ERRATA

Page 15	Line 17	Insert	years 1891
Page 29	Line 15	Insert	delta mud
Page 30	Line 17	For "35"	read 85
Page 98	Line 14	Insert	trench numbers
Page 107	Line 15	For "absorbed"	read adsorbed
Page 134	Line 34	For "200"	read 300
Page 174	Line 19	For "Convolvuladeae"	read Convolvulaceae

GEOBOTANICAL, BIOGEOCHEMICAL AND GEOCHEMICAL STUDIES IN THE MOSAIC OF SAVANNA TYPES IN SOUTHERN NGAMILAND, WITH SPECIAL REFERENCE TO THEIR USE IN MINERAL EXPLORATION IN CALCRETE AND SAND COVERED AREAS

A thesis
presented to
the Geography department, Bedford College
University of London

In Partial Fulfillment
of the Requirements for the Degree
Master of Philosophy

---

by
Alan Douglas Buerger
1976

ABSTRACT

A thesis written in four parts; part 1, the physical background of southern Ngamiland; part 2, geobotanical, geochemical and biogeochemical investigations in the Ngwako pan area; part 3, geobotanical, geochemical and biogeochemical investigations in the Mawani area; part 4, conclusions and recommendations.

The area of principal study falls between Latitude 20° 30′N, 21° 00′S and Longitude 22° 10′W, 23° 10′E.

The study in the Ngwako pan area was concentrated in the vicinity of known copper mineralization in Ghanzi series rocks to the north east of older Kgwebe series porphyries, sandstones and diabases.

The results of geobotanical, geochemical and biogeochemical investigations demonstrated the applicability of these methods to prospecting here.

A close study of plant species distribution showed that <u>Ecbolium lugardae</u> distribution outlines an area within which a soil copper anomaly exists. These geobotanical studies also revealed a close relationship between high copper contents in plant tissue and soil, and the shrubs <u>Anticharis linearis</u>, and to a lesser extent <u>Abutilon fruticosum</u>.

The savanna vegetation of the area comprises a mosaic of vegetation associations, varying in structure and life form with prevailing climatic and edaphic conditions and with the residual influences of geomorphology. Distinctive vegetation associations are shown to distinguish various lithological units.

Biogeochemical studies showed a close correlation of high copper values in the soil with high copper content in the plant tissue. A correlation more easily recognised if the copper content in the plant tissue is expressed as number of standard deviations from the mean p.p.m. dry weight.

The biogeochemistry also indicated an area of anomalous copper values in plant tissue outside the geochemical anomaly, and which may be reflecting deeper seated mineralization.

The potential use of geobotanical and biogeochemical techniques in mineral exploration are pointed out.

Geochemical studies showed a dispersion of anomalously high copper values to surface through more than three metres of calcrete overlying minor copper mineralization. The best contrast of anomalous to threshold values was found in the -30 + 60 mesh fraction and in the -120 and finer mesh fractions. The highest absolute contrast was seen in the -270 mesh fraction, the finest fraction analysed.

In the Mawani area a search for kimberlite pipes proved unsuccessful. Distinctive vegetation associations are recognised over the different lithological and pedological units.

ACKNOWLEDGEMENTS

The writer would like to acknowledge the assistance and guidance given during this study by Professor M.M. Cole of the Geography department, Bedford College, University of London. A special thanks to her for the photographs she made available for inclusion in the thesis.

Thanks also to the Beta Mining and Prospecting Company, a wholly owned subsidiary of Anglo Transvaal Consolidated Investment Company Limited, in whose exclusive prospecting grant the work was conducted. Acknowledgement is made to the professional and technical staff of that Company, and especially Dr. H.D. le Roex their New Projects Manager, who gave invaluable professional advice as well as logistic support. Data was made available by Beta Mining and Prospecting Company for inclusion in this thesis and due acknowledgement will be made during the course of writing, special mention can be made of the photogeological work done by Mr. J. Garske acting in a consulting capacity for Beta Mining and Prospecting Company.

During this study geological mapping was done in the area by C.M. Thomas of the Botswana Geological Survey, and his maps and report were made available to me.

Gratitude is extended to the technical staff of the Geography department, Bedford College, University of London. Here special mention can be made of Mr. F. Huthwaite the chief technician, his assistant Mr. W. Ansell and Mrs. J. Candy. Mrs. Candy aided with the plotting of data, Mr. Ansell photographed all the maps and printed all the photographs used in this thesis, Mr. Huthwaite made available technical assistants during the analytical work.

The identification of plant specimens was done with the aid of the Kew and Pretoria Herbaria.

The work was done while the author was employed as a Research Assistant to Professor Cole under the grant made available to her by the Natural Environmental Research Council for the Investigation of Plant Indicators of Mineralization.

TABLE OF CONTENTS

LIST OF PLATES

LIST OF FIGURES

INTRODUCTION

This thesis deals with the results of a geobotanical, biogeochemical and geochemical study of an area in Southern Ngamiland, Botswana. In figure 1 this area falls within the, so called, Zeta Concession Area. This concession area was, at the time of the study, an exclusive prospecting grant area of Anglovaal (S.W.A.), a wholly owned subsidiary of Anglovaal Consolidated Investment Company Limited.

A correlation of the Tsumis System sediments of South West Africa and Botswana with the copper bearing Katanga System sediments in Zambia was suggested, (Figure 2.) after reconnaissance studies by staff of Anglovaal Consolidated Investment Company Limited, Anglo American Corporation, Tsumeb Corporation Limited, the assistant director of the Botswana Geological Survey and Professor M.M. Cole of Bedford College. This correlation is supported by evidence from space images, existing air photographs and limited geological investigations.

It was decided to explore the Tsumis System sediments for copper mineralization. The target areas chosen for mineral exploration were;

(a) Witvlei area in South West Africa (Long. 18° 30′ Lat. 22° 30′), where Professor Cole and her Research Assistants had recognised anomalous plant communities and located copper mineralization in concealed bedrock.

(b) The area around Ghanzi, Botswana, in the Theta Concession Area (Figure 1) where aerial photographs suggested areas of fairly intense folding and drag folding of the sediments, structural deformation often associated with economic ore deposits.

(c) The area to the north of the Kgwebe hills, Ngwanalekau hills and Mabeleapudi hills, Botswana, in the Zeta Concession Area (Figure 1). These hills are formed of essentially, quartz feldspar porphyry of

Figure 1. Map of Botswana showing the location of major towns and roads as well as the location of the Theta and Zeta Concession areas. (See text for explanation) Inset shows the position of Botswana in southern Africa.

Figure 2. A suggested correlation of certain Precambrian rock types of South West Africa, Botswana & Zambia (after Toer

SOUTH WEST AFRICA Witvlei (Toens 1970)				BOTSWANA Ngamiland (Geological Survey)				ZAMBIA (Mendelsohn 1961)				
System	Series	Stage	Rock types	System	Series	Stage	Rock type	System	Series	Group	Formation	Rock types
				Tertiary to Recent			Aeolian sand, fossil sand dunes, lake and pan sediments, old pan calcrete, silcrete, calcrete, boulder and pebble beds.					
				Karoo	Stormberg		Basalt and Bodibeng sandstone.					
Nama	Buschmannsklippe		Shale, dolomite, red and white quartzite, tillite and limestone.					Katanga	Kundulungu	Upper		Shale and quartzite.
										Middle		Shale and tillite.
										Lower	Kakontwe	Shale, dolomite and tillite.
Tsumis	Witvlei	Tsumis C	Brown feldspathic quartzite and conglomerate.	Tsumis	Ghanzi		Feldspathic sandstone, feldspathic sericitic sandstone, epidotic sandstone, argillite, phyllite, shale and thin bands of limestone. Stratiform Copper occurs in two zones.		Mine	Mwashia		Carbonaceous shale.
										Upper Roan		Dolomitic argillite, argillite and quartzite.
		Doornpoort	Maroon quartzite, calcareous arenites, green shales, mud-pellet conglomerate and local limestones overlying basal conglomerate.							Lower Roan	Hanging wall	Quartzite, argillite and dolomite.
											Ore	Micaceous, quartzite, argillite and impure dolomite.
											Footwall	Argillaceous quartzite, feldspathic quartzite, aeolian quartzite and conglomerates.
Dordabis	Skumok & Opdam		Quartz-feldspar porphyry, pyroclasts, lavas, basaltic andesites and rhyolite.		Kgwebe		Quartz-feldspar porphyry, pyroclasts, epidotic tuffaceous sandstone and diabase.	Lefubu & Muva				Granites, porphyry, schists, gneisses, quartzites, meta-quartzites and argillites.
				Basement			Not exposed.					

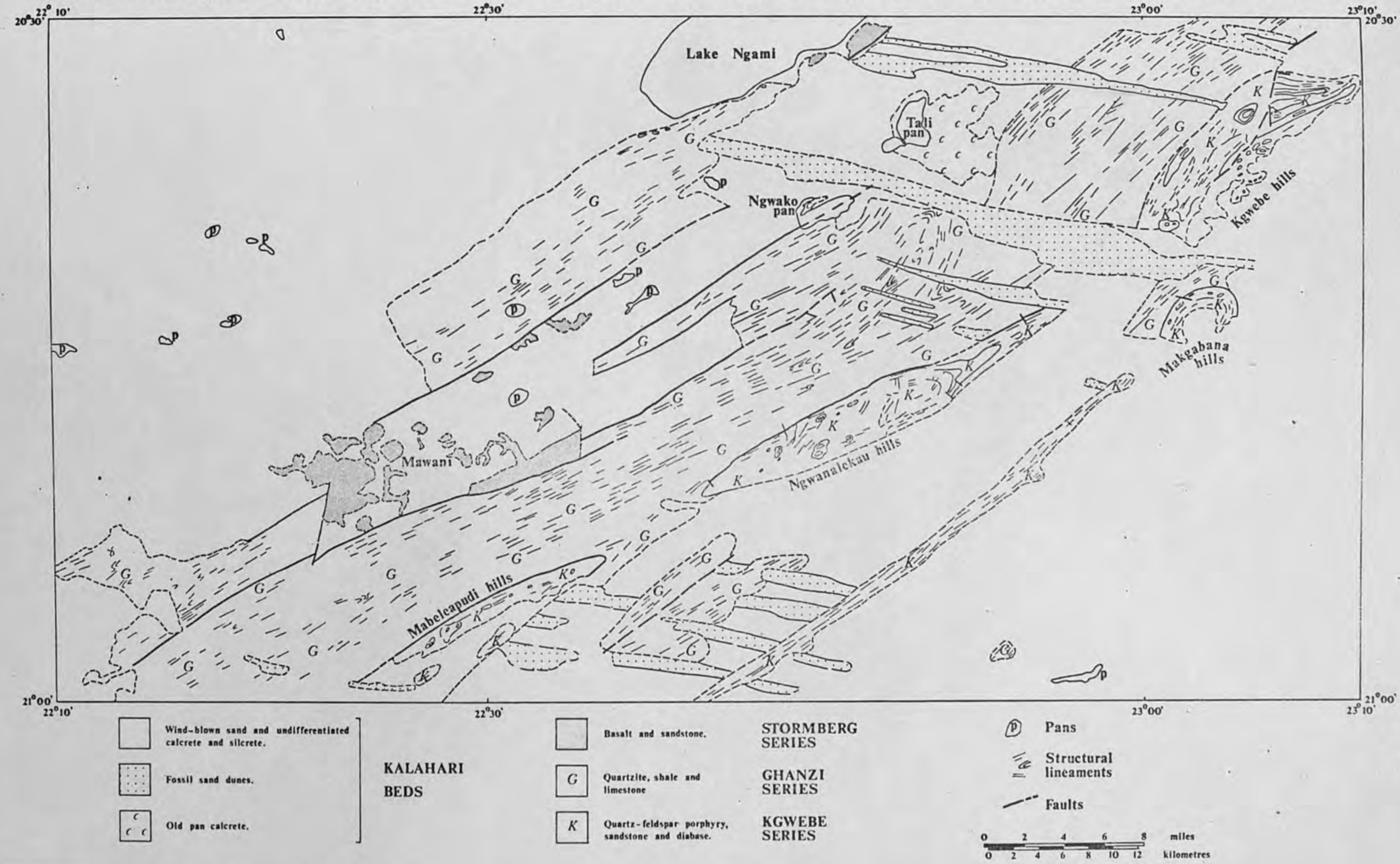
Late to Mid Precambrian age, around which wrap a sequence of sedimentary rocks of the Tsumis System. (Figure 3). The geobotanical, biogeochemical and geochemical studies of this area form the subject of this thesis.

Aspects of each of these studies will be discussed with special reference to an area north of the Ngwanalekau hills. Passing reference will be made to studies of a similar nature which were conducted in target areas (a) and (b).

Also forming part of the subject of this thesis are geobotanical, biogeochemical and geochemical studies done in the Mawani area. (Figure 3). This area became the subject of study with a view to the possible discovery of kimberlite pipes, an idea stemming from the recognition of prominent circular features on aerial photographs of the area.

Firstly the physical background of southern Ngamiland will be discussed. In which aspects of geology, climate, geomorphology, soils and overburden and vegetation will be discussed. Then will follow the geobotanical, geochemical and biogeochemical investigations in the Ngwako pan area. Then discussion of the geobotany, biogeochemistry and geochemistry done in the Mawani area will follow. In the final chapter conclusions are drawn and recommendations made.

Figure 3. Geological map of a portion of southern Ngamiland. Map also gives localities of areas referred to in text.



PART 1

THE PHYSICAL BACKGROUND OF SOUTHERN NGAMILAND.

Chapter 1

GEOLOGY

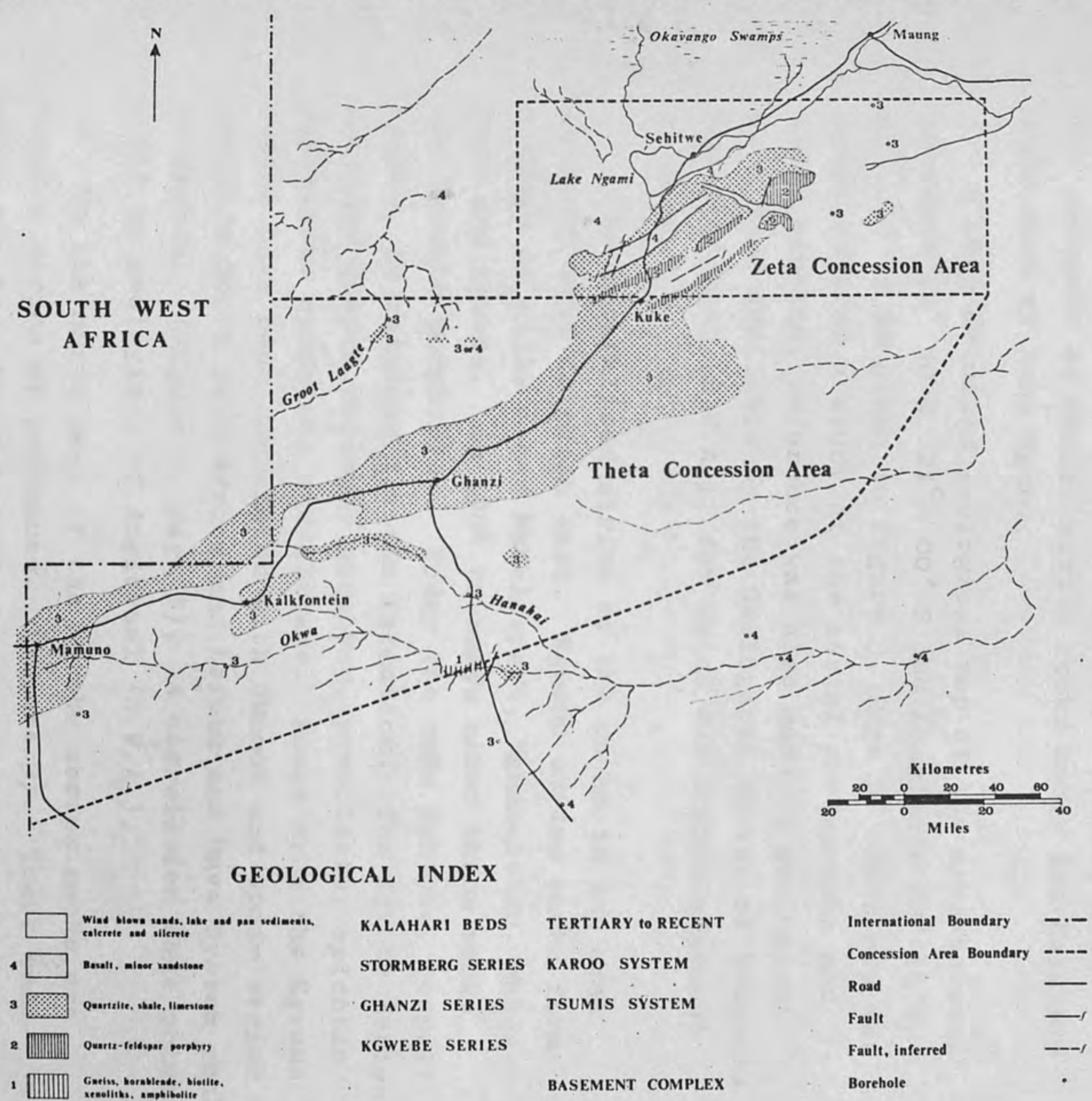
The area of interest was initially selected on the basis of broad scale geological correlations. These will be referred to further on in some detail. A study of ERTS images by consultants and staff members of Anglovaal (S.W.A.) largely aided in drawing these correlations. The dry arid areas of Botswana produce excellent ERTS images, ~~Images~~ which show great geological detail particularly where large outcrops are exposed in entrenched river valleys. In areas of thin sand cover, as well as areas covered by a surficial layer of calcrete, it is possible to trace sporadic outcrops of resistant formations.

An examination of ERTS images showed the apparent extension of the Tsumis System rocks in S.W.A. through into Botswana, outcropping in the Ghanzi area and in the vicinity of Lake Ngami (Figure 4).

The regional geology of the north western part of Botswana, including the area of study, is given in figure 4. The area is believed to be underlain by Proterozoic and older Precambrian rocks. A large part of the area is covered by the largely unconsolidated Kalahari beds of Tertiary to Recent age. Dividing the area is a south west to north east trending rib of outcrop and suboutcrop. This comprises largely of quartzites, shales and limestones of the Tsumis System, Ghanzi series, believed to be of the late Precambrian age. Towards the north east in the vicinity of Lake Ngami, rocks of Karoo age, Late Carboniferous to Jurassic, as well as porphyries, diabase and sandstone of late Precambrian to Mid Precambrian age occur.

Scattered outcrops of Ghanzi series rocks are reported in areas where watercourses have exposed them, such as the Groot Laagte, Hanahai and Okwa in figure 4.

Figure 4. Regional geology of northwestern Botswana, including Theta and Zeta Concession areas (see text)



The only exposure of the Basement complex, of Archaean age, is in the Okwa (Figure 4).

Geological data from water boreholes have also been recorded on figure 4. From these data it is evident that Karoo age rocks underlie much of the Kalahari sediments to the south of the area, also the presence of Ghanzi series rocks under the Kalahari beds east of Lake Ngami.

A more detailed geological map of the area between Latitude 20° 30′N, 21° 00′ S and Longitude 22° 10′W, 23° 10′ E is given in figure 3, Page 5. This map was compiled from a study of the aerial photographs and field mapping, reference was also made to geological data made available by the Geological Survey of Botswana and Anglovaal (S.W.A.), for which due acknowledgement is made.

The generalised strike of the rocks in the area is south west to north east. Kgwebe series rocks form a range of hills named Mabeleapudi, Ngwanalekau, Makgabana and Kgwebe. In 1904 Passarge named these rocks the Kghwebe porphyries. Today the name Kghwebe, respelt Kgwebe, is retained for the formation. The Kgwebe series includes quartz feldspar porphyry, pyroclasts, epidotic tuffaceous sandstone and diabase. Rocks from the Kgwebe series have been correlated with Skumok and Opdam series rocks in South West Africa and Lefubu and Muva System rocks in Zambia (Figure 2, page 3), a correlation done principally by geologists of Anglovaal (S.W.A.).

To the north west of the Kgwebe series rocks are found a series of sediments. (Figure 3). These sediments are from the Tsumis System, and are locally named the Ghanzi series. The precise relationship between the Ghanzi and Kgwebe series rocks is obscure.

The Ghanzi series comprise a thick succession of alternating quartzitic and calcareous argillites and shales, and thin limestone beds. Evidence from trenches and drill holes indicate the whole sequence to have a nearly vertical dip. Over much of the area calcrete, silcrete and sand mask the geology. In places the sandstone member outcrops while the argillites and calcareous rocks are generally covered by soil.

The information available shows that the sandstones are well sorted and fine grained, with rounded quartz and feldspar grains. The bedding is commonly marked by bands of heavy mineral concentrates. Ripple markings occur on bedded surfaces. The shales and argillites are largely red or brown in colour, with occasional green coloured shales.

The Ghanzi series has been divided into lower, middle and upper series rocks by Vermaak (1961), a division adopted by the photogeologist Garske (1968). However, it should be pointed out, that in the absence of detailed geological studies such a division is somewhat arbitrary.

Relatively little is known of the structural relationship of the Kgwebe and Ghanzi series rocks. The Makgabane hills are offset, relative to the Ngwanalekau and Kgwebe hills, to the south east. This suggests that these rocks have been faulted along east north east/west south west lines. This is supported by studies of the air photos, but no field information is available.

The air photos indicate the presence of complex fold structures in the Ghanzi series rock. (Figure 3 page 5). Field studies have confirmed these features, visible on the air photos, to be vegetation "banding" which reflects concealed geological structures.

The Ghanzi series is overlain unconformably by rocks of Late Carboniferous to Jurassic age of the Stormberg series. These rocks outcrop in two distinct areas, namely south of Lake Ngami and in the Mawani area. (Figure 3 page 5). The outcrop south of Lake Ngami consists primarily of grits and sandstones dipping eastwards at a low angle. These rocks were mapped by Passarge (1904), together with calcareous sediments of Tertiary age, as Ngami beds. The outcrop in the Mawani area is essentially of sandstone outliers on a soil covered plain underlain by basalt.

In the Mawani area the contact between the Ghanzi and Stormberg series is a well defined north east to south west trending fault (figure 3). Below the prominent scarp feature, produced by the Ghanzi series, rocks of the Stormberg series occupy a downfaulted trough forming the Mawani plain. This plain is largely floored by basalt, principally soil covered. In several localities sandstone outliers form slight hills. (Plate 1). This sandstone is believed to represent the old land surface prior to the outpouring of the basalt.

Over much of the area the bedrock geology is concealed by essentially unconsolidated deposits, ranging in age from Tertiary to Recent. These comprise silcretes, calcretes and wind blown sand. In the Ngwako pan area (Figure 3), borehole information suggests a total thickness of calcrete and wind blown sand exceeding 50 metres. Gastropod shells have been found in the calcrete around pans. Generally, over the area, the sand cover is variable in extent and thickness. North and north east of the Ngwanalekau hills it has been piled into dunes. (Figure 3). To the south east of the range of hills the sand cover is extensive, whereas to the north of the hills there is little or no sand cover. This suggests an eastern source of supply for the wind blown sand.

Plate 1. A view of a hill of Karoo sandstone as seen from a plain floored by Karoo basalt, Mawani area. (MMC/Bot./30/12).
The tall trees are Acacia erubescens while the shrubs are Dichrostachys cinerea.

CHAPTER II

CLIMATE

The climate in the area of study is semi-arid. Rainfall is the climatic factor affecting the plant growth most, and as such is of special interest here where a study was made of plant associations. For this reason the larger part of this chapter on climate will be taken up in discussion of the rainfall. Temperature variations have an effect on plant growth and mention will be made of these.

The highest rainfall is recorded during the months of October to March. This is evident when studying Figure 5. Here the total annual rainfall for Sehitwa, latitude 20° 20′ S., longitude 22° 24′ E., for the years 1959 to 1969 is given in histogram form. Also in this figure is given the "seasons" when the rain fell, the cross hatched portion of the histogram depicting the millimetres of rain which fell during October to March and the clear portion representing the millimetres of rain which fell during April to September. The percentage of the total annual rainfall which fell in the "seasons" is given alongside the histogram. Some explanation of the division of the time period into "seasons" is probably necessary. The period October to March includes the months October to December of one year and January to March of the next, hence 1969/70, 1968/69 etcetera. In figure 5 the rainfall which fell during this period is recorded in the total of the year including the months January to March. The rain which fell during the period April to September is recorded in the year including these months. The seasonal average for the years 1959 to 1969 was calculated and 85% of the total annual rain fell during the months October to March, while the

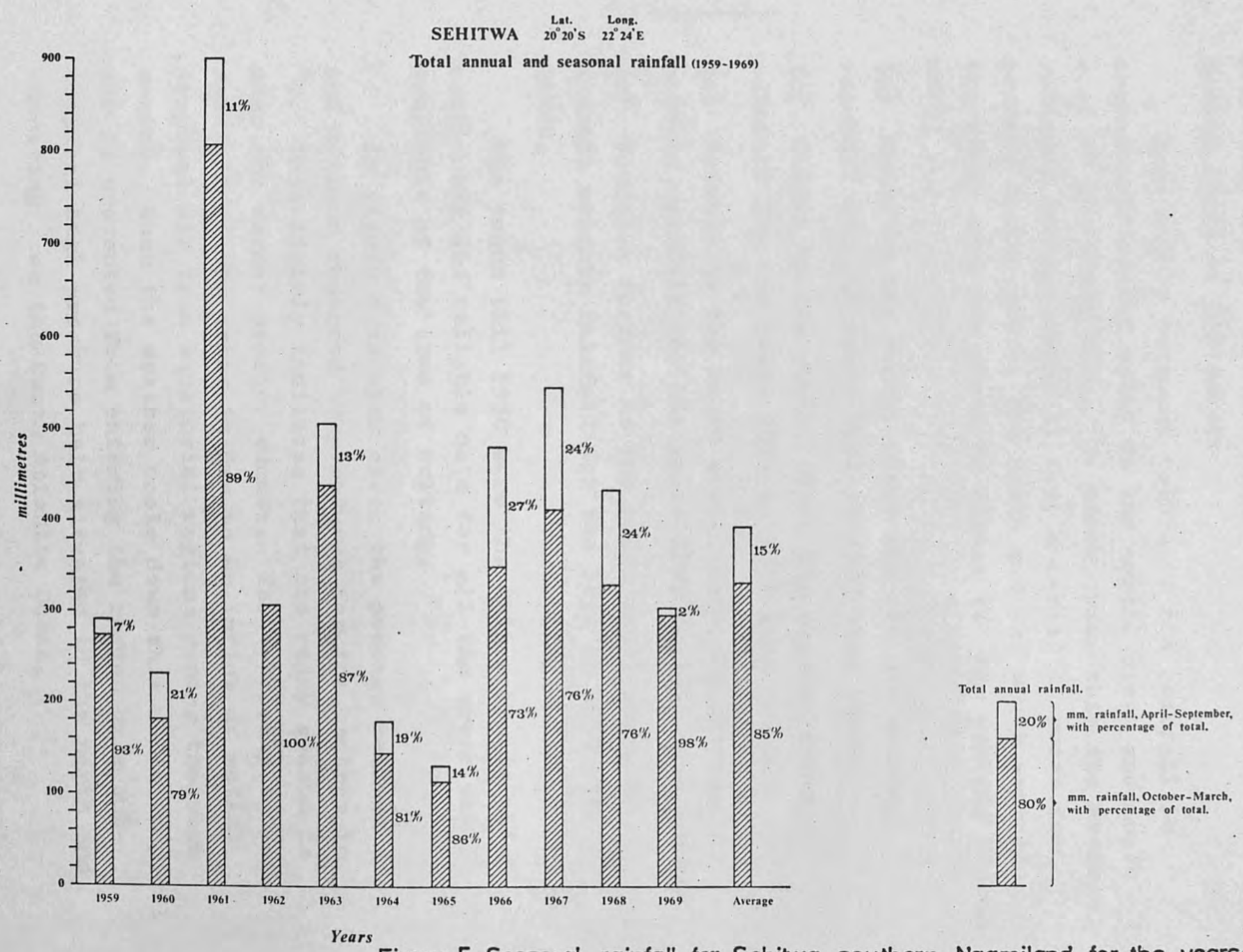


Figure 5. Seasonal rainfall for Sehitwa, southern Ngamiland, for the years 1959-1969.

remaining 15% of the total annual rainfall was recorded during April to September.

This highly seasonal nature of the rainfall is characteristic for areas to the north, south and south west of the study area. To demonstrate this the average recorded monthly rainfall over a period of years for centres to the north, the south and the south west of the study area are given in figure 6. The centres chosen were;

(a) Maung to the north, where the average monthly rainfall for the years 1931 to 1950 were taken.

(b) Ghanzi to the south, where the average monthly rainfall for the years 1923 to 1950 were taken.

(c) Gobabis to the south west, where the average monthly rainfall for the years 1897 to 1950 were taken.

(d) Windhoek further to the south west, where the average monthly rainfall for the 1891 to 1950 were taken.

The years till 1950 were the only years in which continuous and reliable data for all the areas was available at the time of writing.

In figure 6 is also given the average maximum and minimum recorded temperatures for the centres in ^{o}C. This clearly indicates that the rainy season is also the warmer season, summer. The typically summer rainfall of the areas is due to an influx of moist tropical air from equatorial regions during the warm months. When the weather cools down this moist tropical air is prevented from entering the region by a sub-tropical high pressure belt situated to the north and emanating from the South Atlantic Ocean.

Besides the rainfall showing a highly seasonal variation, there is also a marked variation in total

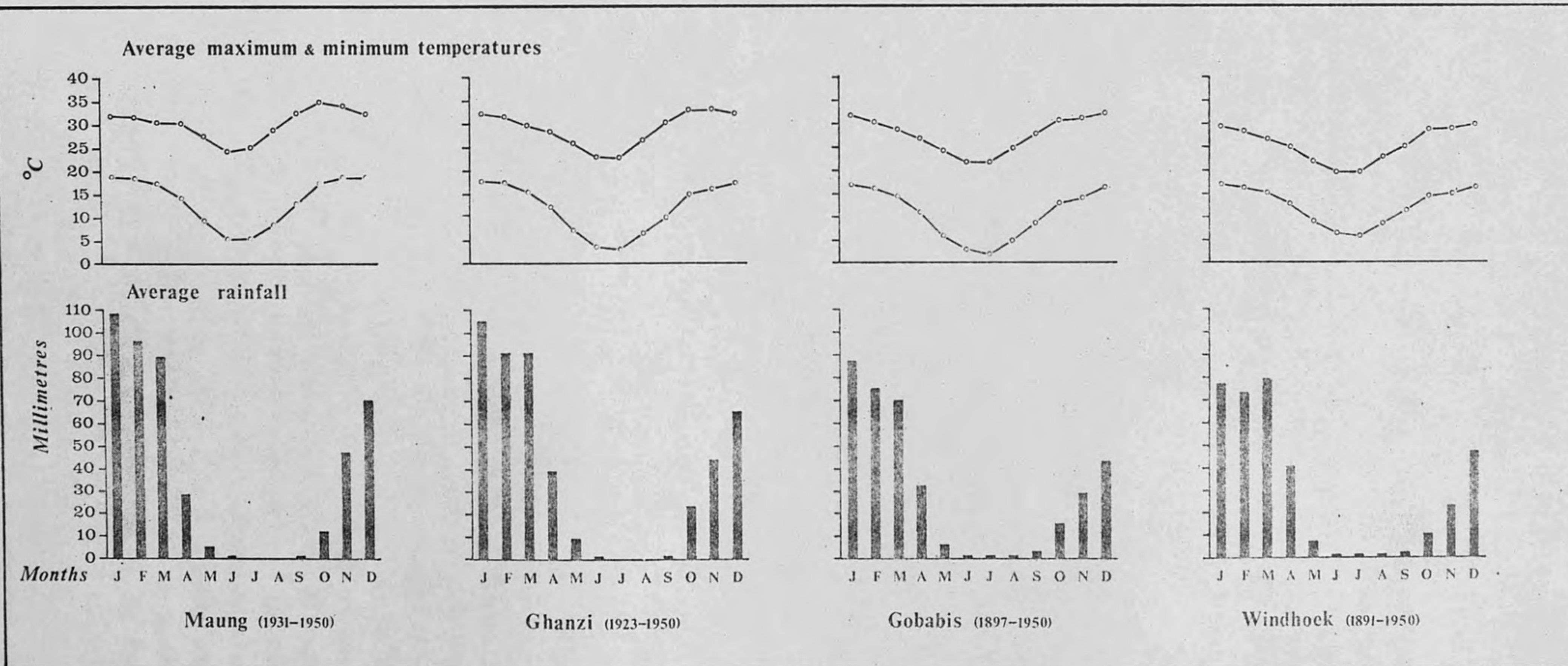


Figure 6. Average monthly rainfall as well as average maximum and minimum temperatures for Maung and Ghanzi in Botswana and Gobabis and Windhoek in South West Africa.

rainfall from year to year. This is evident from figure 5 where the recorded average annual rainfall for Sehitwa from 1959 to 1969 was 380 millimetres with a recorded maximum of 900 millimetres in 1961 and a recorded minimum of 130 millimetres in 1965.

This temporal variation of the rainfall with the periods of good rains followed by periods of relative drought, has a profound affect on the vegetation. This must be taken into consideration when any studies are done on the vegetation communities. For example, during a period of sustained drought many of the less hardy species may temporarily "disappear" from a community, to survive as seeds, tubers etcetera, only to "appear" again following a good rainy season.

Another feature of the rainfall in the study area which affects plants and their growth, is that most of the rainfall is from instability showers and thunderstorms. (Plate 2). These are often accompanied by violent gusts of wind and occasionally by hail. This may, and often does, result in damage to plants, ~~Damage~~ which may inhibit the plants' growth and may often kill them.

Mention has already been made about the close link up between warmer weather and rain. (Figure 6). A closer study of the average maximum temperature figures for Maung will show an average daily maximum temperature of 30 to 33°C during the months October to March and an average daily maximum temperature of 23 to 30°C during the months April to September. These figures agree well with maximum temperature recordings taken in the study area during the field seasons. During the months October to March an average daily minimum temperature in Maung of 15 to 17°C is recorded, whereas during the months of April to September the ambient temperatures drop to 3 to 12°C. Very rarely is frost recorded.

Plate 2. Overlooking Ngwako pan showing a rain storm in the distance to the right of photograph. (MMC/Bot./25/5).

The taller trees are Terminalia prunioides and Boscia foetida while to the left of the photograph a shrub layer of Catophractis alexandrii can be distinguished.

The effect on plant growth of ambient temperatures experienced in the study area, are mainly the result of wilting in the higher temperatures which may cause plant cell damage and affect growth. The slight but perceptible drop in temperature experienced in the winter months results in leaf fall in deciduous species and also herald the advent of a period of reduced plant growth rate.

Chapter III

GEOMORPHOLOGY

The area of study falls on the northern most boundary of the Kalahari desert. (Figure 1 page 2). The relief of the area can best be described as gently undulating plains with inselberg hills. These hills are of quartz porphyry. The inselberg type topography is aptly illustrated in plate 3 which is a view of the Mabeleapudi hills found in the south west of the study area. A view of the Ngwanalekau hills rising out of the surrounding plain (Plate 4), also illustrates the generally level terrain with the positive relief being provided by the quartz porphyry hills. These hills rise to a maximum height of 200 metres above the surrounding plain, which is approximately 1200 metres above sea level.

The Kalahari sand covers the area to the north east of the range of quartz porphyry hills. Fossilised sand dunes finger onto the older sediments north west of the hills.

The generally level nature of the area, combined with the SPORADIC ~~spurious~~ nature of the rain, has meant that there is a very poorly developed drainage system. This drainage system is largely in the form of ill-defined water courses draining into flat bottomed pans. These water courses are locally termed "omuramba", and are characteristically grass covered with little or no shrub cover and with the banks lined by a relatively dense low tree and shrub cover, as can be seen in plate 5. The larger of these omuramba are easily identifiable on the aerial photographs and have been indicated on figure 4 page 8. To the south are the Okwa and the Hanahai, and to the north west the Groot Laagte. There are no well defined water courses draining off the quartz porphyry

Plate 3. A view of the Mabeleapudi hills illustrating the generally level terrain with the inselberg type hills. (MMC/Bot/15/21-24).

Plate 4. A panoramic view of the Ngwanalekau hills, looking south east. (MMC/Bot/26/2-7).

Plate 5. The dense low tree and shrub vegetation characteristically found on the banks of an omuramba. (MMC/Bot/14/9).

hills, instead a multitude of rivulets "appear", to drain the hills during a rainstorm only to "disappear" virtually without trace, after the rain.

To the north of the study area are the Okavango swamps. (Figure 1 page 2). These are in fact an internal delta of the Okavango river, flowing from the Angolan highlands in the north west. Wellington (1949) suggested that the flow of the Okavango river was halted by faulting of pre-Tertiary rocks in Southern Ngamiland, to form a rib of higher lying land trending northeast-southwest.

After this period of faulting it is likely that there was a period relatively free of faulting, the Pleistocene. It was during the Pleistocene that the aeolian sand was introduced into the area. The general direction of sand derivation is from the south east as is evident from the accumulation of sand to the east and south east of the porphyry hills. The spread of the sand was after any folding, tilting and faulting of hard rock sediments in the area. These sediments, the Ghanzi beds, were tilted and folded after their sedimentation in the late Precambrian. Then followed a period of erosion during which the older Kgwebe rocks were exposed. These rocks are more resistant to weathering and form topographic highs. Then Karoo sediments were deposited, followed by a period of extensive erosion removing large tracts of Karoo rocks. There is evidence of post Karoo faulting with Karoo age rocks found in troughs within the older Ghanzi beds, as in the Mawani area. (Figure 3 page 5).

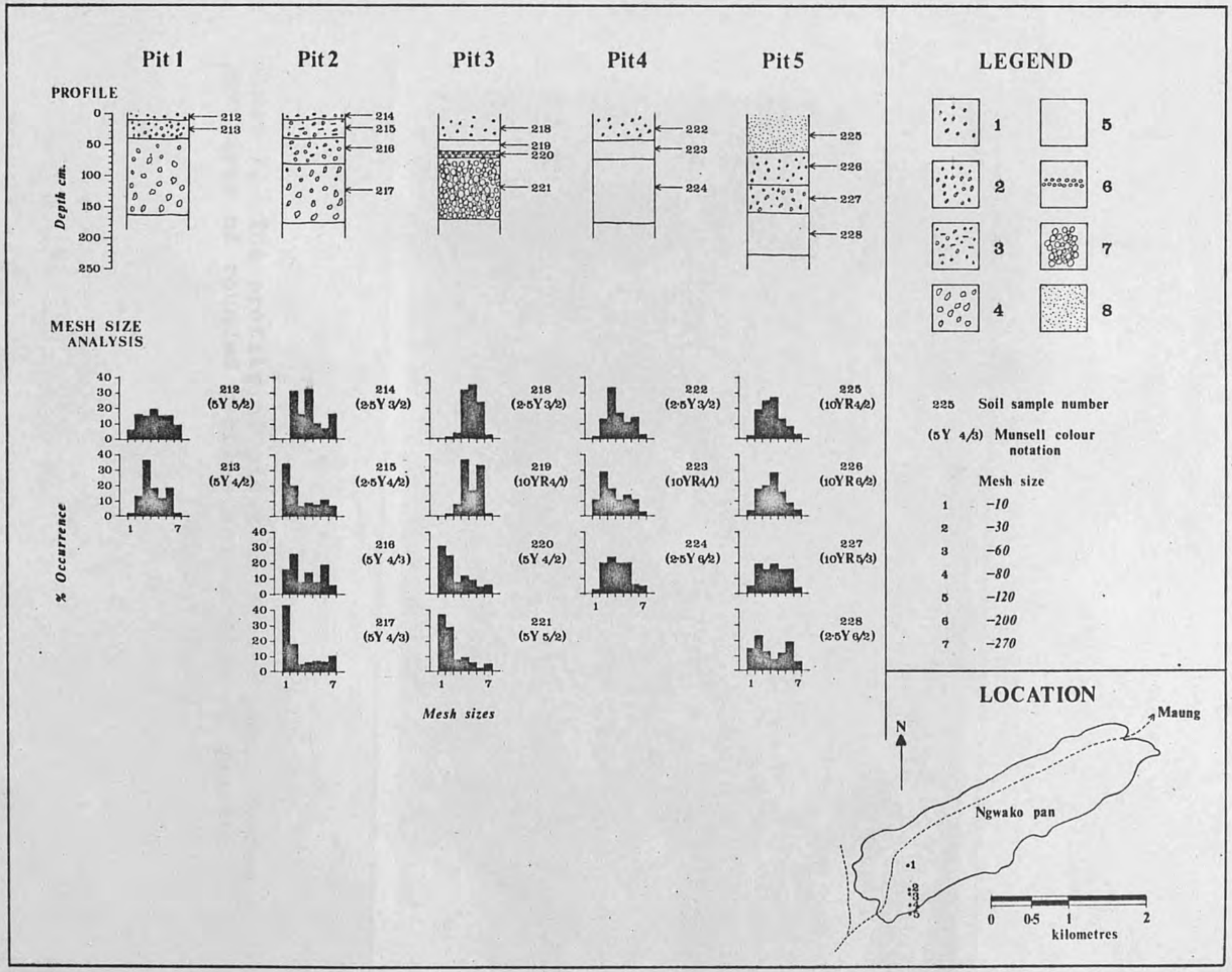
The present day drainage is internal into the many flat bottomed pans found throughout the area. These pans can vary in size from a few metres across, to a few kilometres across. The smaller pans probably formed as a result of a slight hollow in the plain into which rainwater flowed. Once this natural dam for water had been established, animals ~~will~~ would have gathered around for water and in the course of time much of the vegetation in and around the pans ~~will~~ would have been trampled and eaten. Then in drier periods the now bare pan ~~is~~ would have been exposed to the action of wind, and by deflation the pan ~~is~~ would have increased in size. Pans of this type are found to the west of the area. (Figure 3 page 5).

The larger pans in the area, such as Ngwako pan and Tali pan (Figure 3) were initially formed in a slightly different way. They were formed as a result of water overflow from Lake Ngami, and the water standing in slight depressions. These depressions would then eventually become established pans as a result of a combination of deflation during dry periods and subsequent flooding as a result of water overflow from Lake Ngami. This flooding, often resulted in the pans being full of water for long enough periods of time for the water to etch out more of the surrounding banks and thus enlarge the pans. This water action, in enlarging the pans, resulted in steep sided banks being formed. (Plate 6).

Once these large pans were established, water, other than that from the overflow from Lake Ngami, would flow into the pans. This may well have been along omuramba. Evidence of this was exposed in pit 3 on Ngwako pan. (Figure 7). Here, at a depth of 70 centimetres, a layer of quartz gravel was exposed. (Figure 7 no. 7). The gravel particles are of varying sizes and show evidence of rounding as a result of water action. The type of water action necessary to round off the edges of quartz can best be provided by an actively flowing river. In pit 3 (Plate 7) the gravel of rounded quartz particles is comprised of pebbles smaller than 10 centimetres to cobbles of larger than 30 centimetres. This variation in particle size, as well as the fact that there is no apparent sorting of sizes, indicates a swift flowing river to

Plate 6. A view to the southeast of Tali pan showing characteristic steep sided bank. (MMC/Bot/4/17A-18).

Figure 7. Profile logs of pits dug on Ngwako pan. For legend see text. The figure also shows mesh size analyses on soil sampling as well as colour matching. Inset gives location of pits.



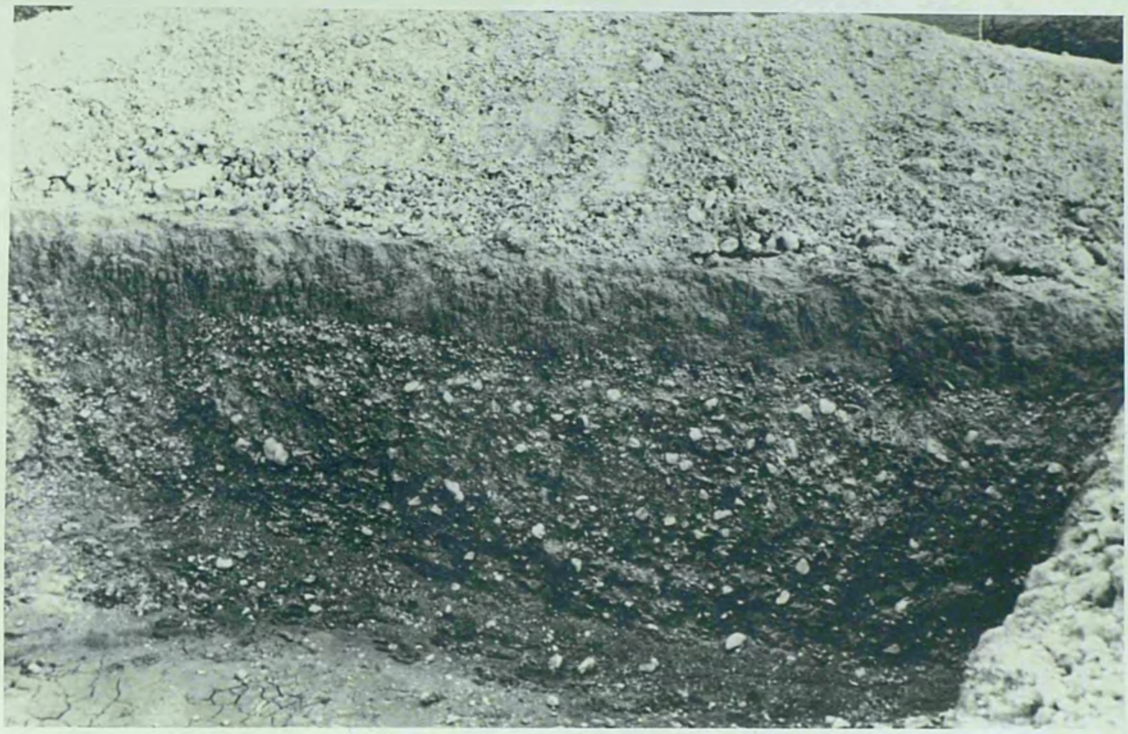


Plate 7. The profile of pit 3 on Ngwako pan. Notice the layer of rounded pebbles and cobbles of quartz. (MMC/Bot/25/7).

have acted as transport medium. The quartz was probably transported from the porphyry hills south of Ngwako pan, where many vein quartz occurrences are found. As the bottom of such a river filled with sediment, the flow would slow and the size of particles able to be transported would decrease. Evidence of this is also seen in pit 3 on Ngwako pan (Figure 7), where, immediately above the ill sorted gravel layer, is a gravel layer of rounded quartz pebbles all of approximately 10 centimetres in size. Above this layer there is a fine silty mud showing evidence of horizontal grading. This layer of mud probably represents a sedimentation of fine grained clayey soils by slow moving water. This sedimentation may have been in the form of mud which would account for a similar mud layer at the corresponding depth down profile in pit 4. (Figure 7). Besides the river sediment accumulation in the pans, there would be a tendency for sediment to accumulate as a result of sheet wash off the banks of the pans. Evidence of this type of sediment accumulation in the pans is found in the profiles of pits 1 and 2. (Figure 7). At this stage it is relevant to point out, that in the discussion of figure 7 the classification of the various profile categories is an essentially subjective one based on types of rock fragments, i.e. sandstone, quartz, argillite, as well as colour. This is why when samples taken from profiles appearing similar are analysed for their mesh size distribution, some differences are seen.

An accumulation of sediment in a pan as a result of sheet wash off the surrounding slopes is largely influenced by the gradient of the slope. When the slope is steep the water washing into the pan will transport coarse material. The gravel layer in pit 2 from 85 centimetres to the pit bottom at 170 centimetres reflects this stage of accumulation. This gravel layer consists of unsorted angular to sub-angular fragments of sandstone and quartz in an olive coloured clayey soil matrix. A mesh size analysis on sample 217, from this horizon, indicates 43% of the material to be in the coarse -10 + 30 mesh size fraction, with a tailing off through 18% in the -30 + 60 mesh size range, then 18% spread evenly through -60 + 270 mesh sizes and the remaining 11% in the silt-clay -270 mesh size fraction.

This period of rapid sheet erosion, will serve to reduce the gradient of the slope. (Plate 8). The flow of water off the gentler slope into the pan will be relatively slower and a larger proportion of finer grained material will be transported. This stage is depicted in the upper three horizons logged in pit 2. The boundaries indicated on the log are essentially subjective, as there is a down profile intergradation of the various horizons. In the horizon from 40 centimetres down to 35 centimetres is found poorly sorted angular to sub-angular fragments. A mesh size analysis on sample number 216 shows a fairly erratic distribution of material in the size ranges from coarse to fine. There are peaks in the distribution histogram in the medium grained -30 + 60 mesh, in the fine grained -80 +120 mesh and in the silt fraction of -200 + 270 mesh size. The horizon from 25 to 40 centimetres shows a more even size range distribution with 45% of the material being evenly distributed in the -60 to -270 mesh size fraction, as was shown by a mesh size analysis on sample 215. A mesh analysis on sample 214 taken from the surface to 25 centimetre horizon shows two peaks of 30%, one at the medium grained -30 + 60 mesh size and one at the fine grained -80 + 120 mesh size range. When compared to the mesh size distributions in the lower lying horizons, the upper 25 centimetres is seen to have the highest relative concentration of material in the silt to clay -270 mesh size range.

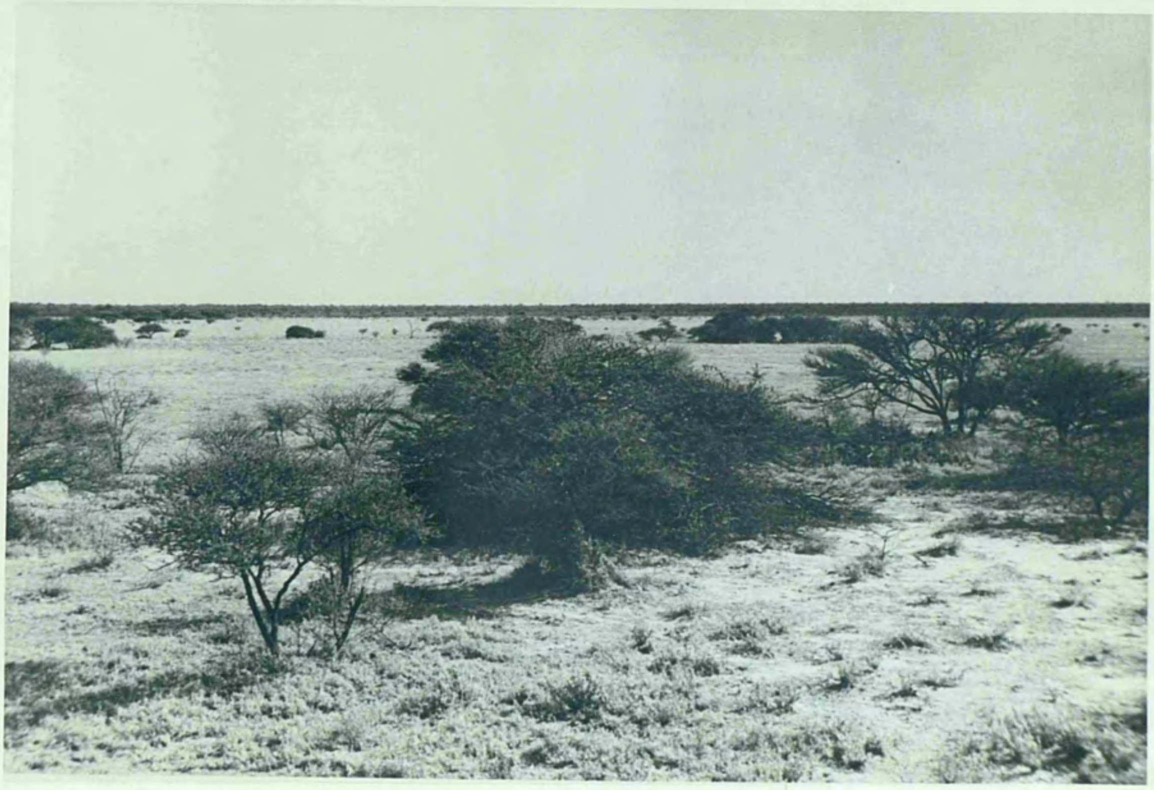


Plate 8. A view to the northeast of Ngwako pan from the bank showing the gradual gradient the bank slope makes to the pan floor. (MMC/Bot/4/10A-11).

There is a further type of sediment accumulation in the pans, namely wind blown sand. Evidence of this was found in pit 5. (Figure 7). The uppermost 70 centimetres of this profile ~~is~~ are dark greyish brown sand. An examination of the grains showed a predominance of quartz with evidence of "sand blasting" on the grains typical of aeolian sands. A look at the mesh size distribution histogram of sample 225 from this horizon shows a log normal distribution with a skewness to the finer grained material.

The only expanse of semi-permanent water in the area is Lake Ngami to the north. (Figure 3 page 5). This relatively shallow lake is fed by water from the Okavango swamps (Figure 1 page 2), along the Nghabe and Kuyene rivers flowing east and west of Sehitwa respectively. (Figure 4 page 8). In recent times the flooding of Lake Ngami has been extensive and the lake extended into the surrounding low tree and shrub vegetation. The standing water would effectively kill the vegetation. Then the lake dried out somewhat and the lake edge receded leaving behind the skeletons of trees. (Plate 9).

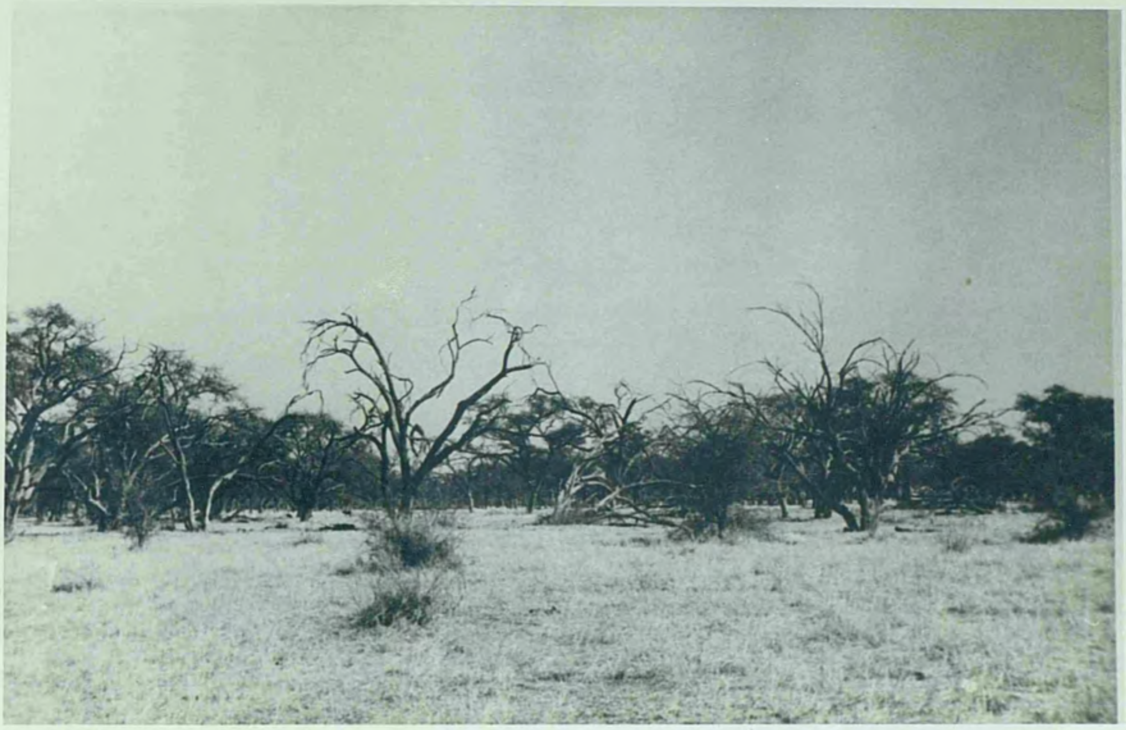


Plate 9. Dead trees found around Lake Ngami - evidence of the recent level of lake waters. (MMC/Bot/4/29A-30).

Chapter IV

SOILS AND OVERBURDEN

The residual soils in the area (Figure 3 page 5) are largely skeletal, this is caused by the nature of weathering of the bedrock which is principally mechanical with little chemical weathering taking place. Where ground water acts on the bedrock the fact that many of the Ghanzi bed rocks are rich in calcium results in the calcium being preferentially dissolved. This calcium rich ground water then moves through the soil often to redeposit the calcium as calcium carbonate, (calcrete) elsewhere in the soil horizon. This type of weathering of the bedrock will result in a distinctive soil forming over the bedrock. In the Ghanzi sediments the arenaceous beds have a yellowish brown soil cover and the argillites a brown soil cover. This distinctiveness of soil colour to underlying rock type is also true for the quartz porphyries with a reddish brown soil, and the Karoo basalts with a dark grey to brown soil cover. In the case of pans the sediment found in them does not reflect the underlying bedrock geology. The soil in pans is clayey and very dark greyish brown to olive grey in colour.

A large part of the area in figure 3 is covered by wind blown sand. This sand does not reflect the nature of the underlying bedrock. It is piled up against the south eastern flanks of the range of quartz porphyry hills, suggesting an accumulation from an easterly direction. The aeolian sands have also accumulated to form linear dunes in the area. (Figure 3). These dunes strike north west, south east and extend to the north west of the quartz porphyry hills.

The aeolian sands are fine to medium grained with an overwhelming predominance of quartz particles, and a low concentration of clay forming minerals. The quartz particles are somewhat rounded and show evidence of "frosting" of their surfaces. The wind blown sands are reddish yellow (5YR 7/6 moist) to a light grey (5YR 7/1 moist) in colour. The reddish yellow colouration is due to a pellicle of ironoxide formed on the sand grains. This iron oxide pellicle is removed by the reducing action of ground water to leave a light grey coloured sand.

Since the accumulation of the aeolian sands there has been extensive vegetation establishment on the sands which has prevented any further large scale sand movement by wind. The establishment of vegetation has also consolidated the sand dunes in the area.

The wind blown sand cover reaches thicknesses of over 100 metres in places. The great thicknesses of this transported overburden covering the bedrock geology, cause great difficulty in mapping the bedrock geology, which, together with the chemically inactive nature of the sand, poses some problems to a geochemical method of mineral exploration.

In areas to the north west of the porphyry hills, where there is little wind blown sand, over large tracts of country the bedrock geology is masked by calcrete. Areas where calcrete is close to surface are easily recognised by the presence of a low shrub savanna dominated by Catophractis alexandrii (Plate 10). As the effect of calcrete on soil geochemistry was not fully understood, studies of the calcrete formation were undertaken. These involved the excavation of pits number 7 and 8 in an area of calcrete cover. (Plates 11 and 12).

Pit 7 (Plate 11) was dug in the centre of a patch of Catophractis alexandrii. The surface 40 centimetres is of fairly evenly sorted fine to medium grained brown soil. This horizon has very few pebbles and concretions

Plate 10. Low shrub savanna dominated by Catophractis alexandrii typically found in areas of near surface calcrete. (MMC/Bot/33/24A).

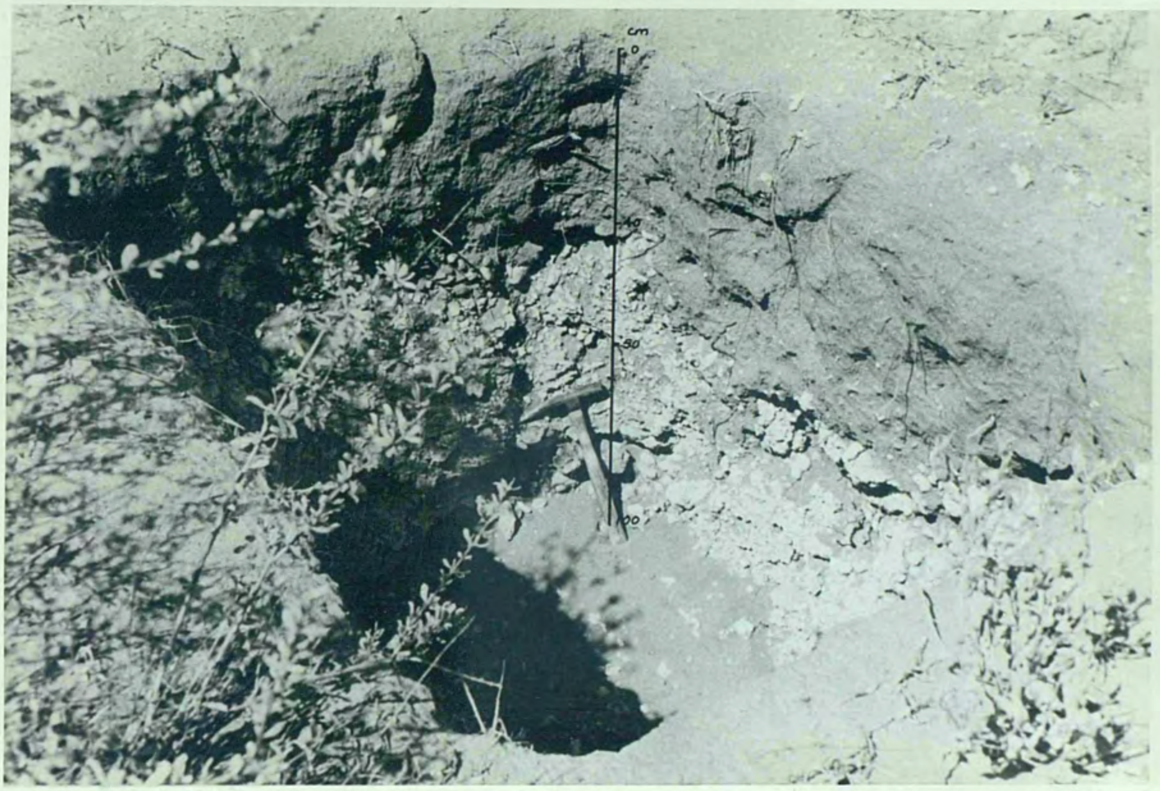


Plate 11. A profile section of pit 7 exposing sub-outcropping calcrete under 40 centimetres of soil, excavated in a patch of Catophractis alexandrii.

(MMC/Bot/33/32A).

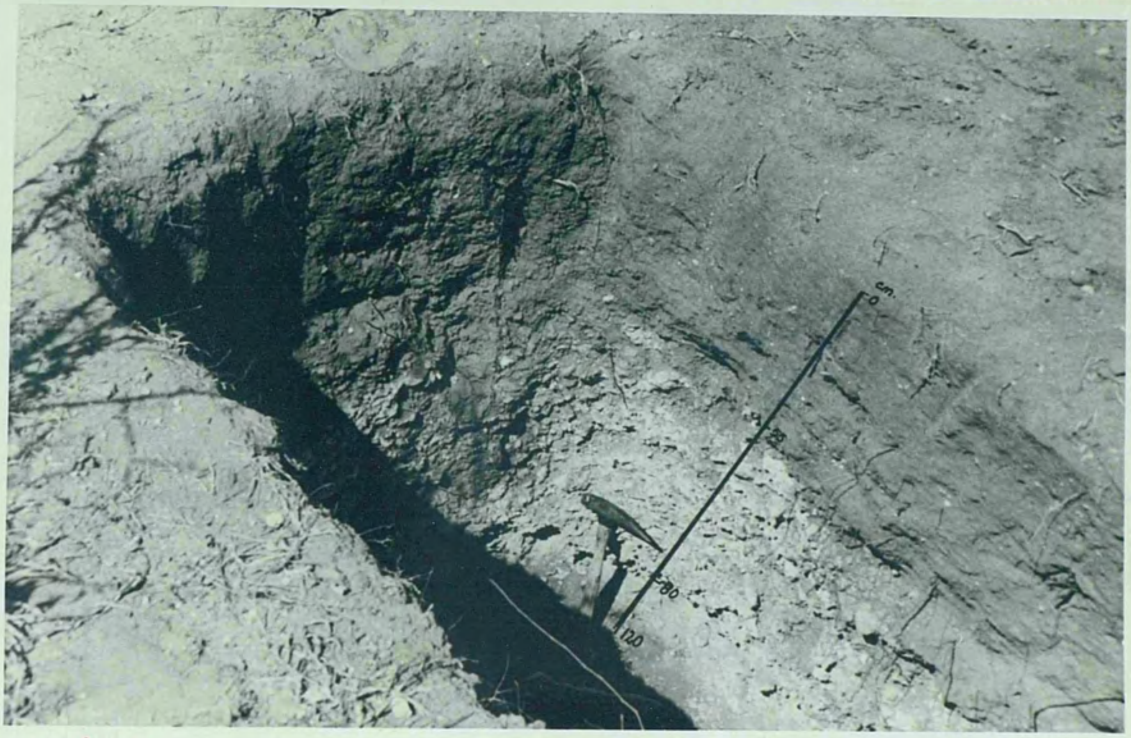


Plate 12. A view of the profile of pit 8 excavated on the edge of a patch of Catophractis alexandrii.

(MMC/Bot/32/34A).

of calcrete. From 40 to 50 centimetres is an ill-defined rubble layer of angular to sub-angular quartz pebbles, some of which are calcrete coated. From 50 centimetres to the pit bottom at 100 centimetres is a horizon of calcrete boulders and mauve quartzite boulders and fragments, with a calcrete coating. Exposed in the bottom of the pit is mauve quartzite suboutcrop.

Pit 8 (Plate 12) was dug on the edge of the patch of Catophractis alexandrii where tall Terminalia prunioides trees were present in the vegetation association. (Plate 13). From surface to a depth of 55 centimetres is found a fine to medium grained brown soil. This horizon shows an increase in pebbles with depth, the pebbles being of quartz and calcrete. From a depth of 55 centimetres to 80 centimetres from surface, the profile reveals a gravel layer of sub-angular quartz pebbles up to 30 centimetres in diameter. This gravel layer also contains calcrete pebbles and argillite chips, there is evidence of calcrete accumulation with the calcareous coating of pebbles and fragments. From 80 centimetres to the pit bottom at 120 centimetres is found weathered argillite suboutcrop with calcrete coating and concretions.

From studying the profiles of pits 7 and 8, it was concluded that the calcium necessary for calcrete formation was derived from the suboutcrop. This would be by the action of ground water, dissolving out the calcium from the rocks and the redepositing it as calcrete in the zone of evaporation. This qualifies as chemical weathering and will proceed along with the mechanical weathering of the rocks. The mechanical weathering cycle accounts for most of the soil formation.

Overburden of calcrete formed by the above described mechanism, would have little effect on the surface soil geochemistry. This was aptly illustrated in a prospect trench dug on a surface soil copper anomaly in the area. (Figure 8). In this trench section, a weakly copper

Plate 13. The position of pit 8, notice the tall Terminalia prunioides trees with the Catophractis alexandrii in the background. (MMC/Bot/33/23A).

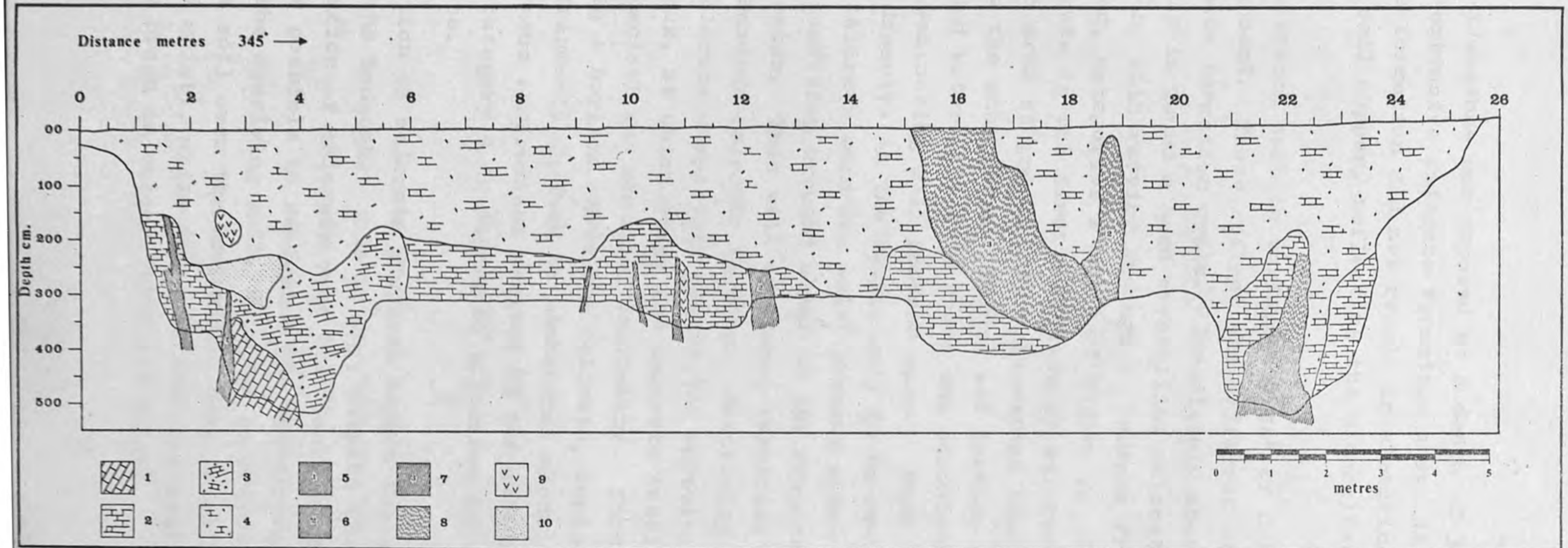


Figure 8. The profile log of trench 8. A detailed description of the various horizons is given in the text.

mineralized limestone was exposed at a depth of 3,5 metres with extensive calcrete formation above it. The calcrete formation did not result in a"masking" of the high soil copper, reflecting the mineralized limestone.

In this trench section various "types" of calcrete are exposed. These reflect the different stages in the calcrete formation cycle. Immediately above the suboutcrop is found a hard crystalline calcrete called hardpan, with varying amounts of bedrock fragments included, categories 2 and 3 of figure 8. This hardpan calcrete is the first formation of calcrete, and is in the area of ground water saturation immediately above the suboutcrop. During wet periods a layer of ground water will form above the suboutcrop and chemical weathering will proceed apace. Much calcium will dissolve in the water, only to be redeposited as calcrete when the water becomes oversaturated, a condition brought about by the evaporation of some water. This will continue, resulting in a layer of hardpan calcrete forming. Eventually the hardpan calcrete completely covers the suboutcropping bedrock, at which stage the calcrete itself undergoes mechanical and chemical weathering. This will result, in a horizon above the calcrete, containing calcrete fragments derived by mechanical means as well as calcareous concretions derived by the action of ground water, category 4 in figure 8, a horizon known as nodular calcrete.

The formation of calcrete proceeds within the soil profile above the bedrock. This is why, despite the extensive formation of calcrete over the Ghanzi beds in the area, it is possible to recognise the underlying rock types by the overlying soil, this can be principally done on colour. The soil over the arenaceous beds is yellowish brown (10YR 5/6 moist), while the soil over the argillaceous beds is brown in colour (10YR 5/3 moist).

The distinctive soil colours over the various rock types of the Ghanzi beds, is also true for sōils formed over other rock types in the area. For example, the soil formed over the quartz porphyry is reddish brown in colour (5YR 4/4 moist), while the soil formed over the Karoo basalts is characteristically dark grey to black in colour (5YR 2/1 moist).

A further soil type found in the area occurs on the pans. This soil is characteristically very dark greyish brown in colour (2,5Y 3/2 moist). It may vary in colour to an olive grey (5Y 2/2 moist). In studying the soil profile across a pan five pit sections were logged on Ngwako pan. (Figure 7 page 27). These sections have been discussed in some detail in the chapter on geomorphology, to which the reader's attention is drawn, and it will suffice here to discuss the techniques used in the study and to describe a typical pan soil profile as found in pit 2. (Figure 7.).

In studying the soil profiles bulk soil samples were collected from the different horizons. A mesh size analysis was done on these samples using a wet screening technique. The A.S.T.M. mesh size were 10 (2000 microns), 30 (600 microns), 60 (250 microns), 80 (200 microns), 120 (125 microns), 200 (72 microns), 270 (53 microns). (Appendix 3). Colour matching was also done on the soil samples using the Munsell Soil Colour charts. The results of this study are depicted in figure 7 (page 27).

During the course of field work, profiles on various other pans in the area were studied and from this it is accurate to consider the section shown in pit 2 of figure 7 as being typical of pans. This pit was excavated towards the centre of Ngwako pan. The surface 25 centimetres is a loosely compacted clayey soil, with quartz fragments approximately 1 millimetre in size. The texture and appearance of this horizon is similar to the surface horizons of pits 1, 3 and 4 and similar in colour to the soils of pits 3 and 4 which is very dark greyish brown (2.5Y 3/2 moist). The surface soil in pit 1 is olive grey in colour (5Y 5/2). The mesh size analysis on soil sample number 214 from this horizon shows two high peaks of 30% one at the medium grained -30 + 60 mesh size, and one at the fine grained -30 + 120 mesh size, 15% of the material is found in the size ranges between these peaks, -60 + 80 mesh size. A lower order peak of 15% of material is found in the silt to clay fraction, -270 mesh size, while the remaining material is more or less evenly distributed in the two fractions covering the -120 + 270 mesh size range.

From 25 to 40 centimetres is a horizon of ill sorted angular and tabular fragments, varying in size from 1 millimetre to 3 centimetres, in a dark greyish brown (2.5Y 4/2 moist) soil matrix. The fragments ~~are~~ comprise~~d~~ ~~of~~ mauve quartzite, glauconitic sandstone and quartz, and were derived from the weathering of surrounding rocks. The tabular fragments tend to be horizontally disposed. A mesh size analysis of material from this horizon, shows a peak of 35% of the material in the coarse -10 + 30 mesh size fractions and the remaining 45% of the material evenly distributed in the five fractions ranging from -60 to -270 mesh size.

From 40 to 85 centimetres is found poorly sorted angular to subangular fragments in an olive coloured (5Y 4/3 moist) soil matrix. The mesh size analysis on sample number 216, shows a fairly even distribution of material through the mesh size ranges with relative peaks of 25% in the medium -30 + 60 mesh size range, 14% in the fine -80 + 120 mesh size range and 19% in the silt -200 + 270 mesh size range.

From 85 centimetres to the pit bottom at 170 centimetres is found a gravel layer of unsorted angular to sub-angular fragments in an olive coloured (5Y 4/3 moist) soil matrix. A mesh size analysis indicates 43% of material to be in the coarse -10 + 30 mesh size range with a tailing off through 18% in the -30 + 60 mesh sizes, and then 28% evenly distributed between the -60 + 270 mesh sizes and a small peak of 11% in the silt to clay -270 mesh size fractions.

The soils on the pans are chiefly derived from the surrounding areas and as such do not reflect the underlying hard rock geology. From a geochemical point of view these soils are found to have a slightly higher than normal background concentration of elements such as copper, a fact attributable to the higher clay concentration found in the pan soils.

Chapter V

VEGETATION

The larger part of Botswana is semi-arid with the only perennial rivers being the Okavango and Chobe in the northwest, and the Marico and Limpopo on the east. This semi-arid climate has resulted in much of the territory being covered with savanna woodland, species of _Acacia_ being most common. There are differences in the predominating species caused by factors such as thick aeolian sands where _Terminalia sericea_ and _Colophospermum mopane_ predominate. On a more localised scale even further differences in the species composition are noted, such as a predominance of _Dichrostachys_ spp. in parts of the Kalahari desert, and monospecific stands of _Catophractis alexandrii_ in areas of near surface calcrete.

The delta of the Okavango river, lying in the region known as Ngamiland, differs in aspect and character from any other part of the republic. The vegetation changes to a taller woodland and eventually forms a forest on the banks of the Chobe river. The predominant tree species are _Pterocarpus angolensis_ and _Burkea africana_.

During the present study the nature and distribution of vegetation associations in the area of western Botswana (Figure 4 page 8) were looked at in some detail.

Aerial photographs of the area exist and were studied and interpreted. This was initially done during the first reconnaissance trip into the area. Immediately obvious from this work is a distinct rib of vegetation stretching south west and north east of Ghanzi. The rest of the area has a uniform vegetation cover broken only by the distinctive vegetation assemblage found growing in internal drainage ways.

Ground control traverses were undertaken to ascertain the precise nature and composition of the vegetation units recognised on the aerial photographs. These were mainly along roads and tracks. The studies confirmed a close relationship between the broad vegetation associations and the pedology. The most widely distributed vegetation association in the area is found over the unconsolidated Kalahari sediments, this contrasts with the vegetation covering the area of older consolidated sediments of the Stormberg, Ghanzi and Kgwebe Series which form a central spine in the area of study.

It was as a result of this work that Professor M.M. Cole recommended a more detailed investigation of the vegetation assemblage in the area. Two projects were initiated, one in the area around Ghanzi, and the other in the area around Lake Ngami. This present study was conducted principally in the latter area. (Figure 3 page 5).

Detailed vegetation mapping of the area was done using aerial photographs and extensive field checking. Seven principal vegetation associations were recognised, and a map giving their broad distribution in the area was drawn up (Figure 9). Each of the vegetation associations on the map are numbered and will be discussed in numerical order.

Growing on slightly undulating terrain over Ghanzi Series rocks is a low tree savanna woodland (Figure 9, Category 1), characterised by the trees *Terminalia prunioides* and *Acacia erubescens*, associated with *Boscia foetida*, *Acacia tortilis* and *Commiphora pyracanthoides* ssp. *glandulosa*, and the shrubs *Croton menyhartii*, *Grewia bicolor*, *Dichrostachys cinerea* and *Combretum erythrophyllum*. The main perennial grasses are *Aristida hordeacea*, *A. scabrivalvis* and *Cenchrus cilliaris*. (Plate 14).

Figure 9. A vegetation map of an area of southern Ngamiland. Indicated on the figure are the position of traverse A – B (see text), and the block for detailed work.

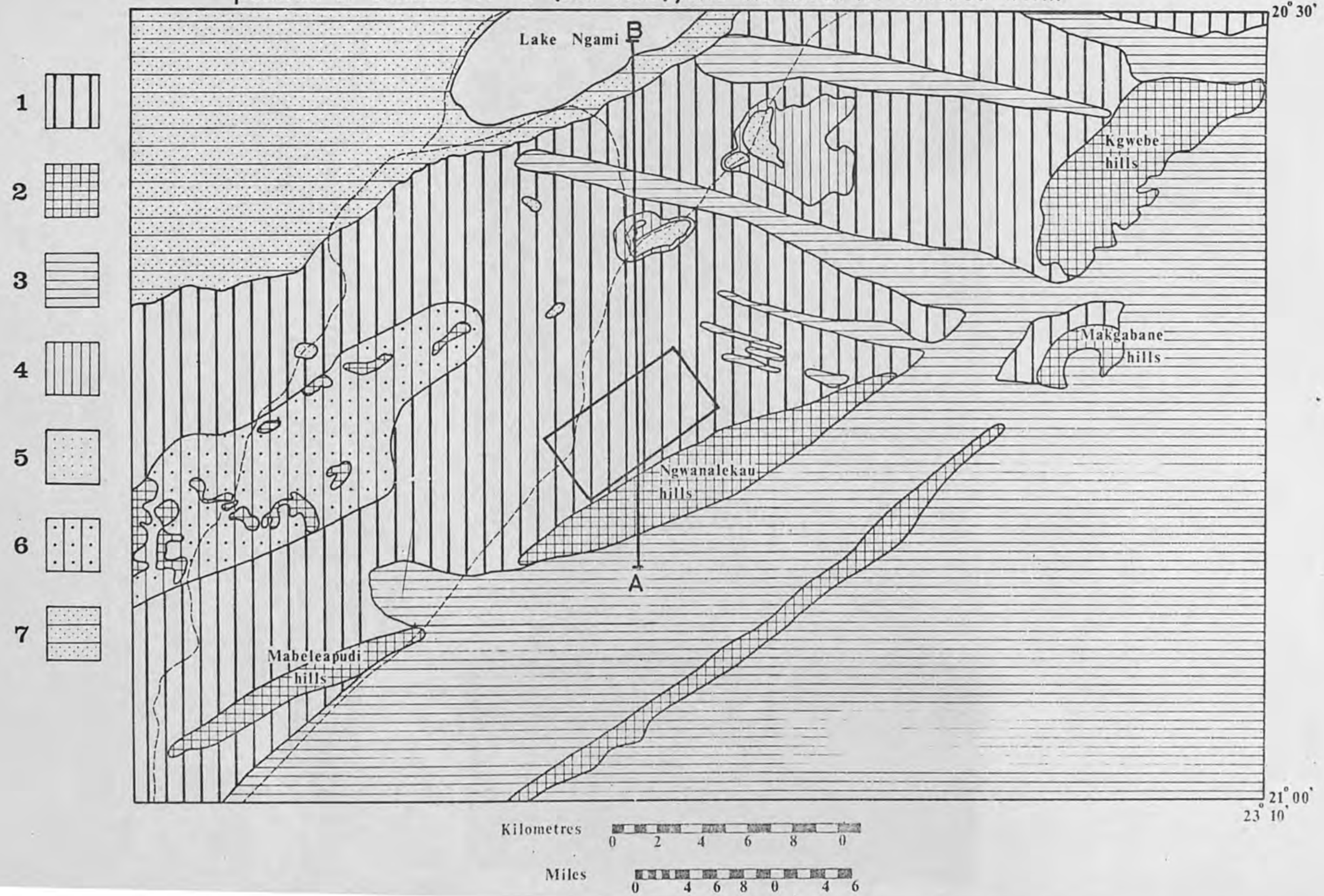


Plate 14. A panoramic view of the low tree savanna woodland characteristically found over Ghanzi series rocks. To the right of the photograph is a Boscia foetida tree. (MMC/Bot/33/10A-12A).

This vegetation association is found in a broad belt stretching from the south west to the north east of the area.

Category 2 is a low tree and shrub savanna. The vegetation association is dominated by Combretum apiculatum, occurring as a tree and shrub, and the shrub Grewia bicolor in association with the trees Acacia erubescens, Markhamia acuminata, Commiphora pyracanthoides ssp. glandulosa and the shrub Grewia villosa. The prevailing grass species is Eragrostis superba with areas of Stipagrostis uniplumis where there is a thicker cover of sandy soil.

This vegetation association is found on areas with skeletal soils on ridges and low hills formed by siliceous bedrock. These rocks are typically the sandstones of the Stormberg series, found in the south west of the area, and the quartz porphyries of the Kgwebe series which form the belt of hills striking south west - north east across the area.

A low tree and shrub savanna found on aeolian sands, either occurring as a slightly undulating plain in the south east or as dunes fingering out to the west, is found in the south eastern portion of the area with "tongues" extending across to the north and central part. This low tree and shrub savanna (Category 3) is dominated by Terminalia sericea and Dichrostachys cinerea, species occurring as trees and shrubs. These are associated with the shrubs Croton gratissimus, C.menyhartii and Maerua angolensis, and the perennial grasses Aristida meridionalis, Eragrostis horizontalis and Stipagrostis uniplumis.

The vegetation of category 4 is a low tree and shrub savanna characterised by Acacia mellifera, A.karroo A. nebrownii, Catophractis alexandrii and Dichrostachys cinerea. There are two principal occurrences of this

Plate 15. The low tree and shrub savanna found on areas of near surface calcrete around pans, view around Ngwako pan. The small greyish shrub in the foreground is Petalidium englerianum.

(MMC/Bot/4/11A-12).

vegetation association, around Ngwako pan and around Tali pan. These areas typically have near surface calcrete suboutcrops. (Plate 15).

Growing on the pans, such as Ngwako and Tali pan, is found a savanna grassland (Category 5, Figure 9) characterised by Enneapogon brachystachus, Sporobolus spicatus and Oropetium capense with occasional Cyperus spp. The grassland is studded with suffruticose Leucosphaera bainesii and Plinthus karrooicus. This vegetation assemblage is found on the pans, such as Ngwako and Tali pan, in the area. (Plate 16).

Savanna parkland characterises the western part of the area, where the association is dominated by Acacia erubescens trees and the perennial grasses Stipagrostis uniplumis, Aristida scabrivalvis, A. hordeacea and Eragrostis porosa. (Figure 9, category 6). The terrain is level and the soil typically clayey and dark grey to black in colour. (Plate 17). Excavations and drilling have shown these soils to be underlain by basalts of the Stormberg series.

The north western portion of the area, including the area around Lake Ngami is vegetated by savanna parkland characterized by Acacia giraffae and A. tortilis trees with Enneapogon brachystachus as the dominant perennial grass species. (Figure 9, category 7). The area is studded with pans and includes the flood plain of Lake Ngami. The soils are clayey, and dark grey to black in colour.

A traverse across these different vegetation associations was done (A-B on figure 9). The vegetation associations were noted and the characteristics of the pedology, and geology where possible, also recorded. (Figure 10).

Proceeding from south to north along the traverse the following was noted: On the extreme south is a uniform low tree and shrub savanna found growing on

Plate 16. A view over Tali pan showing savanna grassland on the pan, devoid of any tree or shrub growth. (MMC/Bot/4/16A-17).

Plate 17. A photograph taken in the Mawani area showing the typically clayey black soils over basalts. Notice the savanna parkland vegetation. The tall trees are Acacia erubescens. (MMC/Bot/29/17A-18).

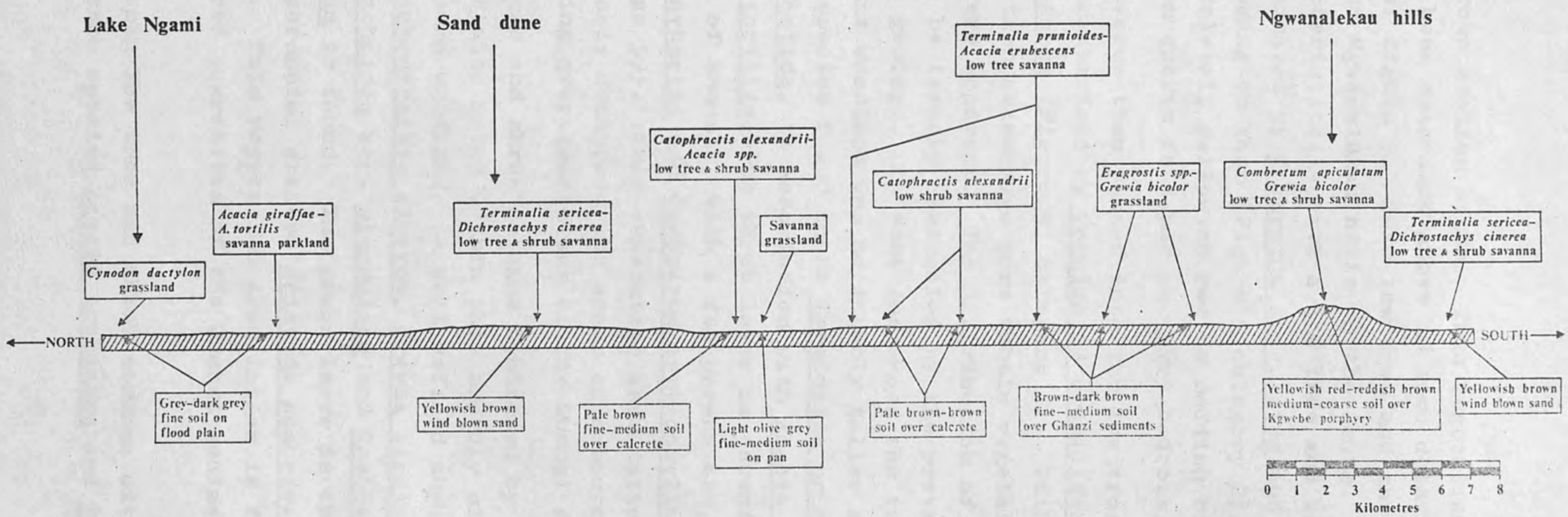


Figure 10. A presentation of traverse line A - B, done to the north of the Ngwanalekau hills on which vegetation associations and edaphic conditions are recorded.

yellowish brown aeolian sands. This vegetation association has been described above in some detail under category 3 of figure 9. This low tree and shrub savanna flanks the Ngwanalekau hills on the south. These hills characteristically have a low tree and shrub savanna, dominated by Combretum apiculatum and Grewia bicolor, growing on them (Figure 9 category 2). The soils are skeletal, yellowish red to reddish brown and are formed on quartz feldspar porphyry bedrock.

The traverse then passed into the low tree savanna woodland characterized by Terminalia prunioides and Acacia erubescens (Figure 9, category 1). Within this broad vegetation assemblage more subtle vegetation associations were apparent. The distribution of these was found to be largely controlled by the prevailing pedology and geology. In some instances the tree layer of the savanna woodland was noticeably taller and the co-dominant species found to be Terminalia prunioides and Boscia foetida, in association with Acacia erubescens and A. tortilis. The shrub layer is essentially open, mainly of annuals, with a few perennials, such as Croton menyhartii and Combretum erythophyllum. (Plate 19 page 59). This vegetation association was found to clearly demarcate the areas of suboutcropping and outcropping grey quartzites of the Ghanzi sediments.

A low tree and shrub savanna dominated by Combretum apiculatum is also noted within this broadly classified low tree savanna woodland. A well defined shrub association of Dichrostachys cinerea, Grewia bicolor, Commiphora pyracanthoides ssp. glandulosa and Combretum erythrophyllum is found. The grass layer is characterized by the perennial grasses Aristida scabrivalvis and A. hordeacea. This vegetation association is found on areas where red quartzites of the Ghanzi sediments suboutcrop.

A more open low tree and shrub savanna with the co-dominant tree species Acacia erubscens and Terminalia pruniodes is also present. Associated tree species are Boscia foetida and Acacia tortilis. The distinct shrub layer is characterized by Grewia bicolor, Croton menyhartii and Combretum erythrophyllum. In these areas are a wide range of perennial grass species characterized by Cenchrus cilliaris, Stipagrostis uniplumis, Eragrostis porosa, E. echinochloidea, Aristida scabrivalvis and A. hordeacea. This vegetation is found growing over subout-cropping argillaceous sediments of the Ghanzi series.

These three vegetation associations found growing on discrete rock types of the Ghanzi series have different and distinct aerial photo expressions. The taller tree savanna woodland growing on the grey quartzites has a dark aerial photo expression, whereas the other two associations have somewhat lighter expressions on the aerial photographs. These photo trends are apparent on plate 18. An annotated overlay (3/1) has been drawn up for this plate. Also noticeable on this plate is the photo expression of the low tree and shrub savanna found growing on deposits of recent aeolian sands. These photo trends caused by the natural vegetation distribution can be destroyed by factors such as fire. This results in a pale irregular area on the photograph, such as in the upper left hand corner of plate 18.

The traverse A - B also crosses an internal drainage line to the north of the Ngwanalekau hills. This is clearly reflected in the vegetation by a distinctly uniform vegetation cover of savanna grassland studded with shrubs. The characteristic grass species association is Eragrostis porosa, E. superba, E. echinochloidea, E. curvula, Panicum maximum and P. coloratum. Grewia bicolor is the most frequently occurring shrub. These internal drainages on the Ghanzi sediments in the area are too small to be shown on figure 9.

Areas also too small to be shown on figure 9 are those of near surface calcrete. The traverse crosses

Plate 18. An aerial view of vegetation patterning seen to the north of the Ngwanalekau hills. See overlay 3/1 for a description.

Plate 19. The tree and shrub savanna found over grey quartzite suboutcrop. Notice the characteristic tall tree layer of <u>Terminalia prunioides</u> and <u>Boscia foetida</u>.

(MMC/Bot/34/14-16).

Plate 20. A view of the shrub community characterized by Catophractis alexandrii and found on areas of near surface calcrete. (MMC/Bot/34/3-5).

some of these, and they are characterized by the shrubs *Catophractis alexandrii* and *Petalidium englerianum*, associated with *Combretum englerii*.

The traverse crosses Ngwako pan with the characteristic savanna grassland cover. (Figure 9 category 5). The pan is surrounded by the low tree and shrub savanna described in category 4 of figure 9. To the north of Ngwako pan, along the traverse, is found the *Terminalia sericea* - *Dichrostachys cinerea* low tree and shrub savanna found on the sand dunes.

The northern end of the traverse ends at Lake Ngami. The lake is immediately surrounded by grassland characterized by *Cynodon dactylon*. Further away from the lake trees enter the association to form a savanna parkland. The characteristic tree species are *Acacia giraffae* and *A. tortilis*. The area around Lake Ngami is badly overgrazed and virtually all grass and shrub species have been trampled. (Plate 21).

The vegetation formation in southern Ngamiland is characteristically a semi-arid low savanna woodland, composed of a mosaic of vegetation associations. These vegetation associations were found to vary in structure, life form and species composition, variations resulting from an interplay of microclimatic, geological, edaphic and geomorphological factors.

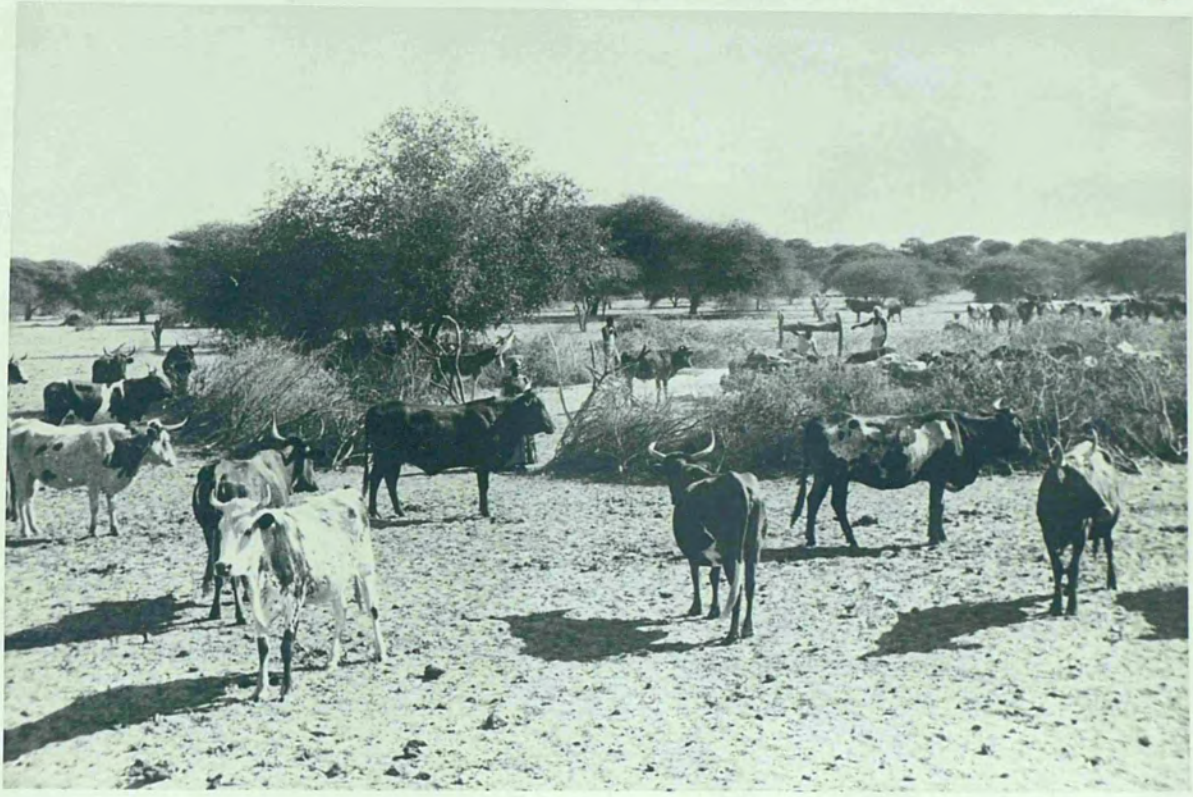


Plate 21. Cattle around Lake Ngami, notice the over-grazing of the area. (MMC/Bot/4/24A-25).

PART 2

GEOBOTANICAL, GEOCHEMICAL AND BIOGEOCHEMICAL INVESTIGATIONS IN THE NGWAKO PAN AREA

CHAPTER VI

GEOBOTANICAL INVESTIGATION

During the initial reconnaissance of the area a definite distribution of vegetation associations and plant communities was recognised. An anomalous shrub association was also noticed, and it is characterized by Ecbolium lugardae growing in a savanna woodland dominated by Terminalia prunioides trees (Plate 22). Elsewhere a different variety of shrubs and grasses are associated with these trees. At first the distribution of Ecbolium lugardae in the shrub association was found in an area immediately north of the Ngwanalekau hills, where suboutcropping copper mineralization was subsequently revealed.

These facts were all known at the beginning of this study, and the geobotanical investigation was designed to examine the distribution of vegetation associations and plant communities and the factors influencing them. Special attention was paid to the distribution of Ecbolium Lugardae and associated species. This was compared with certain geochemical and biogeochemical characteristics of the area.

The regional distribution of vegetation associations has been described in some detail in the chapter on vegetation, to which the reader is referred. Apparent from this work is the close association between the distribution of plant communities and the prevailing pedological conditions. A closer look at some of these plant communities revealed vegetation associations within them which are found to be closely related to lithological conditions. These too have been described in Chapter V on vegetation.

The recognition of plant communities and vegetation associations and their apparent relationship to pedological and lithological conditions can be profitably used

Plate 22. The shrub association dominated by Ecbolium lugardae growing in tall tree savanna characterized by Terminalia prunioides.
(MMC/Bot/25/22-26).

in regional geological mapping in areas such as southern Ngamiland where there is a dearth of rock outcrops.

More detailed geobotanical investigations were done in an area to the north and north west of the Ngwanalekau hills. For location see figure 9, page 48. In this area the distribution of _Ecbolium lugardae_ was mapped, and this was then compared to the geochemistry and biogeochemistry of copper in the area. The distribution of other tree, shrub and grass species was also recorded and studied, with the aid of histogram plots, in an endeavour to recognise species associations which may be relevant to mineral exploration. It is with the description and discussion of these detailed studies that the remainder of this chapter will be concerned.

Using transect lines over the area (Figure 11), the distribution of _Ecbolium lugardae_ was mapped. The distribution of other obvious vegetation associations was also mapped. This information is all on plan (Figure 12). The various categories on the figure are:

1. The distribution of _Ecbolium lugardae_ in the shrub layer of a low savanna woodland characterized by _Terminalia prunioides_ trees.

2. A low savanna woodland characterized by _Terminalia prunioides_ trees and a variety of shrubs and grasses.

3. A low tree and shrub savanna dominated by _Combretum apiculatum_ trees and _Grewia bicolor_ shrubs.

4. An open savanna woodland characterized by _Acacia erubescens_ trees and the perennial grasses _Cenchrus cilliaris_ and _Eragrostis lehmanniana_.

The demarcation of the boundary between the distribution of _Ecbolium lugardae_ and the low tree and shrub savanna dominated by _Combretum apiculatum_ and

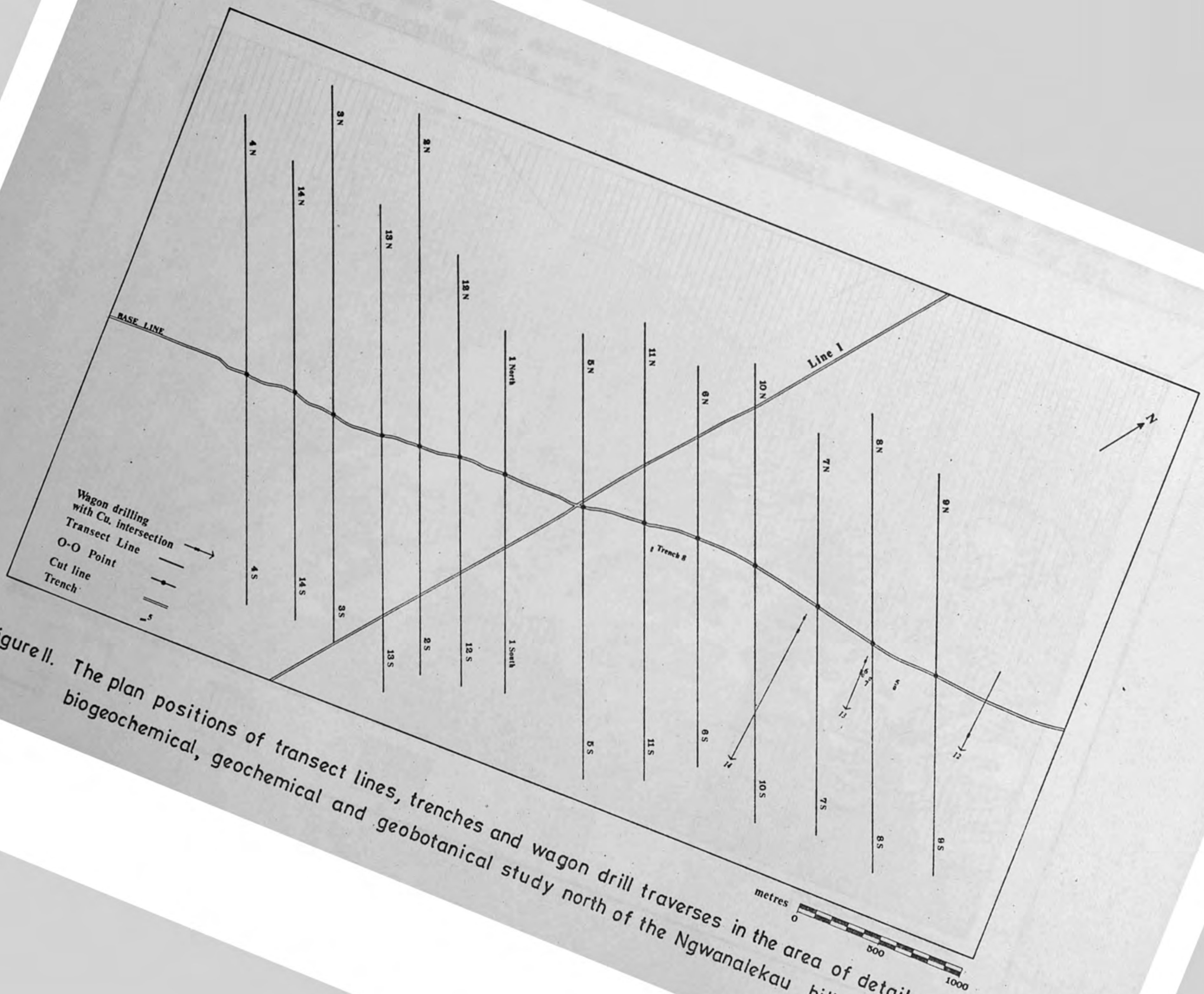
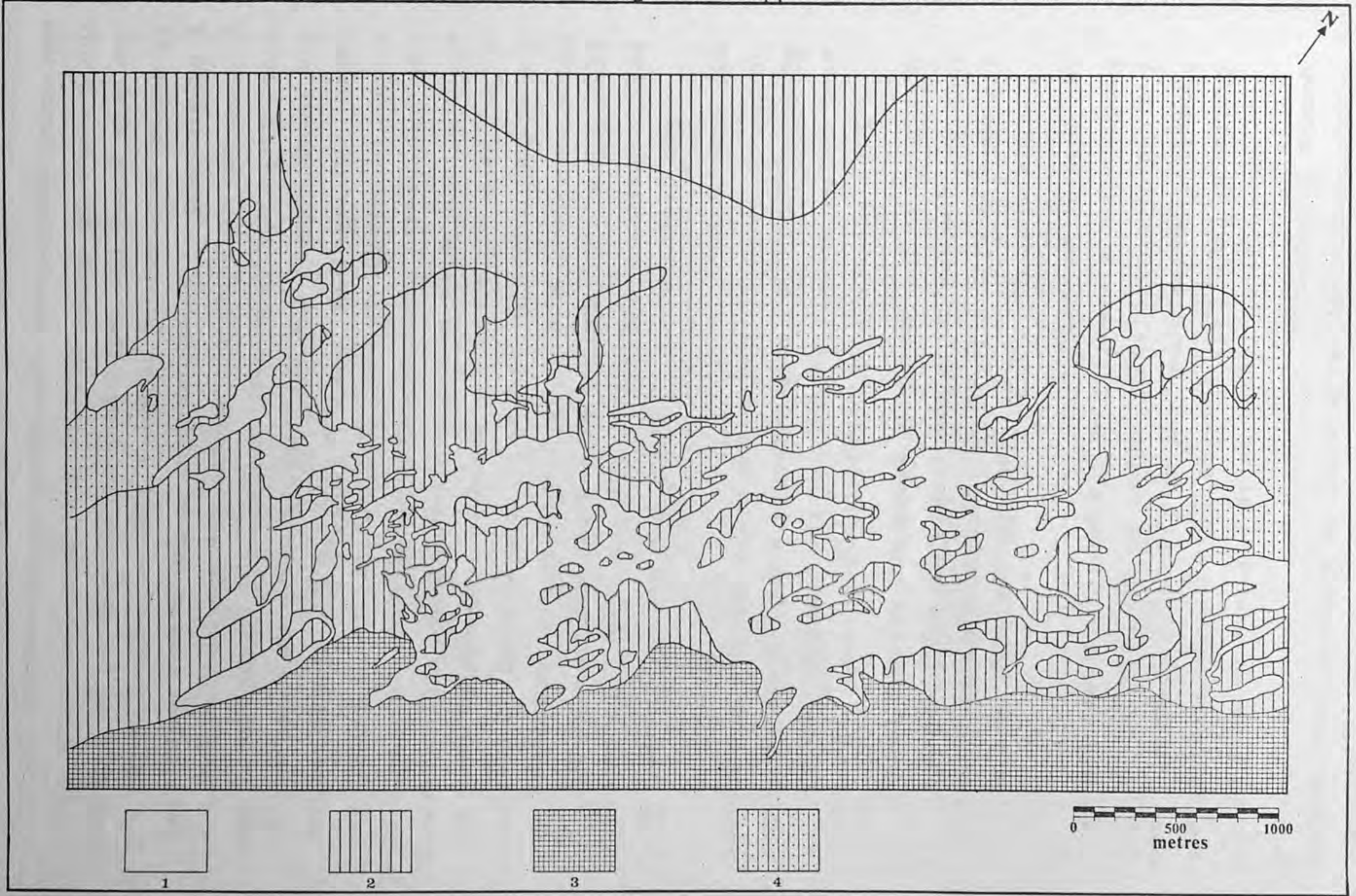


Figure II. The plan positions of transect lines, trenches and wagon drill traverses in the area of detailed biogeochemical, geochemical and geobotanical study north of the Ngwanalekau hills.

Figure 12. The distribution of plant species associations in the area immediatly north west of the Ngwanalekau hills. A description of the various categories mapped can be found in the text.



Grewia bicolor is very distinct. The latter association characteristically grows on areas of near surface quartz porphyry.

The scale of figure 12 is the same as that of figure 36 (page 133) showing the biogeochemical copper anomalies in the area, and of figure 23 (page 97) showing the distribution of copper in the soil in the area. Furthermore, a viewfoil of figure 12 has been prepared for ease of comparison.

The distribution of Ecbolium lugardae shrubs is not specifically related to the distribution of anomalous geochemical and biogeochemical copper, however, it does include the anomalous areas and extends beyond them.

Once the apparent relationship between suboutcropping copper mineralization and the distribution of Ecbolium lugardae was recognised a more detailed study of the distributions of other plant species in the area was undertaken.

The distribution of plant species was studied in belt transects conducted across the area. The transect lines shown on figure 11 were used, and an area one metre on either side of the transect line examined. The actual number of plants of each species of tree, shrub, herb and grass was recorded. Recording done in areas of one metre square was found to be representative and practical. The individual trees and shrubs were recorded in height classes, 0 - 1 metre, 1 - 2 metre, 2 - 4 metre, and +4 metre. In the case of the plants forming the ground cover, for each square metre recorded the % cover attributable to each species was determined. The % cover due to trees and shrubs was recorded as was the % bare ground. The recordings of the square metre area on either side of the transect line were grouped and all the data along the belt transect represented on a figure. The % cover is represented in histogram form while the tree and shrub species are symbolised in the various height categories. Geochemical and biogeochemical data are also given on the figures.

The data for transects 1, 2, 3 and 4 are presented on figures 13 to 19 inclusive. These transects cover the geochemical and biogeochemical copper anomalies to the south west of the area. A brief description of each of the figures will be followed by a discussion of the salient points.

Figure 13 represents the geobotanical, biogeochemical and geochemical data of transect 1 North.

The copper distribution in the soil is given in the -270 mesh and -80 mesh fractions. From this graph an above threshold copper concentration is seen in the -270 mesh from 0 - 70 metres, this above threshold soil copper is not as marked in the -80 mesh fraction.

The copper content of the leaves and stems of the plants sampled does not in any way reflect the geochemistry, in fact the copper content in the leaves and stems sampled is low where the -270 mesh soil copper shows above threshold copper concentrations. Anomalous copper concentrations are found in biogeochemical samples from 70 to 360 metres along the transect.

The main distribution of Ecbolium lugardae is from 0 to 110 metres along the transect. This includes the area of the above threshold soil copper while extending slightly beyond. There is a small occurrence of Ecbolium lugardae between 170 and 180 metres, which is not associated with a rise in soil copper. There is a slight copper anomaly in the plant tissue, however, the fact that there are similar biogeochemical anomalies not associated with Ecbolium lugardae detracts from the significance of this single coincidence. The annual grass Enneapogon cenchroides shows a distribution markedly similar to that of Ecbolium lugardae. The Ecbolium lugardae is seen to grow under taller trees and shrubs

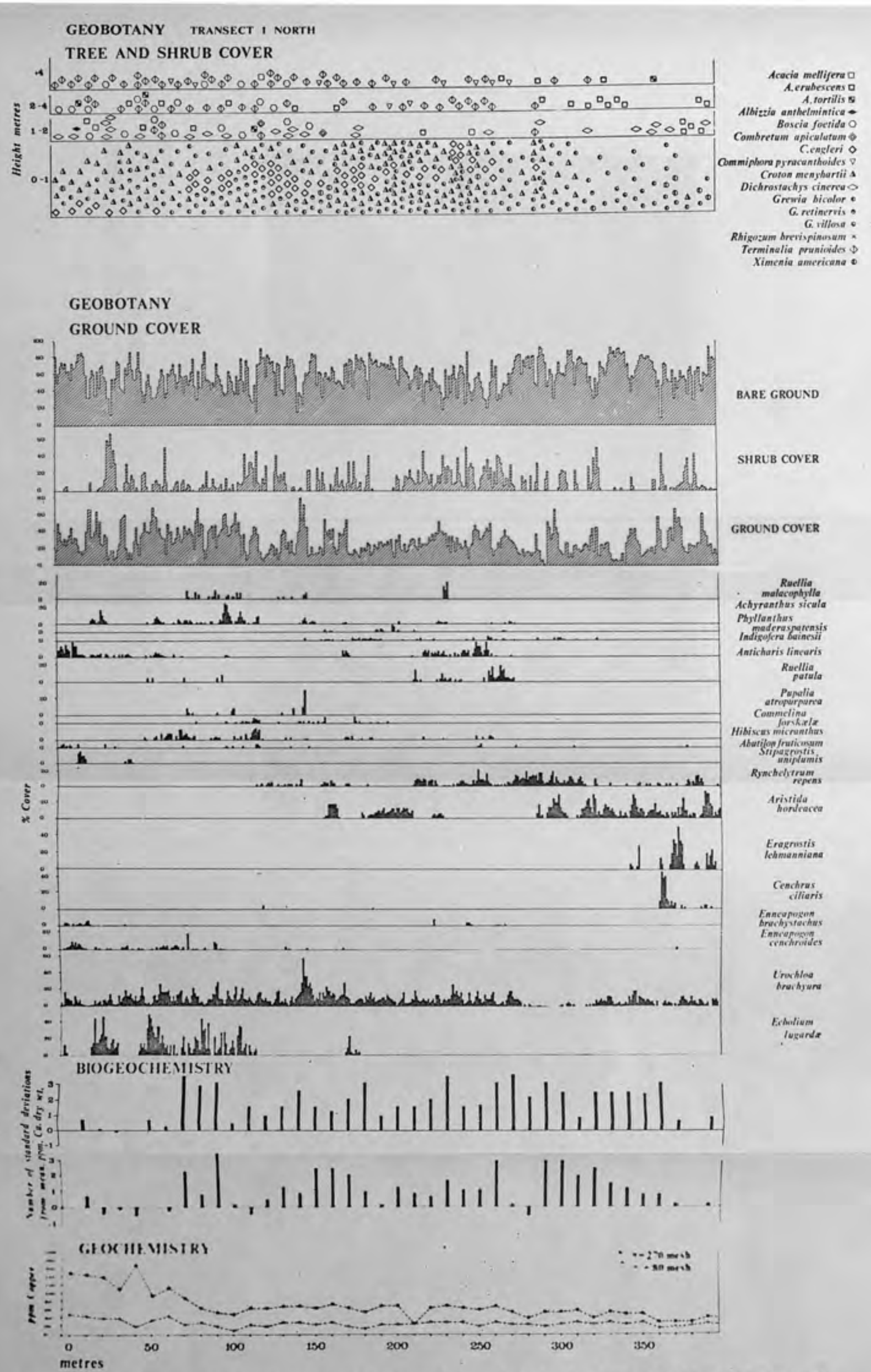


Figure 13. Geobotanical, biogeochemical and geochemical data of transect 1 North.

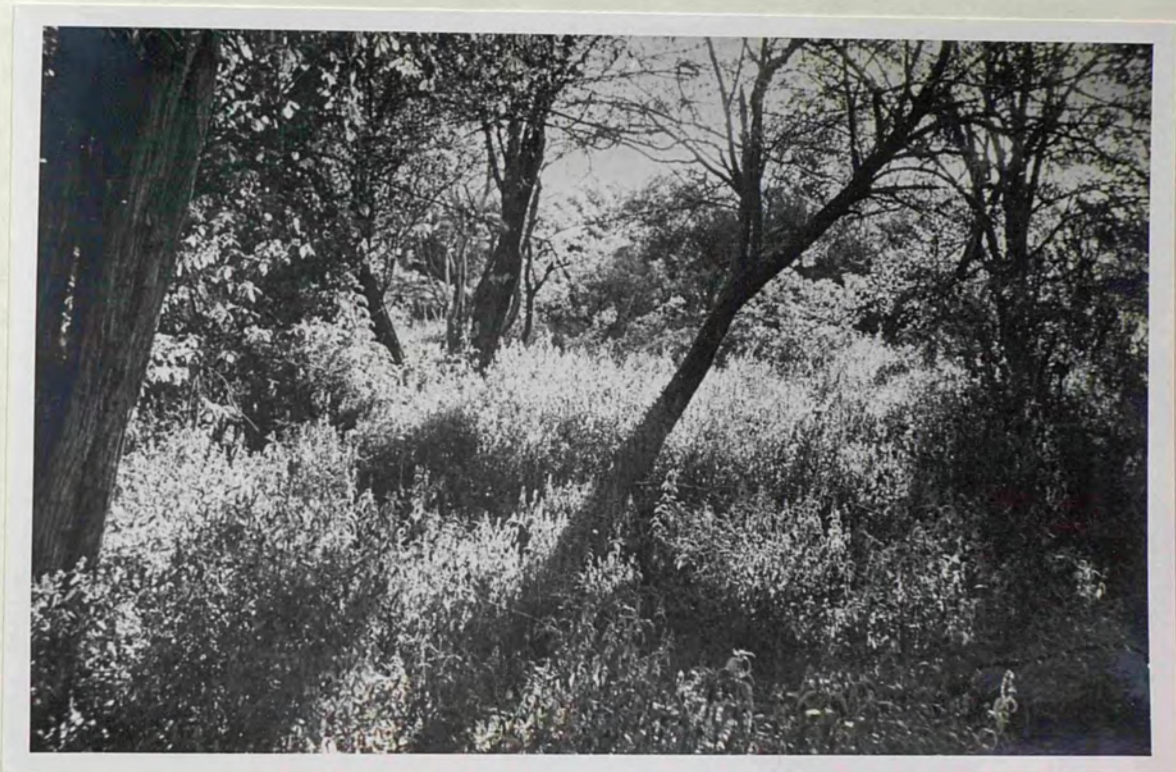


Plate 23. Ecbolium lugardae growing under tall Terminalia prunioides trees. (MMC/Bot/13/32A).

as is evident from the increase in number of plants recorded in the taller height categories. This is also illustrated in plate 23.

The annual grass Urochloa brachyura is found virtually along the entire length of the transect in varying concentrations. Enneapogon brachystachus, a small annual grass species, is found only sparsely while the perennial grasses Cenchrus cilliaris and Eragrostis lehmanniana are found in some concentration at the northern extremity of the transect. It is here that the transect line crosses into the open savanna woodland characterized by Acacia erubescens trees. (Figure 12, category 4). In this vicinity the annual grass Aristida hordeacea is found in some profusion. It must also be noted that this grass species is recorded in the vicinity of 200 metres along the transect in a low shrub savanna.

The perennial grass Rhyncheletrum repens is conspicuous by its absence over the area of above threshold soil copper. This species is found scattered along the rest of the transect.

Immediately apparent from the distribution patterns of the ground cover is the low concentration of ground species, other than grasses, in the open savanna woodland characterized by Acacia erubescens. The species Hibiscus micranthus, Commelina forskaelae, Pupalia atropurpurea, Ruellia patula, Anticharis linearis, Phyllanthus maderaspatensis, Achyranthus sicula and Ruellia malacophylla are distributed in among the low tree and shrub savanna dominated by Terminalia prunioides.

Within this low tree and shrub savanna the upper story of 2 metres and higher is dominantly Terminalia prunioides, while the lower story, less than 1 metre in height, is characteristically the shrub Croton menyhartii.

The data for the southern part of transect 1 are recorded on figure 14.

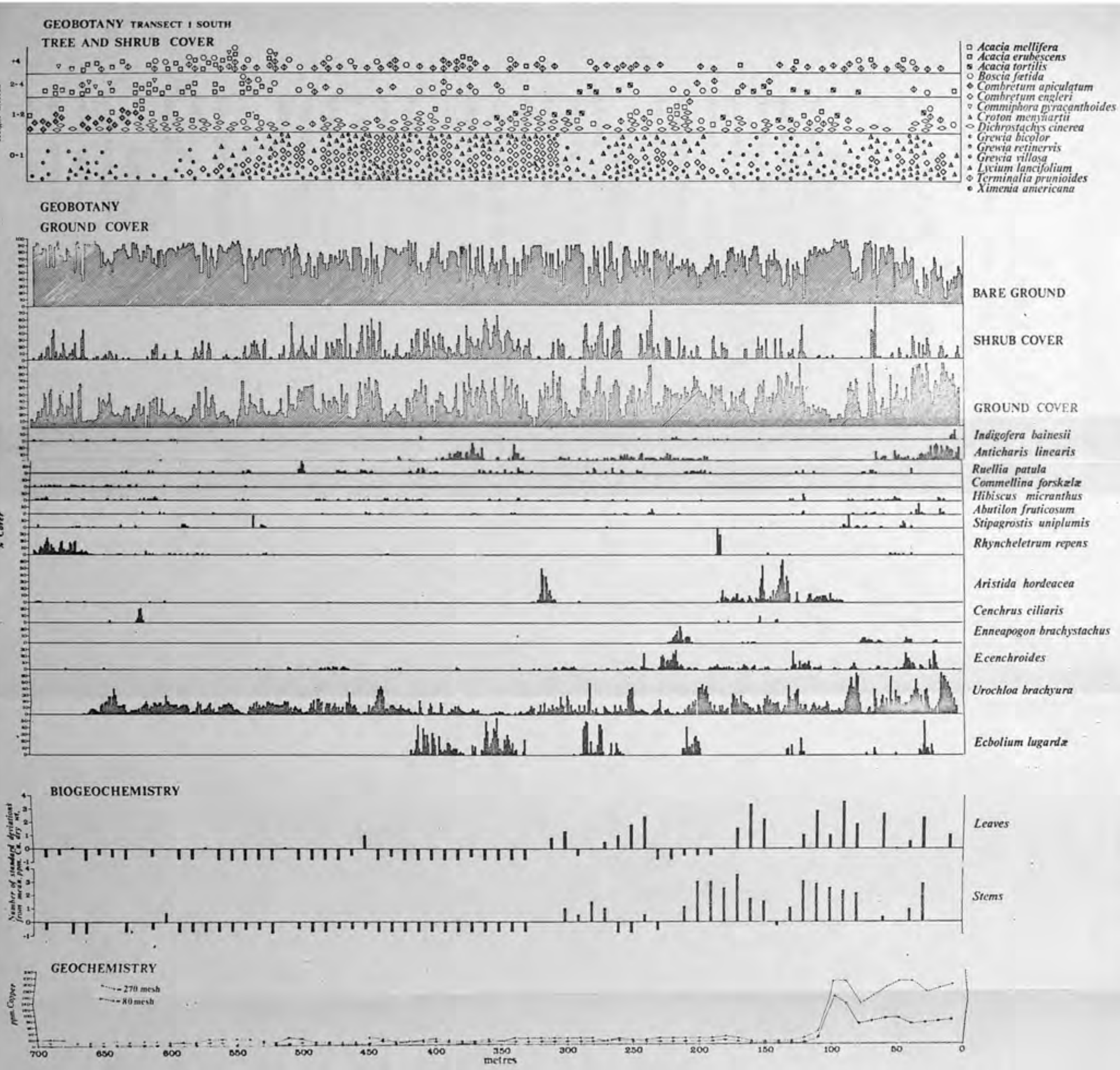


Figure 14. Geobotanical, biogeochemical and geochemical data of transect I South.

The six remaining species in the ground cover of this transect, are found in greater or lesser concentrations along the length of the transect line. They are, Stipagrostis uniplumis, a perennial grass, and the herbs Abutilon fruticosum, Hibiscus micranthus, Commelina forskaelae, Ruellia patula and Indigofera bainesii.

From the data on the tree and shrub cover, it is apparent that there is a marked increase in the number of smaller shrubs from 300 metres to about 450 metres. Beyond this, there is an increase of the number of taller trees of +4 metres, up to 600 metres along where the transect passes onto quartz feldspar porphyry. At this point the presence of Combretum apiculatum as shrubs and trees 1 - 2 metres tall is noted.

Figure 15 shows the geochemistry, biogeochemistry and geobotany of transect 2 north. The length of the transect from the base line, at 0, is 400 metres.

The soil copper in the -270 mesh fraction is shown graphically. Anomalously high copper is found at 0, where values of 320 p.p.m. copper were recorded. The anomaly tails off to 140 metres along the transect, where background values of 40 p.p.m. copper are found.

In the biogeochemistry only one leaf sample shows an anomalously high copper value of +3 standard deviations from the mean p.p.m. copper dry weight. There are sporadic high copper concentrations in stems and leaves sampled throughout the length of the transect.

Ecbolium lugardae is found in fair concentration from 0 to 100 metres along the transect. This is an area of above threshold copper in the soil. Then from 130 to 160 metres along the transect is a location of Ecbolium lugardae where background soil copper values are found. Over the areas where Ecbolium lugardae is

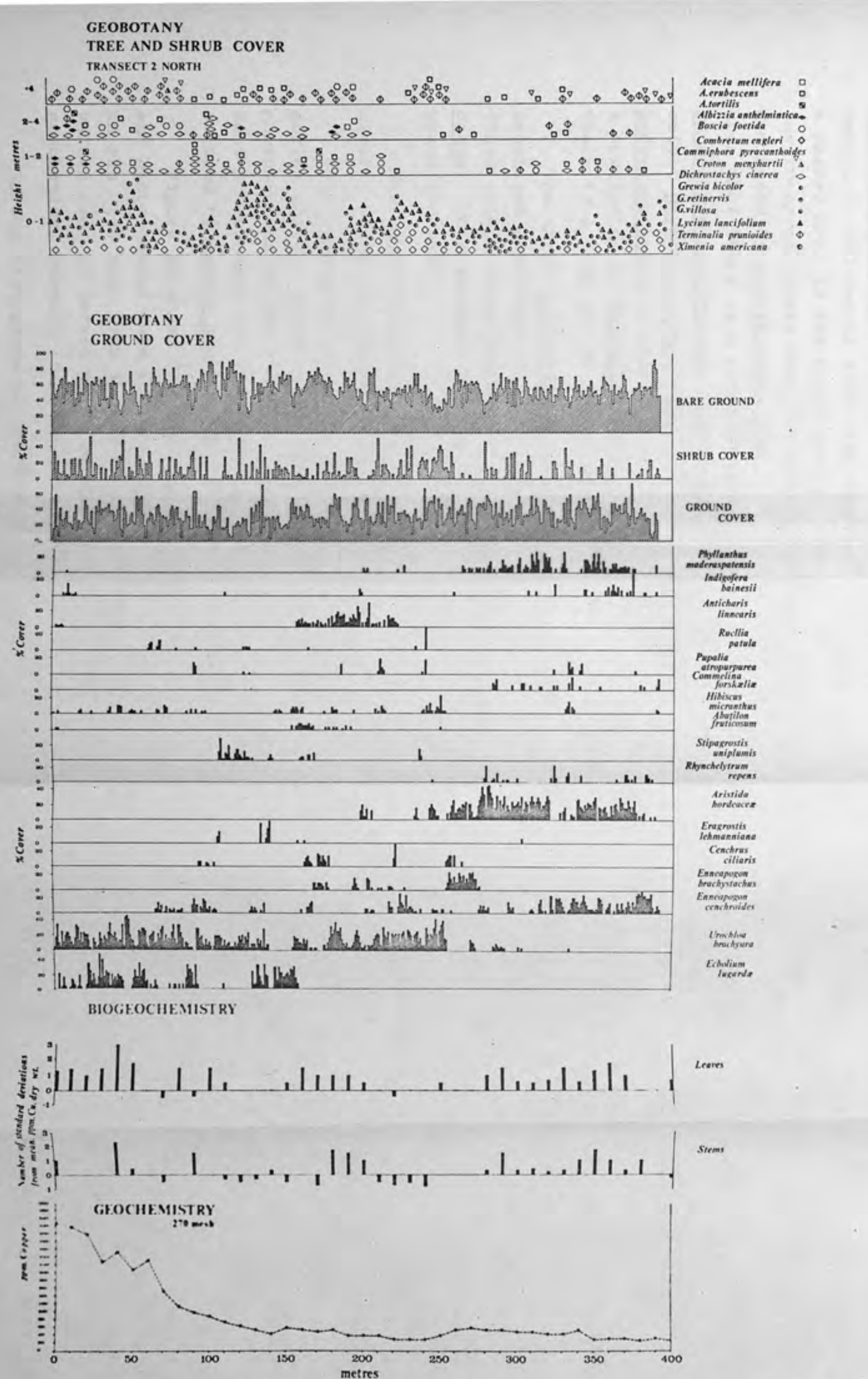


Figure 15. Geobotanical, biogeochemical and geochemical data of transect 2 North.

found is a marked increase in the number of trees and shrubs recorded in the +4 metre height category. Urochloa brachyura is prominent in the ground cover from 0 to 250 metres along the transect then there is a marked drop in the occurrence of this species where the transect passes onto the open savanna woodland, dominated by Acacia erubescens. It is in this latter area that there is a conspicuous increase in the grasses Enneapogon cenchroides, Aristida hordeacea and to a lesser extent Rhyncheletrum repens, the shrub Phyllanthus maderaspatensis is also present in fair concentration. A scattering of Commelina forskaelae is also evident. There is a drop in the % tree and shrub cover.

The shrub Anticharis linearis shows a distinctly localised distribution, from 160 to 230 metres. Confined within these boundaries is found Abutilon fruticosum. This includes an area of anomalous copper in plant tissues.

The remaining ground cover species are found sporadically along the length of the transect.

The number of trees and shrubs in the height categories above 1 metre show a marked drop towards the northern end of the transect. It is here that the transect passes into the open tree savanna woodland characterised by Acacia erubescens. (Figure 12, category 4).

Figure 16 shows the geochemical, biogeochemical and geobotanical data for transect 2 south. The copper in the -270 mesh soil fraction shows above threshold values from 10 metres to 50 metres along the line. This geochemical anomaly is reflected in the biogeochemistry.

In the histograms of the % ground cover the gaps at 300 and 400 metres along the transect are where tracks cross the line.

Ecbolium lugardae is found sporadically along the

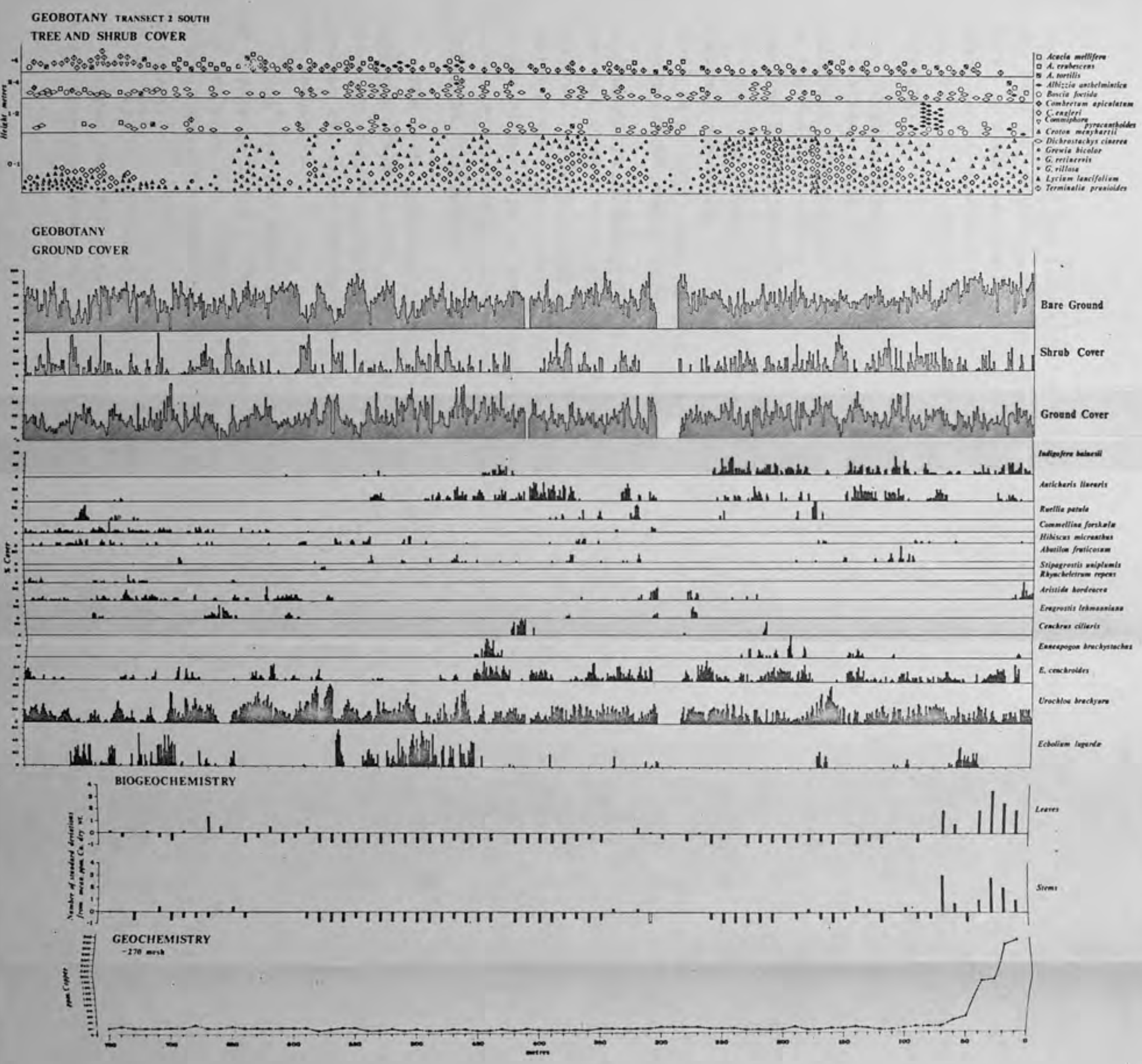


Figure 16. Geobotanical, biogeochemical and geochemical data of transect 2 South.

entire length of the transect. The largest concentrations are from 440 to 560 metres and from 690 to 770 metres. There is a smaller concentration of Ecbolium lugardae which can be associated to the copper anomaly. No species show a distribution similar to that of Ecbolium lugardae.

Urochloa brachyura is found in ~~more~~ greater or ~~less~~ lesser concentrations along the entire length of the transect. Eragrostis cenchroides is scattered along the length of the transect with a marked tailing off in concentrations beyond 450 metres.

The grass Enneapogon brachystachus is found in discrete concentrations up to 440 metres, beyond which there is no more. Cenchrus cilliaris is only found from 0 to 450 metres along the transect.

Aristida hordeacea is scattered all along the transect with a noticeable increase from 590 metres to the end. Rhyncheletrum~~s~~ repens is found in low concentrations from 700 metres to the transect end, which is on the scree slope of the quartz feldspar porphyry hill. Also found in the ground cover on the scree slope is Commelina forskaelae.

The herbs Anticharis linearis and Indigofera bainesii are both only found in the northern half of the transect, from 0 to 510 metres. The remaining herbs and grasses are found scattered along the entire length of the transect.

The tree and shrub cover shows a drop in the number of plants in the 0 - 1 metre category from 600 metres to the transect end. There is a corresponding slight increase in the number of plants recorded in the +4 metre height category.

These observations can all be linked to a change in the pedology and geology where at the southern end the transect crosses onto quartz feldspar porphyry with quartz rich skeletal soils. Here there is a definite change in the species making up the ground cover as well as a relative increase in the taller trees and shrubs.

Figure 17 gives the data for transect 3 north. Soil and plant tissue samples were analysed for their iron content. This will be discussed in the chapter dealing with biogeochemistry.

The copper concentration in the soil shows above threshold values from 0 to 100 metres. Once again the copper concentration in the plant tissues shows anomalous fluctuations along the entire length of the transect, with no marked anomaly associated to the geochemical anomaly.

Ecbolium lugardae is found over the geochemically anomalous area and extends slightly beyond. Showing a similar dispersion pattern to Ecbolium lugardae are Hibiscus micranthus and Abutilon fruticosum. To a lesser extent so does Anticharis linearis, excepting for a concentration from 400 to 450 metres which is coincidental with a concentration of Indigofera bainesii It is relevant to note that there are anomalous copper concentrations in the plant tissue of samples analysed from this area. The grasses Urochloa brachyura and Enneapogon cenchroides are found along the entire length of the transect.

Towards the northern end, the transect crosses into the open savanna woodland characterized by Acacia erubescens trees. The soil in this area is clayey and dark brown in colour. There are definite changes in the plant species associations in this area. The perennial grasses Eragrostis lehmanniana and Cenchrus cilliaris are found in the ground cover. There is also a relative increase in the taller tree and shrub cover with Acacia erubescens trees characterizing the 2 - 4 and +4 metre categories and the shrub Dichrostachys cinerea the 1 - 2 metre category.

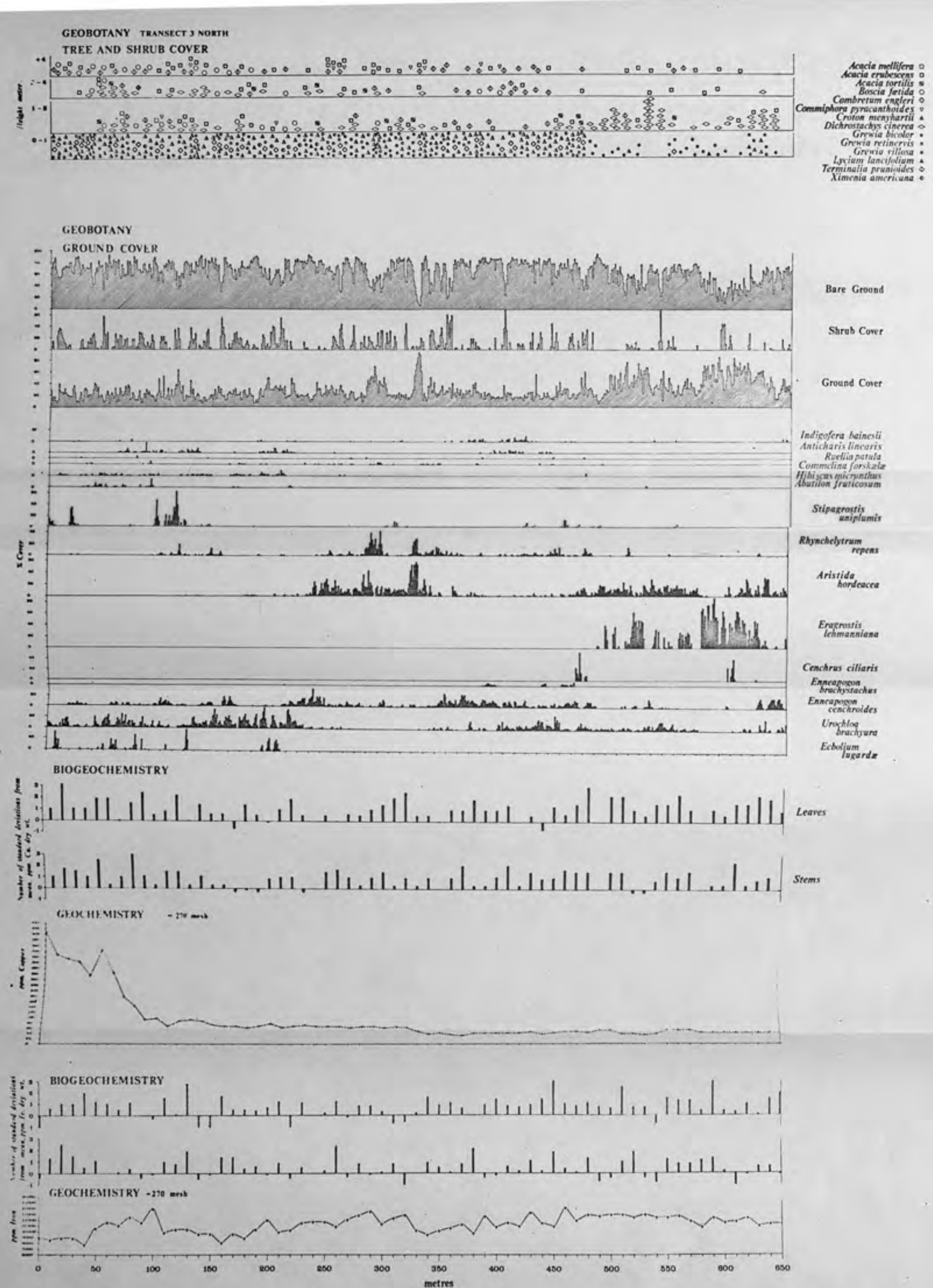


Figure 17. Geobotanical, biogeochemical and geochemical data of transect 3 North.

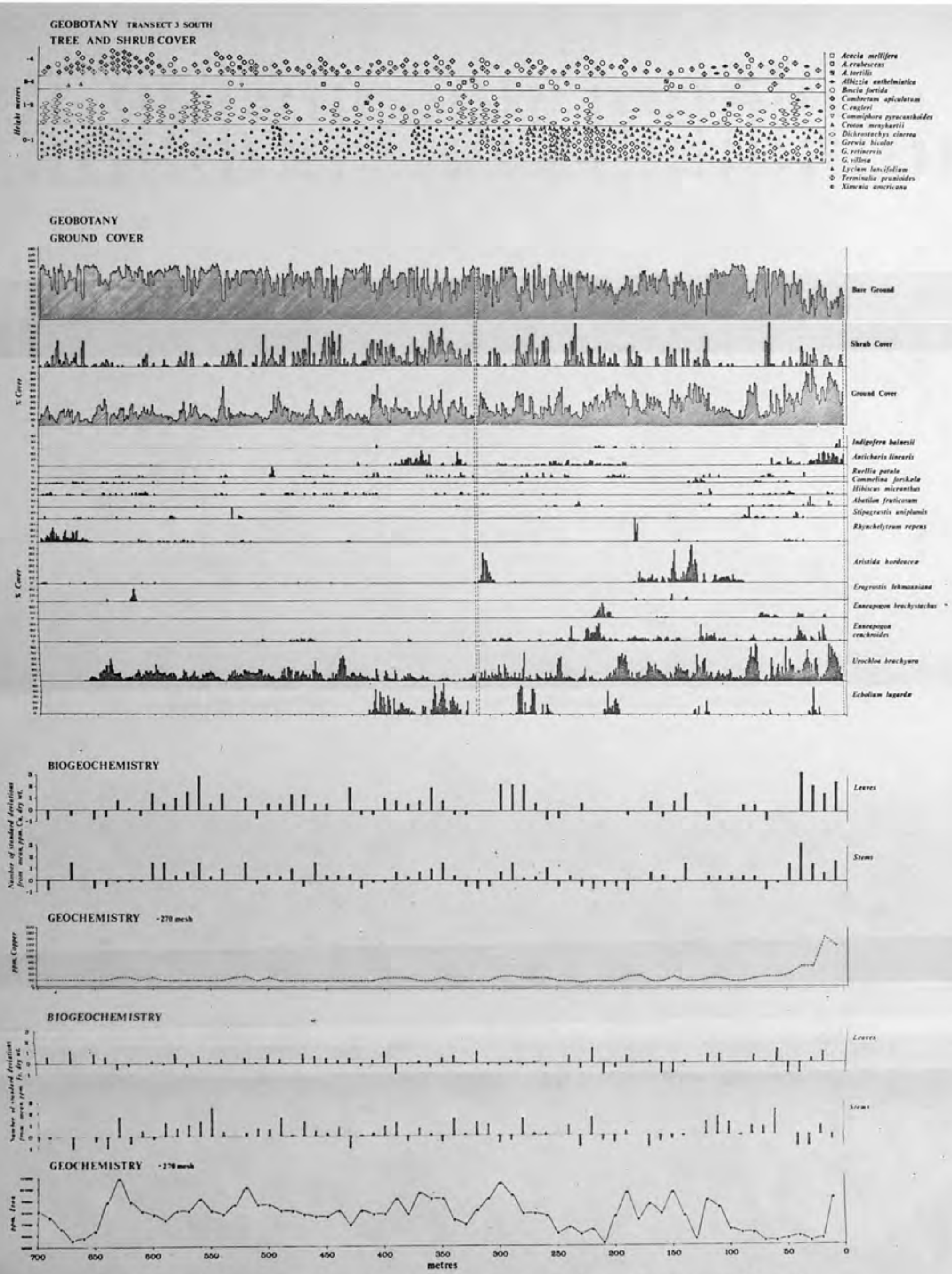


Figure 18. Geobotanical, biogeochemical and geochemical data of transect 3 South

The data for the southern half of transect 3 is on figure 18. The transect is 700 metres long and crosses a track at 320 metres.

The concentration of both iron and copper in soil and plant tissues is given on the figure. The copper in the soil is found in above threshold concentrations in the first 50 metres of the transect. Coincident with this above threshold copper in the soil are anomalous copper concentrations in the plant tissue analysed. There are positive fluctuations in the number of standard deviations from the mean p.p.m. copper dry weight for the leaves and the stems all along the transect, but the level over the high soil copper is markedly anomalous.

Ecbolium lugardae is found in varying concentrations from 0 to 400 metres along the transect, including the area of high copper concentrations in soils and plant tissue. Anticharis linearis and Indigofera bainesii show a distribution more or less sympathetic with that of Ecbolium lugardae.

There is a definite concentration of Anticharis linearis from 350 to 400 metres along the transect associated with which is Ecbolium lugardae. Significantly, there are anomalous copper concentrations in the plant tissues analysed from this vicinity.

At the southern end the transect crosses onto quartz feldspar porphyry with its characteristically skeletal soil developed. Here the grass Rhyncheletrum repens is conspicuous in the ground cover. The lower shrub cover is characterized by Grewia bicolor and the taller tree cover by Combretum apiculatum.

The following species are found indiscriminately scattered throughout the ground cover on the transect: Ruellia patula, Commelina forskaelae, Hibiscus micranthus, Abutilon fruticosum and the grass Stipagrostis uniplumis.

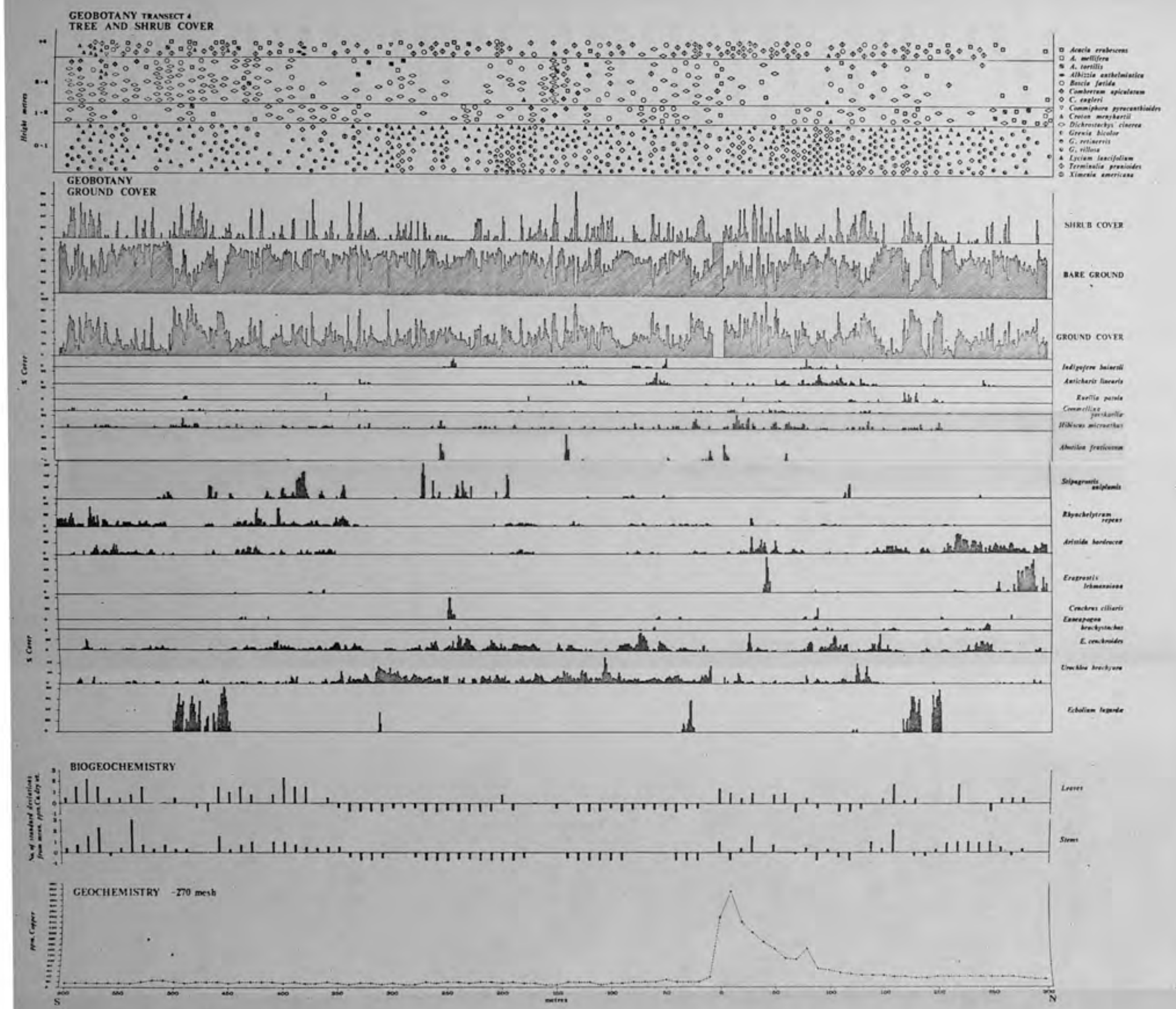


Figure 19. Geobotanical, biogeochemical and geochemical data of transect 4 North and South.

A consideration of figure 19 shows anomalous copper concentrations in the soil from 0 to 90 metres north along the transect. Also noticeable is the higher copper background in soils to the northern end of the transect.

The copper concentration in the plant tissues to the north of the baseline is seen to show positive fluctuations of the number of standard deviations from the mean p.p.m. copper dry weight of the leaves and stems.

To the south of the baseline there are anomalous copper concentrations in the plant tissue from 380 metres to the end of the transect. In this area there is a significant concentration of Ecbolium lugardae.

Ecbolium lugardae is not found directly associated with the anomalous copper geochemistry, there is a small concentration of this species to the south of the baseline from 30 to 40 metres. Then to the northern end of the transect Ecbolium lugardae is found from 160 to 180 metres and from 190 to 200 metres.

In the areas of open tree savanna woodland, characterised by Acacia erubescens, there is an increase in the relative concentrations of the grasses Eragrostis lehmanniana and Aristida hordeacea. The latter grass species is also found elsewhere on the transect, characteristically in areas of less shrub cover.

To the southern end, the transect passes onto ground underlain by quartz feldspar porphyry. Found growing in this vicinity is Rhyncheletrum repens as well as some Aristida hordeacea, here the remaining ground cover species show a marked drop in concentration.

This detailed geobotanical investigation shows that the shrub Ecbolium lugardae generally, but not specifically, reveals the areas of anomalous copper concentrations in the soil. This shrub characteristically grows in areas of relatively dense tree and shrub cover, the taller tree cover being dominated by Terminalia prunioides. Associated with Ecbolium lugardae are the herbaceous species Anticharis linearis and to a lesser extent Hibiscus micranthus, Abutilon fruticosum and Indigofera bainesii.

The relationship of Ecbolium lugardae distribution to anomalous copper in the surface soil, and the lack of relationship between the biogeochemical and geochemical values, could suggest that the Ecbolium lugardae distribution is indicative of higher copper values near surface whereas the analysis of plant tissues detects higher copper values at depth.

Ecbolium lugardae has been reported in areas to the north of the Mabeleapudi hills and in the vicinity of the Kgwebe hills. An investigation in the latter area did reveal suboutcropping copper mineralization similar to that found in the area of study.

A significant relationship between anomalous copper concentrations in plant tissue and the distribution of Anticharis linearis and to a lesser extent Abutilon fruticosum is apparent.

Definite species associations were revealed in areas of different pedology. To the north the soil is clayey and dark brown in colour. Here an open tree and shrub savanna woodland is found, and is characterized by Acacia erubescens trees and Grewia bicolor shrubs. There is a definite grass species association, namely Cenchrus cilliaris, Eragrostis lehmanniana and Aristida hordeacea.

To the south of the area of study is found quartz feldspar porphyry, with quartz rich skeletal soils developed. Here the ground cover is largely the grass Rhyncheletrum repens. The other ground cover species show a drop in relative concentration. The tree and shrub cover is characterized by the tree Acacia erubescens and the shrub Grewia bicolor.

CHAPTER VII

GEOCHEMICAL INVESTIGATION

The selection of the area around Ngwako pan for further investigation resulted from a reconnaissance trip to the area by Dr. le Roex, Dr. Nel, Dr. Söhnge and Professor M.M. Cole in 1967. A reconnaissance geochemical investigation, done under the direction of E.W.B. Miller and Associates, disclosed the presence of a copper anomaly in the surface soil north of the Ngwanalekau hills. In March 1968 the geobotanical anomaly characterised by Ecbolium lugardae was recognised and the results of the early geobotanical and geochemical work led to the selection of the area north of the Ngwanalekau hills for detailed studies.

Trenches were dug within the Ecbolium lugardae anomaly. These disclosed the presence of copper mineralization in argillite and limestone bedrock beneath a considerable thickness of calcrete.

The results of the reconnaissance geochemical survey indicated lower background levels of copper content in samples collected over areas of wind blown sand and certain areas where outcropping calcrete was reported.

The aim of this geochemical study was two fold. Firstly, to study the effect of calcrete overlying bedrock on the trace element levels in the surface soil, with particular reference to areas of sub-outcropping copper mineralization. Secondly, to study the relationship between the metal content in plant tissue and the metal content in soil.

The surface geochemical samples were collected along the grid lines shown in figure 11 (page 67). The sampling interval was 10 metres, and a biogeochemical sample was collected in the vicinity of the soil sample site. Soil samples were collected at a depth of 20 to 30 centimetres. It is at this depth that there is some evidence of oxide

CHAPTER VII

GEOCHEMICAL INVESTIGATION

The selection of the area around Ngwako pan for further investigation resulted from a reconnaissance trip to the area by Dr. le Roex, Dr. Nel, Dr. Söhnge and Professor M.M. Cole in 1967. A reconnaissance geochemical investigation, done under the direction of E.W.B. Miller and Associates, disclosed the presence of a copper anomaly in the surface soil north of the Ngwanalekau hills. In March 1968 the geobotanical anomaly characterised by Ecbolium lugardae was recognised and the results of the early geobotanical and geochemical work led to the selection of the area north of the Ngwanalekau hills for detailed studies.

Trenches were dug within the Ecbolium lugardae anomaly. These disclosed the presence of copper mineralization in argillite and limestone bedrock beneath a considerable thickness of calcrete.

The results of the reconnaissance geochemical survey indicated lower background levels of copper content in samples collected over areas of wind blown sand and certain areas where outcropping calcrete was reported.

The aim of this geochemical study was two fold. Firstly, to study the effect of calcrete overlying bedrock on the trace element levels in the surface soil, with particular reference to areas of sub-outcropping copper mineralization. Secondly, to study the relationship between the metal content in plant tissue and the metal content in soil.

The surface geochemical samples were collected along the grid lines shown in figure 11 (page 67). The sampling interval was 10 metres, and a biogeochemical sample was collected in the vicinity of the soil sample site. Soil samples were collected at a depth of 20 to 30 centimetres. It is at this depth that there is some evidence of oxide and sesquioxide accumulation typical of the B horizon. All samples collected were placed in Kraft type envelopes, and shipped to London for analysis in the laboratories of the Bedford College Geography department.

A full description of the decomposition technique used can be found in Appendix 2 (page 168).

The analysis precision control employed in the geochemical determinations is based on the Craven technique. A series of samples are prepared by mixing known proportions of two natural samples, one having a relatively low content of copper and the other a relatively high content. The control samples are submitted along with the routine samples. Once a sufficient number of determinations have been done the standard deviation on the results can be calculated, and will give an idea of the accuracy of the geochemical analysis.

The high copper and low copper samples were sieved to -270 mesh, and one hundred copper determinations were done on them. From these the average copper concentration was calculated, and the high copper was found to be 200 p.p.m. and the low copper 30 p.p.m. Then these samples were mixed in the following proportions by weight: 1:0; 0,9:0,1; 0,8:0,2; 0,7:0,3; 0,6:0,4; 0,5:0,5; 0,4:0,6; 0,3:0,7; 0,2:0,8; 0,1:0,9; 0:1.

This gave eleven control samples, of which one was submitted with every ten routine samples for copper assay. The expected p.p.m. copper of each sample, was calculated from the average copper concentration and proportion of each of the two constituents. These calculated values fall on a straight line when p.p.m. copper is plotted against the proportion of high component in the sample. (Figure 20). From this calculated concentration of copper the + and - 25% confidence levels were determined and depicted on the graph. The actual copper concentration of each control sample, was plotted on the above graph as it was determined. From this exercise

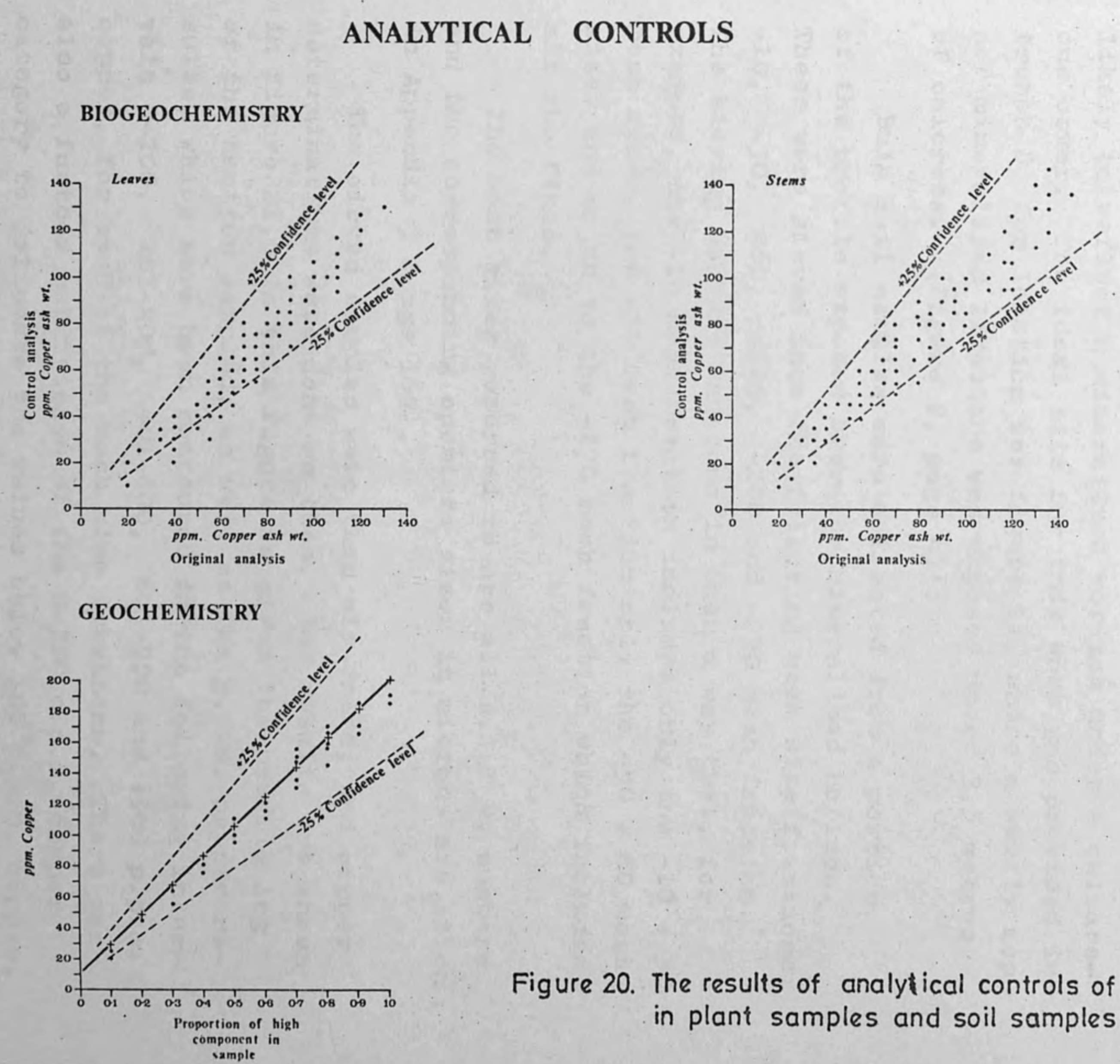


Figure 20. The results of analytical controls of copper determinations in plant samples and soil samples.

it can be seen that the deviation of the analysis falls well within the $\pm$ 25% confidence levels. (Figure 20).

During this geochemical survey, particular attention was paid to the relative concentration of copper in the various mesh size fractions. This was done, in an endeavour to select a mesh size fraction, which would be most likely to reflect a mineralized horizon under a calcareous cover. The ideal site for this work was provided in trench 8, for location see figure 11, where a weakly copper mineralized limestone was exposed under 3,5 metres of calcrete. (Figure 8, page 41).

Bulk soil samples were collected from a portion of the profile exposed over the mineralized horizon. These were sieved into the following mesh size fractions: -10, -30, -60, -120, -200 and -270 mesh fraction. The sieving was dry and done in such a way that, for example, the -10 mesh fraction includes only the -10 + 30 mesh sizes, the -30 mesh fraction only the -30 + 60 mesh sizes and so on to the -270 mesh fraction which includes all the fines.

The mesh sizes referred to are all A.S.T.M. numbers and the corresponding aperture sizes in microns are given in Appendix 3 (page 169).

The sieved samples were then air dried, and copper determinations were done on them. The results are shown in figure 21. In this figure is given the profile log of the section sampled, as well as the p.p.m. copper results, which have been contoured in the following intervals 0-200, 201-400, 401-600, 601-900 and +900 p.p.m. copper, for each of the mesh size fractions. There was also a further subdivision of the 0-200 p.p.m. copper category to delineate the values below 100 p.p.m. copper.

The immediate consideration for practical prospecting purposes, is which of the fractions gives the best indication of the mineralized horizon at the sampling depth decided on, namely 20 - 30 centimetres. From figure 21

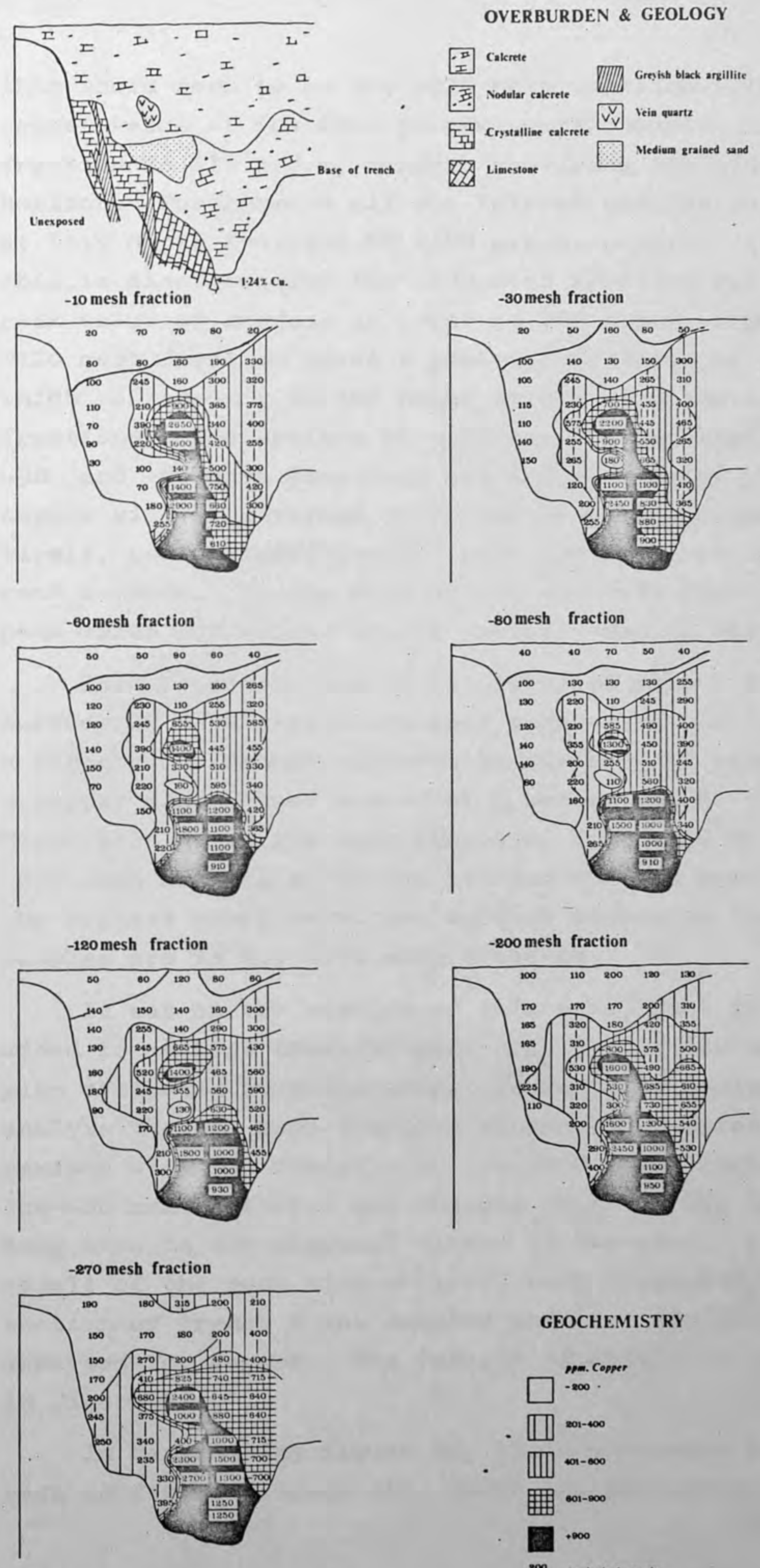


Figure 21. Profile distribution of copper in various mesh sizes - trench 8.

this would seem to be the -270 mesh fraction. The peak copper value of the 20 - 30 centimetre samples in this fraction is 315 p.p.m. copper, overlying the mineralized horizon. Furthermore all the lateral samples collected at this depth analysed at +100 p.p.m. copper. (Figure 21). This is also true for the -200 mesh fraction but here the peak value at surface is lower at 200 p.p.m. copper. The -120 mesh fraction shows a peak copper value of 120 p.p.m., which corresponds to the peaks in the -200 and -270 mesh fractions. The surface 20 - 30 centimetre samples of the -30 and -60 mesh fractions all analysed below 100 p.p.m. copper with peak values of 70 and 90 p.p.m. copper respectively, peaks significantly above the level of the adjacent samples. In the case of the -30 mesh fraction a peak value for copper in the surface samples was 160 p.p.m.

This consideration of the level of copper in the surface 20 - 30 centimetre soil samples, seems to indicate a dispersion through calcrete to surface, of copper from a copper mineralized source at 3 metres depth. The widest dispersion is in the fine fraction, from -120 mesh to -270 mesh as well as in the coarser -30 +60 mesh fraction. The highest absolute values of soil copper in the surface samples are in the -270 mesh fraction.

It was on the results of this work, that it was decided to analyse the -270 mesh fraction of the soil samples collected over the area. It was also decided, to analyse the -80 mesh fraction of certain samples for comparison with the analysis of the -270 mesh fraction. The -80 mesh fraction was decided on as it was the fraction used in the regional survey of the area. Also as a result of the mesh size analyses work described, a further section of trench 8 was sampled and the -270 mesh fraction analysed for copper. The results of this work are shown in figure 22.

In considering figure 22, it is necessary to refer back to figure 8 (page 41), where the geological log of

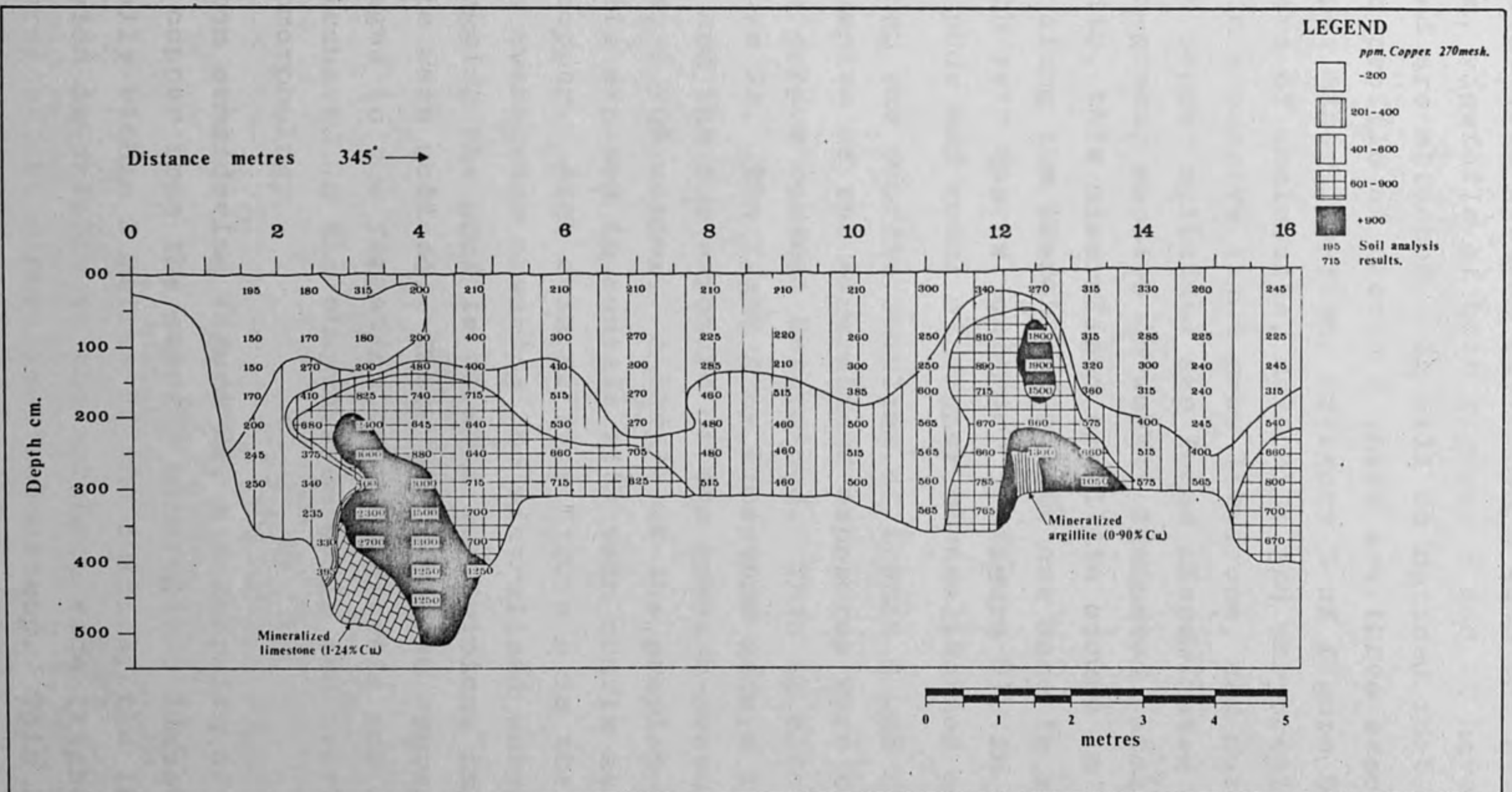


Figure 22. The distribution of copper in the -270 mesh fraction of samples collected in the profile of trench 8.

the entire profile of trench 8 is given, including the section sampled in detail. For ease of comparison of the geochemical section of trench 8 with the geological section, viewfoils of both figures 8 and 22 have been made and are attached. It will be noticed that in the sampled profile of trench 8 there are three exposures of copper mineralization, category 1 of figure 8 where stringers of chalcocite, malachite and chrysocolla are found in a massive light grey limestone, and category 6 where copper sulphides are found disseminated in a greyish-green, massive to weakly laminated calcareous argillite, this mineralized argillite occurs in two places along the trench and in the one case is associated with vein quartz (category 9, figure 8), in which blebs, pods and veins of copper mineralization occur.

When the profile sampling of trench 8 was done, rock samples of the mineralized exposures were taken and the copper content determined. This is also given on figure 22. The light grey limestone assays 1,24% copper and the one exposure of the greyish-green argillite, 0,90% copper. A sample of the greyish-green argillite exposed in contact with vein quartz assayed 0,05% copper. Also evident from figure 8 is the calcareous overburden covering the mineralized suboutcrop. When logging the profile various subdivisions in the calcrete were noticed. These are taken to represent the stages in the formation of the calcrete and have been discussed in the chapters on soils and overburden, and geomorphology.

When considering figure 22, a dispersion of +900 p.p.m. copper from the exposed mineralized limestone is vertically within 2 metres of the surface, the lateral dispersion is chiefly to the northern side (right hand of figure) of the mineralized suboutcrop. This level of copper was found chiefly in the nodular calcrete containing fragments of unreplaced argillite, limestone and quartz. A kink in the vertical dispersion pattern of copper is caused by lower copper values in a fine to medium grained sand immediately above the mineralized limestone.

The +900 p.p.m. level of copper, in the vicinity of the mineralized argillite, occurs in two discrete areas. The one immediately above and lateral to the mineralized suboutcrop, the lateral dispersion tends to the north. The second area of +900 p.p.m. copper is +50 centimetres above the mineralized suboutcrop, in a horizon of nodular calcrete with unreplaced fragments of argillite and limestone.

The 601 - 900 p.p.m. level of copper above the mineralized limestone, shows a lateral dispersion predominantly to the north. A zone of 601 - 900 p.p.m. copper encompasses the two areas of +900 p.p.m. copper found in the vicinity of the mineralized argillite.

The 401 - 600 p.p.m. copper level occurs along the entire length of the profile samples, and is largely found in and immediately above, the hard crystalline calcrete horizon. (Figure 8, category 2).

The 201 - 400 p.p.m. level of copper is found to within 30 centimetres of the surface, and from 2,5 metres along the entire length of the trench sampled to 16 metres.

From this study in the profile of trench 8, where mineralized suboutcrop is exposed beneath 3 metres of calcrete, it is apparent that there is a dispersion of above threshold copper values in the -270 mesh fraction to within 20 centimetres from surface.

Once the extent of copper dispersion in the -270 mesh fraction had been established, this fraction in all samples collected over the area was analysed for copper. The results of these determinations on samples collected on a grid over the area were plotted on plan and contoured at intervals of 0 - 20, 21 - 50, 51 - 100, 101 - 150, 151 - 200, 201 - 250 and +250 p.p.m. copper. (Figure 23).

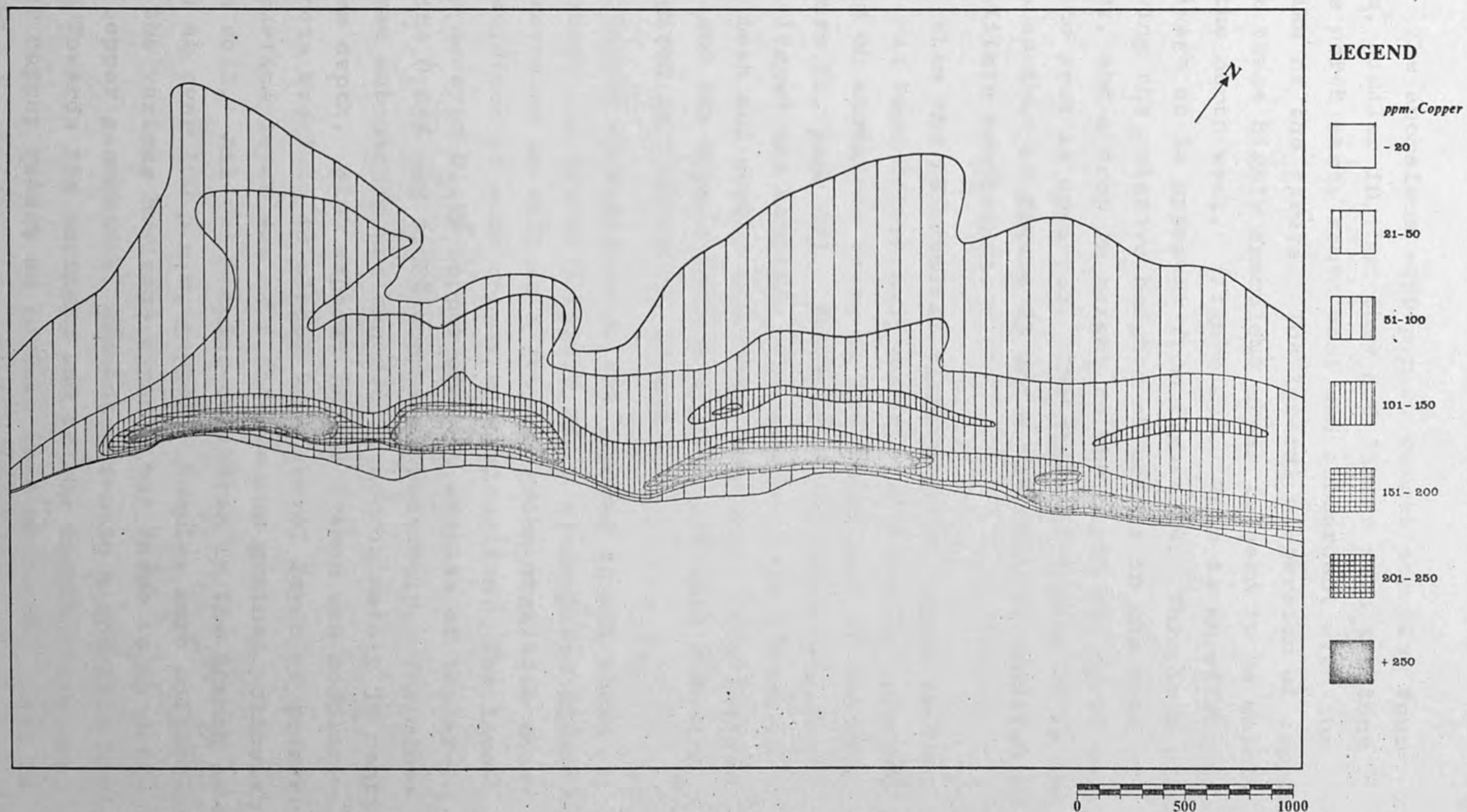


Figure 23. The secondary dispersion of copper in the - 270 mesh fraction of surface soil in the area north of the Ngwanalekau hills.

The anomalous +250 p.p.m. copper occupies four areas, similar in that they are linear with the long axis north east, south west and concordant with the strike of the strata. The lateral dispersion of copper from these highly anomalous areas is seen to be mainly to the north west. (Figure 23). This is an effect of drainage as is apparent from figure 24. This is a plan showing the relative heights of points in the area of study, and a drop in height to the north and north west of the area is apparent. The scale of figure 24 is the same as that of figure 23 and a viewfoil is supplied to facilitate comparison.

When the geochemical dispersion of copper in the area had been determined, numbers 5, 6 and 7, were excavated on anomalous areas to the north east of the area. (Figure 11, page 67). The profile of these trenches were logged and sampled. The samples were sieved to -270 mesh and copper determinations done. The profile logs and the copper content in the -270 mesh fraction are given in figures 25, 26 and 27.

Copper mineralization was exposed in all three trenches. In trench 5 figure 25, a mineralized limestone was revealed as well as a greyish green argillite showing evidence of some copper mineralization. The limestone assayed 0,15% copper and two samples of the argillite 0,05% and 0,08% copper respectively. The mineralized suboutcrop was exposed at approximately 50 centimetres depth. Also exposed in the trench was nodular calcrete overlain in places by a gravel layer of quartz. The surface layer was of a fine-medium grained yellowish brown soil. All the samples collected in the trench assayed at over 100 p.p.m. copper. Samples were collected from the various horizons exposed but there is no definite copper geochemical concentration in a specific horizon. Towards the northern end of the trench there are higher copper values on surface than at depth. This is probably due to drainage which is in a northerly to north westerly direction.

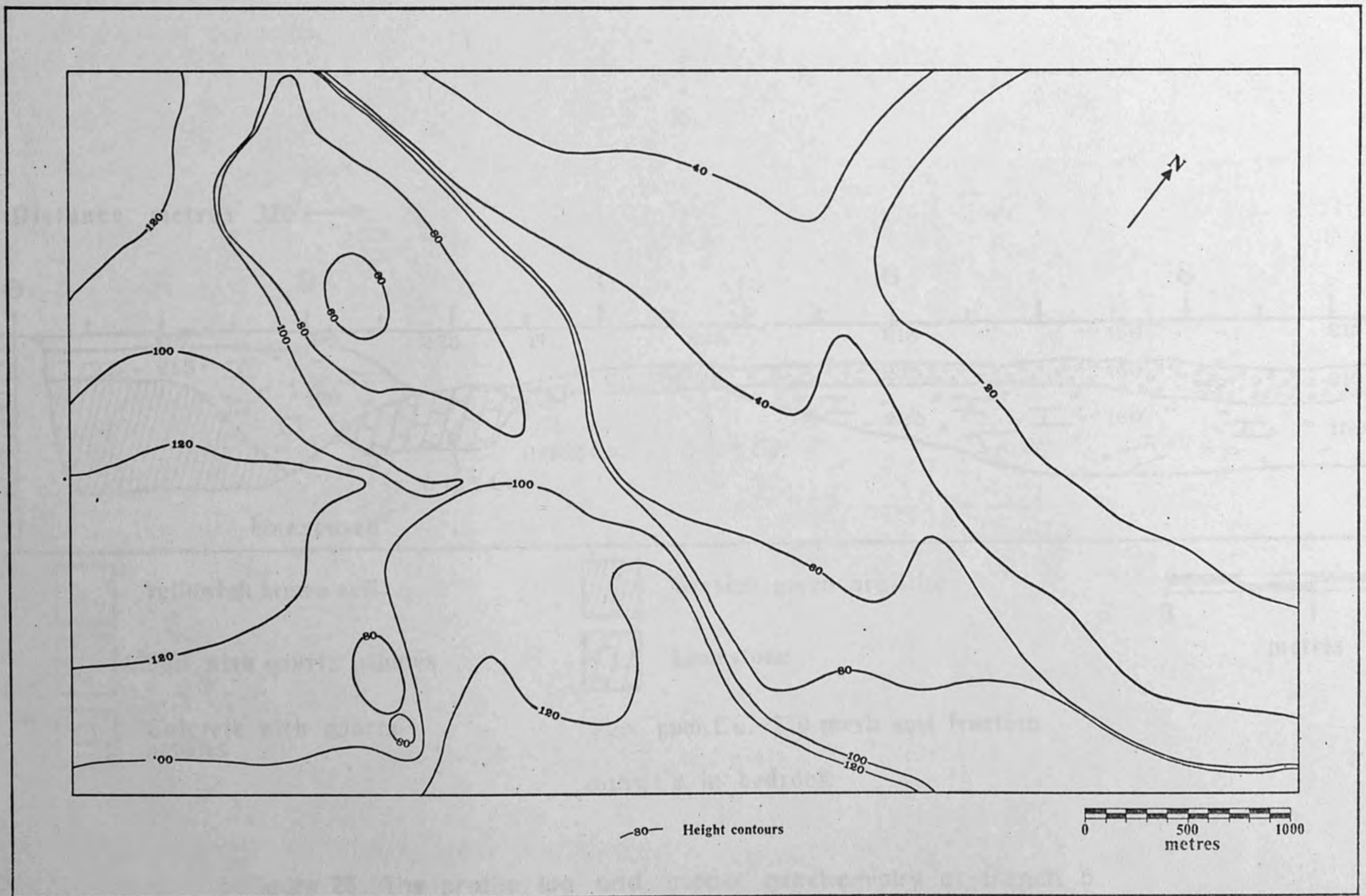


Figure 24. Topography of area to the north of the Ngwanalekau hills.

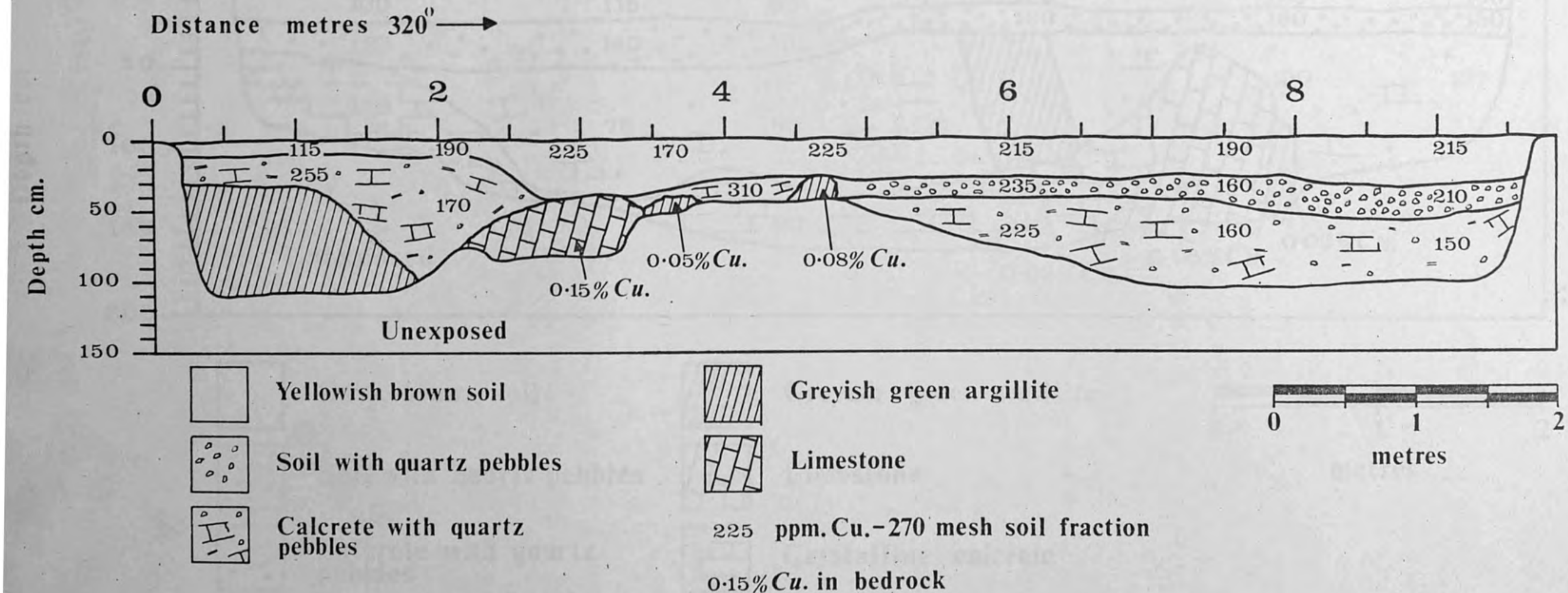


Figure 25. The profile log and copper geochemistry of trench 5.

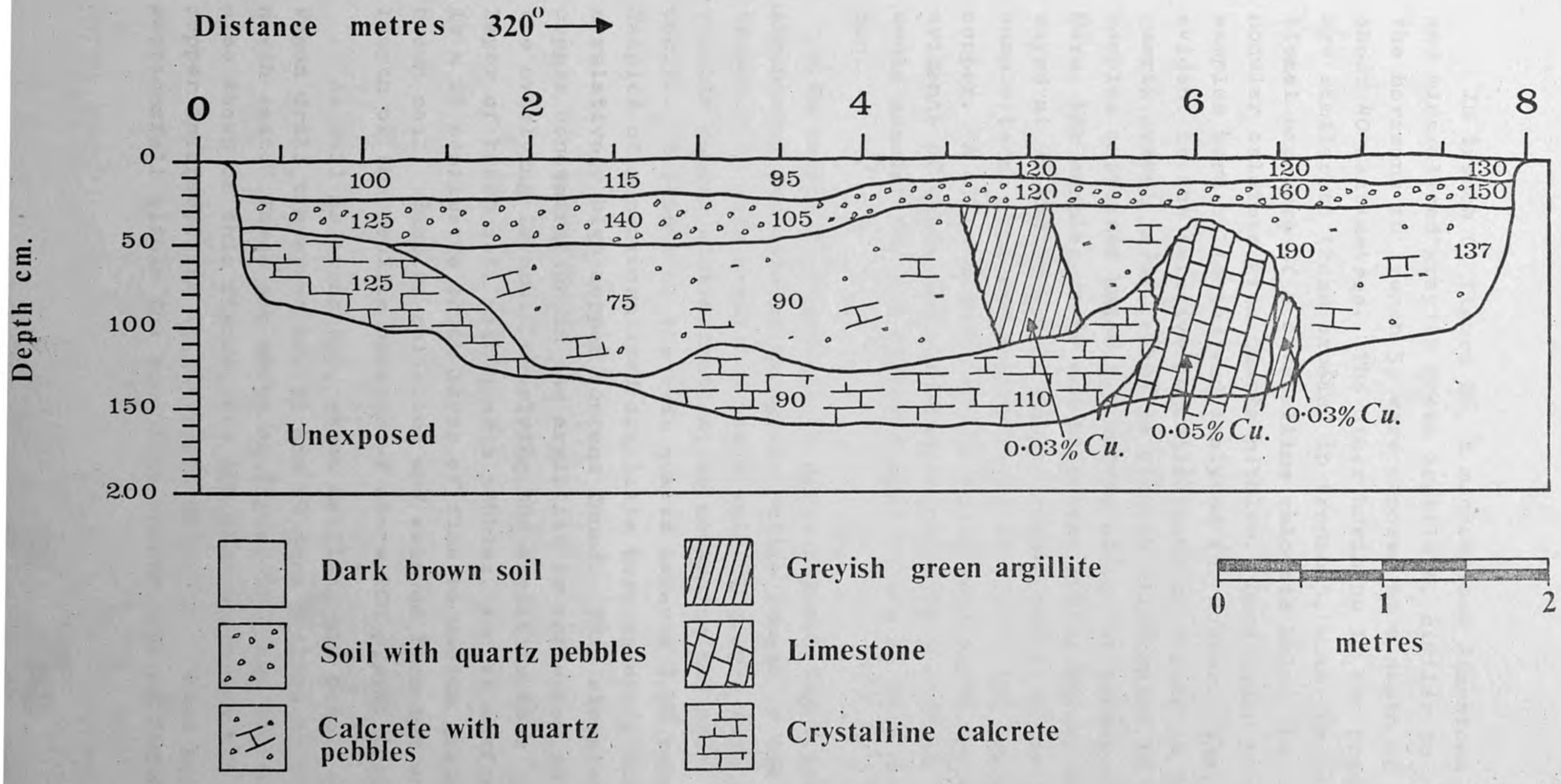


Figure 26. The profile log and copper geochemistry of trench 6.

In trench 6, figure 26, a mineralized limestone and mineralized greyish green argillite, similar to the horizons in trench 5, were exposed at a depth of about 40 centimetres. The other horizons in the profile, are similar to those exposed in trench 5, with the additional exposure of a crystalline calcrete below the nodular calcrete with quartz pebbles. Once again profile samples were collected and analysed for copper. What is evident is the relative concentrations of copper in the quartz gravel layer. This is clearly illustrated in the samples collected below 3,5 metres along the trench. Here, the samples above and below the gravel layer, assayed at 95 and 90 p.p.m. copper respectively, while the sample taken from the gravel layer assays at 105 p.p.m. copper. A close examination of the gravel layer shows evidence of oxide and sesquioxide accumulation which would account for the higher copper values in this horizon.

In trench 7, figure 27, a greyish green argillite suboutcrop was exposed along the entire length of the trench. In this argillite was a vein of quartz with visible copper mineralization, as malachite and chalcocite. A sample of the vein quartz assayed 2,5% copper. Samples of non-mineralized argillite were assayed, and a relatively high copper content found. This elevated copper concentration in the argillite is reflected in the overlying layers. Overlying the argillite is a layer of brown soil with quartz pebbles, and at surface is a 15 centimetre thick layer of fine to medium grained brown soil. Samples collected and assayed from the entire length of the profile assayed at above 200 p.p.m. copper.

As well as trenching, wagon drilling was done. Wagon drill traverses 12, 13 and 14 were drilled in the north east. These are shown on figure 11 (page 67) and also shown on this figure, are the plan positions of copper intersections in the wagon drilling. These intersectionsfall within the anomalous copper zone of figure

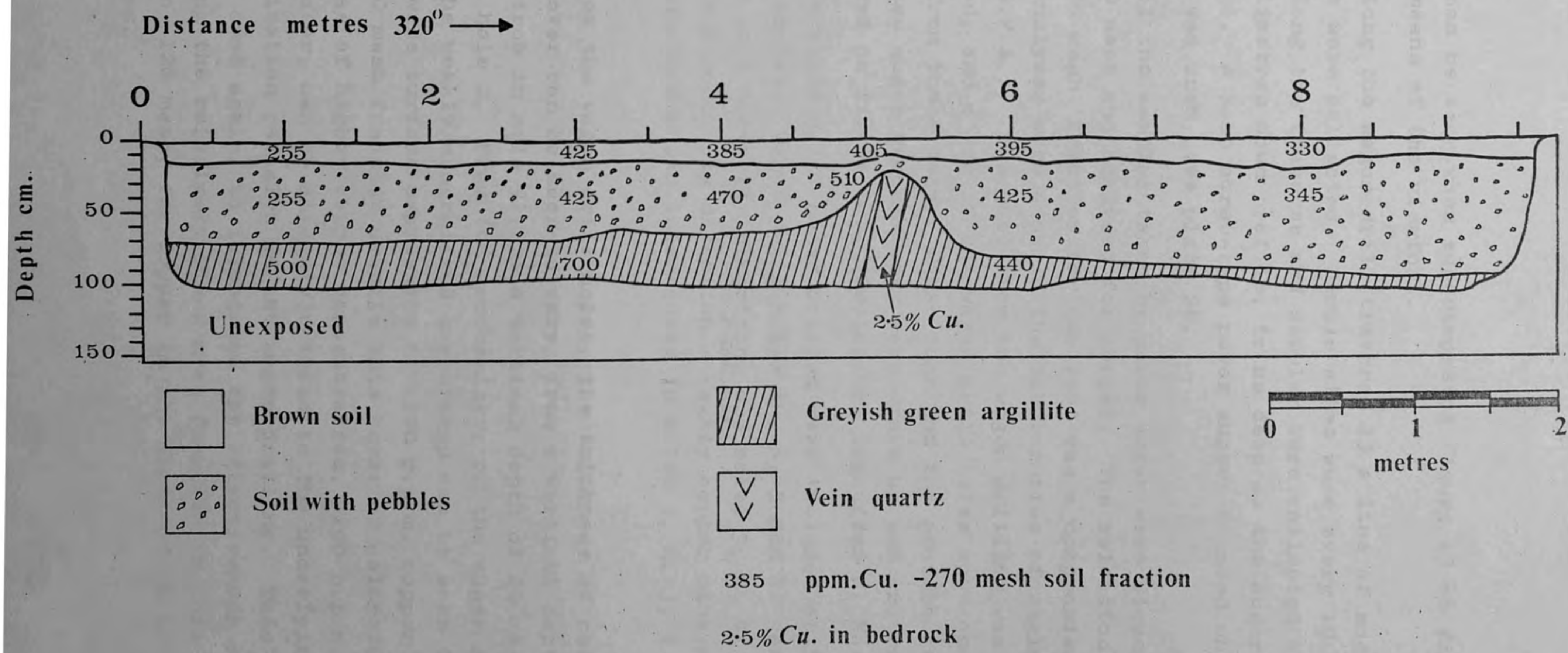


Figure 27. The profile log and copper geochemistry of trench 7.

23 as can be seen when superimposing figure 23 on figure 11 by means of the viewfoil.

Along the wagon drill traverse 13 a line of auger samples were collected. Sample sites were every 10 metres along the traverse and samples were collected every 50 centimetres down profile, to as deep as the auger would go. A Seco screw-type power auger, mounted on a truck, was used, see plate 24.

All the samples taken by power auger were sieved to -120 mesh and analysed for copper. The selection of the -120 mesh fraction for analyses was a compromise. These analyses were done in the laboratories of Anglovaal (S.W.A.). The dust from the wagon drilling was examined, and a log of the wagon drill holes was compiled from these data. These logs and the profile of the power auger geochemistry were drawn up and are represented on figure 28. (Geological log after N. Norman).

The wagon drill holes drilled were inclined at 55° to horizontal. Wagon drill holes 80, 4, 3 and 82 were drilled in a northerly direction, and holes 5, 2, 91 and 1 in a southerly direction. A suboutcrop, Weakly copper mineralized, ~~suboutcrop~~ was intersected in holes 4, 2, 3, 1 and 91.

From the wagon drill holes, the thickness of calcrete cover can be seen to vary, from a vertical depth of 7 metres in hole 91, to a vertical depth of 20 metres in hole 2. From the geochemistry of the auger samples, the weakly mineralized suboutcrop can be seen to have a wide surface expression of +100 p.p.m. copper in the -120 mesh fraction despite this cover of calcrete. The areas of higher copper concentration, +200 p.p.m. and greater, can be directly related to the underlying mineralization revealed in the wagon drilling. This serves, once again, to illustrate the effectiveness of analysing the relatively finer mesh fraction in this case the -120 mesh, for copper in the areas of calcrete formation.

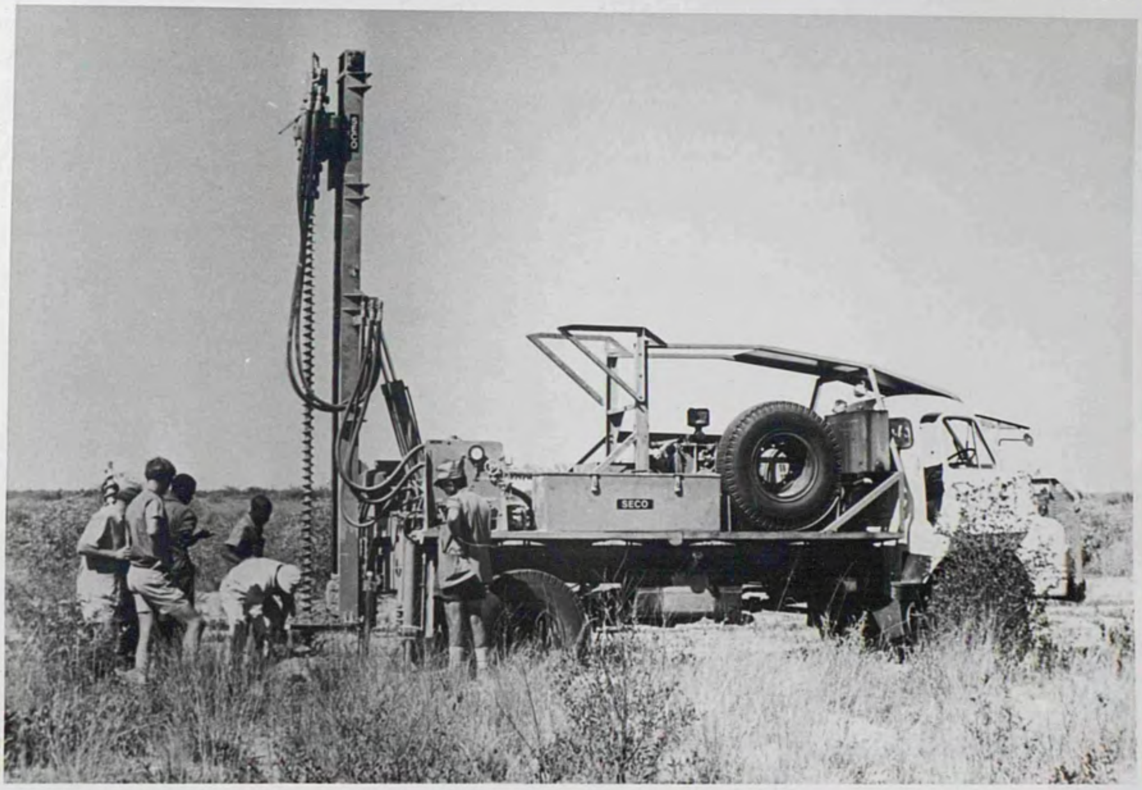


Plate 24. The Seco power auger used for sub-surface geochemical sampling. (MMC/Bot/38/6A).

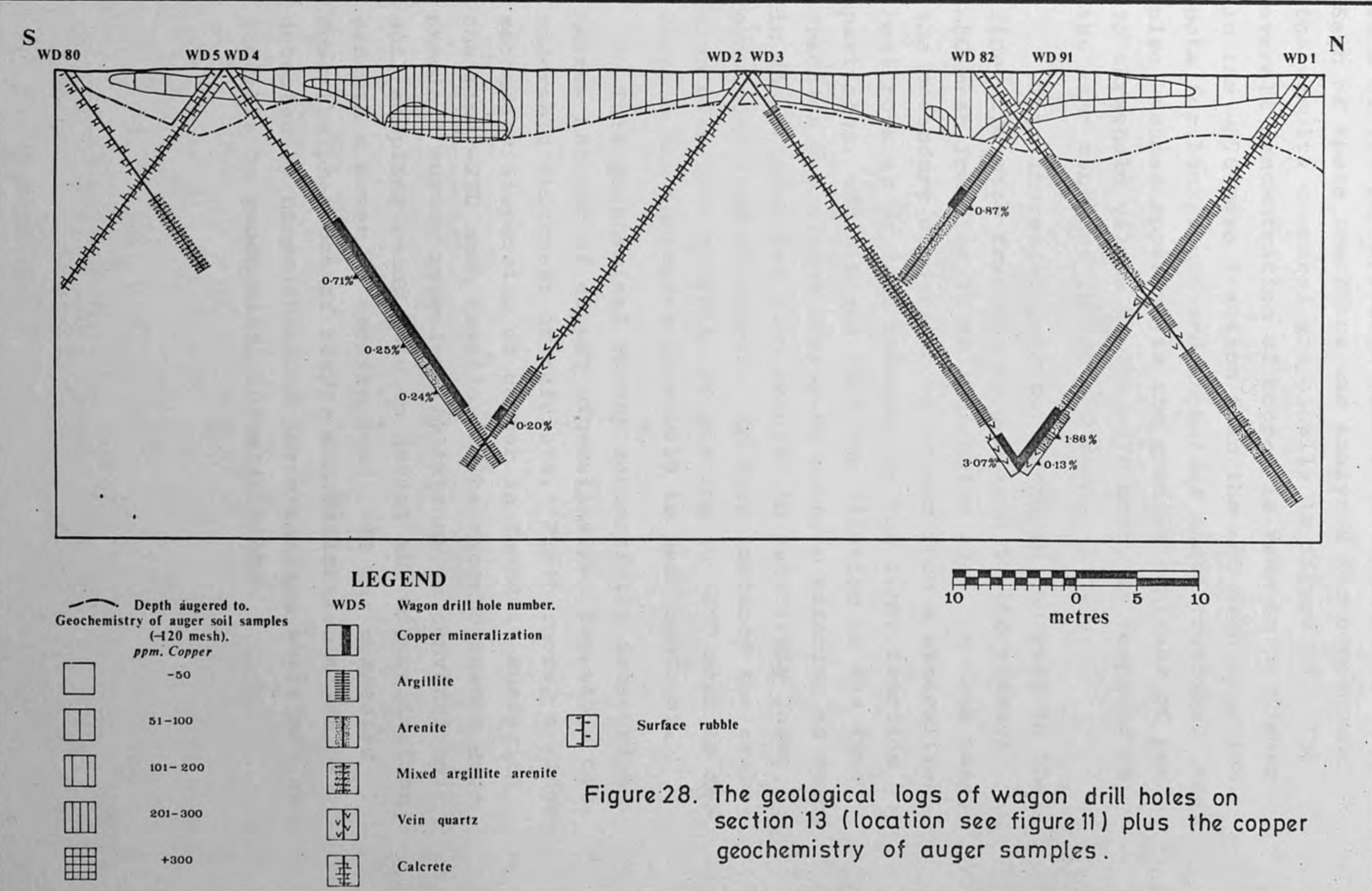


Figure 28. The geological logs of wagon drill holes on section 13 (location see figure 11) plus the copper geochemistry of auger samples.

Certain surface soil samples from transect 12, were sieved to -270 mesh and to -80 mesh fractions. Each of these fractions was analysed for copper and the results compared graphically in figure 29. The overall concentration of copper is seen to be higher in the -270 mesh fraction than the -80 mesh fraction, both for background and anomalous concentrations. What also becomes apparent is the greater contrast of peak to threshold values in the -270 mesh, as compared to the same contrast in the -80 mesh.

This increased peak to threshold contrast in the fine -270 mesh fraction as compared to the coarser -80 mesh fraction is an indication that, in this case, the secondary dispersion of copper from a mineralized host rock is as ions absorbed to the finer fraction particles. This means that the dilution of the fine fraction containing copper by coarser material as found in the-80 mesh fraction results in relatively lower concentrations of copper. In this instance the exclusion of coarse material by sieving to -270 mesh is desirable and increases threshold to peak contrast.

This geochemical survey successfully detected a narrow horizon of copper mineralization beneath a considerable thickness of calcrete. Furthermore, a wider secondary dispersion of copper is found in analysing the fine -270 mesh fraction. The reconnaissance geochemical survey revealed limitations in conventional soil sampling being able to detect any mineralization beneath a cover of aeolian sand. It was suggested that the presence of copper mineralization might be detected by biogeochemical investigation where not detectable by geochemical investigation.

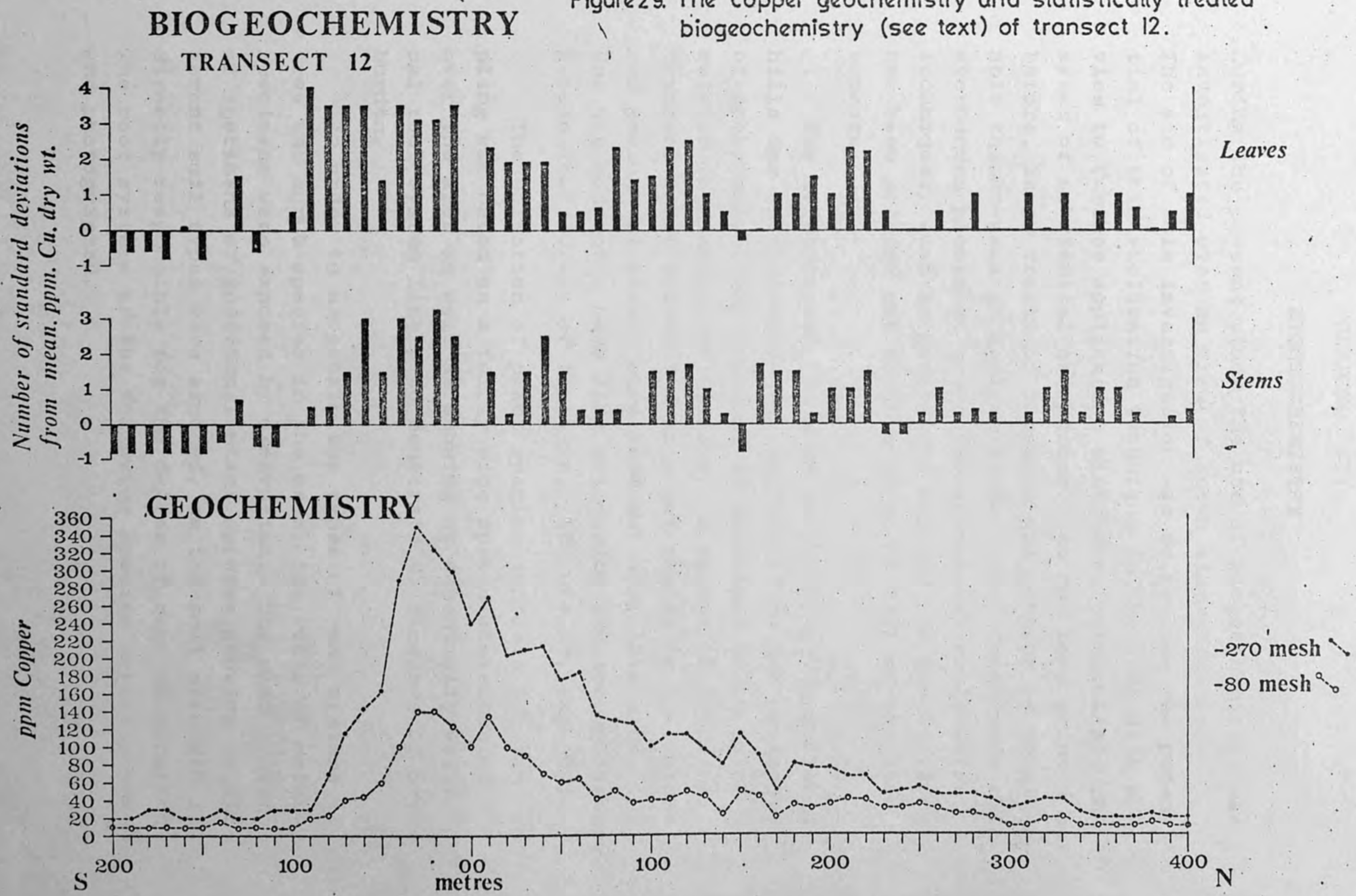


Figure 29. The copper geochemistry and statistically treated biogeochemistry (see text) of transect 12.

CHAPTER VIII

BIOGEOCHEMISTRY

During the present study the use of biogeochemistry was investigated over an area of known mineralization. The aim of this investigation was to realise the potential of this exploration technique in the area with a view to further application elsewhere, particularly in areas of substantial overburden. As has been pointed out before, large tracts of Botswana are covered by considerable thicknesses of aeolian sands. The limitations this overburden places on conventional mineral exploration techniques, such as geological mapping and geochemistry, has been pointed out in this work, as well as by other workers.

The selection of the area north of the Ngwanalekau hills for initial study was influenced by the presence of geobotanical and geochemical anomalies found to be related to mineralized bedrock. A series of parallel transect lines orientated at right angles to the inferred geological strike were laid out over this area. Use was made of a base line cut during the reconnaissance geochemical survey of the area. (Figure 11, page 67).

The selection of plant species suitable for sampling was based on a fairly wide spread distribution over the area as well as showing an essentially vertical root system likely to penetrate thicknesses of overburden.

In order to ascertain the types of root systems of tree and shrub species in the area, the roots of mature specimens were exposed by excavation. The root systems of specimens of individual plant species growing on different soil types were exposed, as the soil strength is directly responsible for the degree of root penetration. The root systems of the following species were exposed and photographed.

Plate 25. Terminalia prunioides showing partially exposed root system. (M.M.C/Bot/29/8A-9).

Plate 26. A close up view of a partially exposed root system of Terminalia prunioides showing the well developed tap root and lateral roots. (MMC/Bot/29/9A-10).

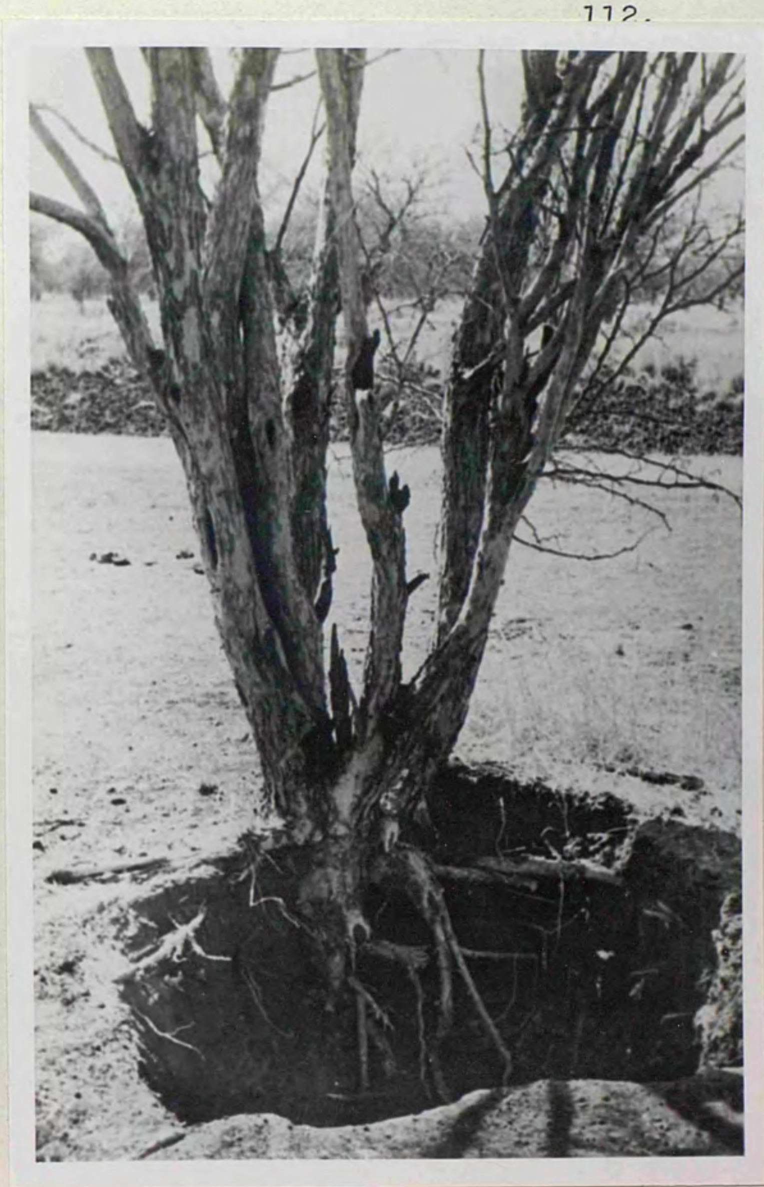


Plate 27. A view of an Acacia erubescens plainly showing the exposed root system. (MMC/Bot/29/20A-21)

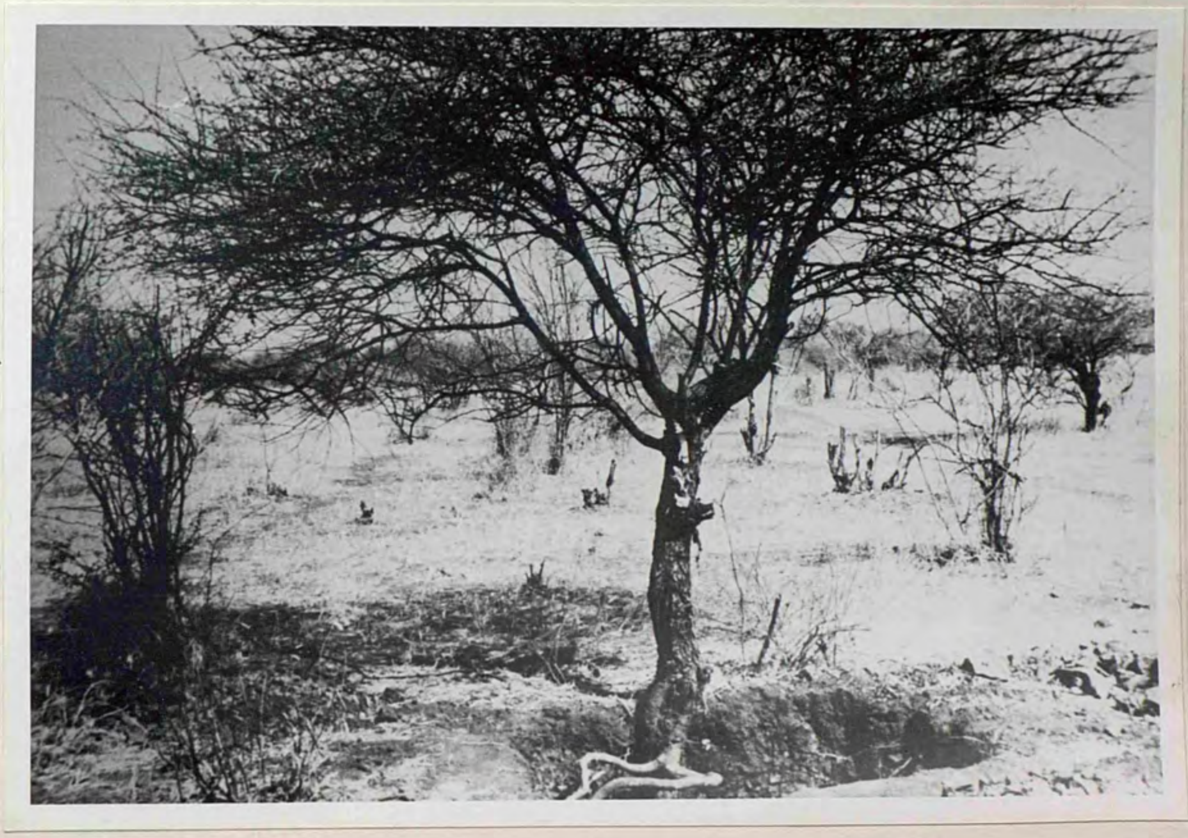


Plate 28. Acacia tortilis with part of the root system exposed. (MMC/Bot/29/21A - 22).

Plate 29. A close up view of the partially exposed root system of <u>Acacia tortilis</u>. (MMC/Bot/29/23A-24).

Terminalia prunioides (Plate 25 and 26)
Acacia erubescens (Plate 27)
A. tortilis (Plate 28 and 29)
A. mellifera (Plate 30 and 31)
Croton menyhartii
Dichrostachys cinerea (Plate 32)
Commiphora pyracanthoides ssp. glandulosa (Plate 33)
Grewia bicolor (plate 34)
Combretum apiculatum (Plate 35)

In order to determine the relative occurrence of tree species over the area, various belt transects were run. In these, the number of mature specimens of tree and shrub species were noted. On the results of these selection techniques, the following species were selected as being the most suitable for biogeochemical sampling:

(a) Terminalia prunioides a tree species making up 30% of the tree and shrub community and with a well developed tap root. (Plate 26).

(b) Acacia erubescens which accounts for about 20% of the trees and shrubs in the area and has a fairly prominently developed vertical root system. (Plate 27).

(c) Croton menyhartii a shrub species totalling 15% of the community and with a well developed tap root.

(d) Dichrostachys cinerea a large shrub species which accounts for 10% of the tree and shrub community and has a well developed tap root. (Plate 32).

Once the species for biogeochemical sampling had been selected, plant samples were collected at 10 metre intervals along the transect lines. (Figure 11, page 67). A sample for geochemical analyses was collected at the same site. In taking the plant samples care was taken to adopt a uniform procedure, a procedure which had been decided on, on the basis of findings of other workers in the field of biogeochemistry. Among these, were Warren and Delavault (1949) who found that the element content of a plant sample was affected by the maturity of the plant part collected and also by the relative position of the part on the plant.

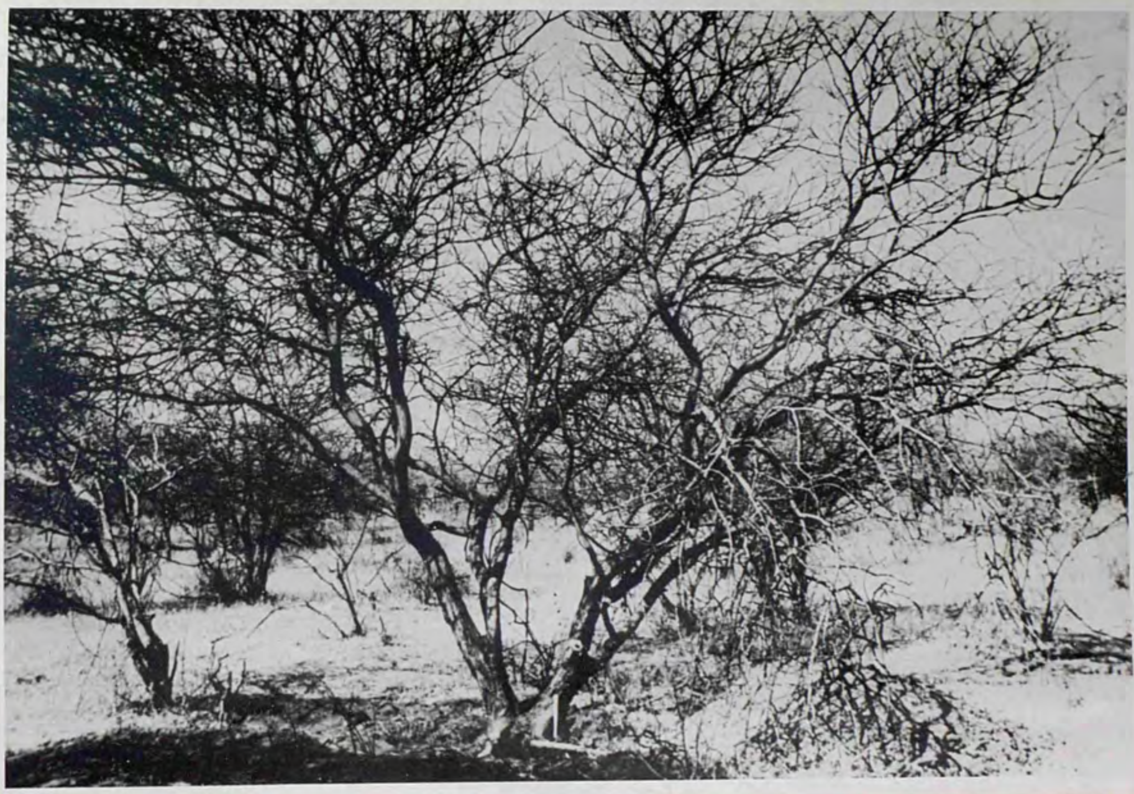


Plate 30. Acacia mellifera tree with part of the root system exposed. (MMC/Bot/29/27A - 28).

Plate 31. A close up view of the partially exposed root system of <u>Acacia mellifera</u> showing the well developed lateral roots. (MMC/Bot/29/28A-29)

Plate 32. A Dichrostachys cinerea plant with part of the root system exposed to show the well developed tap root. (MMC/Bot/29/10A-11).

Plate 33. A view of the Commiphora pyracanthoides ssp. glandulosa tree showing the partially exposed root system with the well developed tap root.

(MMC/Bot/29/25A-26A).

Plate 34. A close up view of a partially exposed root system of Grewia bicolor showing the characteristically lateral root system. (MMC/Bot/29/30A-31).

Plate 35. A view of the root system of <u>Combretum apiculatum</u> illustrating the well developed lateral roots. (MMC/Bot/29/11A-12).

Plate 36. Collecting a biogeochemical sample from a <u>Boscia foetida</u> tree. (MMC/Bot/20/10).

All sampling was done during the months January - February 1970. All specimens sampled were mature plants. The leaves and second year growth of stems were sampled at approximately the same heights in each specimen and from all the way around the plant. (Plate 36).

The samples were divided into leaves and stems in the field (Plate 37), and put directly into Kraft type envelopes and sealed to prevent contamination. All the samples were air dried and shipped to London where chemical determinations were done in the laboratories of the Geography department, Bedford College.

All the plant samples collected were analysed for their copper content. The determinations were done by atomic absorption spectrophotometer (Appendix 4, page 170).

During the course of the biogeochemical analysis an analytical control was carried out. For this purpose a range of plant samples were collected. Various species were sampled, growing over areas of known copper mineralization and over areas devoid of copper mineralization. These samples were collected and treated the same as the samples collected on the grid, excepting that much larger samples were taken. In the laboratory a portion of these samples was ashed and prepared for chemical determination in the above described method. Then 100 copper determinationswere done per sample, and the average copper content in the ash weight calculated. This figure was termed the "original analysis" of the sample. Then during the routine analysis of biogeochemical samples, control sample material was also submitted for ashing and determination. Every twentieth plant sample was a control sample. The p.p.m. copper ash weight of the control sample then determined, was called the "control analysis" and was compared to the "original analysis". A graphic presentation of this comparison is given in figure 20 (page 90). The + and - 25% confidence levels for the "original analysis" were calculated and also represented on the figure 20. In both the case of p.p.m. copper ash weight in the leaves, and in the stems, the majority of the "control analyses" fall within the 25% confidence levels. From the figure 20 it is apparent, that any "control analyses" figures falling outside the

Plate 37. The dividing up and preparation of a plant sample prior to putting it into a Kraft sample packet. (MMC/Bot/20/12).

25% confidence levels, are at the lower p.p.m. copper ash weight levels. At these levels of p.p.m. copper a small actual variation in p.p.m. gives a high % variation.

On the results of this analytical control of the biogeochemical analysis, the determination of copper content in the plant samples can be viewed with confidence.

The copper content of the samples were first determined as parts per million (p.p.m.) of ash. (1 p.p.m.= 0,0001% or 1 g/ton). Then by calculation the p,p.m. of copper in the dry weight of plant material was determined using the following equation: p.p.m. Cu in ash x ash weight percent ÷ 100 = p.p.m. Cu in dry weight of plant sample.

When sufficient data were available, the p.p.m. copper dry weight was plotted versus the p.p.m. copper ash weight. This was done for the leaves and stems. These results are plotted in figure 30, and when studying this figure it is apparent that there is a linear relationship between the copper content in the ash of the plant sample, as determined, and the copper content in the dry weight of the plant sample, as calculated.

In the interpretation of the biogeochemistry the geochemistry was taken into account. An initial hurdle in this interpretation was the presentation of the biogeochemical analysis results. At first p.p.m. copper in the leaves and stems of the various species analysed was presented in histogram form. (Figure 31). In each case the p.p.m. copper dry weight and ash weight was given. When studying figure 31 where the geochemistry is also represented, no obvious relationship with the copper anomaly in the soil is seen in the biogeochemistry. The results of various other transects were also presented in this way and the same was found. (Figures 32 and 33). The reason for this, is the fact that different species have different concentrations of copper in their leaves and stems. This is because the uptake of any particular element by a plant, is not merely a function of the concentration of the element in the soil. Several other factors affect the uptake of elements by the roots of

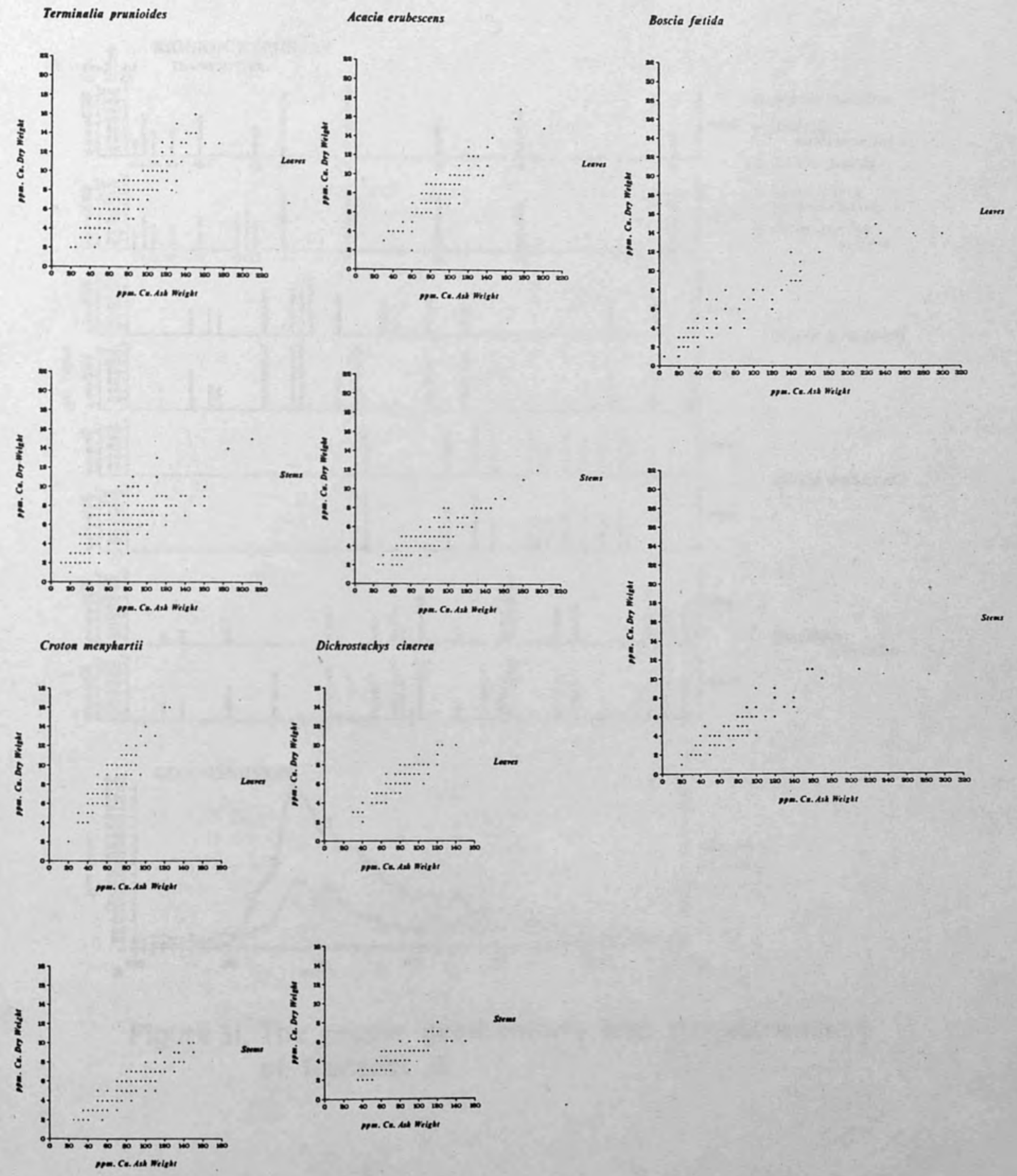


Figure 30. The p.p.m. copper ash weight versus p.p.m. copper dry weight in the leaves and stems of some 5 plant species analysed.

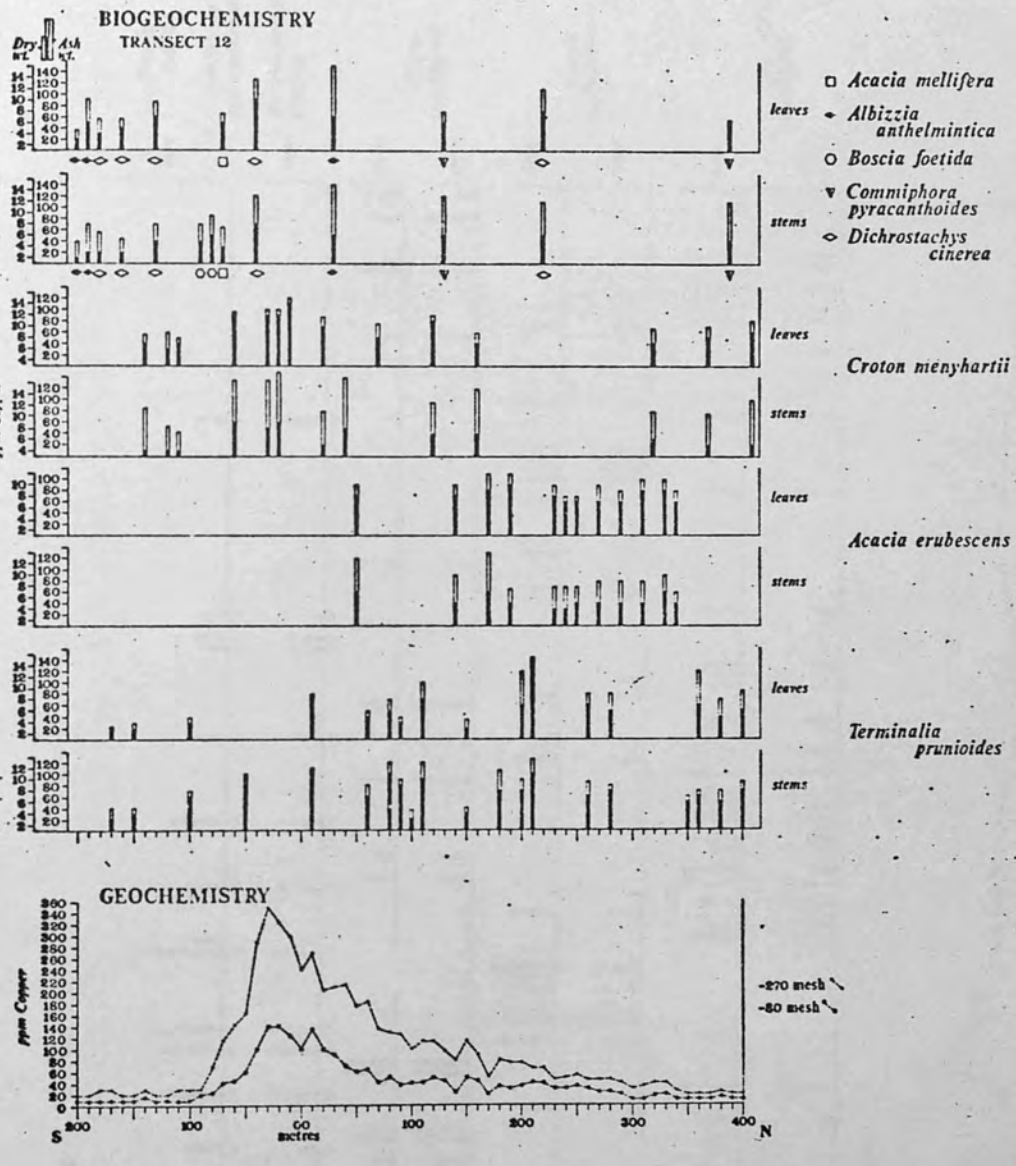


Figure 31. The copper geochemistry and biogeochemistry of transect 12.

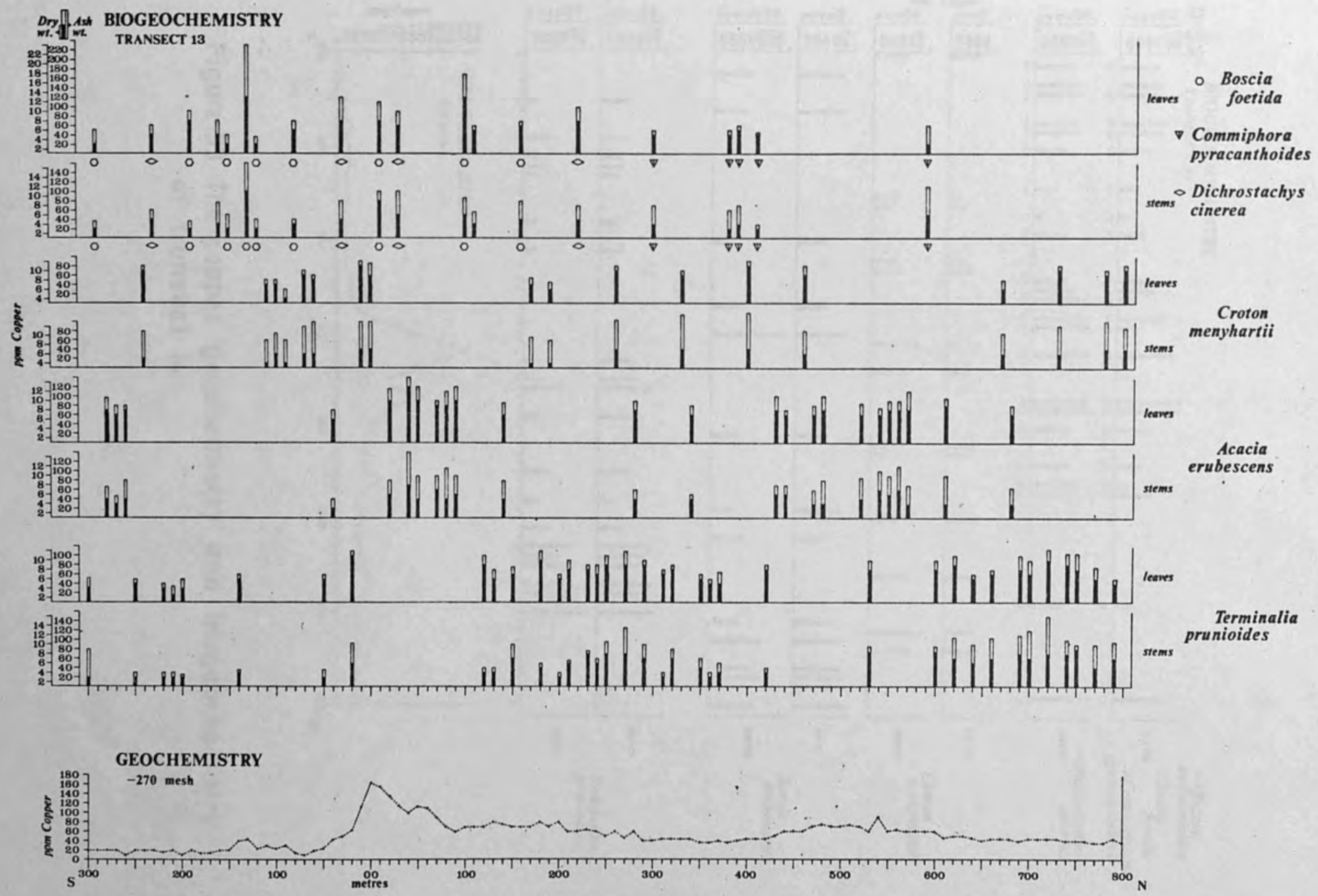


Figure 32. The copper geochemistry and biogeochemistry of transect 13

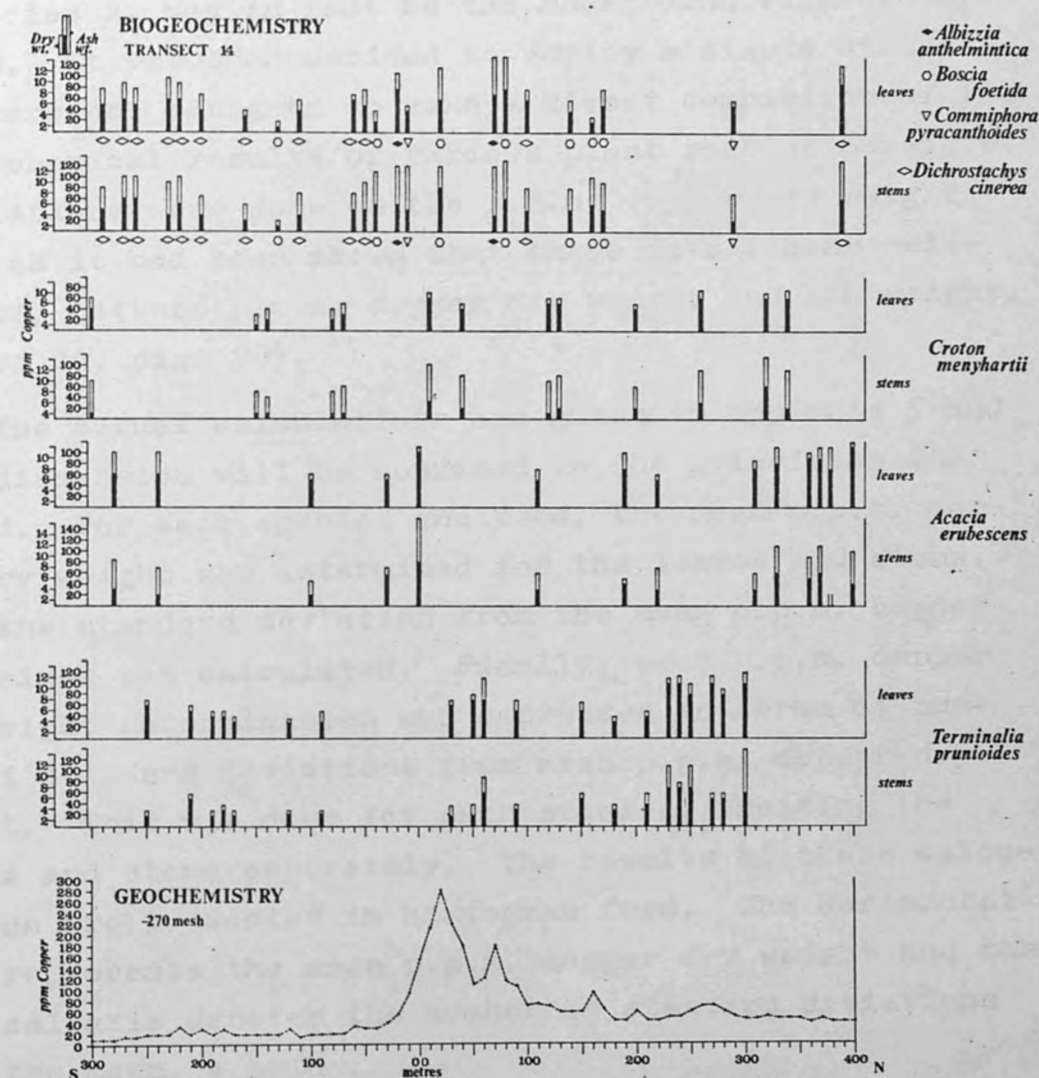


Figure 33. The copper geochemistry and biogeochemistry of transect 14.

of plants, factors such as: The availability of the element, the relative proportions of ions in available form in the soil, the ability of some plants to accumulate certain elements and not others.

This means, that if the absolute values of copper in the various species are compared, the anomalous value in species A, may in fact be the background value in species B. It was then decided to employ a simple statistical exercise, designed to make a direct comparison of the biogeochemical results of various plant species possible. Calculations were done on the p.p.m. copper dry weight only, as it had been shown that there is a linear relationship between p.p.m. copper dry weight and ash weight. (Figure 20, page 90).

The actual calculations are given in appendix 5 and this discussion will be confined to the principles involved. For each species analysed, the mean p.p.m. copper dry weight was determined for the leaves and stems. Then the standard deviation from the mean p.p.m. copper dry weight was calculated. Finally, each p.p.m. copper dry weight determination was expressed in terms of number of standard deviations from mean p.p.m. copper dry weight. This was done for each species, treating the leaves and stems seperately. The results of these calculations are presented in histogram form. The horizontal axis represents the mean p.p.m. copper dry weight and the vertical axis denotes the number of standard deviations from the mean, + or - .

The biogeochemical results presented this way in figure 29 (page 108), are the "treated" results originally seen in figure 31 (page 127) transect 12. This statistical treatment of the biogeochemical copper analyses results in a well defined biegeochemical copper anomaly. Further evidence of this is found, when comparing figure 32 and the lower portion of figure 34, and figure 33 and the upper portion of figure 35.

Also evident from the histogram of the statistically "treated" biogeochemical results, are biogeochemical copper anomalies off-set from the geochemical copper anomalies.

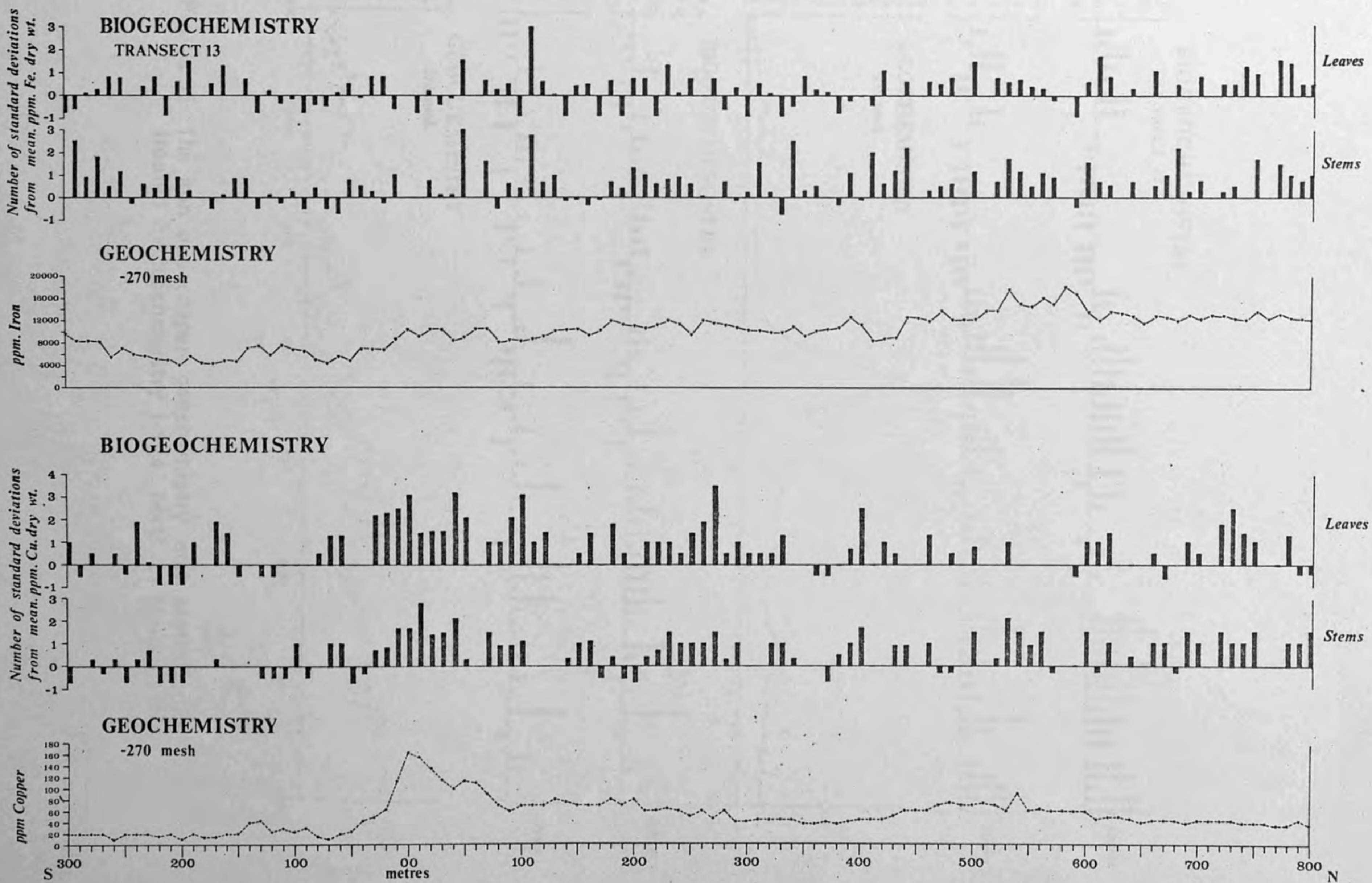


Figure 34. The iron and copper geochemistry and statistically treated biogeochemistry (see text) of transect 13.

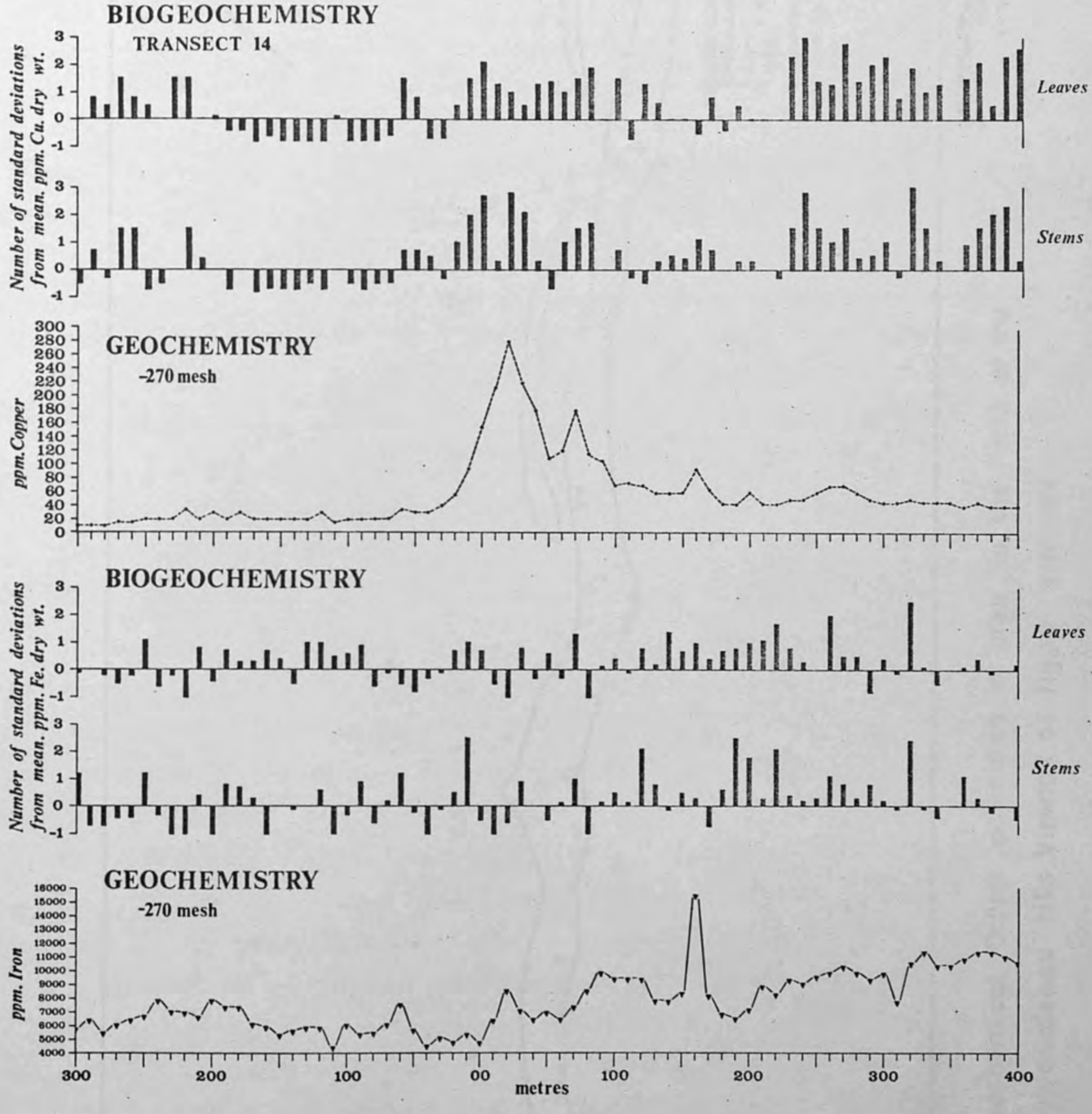


Figure 35. The iron and copper geochemistry and statistically treated biogeochemistry (see text) of transect 14.

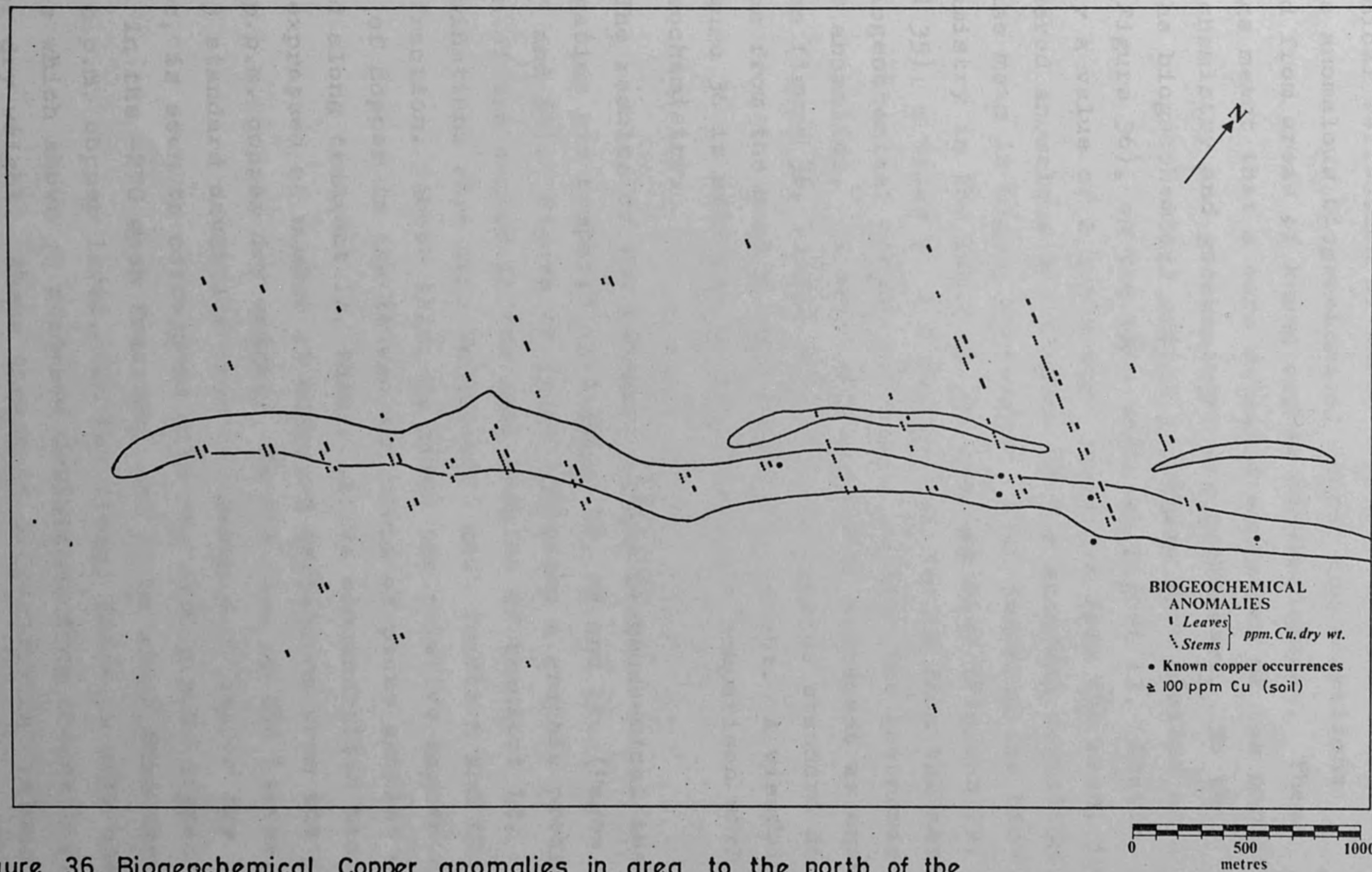


Figure 36. Biogeochemical Copper anomalies in area to the north of the Ngwanalekau hills. Viewfoil of figure available.

This can be seen in the copper biogeochemistry and geochemistry of figures 34 and 35. This meant that the biogeochemical study of the area had shown, that a simple statistical treatment of biogeochemical analytical results gave a biogeochemical reflection of known copper mineralization, as well as anomalous biogeochemical copper concentrations removed from areas of known copper mineralization. These findings meant that a more detailed appraisal of the copper biogeochemistry and geochemistry was necessary. To this end, the biogeochemical copper anomalies were plotted on a plan (Figure 36), on the same scale as figure 11. Statistically a value of 2 x standard deviation from the mean, is considered anomalous and a value of 3 x standard deviation from the mean is highly anomalous. When studying the biogeochemistry in the light of the geochemistry (Figures 29, 34 and 35), a value of 2 x standard deviation from the mean for biogeochemical copper is seen to reflect the geochemical copper anomalies. It was then decided to represent as anomalous on figure 36, values of + 2 x and greater standard deviation from the mean p.p.m. copper dry weight. A viewfoil of figure 36 is attached to facilitate the comparison with the geochemistry.

The results of the geochemical and biogeochemical investigation are compared in figures 17, 18 and 19. (Pages 82, 83 and 85). Figure 29 (page 108)gives a graphic presentation of the copper in the soil samples of transect 12. Determinations were done on the -270 mesh fraction and the-80 mesh fraction. Above this, is given the relative concentrations of copper in the leaves and stems of plant samples collected along transect 12, this relative concentration has been expressed as number of standard deviations from the mean p.p.m. copper dry weight. In the case of the leaves, the +3 standard deviation from the meanp.p.m. copper dry weight, is seen to correspond with the +200 p.p.m. copper level in the -270 mesh fraction, and to be wider than the +250 p.p.m. copper level. In the stems, there is only one sample which shows +3 standard deviations from the mean p,p.m. copper dry weight. Above threshold biogeochemical values are wider than the geochemical ones, with possibly higher deviations for the stems.

In figure 34 the highest copper value in the -270 mesh fraction of the soil is 160 p.p.m. as compared to 350 p.p.m. in figure 17 (page 82). In the leaves the +3 standard deviation from the mean p.p.m. copper dry weight is seen to correspond to +140 p.p.m. soil copper values. There are also higher deviations in the leaves in an area of low geochemical value between 200 and 300 metres north. There are no values in the stems as markedly anomalous as in the leaves, however, correspondingly higher deviations are apparent. The biogeochemical anomaly in an area of low geochemical value could be reflecting mineralization at depth.

In figure 35, for transect 14, there are also higher deviations in the leaves and stems, to the north, in an area of low geochemical values. In this case the deviations for the leaves are higher in the area of low geochemical values than over the geochemically anomalous area. The biogeochemistry could be reflecting mineralization at depth not being reflected in the geochemistry.

From the data on figures 29, 34 and 35 (pages 108, 131 and 132), the following ~~is~~ are apparent.

1. The method of presenting the biogeochemical data facilitates the recognition of peaks in the values.
2. Geochemical peaks are found to be reflected in the biogeochemistry.
3. The magnitude of the biogeochemical peak, expressed as number of positive standard deviations from the mean p.p.m. copper dry weight, does not necessarily reflect the magnitude of the geochemical peak. In the case of transect 12 (Figure 29, page 108), a geochemical peak of 350 p.p.m. copper gave a +3 standard deviation from the mean p.p.m. copper dry weight in the leaves, while in transect 13 (Figure 34) a similar biogeochemical peak value in the leaves corresponded to a lower p.p.m. copper in the soil. Then again, in transect 14 (Figure 35) a geochemical peak of 280 p.p.m. copper is reflected as only +2 standard deviations from the mean copper dry weight of the leaves.
4. The copper biogeochemical reflection of the leaves is better than for the stems.

5. There are biogeochemical peaks which are not reflected in the geochemistry, principally to the north of the geochemical anomaly.

Once these facts had been established, biogeochemical anomalies were plotted on to a plan. (Figure 36). Only +2 standard deviations from the mean p.p.m. copper dry weight were taken as being truly anomalous. When referring to figure 36 reference should be made to figure 23 (page 93) showing the dispersion of copper in the soil of the area as well as figure 12 showing the distribution of plant species associations. Viewfoils of these figures are attached to facilitate comparison.

Of the four geochemical copper anomalies in figure 23 (page 93) the three to the south-west, have associated bio-geochemical copper anomalies of the leaves and the stems. The geochemical anomaly to the north-east does not have a biogeochemical expression.

Biogeochemical anomalies are found beyond the limits of the highly anomalous geochemistry, into what may be considered background geochemical values. These biogeochemical anomalies occur mainly to the north and north-west of the geochemically anomalous area, and may be reflecting mineralization at depth.

When comparing the extent of the biogeochemical anomalies to the distribution of <u>Ecbolium lugardae</u> (Figure 12, page 68) they are found to extend beyond the northern limit of main <u>Ecbolium lugardae</u> distribution.

This biogeochemical investigation over known mineralization illustrated the effectiveness of the technique in detecting this mineralization. Besides anomalies reflecting the known mineralization there are biogeochemical anomalies beyond these limits. These occur principally to the north and north-west of the area of known copper, and they may well reflect mineralization at depth. The anomalies should be examined and this can satisfactorily be done by a programme of percussion drilling.

During this biogeochemial study a limited study on iron as a possible copper pathfinder in biogeochemical analysis was conducted. The selection of iron as an element in this study, was based on the findings of various workers. Among these were Cannon (1960), and Russell (1961), who independently report that an excess of copper in the supporting medium interferes with the iron assimilation of a plant. In extreme cases this affects the manufacture of chlorophyll, of which iron is a constituent, causing chlorosis in the plant. In the study area the supporting medium, the soil, over known copper mineralization, has a relatively high copper concentration and it was decided to see if the assimilation of iron by the plant was affected by this.

Samples from selected lines were analysed for their iron content. Lines crossing a good copper geochemical anomaly were selected. Both the soil and plant samples were analysed for their iron concentration. The analysis of the soil samples for iron, was to establish any fluctuations of iron concentration in the soil which may affect the concentration of the element in the plant. The results of certain of these iron analysis are given in figures 34 and 35. When studying these figures it is apparent, that the iron in the soil fluctuates considerably, however, it does show a tendency to increase to the north of the transect. Furthermore this fluctuation and overall increase in soil iron is not reflected in the biogeochemistry. The biogeochemical data have been treated statistically as for the copper geochemistry, and no apparent relationship is seen. The relative iron concentrations in the plants show considerable variation but no trends are apparent.

The use of iron as a pathfinder for copper in biogeochemistry is not recommended in this area.

PART 3

GEOBOTANICAL, GEOCHEMICAL AND BIOGEOCHEMICAL INVESTIGATIONS IN THE MAWANI AREA

CHAPTER IX

GEOBOTANY, GEOCHEMISTRY AND BIOGEOCHEMISTRY OF THE MAWANI AREA

A photogeological interpretation of southern Ngamiland picked out a cluster of circular and near-circular features in the Mawani Area. (Figure 3 page 5). These aroused interest for possible kimberlite pipes following the discovery of the Orapa pipe in eastern Botswana.

An examination of the features on the ground indicated that these formed slight eminences and carried vegetation associations which differed from that over the surrounding plain. The occurrence of Aptossimum leucorrhizum on certain of the features was of particular interest as it was known to occur over the Orapa pipes.

Investigations formulated for the exploration programme included geophysical studies, and the examination of bulk soil samples for heavy mineral suites by Anglovaal staff, and geobotanical, geochemical and biogeochemical investigations by Bedford College.

Geophysical studies included the measurement of magnetic susceptibility and radioactivity. Magnetics has been used with limited success in the search for kimberlite pipes, as the magnetic susceptibility of kimberlite is perplexingly variable from district to district. In the case of radioactivity very little work has been done on kimberlites, however the relatively high concentrations of potassium, (up to 3%) with it radioactive isotope, potassium 40, in kimberlites is encouraging.

The choice of elements for geochemical and biogeochemical analyses was determined by reference to those known to be characteristic of kimberlites in other parts of the world. Samples were analysed for chromium, nickel, magnesium, potassium, sodium and iron.

Chromium. Kimberlite is defined as a porphyritic alkalic peridotite, and peridotite is a chromium rich mineral.

Nickel. Is reported in concentrations in excess of 1 000 p.p.m. in kimberlite.

Magnesium. A constituent element of many of the minerals more commonly found in kimberlite, such as, olivine, serpentine, phlogopite and chlorite.

Potassium and Sodium. (The alkali metals). In kimberlite potassium is reported in concentrations of up to 3% whereas there is little or no sodium. It is necessary to determine both the alkali metals as their chemistry is intimately associated, and then to determine the ratio of potassium to sodium, which should be high in the case of kimberlite.

Iron. An element found within the chemical composition of minerals, such as olivine, phlogopite, chlorite and ilmenite, all characteristically found in kimberlite.

The results of the geophysical, geochemical and biogeochemical studies are represented on figures 37 and 38. It will be noticed that neither of the figures have any chromium or nickel reported on them, this is because all the samples, plant and soil, contained concentrations below the limit of detection. The biogeochemical data was statistically treated as described in chapter VIII, and is represented as number of standard deviations from mean p.p.m. dry weight.

The distribution of plant associations was examined over the circular features and over the surrounding plains. Field mapping was done with the aid of aerial photographs and figures 39 and 40 drawn up.

A low tree and shrub savanna dominated by Combretum apiculatum is found on the hillocks and eminences. (Plate 38) This tree and shrub cover can be very dense. (Plate 39). A skeletal reddish brown, siliceous soil is found. Where a thicker cover of this soil has formed the tree and shrub cover is more open with the perennial grass Stipagrostis uniplumis strongly in evidence. (Figure 39).

On the plains is found a savanna parkland dominated by Acacia erubescens. (Plate 40). The soil is dark brown and clayey.

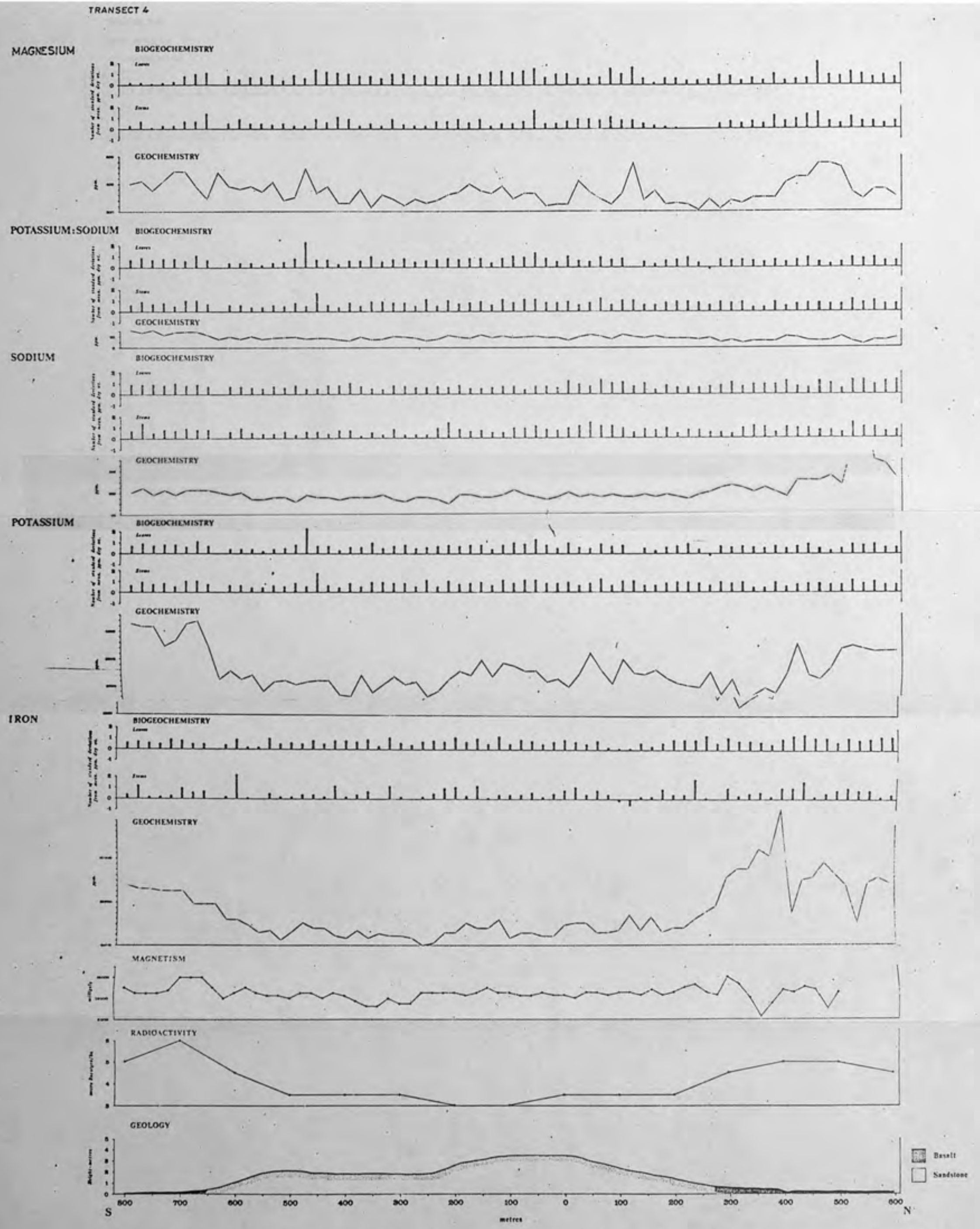


Figure 37. The geology, geophysics, biogeochemistry and geochemistry done along transect 4.

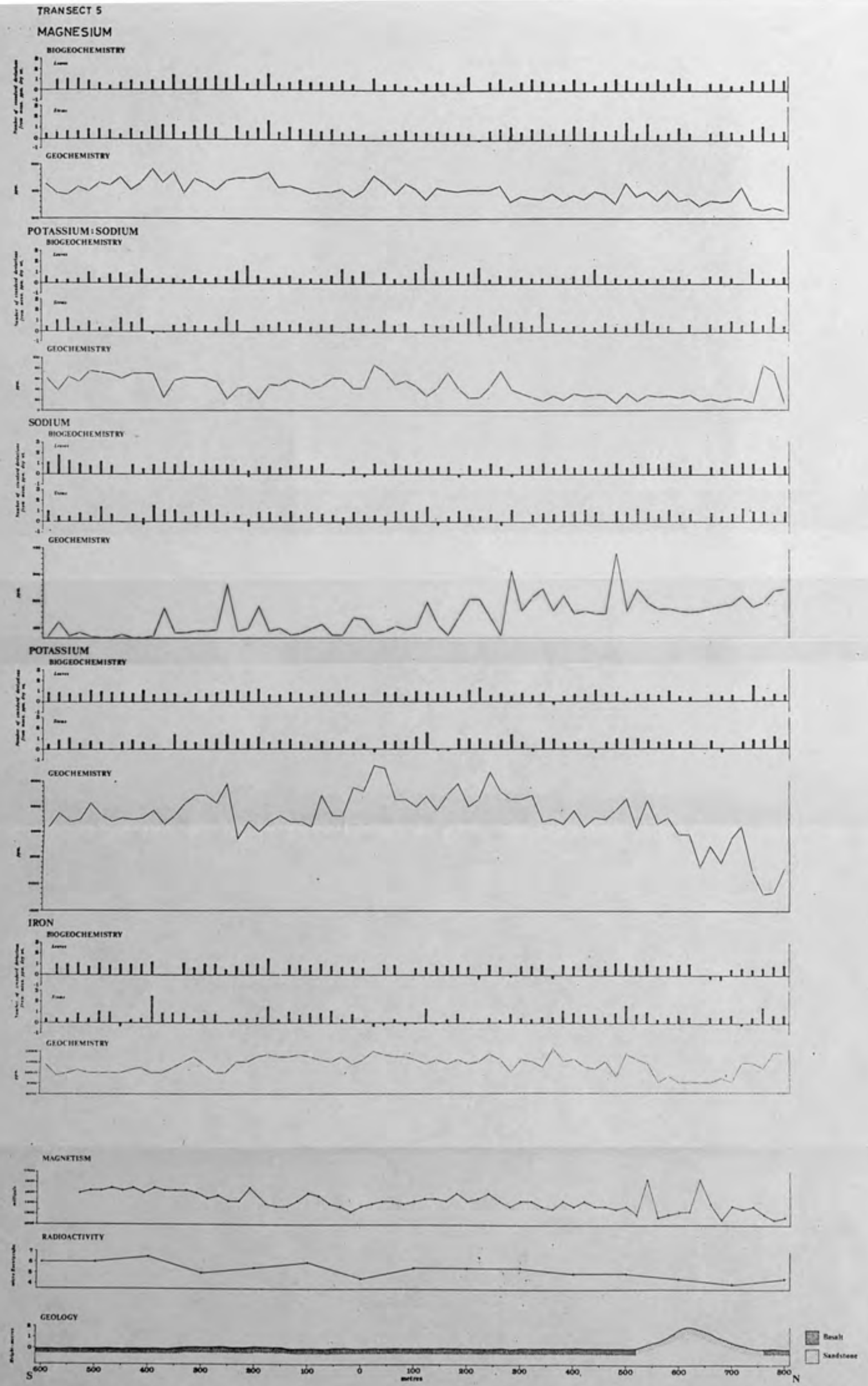


Figure 38. The geology, geophysics, biogeochemistry and geochemistry done along transect 5.

Plate 38. A view along transect 4 showing the low tree and shrub savanna dominated by Combretum apiculatum characteristically found on sandstone hillocks in the Mawani area. (MMC/Bot/30/14).

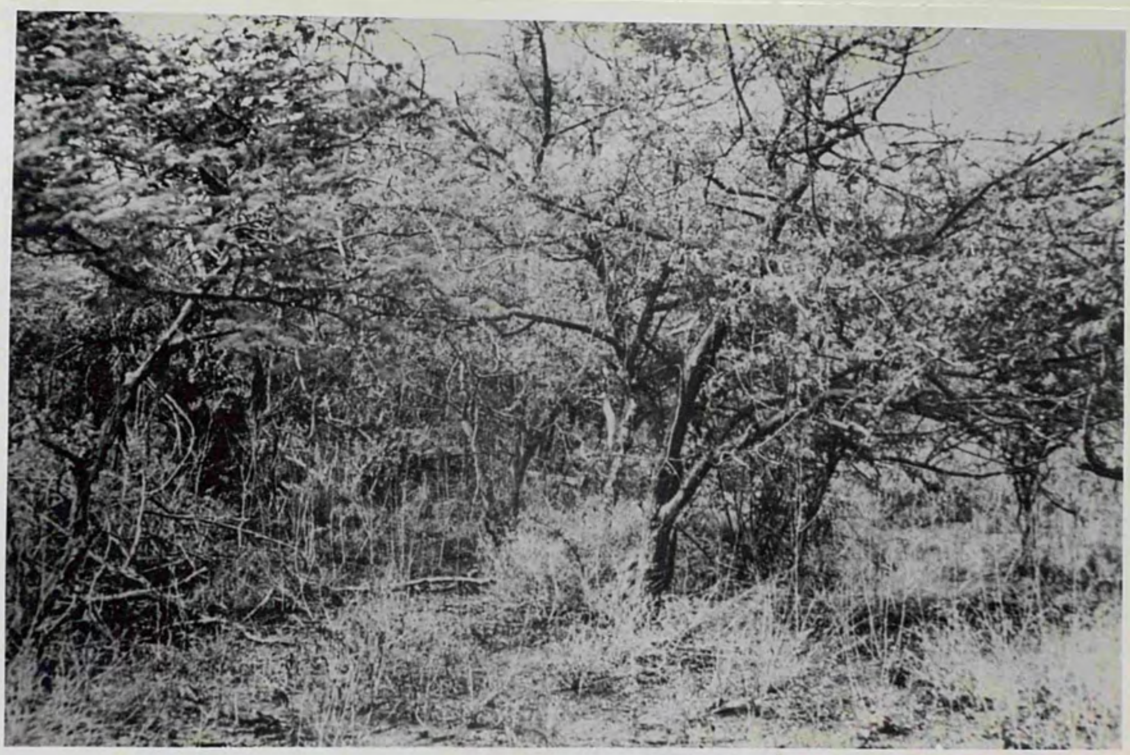
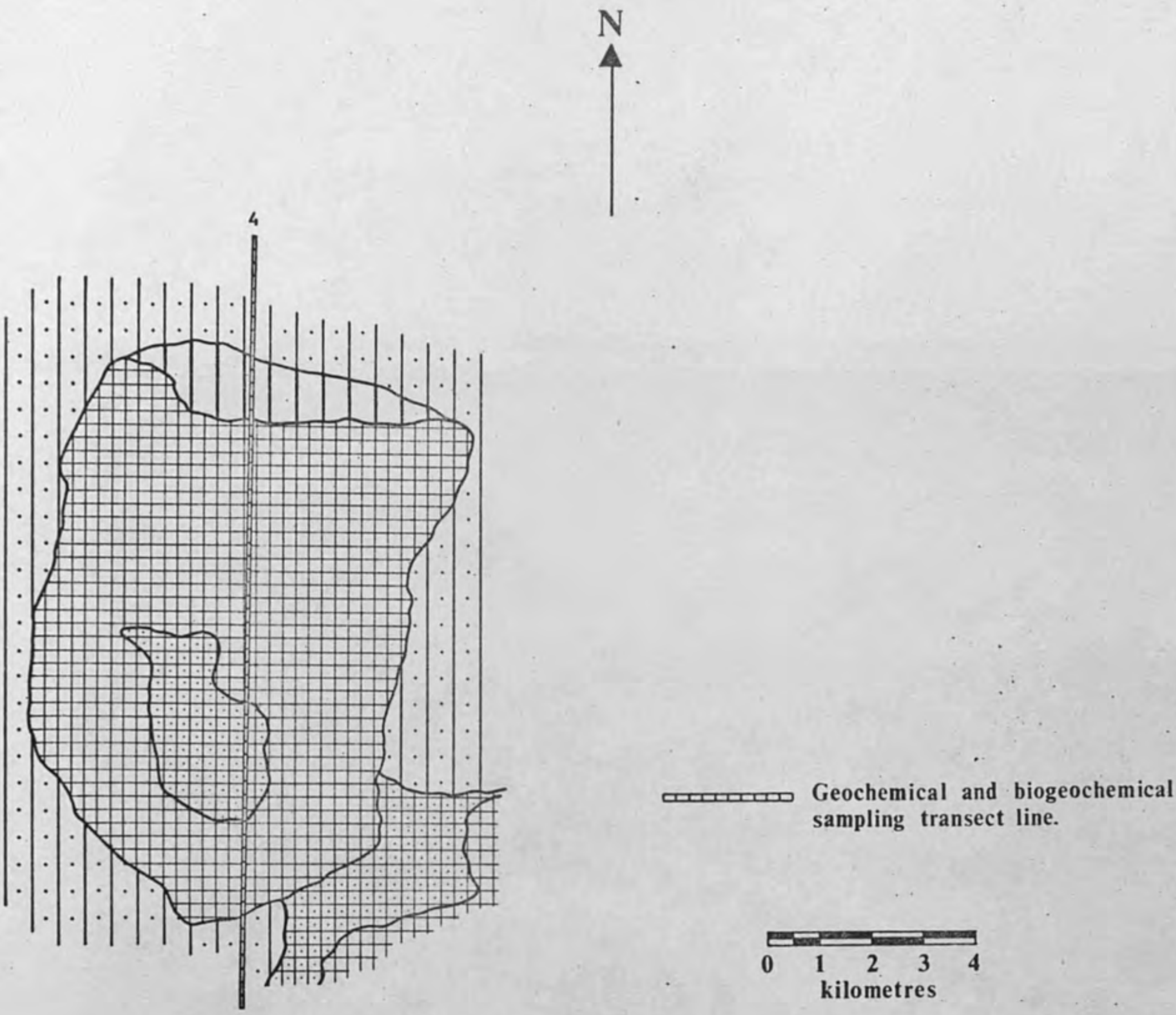


Plate 39. Low tree and shrub savanna dominated by Combretum apiculatum on Karoo sandstone.

(MMC/Bot/24/6A-7).



	Low tree and shrub savanna, dominated by *Combretum apiculatum.*	On areas of near-surface sandstone.
	Low tree and shrub savanna, dominated by *Combretum apiculatum*, with *Stipagrostis uniplumis* the dominant grass.	On areas of near surface sandstone, with a thicker soil cover.
	Low tree savanna woodland, characterized by *Terminalia prunioides* and *Acacia erubescens.*	On level terrain, with brown sandy soil.
	Savanna parkland, dominated by *Acacia erubescens.*	On level terrain, with dark-brown clayey soil.

Figure 39. The plant species distribution and edaphic characteristics on and around a circular feature- Mawani area.

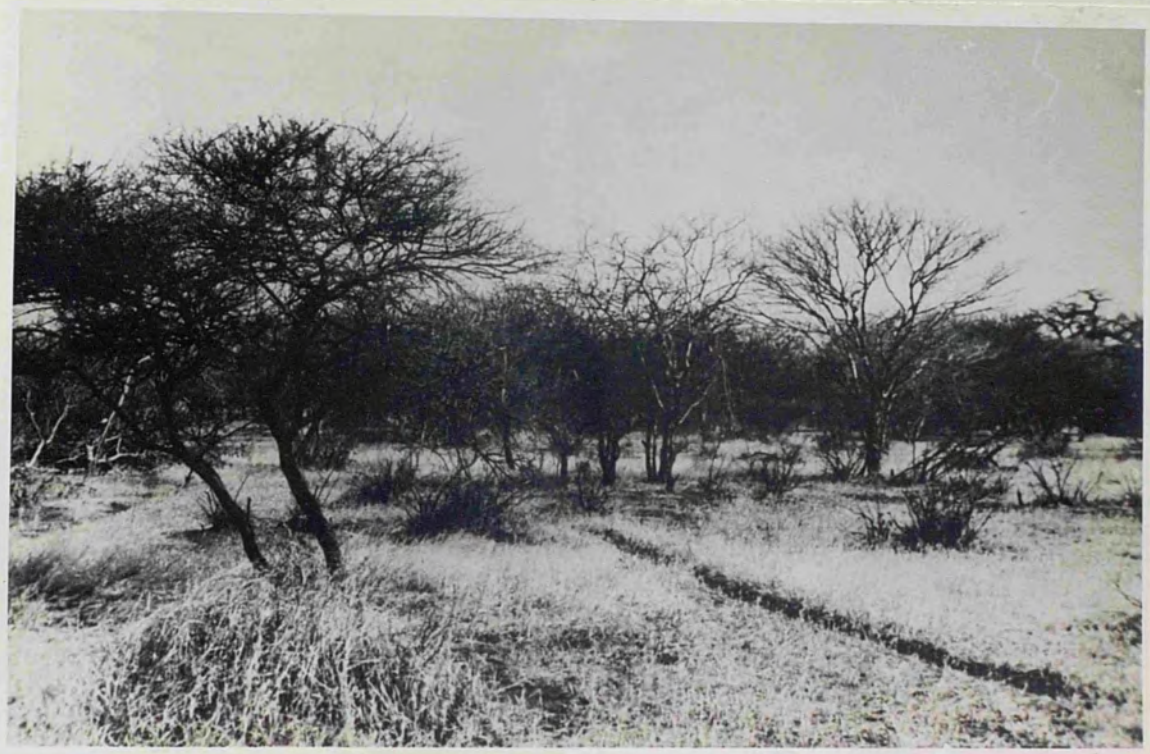
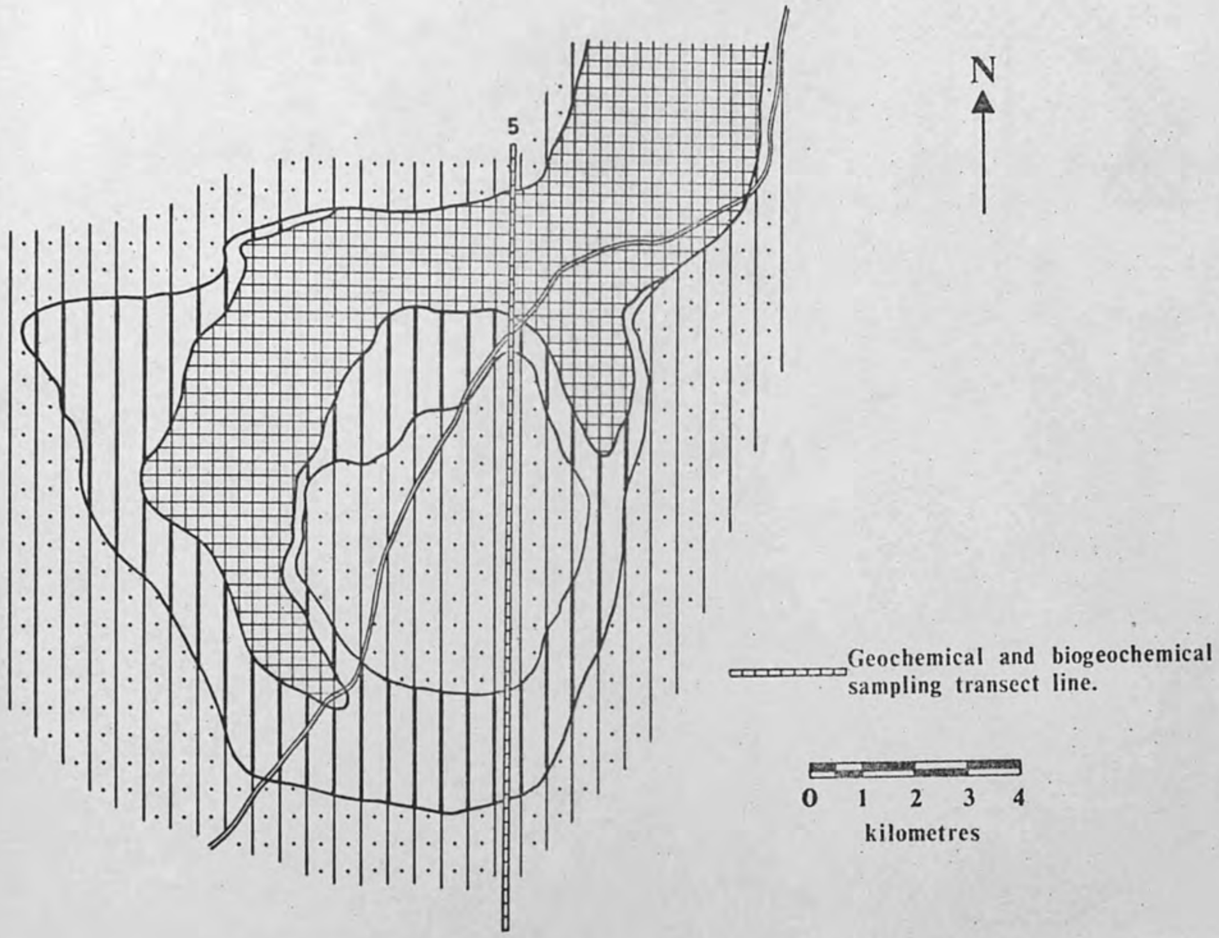


Plate 40. Savanna parkland dominated by Acacia erubescens, found on basalt underlain plains in the Mawani area.

(MMC/Bot/29/31A-32).



	Low tree and shrub savanna, dominated by *Combretum apiculatum.*	On areas of near-surface sandstone.
	Low tree savanna woodland, characterized by *Terminalia prunioides* and *Acacia erubescens.*	On level terrain, with brown sandy soil.
	Savanna parkland, dominated by *Acacia erubescens.*	On level terrain, with dark-brown clayey soil.

Figure 40. The plant species distribution and edaphic characteristics on and around a near circular feature - Mawani area.

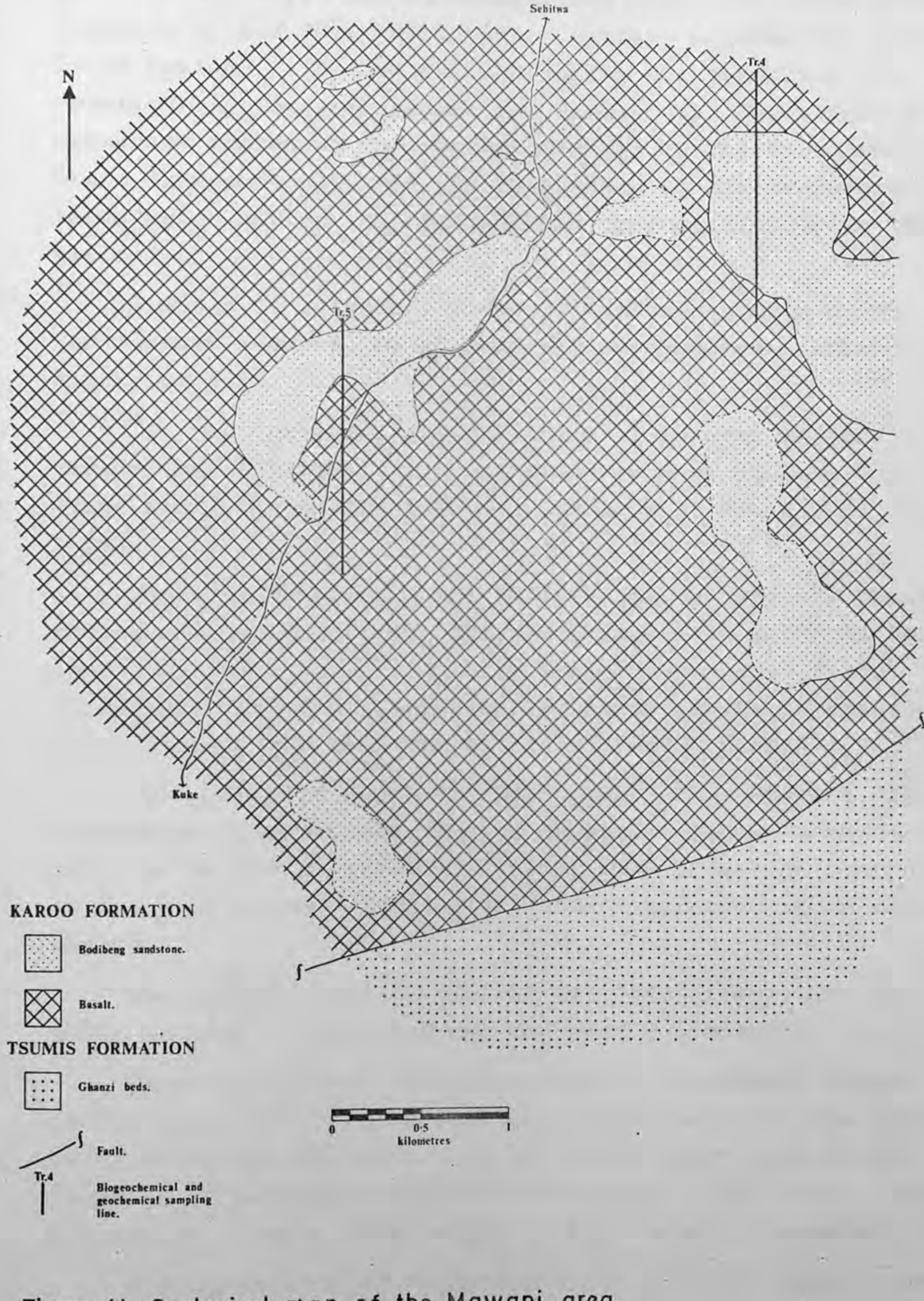


Figure 41. Geological map of the Mawani area

Also in these areas is a dark brown sandy soil on which is found a low tree savanna woodland characterized by the trees Terminalia prunioides and Acacia erubscens.

Transect lines were laid across these features. (Figures 39 and 40). All investigations were done along these. (Figures 37 and 38). Exploration pitting exposed the underlying geology. (Figure 41). Drilling did establish the relationships between basalt and sandstone. The slight eminences represent the concealed hills of the Karoo sandstone landscape prior to the outpouring of the Stormberg lavas which buried it. These lavas, basalts, underlie the plains.

Transect 4 (Figures 39 and 37) crosses a near circular feature found to be an eminence of sandstone, surrounded by basalt.

The radioactivity shows a slight rise over the basalts versus the sandstone. The magnetism is more or less constant along the entire transect, between 12 000 and 18 000 gamma.

The iron content in the soil is higher over the basalt than over the sandstone. Anomalous values of up to 18 000 p.p.m. is found in the soils to the northern end of the transect. The iron content of the plant tissue is closely related to the iron content of the surface soil.

The potassium concentration in the soils shows a wide background fluctuations, with a generally higher threshold over the basalt than the sandstone. The potassium content of the plant tissue shows very little variation along transect 4.

The sodium concentration in the plant tissue and the soils is high to the northern end of the transect.

The proportional concentrations of the alkali metals in the soil (Potassium : Sodium) is constant over the larger part of the transect. In the south there is a slight increase of potassium relative to sodium in the soil. The potassium : sodium ratio in the plant tissue is constant.

The concentration of magnesium in the soil shows wide background variation with a marked low to the northern end of the sandstone hill. This low is flanked by high values on the basalt to the north and on the sandstone to the south. The magnesium content of the plant tissue is closely related to the magnesium content of the surface soil, however, the magnesium concentration in plants growing over basalt to the south of the sandstone, is much lower than the corresponding soil values.

The results of the investigations along transect 4 do not indicate the presence of a kimberlite. The examination of the bulk soil samples for heavy minerals did not disclose the presence of the diagnostic garnets, ilmenites and chrome diopsides. Variations in the concentrations of elements in the soil and plant tissue can be attributed to background concentration variations in the different underlying rock types. The basalt soils show a higher concentration in iron, potassium, sodium and, to some extent, magnesium than do the soils over the sandstone. The iron and magnesium concentration in plant tissues are closely related to the concentrations in soils, this is also to some extent the case for sodium. In the case of potassium there is little or no relationship.

Transect 5 (Figures 37 and 40) crosses a sickle shaped eminence of sandstone in a plain of basalt.

The radioactivity along transect 5 shows a slight, but perceptible, drop over the sandstone. The radioactivity over the basalt ranges between 5 and 6 micro Roentgen/hour whereas over the sandstone a low of 4 micro Roentgen/hour was found. The magnetism along the transect 4 has a threshold of 1 600 gamma over the basalt and 1 400 gamma over the sandstone. On the southern flank and on the crest of the hillock are two magnetic peaks of 1 800 gamma. An examination of the sandstone at these points revealed the presence of magnetite in hand specimens not visible elsewhere, this would account for the magnetic anomaly.

The results of the geochemical and biogeochemical investigations are similar to those for transect 4. The soils over the basalts show higher concentrations of iron, potassium and to some extent magnesium than do the soils over sandstone. In the case of sodium, however, there is a very slight increase in the threshold soil content over sandstone.

The content in plant tissue of magnesium, potassium and iron is related to the soil content of these elements.

Results of the investigation of this feature gave no indication of the possible presence of kimberlite. No diagnostic heavy minerals were found in bulk soil samples collected over this feature.

No kimberlite was discovered in the Mawani Area. The circular and near circular features visible on aerial photographs of the area are sandstone eminences in a plain underlain by basalt. The basalts and sandstone produce very different soils and these in turn are largely responsible for the distribution of the distinctive plant associations.

CHAPTER X

CONCLUSIONS AND RECOMMENDATIONS

During the reconnaissance work done in the Ngwako pan area the distribution of *Ecbolium lugardae* in the shrub layer was noted as being potentially useful as an indicator of copper mineralization. A reconnaissance geochemical survey outlined a geochemical copper anomaly within the area of *Ecbolium lugardae* distribution. Subsequent trenching of an anomaly revealed suboutcropping copper mineralization in argillites and limestone bedrock. Detailed geobotanical, biogeochemical and geochemical investigations were done in the area.

A close study of plant species distribution showed that while *Ecbolium lugardae* distribution outlines an area within which geochemistry revealed a copper anomaly, the occurrence of the species is not specific to localised areas of high copper content in surface soils, as is the case for *Helichrysum leptolepis* found in copper clearings in the Witvlei area, South West Africa. The broad association of *Ecbolium lugardae* and suboutcropping mineralization is also seen in the vicinity of the Kgwebe hills. *Ecbolium lugardae* is reported in the shrub layer in the vicinity of the Mabeleapudi hills where no search for mineralization had been conducted. The presence of the species in that area does warrant investigation.

The geobotanical studies revealed a close relationship between high copper contents in plant tissue and the shrub *Anticharis linearis*. This is also true to a lesser extent for *Abutilon fruticosum* shrubs.

A more regional investigation of the distribution of these indicator species shows these not to occur in areas where aeolian sand cover occurs. Over aeolian sands, the results of the regional geochemical survey show a lowering of regional threshold as well as no anomalous values. This blanketing effect of aeolian sands to geochemistry and geobotany is also experienced in areas of transported calcrete cover. With the aim of exploring below these transported overburdens for base metals, a study of biogeochemical methods was done.

This work was done where there is known copper mineralization. Care was taken to sample deep rooting species. A close correlation between high copper values in the soil and in plant tissue was shown once the copper content in the plant tissue was expressed as number of standard deviations from the mean p.p.m. dry weight. This relatively simple statistical evaluation of data eliminates the effect of different background copper concentrations in different species sampled. The profound effect this has on the data is seen when examining the actual copper concentrations in the plant tissue and no anomalous values are discernible in the vicinity of the soil copper anomaly.

The biogeochemistry also indicates an area of anomalous copper values in plant tissue outside the geochemical anomaly. This is underlain by Ghanzi System rocks in which the known mineralization is found, and the biogeochemical anomaly may well be reflecting deeper seated mineralization. This would need to be investigated by a programme of drilling.

The effectiveness of biogeochemistry has been shown in areas of suboutcropping copper mineralization. The work revealed further biogeochemical anomalies which should be investigated. Then the use of biogeochemistry in the exploration of areas of thick transported overburden should be considered. Deep rooting species should be sampled and analytical results should be statistically evaluated as done in this instance.

This application of biogeochemistry is the next logical step in the chemical exploration of areas of transported overburden. The limitations of geochemistry in these areas is well known.

The geochemical investigations in this study were concerned with the selection of a mesh size fraction giving the best threshold to anomaly contrast. Work was done on a profile of over three metres of calcrete overlying copper mineralization in limestone. A distribution of anomalous copper values from the mineralization to surface was found in all the mesh sizes analysed. The best contrast of anomalous to threshold values was found in the -30 + 60 fraction and in the -120 and finer mesh fractions. The highest absolute contrast was found in the -270 mesh fraction, the finest fraction analysed.

All copper analyses were done on the -270 mesh fraction soil samples collected in the area. This survey outlines a linear north east - south west orientated anomaly. Trenching on the anomaly revealed suboutcropping mineralization. A programme of wagon drilling showed mineralization under calcrete cover, of up to 20 metres vertical thickness. There was no evidence of the calcrete overburden masking the expression of anomalous copper in the surface soil. This is as a result of the mechanism whereby the calcrete formed, i.e. from calcium carbonate derived from the immediately underlying bedrock. This would ensure that the geochemical characteristics of the bedrock are remnant in the calcrete. However, if calcrete is formed by calcium carbonate transported in, such as downslope from a limestone hill or in a river bed or in and around a pan, the calcrete cover over the bedrock will blanket any surface soil geochemical expression of the bedrock. It is thus important to evaluate the type of calcrete cover likely to be found in an area being explored for mineralization, and then accordingly adjust the exploration techniques being applied. If transported calcrete cover is found over the area the use of biogeochemistry should be considered.

A study of the regional distribution of vegetation associations showed these to provide a good indication of subsurface lithological units. The lithological variations found within the Ghanzi sediments are typified by vegetation association, and these associations have different aerial photo expressions. The taller tree savanna woodland found on the grey quartzites has a darker photo expression, whereas, the vegetation associations found on the red quartzites and argillites result in lighter trends on the photographs. These facts enhance an aerial photograph interpretation and aid in identifying rock types, in areas of little outcrop.

There is also a close correlation between pedological conditions and certain vegetation associations. As in the case where aeolian sand cover is thick, a characteristic low tree and shrub savanna association is found. Also areas of near surface calcrete are characterised by the shrubs Catophractis alexandrii.

The recognition of vegetation associations and the identifying of causative pedological and lithological factors can greatly aid in mineral exploration in areas of little outcrop and transported overburden. Vegetation mapping can help in drawing up geological maps as well as maps of surficial deposits, but care must be taken as biotic factors such as burning and overgrazing can locally change a vegetation association and thereby confusing the picture.

In the Mawani area a search for kimberlite pipes proved unsuccessful. The search was initiated by the recognition of a cluster of circular and near circular features on aerial photographs, as well as by the subsequent recognition of a shrub species Aptossimum leucorrhizum growing on such a feature. This shrub is found on the Orapa kimberlite pipes in eastern Botswana. The features were found to be Stormberg sandstone eminences in a plain underlain by basalt. The basalts and sandstone produce very different soils and these support distinctive vegetation associations clearly discernible on the aerial photographs.

REFERENCES.

Abelson, P.H. (Ed.) 1959. Researches in geochemistry.

Acocks, J.P.H. 1953 Veld types of South Africa.

Adams, F. and Weir, J.I. 1957. Manganese toxicity and soil, acidity in relation to crinkle leaf of cotton. Soil Sci. Soc. Am. Proc. 21: 305-8.

Adamson, R.S. 1939. The vegetation of South Africa.

Anderson, R.V. and Kurtz, E.B. (Jr.) 1955. Biogeochemical reconnaisance of the Annie Lauri Uranium prospect, Santa Cruz County, Arizona. Econ. Geol. 50(2): 227-232.

Arnon, D.I. 1948. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in Beta vulgaris. Plant physiol. 24(1): January 1949: 1-15.

_____ and Stout, P.R. 1939. The essentiality of certain elements in minute quantity for plants with special reference to copper. Plant Physiol. 14: 371-5.

Aubouin, J. 1965. Geosynclines.

Bagnold, R.A. 1941. The physics of blown sand and desert dunes.

Baines, T. 1864. Exploration in South West Africa.

Barakaso, J.J. 1969. Soil and plant relationships to bedrock at some mineralized areas in British Columbia. Intern. Geoch. Explor. Symposium. Quart. Colorado School of Mines 64 (1): January 1969.

Barghoorn, E.S. and Spackman, W. 1950. Geological and botanical study of the Brandon lignite and its significance in coal petrology. Econ. Geol. 45: 344.

Bawden, M.C. 1965. Some soils of Northern Bechuanaland. D.O.S.

Beadle, N.C.W. 1953. The edaphic factor in plant ecology with a special note on soil phosphates. Ecology 34: 426-428.

Beeson, K.C. 1947. The absorption of mineral elements by forage plants. 1. The phosphate, cobalt, manganese and copper content of some common grasses. Jnl. Amer. Soc. Agron. 39: 356-362.

_____ 1951. Absorption of mineral elements by forage plants. 3. The relation of stage of growth to the micronutrient element content of some legumes. Jnl.Amer.Soc. Agron. 43: 589-593.

_____ 1952. Report on copper and cobalt in plants. Journ. Assoc. Offic. Agr. Chemists. 35: 402-406.

_____ 1953. Report on copper and cobalt in plants. Journ. Assoc. Offic. Agr. Chemists. 36: 405-411.

Beeson, K.C. 1955. Some plant accumulators of the micronutrient elements. Ecology 36(1): 155.

Bekwith, R.S. 1955. Metal complexes in soils. Austral. Journ. Agric. Res. 6(5).

Beliz, J.M. 1963. Some aspects of geo-botanical research in Potuguese Guinea. Gorcia de Onto. 11(1): 143-146.

Bertrand, D. 1950. The biogeochemistry of vanadium. Bull. Amer. Muem Natur. History. 94(7).

Billings, W.D. 1952. The environmental complex in relation to plant growth and distribution. Quart.Rev.Biol. 27.

Black, C.A. 1957. Soil-plant relationships.

_____ (Ed.). 1965. Methods of Soil analysis. Amer. Soc. Agron.

Blackshaw, G.N. 1921. Magnesia impregnated soils. S. Afr. Jnl. Sci. 17.

Boken E. 1957. Investigations on the determinations of the available manganese content of soils. Plant and Soil 9.

Boocock, C. 1958. The geological environment of copper deposits in the Bechuanaland Protectorate. Bech. Geol. Survey (Unpubl.).

_____ 1965. Mineral resources of the Bechuanaland Protectorate. Overseas Geology and Mineral resources 9(4).

_____ & van Straten, O.J. 1962. Notes on the geology and hydrology of the Central Kalahari region, Bechuanaland Protectorate. Trans. Proc. Geol. Soc. S.A. 65(1).

Boss, G. (Translated by Greef, M.H.). 1937. Oor die plantegroei van Suidwes Afrika.

Boulaine, J. 1961. The role of vegetation in the formation of calcareous crusts in the Meditteranean.

Bower, C.A. and Turk, L.M. 1946. Calcium and magnesium deficiencies in alkali soils. Jnl. Amer. Soc. Agron. 38.

Boyle, R.W. and Garrett, R.G. 1970. Geochemical prospecting, a review of its status and future. Earth Science Rev. 6(1) 51-75.

Brade-Birks, S. 1959. Good soil.

Broadbent, F.E. and Ott, I.B. 1957. Soil organic matter-metal complexes. 1. Factors affecting retention of various cations. Soil Sci. 83(6): 419.

Brown, A.G. 1970. Dispersion of copper and associated trace elements in a Kalahari sand environment, N.W. Zambia. (Unpublished PhD thesis, Imperial College London).

Brown, A.L. and Jurinak, J.J. 1964. Effect of lime on the ability of zinc and copper. Soil Sci. 98(3): 170-173.

Brown, J.C. and Foy, C.D. 1964. Effect of copper on the distribution of phospherus, calcium and iron in barley plants. Soil Sci. 98: 362-370.

Broyer, T.C. 1947. The movement of materials into plants. Part 3: The nature of solute movements into plants. Bot. Rev. 13(3): 125-167.

Buck , J.J. 1949. Association of plants and minerals. Journ. N.Y. Bot. Garden. 50: 600.

_____ 1951. Shrub aids in determining extent of orebody. N.Y. Bot. Garden. Garden Journ. 1.

Buckman, H.D. and Brady, N.C. 1960. The nature and properties of soils 6th Edition.

Burd, J.S. 1947. Mechanism of release of ions from soil particles to plants. Soil Sci. 64: 223-5.

Cannon, H.L. 1954. Botanical methods of prospecting for uranium. Mining Eng. 6: 217 -220.

_____ 1960. Botanical prospecting for ore deposits. Science 132(3427): 591-8.

Cheng, K.L. and Bray, R.H. 1953. Two specific methods of determining copper in soil material. Anal. Chem. 25: 655-659.

Chikishev, A.G. (Ed.). 1965. Plant indicators of soils, rocks and subsurface waters. Proc. Indicator Geobot. Consultants bureau N.Y. (Translation).

Clarke, G.R. 1957. The study of the soil in the field.

Clements, F.E. 1920. Plant indicators: The relation of plant communities to process and practice. Carnegie Inst. Wash. Publ. 290.

_____ 1928. Plant successions and indicators: A definitive edition.

Codd, L.E.W. 1951. Trees and shrubs of the Kruger National Park. Dept. Agric. Bot. Survey Memoir 26.

Cole, M.M. 1961. South Africa.

_____ 1963. Vegetation nomenclature and classification with special reference to the savannas. S.A. Geogr. Journ. Presidential Address.

_____ Provan, D.M.J. and Tooms, J.S. 1968. Geobotany, biogeochemistry and geochemistry in mineral exploration in the Bulman Waimuna Springs area, Northern Territory, Australia. Trans. Inst. Min. Metall 77: B81-B104.

Compton, R.H. (Ed.). Our South African flora. National Bot. Gardens. Kirstenbosch Cape Town.

Cotton, C.A. 1939. The landscape cycle under semi-arid conditions. Geol. Mag. 76: 402-7.

_____ 1942. Geomorphology: An introduction to the study of land forms.

Craven, C.A.U. 1954. Statistical estimation of the accuracy of assaying. Trans. Inst. Min. Metall 63: 551-563.

Crockett, R.N. 1964. Geology of part of the Okwa valley, Western Bechuanaland in the vicinity of Long. 22°E. Bech. Geol. Survey (Unpublished).

Cullen, D.J. 1956. Geology of the Dikgomo Di Kae area. Bech. Geol. Survey (Unpublished).

Danserau, P. 1957. Biogeography.

Daubenmire, R.F. 1959. Plants and environment.

Dawson, J.B. 1968. Recent researches on Kimberlite and diamond geology. Econ. Geol. 63.

Debnam, A.H. 1966. The atomic absorption spectrometer in the geochemical laboratory.

de Winter, B., de Winter, M. and Killick, D.J.B. 1966. Sixtysix Transvaal trees.

Dixex, F. 1956. Erosion surfaces in Africa, some considerations of age and origin. Trans. Proc. Geol. Soc. S.A. 59: 1-16.

Du Toit, A.L. 1954. Geology of South Africa. 3rd Edition.

Elwell, W.T. and Gidley, J.A.F. 1966. Atomic Absorption spectrophotometry. 2nd Edition.

Elkington, J.E. 1969. Vegetation studies in the Eastern Goldfields of Western Australia with particular reference to their role in geological reconnaissance and mineral exploration. (Unpublished Ph.D. thesis).

Exell, A.W. and Wild, H. (Ed.). 1961. Flora Zambesiaca. V1. Part 1 and 2 V2 Part 1 and 2.

Eyre, S.R. 1963. Vegetation and soil.

Farini, G.H. 1886. Through the Kalahari desert.

Fortescue, J.A.C., and Hornbrook, E.H.W. 1967. Progress report on biogeochemical research at the geological Survey of Canada. (1963-1967) Geol Survey Canada Paper 67 23 (1).

Garbell, M.A. 1947. Tropical and equatorial meteorology.

Garlick, W.G. How the Copperbelt ore bodies were formed. Horizon 1(8).

Gayel, A.G. 1932. Programme for geobotanical study of sands. Izal. Akad. Nauk. S.S.R. Leningrad.

Gayel, A.G. and Kolokov, M. 1937. Problems of method in the complex investigation of sands. Gos. Geogr. Obsch. 1.

Gerrard, I. 1959. A note on speciments from the Ghanzi beds, Ghanzi district. Bech. Geol. Survey (Unpublished).

Gevers, T.W. 1934. The geology of the Windhoek district. South West Africa. Trans. Proc. Geol. Soc. S.A. 37: 221.

Goldschmidt, V.M. 1945. The geochemical background of minor element distribution. Soil Sci. 60(1).

Green, D. 1966. Karroo System of Bechuanaland, Bech. Geol. Survey (Unpublished).

_____1968. Interrelationships of the Stratigraphy of the Karroo system in the Republic of Botswana and South West Africa. Trans. Proc. Geol. Soc. S.A. 1969.

Gregory, S. 1963. Statistical methods and the Geographer.

Greig-Smith, P. 1964. Quantative plant ecology. 2nd Edition.

Hall, A.D. 1938. The soil. An introduction to the scientific study of the growth of crops.

Hammett, F.S. 1928. Studies in the biology of metals. Protoplasma 4.

Harmer, P.M. 1946. Plant responses to copper. Proc. Soil Sci. Soc. Amer. 10.

Haughton, S.H. 1961. Review of a probable late Precambrian glacial period in Central and West Africa. Trans. Proc. Geol. Soc. S.A. 64: 73-84.

_____(Ed.). 1964. The geology of some deposits in Southern Africa V2.

_____1969. Geological history of Southern Africa.

Hawkes, H.E. 1950. Geochemical prospecting for ores. Applied Sedimentation.

_____1957. Principles of geochemical prospecting. U.S. Geol. Survey Bull. 1000F.

_____and Webb, J.S. 1965. Geochemistry in Mineral Exploration.

Heckel, E. 1899. The presence of copper in plants and the quantities they contain. Bull. Soc. Bot. France. 46: 42-43.

Heslep, G.M. 1951 A study of the infertility of two acid soils. Soil Sci. 72.

Hewitt, E.J. 1966. Sand and water culture methods used in the study of plant nutrition.

Hooker, J.D. and Jackson, B.D. (Ed.). Index Kewensis. Plantarum Phanerogramum.

Hunter, J.G. and Vergnano, O. 1952. Nickel toxicity in plants. Ann. Appl. Biol. 39: 279-284.

Jacobson, J.D. 1956. Geochemical prospecting studies in Kilembe area of Uganda. Tech. Comm. 6.G.P.R.C. Imperial College London.

Jacobsen, W.B.G. 1964. The geology of the Mangula copper deposits in Southern Rhodesia. The geology of some ore deposits in Southern Africa. V2: 339-351.

_____1967. The influence of copper content of the soil on trees and shrubs of the Molly South Hill, Mangula. Kirkia 6(1).

James, C.H. 1970. A rapid method for calculating the statistical precision of geochemical prospecting analysis. Trans. Inst. Min. Metall. 79: 888-889.

Jamison, V.S. 1956. Absorption and fixation of copper in some sandy soils of central Florida. Soil Sci. 53: 287-297.

Jennings, C.M.H. 1962. Note of the soil type derived from geological formations in the Palapye Mahalapye and Serowe areas. Bech. Geol. Survey. (Unpublished).

Jenny, H. and Overstreet, R. 1939. Surface migration of ions and contact exchange. Journ. Phys. Chem. 43: 1185-1196.

Jones, M.T. 1961. Report on the underground water development scheme for the South Western Ghanzi district. Bech. Geol. Survey. (Unpublished).

Kilmer, V.J. and Alexander, L.T. 1949. Methods of making mechanical analysis of soil. Soil Sci. 68: 15-24.

King, L.C. 1958. Geomorphology of Africa. Science Progress 1957-58.

_____1964. The South African scenery. 3rd Edition.

Kulp, L.J., Holland, H.D. and Volcholk, H.L. 1952. Scintillation alpha counting of rocks and minerals. Trans. Amer. Geophys. 33: 101-103.

Laughton, C.A. 1965. Preliminary list of references to geological literature on Bechuanaland. Bech. Geol. Survey (Unpublished).

Lawrence, H.G.M. 1963. An introduction to plant taxonomy.

Liebig, G.F. 1942. Effects of aluminium on copper toxicity as revealed by solution culture and spectrographic studies on citrus. Soil Sci. 53.

Livingstone and Hawkins. 1915. Water relationships between plant and soil.

Lugard, E.G. 1909. The flora of Ngamiland.

Maier, R.H. and Cattani, A. 1966. Growth and copper content of anatomical plant parts as influenced by copper supply and time. Plant and Soil 24: 339-342.

Malyuga, D.P. 1964. Biogeochemical methods of prospecting. (Translation, Consultants Bureau Enterprises Inc., N.Y.).

Manskaya, S.M. and Drozdova, T.V. 1968. Geochemistry of organic substances.

Mannard, G.W. 1968. The surface expression of Kimberlite pipes. Proc. Geol. Ass. Can. 19: 15

Martin, H. 1965. The Precambrian geology of South West Africa and Ngamiland.

McConnel, R.B. 1954. Annual report of the director. Bech. Geol. Survey. (Unpublished).

_____1956. Notes on geology and geomorphology of the Bechuanaland Protectorate. CRxx. Int. GEol. Cong. Mexico.

McKenzie, R.M. 1955. Sampling variations in the concentration of elements in the soils. Austral. Journ. Agric. Res. 6: 699-706.

Mendelson, F. 1961. The geology of the Northern Rhodesian Copper belt.

Meredith, D. (Ed.). 1955. The grasses and pastures of South Africa.

Mill, D.B. 1952. Boscia albitrunca. Journ. S.A. Bot. 18.

Mitchell, R.L. 1970. Trends in applied Geochemical and Biogeochemical analysis. Bul. Geol. Minero. 80(5): 394-401.

Masier, E.L. 1972. A method for semiquantitative spectrographic analysis of plant ash for use in biogeochemical and environmental studies. Applied Spectroscopy 26(6): 636-641.

Nesvetaylova, N.G. 1961. Geobotanical investigations for prospecting for ore deposits. Int. Geol. Rev. 3: 609-618.

Netterberg, F. 1969. The geology and engineering properties of South African calcretes. (In four volumes). Unpublished Ph.D. thesis. University of Witwatersrand.

_____1969. Ages of calcretes in Southern Africa. S.A. Arch. Bull. 24: 88.

_____1969. The interpretation of some basic calcrete types. S.A. Arch. Bull. 24:117-

Nicholas, D.J.D. 1953. Chemical tissue tests for determining the mineral status of plants in the field.

Nicolls, O.W., Provan, D.M.J., Cole, M.M. and Tooms, J.S. 1966. Geobotany and geochemistry in mineral exploration in the Dugald River area, Cloncurry District, Australia. Trans. Inst. Min. Metall. 74.

Oliver, H.D. 1956. South African earthquakes. Jan. 1953 - Dec. 1955. Trans. Proc. Geol. Soc. S.A. 59.

Page, E.R., Schofield-Palmer, E.K. and McGregor, A.J. 1962. Studies in plant and soil manganese. 2. The relationship of soil pH to manganese availability. Plant and Soil. 16.

Passarge, S. 1904. Die Kalahari.

_____(Ed.). Stadtlandschaften der Erde.

Pettersen, S. 1956. Weather analysis and forecasting.

_____Introduction to meteorology.

Phillips, J.F.V. Fire: Its influence on biotic communities and physical factors in South and East Africa. S.A. Journ. Sci. 27.

Piper, C.S. 1950. Soil and plant analysis.

Poldervaart, A. 1951. Note on the extension of the Karoo system in the North Eastern Bechuanaland Protectorate. Trans. Proc. Geol. Soc. S.A. 53: 73-80.

Pole-Evans, I.B. 1931. A reconnaissance trip through Eastern Botswana.

Provan, D.M.J. 1965. An investigation of the factors governing the distribution of savanna plant communities in Northern Australia, with special reference to geology and bedrock mineralization. (Unpublished PhD thesis. Birmingham.).

Ramann, E. 1928. The evolution and classification of soils (Translation by Whittles).

Ray, R.G. 1960. Aerial photographs in geological interpretation and mapping.

Reilly, C. 1967. Accumulation of copper by some Zambian plants. Nature 215: 667-668.

Riddell, J.E. 1952. Anomalous copper and zinc values in trees in Holland, North County. Quebec Dept. Mines Rep. 269.

Riehl, H. 1954. Tropical meteorology.

Robinson, G.W. 1936. Soils their origin, constitution and classification. 3rd. Edition.

Rogers, A.W. 1935. The solid geology of the Kalahari. Trans. Roy. Soc. S.A. 23(2): 165-176.

_____1936. The build of the Kalahari. S.A. Geogra. Journ. 17: 3-12.

Russel, E.W. 1961. Soil conditions and plant growth. 9th Ed.

Sandell, E.B. 1950. Colorimetric determination of traces of metals. 2nd Edition.

Schutte, K.H. 1964. The biology of trace elements.

Setchell, W.A. 1936. Essays in geobotany.

Shantz, H.L. and Marbut, C.F. 1923. The vegetation and soils of Africa.

Shaw, B.T. 1952. Soil, physical condition and plant growth.

Shaw, W.H.R. 1959. Studies in biogeochemistry. 1. A biogeochemical periodic table. Geochem. et Cosmochim. Acta. 19(3).

Smales, A.A. and Wager, L.R. 1960. Methods in geochemistry.

Small, J. 1946. pH and plants.

Somers, I.I. and Shive, J.W. 1942. The iron: manganese relationship in plant metabolism. Plant. Physiol. 17: 582-602.

Sommer, A.L. 1945. Copper and plant growth. Soil Sci. 60: 71-79

Spencer, W.F. 1966. Effect of copper on yield and uptake of phosphorus and iron by citrus seedlings grown at various phosphorus levels. Soil Sci. 102.

Steward, F.C. 1935. Mineral nutrition of plants. Annual Rev. Biogeochem. 4: 519-544.

Stiles, W. 1961. Trace elements in plants.

Stoker, H.M. (Ed.). 1960. Official year book of the Union of South Africa, Basutoland, Bechuanaland Protectorate and Swaziland. No. 30.

Sutton, J.R. 1914. Climate. Air temperature at Mochudi. Trans. Royal Soc. S.A. 4: 163-168.

Taylor, H.M., Roberson, G.M. and Parker, J.J. (Jnr.). 1966. Soil strength, root penetration relations for medium to coarse textured soil materials. Soil Sci. 102: Dec. 18-22.

Thomas, C.M. 1969. A short description of the geology of southern Ngamiland. Bech. Geol. Survey (Unpublished).

Timperley, M.H., Brooks, R.R. and Peterson, P.J. 1972. Trend analysis as an aid to the comparison and interpretation of biogeochemical and geochemical data. Econ. Geol. 67(5): 669-676.

Tinsley, A.G. 1935. The use and abuse of vegetational concepts and terms. Ecology 16.

Toens, P.D. 1969. Some thoughts on regional correlations and ore genesis with special reference to the Tsumis formation of central S.W.A. and Botswana. (Unpublished Company report, Anglovaal (S.W.A.)).

Tombesi, L. and Cale, M.T. 1962. Studies on the determination of available phosphorus in soils. Plant and soil 17(2).

Tooms, J.S. 1955. Geochemical dispersions related to copper mineralization in Northern Rhodesia. (Unpublished PhD thesis London).

_____ and Webb, J.S. 1961. Geochemical prospecting investigations in the Northern Rhodesian copper belt. Econ. Geol. 56: 815-846.

Tooms, J.S. and Jay, J.R. 1964. The role of biogeochemical cycle in the development of copper and cobalt anomalies in freely drained soils of Northern Rhodesia, Copper belt. Econ. Geol. 59(5): 826-834.

van Straten, D.J. 1956. A reconnaisance report on salt deposits of Nata river delta. Bech. Geol. Survey. (Unpublished).

_____ 1959. Notes to accompany a provisional soil map of the Bechuanaland Protectorate. Bech. Geol Survey (Unpublished).

Vermaat, J.G. and van der Bie, G.J. 1949. On the occurrence of copper in tropical soils. Plant and Soil 2: 257-282.

Viktorov, S.V. 1960. The use of geobotanical methods in geological and hydrogeological investigations. (Translation 3968 by U.S. Atomic Energy Commission).

_____ Vostokova, A. and Vyshikin, D.D. 1964. Short guide to geobotanical surveying. International Series of Monographs on Pure and Applied Biology 8.

Vlamis, J. 1949. Growth of lettuce and barley as influenced by degrees of calcium saturation of soil. Soil Sci. 67: 453-466.

Voit, F.W. 1907. Kimberlite dykes and Pipes. Trans. Proc. Geol.Soc. S.A. 10: 69-74.

Walter, H. and Volk, O.H. 1954. Grundlagen der Weidewirtschaft in Südwestafrika.

Warren, H.V. and Delavault, R.E. 1948. Biogeochemical investigations in British Columbia. Geophysics 13: 609-624.

_____ and _____ 1949. Further studies in biogeochemistry. Bull. Geol. Soc. Amer. 60: 531-560.

_____ and _____ 1950. History of biogeochemical investigation in British Columbia. Trans. Can. Institute Min. Metall. 53: 236-242.

_____ and _____ 1960. Observations on Biogeochemistry of lead in Canada. Trans. Royal Soc. Canada. 54(4): 11-20.

Warren, H.V. and Delavault, R.E. and Barasko, J. 1964. The role of arsenic as a pathfinder in biogeochemical prospecting. Ecom. Geol. 59: 1381-1389.

_____and _____ and Fortescue, J.A.C. 1955. Sampling in Biogeochemistry. Bull. Geol. Soc. Amer. 66(2) Feb. 229-238.

Warren, H.V. and Howatson, C.H. 1947. Biogeochemical prospecting for copper and zinc. Bull. Geol. Soc. Amer. 58(9): 803-820.

Webb, J.S. 1956. Observations on geochemical prospecting in tropical terrains. Crxx. Int. Geol. Cong. Mexico 1956.

_____and Millman, A.P. 1951. Heavy metals in vegetation as a guide to ore. Trans. Inst. Min. Metall. 60: 473-504.

Wehrmann, J. 1959. The copper flower aides prospecting. The Mining Journ.

Wellington, J.H. 1955. Southern Africa: A geographical study.

Wellington, G.J. 1949. Development of the Okavango delta.

White, W.H. 1950. Plant anomalies related to some British Columbian ore deposits. Bull. Canadian Inst. Min. Metall. 43.

Wild, H. 1968. Geobotanical anomalies in Rhodesia. 1. The vegetation of copper bearing soils. Kirkia 7(1).

_____1968. Geobotanical anomalies in Rhodesia. 2. A geobotanical anomaly occurring in graphic soils. Kirkia 7(1).

Willis, L.G. and Piland, J.R. 1936. The function of copper in soils and its relation to the availability of iron and manganese. Journ. Agric. Res. 52.

Wright, E.P. 1956. Geology of the Gaberones district. Bech. Geol. Survey (Unpublished).

_____1956. Geology of the area south of Lake Ngami. Bech. Geol. Survey (Unpublished).

Young, R.S. 1954. Cobalt in Kimberlites. Amer. Mineralogist 39(1-2): 143-144.

APPENDIX 1.

Atomic absorption spectrophotometer specifications.

Southern Instruments Models A 1750 and A 3000.

Element	Wave length mm.	Current mA	Slit width	Flame
Copper	3247,5	7,5	1	Oxidising non-luminous air-acetylene.
Iron	2483,3	5	2	Oxidising non-luminous air-acetylene.
Magnesium	2852,3	3	2	Oxidising non-luminous air-acetylene.
Chromium	3579,6	5	2	Oxidising non-luminous air-acetylene.
Nickel	2320	5	2	Nitrous oxide-acetylene flame.

APPENDIX 2

Soil Sample analyses - Decomposition technique

1. 0,2 gm of sample weighed and put into a test tube.
2. 10 ml. of 0,1N nitric acid added.
3. Test tube placed in a water bath at $95^{o}C$ for 2 hours.
4. Sample cooled and analysed.

APPENDIX 3

Aperture size in microns of mesh size fractions.

A.S.T.M. mesh number	Aperture size, microns
10	2000
30	600
60	250
80	170
120	125
200	72
270	53

APPENDIX 4

Plant tissue analyses - Decomposition technique.

1. Known weight of air dried plant sample ashed at 420°C in a muffle type furnace. Average ashing time was found to be 12 hours.

2. Ash weighed.

3. Ash thoroughly mixed and 0,2 gm. weighed into a test tube.

4. 10 ml. of 0,1 n nitric acid added.

5. Test tube placed in a water bath at 95°C for 2 hours.

6. Sample cooled and analysed.

APPENDIX 5.

Standard deviation of p.p.m. dry weight, copper and iron, of the plant species collected in the biogeochemical survey.

Species	Standard deviation: ppm. dry weight			
	Leaves		Stems	
	Cu	Fe	Cu	Fe
Terminalia prunioides	2.2	24.6	1.8	18.6
Acacia erubescens	1.8	15.3	1.6	10.4
Croton menyhartii	1.6	23.0	1.4	19.8
Dichrostachys cinerea	1.4	12.7	1.2	19.0
Boscia foetida	2.1	14.6	1.7	12.5
Commiphora pyracanthoides ssp. glandulosa	1.4	16.7	2.0	17.7
Acacia mellifera	1.5	13.4	2.0	17.0
Acacia tortilis	1.2	9.9	1.4	13.1
Albizzia anthelmintica	2.2	3.1	1.0	8.3

APPENDIX 6.

Plant species collected and identified.

Acanthaceae.

Barleria lugardii C.B. Clarke.

B. senensis Klotzsch.

Crabbea velutina S. Moore.

Ecbolium lugardae N.E. Brown.

Justicia dinteri S. Moore.

J. odora Vahl.

Lepidogathis scabra C.B. Clarke.

Monechma nepetoides C.B. Clarke.

Peristrophe bicalyculata Nees.

Petalidium englerianum (Schinz.) C.B. Clarke.

Ruellia malacophylla C.B. Clarke.

R. patulla Jacq.

Amarantaceae.

Achyranthes sicula Roth.

Amaranthus thunbergii Moq.

Leucosphaera baenesii Gilq.

Nelsia quadrangula Schinz.

Pupalia atropurpurea Moq.

Sericorema sericea Lopr.

Ammarylidaceae.

Ammocharis tinneana Milne.

Ampelidaceae.

Cyphostemma puberula (C.A. Smith) Willd & Drumm.

Anacardaceae.

Sclerocarya caffra Sond.

Bignoniaceae.

Catophractes alexandri D. Don.

Markhamia acuminata K. Schum.

Rhigozum brevispinosum Kuntze.

Boraginaceae.

Ehretia rigida Druce

Heliotropium giessii M. Friedrich.

Burseraceae.

Commiphora pyracanthoides Engl. ssp. glandulosa (Schinz.) Willd.

Capparidaceae.

Boscia foetida Schinz.

Cleome angustifolia Forsk.

Maerua angolensis D.C.

Maerua caffra Pax.

M. juncea Pax.

Chenopodiaceae.

Chenopodium album Bos. ex Moq.

Kochia pubescens Moq.

Combretaceae.

Combretum apiculatum Sond.

C. engleri Schinz.

C. erythrophyllum Sond.

C. mechowianum O. Hoffm.

Terminalia prunioides Laws.

T. sericea Burch. ex D.C.

Commelinaceae.

Commelina forskaelae Hochst ex C.B. Clarke.

Compositae.

Blumea gariepina D.C.

Geigeria schinzii O. Hoffm.

Hirpicium gazanioides (Harv.) Roessler.

Vernonia fastigiata Oliver & Hiern.

Convolvuladeae.

Evolvulus alsinoides Linn.

Jacquemontia tamnifolia Griseb.

Cucurbitaceae.

Coccinia quinquiloba Coqn.

Trochomeria debilis Benth, & Hook.

Cyperaceae.

Cyperus bellus Kunth.

C. distans Linn.

C. usitatus Burch. ex Roem.

Fimbristylis exilis Roem. & Schult.

Mariscus aristatus (Rottb.) Cherm.

Euphorbiaceae.

Acalypha indica Linn.

Caphalocroton pueschelii Pax.

Croton gratissimus Burch.

C. menyhartii Pax.

Erythrococca menyhartii Prain.

Phyllanthus burchelli Muell.

P. maderaspatensis Linn.

Ficoideae.

Galenia secunda Sond.

Gisekia pharnacioides Linn.

Hypertalis salsoloides (Burch.) Adamson.

Limeum argute-carinatum Wawra.

L. myosotosis H. Walter.

L. sulcatum Hutchinson.

Mollugo cerviana Ser.

Plinthus karoicus Verdoorn.

Trianthema triquetra Rottl. & Willd.

Geraniaceae.

Monsonia biflora D.C.

M. senegalensis Guill. & Perr.

Gramineae.

Aristida hordeacea Kunth.

A. scabrivalvis Hackel.

Bothriochloa radicans (Lehm.) A. Camus.

Brachiaria deflexa (Schum.) C.E. Hubbard ex Robyns.

B. grossa Stapf.

Cenchrus ciliaris Linn.

Chloris virgata P. Durand.

Cymbosetaria sagittifolia (A. Rich.) Schweickerdt.

Dactyloctenium aegyptium Beauv.

Digitaria debilis Willd.

D. milanjiana Stapf.

Echinochloa colona Link.

Enneapogon brachystachus Stapf.

E. cenchroides (Licht. ex Roem. & Schult.) C.E. Hubbard.

Enteropogon macrostachys K. Schum. ex Engl.

Eragrostis curvula Nees.

E. denudata Hack.

E. echinochoidea Stapf.

E. horizontalis Peter.

E. porosa Nees.

E. superba Peyr.

Heteropogon contortus Beauv. ex Roem.

Odyssea paucinervis Stapf.

Oropetium capense Stapf.

Panicum coloratum Linn.

P. maximum Nees.

Pogonarthria fleckii (Hack.) Hack.

Rhyncheltrum repens Willd.

R. villosum Chiov.

Schmidtia kalahariensis Stent.

Sehima ischaemoides Forsk.

Sorghum versicolor Anderss.

Sporobolus spicatus Kunth.

Stipagrostis uniplumis Licht.

Tragus racemosus Steud.

Urochloa bolbodes Stapf.

U. brachyura Stapf.

Labiateae.

Acrotome inflata Benth.

Becium obovatum N.E. Brown.

Hemizygia bracteosa Briq.

Leguminosae.

Acacia erubescens Engl.

A. fleckii Schinz.

A. luedretzii Engl.

A. mellifera Benth.

A. tortilis (Forsk.) Hayne.

Albizzia anthelmintica Brongn.

Crotalaria teixeinae R. Torre.

Dichrostachys cinerea R. Viguier.

Indigophora bainesii Baker.

I. diphylla Vent.

I. macra E. Mey.

Lonchocarpus nelsii Schinz. ex Heering. & Grimme.

Rhynchosia minima D.C.

Tephrosia semiglabra Sond.

Liliaceae.

Asparagus africanus Lam.

A. exuvialus Burch.

A. nelsii Schinz.

Dipcadi marlothii Engl.

Malpighiaceae.

Sphedamnocarpus transvaalicus Burtt. Davy.

Malvaceae.

Abutilon austroafricanum Hochr.

A. fruticosum Guill & Perr.

Cienfugosia digitata Cav.

Hibiscus damarana Harv.

H. dongolensis Caill. ex Delile.

H. micranthus Linn.

H. praeteritus R.A. Dyer.

Sida chrysantha Ulbrich.

Nyctaginaceae.

Commicarpus africanus (Lour.) Dandy.

Oleaceae.

Ximenia americane Linn.

Onagraceae.

Montinia forskalaei Vahl.

Montinia sp.

Pedaliaceae.

Sesamum triphyllum Welw. ex Aschers.

Polygonaceae.

Oxygonum alatum Burch.

Portulaceae.

Portulaca kermesina N.E. Brown.

P. quadrifida Linn.

Talinum arnottii Hook.

Rhamnaceae.

Helinus integrifolius Kuntze.

Rubiaceae.

Kohautia aspera (Heyn. ex Roth.) Bremek.

K. omahekensis (K. Krause) Bremek.

Scrophulariaceae.

Anticharis linearis Hochst. ex Aschers.

Solanaceae.

Lycium lancifolium Dammer.

Solanum panduraeforme Drege. ex Dun.

S. renschii Vatke.

Sterculiaceae.

Hermannia modesta Planch.

Melhania acuminata Mast.

M. didyma Eckl. & Zeyh.

M. rehmannii Szyszyl.

Waltheria indica Linn.

Tiliaceae.

Corchorus asplenifolius Burch.

Grewia bicolor Juss.

G. flava D.C.

G. flavescens Juss.

G. retinervis Burret.

G. villosa Willd.

Verbenaceae.

Chascanum pinnatifidum E. Mey.

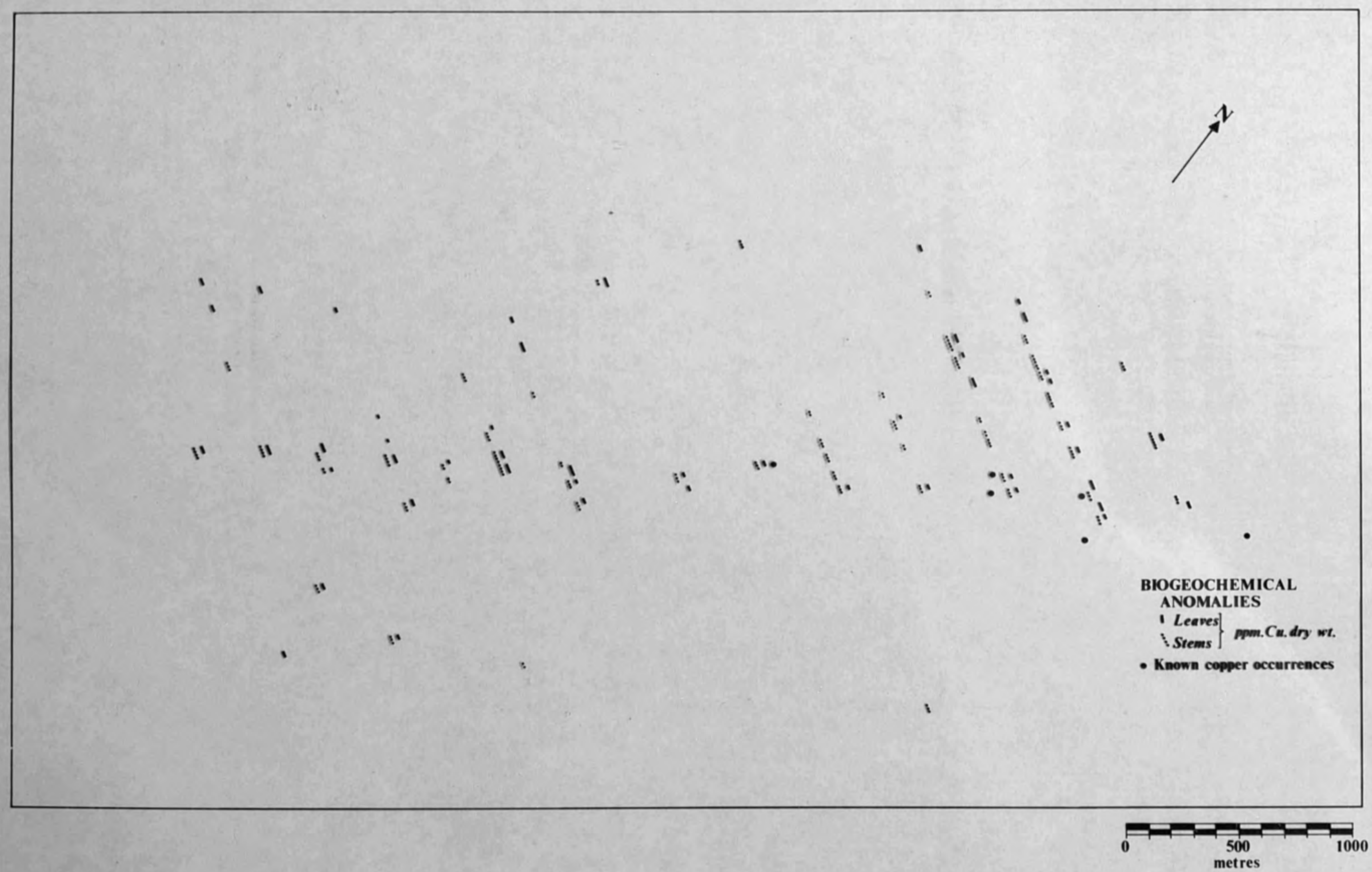
Clerodendrum ternatum Schinz.

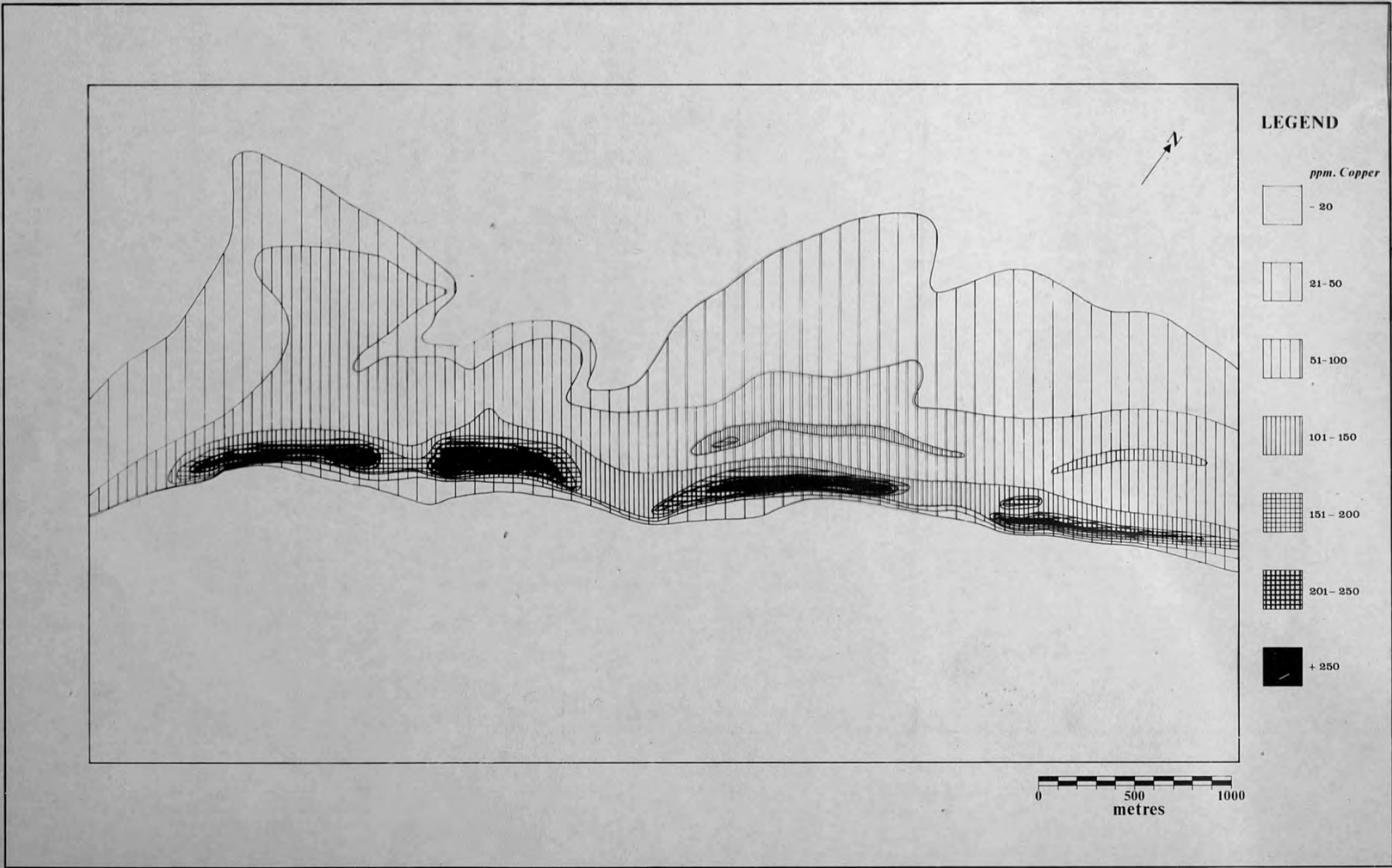
Lantana mearnsii Moldenke.

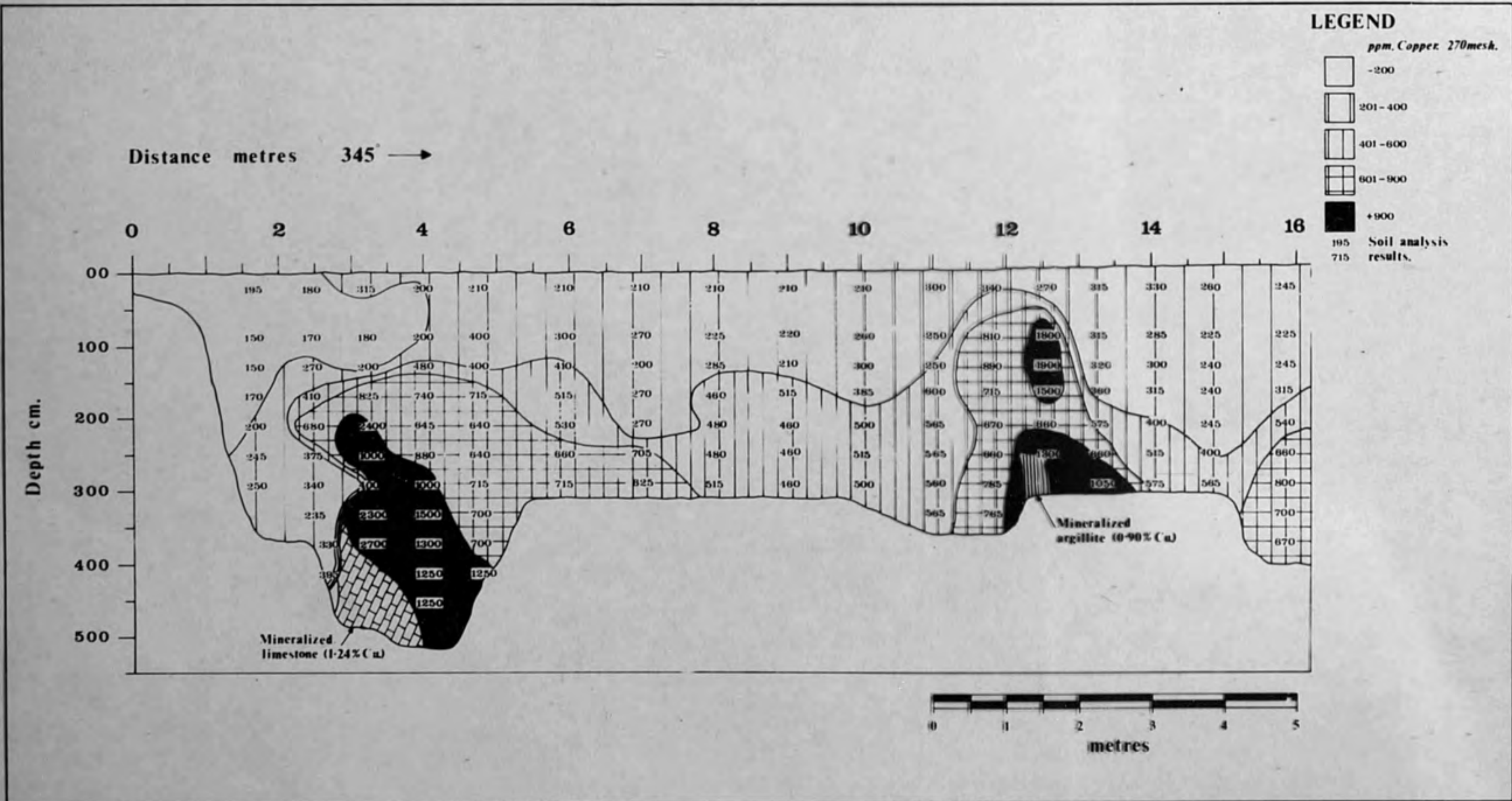
Priva africana Moldenke.

Zygophyllaceae.

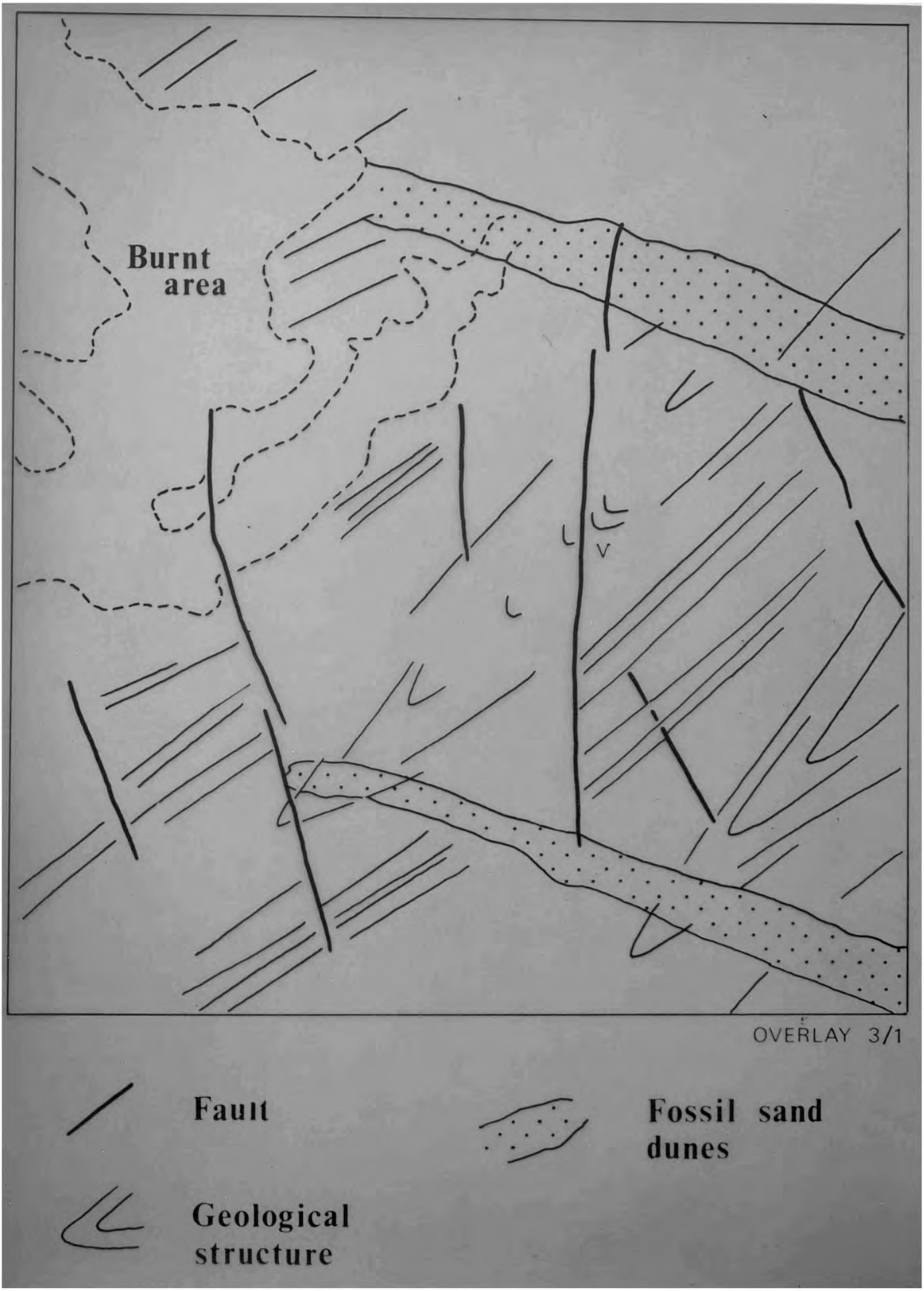
Tribulus terrestris L.


N
BIOGEOCHEMICAL
ANOMALIES
Leaves
Stems
ppm. Cu. dry wt.
Known copper occurrences
0
500
1000
metres

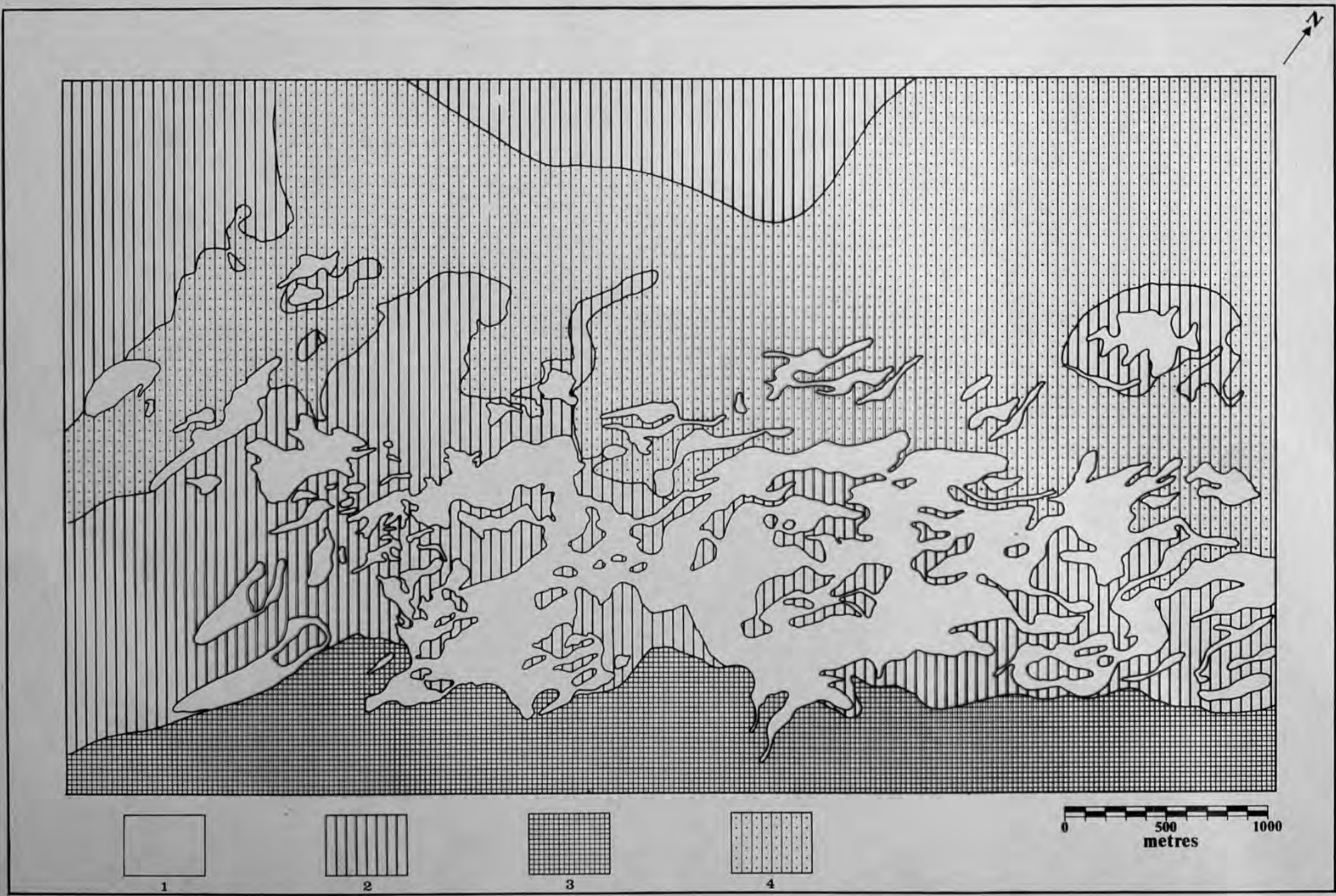

LEGEND
ppm. Copper
- 20
21-50
51-100
101-150
151-200
201-250
+250
N
0
500
1000
metres

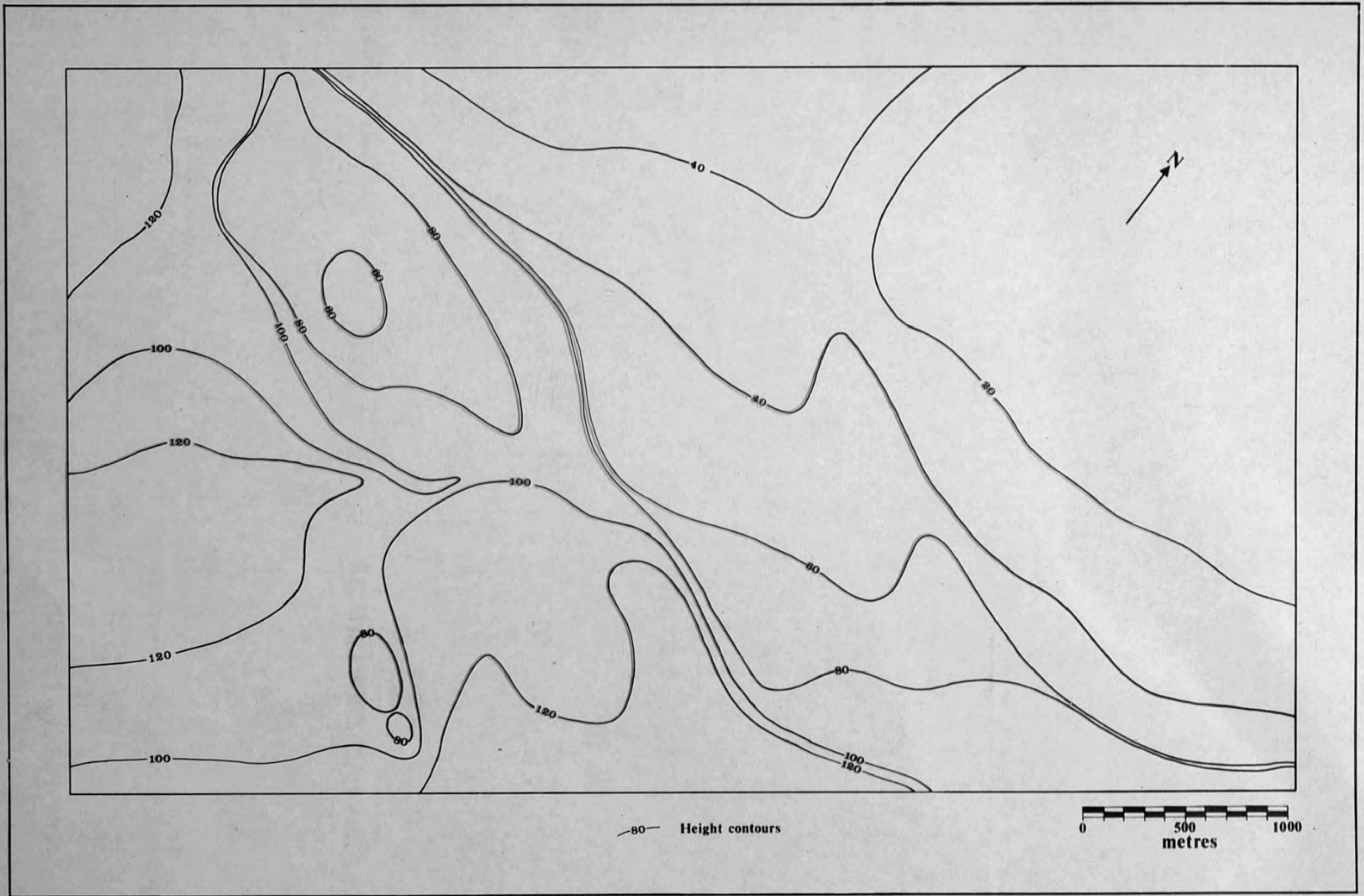


LEGEND
ppm. Copper. 270mesh.
-200
201-400
401-600
601-900
+900
195
715
Soil analysis results.
Distance metres 345°
Depth cm.
Mineralized limestone (1·24% Cu)
Mineralized argillite (0·90% Cu)
metres



Burnt area
OVERLAY 3/1
Fault
Fossil sand dunes
Geological structure


N
1
2
3
4
0
500
1000
metres


N
40
20
80
60
60
100
80
100
120
120
100
40
100
60
80
120
80
80
100
120
120
100
80
Height contours
0
500
1000
metres