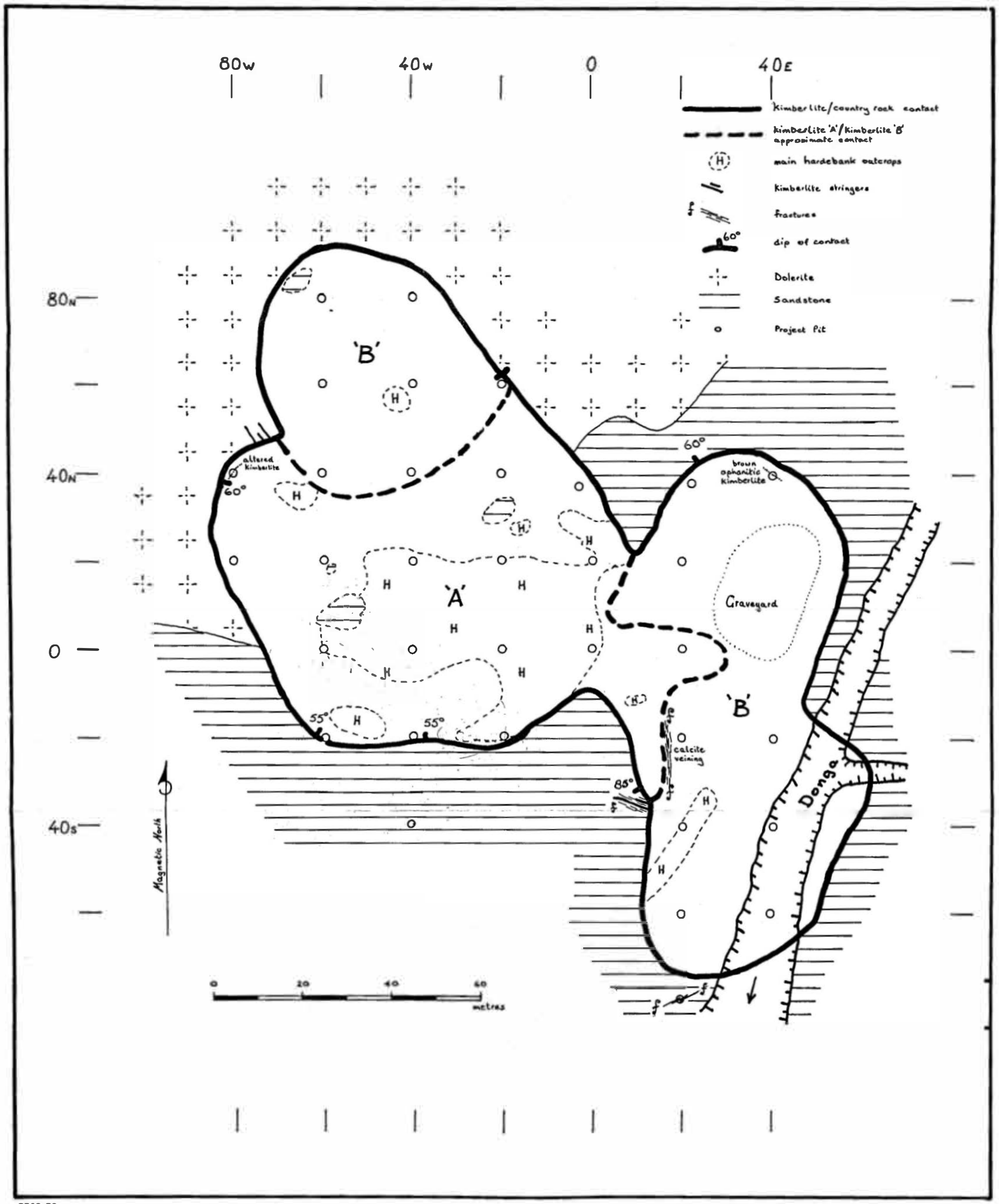
Exploration for Minerals project mapped the pipe and dug 32 circular pits within the pipe boundary. The geological mapping established the presence of two major kimberlite types which sampling showed to have significantly different diamond contents (Hall, 1976). Previous workers do not appear to have recognized the economic significance of this fact. The sampling results indicated a grade of 13.71 carats per 100 tonnes for the Type "A" kimberlite which has a surface area of about 5,600 m^2 and of 2.87 carats per 100 tonnes for Type "B" kimberlite. Most diamonds recovered are small and of poor quality and low value but the Type "A" ground is increased, possibly to economic levels, by the presence of a few larger, high-value stones. The results justify further work particularly large-scale bulk sampling to establish whether the few high values are erratic or form part of the normal population. If indicated grade is confirmed it appears that a viable although small mining operation could be based on the Type "A" kimberlite (United Nations, 1981c).

The distribution of the Type "A" and Type "B" kimberlite is shown on figure 57. Type "A" contains few inclusions and is relatively resistant to weathering. It therefore contains a high proportion of hard undecomposed kimberlite at or near the surface. It forms a single body occupying the central western portion of the pipe, and has a typical bluish-green colour. Type "B" is a more normal kimberlite in that it is easily weathered and is generally represented by a soft friable yellowish-green, yellow or pale brown material. It is more agglomeratic or tuffaceous than Type "A" and contains a much higher percentage of inclusions. It forms two bodies occupying the north-western and eastern parts of the pipe. The contact between the two types is shown in figure 56 and the field relations suggest that Type "A" was the earlier intrusion whilst Type "B" represents a later phase or phases emplaced in zones of weakness at the margins of the original diatreme.

Figure 55. Kolo pipe is unusual in that it forms a positive topographic feature

Figure 56. Kolo pipe showing the contact between the easily weathered diamond-poor kimberlite type 'B' and the harder diamondiferous type 'A'

Figure 57. Plan of Kolo pipe showing kimberlite types.



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10. Koalabata pipe

Koalabata pipe 307 located 7.5 km east of Maseru is crescent shaped, measures about 300 m by 70 m and has a surface area of 1.89 hectares (figure 39) It was the largest kimberlite body discovered by the Exploration for Minerals project and was found in August 1976 following the ground investigation of an airborne magnetic anomaly (Reed, 1978a). Bulk sampling of the eastern part of the pipe was carried out in 1977 and the remaining area in 1979 (Robison, 1980a). Altogether, 48 pits were dug on a 20-m grid and 734 m^3 of kimberlite treated for the recovery of 24 diamonds weighing 3.174 carats. The overall grade of 0.173 carats per 100 tonnes is uneconomic which is disappointing as the pipe was ideally situated from a logistic viewpoint compared with those in the highlands.

Mapping of the pipe indicated two main kimberlite types were present, Type I an olivine-pyroxene association, occurring only in the southern part and Type II, a garnet-ilmenite association with pyroxene, occupying the remainder of the pipe (Smirnoff, 1980). No diamonds were recovered from Type I kimberlite which is a soft, loose, fine-grained, green kimberlite containing abundant phlogopite but with a low heavy mineral content. Type II is whitish yellow, brecciated, with abundant autoliths and a high heavy mineral content.

11. Boranta pipe

Boranta pipe 318 in the Sekameng-Kolo Group (figure 38) was discovered by the United Nations Exploration for Minerals project in August 1978 as a result of the application of standard heavy mineral sampling techniques (Robison, 1979a). It has dimensions of 140 m by 100 m and a surface area of about one hectare (figure 39). Strong airborne and ground magnetic anomalies and noticeable spectrometric anomalies are associated with the pipe. The kimberlite is weathered, friable and porphyritic. Testing was carried out in 1979 when 17 pits were sunk on a 25 m grid and a total of 160 m^3 of kimberlite was processed with two diamonds recovered weighing 0.395 carats. The sample treated is representative and the indicated grade of less than 0.01 carats/m^3 demonstrates that the pipe has no economic potential (United Nations, 1981b).

12. Sekameng pipe 65, Mafeteng District

Sekameng pipe, situated about 40 km south-south-west of Maseru (figure 38), is the largest kimberlite known in the lowlands with approximate dimensions of 270 m by 230 m and an area of some 3.5 hectares (figure 39). The pipe is deeply weathered and consists of yellow or greenish brown, decomposed, fine- to medium-grained, commonly porphyritic kimberlite. The kimberlite has been tentatively divided into four types on the basis of colour, texture, size and abundance of xenoliths and relative abundance of indicator minerals (Robison, 1980c). At the eastern and western margins of the pipe the kimberlite-to-wall rock relationship is simple with the contact dipping steeply inward but relationships are more complex at the north and south where sill-like apophyses about 3-4 m thick are present. Detailed geological investigations, geophysical surveys and numerous secondary excavations undertaken by the Exploration for Minerals project (Robison, 1978, 1980d) revealed that the pipe was substantially larger than previously indicated with the additions of a lobate extension in the north-east and a south-east tongue.

The pipe has been known for many years and has been the subject of testing programmes by Stockley (1947), Scott (1959-1963), Bleackley and Workman (1964), Meaton (1966) and the United Nations Exploration for Minerals project (Robison, 1980d). The totals for all testing are 656.9 m^3 of ground treated with the recovery of 23 diamonds weighing about 7.5 carats with an indicated grade of 0.48 carats per 100 tonnes. All the available evidence thus points to the pipe being of no economic interest.

13. Alluvial (placer) diamond deposits

An appraisal of the placer diamond potential of Lesotho has been made by Robison (1980c; United Nations, 1981d). Numerous sources or potential sources of diamond are present in Lesotho but in contrast to most other countries in which significant diamond placer deposits occur the climate is not tropical or sub-tropical. The Lesotho climate leads to a predominance of mechanical over chemical weathering, a dearth of vegetational cover and an absence of the swampy areas so frequently associated with diamond placers. The marked seasonal variation in rainfall, with its tendency towards heavy storms and flash flooding, leads to periodic scouring of river channels and the deposition of poorly sorted torrential deposits. This effect is compounded by the high relief and also by the geology, for rivers frequently establish temporary base levels on nearly horizontal rock platforms corresponding to more resistent basalt flows or sandstone beds. These platforms are easily swept clean by rivers in spate. The overall result is that gravel accumulation is limited and that gravel deposits have a relatively short residence time, with only a restricted opportunity for in-situ reworking and reconcentration. Furthermore, the rapid mechanical erosion, lack of vegetation to hold rock debris, and steep slopes, continues to produce an essentially dilutional regime. In general terms, therefore, it seems improbable that the environment of Lesotho is suited to the development of diamond placer deposits on a large scale. This tends to be borne out by the absence of "diggers" activity, which has been a feature of virtually all placer deposits elsewhere in the world and also of the most productive kimberlite pipes in Lesotho.

Gravels with more limited potential are those near the known diamondiferous major kimberlite pipes in the highlands of Lesotho, in the major lowland rivers (Senqu and Mohokare) and in minor drainages below minor kimberlite bodies. As the dominant element in the drainage of Lesotho the Senqu River system forms a major conduit for the transport of liberated diamonds. It drains the major Lemphane-Robert kimberlite group which so far as is known contains the largest and richest diamond occurrences in Lesotho, and also the Qacha's Nek kimberlite group (figure 38). Interest in the Senqu is heightened by the presence of diamondiferous terrace gravels, exploited during the early part of the century, at Aliwal North about 100 km downstream of Lesotho. Deposition here was apparently controlled by a series of dolerite dykes intruding the softer Beaufort sediments and acting as natural riffles, and diamond production was mainly from the higher terraces (Wagner, 1971). According to Bleackley and Workman (1964) the source of the diamonds is controversial but no kimberlite is known between Aliwal North and the Lesotho border. Within Lesotho much of the upper course of the Senqu is too steep and abradies too rapidly for the development of alluvial deposits. Graded sections are present but the tendency for these to bottom on smooth rock platforms is not conducive to concentration and few of the dolerite dykes that do cross the river form features big enough to effect the flow sufficiently to have significant depositional effect.

In the lower reaches of the river within Lesotho, remnants of several different terraces and accumulations of basal gravels are found between the Tele confluence and 10 kilometres upstream of the Sabapala confluence. The individual deposits range in size from a few tens of cubic metres to an estimated 300,000 cubic metres, and occur up to about 90 metres above the present river level (Rombouts, 1978a, 1978c). Bleackley and Workman (1964) indicate a middle Pleistocene age, i.e., that of the diamond terraces at Aliwal North, for a small terrace at Seaka Bridge some 80 ft (24 m) above the Senqu, and suggest that this corresponds with a Pleistocene pluvial period of increased rainfall, during which scouring action moved much of the earlier alluvium from the upper stretches of the Orange (Senqu) River and redeposited it in the higher terraces of the middle reaches.

The gravels accumulated in the lower reaches of the Senqu River may be divided into several units (Rombouts, 1978a, 1978c). These are:

i) Active gravel

This unit comprises all gravel occurring in the present river bed, with important accumulations occurring at the Tele confluence, point bars near Waterfall, at Seaka School (Chinese Agricultural Mission), at Fort Hartley and elsewhere along the river. Active gravels also maintain semi-permanent gravel islands along the river channel (Michel, 1977). The gravels appear to consist largely of reworked basal gravel.

ii) Basal gravel

These semi-consolidated gravels crop out in the lower part of the river channel near the Tele confluence, Waterfall, Seaka School, Seaka Bridge, Fort Hartley, the Sebapala confluence and Bethel, and consist of slightly older "active gravel" which have been isolated by migration of the river channel. The gravel is coarse, with ellipsoidal boulders up to 50 cm in size in the lower part, decreasing upwards to about 20 cm. Basaltic boulders are predominant but sandstone, agate, quartz, zeolite and calcite are also present in the smaller fractions. Coarse gravel is interbedded with finer gravel and more sandy material, and the whole is cemented by sandy silt. Cross-bedding is common and the maximum thickness seen is 7 metres in the occurrence near Waterfall (Alwynskop Donga) (Michel, 1977).

iii) Low terraces

The impressive sandy walls of the present channel are formed by this unit, which consists predominantly of medium-grained sand containing small (1 cm) sub-rounded pebbles. Although larger boulders, to 20 cm, occur occasionally, particularly at the base of the unit, it is essentially arenaceous, and true gravel is rather rare and its volume almost negligible.

iv) Middle terraces

This unit occurs above the low terraces at different elevations which led Rombouts to make a sub-division into "lower middle" and "upper middle" terraces. They occur on both sides of the river, commonly on the lowest sandstone cliff, and the largest terraces are at the Tele confluence, Seaka School, Seaka Bridge, Koali and Nkhoebe. The gravel is generally rather poorly sorted, although individual elements are well-rounded, and are primarily of basalt, sandstone and siltstone. Dolerite, quartz, jasper, agate, chalcedony, minor shale and mudstone are also present. The size range is 2-20 cm, with pebbles and cobbles in the 5-15 cm range predominant, and the matrix is a medium to coarse gritty sand. The gravel as a whole is generally cemented, but the degree of consolidation is varied. Traces of bedding may be seen in the gravel, and intercalated irregular and discontinuous grit layers and lenses, in places cross-bedded, are present. The overall impression is that the deposits are of semi-torrential type (Rombouts, 1979a).

v) High terraces

This unit comprises terraces above the 1,524 m (5,000 ft) level, and is limited to the Solomon area. The gravel is about 1.5 metres thick and consists of basalt, sandstone and mudstone in approximately equal proportions. Moffat (1979) suggests that these gravels may have been deposited by the Masitise River, rather than the Senqu.

From distribution of the gravels in the lower Senqu River it is apparent that many of the groups of smaller deposits are in fact remnants of what were once more extensive terraces which have subsequently been dissected. One result of this dissection is that the volumes of many of the deposits have been reduced below the level necessary to sustain economic interest. Of the 80 deposits documented by Rombouts (1978a, 1978c), the majority have estimated volumes of less than 500 cubic metres. Twenty-one deposits are larger than 2,000 cubic metres, but of these only eight exceed 20,000 cubic metres and only four have estimated volumes greater than 100,000 metres (table 21).

In some cases, for example, the Solomon terraces mentioned above, and the terraces in the lower Mk'pha and Sebapala valleys, it is uncertain whether the gravel was deposited by the Senqu itself, or by the tributaries, which do not drain kimberlite. As the development of the Senqu River has been, and is, characterized by the establishment of numerous local base levels due to the presence of waterfalls and other barriers, the heights of terraces in different river sections are not directly comparable. However, it may be remarked that the active and basal gravels occur in the present channel, with lower, middle and high terraces being, in general, progressively more distant from this.

Most of the major deposits on the Senqu River have been tested with discouraging results (table 22). Although significant volumes of gravel have been treated only three diamonds have been recorded, all by the United Nations Exploration for Minerals project. It seems most improbable that any of the gravel even approach economic grade.

Although the Senqu River system, as both the largest in the country and that draining the most promising source area, is of prime import in any consideration of the alluvial diamond potential of Lesotho, the Mohokare (Caledon) River is also of

Table 21. Major gravel deposits of the lower Senqu river

Deposit code	Type	Locality	Estimated volume (m^3)
BE1	Basal gravel	Bethel	2,250
CA	Basal gravel	Seaka School	2,250
CA4	Middle terrace	Seaka School	2,500
Ph	Basal gravel	Phamong	2,750
SR4	Basal gravel	Seaka Bridge	3,000
SL6	Middle terrace	Seaka Bridge	4,200
SL1	Basal gravel	Seaka Bridge	4,500
Ma2	Middle terrace	Masitise R	6,000
SL4	Middle terrace	Seaka Bridge	7,500
WA1	Basal gravel	Waterfall	11,000
Ki2	Terrace	Koali	12,500
Ki4	Terrace	Koali	14,580
SR5	Basal gravel	Seaka Bridge	15,000
WA2	Basal gravel	Waterfall	15,000
FH4	Basal gravel	Fort Hartley	22,500
SO	High Terrace	Solomon	42,000
MS3	Terrace	Maseribane	50,000
TC5	Middle terrace	Tele Confluence	110,000
CA2	Middle terrace	Seaka School	215,000
Ki3	Terrace	Koali	262,500
BN1	Terrace	Nkhoebe	325,000

Source: After Rombouts, 1978a, 1978c

Table 22. Summary of testing, lower Senqu River

Type of deposit	Locality	Pit/ Trench	Volume treated (m^3)	Diamond stones/ carats	Treated by	Year
Active	Seaka School	-	30.0	-	UN Project	1979
Active (potholes)	"	-	3.0	-	"	"
Active?	Fort Hartley	-	93.0	-	Scott	1960
Active gravels			126.0	-		
Basal	Waterfall	1	49.5	-	UN Project	1976
	"	2	38.5	-	"	"
	"	WA1	15.0	-	"	1979
	"	WA2	20.0	-	"	" "
	Seaka Bridge	SR4a	30.0	-	"	"
	"	SR4b	15.0	-	"	"
Basal gravels			168.0			
Basal/Low Terrace	Tele Confluence	10 pits	86.0	-	Meaton	1965
Middle Terrace	Tele Confluence	HT1E	4.8	-	"	"
	"	HT1W	11.3	-	"	"
	"	HT1N	2.9	-	"	"
	"	HT1S	5.8	-	"	"
	"	HT2E	7.9	-	"	"
	"	HT2W	4.7	-	"	"
	Seaka School	1	115.2	-	UN Project	1976
	"	2	71.4	1/0.13	"	"
	"	3	145.0	1/0.08	"	"
	"	5 pits	40.0	-	"	"
	"	CA2a	10.0	-	"	1979
	"	CA2b	10.0	-	"	"
	"	CA3a	18.0	-	"	"
	"	CA3b	5.0	-	"	"
	"	CA4a	24.0	-	"	"
	"	CA4b	10.0	-	"	"
	"	CA5a	30.0	-	"	"
	"	CA5b	36.0	-	"	"
	"	CA6a	30.0	-	"	"
	"	CA6b	30.0	-	"	"
	Seaka Bridge	SL4a	50.0	1/0.5	"	"
	"	SL4b	50.0	-	"	"
	"	SL4c	15.0	-	"	"
	"	SL4d	50.0	-	"	"
Middle Terraces			777.0	3/0.71		
High Terrace	Solomon	4 pits	10.0	-	UN Project	1979
Grand total, Senqu gravels:			1,167.0	3/0.71		

interest. The Mohokare rises on the north-western flanks of the Lesotho Highlands and flows south-westwards forming the northern border of the country. For most of its length, it and its major tributaries are "lowland" rivers, with perhaps a greater capacity for accumulating gravel deposits than comparable rivers in more mountainous environments. From the headwaters down, the Mohokare system drains in turn into the extreme western part of the Lemphane-Robert, the Butha-Buthe, the Mapoteng, the Maseru and the Sekameng-Kolo kimberlite groups (figure 38). As remarked above, the first of these appears to be the most diamondiferous group in Lesotho, and small quantities of diamond are also known from the Butha-Buthe, Maseru and Sekameng-Kolo kimberlites.

In the lowlands, the Mohokare has low terraces reaching 300 metres in width, accompanied by remnant high terraces and narrow flats (Meaton, 1966). Alluvium is deep in the flats and low terraces, but here overburden is also thick, and as is the case with the Senqu, gravel makes up only a small proportion of low terrace material. The gravel is normally of sub-rounded to rounded basalt and sandstone pebbles, averaging about 9 cm in size. The proportion of basalt present is much less than in the Senqu gravel since the Mohokare catchment is predominantly in sediments. The gravels tend to be poorly sorted. Meaton (1966, p. 44) notes that alluvial diamonds were reported from the Caledon (Mohokare) just east of Ficksburg, and north of Wepener. Investigation of the Mohokare system gravel was primarily carried out by Meaton, with minor work by Scott and the United Nations Phase II project. There has been a tendency to regard the river as having two areas of interest, the upper course draining the northern kimberlite groups, and the lower course draining the southern groups. Two targets of interest are present in the upper course, the Mohokare River itself, and eastern tributaries draining kimberlite more or less directly. Both were investigated by Meaton, although a less systematic sampling programme had previously been carried out by Scott, whose testing of alluvium downstream of kimberlites was primarily designed as an alternative or adjunct to the direct treatment of the kimberlite bodies themselves. All testing operations on the upper Mohokare River and its tributaries are summarised in table 23. The fact that only two diamonds were recovered, and these immediately adjacent to a kimberlite pipe, suggests that the alluvial deposits are not of great interest.

Little work has been carried out in the lower Mohokare River system, and only the Sekameng River, a southern tributary cutting through the western end of the Sekameng-Kolo kimberlite group, has had major testing (United Nations, 1981d). Meaton (1966) treated 18.9 cubic yards (14.4 m^3) of gravel from five pits some 0.7 kilometre downstream of Pipe 65, Sekameng. Although concentration was good, no diamonds were found. In 1974, a United Nations Exploration for Minerals project field team recovered a diamond of 0.12 carat from a follow-up sample (about 0.02 m^3) taken from the river and in the following year the project treated 30 cubic metres of gravel from 4 pits at 100 metre intervals along the Sekameng River about 1.0 to 1.5 kilometres above its confluence with the Mohokare. One diamond of 0.4 carat was recovered, but it was noted that little gravel is being deposited in the lower part of the river, and that a sufficiently large and representative bulk sample was obtained only with difficulty (Dempster, 1976). The total volume of gravel treated from the Sekameng River is 44.4 cubic metres, for the recovery of one diamond of 0.4 carat. Although the river drains a relatively important group of kimberlites, these results, together with the paucity of gravel accumulations, suggest the alluvials have little potential.

Potential placer deposits immediately adjacent to major kimberlite sources include both eluvial and alluvial gravels overlying, in close proximity to, and just downstream of, kimberlite pipes which are known to contain significant, although

Table 23. Summary of testing, upper Mohokare River system

Type of Deposit	Locality	Number of pits/trenches	Volume treated (m^3)	Diamonds stones/carats	
Active gravel	Mohokare R.	9	18.6	-	
Basal gravel	"	5	25.8	-	
Low Terrace	"	9	67.1	-	
"	"	?	112.4	-	Scott
High Terrace	"	1	2.8	-	
	Mohokare R.		226.7		
	Subeng R.	12	64.0	-	
	Matalane R.	3	12.7	-	
	Mofoqoi R.	11	54.3	1/1.95	
		?	49.3	1/0.3	Scott
	Hlotse R.	1	7.9	-	
	Butha Buthe	10	46.1	-	
			26.0	-	Scott
	Sekhaqana R.	7	7.1	-	
	Serutle R.	1	7.2	-	
	Hololo R.	9	36.9	-	
			2.1	-	Scott
	Tuke R.	2	6.9	-	
	Eastern tributaries		320.5	2/2.25	

All testing by Meaton unless otherwise indicated.

not necessarily economic, quantities of diamond. Because of this association with diamondiferous kimberlite, these gravel bodies are almost exclusively restricted to the mountains, and more specifically to the Lemphane-Robert kimberlite group, which contains the major primary diamond occurrences of Lesotho. The gravel deposits present include those associated with the Kao, Liqhobong and Mothae pipes and a few other deposits of lesser importance. As has been remarked previously, conditions in this area are such that accumulations of gravel are likely to be restricted to size, whilst the optimum requirements for deposition and concentration rarely obtain. Summaries of the testing of the deposits in the Kao, Liqhobong and Mothae rivers are given in tables 24, 25 and 26. Testing of minor alluvial deposits downstream of minor sources, undertaken by Scott, Bleackley and Workman (1964) and Meaton (1956), has been detailed by Robison (1980c).

Overall the situation is as follows:-

Environment	Volume treated (m^3)	Diamonds (stones/carats)
Major lowland rivers		
a) Lower Senqu	1,187.0	3/0.71
b) Mohokare	606.6	3/2.65
	1,793.6	6/3.36
Gravel in proximity to major kimberlites		
a) on kimberlite	652.5	?/809.47
b) downstream	1,416.3	?/ 78.51
	2,068.8	?/887.98
Streams draining lesser kimberlites	433.0	3/0.15
Total	4,295.4	?/891.49

Table 24. Summary of testing, Kao River

Distance below pipe (m)		Volume treated (m^3)	Diamonds stones/ carats	Average size (mc)	Grade carats/ m^3	Tested by	Year
500		35.8	5/1.02	0.204	0.03	Meaton	1965
1,000	a.	4.2	4/1.50	0.375	0.36	Bleakcley	1963
	b.	24.5	-	-	-	Meaton	1965
	(a÷b	28.7)	(4/1.50)	(0.375)	(0.05)		
500-1,000?		50.0	27/4.40	0.163	0.09	Scott	1963
1,400-2,000		11.1	1/0.02	0.02	tr.	Meaton	1965
3,000		8.6	-	-	-	"	"
3,500		32.8	-	-	-	"	"
4,500	a.	23.7				"	"
	b.	317.5	12/0.95	0.079	tr	Project	1973
7,500		11.2	-	-	-	Meaton	1965
8,300		1.0	1/0.01	0.01	0.01	Project	1973
Totals		520.4	50/7.90	0.158	0.02		

Eluvial and alluvial gravel in intimate association with the major diamondiferous kimberlites of the Lemphane-Robert group obviously have some potential. The deposits have long been known, significant proportions of them have already been worked, most are or have been included, fully or in part within mining leases and/or are currently being exploited by digger co-operatives operating under the auspices of the Lesotho Government and CIDA. The location of the deposits on high mountain rivers is such that gravel accumulations are of restricted size whilst the diamonds are abruptly dispersed beyond 1 km downstream from the pipes. The potential of the deposits is therefore limited. There is no indication that streams draining minor kimberlites in the Mafeteng, Roma, Maseru, Mapoteng, Lemphane-Robert, and Qacha's Nek regions contain significant concentrations of diamonds and, in any case, the volumes of gravel are low. On the evidence available it can only be concluded that the gravels of the Senqu and Mohokare rivers also lack concentrations of diamond and therefore have little potential for conventional alluvial diamond deposits. These rivers do however contain larger volumes of gravel, albeit of a dilutional nature. There is a remote possibility that these gravels might contain sparsely distributed, perhaps large, diamonds, giving rise to unconcentrated low-grade but large tonnage deposits. Testing for such a deposit would be difficult and highly speculative, would require the treatment of very large volume samples, and large sums of risk capital would be involved.

14. Factors affecting diamond content

Testing of kimberlites and alluvial gravels in Lesotho has shown that although diamonds are widespread the contents are generally very low with the possible exception of one kimberlite type in Kolo pipe in the lowlands and the major pipes of the Lemphane-Robert belt in the northern mountains. Some of the reasons for the low diamond content have been discussed

Table 25. Summary of testing, Liqhobong River

Distances below pipe (m)	Volume treated (m^3)	Diamonds stones/ carats	Average size (mc)	Grade carats/ m^3	Tested by	Year
On pipe	a) 14.2	?/140.24	–	9.88	Scott	1961
	b) 93.4	?/247.69	–	2.65	"	1962
	c) 537.3	?/417.98	–	0.78	"	1964
	(b÷c	4578/665.67	0.145)			
	d) 7.6	14/3.56		0.47	Meaton	1965
Totals	652.5	?/809.47		1.24		
0-30	94.0	686/51.46	0.075	0.55	Scott	1963
0-200	19.8	24/1.79	0.075	0.09	Meaton	1965
130-300	23.9	35/3.15	0.090	0.13	Scott	1963
Sub-totals	137.7	745/56.40	0.076	0.41		
300-500	11.3	5/0.65	0.130	0.06	Meaton	1965
300-700	46.7	89/6/15	0.069	0.13	Scott	1963
Sub-totals	58.0	94/6.80	0.072	0.12		
1,000-1,100	39.6	13/0.55	0.042	0.01	Meaton	1965
2,000-2,500	21.2	4/0.10	0.025	tr.	Meaton	1965
4,300-4,900	79.3	–	–	–	Meaton	1965
5,000-5,100*	11.5	–	–	–	Meaton	1965
Totals	347.5	856/63.85	0.075	0.18		

* Motete River, immediately downstream of Liqhobong confluence.

Table 26. Summary of testing, Mothae River

Distance below pipe (m)	Volume treated (m^3)	Diamonds stones/ carats	Average size (mc)	Grade carats/ m^3	Tested by	Year
0-50	22.1	7/0.8	0.114	0.04	Scott	1960
	2.1	1/0.15	0.150	0.07	Meaton	1965
Sub-totals	24.2	8/0.95	0.119	0.04		
50-500	57.3	/0.36	-	0.01	Scott	1961/2
500	62.2	5/0.73	0.146	0.01	Meaton	1965
Sub-totals	119.5	/1.09	-	0.01		
500-1,000	106.8	/4.27	-	0.04	Scott	1961/2
1,000	15.4	1/0.16	0.160	0.01	Meaton	1965
Sub-totals	122.2	/4.43	-	0.04		
2,200	13.7	1/0.08	0.080	0.01	Meaton	1965
Totals	279.6	/6.55	-	0.02		
Other						
1st tributary	12.0	-	-	-	Meaton	1965
2nd tributary	1.4	-	-	-	Meaton	1965
Total	13.4	-	-	-		

earlier but attention is drawn particularly to a comparison between the Lesotho kimberlites and those in the Yakutia kimberlite province of Siberia. Thus Kharkiv, Smirnoff, Mofolo and Lerotholi (1979) concluded that the kimberlites in Lesotho and northern Yakutia had many features in common including:-

i) Wide distribution of dykes,

ii) Extensive development of lamprophyric (micaceous) kimberlite types,

iii) Relatively higher titanium, total iron and phosphorus contents which are reflected in increased quantities of perovskite, magnetite and apatite in the groundmass,

iv) Close similarity between the garnets in the kimberlites when refractive index histograms are compared, and

v) Relatively low diamond content with predominance of rounded dodecahedral morphological shapes.

Smirnoff (1980) stated that petrographic, mineralogical and chemical investigations of Lesotho kimberlites have shown that they are noticeably similar to those from some northern areas (the mid and lower courses of the Oleneyok River) of the Yakutia diamond-bearing province. It was noted, however, that the kimberlites in northern Yakutia, in comparison with those in the southern Yakutia, are either barren or contain diamonds in negligible amount. The ultrabasic inclusions in the Lesotho kimberlites were also found to be similar to those in kimberlites from northern Yakutia. Further it was statistically established that the vast majority of Lesotho garnets fall within the field of lherzolite paragenesis which is characterized by complete absence of diamonds or by very low diamond contents; similarly the chrome contents of Lesotho chromites are considerably lower that those paragenetically associated with diamonds. These characteristics provided an explanation for the absence or paucity of diamonds in Lesotho kimberlites. The conclusion reached was that all the evidence points to a low potential for diamonds in the Lesotho kimberlites.

Another important factor influencing diamond content appears to be proximity of the Archean basement to the surface, for Bardet (1964) has noted that most diamond-bearing kimberlites in South Africa are in areas where the basement was at less than 1,500 m below the surface at the time of kimberlite emplacement. In Lesotho, however, a minimum thickness of 1,300 m of basalt is found preserved so that the total thickness of the Karoo beds and hence the depth to basement will be about 3,000-3,500 m (Dusar, 1979). The generation of a kimberlite pipe took place at a depth of 2,000-3,000 m below the surface according to Dawson (1970) or 914-2,285 m according to Hawthorne (1975), both far less than the depth to basement in Lesotho. Thus according to the current theories the emplacement of kimberlite pipes in Lesotho within the soft yielding Karoo beds does not favour the preservation of diamonds.

A related consideration is that kimberlites intruded into ancient cratons appear more diamondiferous than those intruded into younger circumcraton belts (Dawson, 1970). The location of the Kaapvaal craton-Nemaqualand-Natal belt boundary in Lesotho could thus have been an important bearing on diamond content. Barthelemy and Dempster (1975) considered that a possible southwestward extension of the Tugela Fault joined the Helspoort Fault and constituted a dividing line between a diamond-bearing area to the north and a diamond-barren area to the south, but this interpretation is not supported by later structural studies (Dusar, 1979) or by the gravity and magnetic data. Dusar considers that the suture between the Kaapvaal craton and the Namaqualand-Natal belt in Lesotho is not necessarily fault controlled and probably follows a more irregular and still unknown line. In this connection Griffin et al. (1979) noted that kimberlites in north-eastern Lesotho contain garnetiferous granulite xenoliths which characteristically are found on or outside the edge of the Kaapvaal craton whereas pipes within the craton apparently lack granulite nodules; this suggests that the craton boundary could be in the far north of Lesotho. That the Lesotho kimberlite magmas moved outside the stability field of diamond during intrusion is supported by the model of a kimberlite diapir put forward for the Letseng-la-Terae pipes (Lock, 1980) which indicates that as soon as the diapir begins to rise, the diamond stability field is breached with destabilizing effect on the diamonds enclosed in the rising magma (figure 58). Primary diamond shapes are octahedra, cubes and macles but the dominant forms at Letseng-la-Terae and elsewhere in Lesotho are dodecahedral and other types which are characteristic of resorption (Harris et al., 1979; Smirnoff, 1980).

15. Production of diamonds

The production of diamonds in Lesotho is given in tables 27-28 and the effect of the opening of the Letseng-la-Terae mine in 1977 is clearly evident. The major contribution diamonds make to Lesotho total exports is shown in figure 59.

C. Uranium

1. History of exploration

The widespread occurrence of uranium in the sedimentary formations of Lesotho was first established by the United Nations Exploration for Minerals project which started in 1974. The progressive stages were as follows:

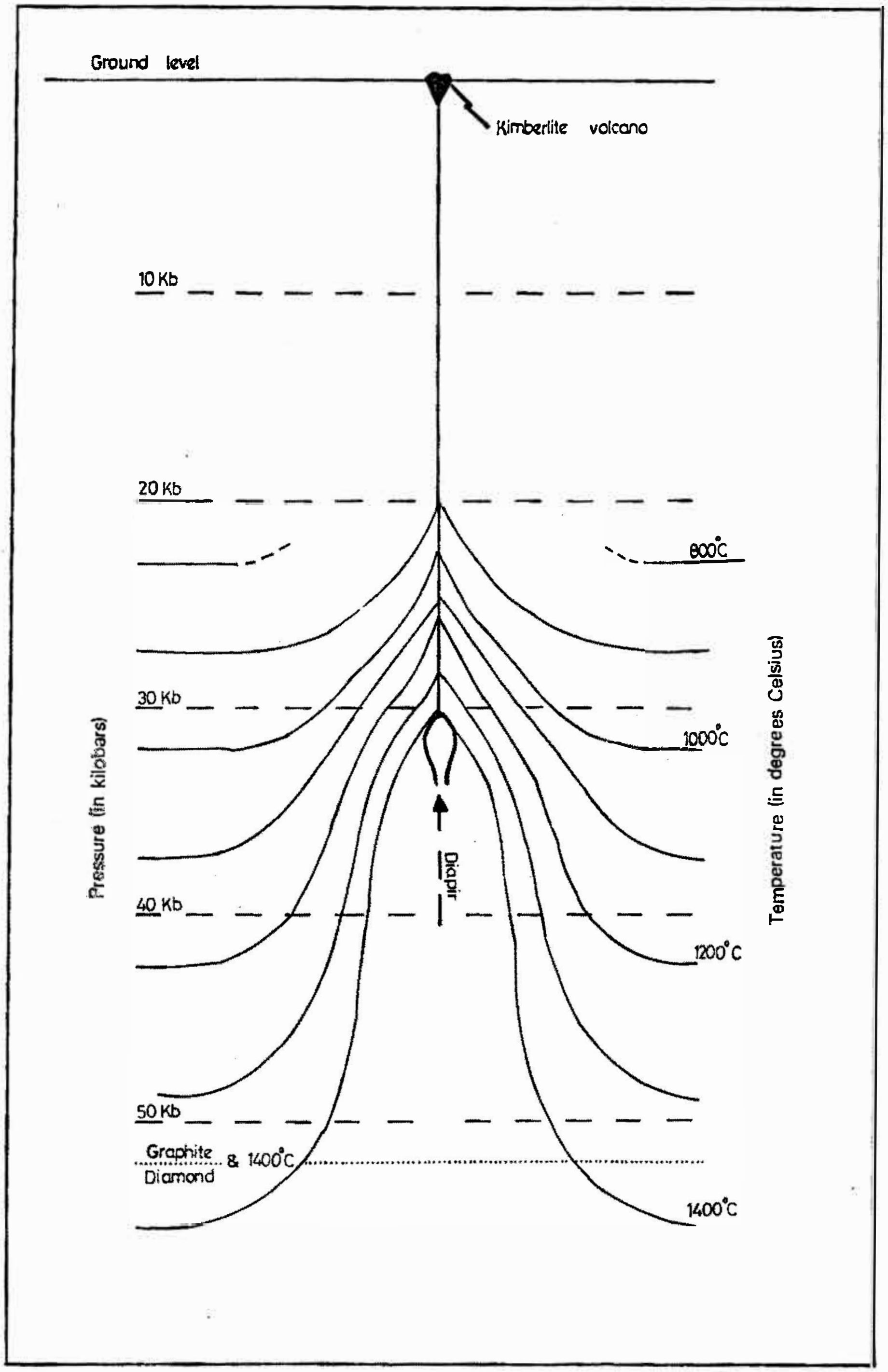
1975 - Airborne radiometric survey of western lowlands

1976 - Discovery of radioactivity in shale and surface iron concentrations (Reed, 1978b), preliminary results of radiometric survey

1977 - Discovery of radioactive phosphatic horizons with recognition of importance of certain stratigraphic levels (Reed, 1978b), full radiometric survey report

1978 - First discovery of secondary uranium mineralization, follow-up ground surveys of radiometric and geochemical anomalies

Figure 58. Model of kimberlite diapir.



3300.34 x

Table 27. Lesotho exports by major category

Year	TOTAL	Live animals	Foodstuffs	Crude materials	Diamonds	Other exports	Diamonds
		(all figures in millions of maloti)					(%)
1972	6.1	0.9	0.6	3.2	0.2	1.1	3.6
1973	8.8	2.0	0.3	4.9	0.3	1.3	14.8
1974	9.8	1.5	0.06	5.1	0.9	2.3	23.5
1975	9.2	0.4	1.1	3.8	0.5	3.5	38.0
1976	14.6	0.2	1.8	3.8	0.5	8.4	57.5
1977	12.2	0.2	0.7	4.6	1.2	3.4	44.3
1978	27.7	0.1	0.2	7.8	16.7	2.9	60.3
1979*	37.9	1.2		7.9	21.2	7.6	55.9

Source: World Bank/UNDP Team, Economic Indicators, (MASERU, June 1981)

* Note: 1979 data are preliminary

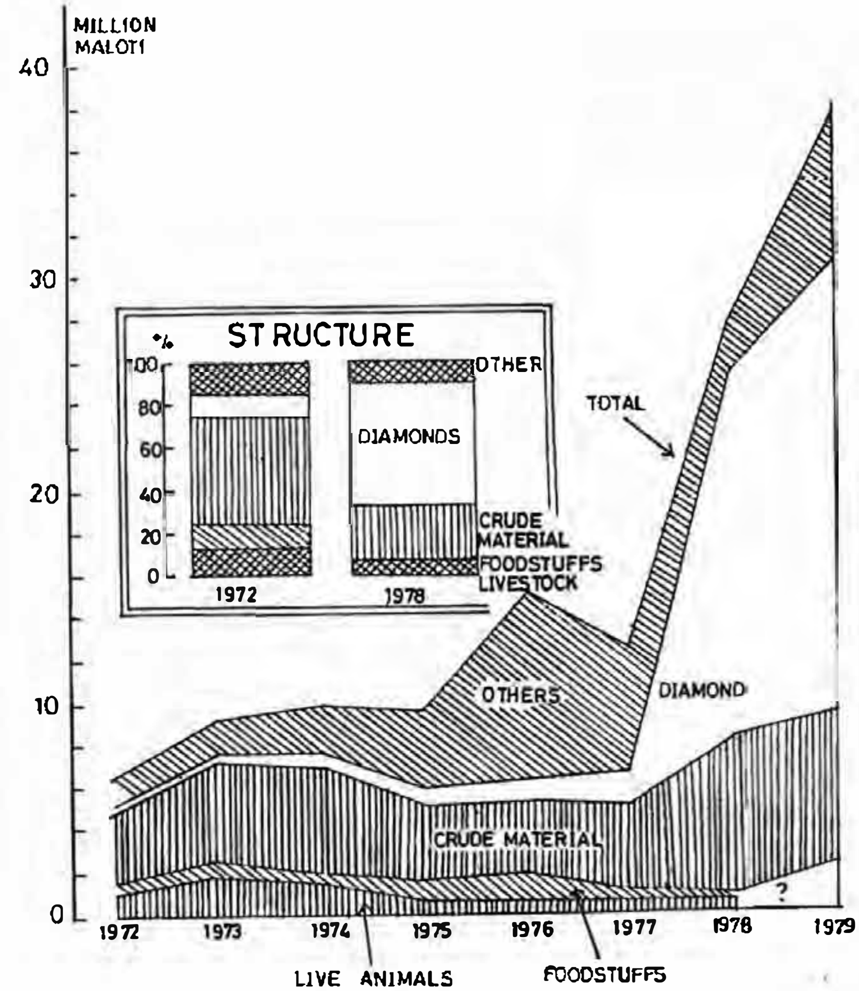
Table 28. Exports of diamonds, 1970-1979

	Quantity (carats)	Value (thousands of maloti)	Average price (maloti per carat)
1970	16,539	652	40.0
1971	6,815	212	31.1
1972	9,019	196	21.7
1973	8,567	255	29.7
1974	11,798	902	76.4
1975	3,466	483	139.3
1976	7,051	455	64.5
1977	14,977	1,249	83.4
1978	67,222	16,695	248.4
1979 *	64,886	21,224	387.1

Source: Annual Statistical Bulletin 1979, Bureau of Statistics, Maseru, June 1980)

* Note: 1979 data are preliminary

Figure 59. Lesotho exports by major category.



3300.35x

1979 - Delineation of 37 areas for detailed study (Evans, 1980)

1980 - Detailed investigations undertaken with drilling of 5 prospects

1981 - Overall assessment of uranium development potential taken over by new United Nations project "Technical Support for the Department of Mines and Geology" (LES 80-007) as from 1 April 1981

2. Favourability criteria

The uranium prospects in Lesotho, like those elsewhere in the Karoo Supergroup of southern Africa and in the Colorado Plateau, are sedimentary sandstone type deposits for which well established favourability criteria of a regional, stratigraphic and lithological nature have been defined by the International Atomic Energy Agency, Vienna (e.g., IAEA Working Group, 1974). These criteria have been applied to Lesotho (Cameron, 1978; United Nations, 1981f). The requirement for a stable tectonic setting is met by the fact that the Karoo Supergroup was deposited on the Kaapvaal craton and the now well stabilized Natal mobile belt. Only gentle folding and minor faulting, such as the Helspoort Fault, have since taken place with the result that the upper Beaufort and Stormberg groups present are almost horizontal and virtually an unfaulted succession, although invaded by numerous dolerite dykes and sills. There is no evidence of a marine excursion in the Karoo formations, hence it is likely that the basin was to all extents and purposes closed during deposition. The sub-Clarens formations in Lesotho are undoubtedly of cyclic fluviatile origin and derived from a land mass containing crystalline metamorphic and acid igneous rocks lying to the south of the present outcrop of the basin. The ratio of channel-fill sandstone to argillite appears adequate to provide impermeable confining strata for control of any hypothetical uraniferous ground-water migration. The thickness of host sandstone beds could be a probable limiting factor for accumulation of large deposits (Wright, 1979). In New Mexico, for example, most ore is in sandstone greater than 30 m thick and in Colorado the larger deposits occur in sandstone not less than 15 m thick, with a tendency for most deposits to be located in the central and thicker parts of the channel. In Lesotho, sandstone units thicker than 15 m are not common. Recent drilling has shown that pyrite is common in small quantities and macroscopically carbonized debris has been noted even if it is not too common; it appears, however, that a reducing environment exists capable of preserving older tabular deposits or of providing the reduction-oxidation interface suitable for the accumulation of younger migration-accretion type bodies. Two sources of uranium are possible. The first is derivation from exposed older rocks at the time of deposition of the sediments with special reference to granitic and metamorphic rocks occurring south of the Karoo basin, the Natal mobile belt and the Nama system. This possibility is supported by the occurrence of pebbles of granite, gneiss and acid volcanics in the Molteno conglomerates, e.g., at Mphoto and Mafeteng (Dusar, 1978b). It may also be of interest that Dusar records small proportion of Witwatersrand conglomerate, possibly an indication that it was exposed and being eroded at this time and, therefore, could have provided some uranium to the basin. The presence of acidic volcanics in the Lesotho Karoo rocks has already been described (figure 26) and these are potential source rocks if they released uranium on alteration and devitrification. Indeed, this could be a decisive factor in the occurrence of substantial deposits of uranium in the Karoo rocks for, in the western United States, Wright (1979) considered the contrasts between the productive Jurassic Morrison Formation and the non-productive Permian of comparable stratigraphy and apparent lithology to be due to the probability that the partly volcanic Brushy Basin Formation provided the uranium for the Morrison sandstone whereas no volcanics and no viable uranium deposits had yet been identified in the Permian formations.

There is little doubt that the Beaufort and Stormberg groups in Lesotho provide an almost ideal environment for the deposition of sedimentary uranium. The only negative feature is the rarity of thick sandstone channel development which would militate against the accumulation of large deposits.

3. Nature of mineralization

Uranium is found in all variants of the sub-Clarens sediments, but the widespread host is sandstone. Important associations are:

i) With medium- to coarse-grained massive or cross-bedded basal or point bar sandstones as at Leluma and Foisani,

ii) Of a similar nature to (i) but situated well above the base of the sandstone; examples are seen at Phiri and Molokong,

iii) With thin, horizontally bedded, silty, finer-grained sandstone and sandstone-argillite sequences of somewhat impermeable aspect commonly overlying the more resistant point bar sandstones. These show little oxidation and low uranium content and may represent original, almost syngenetic, deposition of uranium. Examples are at Tosing and southwest of Phamong.

iv) With surficially dark coloured ellipsoidal carbonate concretions. These may be up to 2m across.

v) With hematite and limonite-stained patches and segregations isolated one from another by barren less iron-stained areas of different sizes,

vi) With fossil carbonized organic matter. Very high count rates may be obtained in these instances,

viii) With phosphatic matter, commonly nodular (Reed, 1978b),

ix) With a sandstone xenolith in dolerite. The single example at Qaqatu shows that the sandstone had been mineralized prior to inclusion in the dolerite, i.e., relatively soon after the deposition of the sandstone.

x) With clay pebble conglomerates, occasionally with secondary uranium minerals, both in lag deposits at the base of individual sedimentary cycles and in isolated beds and lenses contained in sandstone. With the exception of those at Bethel and Khatleng the conglomerates are neither thick nor persistent, but are commonly associated with mineralized sandstones.

xi) With mudstones and siltstones, generally expressed in indeterminate dispersions, generally or low tenor, and lacking any other characteristic to distinguish them from non-uraniferous members of this category.

The secondary uranium minerals identified to date (1982) include an unusual fine-grained barian carnotite found in a sandstone near Bethel mission (Noel, 1980a) where it is intergranular, fills voids or impregnates fine-grained matric material. A barian carnotite had not previously been identified by IAEA, Vienna, so that the discovery in Lesotho appears to be a first type mineral. Electron microprobe analyses are given in table 29. All analyses approach a U: (K +ba): (U +Si) ratio of 1:1:1 and correspond to the formula or carnotite; $K_2(UO_2)_2(VO_4)_2.1\text{-}3H_2O$). Potassium appears to be partly replaced by barium, the ratio K:Ba being close to 2:1. Thus the Lesotho mineral is a barian carnotite with the approximate formula $(K, Ba)_2\ (UO_2)\ (VO_4)_2.3H_2O$. Other secondary uranium minerals identified are meta-autunite/meta-uranocircite, meta-uranocircite, meta-ankoleite, and francevillite. All the secondary minerals are thus barium-bearing types but the origin of the barium is uncertain.

Although minor showings and spot anomalies are common throughout the sub-Clarens sediments, the majority of uranium prospects are concentrated in a zone at and adjacent to the Elliot/Molteno boundary. This time intercal is marked by:

(a) A change in sedimentary environment from one where a majority of coarser-grained sandstones were laid down to one where the sedimentation was less vigorous and typified by the accumulation of finer sandstone accompanied by a greater proportion of argillite,

(b) Increasing aridity in the source area.

A second favourable but less well defined horizon for uranium mineralization is high in the Elliot Formation and has been noted

Table 29. Electron microprobe analyses of barian carnotite from Bethel area

Element	LES-1/A	LES-1/B	LES-1/C
SiO_2	3.2	0.9	1.5
TiO_2	0.1	0.1	0.1
UO_2	57.7	54.2	57.7
ThO_2	-	0.1	-
V_2O_3	15.0	16.4	14.5
FeO	0.4	0.6	0.5
MgO	0.1	0.1	0.1
CaO	1.2	1.2	1.3
BaO	12.3	11.6	12.3
PbO	-	0.1	-
CuO	-	-	-
Na_2O	0.1	0.1	0.1
K_2O	6.2	6.1	6.3
Totals	96.3	91.5	94.4

Source: IAEA, Vienna

at Tosing and Bethel in the south of the country. The deepest radioactivity recorded in Lesotho is that in lower Beaufort sandstone and siltstone at depths of about 628 m and 640 m respectively in the hole drilled for coal at Butha-Buthe (Robertson and Associates Ltd, 1979).

In detail the distribution of anomalous radioactivity within a zone is generally sporadic and patchy although certain occurrences such as those at Khatleng, Qaqaty, Senqu, Phiri, Molokong, Leluma and Bethel exhibit a measure of continuity. It has not yet been established whether the surface indications are relicts of a formerly more continuous body now largely removed by surface oxidation and leaching or whether the surface indications are typical or primary accumulation. These questions can only be resolved by drilling to investigate grades and persistence of mineralization in depth.

4. Comparison with other Karoo occurrences

Uranium mineralization is known in the Karoo rocks in Zambia, Zimbabwe, Malawi, Madagascar, Botswana, Kenya and Tanzania (Cameron, 1978) and the occurrences are summarized in table 30. A notable feature is the wide range of ages suggesting that all sections in Lesotho need to be carefully examined. Probably, comparison is most usefully made with occurrences in South Africa where the mineralization, initially found in lower Beaufort formations in the Beaufort West region, has been described by Backstrom (1974), Turner (1975a), Moon (1977), Toens and Le Roux (1978), Le Roux *et al.* (1979), Eddington and Harrison (1979), Anderson and Fraenkel (1979) and Jakob (1979). Lithology, permeability, ground-water movements and carbonaceous fragments are the common ore controls with the uranium mineralization generally in fine to very fine grained sandstone in few of which the grain size exceeds 0.25 m (Le Roux et al., 1979). The major deposits appear to be associated with sandstone erosion channels (Eddington and Harrison, 1979). Probably the uranium is transported by

Table 30. Age distribution of uranium mineralization in the Karoo sedimentary formations of southern Africa

GROUP	FORMATION	URANIUM OCCURRENCES
Stormberg	Clarens	-
	Elliot	Madagascar Lesotho
	Molteno	South Africa, Kenya, Tanzania Zambia, Zimbabwe
Beaufort	Upper	Lesotho
	Middle	-
	Lower	South Africa, Lesotho
Ecca	-	Botswana

Source: Cameron, 1978

mildly reducing alkaline ground water as uranyl carbonate complexes and is deposited on encountering a strong reductant such as carbonaceous debris. Two types of mineralization have been recognised - dark weathering calcareous sandstone with disseminated sulphides and primary uranium minerals, and light weathering limonitic sandstone with secondary uranium minerals (Moon, 1977; Le Roux et al., 1979). It has also been noted that proceeding northwards from the more important Beaufort West/Sutherland zone in the lower Beaufort Group in the south the uranium deposits occur progressively higher up in the Karoo succession until eventually, near Ficksburg, they occur in the overlying Molteno Formation and present a classic diachronous relationship of lithostratigraphic facies with time (Toens and Le Roux, 1978). Whether, however, the mineralization in Lesotho is comparable to that in Beaufort West remains to be determined. Apparently little subsequent enrichment has occurred in South Africa so that, as a rule, Colorado roll-front conditions do not apply. Consequently uranium grades in South Africa tend to be a low tenor, the deposits ill defined and difficult to delineate and evaluate. The nature of the deposits is such that it may take a number of smaller deposits to constitute a viable unit. These remarks appear applicable to the Lesotho occurrences.

D. Coal

1. History of exploration

Coal was first reported in Lesotho by Dornan (1980) who noted thin seams of coal in the Molteno beds particularly near Mohale's Hoek. This was followed by the comprehensive survey by Stockley (1947) who recorded thin, impersistent, non-payable coal in areas close to Butha-Buthe, Maseru, Matsieng, Masite, Mafeteng and in the Mohale's Hoek district. A reconnaissance mineral survey undertaken by the U.K. Overseas Geological Surveys in 1963 (Bleackley and Workman, 1964) found no new evidence to alter Stockley's conclusions. Analysis of a small coal outcrop south of Qhalasi in the Mohale's Hoek District showed that it was a good-quality bituminous coal. From April 1974 to 1981 the United Nations Exploration for Minerals project carried out systematic regional geological surveys at a scale of 1:50,000, and additional localities with carbonaceous material were located (United Nations, 1981i). In 1975 the Lesotho Department of Mines and Geology undertook drilling and pitting in the Taung Ward area near Mohale's Hoek. Four boreholes were drilled to depths less than 45 m, and two intersected thin impersistent coaly seams. A more comprehensive evaluation of the coal potential was made by David S. Robertson and Associates Ltd, under the sponsorship of the Canadian International Development Agency (CIDA); a two-year programme from 1977 to 1979 included surface investigations and drilling of 15 shallow holes in the Taung Ward, Lechesa-Paki and Tabola areas, and one deep hole near Butha-Buthe. No economic deposits were located (Robertson and Associates, 1979). An assessment of the potential for additional coal exploration in Lesotho was made in 1981 by a consultant for the United Nations Department of Technical Co-operation for Development (Dyson, 1981).

The possibilities for coal in Lesotho are of two categories, shallow coal associated with the upper Karoo Beaufort and Stormberg groups and deep coal associated with the lower Karoo Ecca Group. These two categories will be considered separately.

2. Potential for shallow coal in Beaufort and Stormberg groups

(a) Distribution of surface carbonaceous showings

Surface carbonaceous showings are widespread throughout the Beaufort and Stormberg groups, with drilling being carried out in the well known Mohale's Hoek and Lechesa-Paki localities. Although the occurrences were popularly assigned to the Molteno Formation, mapping by the United Nations Exploration for Minerals project showed that the upper Beaufort and Clarens formations probably contain more carbonaceous material. This points to the distribution of carbonaceous material throughout the section rather than the development of one "coal measure" sequence. The various occurrences are:

(i) Butha-Buthe (Sheets 1A, 1B): A narrow and impersistent seam about 5 cm thick was reported by Stockley (1947), Bleackley and Workman (1964) and by Robertson and Associates (1979) who noted small lenses of coaly material. No occurrences worthy of further exploration could be found in the area.

(ii) Penapena (Sheet 3C): Stockley (1947) refers to a carbonaceous shale zone at this location and Bleackley and Workman (1964) described a 15 cm seam of friable platy and shaly coal in which plant remains were clearly visible. The seam was traced for several metres but was not picked up in neighbouring streams; its limited lateral extent and poor quality indicate occurrence is of no interest. No coal was located in the area by Robertson and Associates (1979).

(iii) Lechesa-Paki (Mazenod) (Sheet 3C): Lenses of coaly shale up to 38 cm thick were reported by Stockley (1947) in the upper Beaufort Formation. Further investigations by Grohmann (1977a) and Robertson and Associates (1979) found several small coal lenses up to 2 cm in thickness when persisted laterally for up to 2 m. The results of CIDA drilling of the region are given below.

(iv) Mohale's Hoek (Taung Ward, Qualasi) (Sheet 12B): This area is the classic location for "coal" in Lesotho and the only place where some local exploitation for fuel has taken place. It was originally described by Stockley (1947) as a seam 15-20 cm thick with a lateral extent of 180-270 m occurring in the Molteno Formation, but mapping by the United Nations Exploration for Minerals project revealed that the occurrences are in the Beaufort Formation (Grohmann, 1977b; Dusar, 1978b).

Bleackley and Workman (1964) reported a seam of good-quality bituminous coal about 15 cm thick which was traced for more than 180 m in the west bank of a stream under an overburden of sandstone, shale and alluvium 3-5 m thick. No outcrops were discovered in adjacent streams and the seam was presumed to have small areal extent. A similar conclusion was reached by Nixon (1971). An analysis of the coal was as follows (Bleackley and Workman, 1964):

		Per cent
Moisture at 105°C		0.72
Volatile matter		21.00
Fixed carbon		62.86
Ash		15.42
	Total	100.00
	Total sulpher	1.18

The analysis was considered to be a good one for Karoo coal and comparable to that of Natal bituminous coal, with remarkably low moisture and not unduly high ash content. The sulphur content was similar to that of other South African coals.

CIDA drilling of the region is described below:

(i) <u>Matsieng-Morija (Sheet 8A):</u> Two distinct types of carbonaceous material have been reported, carbonaceous "skins" on beds of the Molteno Formation and material in Recent alluvium (Stockley, 1947; Robertson and Associates, 1979). No prospect for coal resources exists.

(ii) <u>Masite (Sheet 7D):</u> Coal fragments were reported by Stockley (1947) and van Rooijen (1957b) who found scattered carbonaceous plant remains in both the Beaufort and Molteno formations.

(iii) <u>Sehaoli (Sheet 7D):</u> Coal fragments have been reported by Stockley (1947) and by Appel (1975) who noted that the fragments can be found at several horizons. The thickest seam found was only 2 cm.

(iv) Siloe (Sheet 7D): Carbonaceous shale and coal fragments have been recorded by Stockley (1947) and Appel (1975) but all are less than 2 cm in thickness. The area is of no interest (Robertson and Associates, 1979)

(v) Ha Magele, Leribe (Sheet 1C): A seam of apparently good-quality bituminous coal was examined by Bleackley and Workman (1964) but was found to be only 1 cm thick and overlain by 6 cm of carbonaceous shale with massive sandstone above and below.

(vi) Likhstlane (Sheet 1C+): Reports of coal were found to be carbonaceous material in Recent alluvium (Robertson and Associates, 1979).

(vii) Tsmololo, Mahobong (Sheet 1C): J. King (1978) and Robertson and Associates (1979) reported small lenses of coal but the maximum thickness are 4-5 cm with a lateral extent of 4-5 m.

(viii) Robogha, Mahobong (Sheet 1C): Coal veins up to 2 cm thick have been reported (J. King, 1978) but none are of any interest (Robertson and Associates, 1979).

(ix) Anone-Ha Marjomala (Sheet 13C): Small coal lenses up to 1.5 cm thick and with a lateral extent of 2 m have been noted (Rombouts, 1978b; Robertson and Associates, 1979).

(x) Kanono-Kholoane (Sheet 8C): Single trees buried in the Clarens Formation have been described by Grant (1975).

(xi) Tolonyane (Sheet 13D): Coal lenses were found in the uppermost Clarens Formation and in a sandstone intercalation in the lower Drakensberg basalts (Rombouts, 1978c).

(xii) Seiso (Sheet 3D): Thin coal streaks were noted at the top of the Clarens Formation the largest being 1 cm thick and 50 cm long (Grohmann, 1978).

(xiii) Mapote (Sheet 14B), Raleqheka (Sheet 8A): At Mapote the "coal" was a baked carbonaceous silty mudstone adjacent to a dolerite intrusion (Longerstaey, 1979a) while that at Raleqheka was a black weathered basalt (Robertson and Associates, 1979).

(b) Drilling

Although a small drilling programme was apparently carried out at Mohale's Hoek (Taung Ward, Qualasi) in 1975 by the Department of Mines and Geology (Robertson and Associates, 1979), the main drilling undertaken was the CIDA programme in 1977 when 6 holes were completed with a total depth of 613 m (Robertson and Associates, 1979). Five of the drillholes were concentrated near the principal outcrop in the donga below Qualasi hill, where surface investigations had disclosed the presence of two seams of 8 cm and 10 cm thickness respectively with a lateral exposed extent of about 8 m. The drilling enabled the carbonaceous "zone" to be traced for 1,800 m but the maximum thickness of coal was only 12 cm. Preliminary investigations had indicated the presence of coal streaks and lenses occurring in coarse grit at the base of the Molteno Formation but drilling to test this sequence encountered only thin lenses similar to that exposed in outcrop. The drilling indicated that the area is not prospective for coal resources.

Eight holes were drilled at Lechesa-Paki (Mazenod) as part of the CIDA shallow drilling programme between May and September 1977 primarily to determine whether thicker and persistent coal zones could be located in view of the surface indications of small coal seams up to 2 cm thick and up to 2 m long. In a total tested section of more than 1,000 m of Molteno and Beaufort beds the thickest coal seam encountered.was only 1.1 cm (Robertson and Associates, 1979). Clearly the area holds out no prospect for exploitable coal.

Shallow drilling was undertaken by CIDA near the village of Tabola in the Peka region in 1978 to test the basal Molteno beds following a report that coal at that horizon had been intersected in a drillhole near Ficksburg. The hole was collared in the Elliot Formation and ended in the Burgersdorp Formation at a depth of 148.25 m. At 112.8 m a 4-cm band of shale, vitrain coal and pyrite was found within a medium- to coarse-grained white glittering sandstone. Additional traces of carbonaceous debris were recorded in a lower sandstone unit. The 'coal' was considered to be similar to other occurrences in the basal Molteno sandstone beds and to have no economic potential.

(c) Comparison with Beaufort and Stormberg groups in South Africa

To assess further the prospects for economic shallow coal in Lesotho, comparison can be made with areas in the Republic of South Africa where coal resources have been recognised in the Beaufort and Stormberg groups. The main resources are contained in the Molteno Formation in the Molteno-Indwe coalfield of north-eastern Cape Province (Turner, 1971; Patrick, 1975; De Jaeger, 1976), with coal that had been worked being confined to an area nearly 60 km from the Lesotho border. Turner provided a comprehensive description of the field and concludes that (a) the coal is thin and discontinuous with numerous shale partings between the seams, (b) the coal is of poor quality with low volatile and high ash content (this is not the case with the better quality coal found at Mohale's Hoek), and (c) recoverable reserves are comparatively small. These conclusions are borne out by the fact that commercial exploitation of the field ceased in 1948. Further, Petrick stated that the field is not considered to offer any chance of further exploitation on a commercial scale.

With regard to the existence of coal outside the Molteno-Indwe area Turner (1971) concluded that it was unlikely that any economic deposits will be found very far north of the main coal occurrences around Indwe and Molteno where the deepest part of the basin (300-600 m) appears to have been located and where the thickest and most extensive of the total sequence, a conclusion which is supported by the available data in Lesotho where the thickness of the Molteno Formation at Mohale's Hoek is about 150 m thinning to less than 40 m in the Peka area.

The evidence from South Africa thus provides no encouragement for the presence of economic shallow Beaufort or Stormberg coal in Lesotho.

3. Potential for deep coal in lower Karoo Ecca Group

As the oldest rocks exposed at the surface in Lesotho belong to the upper Beaufort Burgersdorp Formation, the coal potential for lower Karoo Ecca coal in Lesotho can only be evaluated from the results of deep drilling in Lesotho, from peripheral drilling around Lesotho, and from comparison with the occurrence of Ecca coal in the Republic of South Africa. The two deep boreholes in Lesotho, the Westrans Mahobong and the CIDA Butha-Buthe drillhole, have been described earlier (figure 10, table 2). Possibly the Mahobong hole penetrated the middle Ecca but the Butha-Buthe hole did not. There is, therefore, no clear evidence within Lesotho for either the presence or absence of Ecca coal. Both holes indicated, however, that if Ecca coal exists in northern Lesotho it must be at a depth greater than 1,500 m. The log of the Mahobong hole indicated several thin 'seams' of coal in the vicinity of 1,585 m, the maximum thickness being 15 cm. The only coal material encountered in the Butha-Buthe hole was a single streak contained within a coarse-grained sandstone of lower Beaufort age.

Boreholes drilled around the periphery of Lesotho are listed in table 2 and their locations shown in figure 11. The top of the middle Ecca was about 1,570 m in the Ladybrand hole and about 1,470 m in the Ficksburg hole (Roswell and de Swardt, 1976). A structural contour map (Truswell, 1977) clearly indicates that the depth to the upper Ecca deepens abruptly southwards across Lesotho, showing that the boreholes drilled at Mahobong and Butha-Buthe were sited where the Ecca is closest to the surface in Lesotho. No evidence of significant coal was noted in the drillholes around Lesotho. This raises the question whether the Ecca sediments are likely to be coal-bearing in Lesotho itself. The facies studies by Ryan (1967) modified by Truswell (1977) demonstrated that the Ecca Group could be divided into four zones of which only the northern arenaceous zone, deposited in a swampy and deltaic environment, was associated with coal in contrast to the other argillaceous zones where shales were deposited in deep lake or even marine environments. The evidence from the Mahobong and Butha-Buthe boreholes suggests, however, that the boundary between the northern and the southern facies may be farther north in Lesotho as the Ecca beds penetrated in Lesotho were argillaceous and more akin to the southern than the northern arenaceous zone. This inference receives some support from Petrick (1975) who concluded that the southern boundary of commercially exploitable coal resources in the Ecca Group can be roughly represented by an approximately east-west line drawn through Ladysmith in Natal and Bloemfontein in the Orange Free State. Dusar (1978b) postulated the possibility of Ecca coal development in Lesotho based on theoretical structural concepts of basement "highs" beneath Lesotho but more stratigraphic control is required to support this hypothesis; in any case it appears that no coal has been found associated with such "highs" in the Republic of South Africa. Smith and Eriksson (1979) have presented a fluvio-glacial and clacio-lacustrine deltaic model for Permo-Carboniferous coals of the northeastern Karoo basin and this lays emphasis on north-west trending glacial valleys scoured by ice sheets into the underlying Proterozoic floor. At the retreat of the glaciers this irregular basement topography controlled not only the accumulation of sediments carried by meltwaters but also the development and extent of peat bogs. The location of such basement valleys in Lesotho clearly is impractical as no boreholes has yet penetrated basement and the density (and cost) of drillholes required to locate the channels at depths greater than 1,500 m would be prohibitive.

4. Conclusion

Detailed mapping by the United Nations Exploration for Minerals Project has failed to reveal any significant new coal showings in addition to those already known while CIDA drilling of the well known but very poor occurrences has downgraded them even further. There is little prospect for the occurrence of viable coal resources at shallow depths in Lesotho. The potential for deep coal in the Ecca Group is similarly limited owing to the depth (greater than 1,500 m) and the strong probability that the Ecca sediments beneath Lesotho would not be coal bearing.

The overall conclusion is that Lesotho contains no coal resources and additional exploration would be difficult to justify (Robertson and Associates, 1979; Dyson, 1981; United Nations, 1981i).

E. Oil

Two surface occurrences of dark hydrocarbons in basalt and dolerite have been recorded from Lesotho (Stockley, 1947) but their general rarity was confirmed by the regional geological surveys undertaken by the United Nations Exploration for Minerals project. Similar occurrences of hydrocarbons associated with volcanic rock have been reported in the Republic of South Africa, e.g., the Bethlehem and Kestall districts (van Eeden, 1937). Rowsell and De Swardt (1976) noted that in the eastern Orange Free State and southern Transvaal traces of oil are found in vugs and fractures in dolerite intrusions, and although it is possible that they may have originated by the distillation of coal source rocks it is more probable that they were derived from pre-existing oil accumulations in the middle Ecca and possibly lower Beaufort reservoirs. The origin of similar traces of oil in diatremes intersecting the Stormberg sediments around the margin of Lesotho and even in Stormberg lavas near Bethlehem has not been established. In the case of the diatreme near Ladybrand hore hole LA 1/68, the most probable source seems to have been the middle Ecca reservoirs but oil shows in diatremes to the south might have their origin in reservoirs at higher stratigraphic levels. Whatever their origin, the hydrocarbon traces associated with the Drakensberg volcanism have no economic potential.

The possibility of oil or gas being found at depth in Lesotho must be considered in the light of general geological considerations, the evidence of the Mahobong bore hole, and the results of drilling around the periphery of Lesotho (figure 11, table 2). The large amount of data obtained during the search for oil and gas in the Republic of South Africa has been summarized by Rowsell and De Swardt (1976) who concluded that there is an overall decrease in diagenesis from south to north over the Karoo basin as a whole. The state of diagenesis was found to change abruptly at about latitude 29°S (just to the south of Peka in Lesotho, figure 1). To the south of this latitude the Beaufort, Ecca and Dywka sediments are mostly in a state of diagenesis consistent with the preservation of dry gas only. The presence of traces of oil in the middle Ecca sediments from the Ladybrand borehole LA 1/68 showed that the stage had not been reached where oil was entirely replaced by gas. It was concluded that the Ecca and Dywka sediments roughly between latitudes 28°S and 29°S are in a transition stage of diagenesis corresponding to the boundary between oil and gas preservation. North of about latitude 28°S the sediments are still within the oil preservation stage except where locally affected by intrusions.

An important observation was that the only proven occurrences of oil in pre-Stormberg sediments lay north of approximately latitude 29°S. The most significant were encountered in middle Ecca reservoirs where the source of the oil is clearly the organic-rich middle Ecca and in some cases also the lower-Ecca shales. The southernmost known occurrence of this type was intersected in borehole LA 1/68 near Ladybrand over a 3-m interval at a depth of 1,600 m. Minor shows of oil and gas were also recorded in Beaufort and Molteno sediments at higher levels in the well and of oil in a nearby diatreme. No flow was obtained, however, owing to the low porosity and permeability of the sandstones and low oil saturation (the percentage of pore volume occupied by oil). The Ladybrand show was regarded as the residue of a once more extensive accumulation that was largely destroyed by burial diagenesis and dolerite heating. In Lesotho the borehole drilled to the north of latitude 29°S at Mahobeng proved to be barren with no traces of oil or gas. South of latitude 29°S the shales have low organic content which makes them unattractive as source rocks for oil; they are also in a state of strong diagenesis due partly to the effect of dolerite intrusions and partly to relatively deep burial. Fractured shales associated with dolerite traps seem to provide the only prospects for gas accumulation but the location and testing of such occurrences would be difficult and costly, and reserves are unlikely to be economic. All the available evidence is thus against an economic discovery of oil and gas in Lesotho.

F. Hydroelectricity

In the absence of significant deposits of coal, oil and gas and the potential for uranium being long-term, hydroelectricity, utilizing Lesotho's abundant water resources, constitutes the only readily available major energy source, a conclusion supported by the 1981 consultancy mission of a United Nations energy adviser. Sufficient hydroelectricity should be generated by the proposed Highland Water scheme to satisfy Lesotho's immediate needs and there are other promising sites on catchments not related to the scheme. The potential for rural application of small and micro-hydropower developments also appears high. From a geological viewpoint many attractive sites exist such as that on the Quthing River (Read, 1976b).

The geological engineering properties of the Drakensberg lavas have been well documented following investigations in the Oxbow district (Binnie and Partners, 1971). Little time elapsed between successive flows as there is only slight evidence of weathering or oxidation at the top of each flow. No genuine soil layers were noted during field studies but one thin layer of moderately weathered rock was encountered in one drill hole at a depth of 100 m. Some basalts were found to contain montmorillonite and vermiculite in finely disseminated form in the groundmass of the rock. Crushing tests indicated that the unconfined strengths of cores ranged from 48 to 276 N/mm^2 with the sill cores at the higher end of the range. The lavas have strengths from 48 to 172 N/mm^2. Tensile strengths range from 20 to 83 N/mm^2. The sills contain little water and are very dense (of the order of 3,044 kg/m^3) whereas the lavas may contain up to 4 per cent water and their bulk density can be as low as 2,563 kg/m^3. There were indications that the centres of flows lie between these two ranges in value. The extremely low unconfined compressive strength values of the cores of some basalts was considered to result from the development of fine shrinkage cracks on exposure in an unconfined condition. This was probably due to the presence of montmorillonite and other related clay minerals which may readily give up their absorbed water on exposure, especially in dry and warm conditions. It was noted, however, that the percentage of cracked cores was low, less than 5 per cent of the total length of core drilled. The Drakensberg-

Clarens contact was abrupt, sound, tight and unweathered with the sandstone hardened by the heat of the flow to a shallow depth (0.5 - 1.5 m).

G. Base metals

The United Nations exploration projects prospected for base metals primarily through a systematic stream geochemical programme. Approximately 15,500 samples were analysed for copper, nickel, lead and zinc from the phase I area and 25,782 samples from the phase II area (United Nations, 1981g). The results did not lead to the discovery of any base metal mineralization although the results were to be re-assessed by a new United Nations project "Technical Support for the Department of Mines and Geology" (LES 80-007). Possibly some of the lead anomalies in the basalt areas are due to the presence of minute amounts of native lead which has been identified in large drainage samples (United Nations, 1981e). The major basic intrusions including those at Lancers Gap, Mokhotlong, Elephants Head, Majoe Matso, Thaba Pechela, Sinxondo and Sefako (figure 36) afford the most likely source of mineralization but the results to 1982 were disappointing (table 31) and no significant mineralization has been detected. It had been hoped that the recently discovered differentiated sill at Sinxondo in the south of Lesotho (Rombouts, 1979b) would have proved comparable to the Insizwa mineralized sill in the Transkei but geochemical stream sampling (Robison, 1980b; United Nations, 1981i) has markedly reduced the potential. The possibility of significant base metal mineralization in Lesotho appears remote.

H. Mercury

Mercury was first discovered in Lesotho by the United Nations Exploration for Minerals project in 1975 when a few

Table 31. Geochemical analyses of major Lesotho basic intrusives

Map sheet	Locality	Sample nos.	Ni(ppm)	Cu(ppm)	Pb(ppm)	Zn(ppm)	Cr(ppm)	Fe(%)	Source
3C	Lancers Gap	HG 75ABC,80,81	1,080-1,580	123-370	-	-	1,100-1,895	-	a
3B(x)	" "	HG 103-110	107-190	200-550	57-71	14-180	133-300	8.4-11	b
4A(y)	" "	MD 31-36	400-450	150-488	41-50	98-164	250-488	6.6-12.2	b
4A(z)	" "	MD 15-30	109-2,273	55-446	59-82	98-186	227-1,591	7.3-11.4	b
4A	Majoe Matsoe	RW 38-41,46	85-200	98-171	-	-	191-343	-	c
7A	Thaba Pechela	PvR 570,a,b,571	284-1,236	-	19-25	82-334	184-2,250	-	d
15A	Elephant Head-Mpiti	PHN 1707a,b 09,10	240-836	40-510	-	1,100-3,960	30-1,360	-	e
6C	Mokhotlong	AD 151,155	445-836	103-128	-	-	158-190	-	e
12B	Qoalaheng	MD 47-54	193-411	168-490	43-71	47-203	134-634	6.1-12.7	b
2A	Sefako	-	195 *	83 *	-	401 *	84 *	-	f
2C	Malibamatso drill hole 7	76 samples	104-508	47-592	-	187-597	104-508	-	f

* average values

(x) = Sefikeng
(y) = Moletsane
(z) = Phuthiatsana

Sources (column 10):

a. Grohmann, 1977a
b. Dusar and Grohmann, 1978
c. Willan, 1976a
d. Van Rooijan, 1975c
e. Dempster, 1973a
f. Dempster, 1973d

cinnabar grains were identified in two heavy mineral concentrates on sheet 8C, one at Belemane near Mpharane and the other near Masemouse (Grant, 1975). Follow-up sampling, however, failed to trace the source of the cinnabar. Mercury mineralization <u>in situ</u> was subsequently found by the project near Qoane 15 km north-east of Mohale's Hoek on adjacent sheet 13A in 1979 (Rombouts, 1979c), and additional cinnabar grains in heavy mineral concentrates were identified from sheets 11C (Rombouts and Robison, 1980) and 4A (United Nations, 1981h).

The mercury mineralization <u>in situ</u> was discovered in a conspicuous alteration zone straddling the upper slopes of a small spur in the lower basalts 500 m east of Qoane village. This distinctive zone of red, purple and dark tints within a pale buff base contrasts markedly with the surrounding dark brown, weathered, basalt and forms an irregular feature approximately 35 m long, 2-3 m wide and covering the hillside to an equivalent vertical height of 12-15 m. Subsequent examination related the purple coloration to mercuric coating, yellow and brown colours to limonitic material and the black to manganese oxide.
in width and subsequent microscopic examination revealed cinnabar grains as aggregates or in powdered form lining minor cavities and amygdales along with fine quartz crystals. The largest single cinnabar grain observed measured 6 by 3 mm and the sample richest in cinnabar analysed 0.005 per cent mercury. One euhedral crystal of fluorite was noted in a cinnabar geode.

The mercury alteration zone is located about 75-90 m above the Clarens contact and the local succession is as follows:-

<u>Rock type</u>	<u>Thickness</u>	<u>Description</u>
Basalt	extensive	Exfoliated, with zeolites
Basalt	15 m	Strongly altered zone with cinnabar mineralization
Basalt	3 m	Onion-shaped exfoliation, many zeolite veins, locally with thin sandstone intercalations

Sandstone	1 m	Strongly baked intercalations
Basalt	35 m	Onion-shaped exfoliation
Sandstone	6 m	Fine to medium grained, cross-bedded, thins to south, locally pyritic
Basalt	30 m	Compact, columnar, heavily pyritized to upper contact
Clarens sandstone	extensive	Massive

Trenching across the altered zone gave 181 ppm Hg over a channel length of 0.5 m while sectional sampling across a 5-m width indicated an overall grade of 108 ppm. The excavations showed that the brighter-coloured zone disappeared between 1 and 2 m from the surface. The range of values in trench samples was between 50 and 181 ppm Hg in the multi-coloured alteration skin, between 1.5 and 6.5 ppm Hg in the underlying altered basalt, and between 0.21 and 1 ppm Hg in the surrounding less altered basalt. As shown in the localized geological succession above, pyrite impregnations occur at the contact of the basalt and the lower sandstone intercalation, and one outcrop in the Mahau River was grab sampled and analysed 350 ppb mercury, 138 ppm arsenic and 1.5 g/t silver. A pink-purple stained sandstone containing pyrite assayed 450 ppb mercury, comparable to the mercury content of the basalt surrounding the Qoane alteration zone. Two boreholes were attempted with a light-weight drill to test the Qoane surface zone to depth but the drilling proved difficult and core recoveries low. The depths drilled were 11.8 and 8 m and the evidence obtained suggested that the alteration zone ended at about 4.5 m with no further extension into the basalt levels below.

Although no cinnabar was found <u>in situ</u> at Belemane, an alteration zone similar to that at Qoane was located and tested. Two trenches were excavated providing five channel samples which gave values between 3.5 and 9 ppm mercury. These values are of the same order as some of those at Qoane and it is thought that the alteration zone at Belemane is related to a yet undiscovered cinnabar-bearing mineralization. Near Masemouse, follow-up investigations failed to reveal evidence of recognizable alteration zones or even confirmation of cinnabar in heavy mineral concentrates. The source of the cinnabar on sheets 11C and 4A could not be established. The most convincing geochemical anomaly on sheet 13A was located in sections of the Malitjamela drainage in the northern part of the mapsheet west of the Maqoala Fault but no mineralization was detected.

Rombouts (1979c) has drawn attention to the apparent close spatial relationship between the Qoane, Belemane and Masemouse occurrences and the Maqoala Fault but geochemical sampling along the more important Helspoort Fault produced no significant ano-anomalies.

The overall assessment is of uneconomic minor and localized cinnabar enrichment within lower basalt levels, possibly related to thermal solutions and gaseous emanations. The discovery of cinnabar does, however, throw new light on previous reported occurrences of cinnabar in the Natal Drakensberg area which had been regarded as spurious (Dodds, 1975; Hammerbeck, 1976).

I. Clay

Small clay deposits, usually concentrated along and in the vicinity of dongas, have long been worked locally in Lesotho for making brick although in recent years this small-scale production has been susperceded by local concrete block production. The clay-fields in the Maseru area were first surveyed by Urie (1966) and this was followed by country-wide investigations carried out by the United Nations Exploration for Minerals project in close association with a UNIDO project "Development of Heavy Clay Industry" (LES-74-023). During 1074-1975 about 400 clay samples were collected and tested in the UNIDO Clay Testing laboratory (Spurck, 1975a, 1975b) and this led to the selection of specific localities for detailed testing. The main deposits were at Tsikoane (Leribe), Thetsane (Maseru), Tenane (Morija), Remahlape, Raseatle and Phoqoane (Mafeteng), Mohale's Hoek, and Souru (Qacha's Nek). Altogether, 7.3 million tonnes of potentially usable clay deposits were delineated (Buchanan, 1978). The most important deposits were at Thetsane, Tsikoane and Raseatle and the smaller Qacha's Nek Souru deposit.

The Thetsane deposit was estimated to contain at least 2.5 million tonnes of clay suitable for brick (Buchanan and Kashambuzi, 1977a; Enhus, 1979) and in view of its location near Maseru only 7.5 km from the railhead it was selected as the site for Lesotho's first modern brick factory. Production on a commercial scale by Loti Brick Pty Ltd commenced in June 1980. More than two million tonnes of heavy clay were outlined at Tsikoane near Leribe (Buchanan and Reed, 1976); some impurities in the deposit, mainly lime, were recognized but later studies showed that any harmful effect could be minimized by fine grinding. Two deposits of white-firing clay were defined in the Mafeteng area, those at Raseatle and Phoqoane (Tebang), of which the former was the most important. Bulk sampling of the Raseatle deposit indicated its suitability for stoneware pottery but the reserves appear limited to about 9,500 tonnes of buff-firing stoneware clay and 5,400 tonnes of earthenware clay (Buchanan and Kashambuzi, 1976, 1977b). A deposit of about 280,000 tonnes of clay considered suitable for the production of hand-made bricks was delineated at Scuru, 9.5 km north-north-west of Qacha's Nek (Buchanan and Kashambuzi, 1976).

The discovery not only of high quality heavy clay but also of stoneware and earthenware clay points to clay products becoming a growth industry in the future (United Nations, 1981i).

J. Sandstone building blocks

For many years sandstone blocks have been used in Lesotho, particularly in Maseru, providing a building material for the construction of government offices, churches, stores and dwellings. While the porosity of sandstone from the Molteno and Clarens formations, together with its abrasive quality, may have contributed to a decline in their usage, the major cause of this trend is undoubtedly the high cost of production. The potential for establishing an industry based on local stone resources was investigated in 1975 by United Nations project "Sandstone Industry" (LES 75-025) (Shadmon, 1975). Sandstone sequences of the Molteno, Elliot and Clarens formations which occur in the north-west, west and southern region of Lesotho were considered suitable material for the development of the industry on an organized basis. Two localities were considered to warrant further investigation - the Elliot sandstone near Maja village about 20 km south-east of Maseru where slabby layers were exposed with thicknesses up to 4 m and at Ratjomose village near Maseru where a thick ledge of Molteno sandstone crops out.

In a country like Lesotho where limestone and energy sources are scarse, use of the abundant local natural stone appears desirable, especially on a partly mechanized, partly labour-intensive basis. The current non-competitive cost of production could be drastically altered by the introduction of elements of mechanization and revision of quarrying techniques. The advancement of a basically underdeveloped cottage-scale activity to a viable, highly competitive and needed industrial undertaking appears possible, practical and warranted (United Nations, 1981i). In this respect a mechanized sandstone quarry was opened on the Berea Plateau in 1981.

K. Material for aggregate

For many years the weathered surface portion of dolerite dykes has been used for surfacing gravel roads and the countryside is dotted with abandoned sites from which the dolerite has been extracted. A large working example is the Lancers Gap dyke near Maseru (figure 34). With the rapidly growing demand, however, for high-grade aggregate material, crushing plants have been introduced and these use unweathered dolerite and, to a lesser extent, massive basalt. Surveys of the Maseru area (Reed, 1976a; Dusar and Reed, 1977), and subsequent drilling, indicated that a thick dolerite sill on Mokunutlung Hill, 25 km from Maseru, constituted a large deposit of high grade aggregate and this was to be utilized in the construction of an international airport at Theta-Moli about 20 km from Maseru. It is considered that Lesotho has abundant resources suitable for the production of high-grade aggregate material and, provided adequate crushing facilities are available, the importation of aggregate material should not be necessary. Sand deposits, usually of limited size, are found in many river and stream beds and are used in the building industry especially for the local production of concrete blocks.

L. Warm springs

1. Occurrences

Several warm springs are known in Lesotho (Reed, 1980), of which the most important is in the mountains on the Khabulu River near Solane village on sheet 2D. This spring has long been known and was plotted for example on the geological map prepared by Stockley (1947). It covers an area of approximately 15 m by 7 m with scattered centres where water and gas can be seen bubbling up through the sand and mud. A sulphurous smell was noted over the centres. A temperature of 33°C was measured. The spring is situated on a terrace about 5 m above the bed of the Khebulu River and although no precise measurements were made, water flowing over the terrace from the spring is estimated to fill an 8 cm pipe. No obvious structural control was apparent on the ground but the spring appears to be on the intersection of two fractures as observed on aerial photos. Access to the spring is by track from Solane village which is connected by road to the Letseng-la-Terae diamond mine. The spring lies in the deep gorge of the Khebulu River at a height of about 2,530 m whereas Letseng-la-Terae 8 km to the south-west lies on a plateau at a height of about 3,000 m. A cattle yard and a dip have been built next to the spring. An analysis of the water from the spring is included in table 32.

The Senqunyane spring is situated on a terrace in a meander of the Senqunyane River about 2 km north-east of Senqunyane village which is located near the junction of the Tsoelike and Senqunyane rivers on sheet 4C. The spring seeps from a swampy area in the terrace and the maximum temperature recorded was 24°C at a centre where water flow was obvious. The flow rate was insufficient to fill a 2 cm-diameter pipe. No obvious structural control of the spring was noted. An analysis of the water is given in table 32.

The Tabo village spring occurs near Makefane on sheet 8B and is located on a north-east trending (50°) fracture in basalt of the Lesotho Formation. Its outlet is approximately 90 cm long, 14 cm wide and 25 cm deep. A strong sulphurous smell is apparent and the maximum temperature measured was 23.2°C although this value may reflect some cold-water dilution. In comparison a temperature of 9.8°C was recorded in the Likotopong stream into which the spring waters drain approximately 25 m from the spring. The spring flow was estimated to be sufficient to fill a 2.5 cm pipe. The spring is utilised by local villages for domestic purposes.

The Rantuba village spring is located at a sandstone-mudstone contact near the Mohokare River on sheet 1C+. No controlling fractures were observed near the spring which flows from an area about 3 m by 1.3 m. A weak sulphurous smell is apparent but the maximum temperature was only 18°C, a low figure probably due to dilution with cold water. The flow is quite strong and

Table 32. Analyses of warm springs

Characteristic	Spring		
	Solane	Mamathe	Senqunyane
Physical			
pH value (glass electrode)	8.2	5.9	7.3
Conductivity mS/m @ 25°C	11.54	10.0	11.56
Dissolved solids, ppm			
Residue on evaporation @ 180°C	-	110	-
Loss of ignition of solids @ 500°C	-	46	-
Residue on ignition of solids	-	64	-
Proximate, ppm, expressed as $CaCO_3$			
Total alkalinity	52	40	48
Total hardness	3.4	15	5.4
Carbonate hardness	3.4	15	5.4
Non-carbonate hardness	Nil	Nil	Nil
Soda alkalinity	48.6	25	42.6
Hardness due to calcium	3.0	12	5.0
Hardness due to magnesium	0.4	3	0.4
Saline, ppm			
Silica, SiO_2	-	36	-
Iron, Fe	0.1	0.1	0.1
Aluminum, Al	0.1	0.1	0.1

Table 32 (continued)

Characteristic	Solane	Mamathe	Sengunyane
Chloride, Cl	2	2	2
Fluoride, F	0.4	0.2	0.3
Sulphate, SO_4	2	1	2
Nitrate, NO_3	0.4	5.5	0.4
Bicarbonate, HCO_3	63	48	58
Calcium, Ca	1.2	5	2
Magnesium, Mg	0.1	0.8	0.1
Chronium, Cr	0.1	0.1	0.1
Sodium, Na	22	10.1	22
Manganese, Mn	0.01	0.01	0.01
Copper, Cu	0.01	0.01	0.01
Lead, Pb	0.01	0.01	0.01
Zinc, Zn	0.01	0.01	0.01
Arsenic, As	-	0.01	-
Boron, B	-	0.01	-
Potassium, K	0.05	1.7	0.1
Lithium, Li	0.1	0.01	0.1

Analyst: McLachlan and Lazar

would be sufficient to fill a 15-cm pipe. A second spring is known 30 m to the north at Ha Rampai.

The Mamatha village spring rises in Clarens Formation sandstone on mapsheet 28 near Teyateyaneng. Several of the outlets have been cemented to provide a local pipes supply and the flow was estimated to be sufficient to fill a 2-cm pipe. A temperature of 22^{o}C was measured and an analysis of the water is shown in table 32.

2. Discussion

Springs are usually classified according to their temperature, with the division between non-thermal and thermal being set at 25^{o}C, between warm and hot at 37^{o}C (human blood test) and between hot and scalding at 50^{o}C (van Eeden, 1972). The only thermal spring in Lesotho is thus the Solane spring, and all fall in the warm-spring range although the Solane spring approaches the hot-spring category. In comparison, 88 thermal springs are known in the Republic of South Africa with six in the scalding category including that at Aliwal North (van Eeden, 1972). The hottest and strongest spring in South Africa is Brandvlei near Worcestor which has a temperature of 64.2^{o}C and a flow of 11,010 m^3 per day.

Chemical analyses of these springs (table 32) shows that the Solane spring has the highest soda alkalinity (48.6 ppm) but the very low degree of mineralization does not point to the waters having any therapeutic value. The inaccessibility and relatively low temperature of the Solane spring reduces any development potential. Although the warm springs in Lesotho display a low temperature range, the fact that they are sulphur-bearing may throw some light on the origin of mercury mineralization in Lesotho.

M. Carbonates

All the known occurrences of carbonate-bearing strata in Lesotho are of minor significance, a not unexpected fact in view of the terrestrial environment in which the sedimentary formations were laid down. Completely absent are marine sediments with which most limestone of economic importance is associated. Stockley (1947) has described many of the smaller occurrences in Lesotho; he noted that calcareous nodules are not uncommon in the Elliot Formation and that beds of impure limestone are locally developed in some of the transition beds of the Clarens Formation, two examples being at the northern end of Siloe Hill in the Mohale's Hoek district and on the western slopes of Motlejoe hill in the Maseru district. Analysis indicated however that only about half of the rocks are calcium carbonate. Field surveys undertaken during the United Nations exploration programmes verified the absence of true limestone, with calcareous lenses and nodules in the sedimentary formations being impure and of little extent. The occurrences described are on sheet 1C$^+$ (Etoile 1980), 3C$^+$ (van Rooijen, 1975e), 3D (Grohmann, 1978), 9A (Grohmann and Robison, 1980), 10C (Jaggie, 1981c), 12A/B (Grohmann, 1977b), 13A (Rombouts, 1979a) and 13C (Rombouts, 1978b). On sheet 1C$^+$ some calcareous concretionary beds 0.8 m thick were seen in the Elliot Formation not far below the Clarens contact; the nodules with diameters from 10 to 60 cm are composed of brecciated calcareous material in a bluish-grey, fine-grained sandstone matrix containing calcite veins and manganese oxides (Etoile, 1980). On sheet 3C$^+$ carbonate concretions were noted in the Elliot Formation and just west of Qema Plateau two stratiform carbonate beds were observed about 40 cm thick but with limited lateral extent (van Rooijen, 1975e). The red mudstones of the Elliot Formation on sheet 3D commonly contain abundant calcareous nodules (Grohmann, 1978). Some calcareous nodules were noted in the Clarens Formation on sheet 10C (Jaggie, 1981c). Reptile bones occur in minor conglomeratic limestone beds in the Elliot Formation of sheet 12

A/B where also in the Clarens Formation the sandstone and siltstone at some levels contain calcareous nodules and even limestone layers (Grohmann, 1977b). A carbonate breccia is present in the Elliot beds near Maphutseng store on sheet 13A (Rombouts, 1979a) and minor calcareous breccias in the same formation, with a thickness of 1 m, were found near Fort Hartley, Kose and Ha Khoae Matete on sheet 13C (Rombouts, 1978b). Within the Lesotho Formation calcite veins up to 2 m wide have been reported (Grohmann and Robison, 1980) but all are of significant dimensions in terms of economic interest. Likewise some of the volcanic ash beds are calcareous but again the lime content is too low and irregular to be of interest.

The potential for discovery and development of significant carbonate resources in Lesotho must be regarded as minimal (United Nations, 1981i). The most that can be expected would be the discovery of a calcareous lens or layer of sufficient purity and size to have local development potential.

N. Phosphate

Phosphate nodules were first identified in the Molteno-Elliot formations in Lesotho during the United Nations exploration surveys in 1977. Several discrete radioactive spheroidal nodules spaced along a bed of Elliot siltstone about 1.5 m thick were discovered in the Khophole donga near Lipeleng north of Maseru on sheet 3C (Reed, 1978b). Analysis gave the following results:

Sample No.	U_3O_8 (ppm)	P_2O_5 (%)
R1	685	17
R2	470	15
R3	800	20
R5	750	24

Similar phosphatic nodular accretions were found on the northern side of a small mesa within the Helspoort valley on sheet 7D (Reed, 1978b) and other occurrences on sheets 1C, 3C, 7B, 12B and 12D were recorded by Evans (1980). In most cases the phosphatic nodular localities provided limited exposures commonly with a few discrete nodules related to a single horizon rather than to sequences of rock. Investigations showed that occurrences do not continue with depth. On sheet 7B, two diffuse and indeterminate bands of pale coloured phosphatic material 10-20 cm thick and 5-10 m long were observed at a contact where arenite overlays an argillic section (United Nations, 1981i).

The discovery of significant phosphate resources in Lesotho appears remote primarily because the terrestrial paleo-environment in Lesotho was not conducive to the deposition of phosphate on a large scale (United Nations, 1981i).

O. Other minerals

1. Laterite/bauxite

Examination of 25 lateritic soil areas in western Lesotho, led to the recognition of seven larger deposits - at Joel (11 km north-west of Butha-Buthe), north Leribe; near Mahobong; near the Maputsoe road turn off near St. Monica's mission, Motloheloa, Jimisi and Lula-Moholo in the Maseru area (Spurck, 1975b). The lateritic horizons are distinctive and form an orange-red slightly mottled clay soil 1-2 m thick. Analyses of eight samples from the Joel deposit gave an alumina content of about 35 per cent and silica about 20 per cent whereas twelve samples from Motloheloa showed an alumina value over 40 per cent and silica about 9 per cent. These analyses and the relatively small reserves indicate that there is little potential for bauxite in Lesotho (United Nations, 1981i).

2. Zeolites

Zeolites in veins, vugs and amygdales are commonly associated with the Drakensberg lavas but none of the occurrences have sufficient volume to warrant exploitations despite the rapidly growing demand for such minerals (Olson _et al.,_ 1975). Zeolites identified in Lesotho include scolecite, stilbite, heulandite, phillipsite and laumontite-leonhardite (Stockely, 1947; Bleackley and Workman, 1964; Cox and Hormung, 1966; Jaggie, 1981a). The other possible zeolite occurrence in Lesotho is through the alteration of volcanic material in the sedimentary beds for Fuller (1970) noted that zeolites may form up to 50 per cent of some rocks of the Beaufort and Stormberg groups in the Republic of South Africa. The discovery was made using X-ray diffraction technique and the use of similar methods in Lesotho may well reveal the presence of zeolites in the sedimentary formations. In this connection attention has already been drawn to to the occurrences of acidic vitric tuffs in the Elliot Formation.

3. Semi-precious stones

Semi-precious stones in Lesotho include agate, chert, petrified wood, rock crystal, amethyst, olivine, zircon and chrome diopside but only the first three occur in sufficient quantity to have any commercial potential (van Rooijen, 1974). Agate is by far the most important mineral and occurs as residual cover on flat hills, as concentrations in stream beds, and as terrace residuals. Probably opportunities exist in Lesotho for the small-scale treatment of agate and to a lesser extent chert varieties and silicified wood (United Nations, 1981i).

4. Monazite, barite, scheelite and molybdenum

Mineralogical curiosities are the occurrence in stream concentrates of monazite and barite (Bleackley and Workman,

1964) and of scheelite (United Nations, 1981e). The results of stream geochemical sampling have indicated low values of molybdenum (Bleackley and Workman, 1964; United Nations, 1981i) and there seems little chance for the discovery of the unusual (but uneconomic) Mpendle type mineralization found in the Molteno Formation in Natal.

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