PREFACE

The research on which this thesis is based was undertaken while the author held a bursary under a grant made to Professor M M Cole by the Beta Mining and Prospecting Co, a wholly-owned subsidiary of the Anglo-Transvaal Consolidated Investment Trust Co Ltd, for geobotanical investigations in South West Africa and Botswana.

GEOBOTANY, BIOGEOCHEMISTRY AND GEOCHEMISTRY IN MINERAL EXPLORATION ON THE WESTERN FRINGES OF THE KALAHARI DESERT WITH SPECIFIC REFERENCE TO THE DETECTION OF COPPER MINERALIZATION BENEATH TRANSPORTED OVERBURDEN

by

A. F. Boshoff

A B S T R A C T

The investigations outlined in this thesis were conducted in an attempt to establish the role of biogeography / geobotany, geochemistry and biogeochemistry in the detection of copper mineralization in bedrock concealed by transported material. To aid the interpretation of the results a detailed study of the physical background of the study area was necessary.

Orientation studies were carried out over mineralized tilloid and mineralized lava, and comprised the mapping and / or recording of vegetation along transects, the establishment of plant species suitable for biogeochemistry and the copper content of various mesh fractions of the soil. Analytical techniques suitable for plant and soil sample analysis were also investigated. A regional biogeochemical / geochemical programme was carried out to locate extensions to known mineralization and also additional areas of mineralization.

The biogeographical / geobotanical studies reveal the composition of anomalous and background vegetation units and indicate the influence of relief, drainage and lithology on plant species distribution. Over mineralized tilloid two plant species emerge as specific indicators of copper toxicity in the soil. The extent of the overburden limits the use of geobotany as a prospecting tool as vegetation is generally found to reflect overburden and soil types rather than concealed bedrock.

Geochemistry, comprising analysis of the -270 mesh fraction of the soil by the acid leaching / atomic absorption spectrophotometry method, is found to give satisfactory results in areas of near-surface bedrock.

The value of biogeochemistry in areas of thick overburden is discussed, and of the tree and shrub species investigated Phaeoptilum spinosum is found to be the most suitable for further biogeochemical work. Dry ashing / acid digestion followed by atomic absorption spectrophotometry is a suitable method of analysis for plant samples.

The limited success obtained in the regional biogeochemical / geochemical survey is probably due to the absence or low grade of mineralization in the tilloid and the lens-like occurrence of mineralization in the lava.

A C K N O W L E D G E M E N T S

Firstly my sincere thanks go to Dr. H.D. le Roex (Exploration Manager of Anglo Vaal S.W.A. (Pty) Limited during the period of the research and who initiated the project) for his interest and assistance in the field programme; the Anglo Transvaal Consolidated Investment Company Limited, without whose financial aid the work would not have taken place; and my special thanks go to my supervisor, Professor M.M. Cole of Bedford College, who spent much of her valuable time both at Bedford College and in the field directing the project and giving helpful criticism and advice. Professor Cole also kindly allowed me to use many of her photographs for this thesis.

My thanks also go to Dr. P.D. Toens, Mr. P. Fey and Mr. G. Gilchrist - then all of Anglo Vaal S.W.A. (Pty) Limited - for their contribution to the regional geology of the study area; and to Miss V. Ross who analysed some of the plant and soil samples in the laboratories of the above company.

Finally I would like to thank my colleague Mr. M. Mason for his constructive criticism and help in the field and also for allowing me to use several of his photographs; Mr. H. Ansell of the Department of Geography, Bedford College, for the reproduction of the maps, diagrams and photographs; and Mrs. J. Candy for her assistance in the drafting of Figs. 15 and 17 - 20.

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PART I

Chapter 1

INTRODUCTION

The study area (Gamma concession) is located on the western fringes of the Kalahari Desert 110 kilometres SSE of Windhoek, 65 kilometres ESE of Rehoboth and 60 kilometres south of Dordabis, in the mandated territory of South West Africa (Fig. 1).

Interest in the mineral potential of this area began in 1962 when prospecting work was carried out by Anglo Transvaal Consolidated Investment Company Ltd. south of Rehoboth, where a small copper mine with reserves of 2.5 million tons at 2 - 3% Cu was opened in the Klein Aub area. This initial work suggested that the sediments underlying this area, and assigned to the Tsumis System, were lithologically similar to those of the Deweras Series at the base of the Lomagundi System in Zambia dated at ± 500 million years. Inliers of similar rocks were known in Botswana, and hence it was postulated that the Tsumis System in South West Africa might represent a south-westerly extension of the sediments of Lomagundi age. This theory was supported by the stratiform nature of the then known sediments of the Tsumis System.

In 1966 and 1967 prospectors found copper mineralization in the potentially favourable sediments of the Tsumis System at Witvlei (Fig. 2) and at Kojeka, while Dr. H.D. le Roex - then a consulting

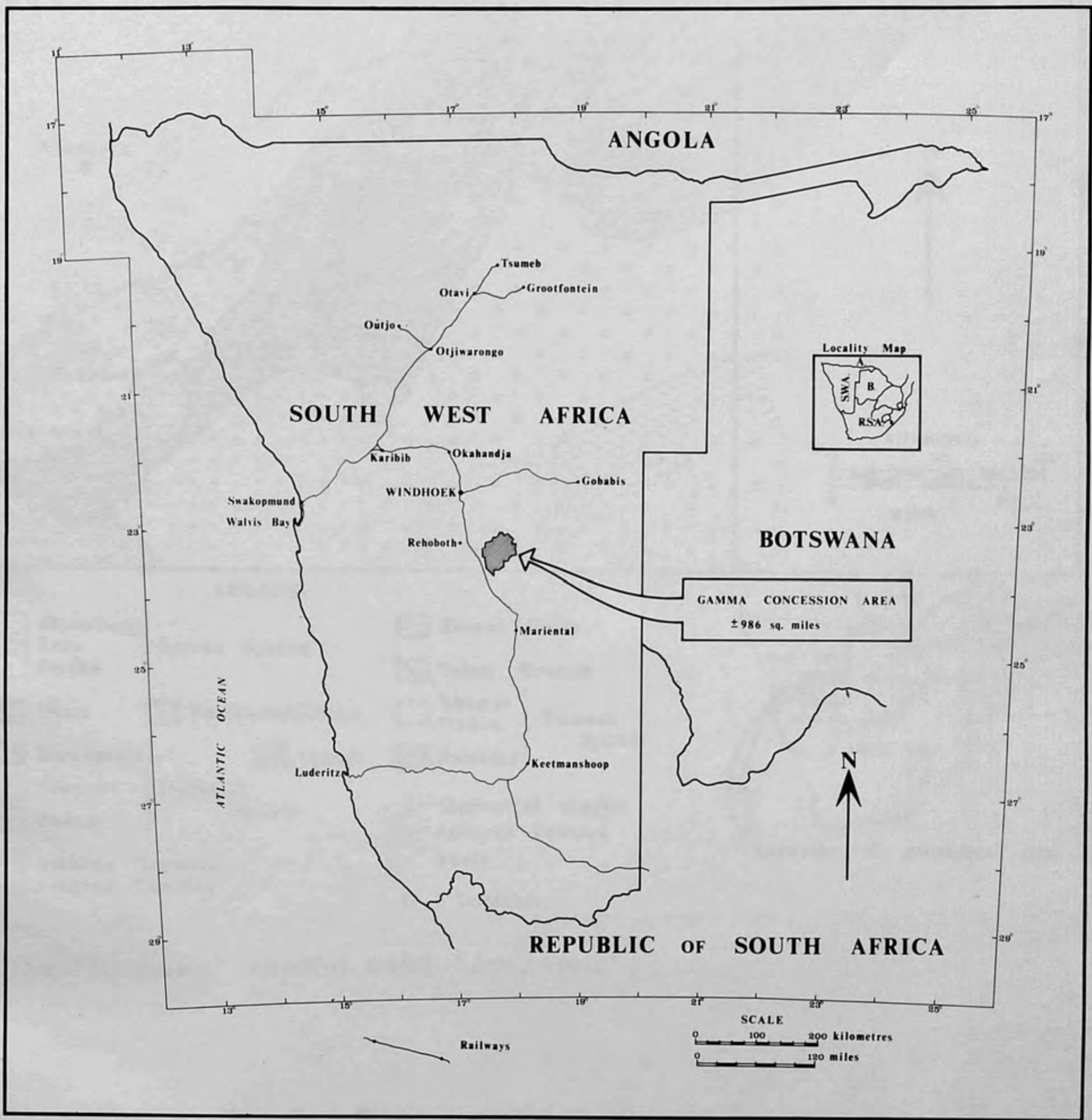
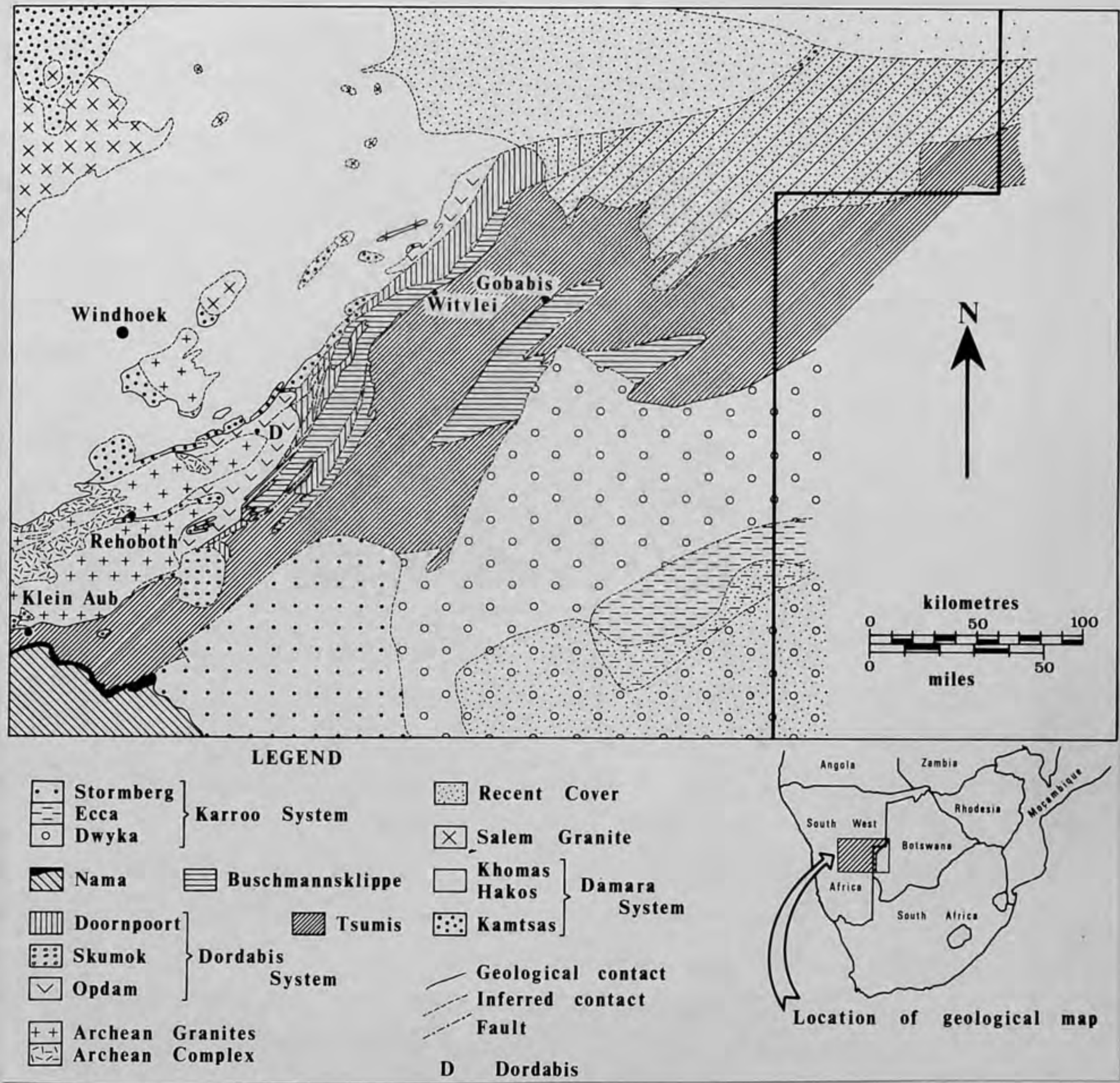


Fig.1: Location of the Gamma concession (study area)



(Note:"Archean" should read "Archaean")

Fig.2: Geology of a portion of South West Africa (from "Geology of South West Africa", Government Printer,Pretoria)

geologist of the Anglo Transvaal Consolidated Investment Company Ltd. - discovered apparently similar mineralization in a small outcrop along a drainage feature on the farm Sib in the study area of this thesis.

Small concessions were acquired by Beta Mining and Prospecting Company Ltd. (a subsidiary of the Anglo Transvaal Consolidated Investment Company Ltd.) at Witvlei and Kojeka, and an extended reconnaissance programme was initiated. Because of the thick cover of superficial deposits, particularly calcrete and Kalahari sand, and the paucity of rock outcrops, techniques which could detect subsurface mineralization beneath such a cover were needed.

In 1967 Dr. le Roex asked Professor M.M. Cole to assess the potential of geobotany in mineral exploration in this environment and engaged E.W.B. Miller and Associates to carry out geochemical reconnaissance surveys over the small concession then held by the company (Fig. 3). Initial work by Miss L.C. Coupland (now Mrs. Gadd) and Miss J. Cudmore (now Mrs. Hughes), research assistants of Professor Cole under NERC grant, led to the recognition of Helichrysum leptolepis as a copper indicator plant in the Witvlei area while the geochemical surveys revealed several copper anomalies which, on field investigation, were found to be delineated by Helichrysum leptolepis.

Dr. le Roex and Professor Cole, together with Dr. H. Nel of the Anglo American Corporation, Dr. (now Professor) G.T. Sohnge, then of Tsumeb Corporation Ltd. and Mr. C.S. Jennings, then Assistant Director of the Botswana Geological Survey, carried out field reconnaissance investigations throughout the whole tract of country extending from Witvlei north-eastwards to Maun in Botswana and conducted follow-up investigations over the Witvlei, Kojeka and Sib areas where the Helichrysum leptolepis plant was again found to be associated with copper mineralization. The promising results from this early work in 1967

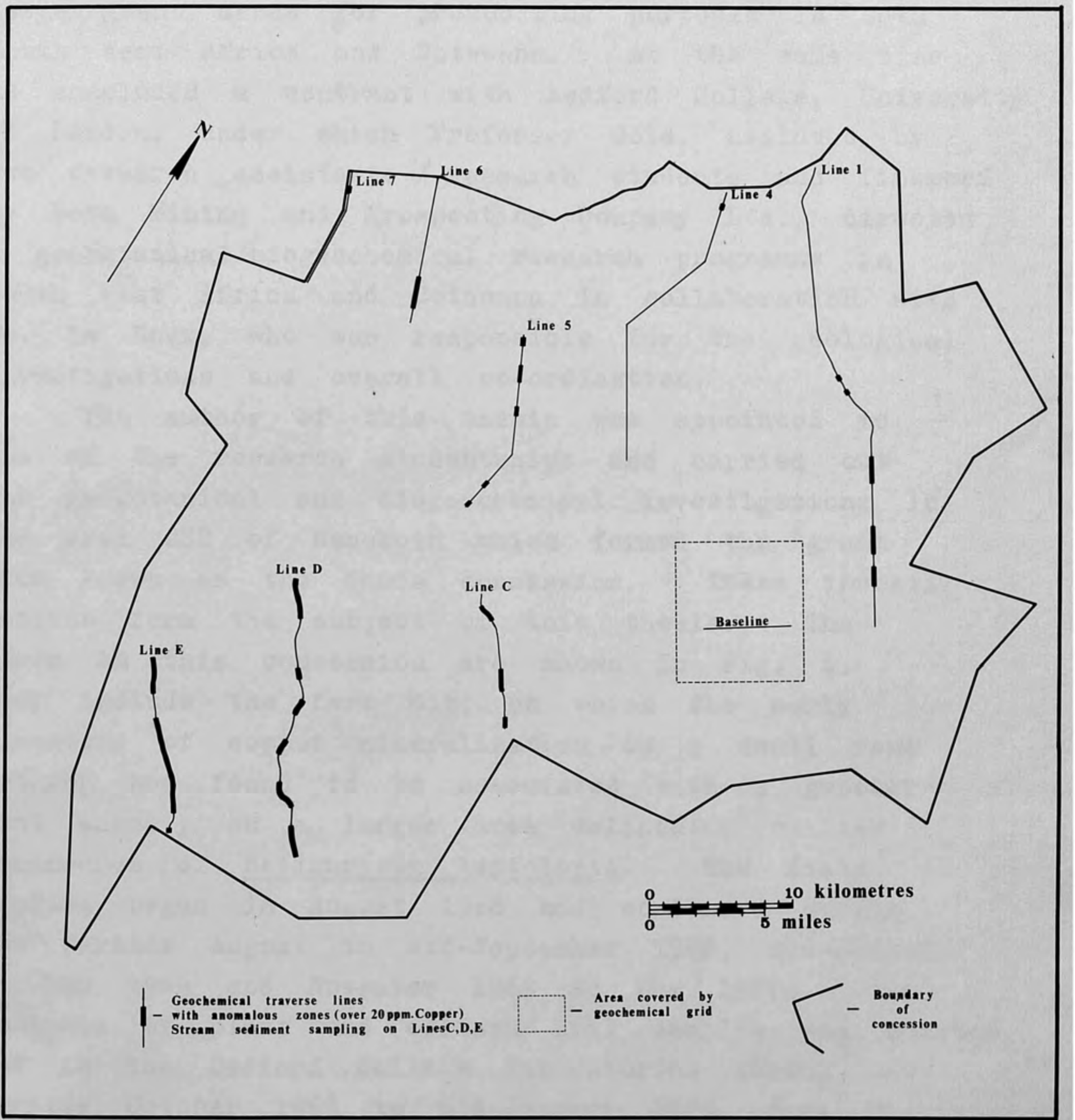


Fig.3: Location of soil sampling traverse lines and stream sediment sampling lines for a geochemical survey conducted by E.W.B.Miller and Associates. The grid for the geochemical survey on the farm Sib is indicated.

encouraged the Anglo Transvaal Consolidated Investment Company Ltd., through its newly formed subsidiary Beta Mining and Prospecting Company Ltd., to acquire large grant areas for prospecting purposes in both South West Africa and Botswana. At the same time it concluded a contract with Bedford College, University of London, under which Professor Cole, assisted by two research assistants / research students and financed by Beta Mining and Prospecting Company Ltd., directed a geobotanical/biogeochemical research programme in South West Africa and Botswana in collaboration with Dr. le Roex, who was responsible for the geological investigations and overall co-ordination.

The author of this thesis was appointed to one of the research studentships and carried out the geobotanical and biogeochemical investigations in the area ESE of Rehoboth which formed the grant area known as the Gamma concession. These investigations form the subject of this thesis. The farms in this concession are shown in Fig. 4. They include the farm Sib, on which the early discovery of copper mineralization in a small rock outcrop was found to be associated with a geochemical anomaly on a larger area delineated by the occurrence of _Helichrysum leptolepis_. The field studies began in August 1968 and continued during the periods August to mid-September 1968, mid-January to May 1969 and November 1969 to May 1970. The analysis of plant and certain soil samples was carried out in the Bedford College laboratories during the periods October 1968 to mid-January 1969, June to October 1969 and June to December 1970. The bulk of the soil samples were analysed in the Anglo Vaal. S.W.A. (Pty.) Ltd. laboratories in Windhoek, South West Africa (hereafter referred to as "Anglo Vaal").

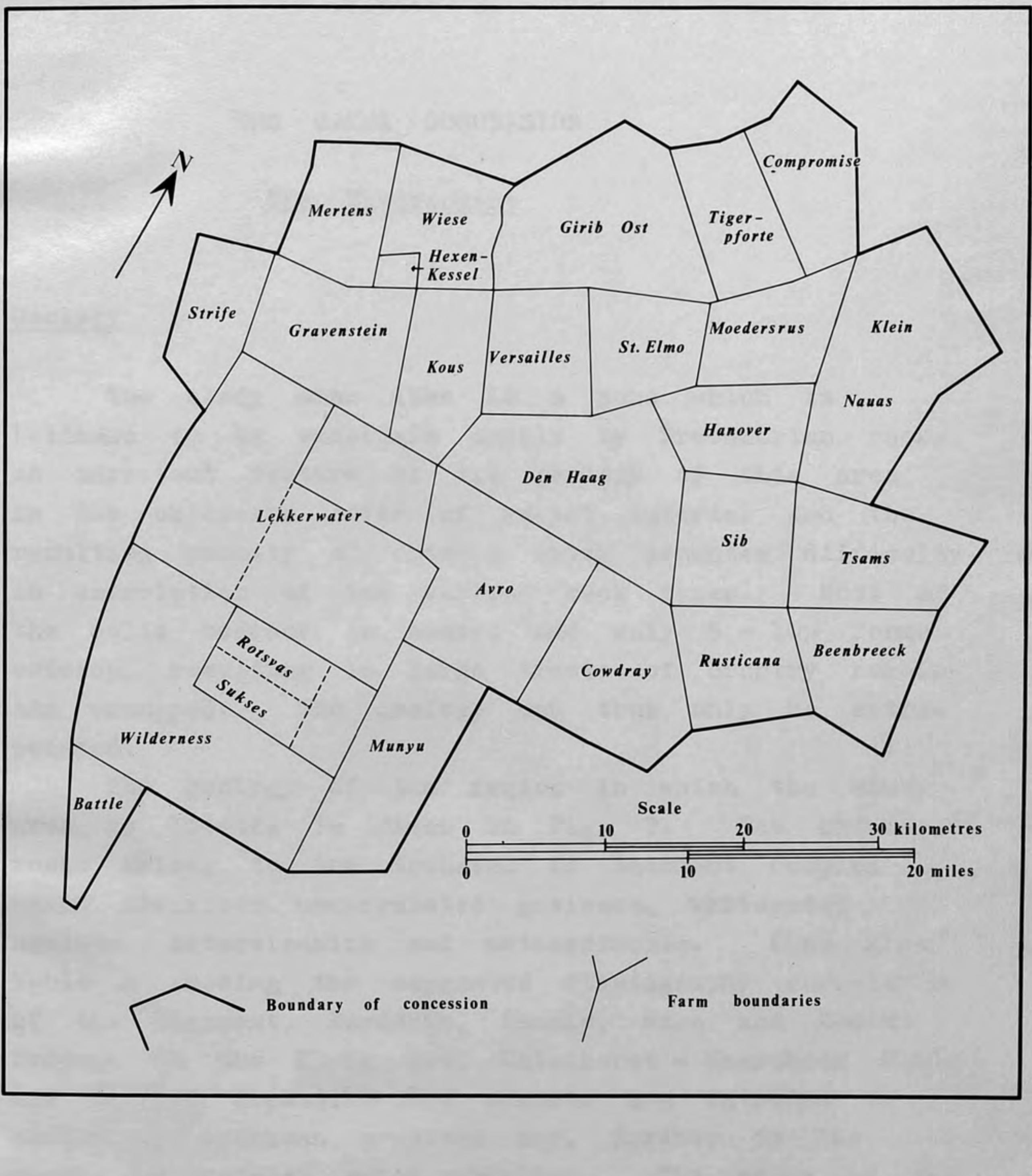


Fig.4: Farms in the Gamma concession (from "Geology of South West Africa", Government Printer, Pretoria)

Chapter 2

THE GAMMA CONCESSION

The Environment

Geology

The study area lies in a zone which is believed to be underlain mainly by Precambrian rocks. An important feature of the geology of this area is the extensive cover of recent material and the resulting paucity of outcrop which promotes difficulty in correlation of the various rock types. Most of the solid bedrock is masked and only 5 - 10% forms outcrop, resulting in large tracts of country remaining unmapped. The geology can thus only be extrapolated.

The geology of the region in which the study area is located is given in Fig. 2. The oldest rocks belong to the Archaean or Basement Complex which comprises uncorrelated gneisses, variegated schists, metavolcanics and metasediments. (See also Table 1 showing the suggested stratigraphy correlation of the Basement, Dordabis, Tsumis, Nama and Recent Systems in the Klein Aub, Uhlenhorst - Kharubeam Hills and Witvlei areas). The schists are intruded in places by Archaean granites and, further to the north, by younger Salem granites. The rocks of the Archaean Complex belong to the Marienhof, Abbabis, Epupa and Huab formations. Martin (1965), Gevers (1934) and Schalk (1961) have called these formations collectively the Abbabis System. These rocks do not outcrop in the study area. Rocks of the Dordabis System, first described and named by Gevers in 1934,

Table 1 : Suggested stratigraphy correlation of the Basement, Dordabis, Tsumis, Nama and Recent Systems

Klein Aub Area (Largely after Handley 1965)

System	Series or formation	Stage	Rock types	Thickness in metres
Tertiary to Recent			Kalahari sediments, windblown sand, calcrete & gravel.	
Nama	Schwarz-rand		Shales and quartzites	
	Schwarz-kalk		Limestones, shales & quartzites	
Tsumis	Klein Aub	C Upper quartzite and conglomerate (Tsumis or Kamtsas)	Pink to grey, granular, fine to coarse grained feldspathic quartzites containing randomly scattered pebbles in places, also banded ferruginous quartzites, conglomerates and possible tillite.	1000 to 2500
		B Calcareous quartzite	Fine-grained pink to maroon or grey calcareous quartzites, no true limestones or shale bands present.	1000 to 2000
		A Calcareous shale	Alternations of fine, shaly and calcareous strata with coarser quartzitic members that are in places pebbly-cupriferous green argillites.	600 to 1000
		Lower quartzite and conglomerate (Doornpoort)	Maroon quartzites, maroon shales, calcareous arenites and sandy limestones overlying ill-sorted basal conglomerate containing boulders of granite, porphyry and quartzite.	800 to 1200
		Intrusives	Basic and acid dykes	
Dordabis	Skumok		Quartz-feldspar porphyry (effusive) rhyolites, ignimbrites, agglomerates, quartzites and sedimentary breccia.	
	Opdam		Not present	
Basement	Marienhof		Metasediments, metavolcanics, variegated schists, gneisses and granites.	

Uhlenhorst - Kharubeam Hills Area (Largely after Toens 1970)

System	Formation	Stage	Rock types
			Kalahari sediments, windblown sand, calcrete and gravel.
Karroo	Stormberg		Basalt
Nama	Busch-manns-klippe		Limestones, white and red quartzites, shales and tilloid
Tsumis	Tsumis or Witvlei	Kamtsas or Tsumis C	Pink to grey, fine to coarse-grained feldspathic quartzites with randomly scattered pebbles banded ferruginous quartzites and conglomerates.
		Doorn-poort or Tsumis A & B	Conglomerates, quartzites
Dordabis	Skumok		Quartz-feldspar porphyry (effusive) rhyolites and agglomerates.
	Opdam		Mafic epidotized lavas with interbedded conglomerates, phyllites, metavolcanics and metasediments.

Witvlei Area (After Martin 1965)

System	Series or Formation	Stage	Rock types
Nama	Busch-manns-klippe		Dolomites, limestones, white & red quartzites, shales, tillite.
Tsumis	Witvlei	Kamtsas or Tsumis C	Brown feldspathic quartzites containing scattered pebbles and some conglomerates, black sands plentiful and cross-bedding marked.
		Doorn-poort	Undifferentiated alternating sequence of maroon quartzites, calcareous arenites, green shales, cupriferous siltstones (argillites) thin bands of mud-pellet conglomerate and local limestones overlying ill-sorted basal conglomerate. Three cupriferous ore zones, one of which is associated with pyritic carbonaceous shale.
Dordabis	Skumok and Opdam		Mafic to felsic lavas - basaltic andesites, rhyolite, quartz-feldspar porphyry, pyroclasts, lavas locally cupriferous.

comprising the Opdam, Skumok and Doornpoort formations (Schalk 1961) overlie the Archaean Complex. Outside the study area this contact is revealed to be unconformable. Within the study area rocks of the Opdam, Skumok and Doornpoort formations outcrop on the farms Compromise, Tigerpforte, Girib Ost, Wiese, Hexen Kessel, Mertens, Versailles, St Elmo and Moedersrus. These rocks are regarded as being of late Precambrian age.

In the Dordabis area the Opdam and Skumok formations rest on diorites believed to be of Marienhof age. The Opdam formation consists of a sequence of mafic to intermediate, epidotized lavas with subordinate metaquartzites, quartzites, phyllites and boulder conglomerates, and is unconformably overlain by the Skumok formation. This formation consists of effusive porphyries forming sills, felsic lavas, rhyolites and conglomerates with intercalated sediments and some intrusive granites. The Skumok formation was originally thought to be only a facies of the overlying sedimentary succession, the Doornpoort formation, but it is now considered to be a separate formation altogether, due to a discordance between the two. The Doornpoort formation begins with a basal conglomerate containing pebbles of Skumok porphyry followed by quartzites with some sandy limestone and a very thick conglomerate mainly of clay pellets.

In 1934 Rogers favoured the correlation of the Doornpoort quartzites - Opdam diabase association with the Matsap beds of the Waterberg System in southern Botswana and South Africa.

Overlying the Dordabis System with a major unconformity is the Tsumis System, indicating the folding of the members of the Dordabis System before the deposition of the Tsumis beds. The Tsumis System strikes in a north-east to south-west direction. Handley (1965) has classified the system into the following stages in the Klein Aub area, where all members are well represented:

Tsumis C or upper quartzite and conglomerate stage
Tsumis B or calcareous quartzite stage
Tsumis A or calcareous shale stage
Basal conglomerate or lower quartzite and conglomerate stage.

The lower quartzite and conglomerate stage consists of maroon quartzites and shales, calcareous arenites and sandy limestones overlying ill sorted basal conglomerates containing boulders of porphyry, granite and quartzite. The Tsumis A or calcareous shale stage comprises fine shaly calcareous strata alternating with coarser quartzitic members which are pebbly in places. The Tsumis B or calcareous quartzite stage consists of a thick succession of fine-grained, pink to maroon or grey calcareous quartzites with 2 - 20% limestone content. This stage was not observed in the study area, although it may be present together with the basal conglomerate and Tsumis A stage at greater depth.

Outcrop of the Tsumis C or upper quartzite and conglomerate stage becomes progressively more evident from east to west which is due to a change in dip and further thickening. The quartzites are pink to grey, granular, feldspathic, fine to coarse-grained, with pebbles (average diameter 6 mm) scattered throughout the rock. These pebbles are well rounded and are of mixed origin, with quartz and quartzite pebbles the most common although porphyry and granite is also encountered. Much of the quartz gravel on the surface could have its origin in the weathering of this stage. The feldspathic quartzites are often cross-bedded and streaked with laminae of dark magnetite rich black sand. It is interesting to note that the Kamtsas formation also exhibits these features, and the Kamtsas quartzites thus appear to be lithologically identical to the quartzites of the Tsumis C stage, which leads to the theory that they are similar in age.

The quartzites exposed in a major synclinal feature in the north-east corner of the study area were originally assigned to the Kamtsas quartzite of the Damara System, but subsequent work has led to their correlation with the Tsumis C quartzite.

Various workers have differing views concerning the correct position of the Doornpoort formation in the geological succession. The Doornpoort of Schalk (1961) and Martin (1965) is lithologically similar to the Basal conglomerate, Tsumis A and Tsumis B of Handley (1965) and, while Schalk and Martin retain it as a member of the Dordabis System, Handley, Toens and later workers consider it to be the lower stages of the Tsumis System. Whereas all the stages of the Tsumis System are conformable upon each other, there is a large unconformity between the Skumok and Doornpoort formations.

As a whole the Tsumis beds show reddish-purple colours, but these appear to be secondary, as boreholes have shown that the colour changes at depths of 100 to 150 metres. The rocks of the system have suffered little or no metamorphism, and show no recrystallization, and owing to the high proportion of shaly and feldspathic material they have a tendency to weather to soft purple-brown sandstones.

Approximately 40 kilometres to the north of the study area the Tsumis beds fringe the southern rim of the cupola formed by the rocks of the Marienhof and Damara Systems and overlie the pre-Damara rocks with a large unconformity. The Tsumis beds have been folded along axes parallel to those of the Damara sediments, forming a series of synclines and anticlines, and therefore must be older than

500 million years. The Tsumis System is the only Precambrian system connecting the central and southern parts of South West Africa.

To the north of Dordabis the Tsumis System is unconformably overlain by the Numees formation which, in turn, is overlain conformably by the Buschmannsklippe formation. The Buschmannsklippe formation is considered to be the lower stage of the Nama System which has been termed a possible facies of the Damara System of the north (Martin 1965). The Damara System could just be a deeper geosynclinal phase and a more highly metamorphosed equivalent of the Nama System in the south. To the east, north-east and south of Dordabis, the Tsumis beds are discordantly overlain by the Buschmannsklippe beds, although the discordance is only slight as both are folded together suggesting no major folding between the time of deposition of the Tsumis sediments and the Buschmannsklippe beds.

Other known and dated systems have never been properly correlated with the Tsumis System, probably due to the lack of intrusives and fossils. There is an apparent break in time between the Tsumis and the younger Buschmannsklippe formation, which can be dated as late as late Precambrian or early Cambrian.

The Buschmannsklippe formation consists of dolomitic limestones, dolomite, shale, sandstone and a very hard flinty white quartzite mottled by pinkish or yellowish feldspar grains. As a contrast to the Tsumis beds the Buschmannsklippe formation shows a high degree of recrystallization of quartzite grains.

A tilloid, varying greatly in thickness, occurs in some areas at the base of the Buschmannsklippe formation. This tilloid is composed of rounded and angular pebbles set in a greenish to blue-grey, shaly and sometimes sandy matrix. The matrix becomes clayey when wet. The pebble inclusions are mostly of quartzite. A tillite south of Gobabis has not been positively correlated with the Buschmannsklippe tilloid.

To the north the phyllites, quartzites, greywackes, marble talc and tremolite schists, tillite and quartzites of the Hakos formation and the pebbly schists, tillite and quartzites of the Khomas series, both of the Damara System, are predominant. These rocks are probably equivalent in age to the Buschmannsklippe sediments in the south and are intruded by Salem granites.

An unconformity separates the Buschmannsklippe beds from the overlying Karroo System which consists of lavas, tillites and other sediments. To the immediate south of the study area Karroo sandstones are unconformably overlain by horizontally bedded basaltic lavas with intercalated layers of sedimentary material. The lavas are equivalent to the Stormberg lavas of the Drakensberg and are probably Triassic-Liassic in age. These volcanic rocks, which are mainly amygdaloidal and obtain their greatest development further south, are the products of great volcanic activity at the close of the Karroo epoch. Where the Buschmannsklippe formation is not present the Karroo lavas overlie the quartzites of the Tsumis System.

The stratigraphical sequence of Precambrian rocks has been extrapolated from studies of relatively infrequent outcrops as most of the study area is covered by Recent to Tertiary sediments. These Recent to Tertiary sediments include Kalahari beds formed by a surface layer of unconsolidated sand of aeolian origin underlain by more or less consolidated calcareous sand and gravel. Sandy marls, varying in thickness from very thin remnant patches of arenaceous limestone near the margin to more than 300 metres at the centre of the basin south of the study area, are also present. In the Auob-Nossob river basin the thickness of these deposits exceeds 400 metres. To the east of Gobabis, along a narrow belt, the older formations rise to the surface of the aggradational end-Tertiary plain.

Climate

Located on the western fringes of the Kalahari Desert, the study area experiences a semi-arid climate with two distinct seasons. The period from May to September is dry and is characterized by warm days and cold nights, while the period from October to April, when the scanty rains are received, is hot and generally wet conditions prevail. Extreme seasonal and diurnal fluctuations of temperature are characteristic.

In winter the days are hot with temperatures averaging 18° - 20°C but the nights are cold with minimum temperatures of 4° - 6°C being recorded (Table 2.)

Table 2: Mean temperatures at Cowdray homestead (in °C.)

	Mean minima.	Mean maxima.
January	23	33
February	21	29
March	19	26
April	14	24
May	12	21
June	7	18
July	5	17
August	10	21
September	15	24
October	17	28
November	20	29
December	21	30

During July, which is the coldest month, temperatures often drop 2^{o} - 3^{o} below freezing point with a maximum drop of 6^{o} recorded. In the Kharubeam Hills area four to six frosty nights a year are usual while on the plains to the south of these hills eight to ten frosty nights a year have been recorded. At Rehoboth village this figure is higher (Table 3).

Table 3: Nights with recorded frost at Rehoboth village

May	1
June	17
July	23
August	3
September	1
Total	45

This may be due to higher altitude and greater exposure but could possibly be due to more complete recording. The first frosts, in May or June, are usually sufficient to kill off most of the annuals from the preceding rainy season, and during the winter months only the hardy perennials survive. Equally damaging to the vegetation are the hot berg winds which periodically descend from the central plateau and cause extreme variations of temperature. Occasional late frosts in September or October are also damaging to the vegetation. Generally the occurrence of frost is unpredictable and certain years have little or no frost, resulting in the vegetation remaining in a fair condition well into the winter.

Summers are warm to hot. December and January are the hottest months of the year with an average maximum temperature of 35°C. Up to 40°C has been recorded in the shade on the farm Sib. Minimum summer temperatures average 22°C (Table 2). The diurnal range of temperatures is generally less in summer than in winter. The highest maximum temperatures are normally recorded in January.

The rainy season may be expected to start in late January and end in March or April but this is extremely irregular and no definite cycle is apparent. The earliest rains may fall in late September, October or November and then again in January, February and March which are the main rainy months (Table 4).

Table 4: Monthly rainfall (in mm) for 1969 for the farm Tsams

January	8
February	134
March	38
April	39
May	3
June	-
July	-
August	-
September	3
October	-
November	-
December	-

In some years no rain falls until late February or March and this has a detrimental effect on the vegetation.

The mean annual rainfall is 220 mm but this varies greatly in amount and in incidence from year to year. Four or five years may pass with little or no rain and the severity of the drought may cause the death of some of the larger trees and shrubs. A good year may bring as much as 500 mm, e.g. the farm Cowdray in 1949/50, and a poor year as little as 15 mm, e.g. the farm Kous in 1958/59. During the great floods of 1933/34, 1058 mm were recorded on the farm Pokweni over a period of two weeks. Good rainfalls were recorded in 1949/50, 1953/54, 1955/56, 1962/63 and 1966/67 (Table 5).

Table 5: Yearly rainfall (in mm) for the period 1949/50 - 1968/69 for the farm Cowdray

1949/50	-	509.00	1959/60	-	211.90
1950/51	-	102.00	1960/61	-	159.80
1951/52	-	236.60	1961/62	-	144.70
1952/53	-	218.80	1962/63	-	380.90
1953/54	-	318.70	1963/64	-	141.80
1954/55	-	263.20	1964/65	-	224.00
1955/56	-	324.10	1965/66	-	258.00
1956/57	-	224.80	1966/67	-	252.80
1957/58	-	287.60	1967/68	-	213.10
1958/59	-	98.50	1968/69	-	161.90

The rain is usually in the form of short thunderstorms in the late afternoon and evening. In some cases as much as half of the entire season's rain has fallen during one single thunder-shower. As a result of the thundershowers flash floods are not uncommon in the Kharubeam Hills and on the plains. The thundershowers are highly localized in their development and areas within 3 kilometres of each other may experience considerable differences in yearly rainfall figures. This localization of rainshowers also has a marked effect on the vegetation in the area. The amount and nature of the rainfall exerts important influences on landscape evolution, soil development and vegetation.

Relative humidity is generally low. During the morning when temperatures are low the humidity is relatively high, while in the afternoon when temperatures are high, the humidity is extremely low.

The air at night and in the early morning is clear, dry and still, and haze is frequent. The daily winds rise in the late forenoon reaching maximum velocity in mid or late afternoon. These winds have an average maximum velocity of 10 knots and have limited powers of erosion.

Storm winds before the rainy season blow mainly from the north-west, and together with occasional south-easterly winds cause the frequent sand storms and "dust devils" which sweep across the countryside. Large quantities of sand and dust are transported and deposited by the storm winds and thus contribute to the geomorphological changes in the country.

Most of the wind occurs from August until late January and while the direction of the winds on the southern plains remains reasonably constant, the winds in the Kharubeam Hills change with remarkable frequency. In the hills it is not uncommon for the wind to blow from four different directions in one day.

Generally the climate is harsh and has far reaching effects on the physiography, geomorphology and vegetation of the area.

Physiography and Geomorphology

Both the geomorphological processes and features have a particular importance in the study area where their understanding is essential for the interpretation of biogeographical, geobotanical, biogeochemical and geochemical information, and for the extrapolation of the geology from infrequent bedrock outcrops.

Field investigations coupled with studies of the literature suggest that the present landscape has been fashioned by the interplay of geological events, climatic changes and geomorphological processes operating over a long period. The most important features result from the following sequence:-

1. widespread planation during several erosion cycles which destroyed the pre-existing landscape;
2. upwarp in the area of the Khomas Highlands which initiated a new erosion cycle leading to cutting of deep poorts through the peripheral ranges of these highlands and to the development of two planation surfaces;
3. the dismemberment of the drainage systems by sand deposition during drier climatic periods;
4. the deposition of calcrete to form the Kalahari Limestone Plain or Plateau;
5. erosion and deposition during flash floods and transport of windblown sands during dry periods, a process which is still active today.

Briefly the study area comprises two main physiographic provinces (Fig. 5):-

a) Kharubeam Hills
b) Plains to the south of the Kharubeam Hills.

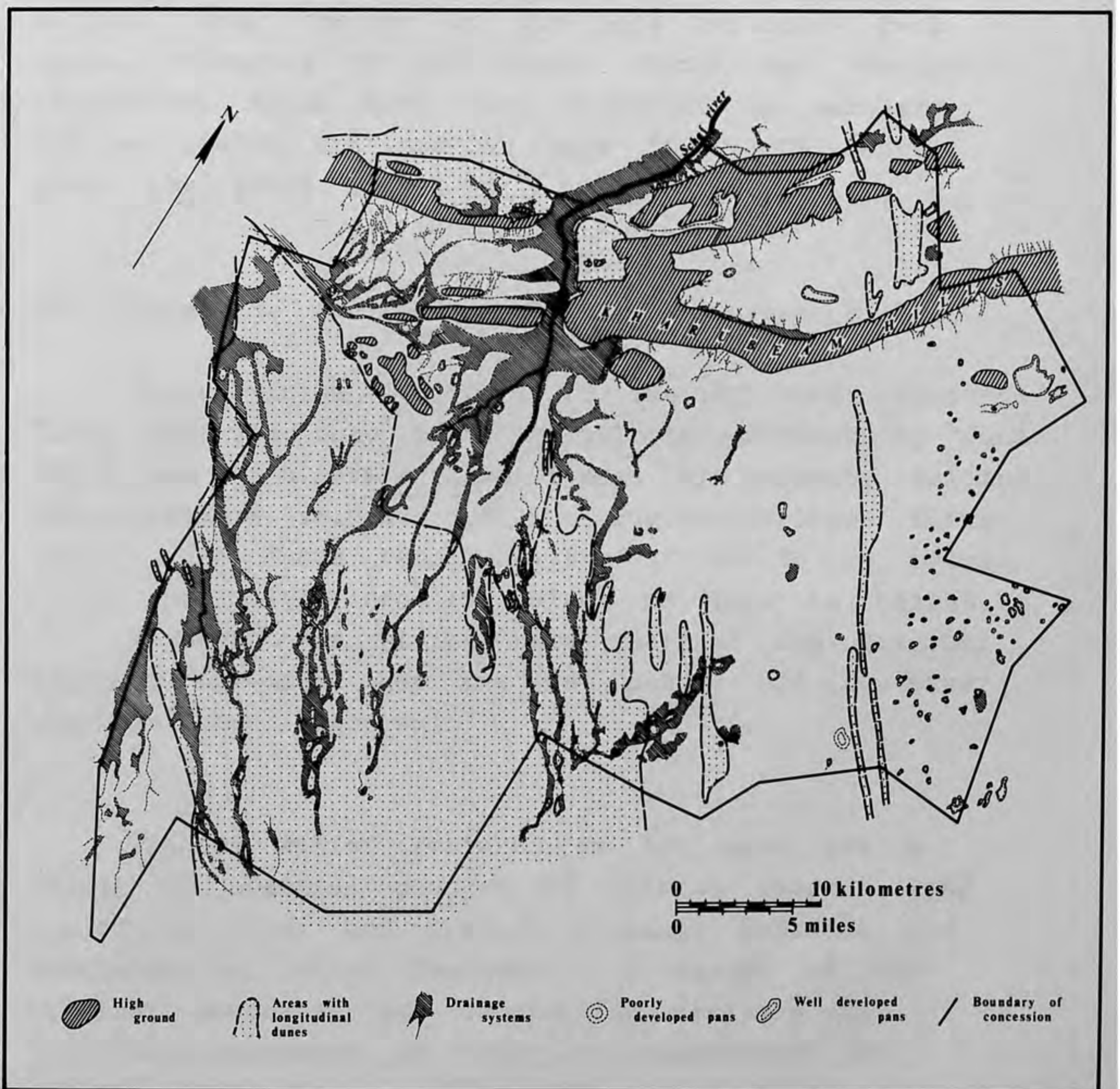


Fig.5: The physiography and geomorphology of the Gamma concession (compiled from an interpretation of aerial photographs by E.W.B.Miller and Associates and supplemented by field studies by the author)

a) Kharubeam Hills

This northern region of the study area is dominated by the hills and ridges of the Kharubeam range. They consist of the more resistant rock types, belonging to the Opdam, Skumok and Doornpoort formations, which have been dissected by earlier erosion cycles and are no more than 1800 metres above sea level (a.s.l.).

b) Plains to the south of the Kharubeam Hills

These plains are part of the Kalahari Limestone Plain and the only major relief is provided by sand dunes and also low ridges formed by calcrete outcrop and quartzite remnants of the Buschmannsklippe formation. The dunes reach heights of 20 to 25 metres, while the ridges are 15 metres or less in height.

Although the plains have internal and external drainage systems, they are not mature and no river channels have been cut.

Present relief features in the area are a legacy of numerous changes of climate over a long period of time, and present drainage patterns are unrelated to relief features. A resumè of the regional processes and outstanding features is therefore necessary in order to understand the present land forms. The study area forms part of the Great African Plateau which extends eastwards from the Auas Mountains and slopes gradually to the Kalahari Basin. This plateau rises to a height of 2000 metres a.s.l. to the west of Windhoek (Fig. 6). The Auas Mountains near Windhoek have an average elevation of 2200 metres a.s.l. with the Molkteblick, at 2700 metres a.s.l., the highest point

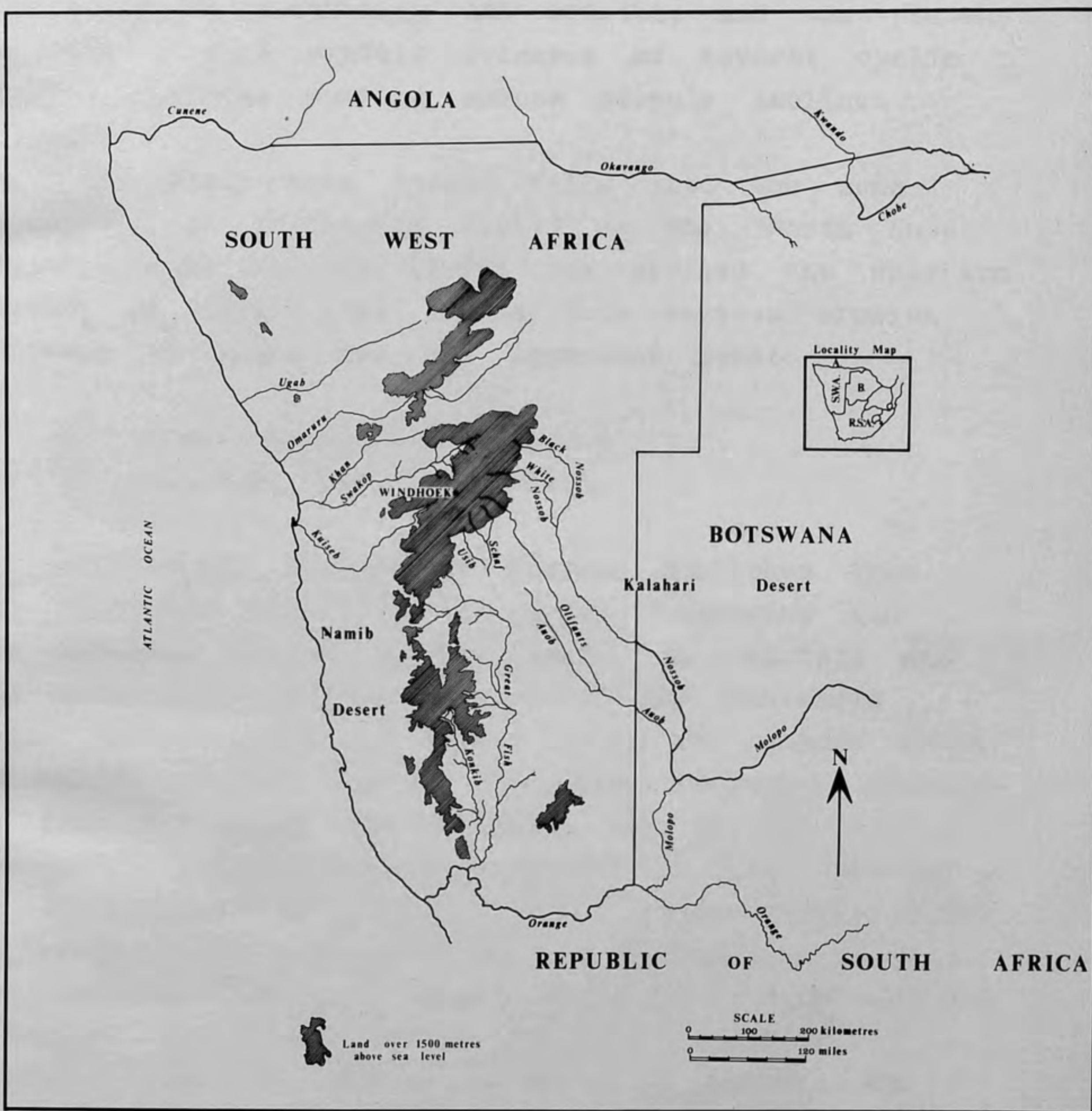


Fig.6: Land over 1500 metres above sea level and the regional drainage systems of South West Africa and south-western Botswana (from Index map, South West Africa, 1:250,000 Topo series, T.S.O. Pretoria)

in South West Africa. These mountains form part of the elevated plateau around Windhoek, known as the Khomas Highlands.

The Khomas Highlands plateau consists of rocks of the Damara System which have varying degrees of resistance to weathering and erosion, and the plateau and its margins exhibit evidence of several cyclic erosion surfaces cutting across steeply inclined strata.

The study area itself falls into the zone classified by Wellington (1967) as the "North Nama Plain", while Mabbutt (1955) has divided the southern portion of South West Africa into various erosion surfaces of which two are important here:-

1) Great Namaqualand Plateau
2) Kalahari Limestone Plain.

The Great Namaqualand Plateau stretches from the highlands bordering the Great Escarpment and the Kalahari margin in the south, to Rehoboth and the lava and quartzite ridges of the Kharubeam Hills in the north. Beyond this, it extends north as valley plains between protruding resistant surfaces to fade out along the southern rim of the Auas Mountains. The northern extension of the plateau, at an altitude of 1200 to 1500 metres a.s.l., has a fairly steep gradient, and is distinguished by its internal "Kalahari type" drainage. This northern extension forms the second surface, called the Kalahari Limestone Plain, which abuts against the foot of the Kharubeam Hills (Plate 1).

The Kharubeam Hills, with a height of 1800 metres a.s.l., represent a southern extension of the Khomas Highlands. The southern boundary of the Kalahari Limestone Plain and the boundary of the Great Namaqualand Plateau is probably a low limestone escarpment just to the north of Kalkrand, which thus

Plate 1: View north-east towards the ridge of Tsumis quartzites forming the Kharubeam Hills and cut by the Klein Nauas water gap. The basin forming the northern limit of the Kalahari Limestone Plain and underlain by Buschmannsklippe quartzites with sand dunes is seen in the foreground. (Ref. MMC/SWA 20/10).

places the study area within Mabbutt's Kalahari Limestone Plain.

The prominent ridges and hills in the area consist of the more resistant rock types which have survived the various erosion cycles which planed the less resistant rocks. Examples of this can be seen in the Kharubeam Hills, which are formed by the quartzites of the Tsumis System and the lavas and quartzites of the Dordabis System. The Kharubeam Hills, forming the northern boundary of the study area, are bounded in the south by the Rehoboth Depression, while towards the east they gradually disappear under the sand cover of the Great Kalahari Basin. The Rehoboth Depression forms a western embayment of the Kalahari Basin.

The most striking geomorphological feature in the Kharubeam Hills are the deep poorts cut through the range of Doornpoort quartzites during an earlier erosion cycle. Through these poorts the rivers, when in flood, have carried large quantities of material weathered from the rocks of the Khomas Highlands and deposited it as alluvium over pre-existing land surfaces between the hills. This material, together with windblown Kalahari sand, masks the bedrock geology and poses exploration problems which will be dealt with in Chapters 4 - 13.

East of the Windhoek - Rehoboth railway line and north of the Kharubeam Hills the narrow range of the Nauas Mountains, consisting of quartzites, dolomite and shale of the Buschmannsklippe formation, rises abruptly to a height of 2000 metres a.s.l. It is cut by the southward flowing Usib River in the Nauas poort (Plate 2). The Usib then cuts through the Langeberg Mountains, formed of Skumok porphyry, seven kilometres east of Rehoboth before running into dune country. To the south-east of Rehoboth this range loses height and becomes buried by the sands of the Kalahari, its only remnants being a series of low ridges and inselbergs protruding through the sand cover (Plate 3). To the south and south-east of Dordabis low hills of lava and quartzite of the Opdam, Skumok and Doornpoort formations form similar parallel ridges separated by wide plains covered by windblown sand and devoid of outcrop. Further eastwards these ridges also become buried by Kalahari sand with only scattered remnants projecting through the cover of sand.

The Khomas Highlands have been thoroughly planed and while in the central portion of the highlands the planation surface exceeds 2000 metres a.s.l. it declines on the northerly and southerly sides. To the south it can be traced across the summit planes of the outliers, an example being the ridges of the Kharubeam Hills with a slope of more than 3 metres per mile, until at Tsumis the surface stands only 70 metres above the Kalahari Limestone Plain. This slope from the Auas Mountains and other residual relief above the Khomas Highlands may mark a pre-Karroo watershed. Martin (1965) has stressed the importance of these tilted pre-Karroo surfaces in the formation of the present landscape. The drainage systems may have originated on a cover of Karroo rocks which was stripped away with the associated cutting of the poorts following upwarp towards the Khomas axis.

Large river boulders are common beneath a cover of windblown sand in old water courses and can only owe their origin to a great pluvial period as they could only have been transported by strongly flowing waters. It is therefore possible that during this pluvial period large streams of water, eroding the Karroo sandstones and Nama series, carried sand, limestone and boulders which were ultimately deposited in the depression to the south of the Kharubeam Hills, doubtless during frequent variation of the course of streams.

Plate 2: Water gap carved by the Usib River in the Nauas range to the north-east of Rehoboth village. (Ref. MMC/SWA 2/7)

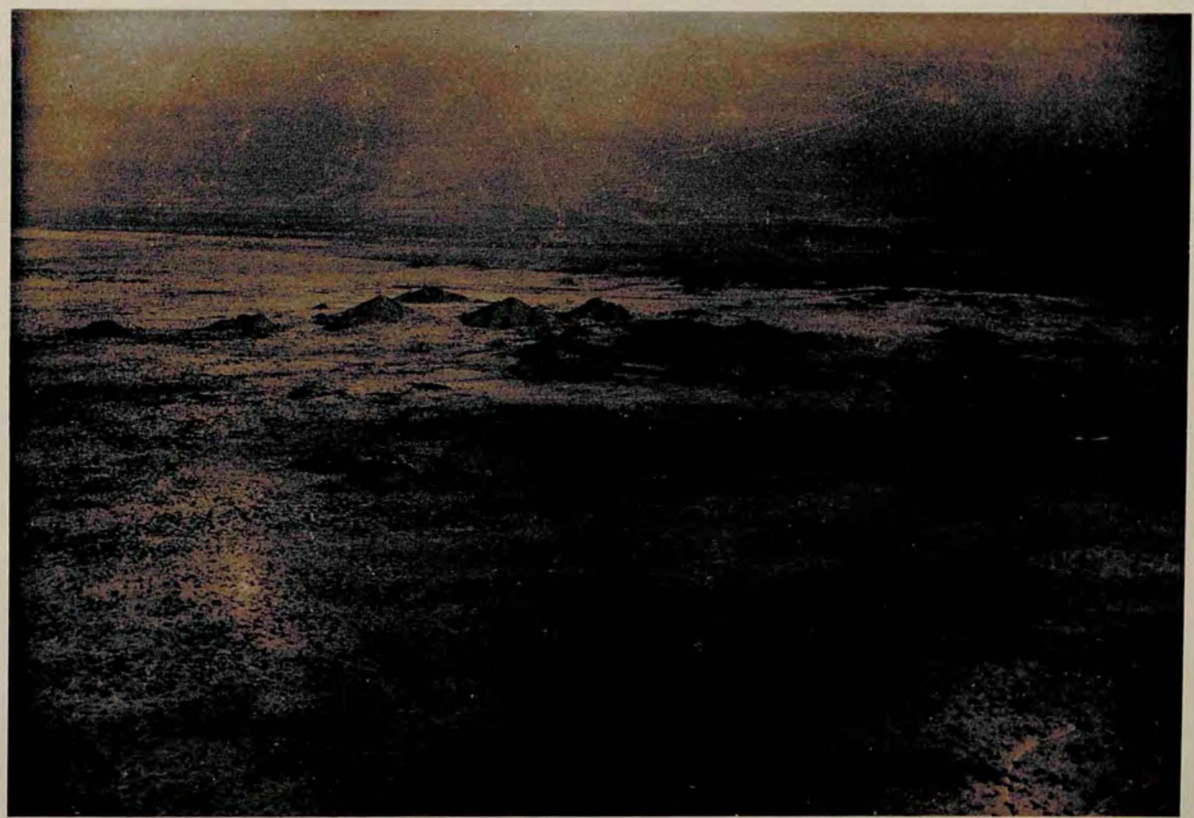


Plate 3: Outcrops of Skumok porphyry, protruding through the cover of windblown sand, gravel and calcrete to the south-east of Rehoboth village. (Ref. MMC/SWA 20/7)

Two geomorphological features in the area are of outstanding significance. The first is the planation in later erosion cycles of the outcrops or sub-outcrops of the less resistant sedimentary horizons of the Doornpoort and Tsumis formations, and the second is the blanketing of these formations by transported soils and gravel or windblown Kalahari sand. Originally the landscape was attributed to eolian erosion, but it is doubtful whether wind erosion is capable of reducing extensive areas to conditions simulating a peneplain. Later work implies that it is more likely a "relict landscape" of more humid climatic conditions, when streams were more widespread and powerful than at present and carried on active lateral erosion and deposition which mantled the surface with transported material, making the presence of residual soils unlikely on the plains above which the inselbergs stand. Surface material, therefore, does not necessarily indicate the nature of the underlying bedrock.

Although the area to the south of the Kharubeam Hills has its pre-Kalahari topography obscured by sand and alluvium, it appears, from water boreholes in the area, that this surface possessed a relief greater than the present day Kalahari Limestone Plain. Its valley beds were filled with river gravels and boulders and its topographic prominences were rounded off before the Kalahari limestone (or calcrete) was deposited. Therefore the pre-Kalahari surface may be recognized as "the remains of a great peneplain" traversed by a "fossil" drainage system. This sub-Kalahari surface was basinned at the time of the Khomas Highlands upwarping, which initiated the erosion and which carved the 170 to 270 metre deep poorts through the Kharubeam Hills. These processes probably took place during late Cretaceous times. This era was then followed by a drier period (end Cretaceous - early Tertiary) with the deposition of "fossil" dune sands, followed in turn by a wetter period (early to late Tertiary) and the deposition of Kalahari limestone which ended in the early Pliocene. The upper Tertiary was a drier period and it was during this era that the plateau sands were deposited.

These plateau sands are the original Kalahari sands and overlie the surface unconformably, but are themselves truncated by the end Tertiary river systems and by Kalahari valleys of a Pleistocene pluvial or pluvials. This was followed by a post-pluvial decrease in rainfall when drainage became fossilized and the Kalahari sands were redistributed to form the present day landscape. The redistribution of sand began in the middle Pleistocene.

Apart from the Kharubeam Hills in the north, the main relief in the area is provided by the sand dunes and remnants of former topographic features. The cover of sand begins to the south and south-east of Rehoboth, and extends south-east as well as in a north-easterly direction towards Gobabis. To the west of the Uhlenhorst-Rehoboth road, which runs along the southern boundary of the farm Mertens, the northern boundary of the farm Kous and traverses the farms Versailles, Den Haag and Cowdray, the sand cover is almost continuous. There is a complete absence of outcrop and Kalahari limestone is exposed only in a few places in pans and between the dunes. The linear sand dunes, spaced some 150 to 1000 metres apart and with a NNE - SSW trend, completely dominate the relief.

A great majority of the dunes are of a "fossil" nature, the sand having been halted in its movement by tufts of grass and a sparse tree and shrub cover. The dunes tend to be parallel or sub-parallel and alternate with strips of hard ground known as "straate". These "straate" consist almost entirely of waterborne sand, silt and windblown sand.

The dunes have a uniform shape and size, although the crests vary from flat on the smaller dunes to sharp on the higher ones. The drop from the crest to the "straat" is always steeper on the leeside than on the windward side. The steeper slopes are on the south-west sides of the dunes and therefore it may reasonably be assumed that the prevailing winds, which caused the sand to be piled up into dunes, came from the north-east. In this area the prevailing wind probably blew approximately 36° east of north. At the present time it is more northerly and therefore appears to have changed direction subsequent to the formation of the dunes.

A number of the higher dunes in the area are still mobile, but in these cases it is only the crest which moves any significant distance as the lower slopes have been colonized by grass, shrubs and trees.

To the east of the Uhlenhorst-Rehoboth road the dunes are less frequent and may be up to 10 kilometres apart. Although the areas between the dunes still have a considerable sand cover in places, the sedimentary horizons and Kalahari limestone underlying the sand outcrop with a greater frequency. The characteristic "straat" swale or alluvium is also absent from this area and its deposition in the westerly areas can be attributed to lying within the Schaf River delta between the dunes.

The average height of the dunes is 12 to 15 metres although they sometimes exceed 25 metres. The width varies from 50 to 500 metres and the length is very irregular, e.g. a dune passing over the farm Sib runs for ± 200 kilometres without a break in its continuity and ends north of Stampriet, a village to the south of the study area.

The sand dunes tend to run obliquely to the river systems, e.g. the Auob and Nossob Rivers, and only 20 to 30 kilometres to the east of the Nossob River does the slightly undulating sand veld of the Central Kalahari begin.

During present times, as in the past, water is probably the major factor contributing to geomorphological features. It is therefore necessary to study the drainage systems, both regionally and locally, in order to understand the geomorphological changes taking place.

The general drainage in the south-western Kalahari is towards the south-east, and consists mainly of the Black Nossob River, White Nossob River and the Rehoboth, Usib, Auob, Schaf and Elephant Rivers (Fig. 6). The Black and White Nossob Rivers rise to the north of Gobabis and east of Okahandja respectively, but join south of Gobabis to form the Vereinigte Nossob, which crosses the border into Botswana to join the Molopo River which subsequently joins the Orange River.

The Rehoboth, Usib, Schaf and Elephant Rivers flow in a southerly direction across the Kalahari Limestone Plain and Great Namaqualand Plateau to the southern Kalahari. The Schaf River runs through the study area and drains into the Auob River which first appears as a watercourse north of Stampriet and is in turn joined by the Elephant River to the south of Stampriet. The Auob River then crosses the Botswana border and joins the Vereinigte Nossob before it joins the Molopo River.

All these river systems appear to be of great antiquity and their pattern has been largely determined by the post-Karroo movement; the Kalahari Basin, for example, has led to a centripetal system of rivers. None of the abovementioned rivers are perennials and they only flow for short periods with considerable intensity after torrential rainfall, and water has never been known to reach the Orange River from this entire system.

The Rehoboth, Usib, Schaf and Elephant Rivers rise in steeply sloping areas consisting of bare outcrops of gneisses, schists, quartzites, granites and lavas of the Auas and Nauas Mountains and the Kharubeam Hills. These areas have a high percentage of runoff, and characteristic features are the well developed dendritic drainage pattern and the lack of pans in the hills (Fig. 5). This dendritic pattern has the effect of carrying the water out of the mountains to the Kalahari Depression to the south of the Kharubeam Hills where the water then comes into contact with the thick cover of windblown sand, resulting in the characteristic "Kalahari" type drainage. Due to the high percentage runoff in the hills, much lateral corrosion takes place and large quantities of sediment are deposited by the rivers on the valley floors, a good example being the Schaf River.

The Usib River has carved a spectacular poort in the Nauas range, and yet another striking water gap is the Klein Nauas or Tiger poort in the Kharubeam Hills (Plate 4). As mentioned earlier the present drainage pattern is unrelated to relief features, and the Nauas and Klein Nauas (Tiger) poorts suggest that the present drainage originated on a surface above that of the present summit levels.

Due to the Kalahari Limestone Plain, south of the Kharubeam Hills, having very little local relief, the overall average runoff is slight and in most cases, non-existent. The main drainage feature of the study area, which lies in the Schaf-Usib "interior basin", is the Schaf River which, after rising in the Khomas Highlands and Auas Mountains, runs south-east from the Khomas ridge and finally breaks through the Kharubeam Hills in a 400 metre wide poort on the farm Wiese. Here the river channel is easily recognised (Plate 5), but on coming into contact with the windblown sand and dunes the water course becomes dismembered, the only remaining evidence of the river being a series of interlocking pans between the dunes (Fig. 5). Both well developed and poorly developed pans are present between the dunes depending on the proximity of the individual dunes. Well developed pans are found in areas where the dunes are approximately 1 to 10 kilometres apart, while poorly developed pans are found between dunes approximately 50 metres to 1 kilometre apart. A case is observed where a long string of pans lies at right angles to the trend of the dunes, each pan lying in a successive "straat". This phenomenon could bear some relationship to the underlying bedrock as this line of pans follows the general strike of the sedimentary horizons very closely. The pans south of the Schaf River poort are concentrated along at least three parallel north-south lines and the centre line is the present course of the Schaf River. All the pans are dry for the major part of the year, and only contain water for short periods during the rainy season. Before the 1933/34 floods, the Schaf River poort was completely blocked by a large sand dune which caused the river to break its banks and flow westwards along the valley north of the hills. Eventually the stream broke through the Lekkerwater poort at the site of the present main road from Uhlenhorst to Rehoboth. The sand dune in the original poort was finally moved by water and the river broke through onto the sand covered flats to the south. Due to sand dunes impeding its flow the main stream was diverted to run 800 metres to the east of the original course and it deposited up to 5 metres of alluvium.

From old records, it has been confirmed that the Schaf River carried alluvium as far as 20

Plate 4: View south to the Klein Nauas or Tiger poort cut through the Tsumis quartzites of the Kharubeam Hills on the farm Tigerpforte. (Ref. MMC/SWA 7/30)

Plate 5: Main river channel and poort cut through the Kharubeam Hills on the farm Wiese by the Schaf River. (Ref. MMC/SWA 50/28)

kilometres south of the poort in the Kharubeam Hills. The farms Tsumis Park, Lekkerwater and Den Haag report vast amounts of silt and sand being deposited during this flood. On the farm Kous, to the immediate south of the Schaf River poort, 1 metre of alluvium was deposited in 1962/63, while 3 metres were deposited in 1933/34. The deposition of this alluvium has effectively blanketed the bedrock geology and eliminated vegetation patterns reflecting bedrock geology and thus emphasises the geomorphological importance of the Schaf River in the study area.

It should also be pointed out that present drainage patterns in the Kharubeam Hills are unrelated to previous ones, and that present day drainage is influenced by the 1933/34 and subsequent floods of the Schaf River.

There are also many limestone pans in the area and these, together with the sandy pans, form part of the "Kalahari" or internal drainage system. The water never runs further than these pans and is usually absorbed by the sand and silt, presumably to find its way to the underlying limestone and other rocks of the Tsumis and Karroo Systems. Because of this high water loss through seepage, and also evaporation, there is no surface water in the region.

The invasion of the dry river channels by sand dunes occurred in a previous drier period which was halted by the onset of a wetter period, resulting in the dunes being "fixed" by vegetation.

It can be concluded that there are four distinctive types of drainage in the area. These are as follows:-

a) a well developed dendritic drainage system in the Kharubeam Hills with the consequent relative absence of pans;

b) a semi-fossilized river system, i.e. the Schaf River south of the Kharubeam Hills;

c) a very poorly developed stream drainage terminating in poorly developed pans;

d) a well developed stream drainage which terminates in well developed pans between widely spaced dunes.

It is evident that the Nossob and Auob River systems must have been important in the past, judging from the present depth of their channels. Mabbutt (1955) postulates that the present major river valleys must have existed at least during the final stages of the formation of the Kalahari limestone, and gives the following reasons:-

1) the Auob and Nossob Rivers are bordered by high limestone terraces containing river gravels;

2) the limestones are proved thicker along river valleys;

3) the limestone surface can be frequently observed to slope downwards towards valley axes.

Such river valleys must have been in existence before the deposition of the Kalahari sands, for it is difficult to envisage the development of major river channels with the highly absorbent sand dunes, which trend obliquely to the river courses, forming a natural barrier. The cutting of the present valleys into the limestone dates from one or more pluvials, probably during the Pleistocene era. The dunes became fixed by vegetation under an increased rainfall, although not sufficiently to prevent flow along already existing master channels.

To the south of Uhlenhorst there is evidence of a great Artesian basin, with its western boundary being the scarp of the Kalk plateau and the northern boundary an indefinite line from Gruneberg on the Nossob to the farm Lekkerwater in the Rehoboth district. The records of strata penetrated by boreholes in the lower Nossob indicate the absence of sedimentary Karroo beds, and only sands, limestones and marls of the Kalahari series underlain by dolerite appear to mark the southern limit of the flowing water, apparently disrupting the continuity of the water bearing beds so that the Karroo sediments in the north are not connected with those in the south (Frommurze 1931).

Overburden and Soils

The nature and thickness of the overburden varies considerably in response to the interplay of geomorphological processes on rocks of varying resistance to erosion. Some information on the nature and thickness of the overburden is available from trench sections, diamond and wagon drill holes and waterboreholes.

Five main types of overburden and three categories of soils may be recognised, namely:-

1. Windblown Kalahari sand
2. Alluvium
3. Colluvium
4. Calcrete
5. Gravels
6. Residual soil
7. Soils derived from transported material
8. Pan soils.

1. Windblown Kalahari sand

Windblown Kalahari sand deposits constitute the major portion of the overburden in the area. This sand cover takes two forms:-

a) Sand cover on plains
b) Sand dunes.

A detailed description of the area covered by Kalahari sand has been given in the section on physiography and geomorphology.

a) Sand cover on plains

To the east of the Uhlenhorst-Rehoboth road where dunes are 10 to 12 kilometres apart, the plains have a cover of windblown sand varying in thickness from 10 cms to 30 metres or more. Here erosion, transport and deposition during the rains have brought about a mixing of the windblown sand, fine soil and small rounded quartz pebbles. No profile development has been observed in pits and trench sections. To the west of the Uhlenhorst-Rehoboth road the sand cover is mainly in the form of sand dunes.

b) Sand dunes

A description of the form of the dunes is given in the section on physiography and geomorphology.

The sand dunes consist entirely of windblown Kalahari sand and there is a complete lack of profile differentiation. They were deposited under more arid conditions than prevail today, and although once mobile, are now semi-fossilized due to colonization by tree and shrub species. Only the apices are mobile in some cases at present.

The windblown Kalahari sand is reddish to reddish-brown in colour, a factor attributed to the abundance of red and pink feldspar and also to a coating of iron oxide on each grain. Between the dunes, in areas of internal drainage, the sand is often beige coloured due to the leaching action of the water. It has been suggested that the clay and iron content of the sand is derived from the underlying residual soils and transported upwards by soil moisture. This is possible on the plains where the clay content is high.

The sand consists almost entirely of coarse quartz grains with listed accessories such as feldspar, zircon and garnet. The grains exhibit typical aeolian surface textures, being partly rounded and slightly angular, and surfaces may be pitted and chipped.

A large percentage of the sand in the Rehoboth Depression was probably derived from the disintegration of the granitic and gneissic rocks of the Basement Complex, and the quartzites and sandstones of the Karroo System.

Correlation of the sand horizons is difficult, and their age is disputed by most authors. The earliest deposits of windblown sand may have been lithified and redistributed without detectable change. Various ages ranging from Tertiary-Pliocene to Quaternary have been suggested, and Du Toit (1954) proposes South West Africa as the origin.

2. Alluvium

Due to the geomorphological processes described earlier, the valleys in the Kharubeam Hills and the plains to the south of these hills have a deep cover of alluvium in certain areas.

This alluvium is composed of silt and sand deposited by floods during good rainy seasons. It consists of a fine light brown to grey micaceous material of a homogeneous nature. A recorded depth of alluvial cover of 20 metres has been reached by wagon drilling in the Schaf River delta south of the Kharubeam Hills. There does not appear to be any profile differentiation in pits dug in the alluvium.

It appears that alluvium was deposited in most cases before the deposition of the sand dunes and has been added to by recent floods.

The alluvium effectively masks any pre-existing topography and bedrock geology, and prevents the development of vegetation patterns reflecting bedrock.

3. Colluvium

A certain amount of colluvial cover occurs in the valleys between the Kharubeam Hills, the semi-rounded to angular fragments of quartzite and lava being derived from the slopes of the hills and mixed with alluvium and windblown sand. Colluvial cover is rare on the plains to the south of the Kharubeam Hills.

4. Calcrete

Over most of the area to the south of the Kharubeam Hills, and to a large extent among these hills, there is evidence of a layer of calcrete. In certain areas the calcrete forms a capping to low ridges while in others it covers the plains in sheet form. It may be outcropping, sub-outcropping or buried below varying depths of windblown sand and water transported soils and gravels.

From drilling records the calcrete is shown to vary in thickness from a few centimetres to more than 60 metres. This variation in thickness is due to the deposits being formed on an uneven surface fashioned over rocks of differing resistance to erosion (Frommurze 1931).

The calcrete consists of porous calcium carbonate and is normally a whitish-grey colour. Frequently the calcium carbonate acts as a matrix for debris consisting of rounded quartz or quartzite pebbles (2 - 10 mm diameter). In some areas the calcrete takes the form of a calcareous sandstone and contains coarse quartzite pebbles. The calcium carbonate may also form nodules, thereby imparting a concretionary nature.

There are two theories regarding the formation of these calcrete deposits, namely that the calcium carbonate is either derived by upward movement in solution or is transported from elsewhere in solution and precipitated out at surface.

In the study area the calcrete overlies the non-calcareous Tsumis C stage and this rules out the possibility of the calcium carbonate being brought to the surface by capillary action from below. It is more likely that the origin of the calcrete is the calcareous shale of the Tsumis A stage to the north. The weathering of this shale, transport of the calcium carbonate in solution and ultimate precipitation on the plains to the south of the Kharubeam Hills is a more feasible explanation. It is also possible that calcareous horizons of formations other than the Tsumis A could also have been a source of calcium carbonate.

5. Gravels

Pitting and trenching has revealed the existence of one or more layers of gravel over large areas of country. Because of overlying sand cover their full extent is not known. Wagon drilling, however, has disclosed thicknesses of 5 cms to 20 metres.

The gravel fills the troughs left by previous erosion cycles and is consequently deeper in old stream courses. It is usually found overlying the calcrete, and shows a definite grading and sorting with the coarser material at the top and fine material at the bottom.

The gravel consists of subangular to rounded pebbles, varying in size from 5 to 8 mm, and sub-angular to angular quartzite fragments. The matrix is normally a fine to medium-grained sand. Compaction of pebbles is also evident in certain areas. The pebbles consist mainly (90%) of vein quartz, but lavas, quartz porphyry, arkose, quartzite and jasper have also been recorded in the area.

6. Residual soils

As a result of the low rainfall and the large diurnal fluctuations of temperature the weathering is mainly of a mechanical nature. There is, however, evidence of chemical weathering and in certain areas soils derived from residual material have been observed. These soils show a certain degree of maturity and in most cases the C horizon has partially developed. Pit and trench sections have revealed, however, that in many cases, before maturity was reached, erosion and subsequent deposition during pluvial periods laid transported sand and gravels on top of the developing profiles. This was followed, in a drier period, by the deposition of windblown Kalahari sand over a large area forming an effective and thick cover. The depth of the present overburden inhibits chemical weathering of the underlying bedrock.

Where residual soils do occur, they are generally of the arid red-brown type derived from arenaceous bedrock. In the mineralized zone on Sib the soil is greyish-brown in colour, being derived from the disintegration of the tilloid.

On the steep slopes of the Kharubeam Hills, soils derived from residual materials are skeletal and stony with a total lack of profile development. These soils are fine to medium-grained and brownish in colour.

7. Soils derived from transported material

Soils derived from water transported material are immature and generally exhibit a homogeneous profile. They are generally fine to medium-grained, reddish-brown, and contain small (2 - 5 mm diameter) rounded quartz fragments. The depth of this material varies from a few centimetres to ± 30 metres.

8. Pan soils

Pans formed by internal drainage between closely spaced sand dunes normally have, in addition to a fine-grained, greyish-brown silt, a large percentage of coarse-grained leached Kalahari sand; the latter may form a thin cover. Those pans formed on the plains between widely spaced sand dunes have a fine to medium-grained grey-brown silt cover.

In areas of extensive calcrete cover the pans have a calcrete floor covered in turn by fine-grained grey to dark brown soil and calcareous gravel. A thin layer of laterite occurs below the silt in certain pans.

<u>Vegetation</u>

On the earliest vegetation map covering South

West Africa (Pole - Evans 1936) the study area lies close to the boundary of the categories designated "thorn and desert". The thorn country, in which thorn bush and thorn trees constitute the dominant vegetation, is associated with a rainfall of 125 - 150 mm per annum and deep sandy soils. _Acacia giraffae_ is cited as the most common tree with _Acacia haematoxylon_ dominating in alkaline soils. _Boscia_ spp. and other species of _Acacia_ are referred to as common while large tracts are referred to as covered by _Rhigozum trichotomum_ shrubs which are usually associated with _Catophractes alexandri_ shrubs and _Parkinsonia africana_ trees.

On the later map of Keay (1959) the study area falls on the boundary between the plateau sub-desert steppe and the wooded steppe and savanna of the south Kalahari thornveld. This area is broadly defined as the Damara thorn-tree savanna by Wellington (1967). Keay divides the wooded steppe and savanna of the south Kalahari thornveld into the following:-

a) South Kalahari thornveld
b) Kaukauveld
c) Damara thornveld.

The Kharubeam Hills, in the study area, fall within the southern limits of the Damara thornveld where Keay recognises the following common species:-

Acacia giraffae
Acacia karroo
Acacia hebeclada
Acacia mellifera
Boscia sp.
Commiphora sp.
Combretum apiculatum.

The area to the south of the Kharubeam Hills corresponds to Keay's south Kalahari thornveld with its parallel dune system and internal drainage. Here Keay recognises the following common species:-

Albizzia anthelmintica
Acacia giraffae
Acacia haematoxylon
Stipagrostis namaquensis
Stipagrostis uniplumis.

To the west of the study area the south Kalahari thornveld merges with the sub-desert steppe which occupies almost the entire southern portion of the plateau.

In the world scale classification of savanna vegetation proposed by Cole in 1963 the vegetation of the study area falls within the low tree and shrub savanna category which is characterized by low growing trees and shrubs, often less than 2 metres high, with a ground layer of low growing perennial grasses, less than 80 cms high, together with abundant annuals. This broadly defined category accomodates low tree communities, shrub communities and communities largely dominated by grasses and other herbs.

In the study area the vegetation is open, generally with few trees and comprised mainly of small shrubs with large areas of bare ground between the plants, while perennial trees, shrubs and grasses dominate the vegetation. The species composition varies with the nature of the relief, soils, superficial and bedrock geology. After rains some areas may carry a ground cover of annual grasses.

A total of 91 tree, shrub and ground species are recorded in the study area (See Appendix to thesis for complete list). Some of the common trees occurring are Acacia giraffae, Boscia albitrunca and Boscia foetida, together with Acacia haematoxylon, Acacia senegal, Albizzia anthelmintica, Combretum apiculatum, Parkinsonia africana and Ziziphus mucronata in some areas. Common shrubs found are Phaeoptilum spinosum, Rhigozum trichotomum, Acacia mellifera and Catophractes alexandri, with Acacia hebeclada in some areas.

Grasses, which contribute the greatest number of species in the study area, are most commonly represented by the perennial species Stipagrostis uniplumis, Stipagrostis ciliata, Asthenatherum glaucum and Anthephora pubescens. Annual grasses are very common after rains and are represented mainly be Schmidtia kalahariensis, Aristida congesta, Eragrostis porosa, Eragrostis denudata and Rhynchelytrum repens.

Ground vegetation is almost entirely of an annual, herbaceous nature and common annual herbs are Gisekia pharnacioides, Evolvulus alsinoides, Cassia italica, Limeum viscosum, Helichrysum argyrosphaerium, and in certain areas Aptosimum leucorrhizum and Tribulus zeyheri.

Early rains often fall in October/November, during which the vegetation revives and the numerous annual herbs make their appearance, but lack of continued precipitation results in these plants being parched by the sun and dying very quickly. During and immediately after the main rainy season in February, March and April the vegetation is in peak condition.

Due to a high water loss through seepage into the underlying sand there is little surface water and most species rely on rainfall and available groundwater for their moisture requirements. During long periods of drought only the deeprooted species will survive.

The vegetation, although controlled on a regional basis by altitude and rainfall, is locally more influenced by the various soil types and, to a lesser degree, underlying bedrock. In the study area numerous factors influence the growth of plants, and although these may overlap to a certain extent to produce variations in the plant communities, the major associations are nevertheless easily distinguished. The variations in the communities are caused mainly by changes in soil profile, physical and chemical composition of the soil and the drainage. As described earlier five major categories of overburden and three categories of soil have been listed in the study area. These categories also overlap to a certain extent but each supports a distinct climax community of which a total of 15 have been noted in the area.

The considerable amount of transported overburden prevents the vegetation from reflecting the underlying bedrock to a large extent, and only when bedrock outcrops or sub-outcrops may any trend or lineation be observed in the plant assemblage. The vegetation, however, reflects very accurately the various soil types whether they are transported or derived from residual material. For the plants to reflect accurately the bedrock it is neccessary for them to possess deep root systems which penetrate to bedrock level, or alternatively to absorb minerals in solution which have migrated upwards through the soil.

The high percentage of outcrop in the Kharubeam Hills area gives rise to plant species not encountered on the plains to the south of these hills, the two most frequently occurring examples being the trees _Acacia senegal_ and _Combretum apiculatum_. The plant assemblage on the rocky hill slopes differs significantly from that occurring in areas of windblown sand, alluvium, calcrete etc. All plant associations will be dealt with in detail in the relevant sections on the study area.

The shrubs are mostly equipped with small ericoid leaves to reduce the amount of water lost through transpiration. These shrubs can withstand the long dry winter months, and, if they perish during a prolonged drought, the seeds will germinate with the next rain. Most of the shrubs are perennials and produce soft green shoots each year from pre-existing woody branches. Because of the dry winter these shoots have secondary thickening laid down on the cell walls for added protection and also to form a basis for the following season's growth.

The trees are also equipped with small thin leaves which are characteristic of this type of vegetation. They come into leaf at various times before and after the rains, but retain their leaves longer than the shrubs as a result of their advanced root systems.

Shortly after the rains in February and March the annual grasses germinate from wind dispersed seeds and cover most of the area. Common species occurring are Schmidtia kalahariensis and Eragrostis porosa. Perennial grasses store water and nutritive elements in their roots which become available to the plant during the following dry months.

Chapter 3

Review of previous geobotanical and biogeochemical work and the choice of techniques for mineral exploration in the Gamma concession

Review of previous geobotanical and biogeochemical work

1. Geobotany

The use of indicator plants in the search for mineralization has been known since the 18th and 19th centuries. Malyuga (1964) mentions Lomonosov (1763) who commented on the depauperating effects on plant species by mineralization, and the discovery by Tyson, in 1810, of chromite deposits in Maryland and Pennsylvania by the depression of flora on the serpentines. Malyuga also mentions Linstow, who in 1929 cited the affinity of plant species to geological soil conditions.

In 1899 Haeckel described Polycarpaea spirostylis as a common indicator of copper mineralization in Australia, while Viola calaminaria indicated the presence of zinc. Bateman and Wells (1917) noticed Rosa woodsii, Equisetum variegatum and Dasiphora fruiticosa thriving in a copper tailing region where the other species were killed off by the copper toxicity. Hawkes (1957) describes the California poppy growing in profusion over the copper mineralization in the San Manuel area of Arizona, and Cannon (1960) has isolated many species of Astragalus and Stanleya as selenium indicators. Astragalus is the only plant known to depend entirely on the presence or absence of one element, in this case selenium, and some species absorb up to 8500 ppm.

Horscroft (1954) describes the vegetation characteristic of the Copperbelt in Zambia and the isolation of Becium (≡ Ocimum) homblei as an indicator species. This plant will not grow in soils containing less than 100 ppm copper. Becium homblei was first described by Wehrmann (1959) who made observations, in 1954, at thirty copper occurrences from Lusaka, Zambia, to the Belgian Congo border. All but two occurrences had Becium homblei present, even though the soil over the ore bodies was leached. Analysis of leaves and roots of Becium homblei gave 2500 ppm and 4500 ppm respectively, and studies showed that the seeds would only germinate in solutions of ± 600 ppm copper. Wild (1970) also described Dicoma macrophala as being the best single taxon indicator of nickel bearing soils, with a nickel content of 7375 ppm being recorded at the Tipperary Mine in Rhodesia.

In addition, Webb and Millman (1951) list the following examples of the search for geochemical anomalies using indicator species:- copper and zinc deposits in British Columbia (Warren and Howatson, 1947; Warren and Delavault, 1948 and 1949; White, 1950); Norway (Vogt et al, 1943); and the United States of America (Robinson et al, 1947; Lovering et al, 1950); lead zinc ores in Finland (Rankama, 1940); Sweden (Hedstrom and Nordstrom, 1945); England (Lundberg, 1948); Germany (Buschendorf, 1950); and the United States of America (Horbaugh, 1950); nickel deposits in Russia (Malyuga, 1947); and Finland (Rankama, 1940); tin-tungsten veins in England and chromium in Greece (Lundberg, 1948); and gold deposits in British Columbia (Warren and Delavault, 1950).

Nicolls, Provan, Cole and Tooms (1964 - 5) isolated Polycarpaea glabra, Bulbostylis barbata, Fimbristylis sp., Eriachne mucronata and Tephrosia sp. as indicators of copper in the Dugald River Lode area, Queensland, Australia.

2. Biogeochemistry

Early biogeochemical work was carried out in order to establish the relationship between plants and the metal content of the soil.

Bateman and Wells (1917) discovered that plants in the region of a copper tailings dump gave values of 62 - 6210 ppm copper, and concluded that plants had a selective ability to absorb metals. Most of the work carried out in Canada by Warren and Howatson (1947), Warren and Delavault (1948), White (1950), and Riddell (1952), was concerned with sampling of trees over zones of known mineralization. As a result of this work it became obvious that certain parts of the plants were preferable to others for sampling purposes. For example, the second-year twigs gave more satisfactory results than first-year twigs, while the leaves were more successful than the second-year twigs. In 1953 Clarke, in America, demonstrated the ability of leaf analysis to detect copper mineralization below a leached capping to an ore body.

Cannon (1957) showed that uranium bearing deposits on the Colorado Plateau could be detected through 25 metres of barren rock by biogeochemical analysis.

In 1963 Duvigneaud and Denaeyer-de Smet compared the copper content of background vegetation to that of species growing over copper ore bodies, using the leaves for analysis. Nicolls, Provan, Cole and Tooms (1964 - 5) demonstrated that both trees and shrubs exhibited an increase in copper, lead and zinc levels over areas of mineralization in the Dugald River Lode area, Queensland, Australia. Cole

(1971) proved biogeochemistry to be a useful exploration tool in the defining of the sub-outcrop of the Empress copper/nickel ore body in Rhodesia.

From this work it appears that the uptake of elements from the soil by plants is affected by different conditions and that various species of plant will react to these conditions in different ways. In areas of mineralization, and consequently high concentrations of metals in the soil, plants may flourish or alternatively find the soil toxicity too great and will not survive.

Some plants growing in soil with an extremely high metal content accumulate this metal in certain parts of the plant, in which case they are termed accumulator plants and include the indicator plants. These plants should not be confused with plants which take up metals according to metal concentration in the soil but do not accumulate the metal in the plant. Certain other species may grow in soils with a high metal content but will resist the uptake of these metals by non-absorption techniques.

The uptake of metals in plants depends on their availability which in turn depends on various factors to be dealt with later.

The choice of techniques for mineral exploration in the Gamma concession

The physical environment of the Gamma concession posed many questions for mineral exploration. The paucity of bedrock outcrop and the extent and depth of the superficial cover of calcrete, alluvium, colluvium and Kalahari sand focussed attention on those techniques most likely to assist the detection of mineralization in concealed bedrock, possibly at considerable depth below the surface.

The general success of geobotany, but especially that in the Dugald River Lode area, Australia (Nicolls, Provan, Cole and Tooms 1964 - 5), where the copper deposit (stratiform and syngenetic), climate and vegetation is similar to the study area, and to a lesser extent areas such as the Copperbelt in Zambia (Horscroft 1954) and deposits in Rhodesia (Wild 1970) where the geology is again similar but the climate and vegetation differ slightly from the study area, resulted in the application of this technique in the study area in the hope of outlining near-surface mineralization.

The decision to use geobotany was supported by the success of the indicator species Helichrysum leptolepis in the Witvlei area, which was also found growing in the study area.

Biogeochemistry had been proved successful in various world localities exhibiting different types of overburden, e.g. glacial deposits in Canada. In areas such as the Dugald River Lode, Australia (Nicolls, Provan, Cole and Tooms 1964 - 5), and the Empress Mine, Rhodesia (Cole 1971), where the environment is similar to that in the Gamma concession, biogeochemistry has successfully outlined the sub-outcropping ore zones.

As a result of this work a basic understanding of the relationship between soil metal content and vegetation was established and the potential of geobotany and biogeochemistry as exploration techniques was realized. Consequently these techniques were appropriately phased into an integrated exploration programme in which geological studies concentrated on evidence from bedrock outcrop and drill cores. Aerial photograph interpretation was used to detect areas of near surface bedrock, and geophysics was used over favourable target areas located by the above mentioned techniques at a late stage in the investigations.

PART II

Chapter 4

THE SIB AREA

The physical background

The discovery of copper mineralization in outcropping bedrock along a drainage feature, together with the occurrence of the copper indicator plant Helichrysum leptolepis over this and adjacent areas on the farm Sib, stimulated geobotanical, biogeochemical and geochemical investigations over a wide area extending some 15 kilometres eastwards and 40 kilometres westwards of the farm. The area including the farms Sib, Klein Nauas, Hanover, Tsams, Beenbreeck, Rusticana, Den Haag, Cowdray, Avro, Lekkerwater, Munyu, Rotsvas, Sukses, Wilderness and Battle is hereafter referred to as the "Sib area". Within this area the possibility of potentially copper bearing Tsumis rocks striking in a NE - SW direction was inferred.

At the outset of the investigations very little was known of the detailed geology, physiography, geomorphology, soils or vegetation of the Sib area itself, and the accounts given below are based on data collected during the course of the work supplementary to the more general investigations already described in Chapter 2.

Geology

The farm Sib is underlain by two major rock types, the Tsumis C (≡ Kamtsas) and Buschmansklippe quartzites (Fig. 7). The Tsumis C quartzites are pink to red in colour, fine to medium-grained and feldspathic. Small well rounded pebbles, ± 5 to 40 mm in diameter, are scattered throughout the rock. They are of mixed origin, being composed for example of granite, jasper and vein quartz. In parts the pebbles are well sorted into distinct conglomerate bands. Generally the sediments are extremely shallow dipping (Section A - B: Fig. 8) and occur as outcrops where the overburden has been eroded.

The quartzites of the Buschmannsklippe formation, the basal unit of the Nama System, rest unconformably on the Tsumis C rocks. They are much lighter in colour than the Tsumis C quartzites as a result of their higher percentage of quartz grains, have a greyish flinty appearance and are mottled with yellowish and pinkish feldspar grains. Like the Tsumis C stage, the Buschmannsklippe formation comprises shallow dipping beds; these have been planed by erosion which has left a few scattered outcrops and low ridges.

Locally, at the base of the Buschmannsklippe beds, and hence overlying the Tsumis C stage, there is a rock loosely termed a tilloid (or greywacke). This is devoid of bedding; it consists of angular to rounded pebbles of mixed origin but notably quartzite, set in a greenish to blue-grey shaly and sometimes sandy matrix. Characteristically the tilloid breaks around the pebble inclusions. The matrix often becomes clayey when wet. The tilloid, where present, varies in thickness from a few centimetres to ± 8 metres and may contain enclosed lenses of quartzite.

A break of deposition is believed to have occurred between the laying down of the Tsumis beds and that of the tilloid. As most of the quartzite inclusions and all the inliers of quartzite

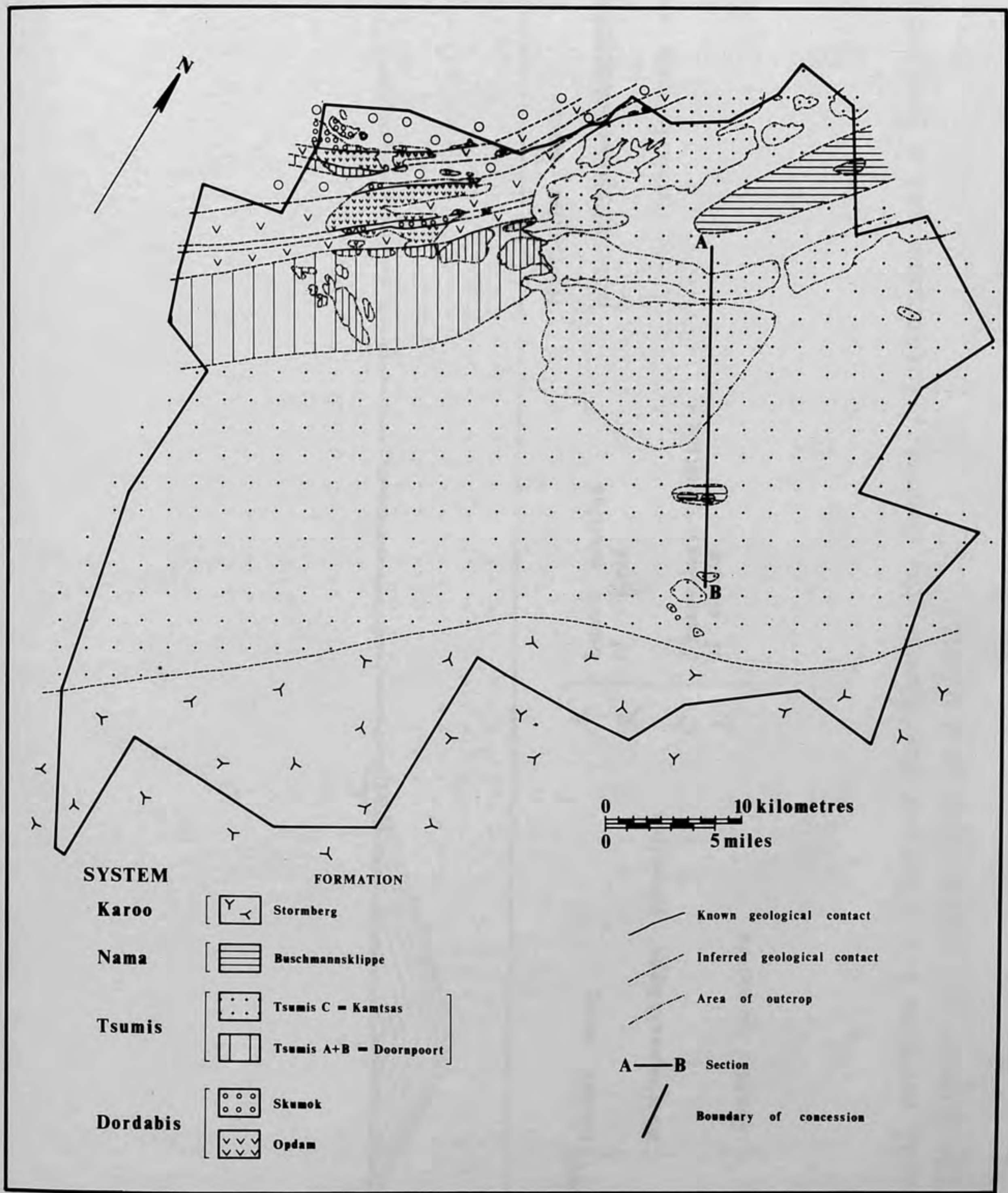
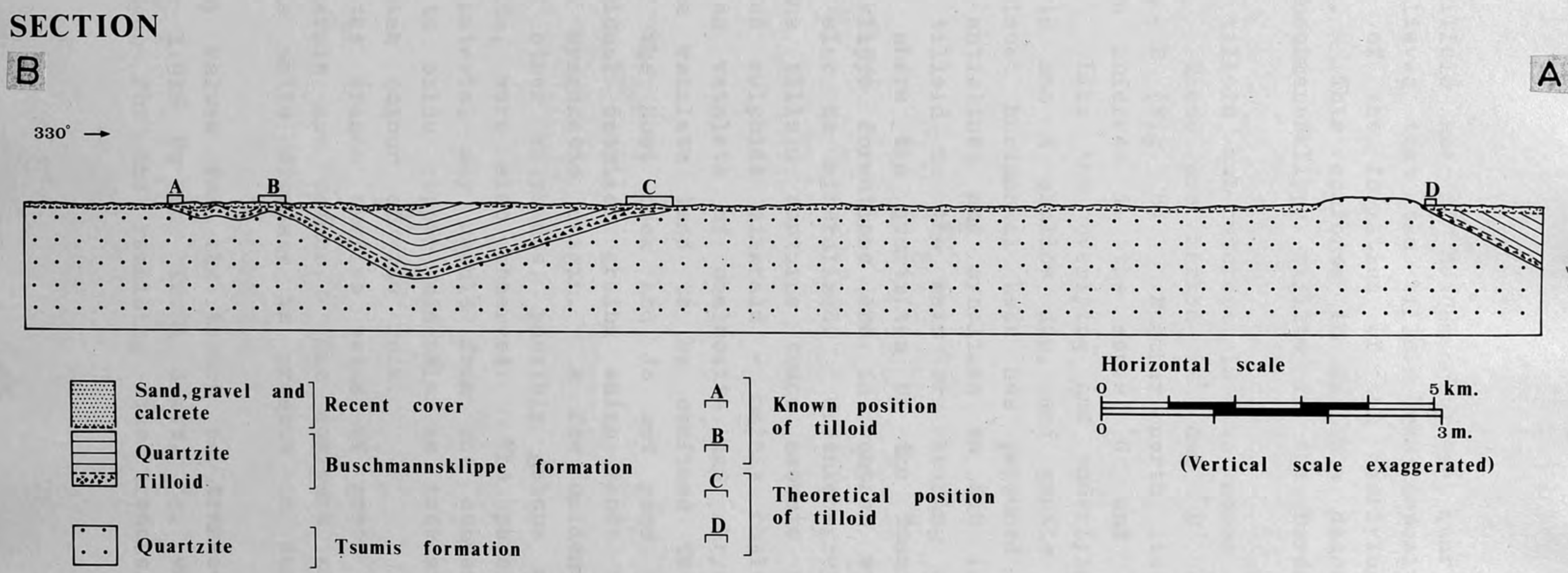


Fig.7: Geological map of the Gamma concession and location of section A - B (Fig.8). Outcrops are shown by closer shading, inferred sub-outcrops by wider shading; geology (after Geological Survey of South West Africa and Anglo Vaal geologists)



<u>Fig.8</u>: Geological section A - B across the farms Sib, Hanover, Moedersrus and a portion of Tigerpforte (after the author and Anglo Vaal geologists)

in the tilloid are of Buschmannsklippe quartzite, it is believed that the tilloid was deposited at the start of the formation of the overlying quartzites. This conforms to Martin's description of the Buschmannsklippe tillite in the Dordabis area.

The tilloid sub-outcrops in two zones on the farm Sib. These are marked "A" and "B" on the section A - B (Fig. 8). Further north its sub-outcrop is inferred in the zones "C" and "D" (Fig. 8). Like the overlying and underlying rocks the tilloid has a shallow dip, and gentle folding of the almost horizontal beds has produced a series of small anticlines and synclines on Sib (Fig. 9).

The tilloid is the main ore bearing rock in the area; where the quartzites of the Tsumis C and Buschmannsklippe formations are in contact with it they may also be mineralized. Greenish-grey in colour, the tilloid contains trace amounts of disseminated sulphide minerals - mainly chalcocite - as well as veinlets of chalcocite and chrysocolla.

These veinlets tend to be confined to the matrix of the host rock and do not pass through the individual detrital grains which tends to suggest a syngenetic origin. A few unidentified specks of other sulphides, possibly galena and chalcopyrite, were also observed. The paucity of sulphide material may result from the conversion of sulphide to oxide copper minerals as indicated by the greenish colour of the rock.

In the trench samples veins of green copper oxide minerals are common. The dominant mineral is chrysocolla while dioptase is present in smaller amounts.

Assay values for the trench on transect 33, Sib, gave 1.91% Cu and 12.81 d.w.t. Ag, while the averages for the remaining five trenches were

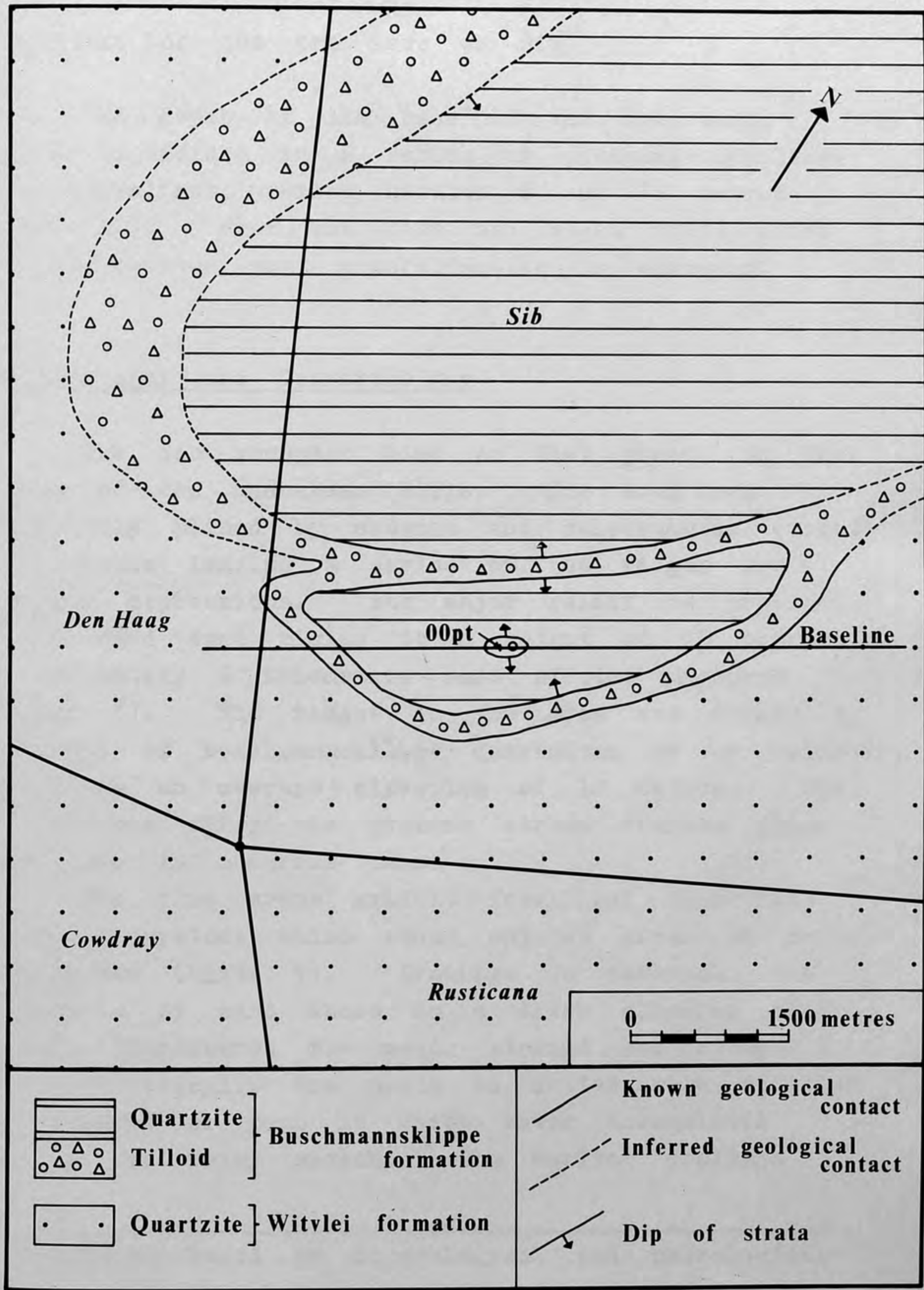


Fig.9: Geological map of a portion of Sib, Rusticana, Cowdray and Den Haag (after the author and Anglo Vaal geologists)

1.19% Cu and 8.55 d.w.t. Ag. (see footnote).

Structure of the ore zone on Sib

The depth of the base of the ore zone, which is folded in a series of plunging synclines and anticlines, varies between 6 and 24 metres (Fig. 10). From the pits and wagon drill holes it is obvious that mineralization is sporadic.

Physiography and Geomorphology

The Sib prospect lies on flat plains to the south of the Kharubeam Hills. The area was originally planed by erosion and subsequently eroded by streams leaving a series of low ridges and shallow depressions. The major relief is provided by a sand dune rising to a height of 25 metres, approximately 6 kilometres east of the prospect (Plate 6). The ridges in the area are formed by remnants of Buschmannsklippe quartzites or by calcrete, and have an average elevation of 10 metres. The depressions carry the present stream courses which terminate in numerous pans.

The flat areas exhibit fossilized dendritic drainage systems which stand out as areas of dense vegetation (Plate 7). Drainage is internal, the formation of sand dunes in a drier climatic epoch having dismembered the major streams and rivers. Characteristically the plain is dotted with circular depressions or pans in which water accumulates during the rainy season. The earlier drainage

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Information based on mineralogical and petrological studies of trench and borehole core samples from Sib by Anhaeuser and Button (1969).

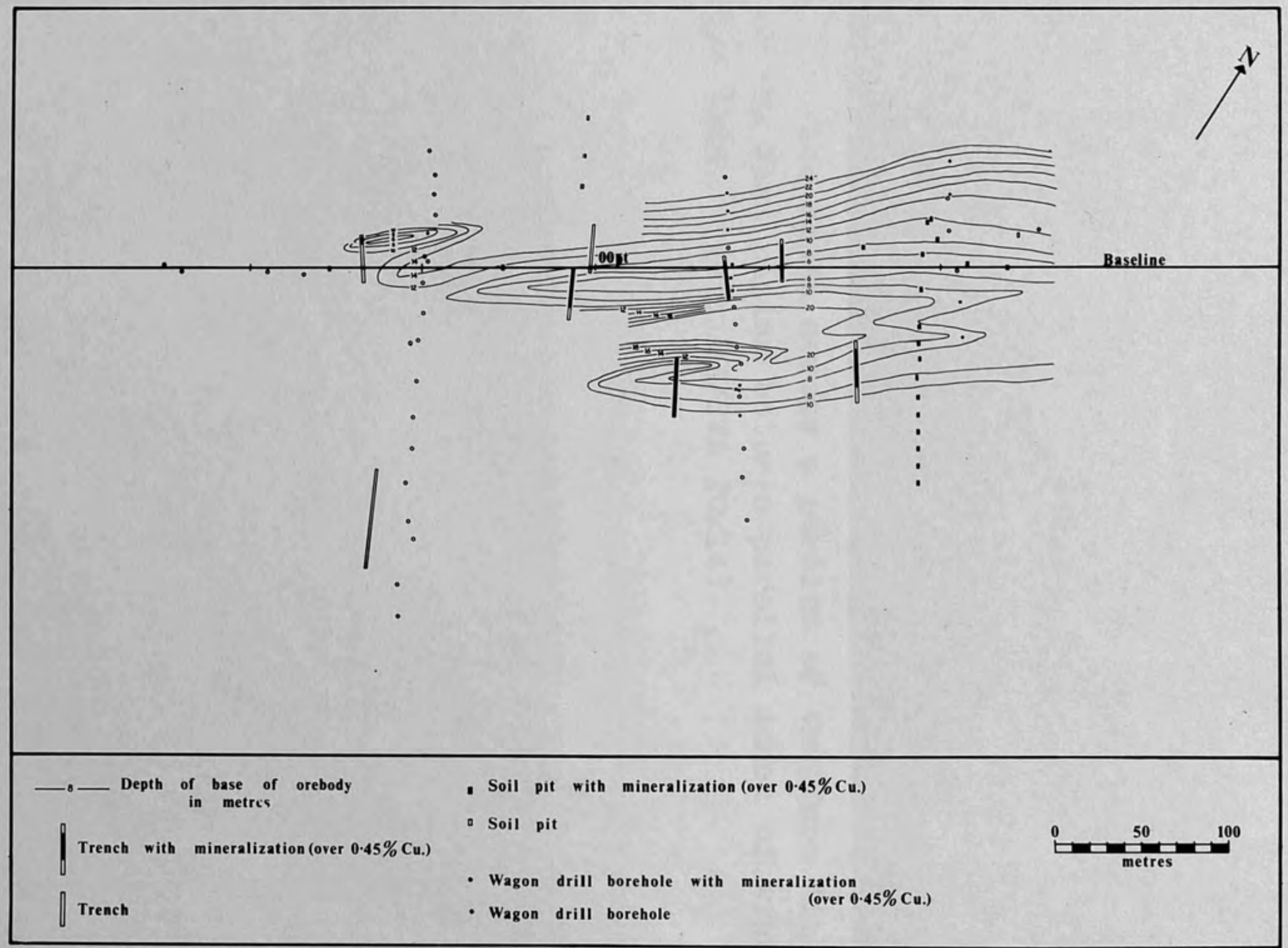


Fig.10: Depth of the base of the Sib ore body (in metres) and the location of trenches, pits and wagon drill holes (compiled by the author from Anglo Vaal data)

Plate 6: View south across a portion of the farm Sib showing the flat plains between parallel dunes of windblown Kalahari sand. (Ref. MM/SWA 20/14)

Plate 7: View south-west across flat plain on the farm Sib showing the fossilized dendritic drainage patterns which stand out as areas of dense vegetation. Present drainage predominantly of a sheetwash nature. (Ref. MM/SWA 19/34)

systems must have had strongly flowing rivers, since large water rounded boulders occur 1 to 3 metres below the surface in old stream channels on the farm Sib. Today the rivers rarely flow and sheet-wash is the erosional/depositional process.

Most of the present stream channels are orientated in a SSE direction and form large pans parallel to a sand dune to the west of Sib and on the farm Den Haag, where the water has been "dammed" by the dune.

On Sib the copper bearing tilloid (hereafter referred to as "the ore body"), occurs on the western edge of a large flat plain containing a major drainage feature which terminates in a large pan. This pan coincides with the western edge of the ore body. The drainage feature affects both the soil chemistry and the vegetation in the area, although it is responsible for a difference in relief of less than one metre. The remainder of the area over the ore body is slightly undulating with some relief provided by a calcrete ridge in the vicinity.

Overburden and Soils

The overburden of the Sib area is of varied nature and thickness. The area containing the Sib ore body briefly consists of the following categories:-

1. Windblown Kalahari sand

Deposits of this coarse-grained, unconsolidated and reddish-brown sand occur on the flanks of low ridges in the area. Profile differentiation is totally absent and no clay, pebble or rock fragments occur in the horizon. Thicknesses of 5 metres have been recorded.

2. Water transported loamy deposits

These occur over most of the area and vary in thickness from a few centimetres to 4 or 5 metres. They give rise to medium-grained brownish soils with angular to rounded fragments of quartzite and vein quartz (2 - 10 mm diameter) (Plate 8). Profile differentiation is generally absent but occasionally there is evidence of the sorting of these fragments into definite bands of varying thicknesses.

3. Water transported gravels

These are common in the area especially along fossilized stream channels. The gravels vary in thickness from 5 cms to 20 metres and consist mainly of coarse, rounded and subangular pebbles (5 mm - 10 cms diameter) of quartz and quartzite (Plate 9). There is often evidence of sorting and grading by size into distinct bands. A matrix of fine to medium-grained sand is common.

4. Calcrete

This varies in thickness from a few millimetres to more than 10 metres and is found over large portions of the farm Sib. It consists of a whitish-grey, porous calcium carbonate commonly with inclusions of quartzite and other desert debris. It may outcrop or sub-outcrop beneath transported cover and to the north of the Sib prospect it forms the floor of a large pan - a feature not uncommon in areas of thick calcrete.

5. Fine-grained grey-brown silt

This occurs in and around the numerous pans

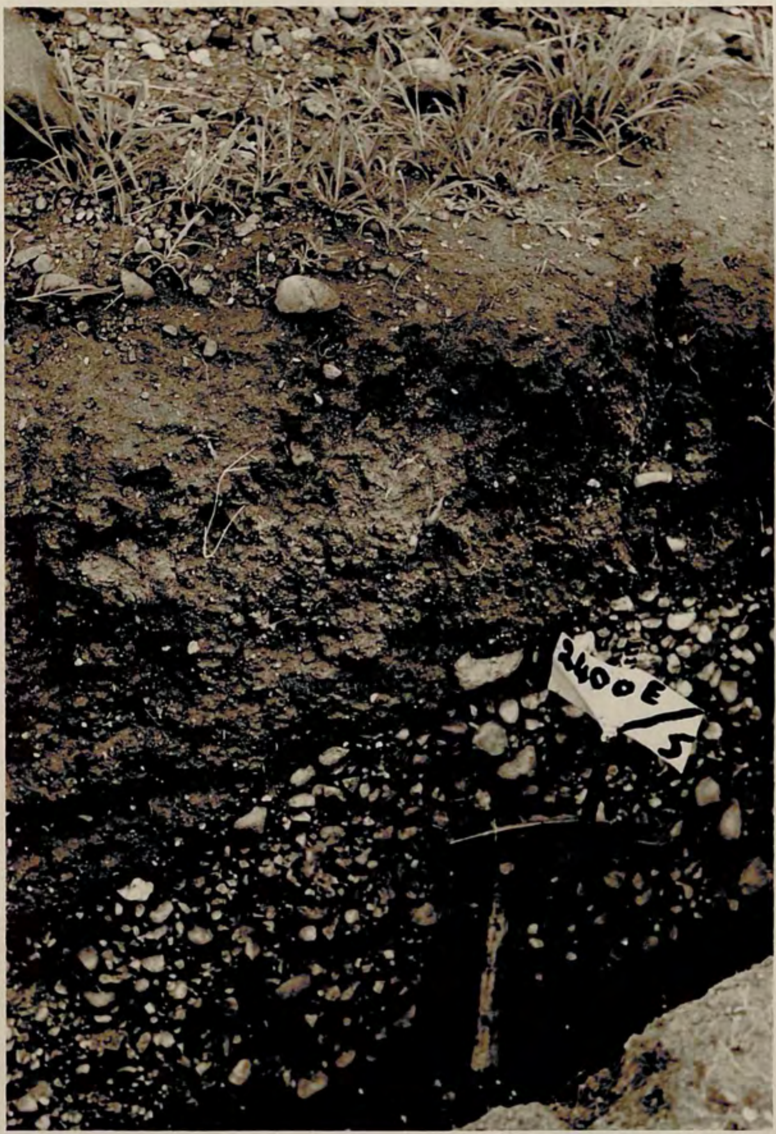


Plate 8: Pit profile on transect 3, Sib, showing coarse gravel covered by a layer of wind and water transported material. (Ref. MM/SWA 17/42)

Plate 9: Subangular, water transported pebbles of quartz and quartzite taken from a depth of one metre in a pit dug on transect 33, Sib. (Ref. MMC/SWA 37/25a)

and may be up to 2 metres thick. It is often covered by a few centimetres of leached coarse-grained Kalahari sand.

6. Laterite

This consists of quartzite pebbles in a matrix of coarse sand cemented by iron. It occurs in association with large pans in the area, and thicknesses of 2 metres have been recorded.

7. Soils derived from residual material

These soils, although not common in the Sib area, occur over the Sib ore body. They consist of medium-grained brownish sandy loams, the product of mechanical and chemical weathering processes in the bedrock. Ususally they are not more than 10 cms thick and where they do occur they are invariably covered by transported overburden of varying thicknesses.

Soil profiles associated with the Sib ore body

A series of pits and trenches were dug across the ore body and logged in order to study more closely the soil profiles associated with the zone of mineralization. From Fig. 11 it can be seen that on transect 33 a trench running from 15.4 metres N to 8.2 metres S and pits 1 - 14 were dug. Pits 1 and 2 lie north of the trench (Fig. 11), while pits 3 - 14 lie to the south of the trench. On transect 6, pits 1 - 8 were dug (Fig. 11). Pits 1 - 3 lie north of the baseline, while pits 4 - 8 lie to the south of it (Fig. 11).
Studies of the profiles (Figs. 12 - 14) reveal

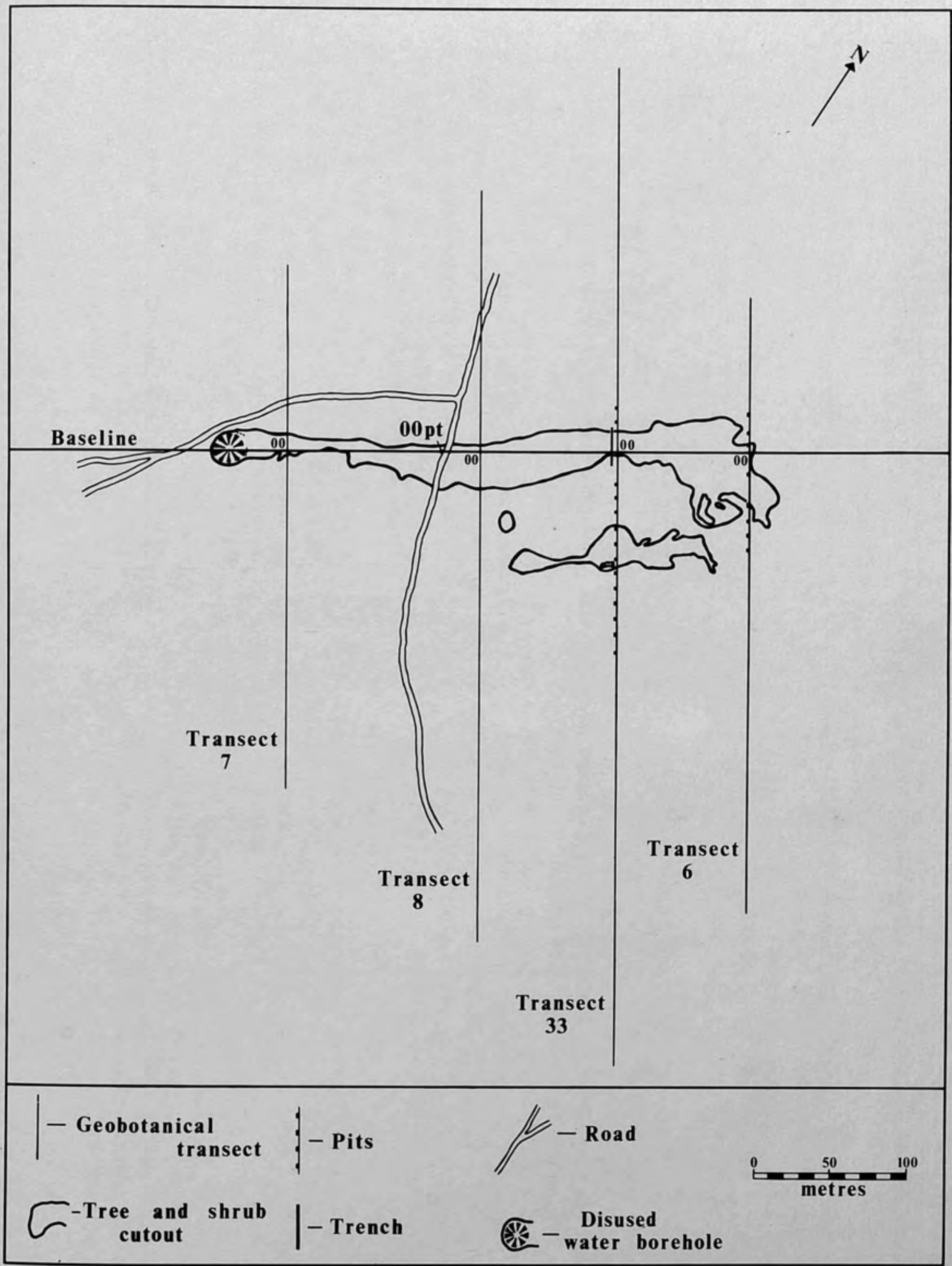


Fig.11: Location of transects 6, 7, 8 and 33, pits, and the trench dug across the Sib ore body

KEY : Figs.12 - 14

1. Fine to medium-grained windblown sand containing approximately 10% small (3 - 5 mm diameter) subangular to rounded vein quartz pebbles. Good root penetration.

2. Water transported gravel comprising subangular to rounded quartz pebbles (1 - 3 cm diameter), angular to subangular blocks of weathered feldspathic and arkosic quartzites (5 - 12 cm diameter) and fragments of granite, jasper and Doornpoort quartzite in a matrix of fine to medium-grained sand. The gravel may comprise an upper layer of coarse fragments and a lower layer of finer material. Penetrated by numerous roots.

3. Medium to small gravel fragments (4 mm to 1.5 cms diameter) in a fine to medium-grained sandy matrix cemented in places by iron.

8. Very fine to medium-grained calcareous horizon, often containing small rounded vein quartz pebbles (2 - 5 mm diameter). Calcareous veins also common. No mineralization observed.

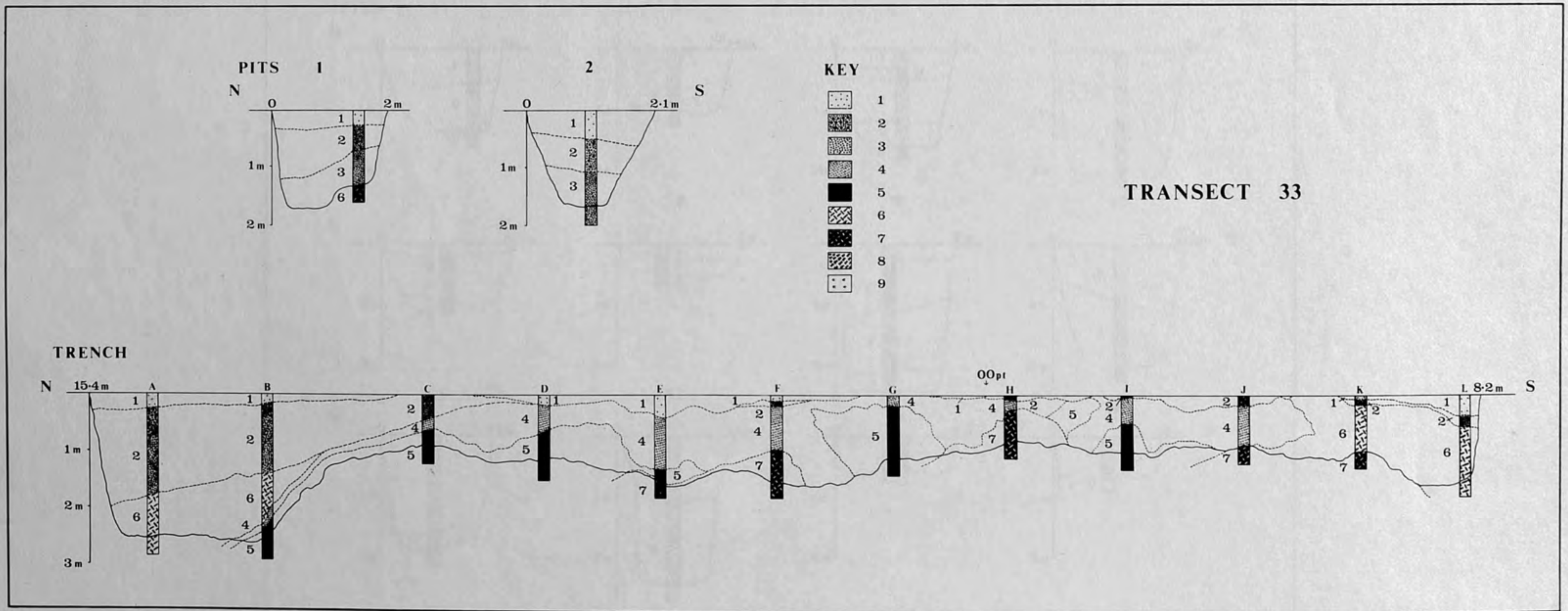
9. Compact layer of hard, whitish calcrete.

6. Highly weathered, angular blocks of coarse-grained feldspathic and arkosic quartzite in a matrix of fine to medium-grained sand or very fine gravel. Malachite and chrysocolla staining on fracture planes - except in sites A and B of trench section. Zone penetrated by roots.

4. Weathered tilloid/greywacke with mineralized veinlets. Light-green to grey in colour with reddish-brown streaks. Where present, roots penetrate to upper contact and may follow weathering planes.

5. Massive tilloid/greywacke with veinlets and dissemination of malachite, chrysocolla and azurite. Dark green to bluish-grey pebbles of quartzite in a clay matrix.

7. Slightly weathered, coarse-grained feldspathic and arkosic quartzite with malachite and chrysocolla along fracture planes.



<u>Fig.12</u>: Profiles through the soil, overburden and weathered bedrock exposed in pits and along the trench dug on transect 33, Sib

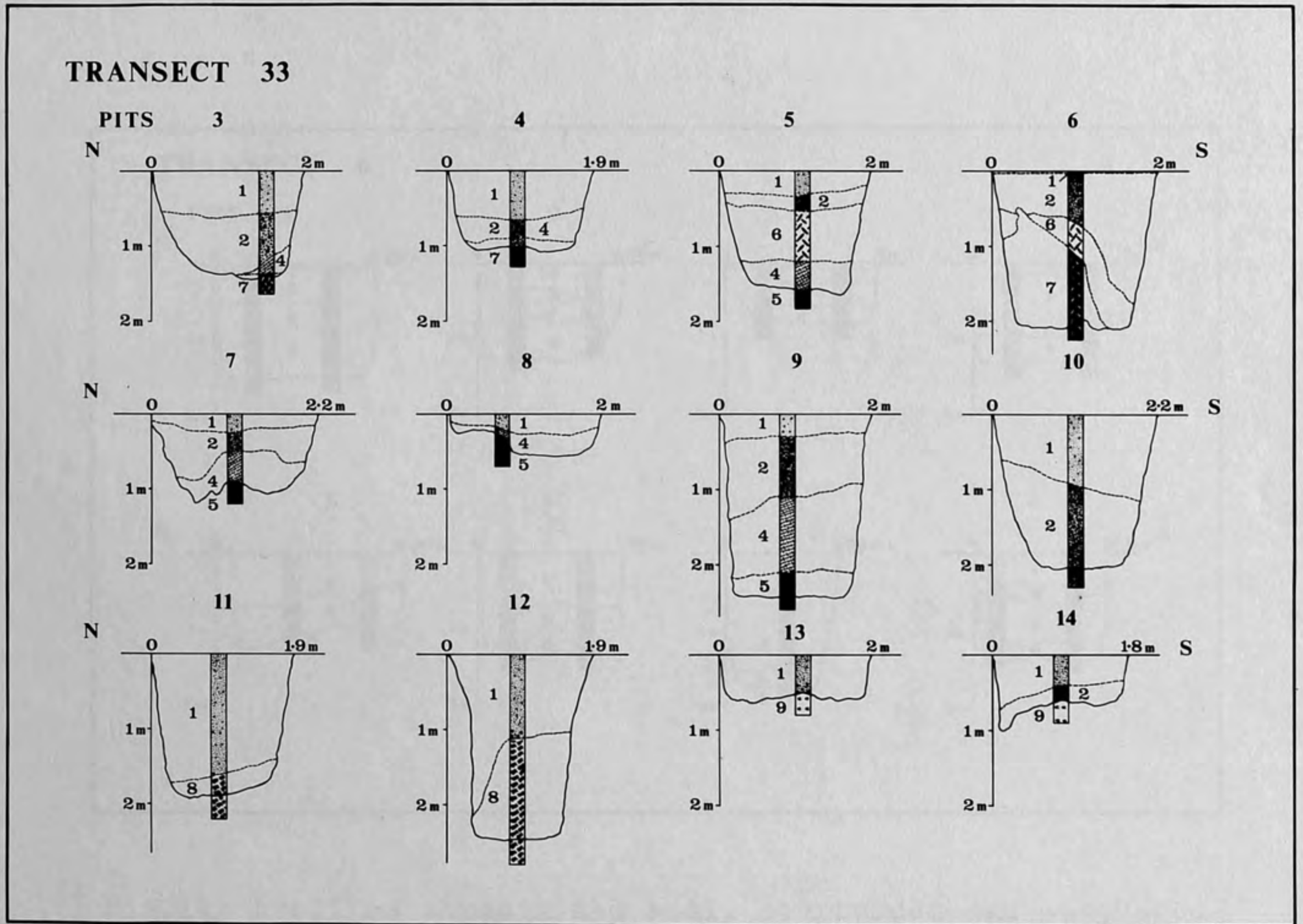


Fig.13: Profiles through the soil, overburden and weathered bedrock exposed in pits along transect 33, Sib

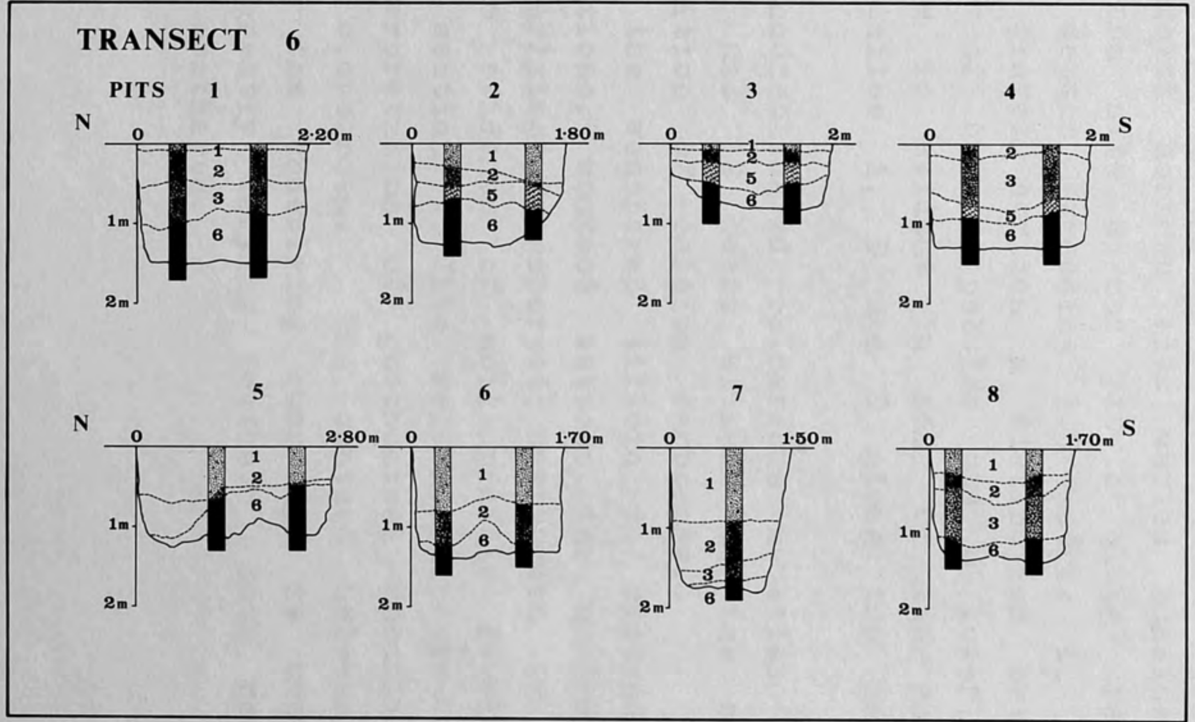


Fig.14: Profiles through the soil, overburden and weathered bedrock exposed in pits along transect 6, Sib

the great variations in the nature and thickness of the transported overburden over short distances. For example along transect 33 the depth of the windblown sand increases from 30 cms to 1.5 metres between pits 9 and 11, while it is virtually absent from the trench section where its place may be taken by transported gravels (sites C, H, I and J).

The gravel horizon also varies considerably in thickness from site G and pit 8 along transect 33 to unknown depths exceeding 1.5 metres in pit 10. Within the gravel horizon a distinction between an upper layer of coarse pebbles and a lower layer of fine pebbles is evident in some of the profiles, notably at sites A, B and C along the trench section.

The unconsolidated calcareous material present in pits 11 and 12 bears witness to the solution and redeposition of calcium carbonate.

Where the weathered tilloid is exposed in profile sections, contact between the weathered zone and the overlying transported overburden is sharp. There is no evidence of soil profile development within the section. This relationship is important in the interpretation of geochemical anomalies in transported overburden. The contact between the tilloid and the underlying quartzite is uneven and occurs at greatly varying depths. Both rock types are highly weathered.

Vegetation

The vegetation of the Sib area falls generally into the low tree and shrub category as described in Chapter 2.

The open vegetation is virtually treeless, scattered shrubs abound and grass dominates the area. The plants are most commonly woody and annuals are common. Plant communities appear to be of a climax nature, i.e. the plant populations are in equilibrium with the soil conditions.

A close study of plant communities has revealed that they fall into the following physiognomic units:-

Low tree and shrub savanna
Savanna grassland
Savanna parkland
Shrub savanna.

These units may include more than one climax community. Studies of the distribution of the climax communities have disclosed relationships with the types of soil which in turn have been influenced by parent material. As has been indicated earlier, parent material is largely of transported origin, bedrock being exposed in less than 5% of the area. Any relationships between the nature and composition of the vegetation and the underlying bedrock are restricted to areas with little or no cover.

The following associations between vegetation units and soil types have been recognized:-

LOW TREE AND SHRUB SAVANNA

1. Low tree and shrub savanna associated with fossilized and semi-fossilized dunes of windblown Kalahari sand

These dunes are characterized by *Acacia haematoxylon*, *Acacia giraffae* and *Boscia albitrunca* trees, *Acacia mellifera*, *Phaeoptilum spinosum* and *Rhigozum trichotomum* shrubs with the perennial grasses *Asthenatherum glaucum* and *Stipagrostis namaquensis*. Patches of *Helichrysum argyrosphaerium* and *Cassia italica* provide the main ground cover.

The lower slopes of the dunes carry a greater plant cover than the crests, a phenomenon caused by the unstable nature of the dune crests which inhibits the establishment of a vegetation cover. Usually only a few trees and grasses will grow on the crests while the shrubs dominate the lower slopes. Where the dunes are completely fossilized the vegetation cover is uniform (Plate 10).

2. Low tree and shrub savanna associated with the plains between widely spaced dunes

These plains, which are covered by 1 - 5 metres of windblown sand, water transported material and soil derived from residual materials, are characterized by *Acacia giraffae*, *Boscia albitrunca* and *Albizzia anthelmintica* trees and *Acacia mellifera*, *Acacia hebeclada*, *Catophractes alexandri*, *Phaeoptilum spinosum* and *Rhigozum trichotomum* shrubs. The perennial grass *Stipagrostis uniplumis* is accompanied by the annual grasses *Eragrostis porosa*, *Eragrostis denudata* and *Pogonarthria fleckii*. The annual herbs *Gisekia pharnacioides*, *Sylitra biflora* and *Limeum viscosum* are common.

The vegetation is a typical low tree and shrub savanna dominated by the grass *Stipagrostis uniplumis* and uniformly studded with trees and shrubs. The relatively large number of species present reflects the varied soils to which general bedrock types have contributed.

SAVANNA GRASSLAND

3. Savanna grassland associated with "straate" situated between closely spaced sand dunes

The grassland occupying the deep buff coloured sand which mantles the "straate" is dominated by the perennial grass *Stipagrostis uniplumis*. Occasional

Plate 10: Panoramic view on the farm Sukses showing a shrub savanna of Phaeoptilum spinosum and Rhigozum trichotomum shrubs on the alluvium covered "straat" in the foreground and a low tree and shrub savanna of Acacia giraffae, Boscia albitrunca trees and Acacia mellifera shrubs over the sand dunes in the background. The borehole S1 is situated where the people are standing in front of the Land Rover.
(Ref. MMC/SWA 29/6a - 11a)

isolated *Acacia giraffae* trees and *Rhigozum trichotomum* shrubs may occur.

SAVANNA PARKLAND

4. Savanna parkland associated with deep alluvium between the dunes in the Schaf River delta

A parkland savanna dominated by *Acacia giraffae* trees, the perennial grass *Stipagrostis uniplumis* and the annual grass *Schmidtia kalahariensis* (Plate 11) occupies the soil derived from deep alluvium which has been deposited between the sand dunes in the Schaf River delta. Immediately after the early rains the annual herb *Tribulus zeyheri* is common.

SHRUB SAVANNA

5. Shrub savanna associated with alluvium deposited between sand dunes in the Schaf River delta

A shrub savanna characterized by *Phaeoptilum spinosum* and *Rhigozum trichotomum* shrubs, with occasional *Acacia giraffae* trees and the annual grass *Eragrostis trichophora*, occupies the alluvial soils which are somewhat shallower and drier than those occupied by the savanna parkland described above (Plate 12).

6. Shrub savanna associated with a thin cover of sand on low ridges formed of calcrete

A distinctive shrub savanna characterized by *Catophractes alexandri* shrubs and *Parkinsonia africana* trees occurs where near surface calcrete forms low ridges. These species are accompanied by *Rhigozum trichotomum* shrubs and the perennial grasses *Enneapogon*

Plate 11: Area of alluvium lying between sand dunes and covered by a layer of windblown sand and exhibiting a savanna parkland dominated by Acacia giraffae trees and the annual grass Schmidtia kalahariensis.
(Ref. MMC/SWA 21/3a - 4)

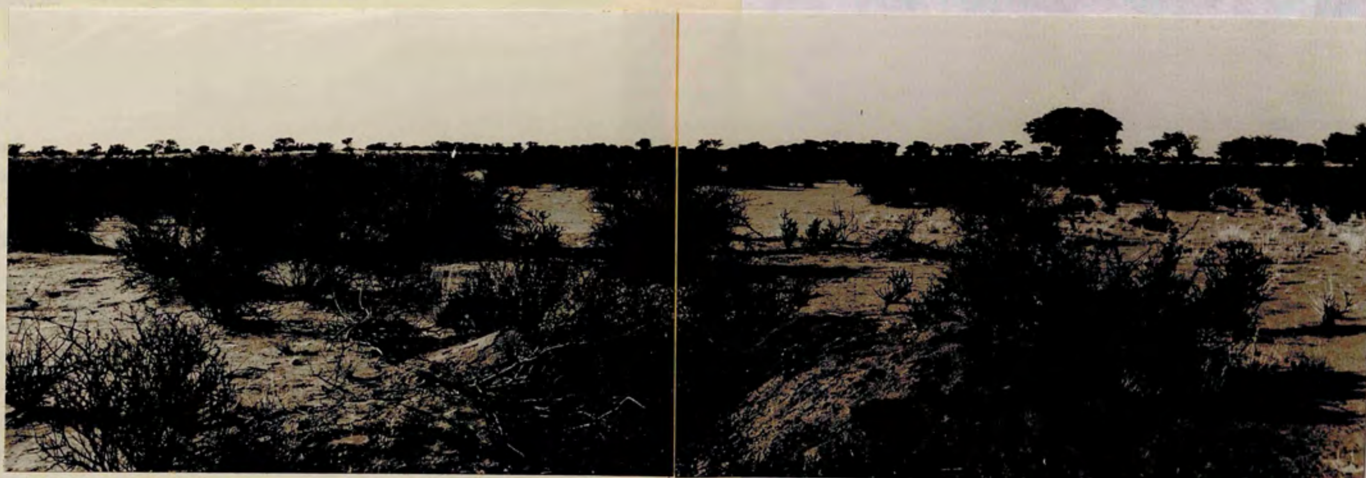


Plate 12: Area of alluvium between the sand dunes on the farm Avro. A shrub savanna characterized by <u>Phaeoptilum spinosum</u> and <u>Rhigozum trichotomum</u> shrubs associated with the perennial grass <u>Stipagrostis uniplumis</u> occupies the alluvium covered "straat". <u>Acacia giraffae</u> trees occur on the sand dune on the horizon. A prospecting pit dug on a geochemical anomaly is seen in the foreground.
(Ref. MMC/SWA 21/6 - 8)

Chapter 5

THE SIB AREA

The biogeographical/geobotanical investigations

While the biogeographical/geobotanical, biogeochemical and geochemical investigations sought data of a complementary nature, to be assessed by evaluation of the inter-relationships between them in the context of the physical environment, each type of investigation followed somewhat different procedures so that it is more appropriate to describe them individually in the first instance. The present chapter describes the biogeographical/geobotanical investigations.

The biogeographical/geobotanical investigations proceeded along two main lines, namely: firstly by mapping the vegetation units over and in the vicinity of the geobotanical/geochemical anomaly on Sib, and secondly by recording the species frequency distribution along a series of transect lines located across the Sib anomaly and extending well into background areas (Fig. 11).

In order to map the vegetation units, a system of grid lines spaced at intervals of 50 metres was established. This used the baseline set out for the initial geochemical survey conducted by E.W.B. Miller and Associates with the 00 point as the point of origin.

Reconnaissance of the area indicated that the infrequency of trees and the high percentage of bare ground (over 90%) precluded the inclusion of trees and ground layer species other than grasses in the compilation of a vegetation map. The vegetation units were clearly characterized by the shrub species which therefore formed the basis for the mapping units. Four main vegetation divisions were recognised (Fig. 15). These encompassed areas which were:-

a) devoid of shrubs;
b) dominated by one characteristic shrub species;
c) dominated by two or more shrub species;
d) dominated by grass species.

The clearly defined area which is devoid of trees and shrubs and characterized by the occurrence of <u>Helichrysum leptolepis</u> within a largely bare area constitutes the most striking feature of the area (Plate 13 and A on Fig. 16). This vegetational cutout (Plates 14 and 15) constitutes a geobotanical anomaly, which subsequent trenching and drilling disclosed was associated with sub-outcropping mineralized tilloid and quartzite (which actually outcropped in places) and which caused high copper values in the overlying soil.

Reference to Plate 13 and Fig. 16 shows that a shallow stream channel (F on Fig. 16) runs through the anomalous area to terminate in a large pan to the west (E on Fig. 16). The anomaly coincides, however, with this drainage line which can be held to have contributed to its occurrence only in so far as it has stripped the cover and exposed the mineralized bedrock in places. At both the eastern and western edges of the anomaly shrubs and trees occupy the stream bed. Drilling during the course of the exploration programme revealed that at the eastern and western edges of the anomaly the ore body plunges downwards and consequently the soil is less toxic, resulting in an increased growth of vegetation. It can therefore be concluded that the toxicity of the soil over the ore body has resulted in a bare zone, while the stream channel, with which the bare zone is associated, is of little

KEY : Fig.15

Geobotanical Anomaly

1. Bare ground with anomalous community of *Helichrysum leptolepis*, *Fimbristylis exilis* and *Aristida congesta*

Shrub savanna

Dominated by:-

2. *Acacia mellifera*
3. *Catophractes alexandri*
4. *Phaeoptilum spinosum*
5. *Rhigozum trichotomum*
6. *Petalidium parvifolium*
7. *Acacia mellifera* and *Petalidium parvifolium*
8. *Acacia mellifera* and *Rhigozum trichotomum*
9. *Acacia mellifera* and *Phaeoptilum spinosum*
10. *Petalidium parvifolium* and *Phaeoptilum spinosum*
11. *Rhigozum trichotomum* and *Phaeoptilum spinosum*
12. *Rhigozum trichotomum* and *Catophractes alexandri*
13. *Phaeoptilum spinosum* and *Catophractes alexandri*
14. *Petalidium parvifolium* and *Boscia albitrunca*
15. *Rhigozum trichotomum*, *Phaeoptilum spinosum* and *Catophractes alexandri*
16. *Rhigozum trichotomum*, *Acacia mellifera* and *Petalidium parvifolium*
17. *Stipagrostis uniplumis*
18. *Aristida congesta*

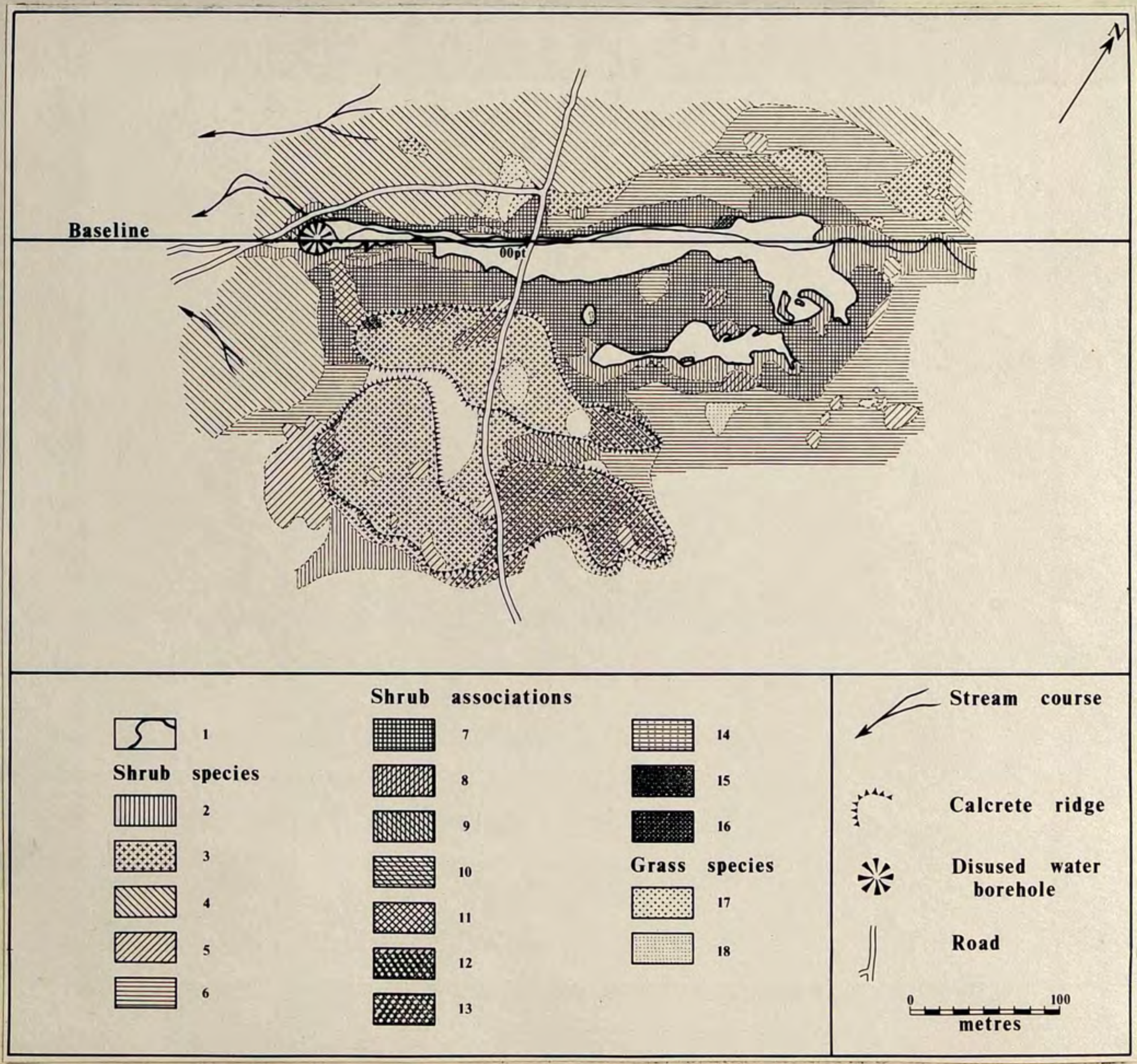


Fig.15: Vegetation associations in the Sib ore body area

Plate 13: Aerial view of the geobotanical anomaly marking the position of the sub-outcropping Sib ore body, the drainage features and the calcrete ridge. See Fig.16 for interpretation of features. (Ref. MMC/SWA 20/17)

A. Geobotanical anomaly associated with copper bearing tilloid and quartzite

B. Shrub savanna dominated by Catophractes alexandri shrubs over calcrete rise

C. Background low tree and shrub savanna

D. Low tree and shrub savanna over area veneered by a thin cover of windblown sand

E. Dry pan

F. Stream channels

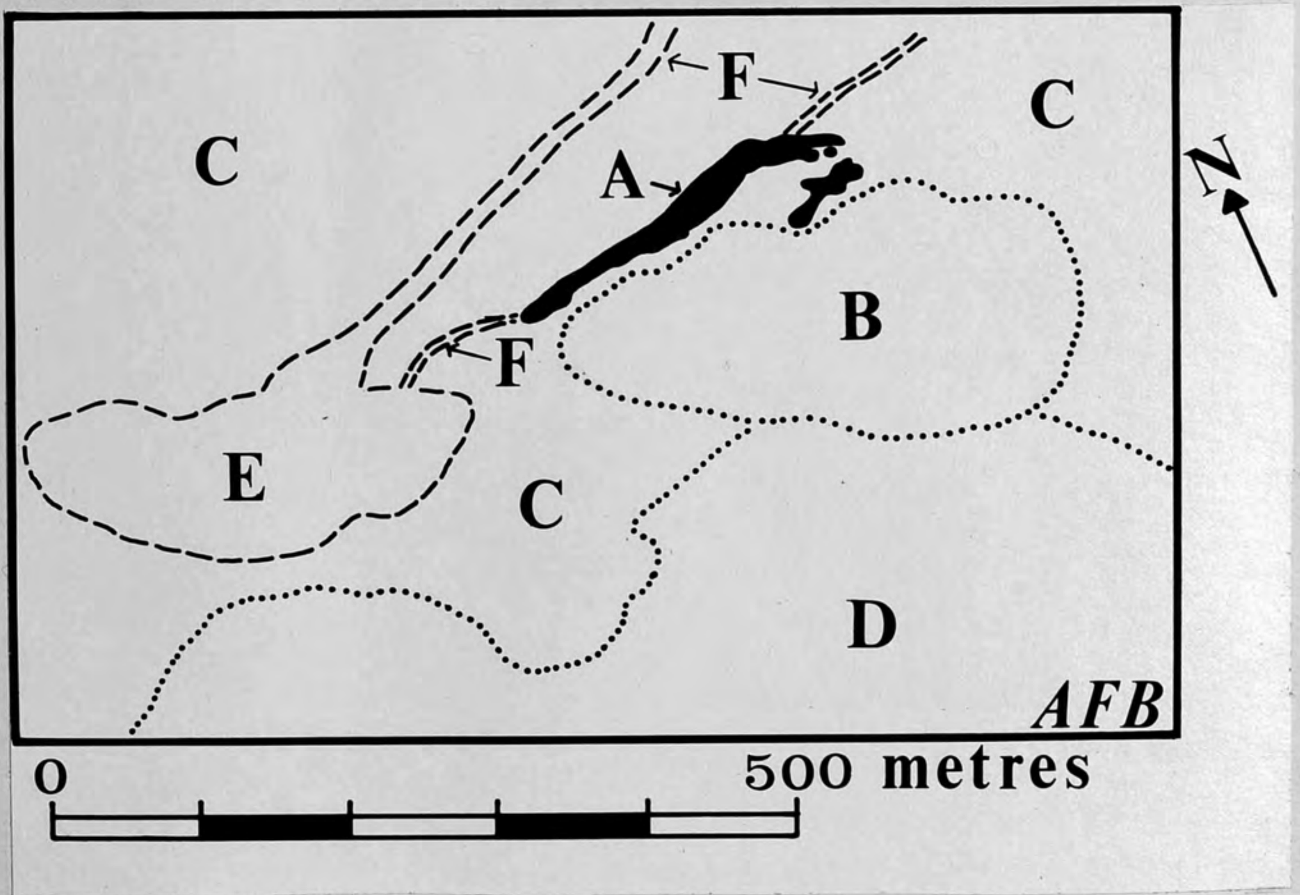


Fig.16: Interpretation of features shown on Plate 13

Plate 14: View west from 00 point showing the tree and shrub cutout over the Sib ore body. (Ref. MMC/SWA 8/12a)

Plate 15: View east from 00 point showing the tree and shrub cutout over the Sib ore body. (Ref. MMC/SWA 8/9a)

significance with regard to the lack of plants.

The woody herb Helichrysum leptolepis (Plate 16) was found growing randomly in the cutout zone. This plant was recognised as an indicator of mineralization in the Witvlei area by the Misses Coupland and Cudmore and Professor Cole in 1967. It grows in association with Fimbristylis exilis (Plate 17), a grass also recognized as an ancillary indicator in the Witvlei area. These plants can tolerate the high copper content of the soil and are called accumulator plants. Over parts of the cutout area the hardy pioneer species Aristida congesta occurs after the rains but cannot be considered an indicator, being relatively common in bare areas especially if overgrazed, and around pans.

The geobotanical anomaly is bordered by a zone in which low trees and shrubs, notably Acacia mellifera, are more common than elsewhere in the vegetation. Reconnaissance elsewhere in the Sib area disclosed that this species frequently follows present and fossil stream courses, and it may be deduced that its concentration around the Sib geobotanical anomaly is a response to the increased moisture in the soil in the vicinity of the stream channels.

To the south of the geobotanical anomaly the concentration of Catophractes alexandri on a calcrete rise (Plate 13, B on Fig. 16, Fig. 15) is a marked feature. Although this species occurs sporadically in the area it is particularly common in calcium carbonate rich areas where it frequently dominates the community.

The areas described above are clearly distinguished from the typically low tree and shrub savanna which covers the greater part of the area. The nature and composition of this background vegetation varies with the nature and depth of superficial cover, as is evident from Plate 13 where the

Plate 16: The copper indicator plant Helichrysum leptolepis. (Ref. MM/SWA 3/18 - photographed at Witvlei)

Plate 17: The ancillary copper indicator plant Fimbristylis exilis. (Ref. MM/SWA 18/37)

occurence of larger trees over the deeper sand in the foreground of the photograph distinguishes this area from that north of the geobotanical anomaly where the cover is thinner.

In order to establish the influence of drainage, soil and rock type on the distribution of the plant species comprising the anomalous assemblage over the Sib ore body, to determine whether these species are indicators of mineralization and to assess their potential in other areas, a series of transects was located across the ore body (Fig. 11). Transect 6 was located across the eastern edge of the geobotanical anomaly, transect 33 across the main portion of the anomaly and transects 7 and 8 extended from the anomaly southwards to traverse the calcrete rise in order to investigate the plant communities associated with calcrete.

Along each transect the frequency of species in the ground vegetation was recorded as the percentage cover in one square metre quadrats on either side of the line. Individual trees and shrubs were counted in quadrats of 5 x 10 metres on either side of the line and their height was noted. Soil samples for analysis for copper content by the acid leaching method followed by atomic absorption spectrophotometry (as outlined in the Appendix to Chapter 6) were collected at 10 or 20 metre intervals. The soil profiles and bedrock geology were studied by means of pits and trenches (transects 6 and 33) while the records from wagon and diamond drill holes, put down in the course of the exploration, were consulted (transects 7 and 8).

From the transect diagrams (Figs. 17 - 20) several features become apparent. Of these the most striking is the occurrence of the herb Helichrysum leptolepis. On all four transects this plant grows only in areas of shallow overburden over the mineralized tilloid and generally its occurrence is

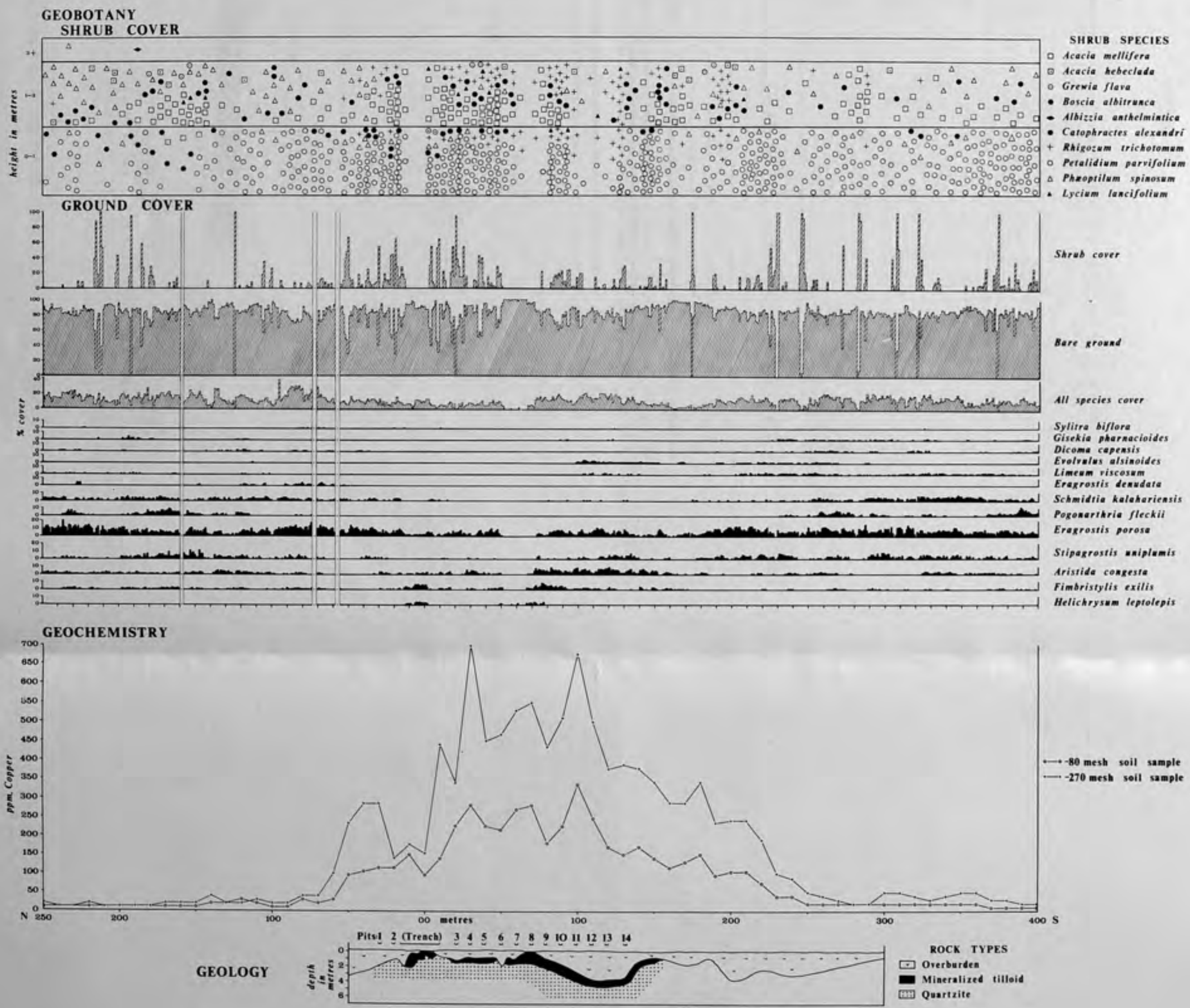


Fig.17: Transect 33 across the Sib ore body area showing the relationship between the distribution of plant species and the geochemistry, relief and geology

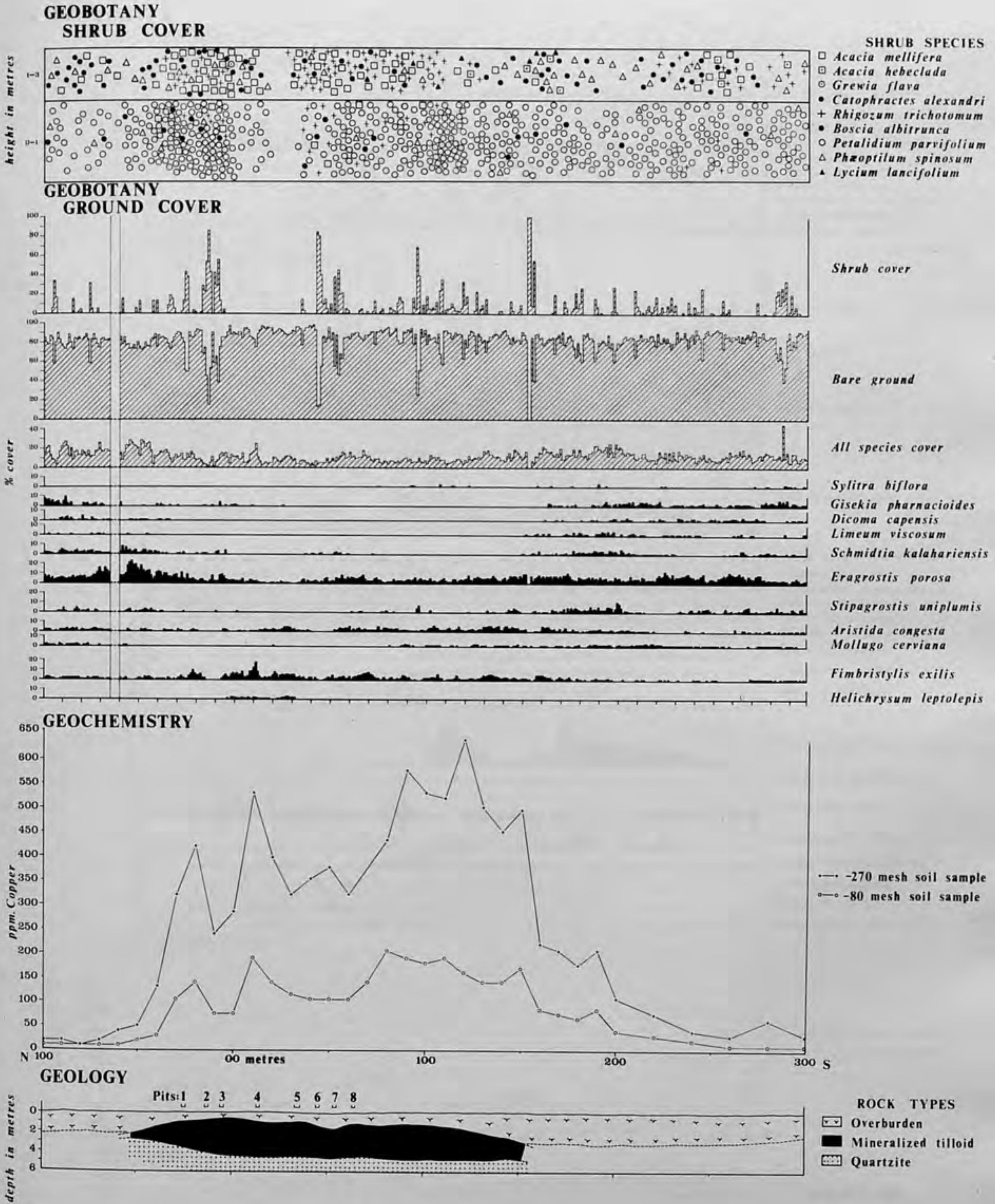


Fig.18: Transect 6 across the Sib ore body area showing the relationship between the distribution of plant species and the geochemistry, relief and geology

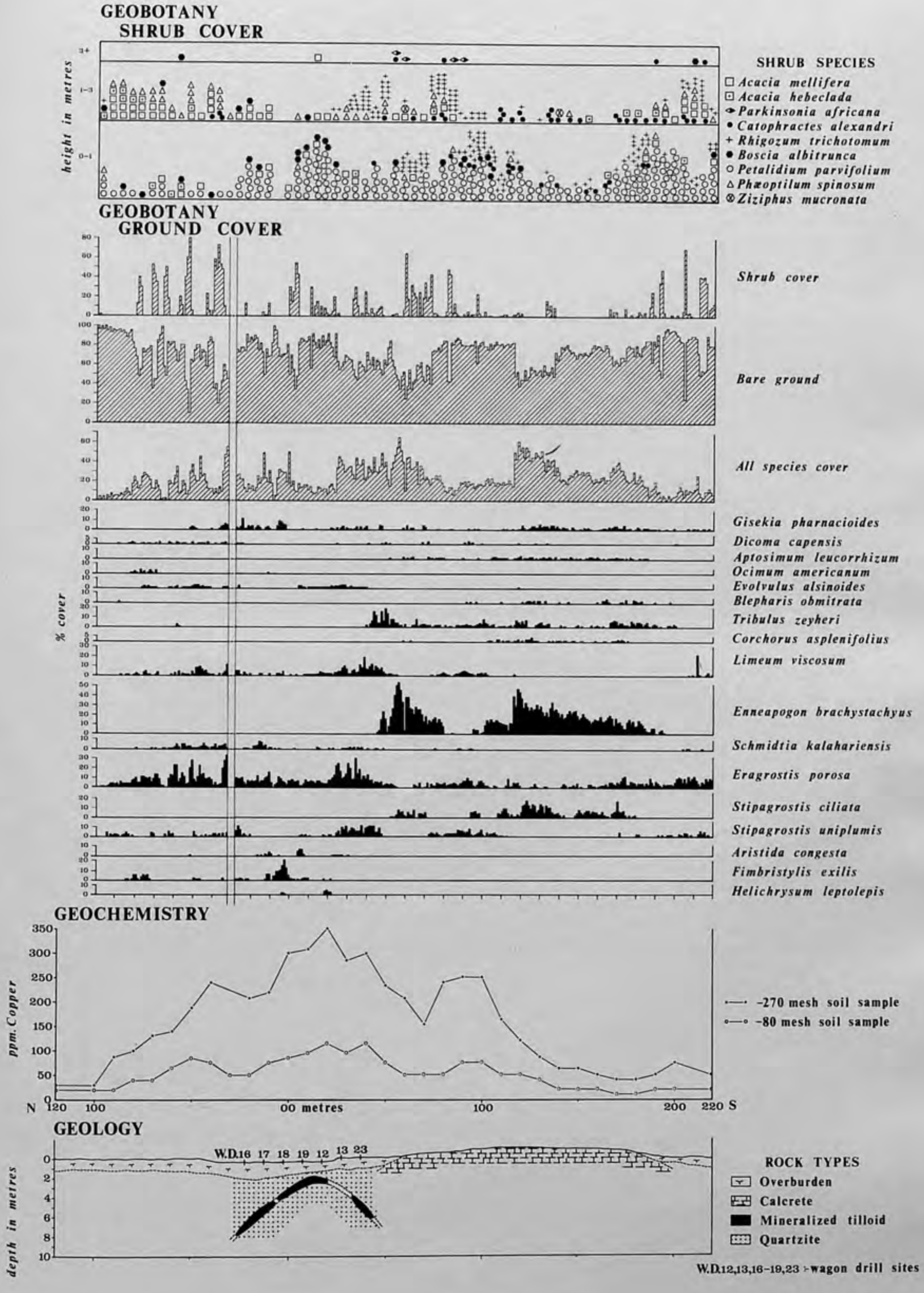


Fig.19: Transect 7 across the Sib ore body area showing the relationship between the distribution of plant species and the geochemistry, relief and geology

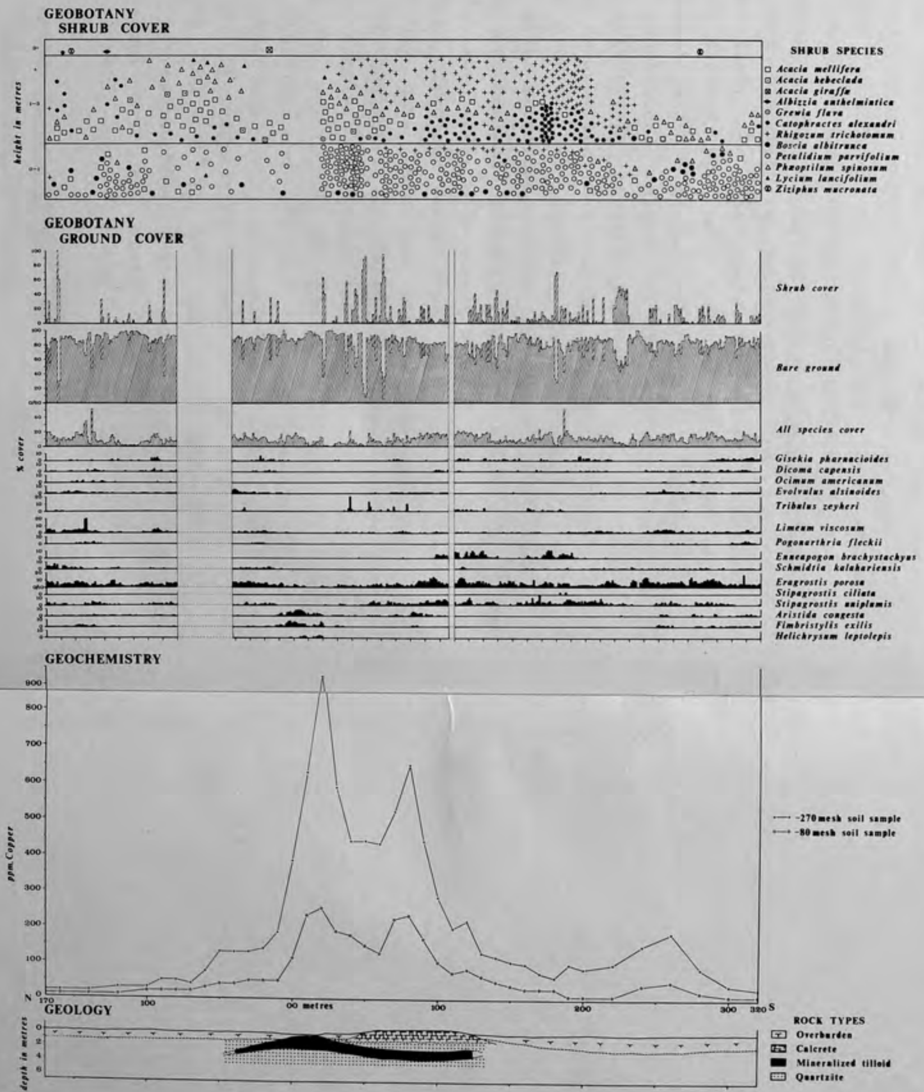


Fig.20: Transect 8 across the Sib ore body area showing the relationship between the distribution of plant species and the geochemistry, relief and geology

associated with the peak copper values in the soils. This, however, is not the case on transects 6 and 33 where the mineralized rock is crossed by the main stream channel. Here there is evidence of leaching processes in the soil, which may account for the fact that copper levels in the surface soil samples (collected at 10 cms) are lower than those in samples from nearby sites unaffected by stream action. The roots of Helichrysum leptolepis, however, were observed to penetrate to the weathered tilloid so that, in this case, the distribution of this plant species may well reflect the tenor of copper mineralization in the tilloid more accurately than the geochemical values in the surface soil.

The Helichrysum leptolepis occurs in the area from which all trees and shrubs and most ground vegetation species are absent; this in turn coincides with anomalous copper levels in the soil. Within the geochemical anomaly, maximum values of 925 ppm in the -270 mesh fraction and 350 ppm in the -80 mesh fraction were found in one sample, but these may have been due in part to the inclusion of weathered fragments of copper oxide in the sieved sample. Overall the geochemical anomaly is defined by values of 50 ppm to 300 ppm in the -80 mesh fraction and 100 ppm to 700 ppm in the -270 mesh fraction over near surface copper bearing tilloid, and by respective values of 50 ppm to 100 ppm and 100 ppm to 350 ppm where the tilloid is masked by overburden. The Helichrysum leptolepis is not present over the whole of the geochemical anomaly, occurring only in the vicinity of the higher values.

The grass Fimbristylis exilis grows in association with Helichrysum leptolepis and although it has a slightly wider range the areas of dense growth coincide exactly with the zones of Helichrysum leptolepis. It may therefore be said that Fimbristylis exilis is an ancillary indicator of near surface mineralization. It also grows in or near small streams, e.g. at 140 to 150 N and 260 S on transect 8 (Fig. 20) and at 70 to 85 N on transect 7 (Fig. 19), where its presence may reflect a combination of relatively high copper levels and greater moisture availability in the soil at rooting depth.

Initially the occurrence of the annual grass Aristida congesta (Plate 18) with Helichrysum leptolepis and Fimbristylis exilis suggested that the species might be an ancillary copper indicator in the ore body zone, but reconnaissance in the Sib area revealed its presence in disturbed areas such as those bared by sheetwash erosion, sheep stockades etc. This grass is in fact a hardy pioneer species whose presence could nevertheless point to the presence of conditions unfavourable for many species such as those produced by bedrock mineralization.

Most of the other species recorded along the transects make up the background vegetation units and are absent from the area with anomalous copper values in the soil. Of the perennial grasses, Stipagrostis uniplumis (Plate 19) is widely distributed, whereas Stipagrostis ciliata (Plate 20) is virtually restricted to the area of the calcrete rise crossed by transect 7. Its absence from the part of this feature crossed by transect 8 may be due to the presence of a thin layer of windblown sand and transported material over the calcrete.

The most common annual grass is Eragrostis porosa which is a pioneer species and flourishes particularly in disturbed areas, notably along roads and streams as for example at 30 to 70 N on transect 6, 30 N on transect 7 and at several localities along transect 8. The grass Enneapogon brachystachys flourishes in calcareous soils, notably over the calcrete rise on transects 7 and 8 and in the soils receiving wash material from this feature

Plate 18: The annual grass Aristida congesta.
(Ref. MM/SWA 18/33)

Plate 19: The perennial grass Stipagrostis uniplumis.
(Ref. MM/SWA 19/22)

Plate 20: The perennial grass Stipagrostis ciliata which is common on calcrete. (Ref. MM/SWA 19/17)

farther south along the latter transect. By contrast Schmidtia kalahariensis, although widely distributed, is less common over calcareous areas. The other annual grass species, Eragrostis denudata and Pogonarthria fleckii, occur infrequently and sporadically.

The perennial herb Aptosimum leucorrhizum is confined to the calcrete rise from which, however, it is absent where the calcrete is covered by transported overburden. The perennials Ocimum americanum and Blepharis obmitrata occur only sporadically in the background vegetation throughout the area, as also do the annual herbs Mollugo cerviana, Limeum viscosum, Corchorus asplenifolius, Dicoma capensis, Gisekia pharnacioides, Sylitra biflora, Tribulus zeyheri and Evolvulus alsinoides. These species do not occur in soils with high copper content. If they do germinate in such soils they survive for only a few days and then die as a result of the toxic conditions.

Throughout the area there is little difference in the recorded heights of the trees and shrubs along the transects. Trees and shrubs are completely absent from the zones with near surface mineralization and associated copper toxic soils and there are no species exhibiting a peripheral distribution to such areas.

In the background areas most trees and shrubs are widely distributed. Acacia mellifera, Phaeoptilum spinosum (Plate 21), Boscia albitrunca, Rhigozum trichotomum (Plate 22) and Petalidium parvifolium (Plate 23), however, are more frequent at the periphery of the drainage features where doubtless more moisture is available after rains (Figs. 17 - 20), while Catophractes alexandri (Plate 24) is most abundant over calcrete.

Although rock and soil types together with drainage exert an influence on the plant distributions, the trace element anomalies appear to exert the controlling influence. Relief is so little as

Plate 21: The shrub Phaeoptilum spinosum.
(Ref. MM/SWA 21/11)

Plate 22: The shrub Rhigozum trichotomum.
(Ref. MM/SWA 58/29)

Plate 23: The shrub Petalidium parvifolium.
(Ref. MM/SWA 18/43)

Plate 24: The shrub Catophractes alexandri in flower.
(Ref. MMC/SWA 18/6a - photographed at Witvlei)

to exert a negligible influence. Thus the relationships between the plant distributions and the physical, chemical and biological characteristics of the soil are evident from the transects.

In summary the vegetation studies in the Sib ore body area established the composition of the vegetation units and indicated the influence of relief, drainage and soils - notably their copper levels - on plant species distribution. *Helichrysum leptolepis* and *Fimbristylis exilis* emerged as indicators of copper toxicity in their rooting medium and together they formed the anomalous association over the Sib ore body, while the other species recorded in the area formed constituents of the background vegetation. There may be, however, small variations in the structure of the background associations due to influences exerted by the physiography and geomorphology of the area which are independent of copper mineralization. Lithology also has an influence; a good example being the anomalous vegetation over areas of calcrete.

Chapter 6

THE SIB AREA

The geochemical investigations

As part of the regional geochemical survey carried out by E.W.B. Miller and Associates (Fig. 3), a detailed sampling grid was laid down over the Sib prospect (Fig. 21). The grid took the form of a series of lines, alternately long and short, at 300 metre intervals across the area of sporadic outcrops. Two additional lines, A and B, were sited to cover the western extension. Samples were collected at 20 metre intervals and the -80 mesh fraction was analysed using the bisulphate fusion/ colorimetric method.

The isopleth map of copper values obtained from this investigation over the main ore zone (Fig. 21) shows a major geochemical anomaly and two weaker anomalies, one to the north-west (Line 300 W) and the other to the south-west (Line 00) of the ore body. A further anomaly was located on Line 2400 E, to the north-east of the ore body. This isopleth map was used as a basis for subsequent geochemical and biogeochemical work in the Sib ore body area.

In view of the generally low order of the main geochemical anomaly over Sib, and of the particular exploration problems inherent in the environment, it was decided to undertake orientation studies on sampling and laboratory techniques before proceeding with detailed geochemical investigations on a routine basis. This included investigations to establish the mesh size fraction of soil samples most likely to outline geochemical copper anomalies

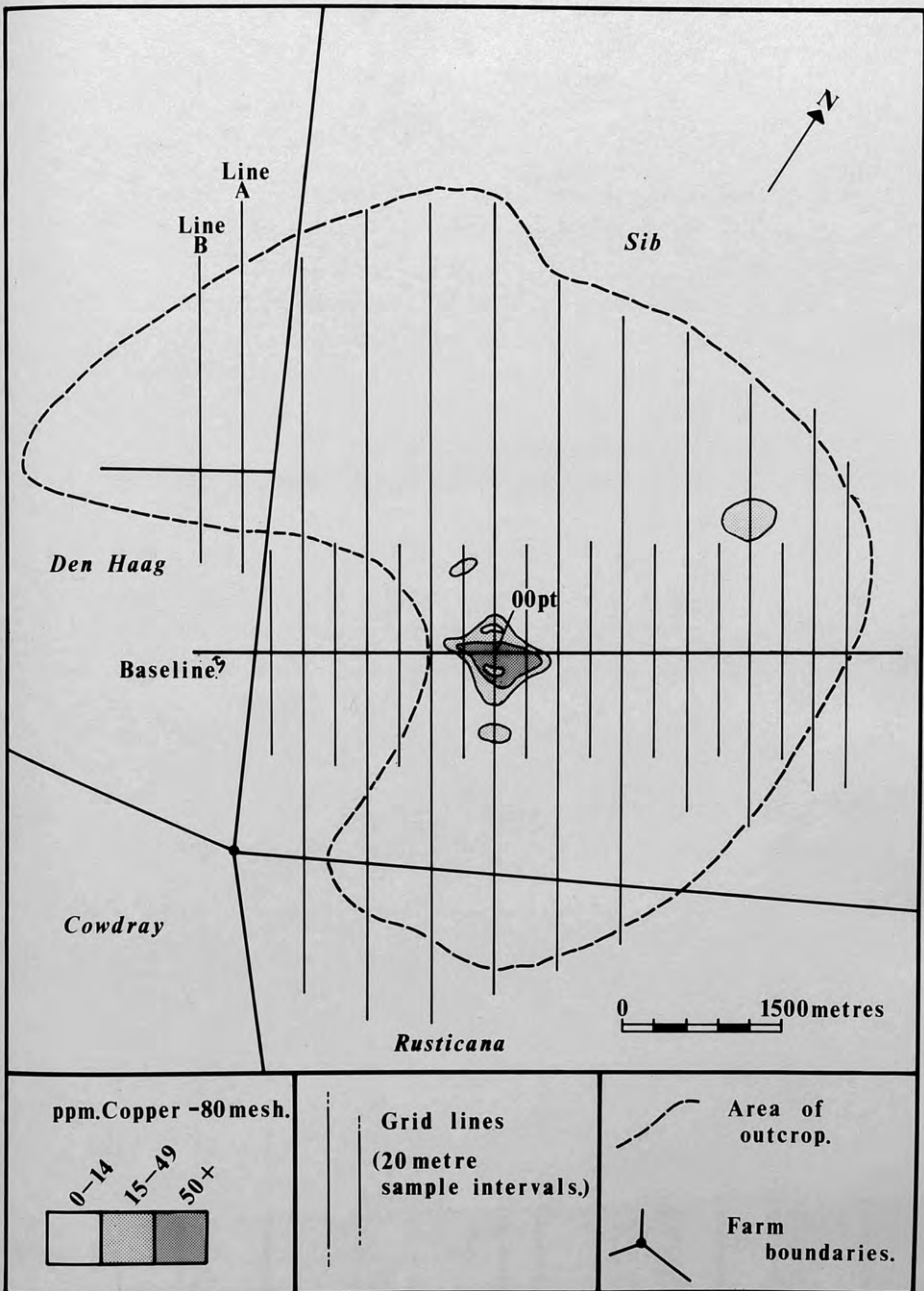


Fig. 21: Geochemistry grid and isopleths of copper values in the soil on a portion of Sib, Rusticana and Den Haag (after E.W.B.Miller and Associates)

in this particular environment, and to ascertain the most suitable procedure in extraction of copper from the samples for analysis purposes.

Orientation geochemical studies

In order to ascertain which mesh fraction contained the most copper, two bulk samples were collected on transect 33, Sib. One was collected in the anomalous zone at 30 S, while the other was collected in the background zone at 400 S. To give some idea of the percentage of each fraction in the sample the sample was weighed in the laboratory (Total weight = 100%) and then sieved through meshes with aperture sizes of 490, 250, 170, 125, 74 and 53 microns. After each sieving the sample was weighed in order to ascertain the percentage of the total sample. Each mesh fraction was then analysed for copper using the acid leaching method followed by atomic absorption spectrophotometry (Table 6).

Table 6: Mesh fraction content of bulk soil samples and copper content of each fraction - transect 33, Sib

Sample	Microns	Mesh fraction	Weight (g)	% of total sample	ppm Cu
400 S (Wt. 468g.)	490	-35	335.5	71.60	10
	250	-60	249.5	53.30	10
	170	-80	197.9	42.30	10
	125	-120	104.2	22.20	15
	74	-200	50.1	10.70	20
	53	-270	8.3	1.76	40
30 S (Wt. 499g.)	490	-35	399.7	80.10	210
	250	-60	279.8	56.00	225
	170	-80	211.2	42.30	240
	125	-120	115.7	23.10	320
	74	-200	48.7	9.80	410
	53	-270	11.4	2.28	600

The percentage (of total sample) was plotted against aperture size (microns) in order to establish the particle size distribution within each sample. The resultant graph (Fig. 22) shows that the finer fractions, containing the clay particles, constitute 2% or less of each sample. The copper content of each mesh fraction was plotted against aperture size (microns), and from Fig. 22 it is seen that the coarser fractions of the samples (i.e. > 170 microns) contained less copper than the finer fractions (i.e. < 170 microns). The finest fraction analysed for copper, i.e. 53 microns and less, gave the highest copper values.

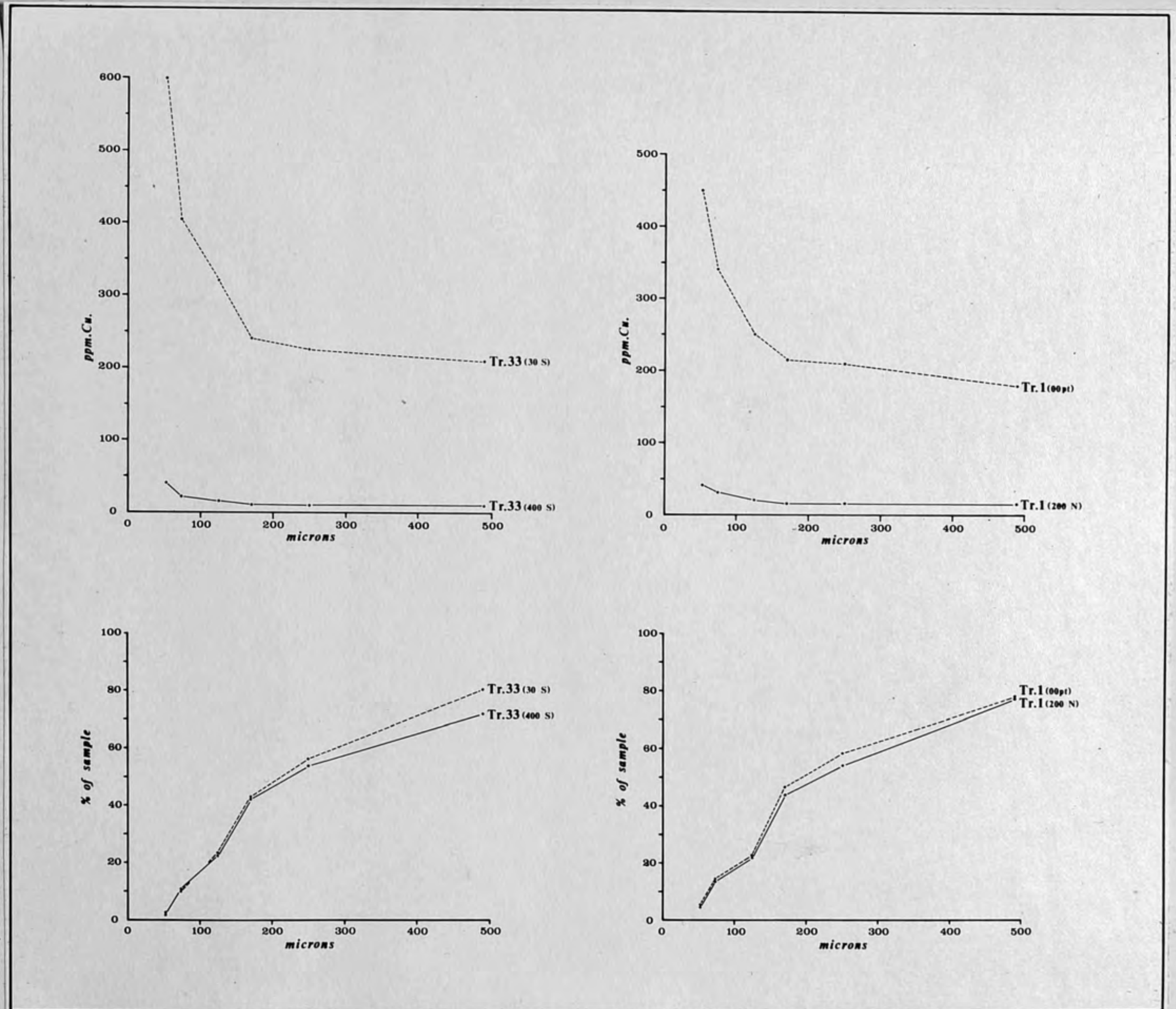
The results of this investigation suggested that the copper adheres to the clay particles contained in the -270 mesh fraction (53 microns and less) and that this mesh fraction might be more suitable for analysis than the -80 mesh fraction for geochemical analysis in the Sib area.

In order to test this, a comparison was made between the copper levels in the -80 and the -270 mesh fractions of samples collected at 50 metre intervals along transect 33. The results (Fig. 23) showed that:-

1. the -270 mesh fraction gave a slightly higher background than the -80 mesh fraction,
2. the peak value in the -270 mesh fraction was three times that in the -80 mesh fraction.

The results of these studies confirmed that most of the copper is associated with the clay fraction which makes up most of the -270 mesh fraction. Analysis of the -270 mesh fraction, therefore, gives a better indication of the copper content of the soil than the -80 mesh fraction which contains coarse particles of wind and water

Fig.22: Particle size distribution and the copper content of individual mesh fractions in soil samples collected in anomalous and background areas along transect 33, Sib, and along transect 1, Mertens



transported material as well as residual soils.

Laboratory studies were also undertaken to ascertain the minimum time required for an acceptable extraction of copper from the soil samples. These showed that analysis by the acid leaching method followed by atomic absorption spectrophotometry following a four hour digestion time (at 95°C in 1 N HNO_3), resulted in higher copper levels in both the -80 and -270 mesh fractions than analysis following a one hour digestion (Fig. 23 and Table 7).

<u>Table 7</u>: Analysis of soil samples collected on transect 33, Sib, in order to investigate the effect of varying digestion times on the extraction of copper

Collection site	1 hour digestion (95°C) ppm Cu.		4 hour digestion (95°C) ppm Cu.		Rock type
	-80 mesh fraction	-270 mesh fraction	-80 mesh fraction	-270 mesh fraction	
250 N	7	12	7	17	Quartzites
200 N	7	17	12	25	Quartzites
150 N	7	17	12	25	Quartzites
100 N	7	17	12	30	Quartzites
50 N	40	137	87	205	- 20 N -
00 pt	52	255	92	300	Tilloid
50 S	87	335	150	507	Tilloid
100 S	155	497	250	630	Tilloid
150 S	115	330	200	482	Tilloid
200 S	62	227	107	335	Tilloid
250 S	17	62	40	87	Quartzites
300 S	12	25	17	45	Quartzites
350 S	12	30	17	57	Quartzites
400 S	7	40	12	30	Quartzites

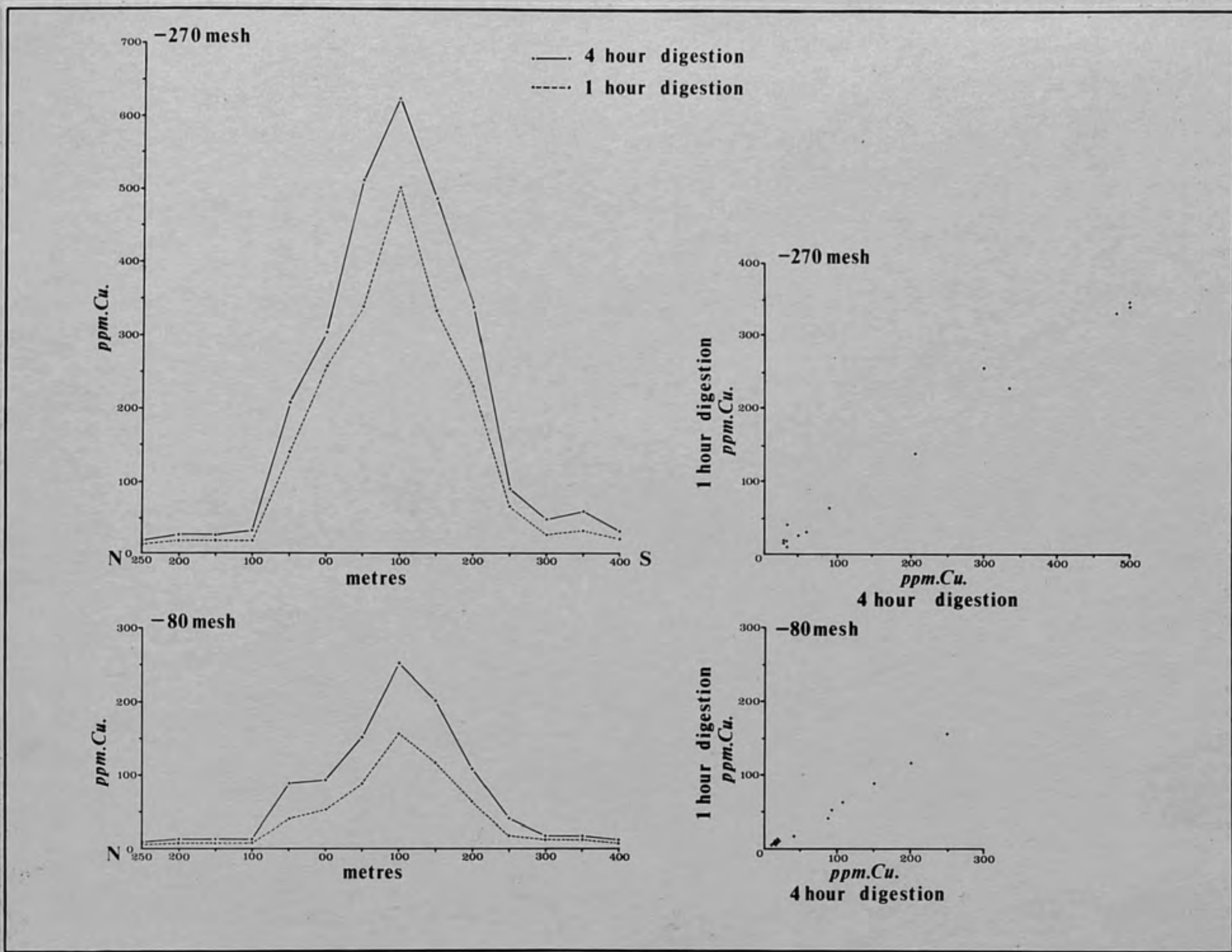


Fig. 23: The copper contents of the -80 and -270 mesh fractions of soils collected along transect 33, Sib, and analysed after digestion periods of one and four hours. The scattergrams (right) show the relationship between the digestion time and copper extraction.

In the -80 mesh fraction 60% more copper was extracted during the four hour digestion period, while in the -270 mesh fraction only 20% more was extracted. The actual increase of copper extraction with increased digestion time is linear (Fig. 23). Since only 20% more copper was extracted from the -270 mesh fraction during a four hour digestion period than during a one hour digestion period, it was decided to use the latter as the amount of increased extraction possible did not warrant the extra time required for the four hour digestion.

Three methods of extraction of copper from the -80 mesh fraction of the soil were also compared in order to ascertain the one most suitable for exploration in the Sib area. These were acid leaching and the Stanton method of total copper extraction, both followed by analysis by atomic absorption spectrophotometry, and the cold extraction method followed by colorimetric determination of copper content (these three methods are outlined in the Appendix to Chapter 6). For this purpose the samples collected at 20 metre intervals along transect 33 were used.

The results showed that higher values were obtained by using Stanton's method (Fig. 24) in preference to acid leaching followed by atomic absorption spectrophotometry (Fig. 23), and that the values obtained from the latter were similar to those obtained from the cold extraction method followed by colorimetric determination (Fig. 24). Because of the relatively simple method of preparation involved in the acid leaching method it was decided to use this, followed by atomic absorption spectrophotometry, for all the geochemical work.

Initially all the soil samples (as well as the plant samples) collected for this project were analysed in the laboratories of Anglo Vaal in Windhoek but in 1968 comparisons were made of the results obtained on split samples analysed respectively

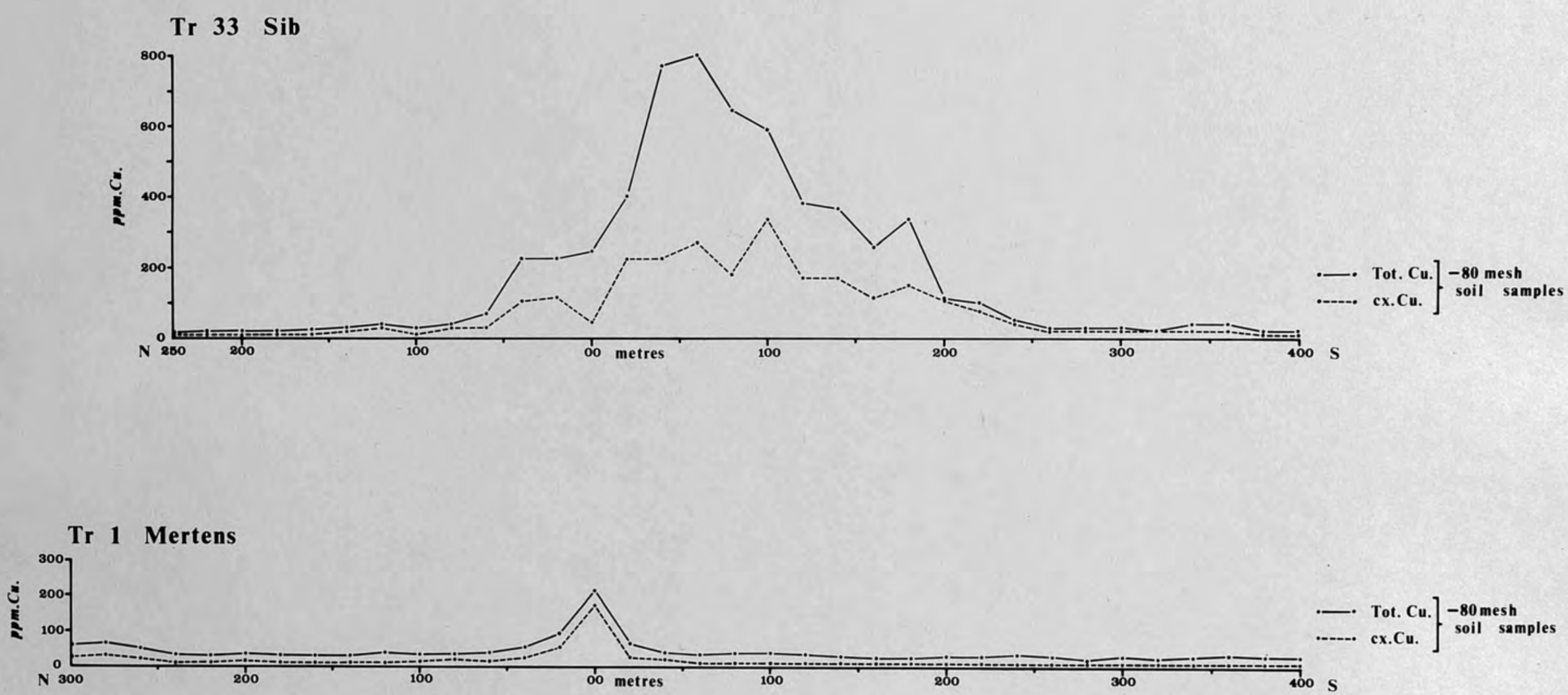
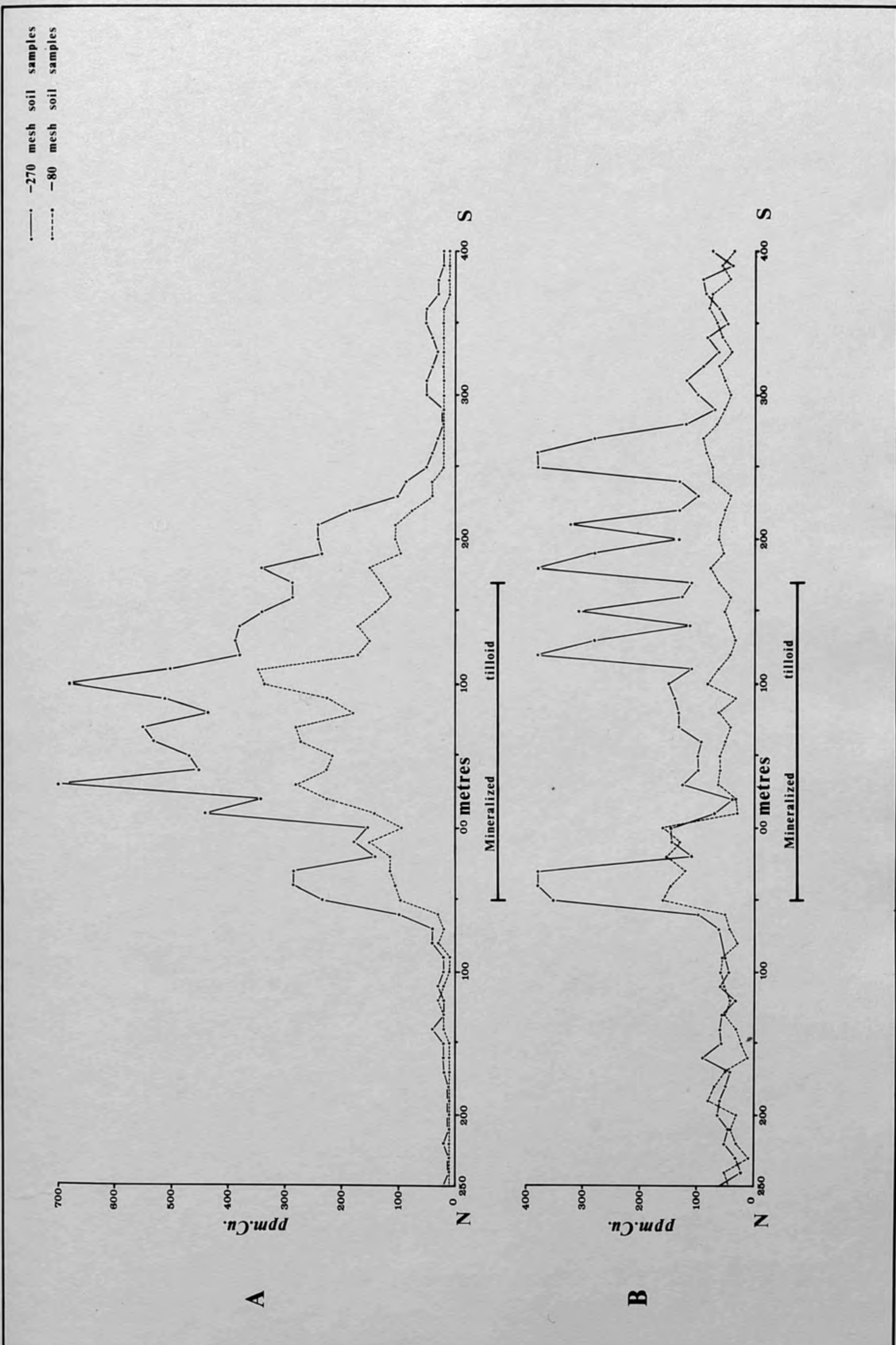


Fig.24: The copper content of the -80 mesh fraction of soils collected along transect 33, Sib, and transect 1, Mertens, and analysed by the Stanton method for total extraction followed by atomic absorption spectrophotometry and by cold extraction followed by colorimetric determination

in the Anglo Vaal laboratories and in the Bedford College laboratories in London. The samples used were those collected at 10 metre intervals along transect 33 and sieved to the -80 and -270 mesh fractions. The analyses in the Anglo Vaal laboratory were made using the bisulphate fusion/colorimetric method, whereas those undertaken at Bedford College used the acid leaching method followed by analysis by atomic absorption spectrophotometry.

The comparison of the results (Fig. 25) showed that whereas the values from the Bedford College laboratories produced regular graphs with normal peak distributions in which the copper values in the -270 mesh fractions were consistently higher than those in the -80 mesh fraction, the values from the Anglo Vaal laboratory were so erratic that in some samples the copper values in the -80 mesh fraction exceeded those in the -270 mesh fraction - a situation suggesting incomplete fusion of the latter fraction with the bisulphate, resulting in poor extraction of the metal. Moreover, whereas the background values in the Bedford College results were low - ± 10 ppm in the -80 mesh fraction and ± 15 ppm in the -270 mesh fraction - those in the Anglo Vaal results were high - ± 50 ppm in the -80 mesh fraction and ± 60 ppm in the -270 mesh fraction. The Bedford College results gave a sharply defined geochemical anomaly in both the -80 and -270 mesh fractions over the mineralized tilloid, whereas the Anglo Vaal results produced erratic peak values at sites which did not accord with the position of the ore body. The erratic nature of the Anglo Vaal results compared with those of Bedford College was further emphasised when they were plotted on scattergrams (Fig. 26), when the relation between the copper levels in the -80 and -270 mesh fractions emerged as random and linear for the respective laboratories.

<u>Fig.25</u>: Comparison of the copper contents of the -80 and -270 mesh fractions of soils collected along transect 33, Sib, and analysed by HNO_3 extraction followed by atomic absorption spectrophotometry in the Bedford College laboratories (graph A) and by bisulphate fusion followed by colorimetry in the Anglo Vaal laboratory (graph B)



A
B
ppm.Cu.
ppm.Cu.
700
600
500
400
300
200
100
0
400
300
200
100
0
N
S
N
S
250
200
100
00
100
200
300
400
metres
metres
Mineralized
tilloid
Mineralized
tilloid
-270 mesh soil samples
-80 mesh soil samples

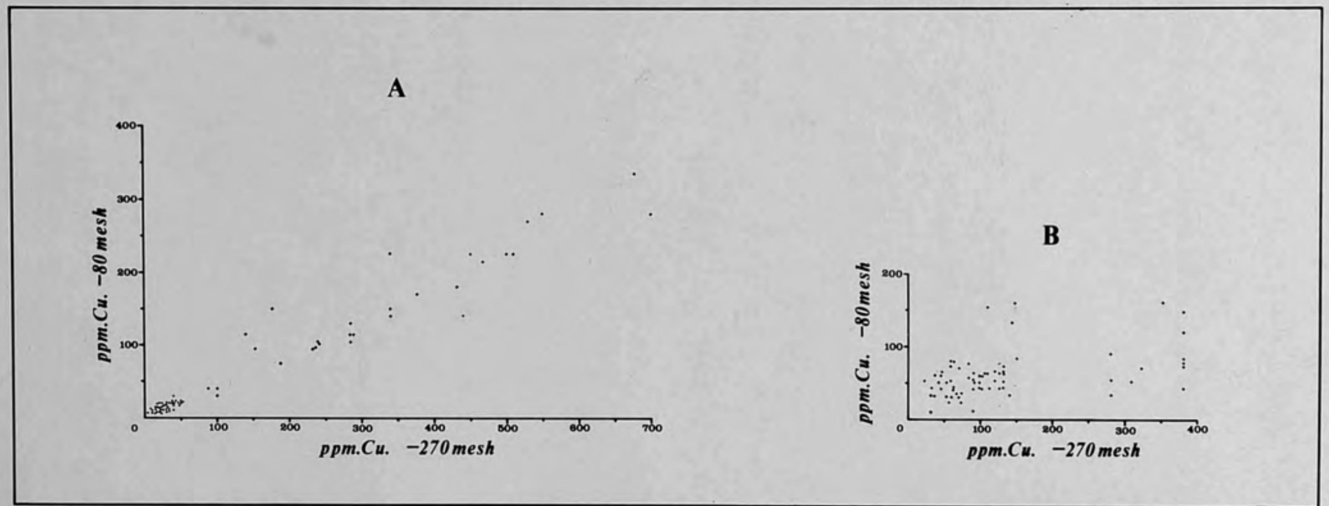


Fig.26: Comparison of the relationship between the copper content in the -80 mesh fraction and that in the -270 mesh fraction of soils collected along transect 33,Sib, and analysed by HNO_3 extraction followed by atomic absorption spectrophotometry in the Bedford College laboratories (diagram A) and by bisulphate fusion followed by colorimetry in the Anglo Vaal laboratory (diagram B)

In view of the results from the comparison of analysis from the two laboratories, most of the soil and plant samples collected during the geochemical/biogeochemical investigations between 1968 and 1970 were analysed at Bedford College.

The geochemical investigations over the Sib ore body

In order to obtain additional information regarding the geochemical anomaly associated with the Sib ore body, a detailed grid was laid down over the area. The lines were spaced at 50 metre intervals and extended 250 metres west of 00 and 300 metres east of 00. The samples were taken at 20 metre intervals at a depth of ± 10 cms and sieved to the -80 and -270 mesh fractions before analysis by the acid leaching method followed by atomic absorption spectrophotometry. The analytical results were plotted as isopleth maps (Figs. 27 and 28).

The maps of values in both the -80 mesh fraction (Fig. 27) and -270 mesh fraction (Fig. 28) show the expected halo of metal values in the soil. Additionally three significant features stand out:-

1. The extension of the soil anomaly to the SSE, on Lines 50 E and 100 E, which coincides with, and could be caused by, a drainage feature running southwards from the zone of mineralization.
2. The low values obtained over the calcrete rise to the south-east of 00 point. These may result from the failure of metal ions to migrate through the calcareous horizons.
3. The possible extension of the geochemical anomaly to the east. Unfortunately another visit could not be made to the field to locate additional lines to determine the limits of the anomaly. However, careful

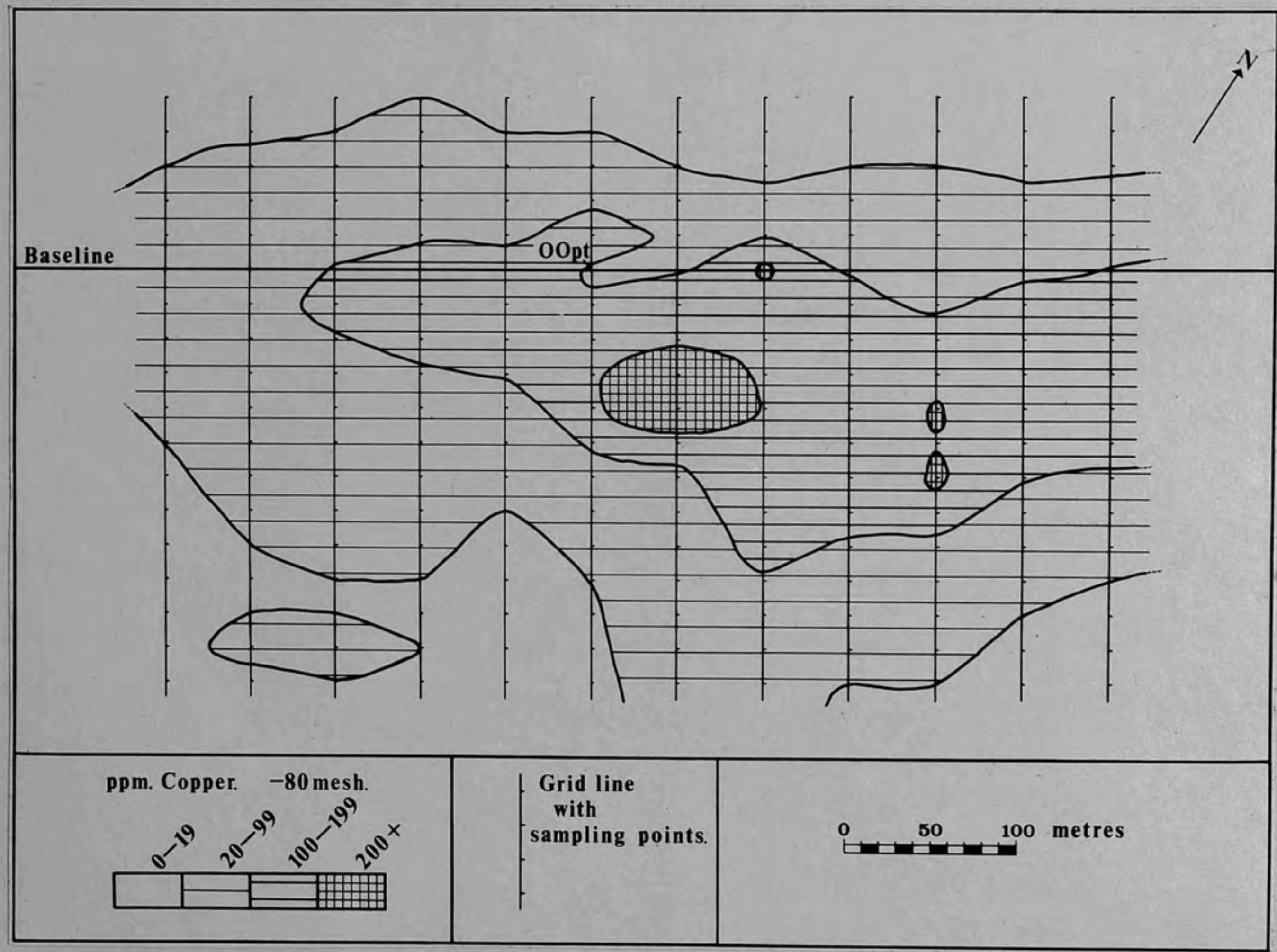


Fig.27: Distribution of copper in the -80 mesh fraction of soil sampled at 10cms over the Sib ore body and analysed by HNO_3 extraction followed by atomic absorption spectrophotometry

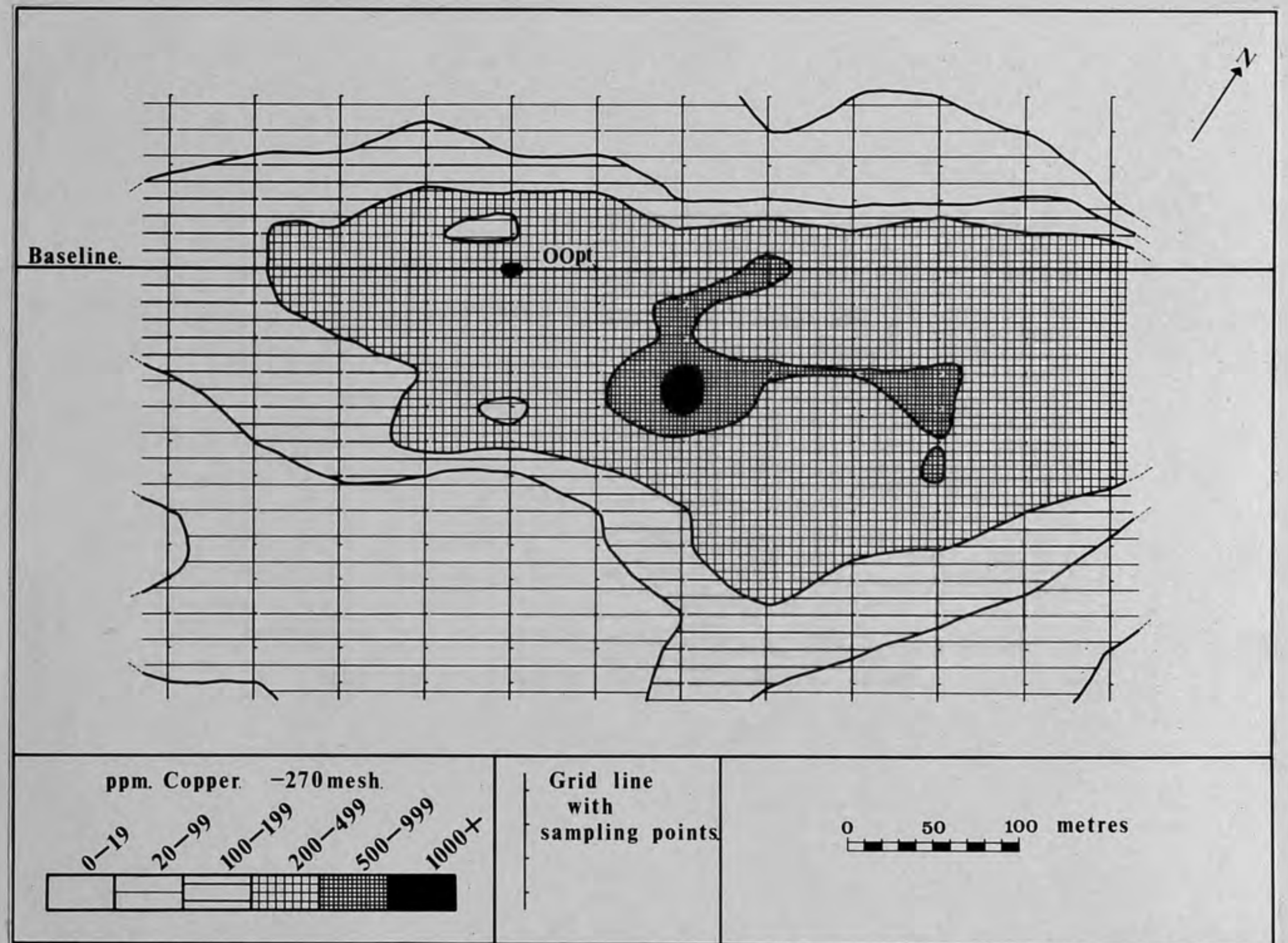


Fig.28: Distribution of copper in the -270 mesh fraction of soil sampled at 10cms over the Sib ore body and analysed by HNO_3 extraction followed by atomic absorption spectrophotometry

study of the -270 mesh fraction contours (Fig. 28) seems to indicate that the anomaly is rapidly closing off and may not exist more than 50 metres east of line 300 E.

From a comparison of the isopleth maps of the -80 and -270 mesh fraction values, it is evident that the position of the ore body and particularly that of the near surface mineralized bedrock is more clearly delineated by the -270 mesh fraction values.

Samples taken at 20 metre intervals on transect 33 were measured for pH and relatively low values (4.9 - 6.8) were recorded (Fig. 29). There is a slight increase in the pH between 100 S and 280 S which corresponds with an area of unconsolidated calcareous material. The pH of 6.8 recorded at 20 S corresponds with the drainage feature which may have affected the value.

It may be concluded that metals, liberated from the primary ore body by weathering, may either remain "in situ" or migrate into the adjoining soil for varying distances. This results in the formation of an abnormal concentration of copper in the soils associated with the ore body, which could play a role in causing the relatively low pH values over the ore body.

In the Sib ore body area geochemical techniques proved successful in outlining the mineralized zone because the ore body is near the surface and the overburden of transported material is thin enough to permit upward migration of metals. However, elsewhere on Sib and the adjacent farms, the extent and depth of overburden is considerable and geochemistry may not be the most suitable exploration technique. Regional geochemical sampling was undertaken along a number of carefully located lines, but as this was associated with the biogeochemical investigations it will be dealt with in Chapter 8.

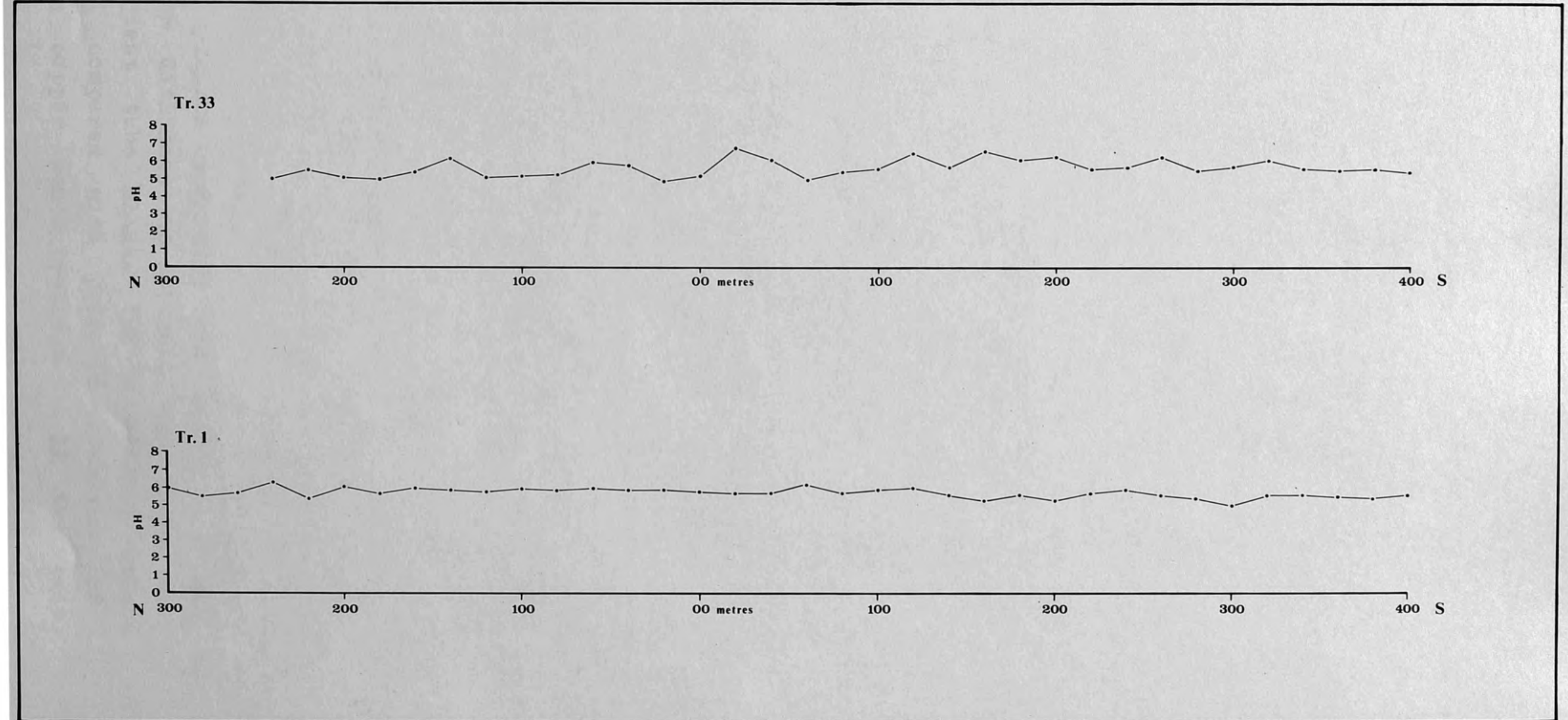


Fig.29: The pH values of bulk soils collected at 10cms along transect 33, Sib, and transect 1, Mertens

APPENDIX

Laboratory methods

a. Acid leaching

0.2 g of the sieved sample was weighed into a test tube and made up to 10 mls with 1 N HNO_3. This solution was placed in a waterbath for 1 hour at 95°C and analysed on an atomic absorption spectrophotometer. Standards of 1, 3, 5, 7.5 and 10 mg/ml were used to give a range of 0 - 1000 ppm.

b. Total copper (After Stanton 1966)

0.1 g of sieved sample was weighed into a test tube and 0.5 g of $KHSO_4$ was added. This was mixed and fused over a flame until a quiescent melt was obtained. The melt was leached with 5 mls of 0.5 N HCI in a waterbath at 100°C for 1 hour. 5 mls of distilled water was added and mixed before the sample was analysed on an atomic absorption spectrophotometer.

c. Cold extractable copper (After Webb and Tooms 1959)

0.2 g of the sieved sample was weighed into a test tube. 5 mls of 10% aqueous ammonium citrate buffer extractant containing 10% hydroxylamine (pH 4.3) was added. 2 mls of 0.001% dithizone in benzene was added and the test tube shaken for 2 minutes before being compared with prepared standards of known copper concentrations. If the test solution colour exceeded that of the top standard, further 2 ml increments of dithizone solution were added until it came into range. A calibration curve was drawn expressing the volume of copper which was calculated by titrating standards containing known amounts of copper. The metal content of the sample was calculated from the volume of dithizone solution and the copper content of the matching standard.

Chapter 7

THE SIB AREA

The biogeochemical investigations

While the biogeographical/geobotanical investigations revealed the relationships between the distribution of vegetation associations and plant communities and environmental parameters, including that of the soils and bedrock, it did not provide the physiological reasons for the relationships. This can be obtained only by biogeochemical analysis of the plant tissues and by experimental studies of plant physiology (see Appendix to the thesis for the role of copper in plant physiology). Biogeochemical investigations were undertaken and form the subject of this chapter. They were aimed at the detection of copper mineralization in concealed bedrock in areas where the depth of overburden precluded geobotanical and geochemical anomalies.

A first necessity for the biogeochemical investigation was the selection of suitable species for sampling purposes. This selection must be governed by consideration of the distribution of individual species, their rooting habits and their physiological behaviour with regard to metal uptake.

Investigation of the copper content of selected tree and shrub species

a. Biogeochemical investigation of *Helichrysum leptolepis*

Four samples of the indicator plant *Helichrysum*

<u>leptolepis</u>, one each from transects 6 and 33 and two from transect 8, were collected in the cutout areas over the Sib ore body for biogeochemical analysis. The flowers, leaves and stems of each sample were separated and analysed individually using the dry ashing method followed by atomic absorption spectrophotometry (as outlined in the Appendix to Chapter 7). The analyses show that the copper content (expressed as ppm dry weight of sample) of the aerial parts of the plant is high, the leaves having an average copper content of 70 ppm and the stems an average content of 33 ppm (Table 8). The flowers and leaves, as anticipated, contained more copper than the stems in all four samples.

<u>Table 8</u>: Analysis of samples of <u>Helichrysum leptolepis</u> collected from sites over the copper bearing tilloid constituting the Sib ore body. (Unmilled, dry ashed material analysed by atomic absorption spectrophotometry at Bedford College). F = Flowers, L = Leaves, S = Stems

Sample no.	Collection site	Part of plant	% ash	ppm Cu.			
				In plant sample		In soil	
				per ash wt.	per dry wt.	-80 mesh	-270 mesh
4303	Tr 8 10 S	F	27.27	420	115	100-200	200-500
		L	16.06	390	63	"	"
		S	6.69	620	41	"	"
4304	Tr 6 20S/40W	F	23.23	400	93	100-200	200-500
		L	14.97	520	78	"	"
		S	7.07	420	30	"	"
4305	Tr 33 60S/20E	F	14.35	355	51	100-200	500-1000
		L	10.21	500	51	"	"
		S	5.24	340	18	"	"
4306	Tr 8 70S/30E	F	14.44	390	56	>200	>1000
		L	11.20	840	94	"	"
		S	6.25	665	42	"	"

As there are no specimens of Helichrysum leptolepis growing in areas of background levels of copper in the soil, information on its copper uptake is confined to areas where anomalous quantities of copper are found in the soil. Here it is apparent that the species takes up and retains large quantities of copper in the aerial parts. The plant appears to require a minimum of 100 ppm copper in the -80 mesh fraction and 200 ppm copper in the -270 mesh fraction of the soil in order to grow. The plant flourishes where the copper levels of soil approach 200 ppm and 1000 ppm in the -80 and -270 mesh fractions respectively. Its behaviour at higher copper concentrations in the rooting medium is unknown and can only be established through further experimental physiological and biogeochemical research.

b. Biogeochemical investigation of selected trees and shrubs

As a first step, plant samples were collected along transects 6, 7, 8 and 33 across the Sib ore body (Fig. 11). Transect 33 was sited across that part of the ore body which exhibited the greatest cover of vegetation, and it was thus hoped to record and sample a representative selection of the plant assemblage. All the tree and shrub species were sampled along the line as close to 10 metre intervals as possible, but in most cases wherever occurring. The leaves of the plants were collected from representative heights from all sides of the plant, and were packed directly into a sample bag in the field ready to be sent for analysis. The twigs, of which a representative sample was collected, were cut into 5 millimetre pieces and also packed into a sample bag in the field. All those species of trees and shrubs which were present were sampled on transects 6, 7 and 8, but because fewer species occurred than on transect 33 fewer samples could be collected. Therefore attention will be focussed on transect 33 for interpretation of the results and comparisons made with transects 6, 7 and 8. All the plant samples on transects 6, 7, 8 and 33 were analysed by the dry ashing method followed by atomic absorption spectrophotometry. Soil samples were collected at a depth of 10 cms at 10 or 20 metre intervals on the four transects, and analysed by the acid leaching method followed by atomic absorption spectrophotometry. The analytical results of the six most common species sampled are tabulated in the Appendix to the thesis.

Due to the varying nature and depth, over short distances, of the mineralized tilloid constituting the Sib ore body and the scattered collection sites of the samples, it is not possible to make an accurate statistical comparison of the values obtained by the various species. It is therefore necessary to discuss each species individually and then to make a general comparison between the species sampled on all four transects.

Study of the copper content in the tissues of the six tree and shrub species which were sampled (Figs. 30 - 33), reveals that <u>Phaeoptilum spinosum</u> takes up from the soil and retains in its leaves and twigs more copper than the other species. This is evident whether the copper content is expressed relative to the ash weight or to the dry weight of the sample. When expressed on a dry weight basis the leaves give higher copper values than the twigs, but when expressed on an ash weight basis the opposite is true. This is because the twigs yield a much lower percentage ash on burning. For a given initial weight of sample the leaves contain more copper than the twigs.

From the analysis of all samples collected

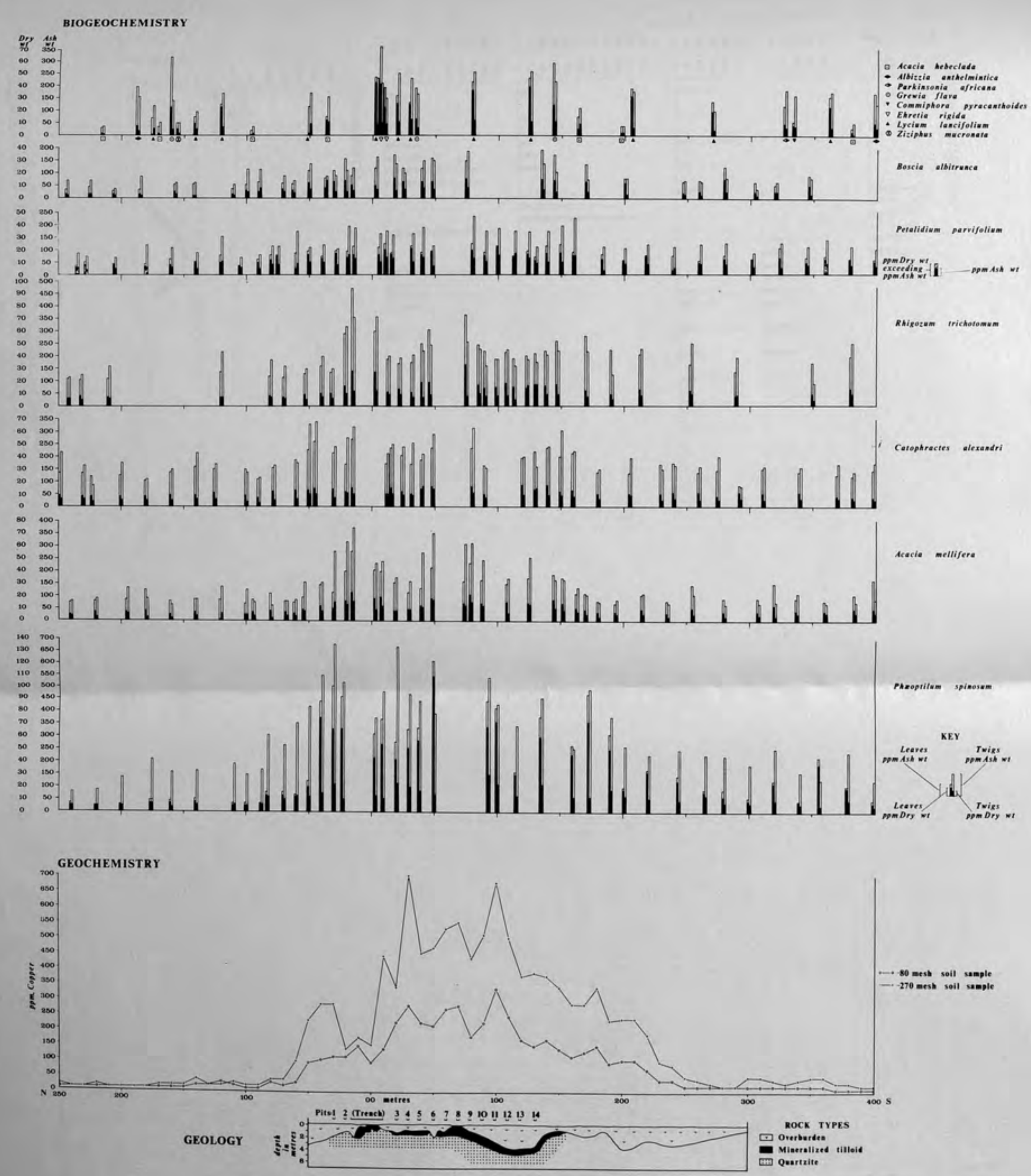


Fig. 30: Transect 33 across the Sib ore body area showing the copper content of the listed species together with the geochemistry, relief and geology

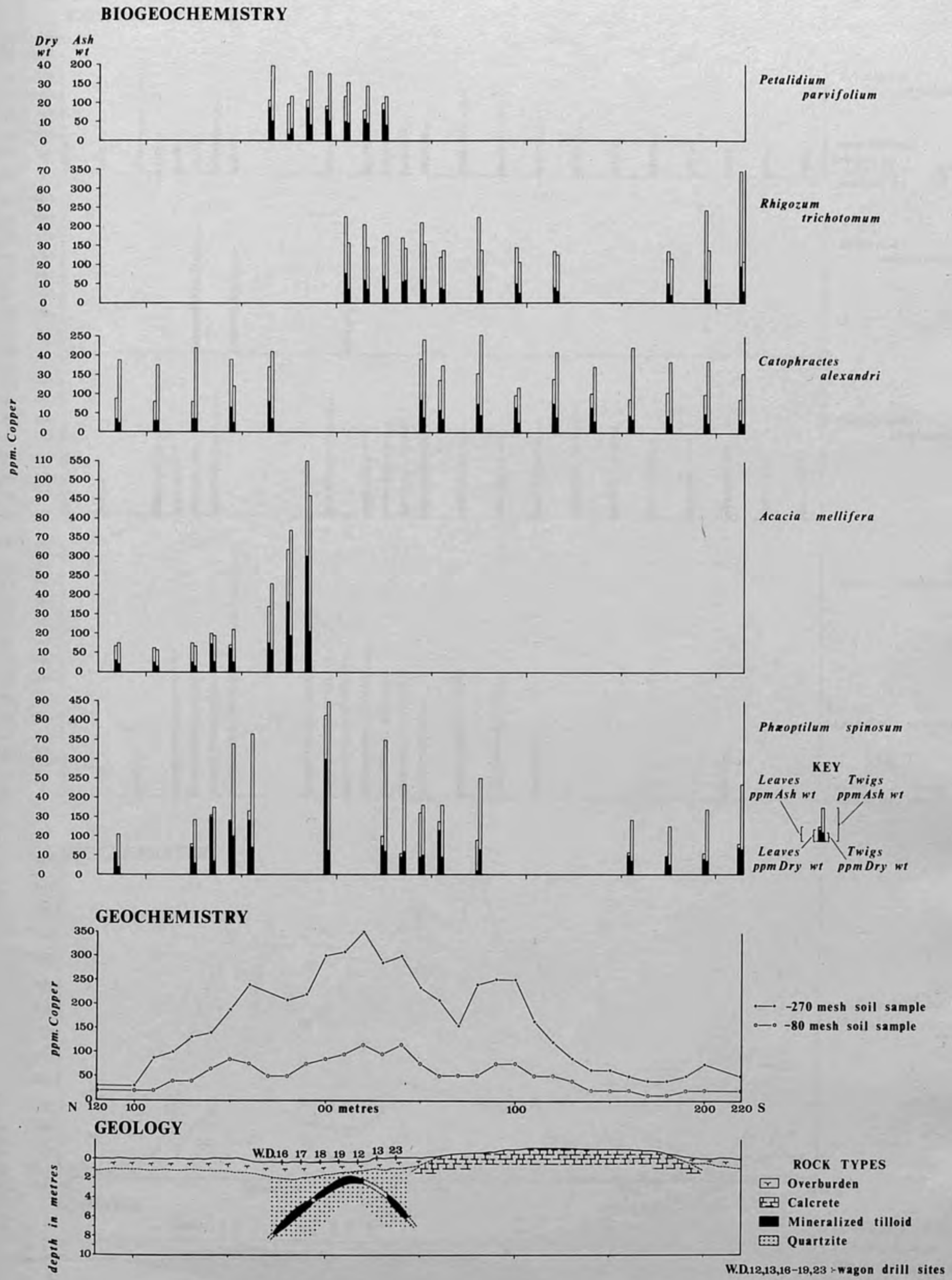


Fig. 31: Transect 7 across the Sib ore body area showing the copper content of the listed species together with the geochemistry, relief and geology

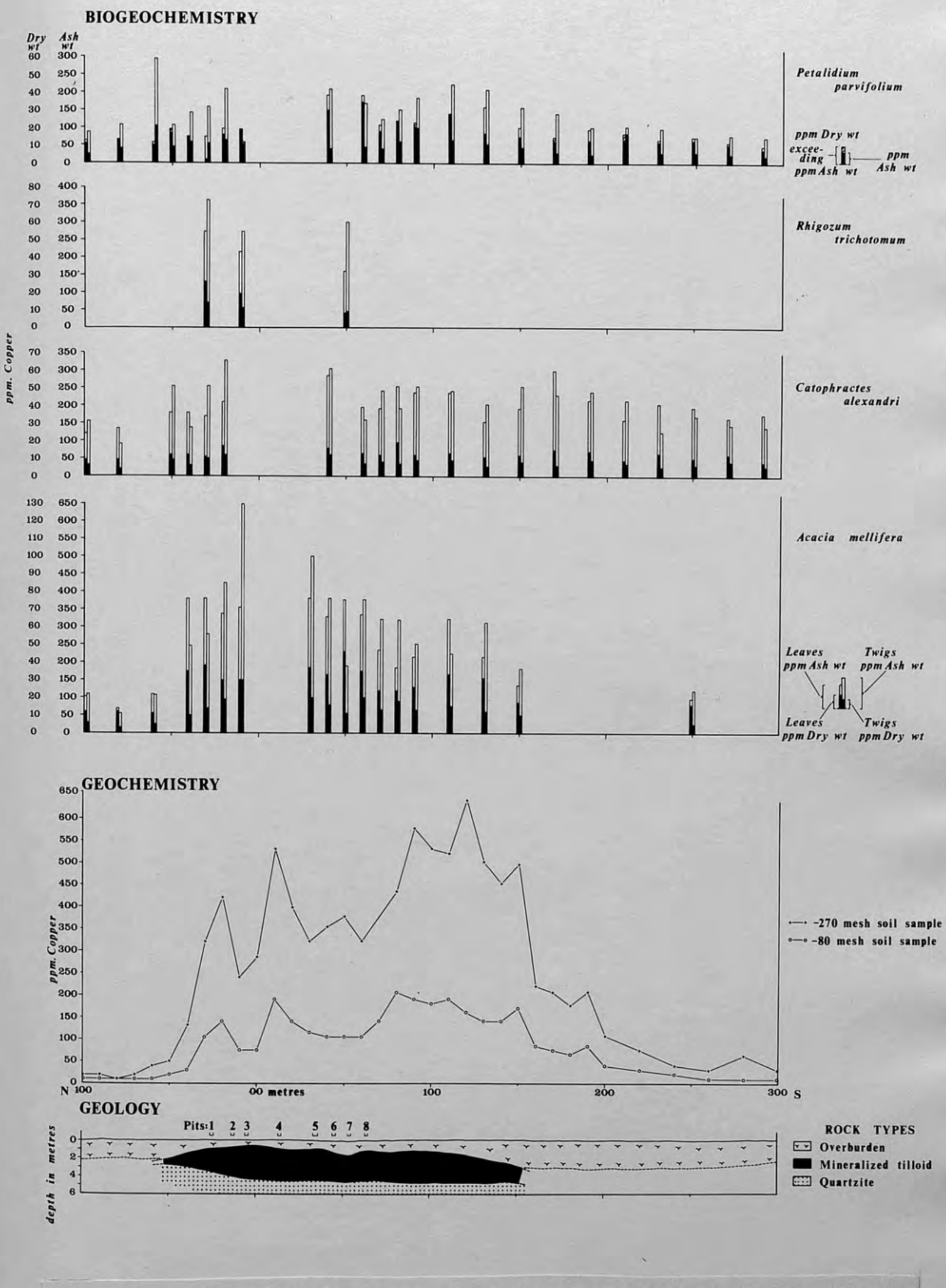


Fig. 32: Transect 6 across the Sib ore body area showing the copper content of the listed species together with the geochemistry, relief and geology

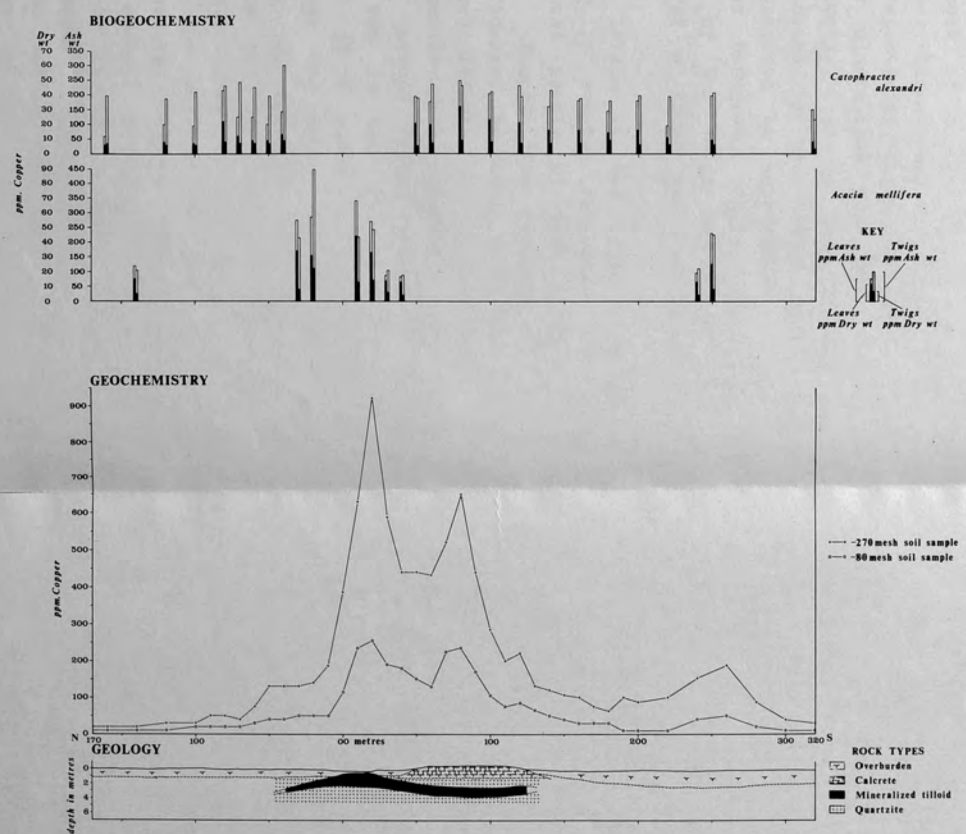


Fig.33: Transect 8 across the Sib ore body area showing the copper content of the listed species together with the geochemistry, relief and geology

along transect 33 (Fig. 30), it is apparent that whereas in background areas the copper content of the leaves and twigs is similar, over the mineralized zone it is markedly higher in the leaves. It is also evident that expressed on a dry weight basis, the leaves and twigs have background values of ± 6 ppm and ± 5 ppm respectively while the peak values obtained over the mineralized zone are 109 ppm and 30 ppm respectively. It is thus evident that the peak value obtained by the leaves over the mineralized zone represents an approximate increase of 18 times the background value, while the peak value obtained by the twigs represents an approximate increase of 6 times the background value.

The highest copper levels in the plant material do not necessarily occur in samples collected from the sites with the highest levels of this metal in the soil (Fig. 30). Whereas the geochemical values appear to be influenced by soil type and drainage, the plant values reflect the mineralization in bedrock. This is particularly noticeable at site 50 S. Similarly, whereas copper values in the soil are low (175 ppm in the -270 mesh fraction) between 00 and 30 N where the drainage feature cuts the transect, the plant analyses show high values, for example 520 ppm per ash weight in the twigs and 66 ppm per dry weight in the leaves. This can be attributed to the fact that the plants are sampling the soil at depths below that at which the geochemical samples were collected.

The biogeochemical anomaly produced by analysis of Phaeoptilum spinosum samples is slightly wider than the geochemical anomaly. This feature is marked both to the north and to the south of the areas where the ore body is near surface, and is related to the fact that the plants are reflecting the copper content in bedrock below the cover of alluvium whereas the soil samples are giving the values in the alluvium (Fig. 30).

The analysis of samples of Phaeoptilum spinosum on transect 7 (Fig. 31) shows that when compared to transect 33, a lower peak value is obtained in both the leaves and twigs over the mineralized zone (dry weight basis). This probably results from the greater depth of overburden and associated lower metal uptake by the plant. In this connection it is notable that the peak values of copper in the leaves are high (60 ppm per dry weight) where the overburden is relatively shallow.

There were too few Phaeoptilum spinosum shrubs on transects 6 and 8 to warrant sampling.

The analysis of the Phaeoptilum spinosum samples thus shows that while the species is absent from the highly toxic areas where the copper bearing tilloid sub-outcrops, elsewhere it takes up relatively large amounts of copper which furthermore are closely related to the levels of the metal at its rooting depth. The species therefore offers promise in biogeochemical investigations for the detection of copper mineralization in areas where bedrock is concealed by overburden.

The analysis of the tissues of Acacia mellifera show that this species takes up less copper than Phaeoptilum spinosum (Figs. 30 - 33). From the analysis of samples along transect 33 (Fig. 30) it is evident that over both background and anomalous zones the copper content of the leaves remains similar to that of the twigs. Expressed on a dry weight basis the leaves and twigs have background values of ± 6 ppm and ± 4 ppm respectively, while the peak values obtained over the mineralized zone are 23 ppm and 17 ppm respectively. Calculations show that the peak values obtained by both the leaves and twigs over the mineralized zone represent an approximate increase of 4 times the background values.

As in the case of Phaeoptilum spinosum, the highest copper values in the plant material do not occur in samples collected from the sites with peak geochemical values. Thus the plant samples collected at 15 N on transect 33 contained the highest amounts of copper in its leaves and twigs although the metal content of the soil sampled at this point was only 177 ppm in the -270 mesh fraction. Clearly the soil was sampled in a leached horizon whereas the plant effectively sampled weathered material or mineralized tilloid. Similarly, at 80 S on transect 33 and 10 N on transect 6 (Fig. 32), the plant samples contained relatively large amounts of copper compared with those in the soils.

The biogeochemical anomaly produced by the Acacia mellifera samples reflects the zone of mineralization more accurately than the geochemical anomaly, a feature which is particularly clear on the southern edge of the ore body where the geochemical values produced a broad anomaly reflecting drainage, whereas the biogeochemical values sharply define the edge of the ore body.

While the peak values obtained on transects 6 (Fig. 32) and 8 (Fig. 33) are approximately 4 times that of background values for both the leaves and twigs (dry weight basis) the levels of copper in these plant samples are generally higher than those on transect 33 indicating an increased uptake of copper by the species in those areas.

Although Acacia mellifera takes up large amounts of copper on some sites it is a less suitable sampling species than Phaeoptilum spinosum, partly because of its lateral root system which will be dealt with more fully later. Nevertheless the fact that the average copper content of the leaves and twigs of samples collected from anomalous sites is four times that of samples from background areas suggests that in some areas the species may provide useful biogeochemical information to supplement that from other species.

The analyses of samples of Boscia albitrunca collected on transect 33 show that this widely distributed tree species takes up and retains appreciable quantities of copper in its tissues where it is growing in sites over copper bearing bedrock (Fig. 30). Samples from these sites show that the copper is held mainly in the leaves. Hence whereas the amount of copper in the leaves and twigs of samples collected in background areas is similar, the amount in the leaves is appreciably and consistently higher than that in the twigs of samples collected from specimens growing over the copper bearing tilloid. When expressed on a dry weight basis, the leaves and twigs have background values of ± 3 ppm and ± 2 ppm respectively, while the peak values obtained over the mineralized zone are 16 ppm and 8 ppm respectively. Thus the peak value obtained by the leaves over the mineralized zone represents an approximate increase of 5 times the background value, while the peak value obtained by the twigs represents an approximate increase of 4 times the background value.

This indicates that the leaves of Boscia albitrunca may be used successfully in biogeochemical prospecting for copper mineralization but that the twigs are unlikely to yield significant results.

The analysis of samples of Rhigozum trichotomum reveal a similar pattern of copper uptake to that of Boscia albitrunca. Over mineralized bedrock Rhigozum trichotomum also takes up and retains appreciable quantities of copper in its leaves. On transect 33 (Fig. 30) the background values of the leaves and twigs, when expressed on a dry weight basis, are ± 7 ppm and ± 6 ppm respectively, whereas the peak values obtained over the mineralized tilloid are 33 and 17 respectively. This represents an approximate increase of 5 times the background value for the leaves and 3 times the background value for the twigs over the mineralized zone.

Study of Fig. 30 shows that where the copper bearing tilloid is relatively near to surface analyses of the leaves of Rhigozum trichotomum provide a better indication of the presence of mineralization than the analyses of the soils sampled at 10 cms. Here attention is directed to the analyses of samples collected at 20 N, 10 N, 00 point and 80 S. On the other hand the analysis of plant tissues of the species fails to detect the presence of mineralized bedrock where there is a thick overburden. Here the species is clearly less effective than Phaeoptilum spinosum. These differences are most probably related to a difference in rooting habit which will be considered later.

While the samples of Rhigozum trichotomum collected over the ore body on transects 6 and 7 appear to indicate an increased uptake of copper, it is difficult to draw any definite conclusions as too few samples were collected on these lines to establish background levels.

As might have been anticipated from its restriction to calcareous habitats, Catophractes alexandri exhibits a pattern of copper uptake which contrasts with that of the species considered so far. From a study of Fig. 30 it is evident that the leaves usually contain more copper than the twigs but the levels of uptake are generally low. Nevertheless there is a contrast in the copper content of samples of this species collected respectively from the mineralized zone and from background areas. Expressed on a dry weight basis the background values of the leaves and the twigs are ± 9 ppm and ± 5 ppm respectively, while the peak values obtained over the mineralized zone are

17 ppm and 16 ppm respectively. Calculations show that over the mineralized zone the leaves show an approximate increase of 2 times the background value while the twigs show an approximate increase of 3 times the background value.

In the case of this species the availability of calcium in the calcareous habitat, which it favours, counters or depresses the uptake of copper but does not restrict it to a uniform level. This is particularly evident from the analysis of samples collected along transect 8 (Fig. 33), where the copper content of the leaves of Catophractes alexandri sampled between 50 S and 150 S clearly reflects the presence of the mineralized tilloid below the capping of calcrete and quartzite as effectively, and perhaps more accurately, than that of the soils sampled at 10 cms in the same area. Provided that low ratios of anomalous to background copper values are to be expected from analysis of Catophractes alexandri samples, the species may prove useful in biogeochemical prospecting for copper particularly in calcareous environments and when sampled along with other species.

Owing to difficulties experienced during the ashing of the samples, which may have caused erratic analytical results, caution is required in assessing the value of Petalidium parvifolium for biogeochemical investigations. Nevertheless it is clear from the analysis of samples collected along transects 33 (Fig. 30) and 6 (Fig. 32) that the tissues, notably the leaves, of this species contain larger quantities of copper when growing over mineralized ground than when growing in background areas.

The trees Albizzia anthelmintica, Parkinsonia africana and Ziziphus mucronata, as well as the shrubs Acacia hebeclada, Grewia flava, Commiphora pyracanthoides, Ehretia rigida and Lycium lancifolium, growing along transect 33, were also sampled and analysed (Fig. 30). Few of these species, however, were present either on or near the transect line and consequently few conclusions can be made from the analytical results. Those species which occurred over the mineralized zone, i.e. Lycium lancifolium, Ehretia rigida and possibly Grewia flava, contained relatively high concentrations of copper in their tissues, notably the leaves of Ehretia rigida and Lycium lancifolium which contained large quantities of copper compared with those of speciemens growing in background areas. In the case of Lycium lancifolium the levels were high even where the overburden is considerable, a fact which suggests that this species may be valuable in biogeochemical investigations in areas of thick cover.

In order to establish the range of copper uptake of the six plant species Phaeoptilum spinosum, Acacia mellifera, Boscia albitrunca, Rhigozum trichotomum, Catophractes alexandri and Petalidium parvifolium, to examine uptake relative to the level of copper content in the soil and at the same time to test the consistency of the analytical results, graphs were prepared showing the relationships between copper content per ash weight and copper content per dry weight in the leaves and twigs and also those between plant metal content and soil metal content, again for the leaves and twigs. For these purposes the analyses of the samples collected along transect 33 were used.

The scattergrams (Figs. 34 and 35) showing the copper content expressed per dry weight of sample plotted against the copper content expressed per ash weight of sample for the leaves and twigs of the six species reveal, in all cases, a clear linear relationship which confirms reliability and consistency in the analytical results. In all cases the slope of the graph is steeper for twigs than for leaves,

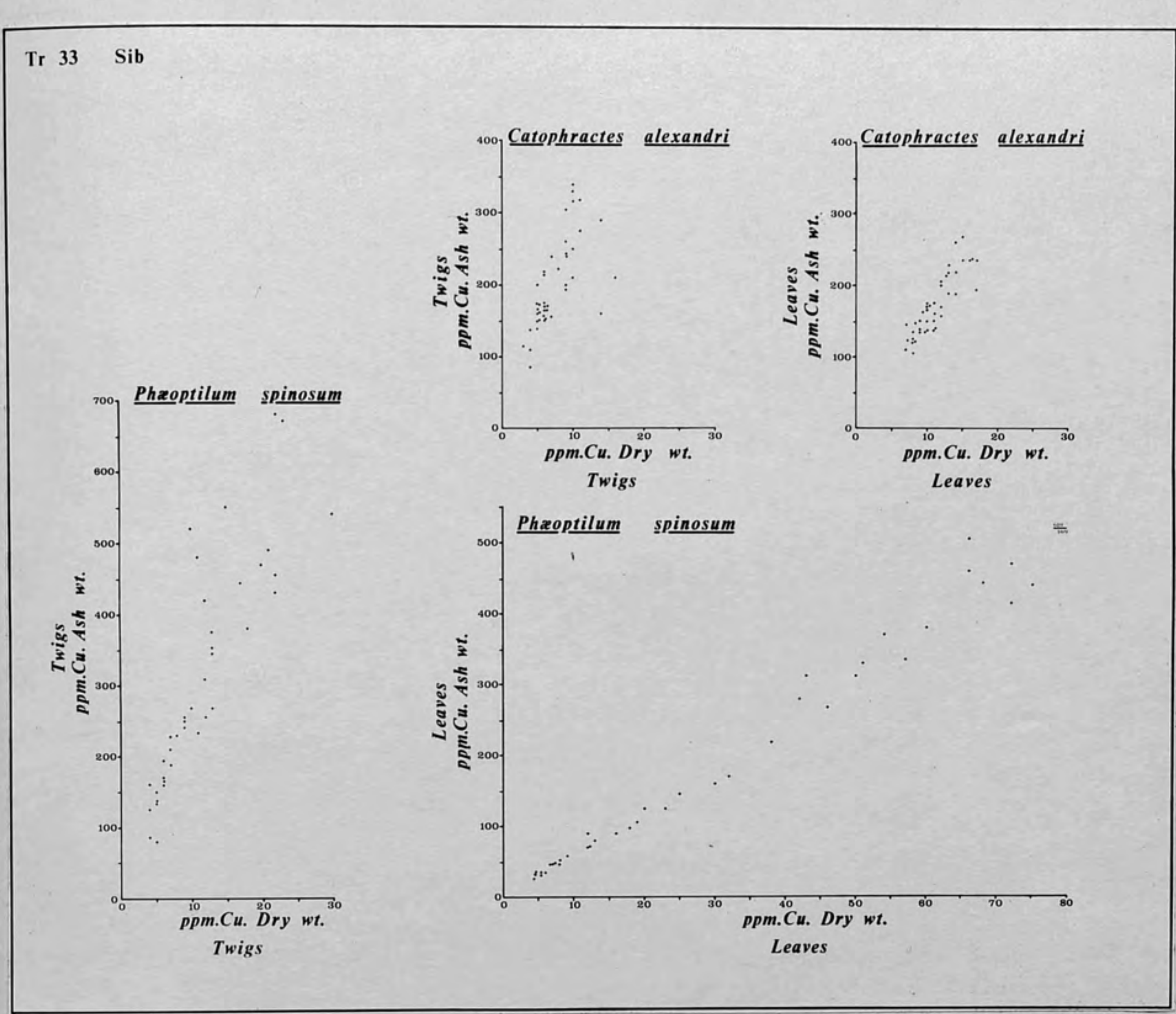


Fig. 34: The relationship between the copper content expressed per dry weight of sample and that expressed per ash weight of sample in the leaves and twigs of Phaeoptilum spinosum and Catophractes alexandri collected along transect 33, Sib

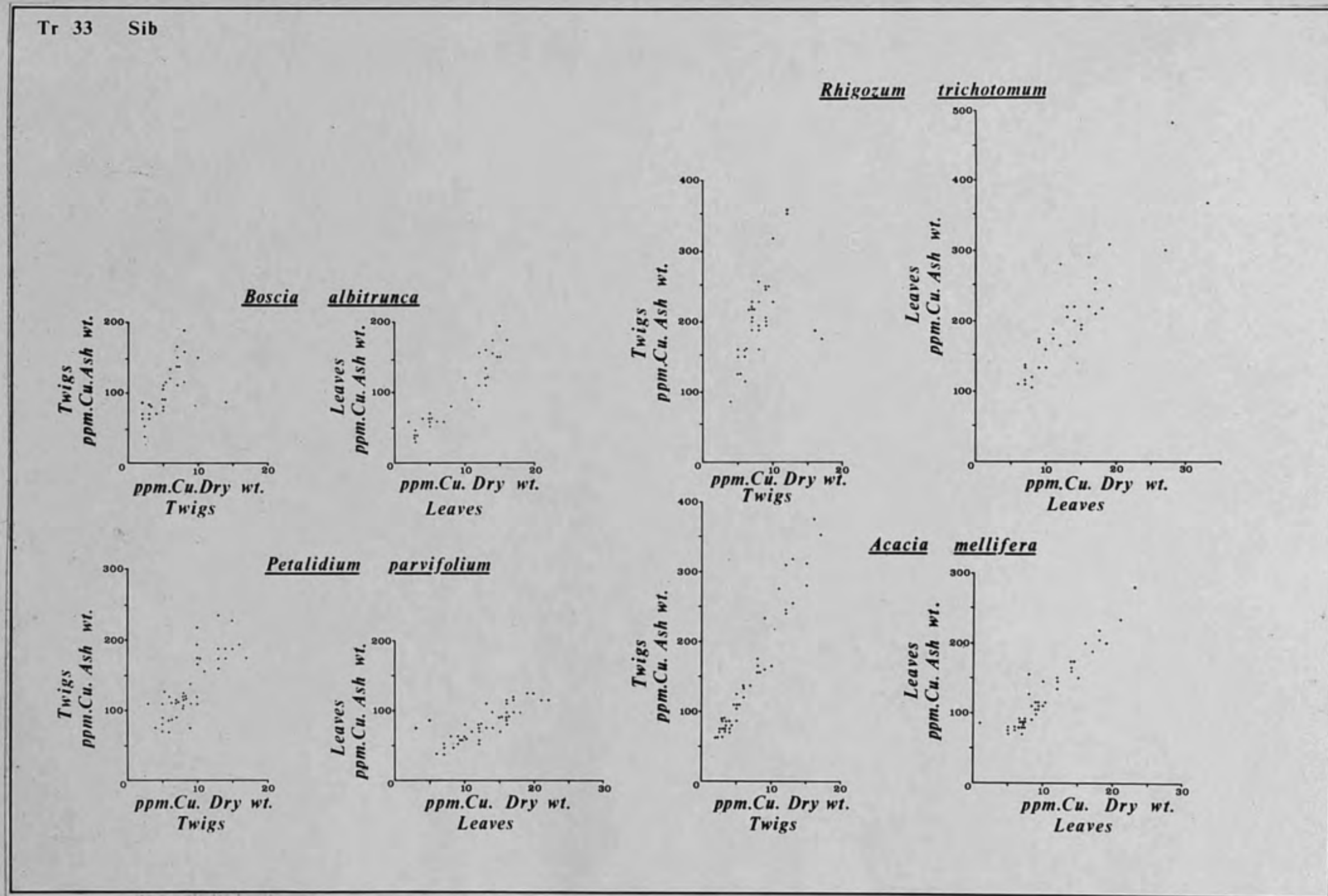


Fig.35: The relationship between the copper content expressed per dry weight of sample and that expressed per ash weight of sample in the leaves and twigs of Boscia albitrunca, Petalidium parvifolium, Rhigozum trichotomum and Acacia mellifera collected along transect 33, Sib

thereby confirming that the copper content expressed per dry weight is higher in the leaves but expressed per ash weight is higher in the twigs. These differences arise because the leaves yield a higher percentage ash than the twigs and confirm the necessity of using values expressed per dry weight of sample in the interpretation of biogeochemical data. The scattergrams also demonstrate the greater range between background levels and anomalous levels of copper shown by the leaves compared with the twigs of most species, and in particular the much greater range in the leaves of Phaeoptilum spinosum compared with that in any other species. They thereby confirm the promise of this species for biogeochemical investigations already indicated from studies of the transects.

The scattergrams showing the copper content in the leaves and twigs of Phaeoptilum spinosum plotted against that in the -80 and -270 mesh fractions of the soils at the sites from which the plant samples were collected (Figs. 36 and 37) show linear relationships. These are more obvious when the plant metal content is expressed on the ash weight basis, but a similar pattern would have emerged had a larger scale been chosen for plotting the plant metal values expressed on a dry weight basis. The important conclusion to be drawn from these graphs is that Phaeoptilum spinosum appears to take up and retain copper in its leaves and twigs according to the amount available in the rooting zone. There is no evidence of restriction of uptake or of accelerated uptake when copper levels in the soil or bedrock exceed a given level. Here, however, it should be borne in mind that copper values in the soils and bedrock are nowhere excessively high, and that this species may behave differently in more toxic environments.

The uptake of trace elements such as copper may be influenced by a number of factors such as

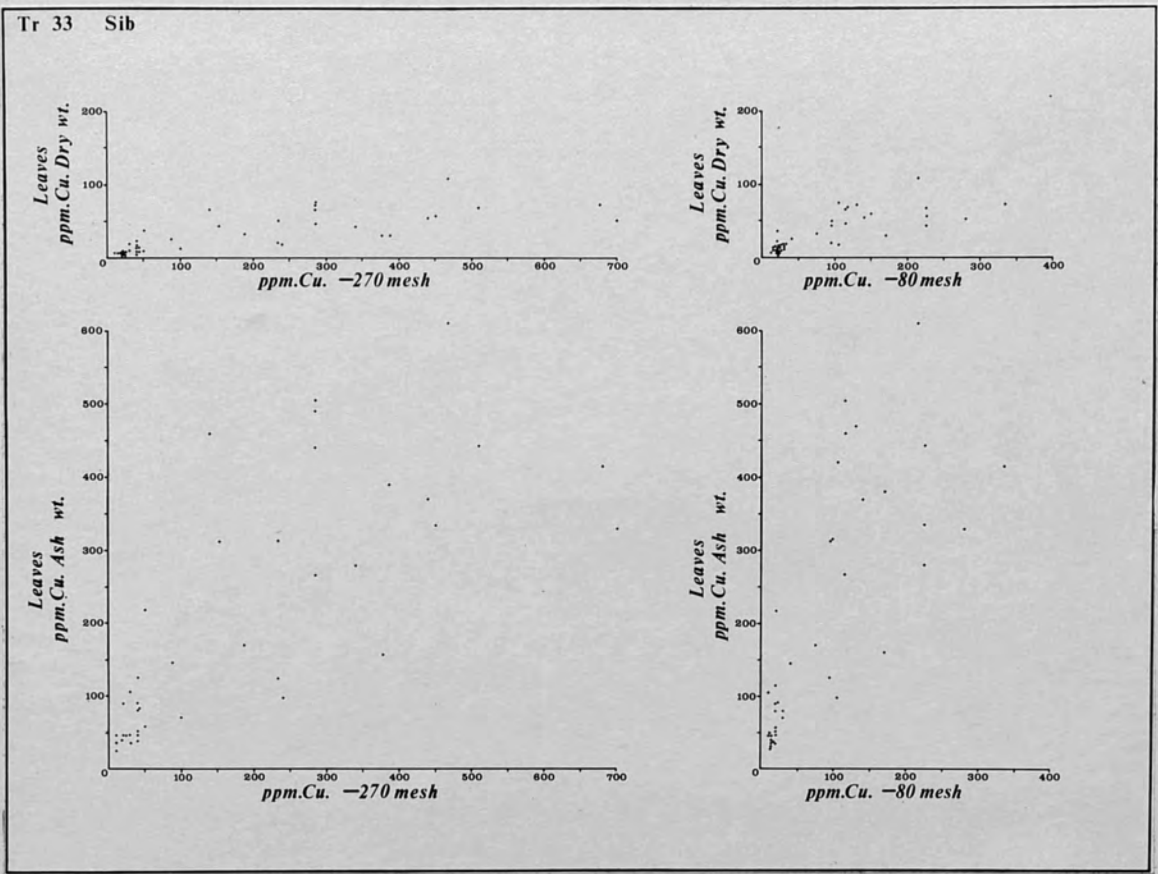


Fig. 36: The relationship between the copper content of the leaves of Phaeoptilum spinosum sampled along transect 33, Sib, and the content of the -80 and -270 mesh fractions of the soil sampled at 10cms at 10 metre intervals

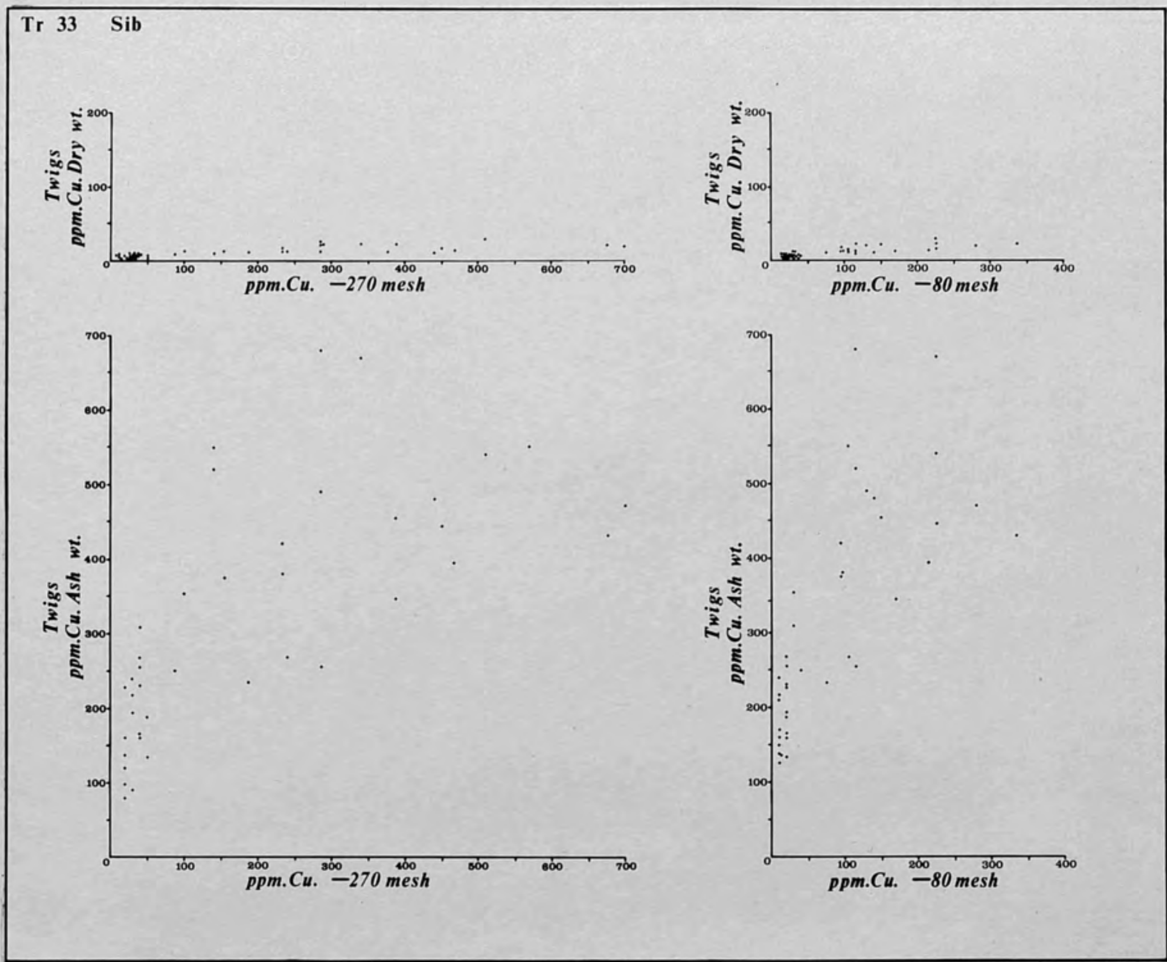


Fig.37: The relationship between the copper content of the twigs of Phaeoptilum spinosum sampled along transect 33, Sib, and the content of the -80 and -270 mesh fractions of the soil sampled at 10cms at 10 metre intervals

the rooting depth and system of the species, the availability of the particular metal ions to the plant and the physiological behaviour of the species to concentrations of available metal ions in the rooting medium.

Iron and Calcium content of plants

Reference has already been made to the reduction of metal uptake in calcareous environments. In order to measure the influence of calcium levels in the soil on copper uptake, the samples of Phaeoptilum spinosum collected along transect 33 were analysed for this element along with the soil samples collected at 50 metre intervals. The analyses revealed that the calcium content of the plant tissues bears some relationship to the amount of calcium present in the soil (Fig. 38). Comparison with the copper levels in the plants and soils at the same sites suggests that relatively high calcium levels may counter or depress uptake of copper. This is evident when the respective values of copper and calcium in plants and soils at sites 50 S and 100 S are compared. The relatively low calcium content of plant tissues and soils at the first site is associated with a high copper content in the plant tissues, whereas at 100 S the higher calcium content of plant tissues and soils is associated with relatively lower copper levels in the plant tissues - notwithstanding the fact that the copper content of the soil reaches a peak value at this site.

The calcium content of the soil influences the soil pH which in turn influences the availability of the copper ions to the plant. The plant/soil relationships are complex and their elucidation requires experimental work on individual species. Here it should be noted that in the Sib environment

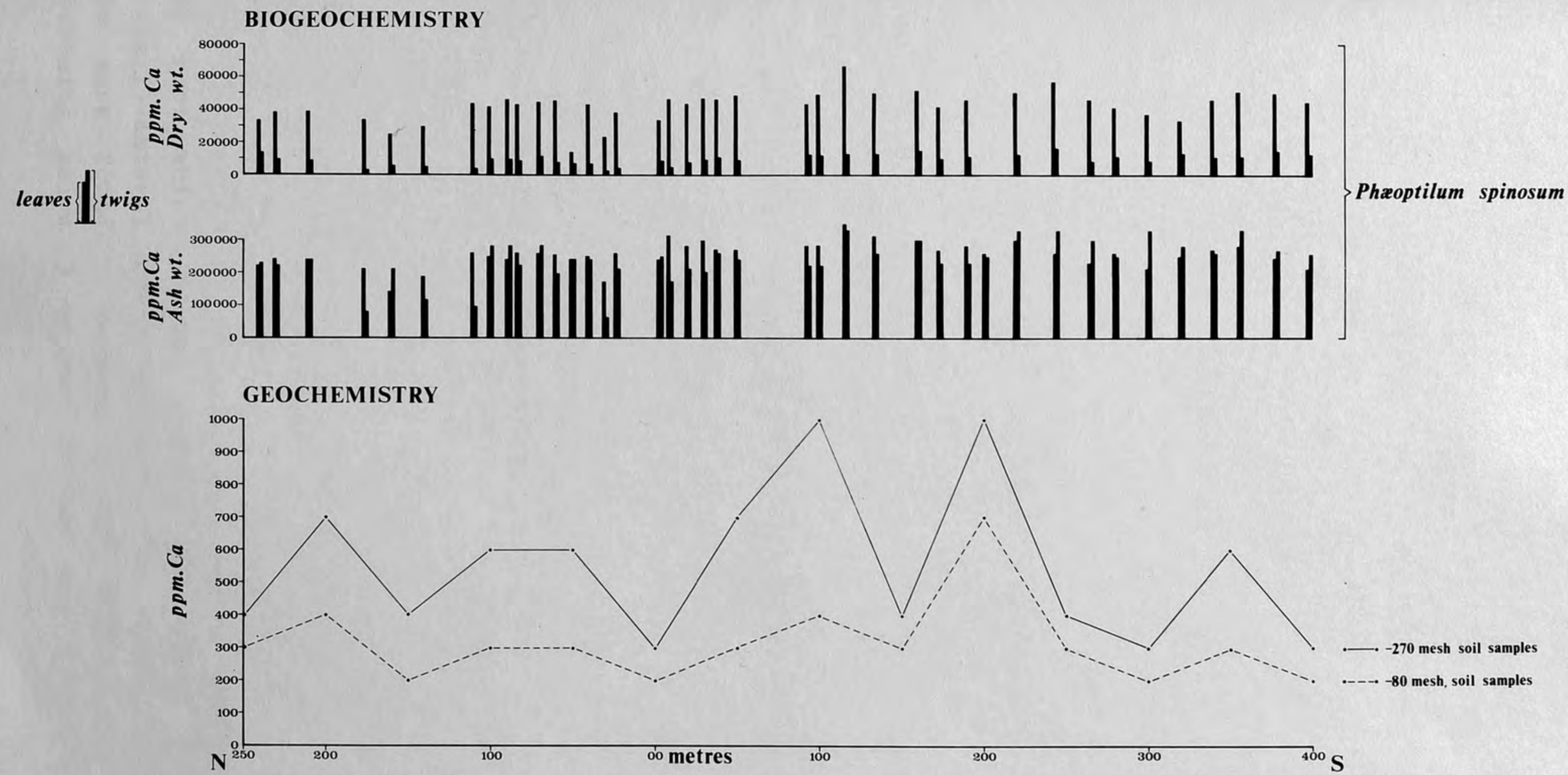


Fig.38: The calcium content of the leaves and twigs of Phaeoptilum spinosum sampled along transect 33, Sib, and that of the -80 and -270 mesh fractions of the soils sampled at 10cms at 50 metre intervals

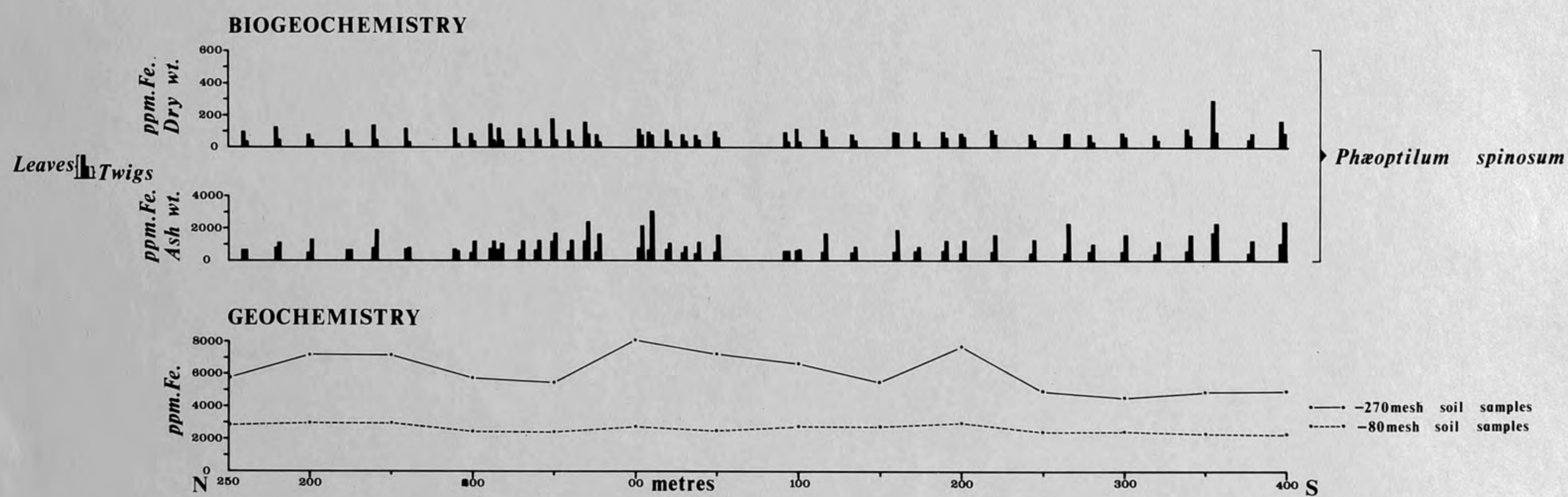
there is evidence to suggest that the calcium levels in the soil do influence the uptake of copper by the plant.

It is well known that high levels of toxic metals in the soils may depress the uptake of the essential element iron by plants and thereby cause chloritic symptoms (Erkama 1950). No evidence of such symptoms were seen in the plants in the Sib prospect area, but the plant and soil samples collected along transect 33 were analysed for iron in order to establish whether any relationship existed between the uptake of iron and copper by plants and the levels of these elements in the soil. The results of the analysis were inconclusive. In fact the iron levels in the soil tended to be higher over the mineralized tilloid and this was reflected by a slightly higher content of iron in the plant tissues of samples from this zone (Fig. 39).

Investigation of the rooting systems of selected tree and shrub species

In order to obtain a better understanding of the relationships between plant metal content and soil metal content and to assess the promise of individual tree and shrub species for biogeochemical investigations in areas of transported overburden, the rooting systems of the six species sampled along transect 33 on the farm Sib were examined.

Phaeoptilum spinosum was found to have a well developed tap root. At surface its diameter measured up to 8 cms but at a depth of 3 metres this had decreased to 3 cms. In the 3 metres of tap root which it was possible to expose only four small lateral roots extending for about 30 to 40 cms were found. Because of the difficulties of trenching below 3 metres it was not possible



<u>Fig.39</u>: The iron content of the leaves and twigs of <u>Phaeoptilum spinosum</u> sampled along transect 33, Sib, and that of the -80 and -270 mesh fractions of the soils sampled at 10cms at 50 metre intervals

to expose the root system below this depth, but the diameter of the tap root at this level suggests that it extends downwards for at least another 3 to 4 metres.

The specimens of Boscia albitrunca growing on the transect were young and their root systems not fully developed. Nevertheless it was possible to ascertain that the species develops a tap root from which a few laterals extend outwards. The tap root was traced to a depth of 2 metres, below which it was not possible to expose it.

By contrast Acacia mellifera exhibited a predominantly lateral root system. The main portion of the system comprised laterals varying from 3 cms to 5 mm in diameter and extending horizontally for distances of up to 6 metres. Additionally vertical roots with a diameter of 4 to 5 cms at surface decreasing to 1 cm at a depth of 3 metres were found. The major lateral roots occupied a zone some 10 to 30 cms below the surface.

Rhigozum trichotomum and Catophractes alexandri also have lateral root systems. In the case of the former they consisted of 2 or 3 main roots which ran laterally for 4 - 6 metres before plunging downwards to an average depth of 2 metres below surface. Numerous root branches were observed. The main roots had an average diameter of 1 to 2 cms. In the latter the roots had an average diameter of 2 cms while many small roots branched off the main roots. The roots extended 8 to 10 metres from the aerial portion of the plant and averaged a depth of 10 - 30 cms below the surface.

The small shrub Petalidium parvifolium had a shallow, highly branching root system. The roots were a few millimetres in diameter and plunged in all directions to depths averaging 15 cms below the surface. The distance from the plant covered by the roots varied from 15 to 25 cms.

The differences in the nature of the root systems of the six species may partly explain the difference in the copper contents of their tissues from the same or nearby sites evident from studies of Figs. 30 to 33. Species with deep tap roots may penetrate the zone of weathered bedrock where ground water may be available and where, in the case of mineralized horizons, metals are readily absorbed. The well developed tap root system of Phaeoptilum spinosum may well explain the relatively high copper content of the tissues of samples collected over mineralized tilloid and also the marked contrast between background and peak anomalous values obtained by this species. By comparison the predominantly lateral root systems of Acacia mellifera, Rhigozum trichotomum and Catophractes alexandri may account for their relatively lower copper contents and less marked contrast between background and peak anomalous values. The shallow, poorly developed root system of Petalidium parvifolium doubtless explains its low uptake of copper and poor contrast between background and peak anomalous values.

Although there are several factors affecting the absorption and uptake of copper from the soil and the degree of accumulation by different species, it appears that the type of root system and the depth to which the roots penetrate are the important factors. Drilling in the Sib area has disclosed that the roots of Acacia giraffae trees extend to depths exceeding 30 metres. This species would therefore appear to be promising for biogeochemical work but unfortunately it does not occur in the immediate vicinity of the Sib ore body and is infrequent in the study area.

The selection of species suitable for biogeochemical investigations

From the work described above it is apparent that there is a relationship between the metal content of the plants and that of the supporting soils. This relationship is most obvious over the mineralized bedrock where the plants take up large amounts of copper, and although the relationship is a sympathetic one it is not direct and the metal content of the plants never reaches that of the soil.

The metal content of plants is an indication of the amount of readily exchangeable, and therefore available, metals in the soil although there are several complicating factors which influence the uptake of metals by plants. These factors are as follows:-

1. the inherited properties of the species;
2. the rooting depth of the species;
3. the part of the plant sampled;
4. the season selected for sampling;
5. the soil type;
6. the availability of metals in the soil;
7. the presence of fragments of metal oxides in the soil;
8. the pH of the soil in the rooting zone;
9. the thickness of overburden and bedrock;
10. the mobility of metals in the zone of weathering;
11. relief and drainage.

Considering the effects of the interplay of the factors listed above the results obtained from the investigations on transects 6, 7, 8 and 33 are encouraging. Of the six species sampled *Phaeoptilum spinosum* appears the most suitable for biogeochemical work. This conclusion is based on three main factors:-

1. the high ratio between peak copper values and background copper values in the plant tissues over anomalous and background zones;
2. the deep tap root system of the species;
3. the high frequency of occurrence of the species.

The remaining five species all take up appreciable quantities of copper. They may be placed in the following order of suitability for biogeochemical work based on the three criteria listed:-

<u>Acacia mellifera</u>

1. relatively high ratio between peak copper values and background copper values in the plant tissues over anomalous and background zones;
2. predominantly lateral root system;
3. high frequency of occurrence of the species.

<u>Rhigozum trichotomum</u>

1. high ratio between peak copper values and background copper values in the plant tissues over anomalous and background zones;
2. predominantly lateral root system;
3. high frequency of occurrence of the species.

<u>Catophractes alexandri</u>

1. low ratio between peak copper values and background copper values in the plant tissues over anomalous and background zones;

2. lateral root system;
3. fairly high frequency of occurrence of the species.

Petalidium parvifolium

1. low ratio between peak copper values and background copper values in the plant tissues over anomalous and background zones;
2. shallow root system;
3. relatively low frequency of occurrence of the species.

Boscia albitrunca

1. high ratio between peak copper values and background copper values in the plant tissues over anomalous and background zones;
2. tap root system;
3. very low frequency of occurrence of the species.

In the Sib area, biogeochemical sampling offers certain advantages over geochemical sampling. These may be listed as follows:-

a. plants suitable for sampling are widespread and the distances between plants varies between 10 and 20 metres on average;
b. the root systems of the plants sample a greater vertical and horizontal area than geochemical samples;
c. suitable plant species may effectively sample horizons below the transported overburden and at or near the weathering zone;
d. deep rooting plants may sample mineral bearing ground water.

Despite the complex nature of metal absorption by plants the results obtained on Sib are fairly constant. The main disadvantage attached to the use of biogeochemical techniques in the Sib area is the relatively shallow rooting depths of the most frequently occurring species. In fact only one widely distributed species, namely Phaeoptilum spinosum, has a suitable root system.

APPENDIX

Laboratory methods

a. Dry ashing followed by atomic absorption spectrophotometry (Unmilled material)

The following procedure was followed at Bedford College for the analysis of plant samples.

Approximately 6 to 9 g of leaves and 15 to 20 g of twigs from each sample were weighed into seperate 50 ml beakers. The beakers were placed into a muffle furnace at a temperature of 400°C and left for approximately 20 hours. If, after this period, samples were not completely ashed they were returned to the furnace until such time as they were completely ashed. During the ashing process the organic matter is burnt off, leaving the inorganic material. The purpose of the low ashing temperature is to minimize the loss of volatailes. After being allowed to cool 0.2 g of ash was weighed into a test tube to which 10 mls of 1 N HNO_3 was added to effect digestion.

The solution was then analysed on an atomic absorption spectrophotometer. The results gave the ppm ash weight of the sample. To obtain the ppm dry weight the percentage ash was calculated as follows:-

$$\frac{\text{weight of ash}}{\text{weight of sample}} = \%\ \text{ash}$$

The % ash was then multiplied by the ppm ash and the result multiplied by 100 (to correct for 10 ml dilution) to give the ppm per dry weight of sample.

b. "Pipe smoker" ashing method

This method was devised for use in the Anglo Vaal laboratory in Windhoek and used for the analysis of the first plant samples collected on the farm Sib.

The apparatus used for ashing the plant samples was comprised of a small aluminium cylinder - open at the top and covered with gauze at the bottom. The cylinder was set in a holder which consisted of a receptacle with a pipe connected to a vacuum pump. Below the holder and cylinder was a Bunsen burner. The following procedure was followed:-

The aluminium cylinder was weighed and then filled with ± 6 to 10 g of twigs or 1 to 4 g of leaves. The twigs used were cut into 5 millimetre pieces. The contents of the cylinder were then compacted. The flame under the sample was lit and the sample, after giving off smoke for a while, ignited. When the smoking stopped (i.e. all volatiles burnt off) the flame was extinguished and the vacuum pump turned on. The valve was opened slowly to begin with, and then fully when the sample was glowing. When ashing was complete - normally after 15 minutes - the sample was dessicated. The cylinder and ash content were then weighed and the weight of the ash content calculated.

± 0.2 g of the ash was weighed into a test tube and 4 mls 3N HCl added. The test tube was then placed into a waterbath at 70°C for 5 - 10 minutes. The solution was then made up to 10 mls volume. A 2 ml aliquot was taken and to this was added 5 mls of buffer solution (pH 6 - 7). Following this 2 mls of biquinoline were added and the solution shaken for 3 to 5 minutes. The colour of the solution was then compared with a range of standards.

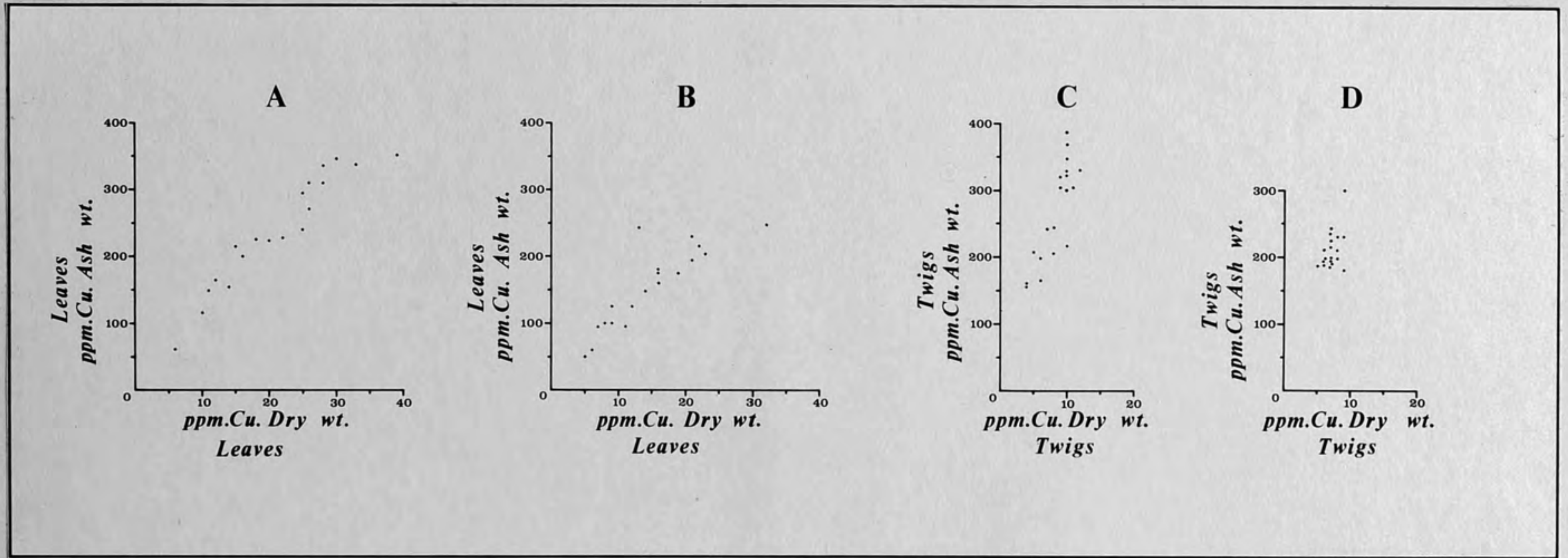
Calculations

$$\frac{\text{mg/ml} \times 500}{\text{ash weight (mg)}} = \text{ppm Cu (per ash weight of plant)}$$

$$\frac{\text{ppm Cu (ash wt.)} \times \text{ash weight (mg)}}{\text{sample weight (mg)}} = \text{ppm Cu (per dry weight of plant)}$$

<u>Comparison of results obtained by muffle furnace ashing followed by atomic absorption spectrophotometry (as outlined in a.) and "pipe smoker" ashing followed by colorimetry (as outlined in b.)</u>

Samples of <u>Catophractes alexandri</u> from transect 8 (over the Sib ore body) were analysed by both methods and the results plotted as scattergrams (Fig. 40). These all show a linear relationship between the ash weight and dry weight copper values. Generally speaking higher values were obtained when



<u>Fig.40</u>: A comparison of the analytical results of samples of the leaves and twigs of <u>Catophractes alexandri</u> collected along transect 8, Sib, expressed per dry weight and per ash weight of sample as obtained by using the "pipe smoker" ashing technique followed by colorimetry (scattergrams A and C) and the muffle furnace ashing technique followed by atomic absorption spectrophotometry (scattergrams B and D)

the "pipe smoker" method was employed. While this method greatly reduced the ashing time, it proved to be impracticable partly because heating of the aluminium "pipe" caused changes in its weight and during the procedure ash was lost while weighing the cylinder. Consequently the results were unreliable and the method was therefore abandoned in favour of an acid leaching method as described below.

c. <u>Acid leaching method</u>

After mid - 1969 this method was used in the Anglo Vaal laboratory in Windhoek for the analysis of all plant samples. The following procedure was employed:-

The sample (leaves or twigs) was pulverized in a small grinding mill, 2.0 g of the powder was weighed into a beaker and 30 mls of 3N HCl was added. The beaker was placed on a hot-plate and brought almost to the boil. The solution was then made up to 100 mls in a volumetric flask with 50% 3N HCl.

This solution was then analysed on an atomic absorption spectrophotometer. The ppm copper was calculated as follows:-

$$\frac{\text{mg/ml} \times 100}{\text{sample weight (mg)}} = \text{ppm Cu (per dry weight of plant)}$$

In order to check the reproducibility of analytical results when the acid leach method was employed, four bulk samples of the leaves and twigs of <u>Phaeoptilum spinosum</u> were collected from two sites, one over mineralized bedrock and the other over barren bedrock along transect 1 on the farm

Mertens in the Kharubeam Hills area (described in Part III of this thesis).

The samples were numbered as given in Table 9.

Table 9: Sites of bulk *Phaeoptilum spinosum* samples collected on transect 1, Mertens, for reproducibility tests on the acid leach method of extraction

Sample	Part of plant	Collection site
A	leaves	00 point - mineralized bedrock
B	twigs	00 point - mineralized bedrock
C	leaves	100 N - barren bedrock
D	twigs	100 N - barren bedrock

They were then coned and quartered and ten sub-samples of each were made up. These sub-samples were given random field numbers - to ensure random analysis - and sent to the Anglo Vaal laboratory for analysis. The results which are given in Table 10 indicated a highly satisfactory level of reproducibility.

Table 10: The copper contents (expressed in ppm dry weight) of ten sub-samples (split samples) of the leaves and twigs of four samples of *Phaeoptilum spinosum* collected along transect 1, Mertens, in the Kharubeam Hills area

Sub-sample	ppm copper per dry weight of sample			
	A	B	C	D
1	73	28	8	8
2	73	28	10	9
3	73	27	8	8
4	73	29	8	8
5	73	28	8	9
6	73	27	9	10
7	72	29	7	8
8	73	28	7	9
9	72	27	8	9
10	71	26	8	8
Mean	72.6	27.7	8.1	8.6

Chapter 8

THE SIB AREA

Biogeographical/geobotanical, biogeochemical and geochemical investigations in exploration for additional copper deposits in the Sib area

As a result of the success of the biogeographical/geobotanical, biogeochemical and geochemical investigations over the Sib ore body and also the establishment of guide-lines for further work, a regional programme was embarked upon in order firstly to locate any probable extensions of the Sib ore body, and secondly to locate further areas of copper mineralization in the Sib area.

a. The search for extensions of the Sib ore body

A series of transects were laid down to cross the inferred eastern and western extensions of the Sib ore body at right angles to the general strike of the rocks. These transects were arbitrarily numbered 1 - 5, 9 and 12 (Fig. 41). Samples of *Phaeoptilum spinosum*, *Acacia mellifera* and *Catophractes alexandri* shrubs were collected at 20 metre intervals where possible, while on transects 1 and 2 additional species were sampled. Soil samples, sieved to the -80 and -270 mesh fractions, were collected at 20 metre intervals on each transect. The plant samples were analysed by the acid leaching method followed by atomic absorption spectrophotometry (as outlined in the Appendix to Chapter 7), while the soil samples were analysed by the acid leaching

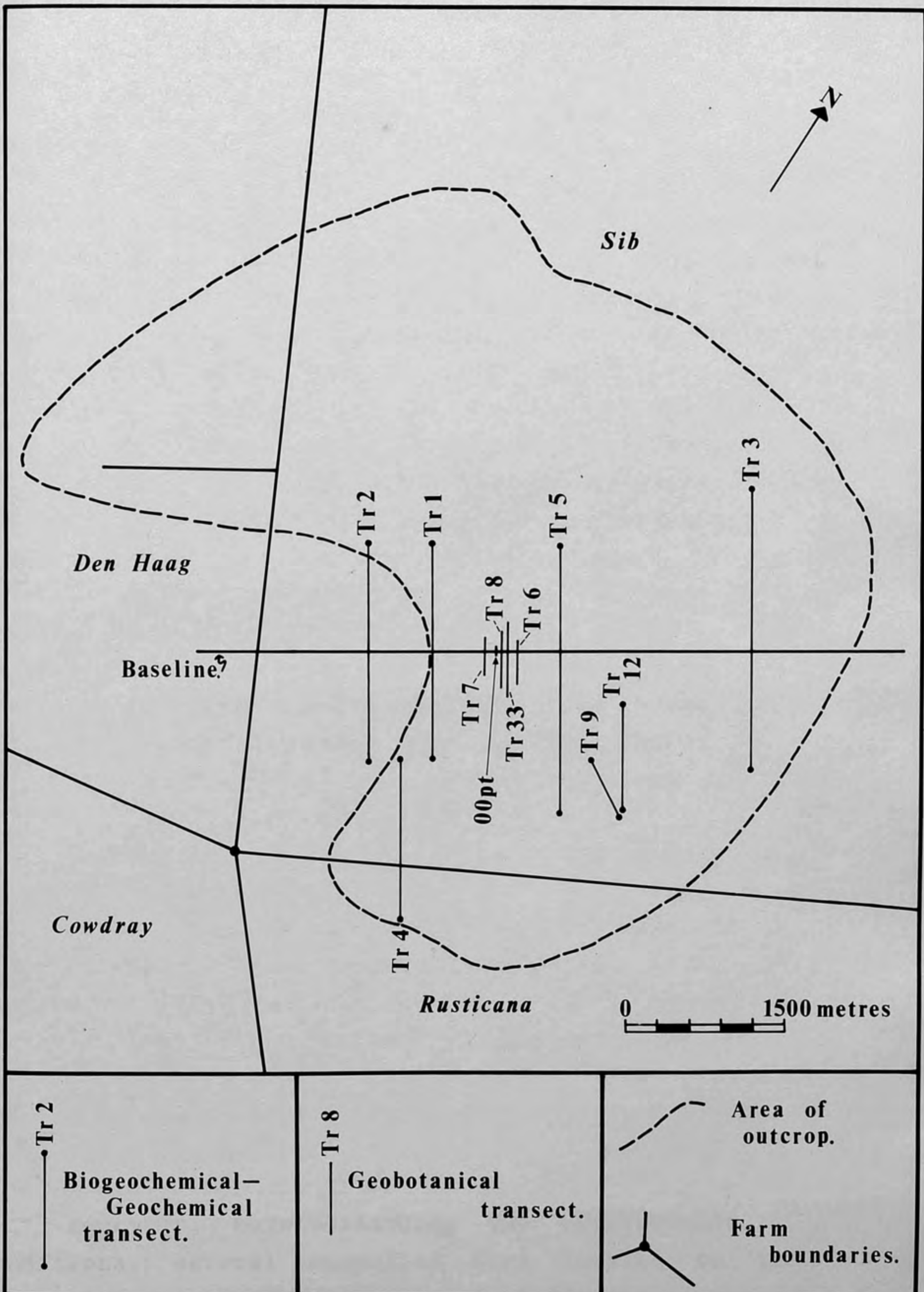


Fig.41: Location of geobotanical and biogeochemical/geochemical transects on the farm Sib and a portion of the farm Rusticana

method followed by atomic absorption spectrophotometry.

Studies of results of the biogeochemical and geochemical investigations revealed several important points (Figs. 42 and 43). In the first place background copper values for all species sampled along transects 1 - 5, 9 and 12 were far lower than those obtained on transects 6, 7, 8 and 33. This could be attributed to the fact that whereas the samples on transects 6, 7, 8 and 33 were collected during and immediately after the rainy season, when active plant growth would lead to an appreciable uptake of metals by the plants, the samples on transects 1 - 5, 9 and 12 were collected well before the rains when the plants were dormant and metal content would comprise only residual amounts remaining from the previous years growth.

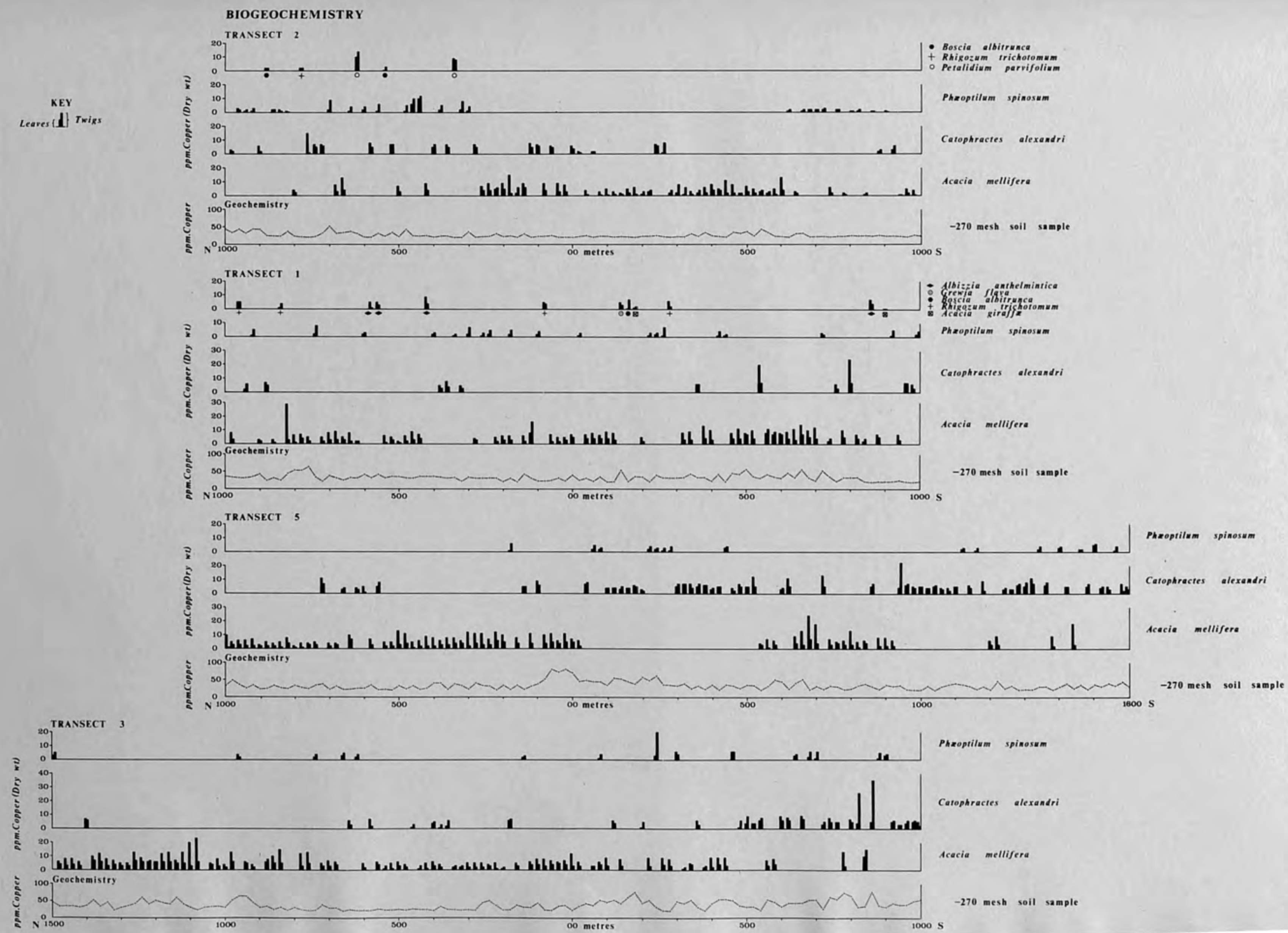
Secondly the background levels of the species sampled were fairly erratic. This could be due to the fact that some of the species were carrying very few leaves and in some cases less than the required amount for a full sample was collected which could possibly have caused unreliable results.

Thirdly the twigs of _Phaeoptilum spinosum_, collected along transects 1 - 5, 9 and 12, contained more copper than the leaves, probably because the ericoid type leaves comprised only the dried up remains of the previous seasons growth which had probably lost their copper by translocation to various other parts of the plant. The leaves of _Acacia mellifera_ and _Catophractes alexandri_, however, which came into leaf before the rains, contained more copper than the twigs.

Fourthly, notwithstanding the unfavourable conditions, several anomalies were located on the transects which were further investigated.

At 820 N on transect 1 (Fig. 42) where the leaves of _Acacia mellifera_ give a peak value of 29 ppm (per dry weight) in soils showing a slight

Fig.42: The copper content of the leaves and twigs of plant species sampled on transects 1, 2, 3 and 5 in the Sib area together with that of the -270 mesh fraction of the surface soils sampled at 10cms


BIOGEOCHEMISTRY
KEY
Leaves Twigs
TRANSECT 2
Boscia albitrunca
Rhigozum trichotomum
Petalidium parvifolium
Phæoptilum spinosum
Catophractes alexandri
Acacia mellifera
Geochemistry
−270 mesh soil sample
ppm.Copper (Dry wt)
ppm.Copper
N 1000
500
00 metres
1000 S
TRANSECT 1
Albizzia anthelmintica
Grewia flava
Boscia albitrunca
Rhigozum trichotomum
Acacia giraffæ
TRANSECT 5
1600 S
TRANSECT 3
N 1500

increase of copper content, a prospecting pit was dug. This uncovered a compact layer of calcrete 1.5 metres below the surface. A series of wagon drill holes were then put down to penetrate this layer and to ascertain the nature of the bedrock below. These revealed the presence of tilloid at a depth of 2 metres below surface. There was no evidence of macroscopic mineralization but on assay samples averaged 0.26% copper. At 540 S and 800 S along the transect, leaf samples of Catophractes alexandri gave peak values of 20 ppm and 25 ppm copper respectively (per dry weight) within a zone of fluctuating copper values in the soil. Prospecting pits put down in this area failed to discover any mineralization and it appeared likely that the somewhat higher copper values were associated with drainage downslope from the known ore body.

The lack of significant anomalies on transect 2 (Fig. 42) resulted in no further investigations being carried out.

Along transect 3 (Fig. 42) the relatively high copper values in the leaf samples of Acacia mellifera collected between 900 N and 1400 N, which were associated with above background copper levels in the surface soils, occurred in a zone where E.W.B. Miller and Associates had located a geochemical anomaly during their survey (Fig. 21). Pits dug at 10 metre intervals failed to reveal any mineralization. The area between 820 S and 860 S, where twig samples of Acacia mellifera and Catophractes alexandri contained 17 ppm copper and 27 and 38 ppm copper respectively (per dry weight) in another zone of fluctuating copper levels in the surface soils, was investigated by means of pits and wagon drill holes. These proved the absence of any mineralization and confirmed the postulation that the anomalies were in both areas caused by drainage from the known ore body, a suggestion

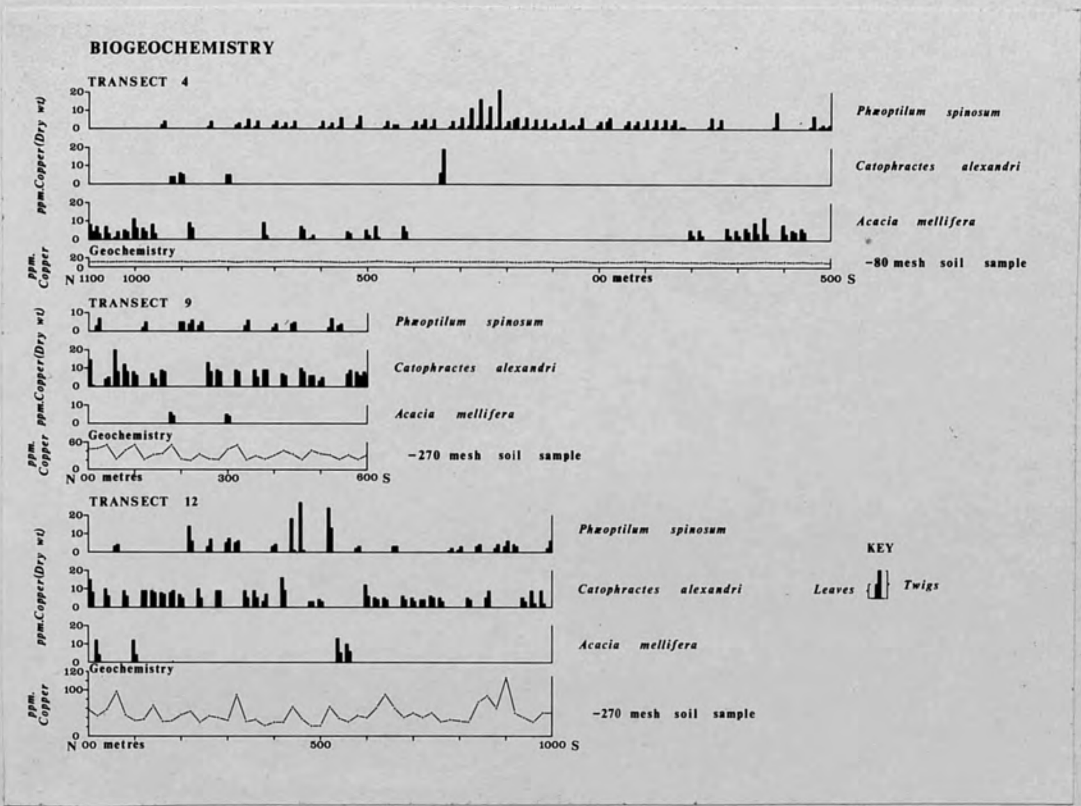


Fig.43: The copper content of the leaves and twigs of plant species sampled on transects 4, 9 and 12 in the Sib area together with that of the -80 or -270 mesh fractions of the surface soils sampled at 10cms

indicated both by the fact that the two species Acacia mellifera and Catophractes alexandri have predominantly lateral root systems, and by the fact that the highest copper value in the soils occurs over a well defined stream channel. A high copper level in the twigs of Phaeoptilum spinosum at 240 S is probably due to an analytical error.

The well defined biogeochemical anomaly outlined by the copper contents of twig samples of Phaeoptilum spinosum between 220 N and 300 N on transect 4 (Fig. 43) posed problems of interpretation. The copper content of the surface soils nowhere exceeded background levels, and pits failed to disclose any mineralization. Since the biogeochemical anomaly occurred on a slight rise, drainage influences at the rooting depth of the plants could be discounted. Possibly mineralization could have been present at depths below those reached by the pits. The presence of very small and poor specimens of Helichrysum leptolepis between 500 N and 1000 N (Plate 25) presented further problems which remained unsolved.

Between 00 point and 90 N and again between 540 S and 700 S along transect 5 (Fig. 42), leaf samples of Acacia mellifera contained above average amounts of copper, which in the former zone were matched by above average levels in the surface soils. Between 600 S and 1000 S small specimens of Helichrysum leptolepis were present. Prospecting pits failed to disclose any existence of mineralization and since the transect was located across an area subject to sheetwash it seems likely that the variable copper values were associated with this phenomenon.

Transects 9 and 12 (Fig. 43) were laid out across what appeared to be tree, shrub and grass cutouts (Plates 26 and 27), in which small scattered specimens of Helichrysum leptolepis were present. Relatively high copper levels were found

Plate 25: Small Helichrysum leptolepis plants growing in association with the grass Stipagrostis uniplumis along transect 4 on the farm Sib. (Ref. MMC/SWA 20/19)

Plate 26: Area devoid of trees and shrubs and occupied only by Stipagrostis uniplumis and Eragrostis denudata grasses on transect 9 on the farm Sib. (Ref. MMC/SWA 20/28)

in the leaves of Phaeoptilum spinosum, Acacia mellifera and Catophractes alexandri collected from a number of sites along transect 12 and in the leaves of the last mentioned species along transect 9. Copper levels in the surface soils fluctuated over short distances along both transects. Pits dug in this area failed to disclose any mineralization in the underlying bedrock, and since the transects crossed an area affected by sheetwash it seems likely that the high copper levels were caused by drainage from mineralized bedrock elsewhere.

The occurrence of the small specimens of Helichrysum leptolepis posed problems in view of the relatively low copper levels in the soil and the absence of mineralization in bedrock. The morphology of these specimens of Helichrysum leptolepis differed, however, from that of the plants growing on transects 6, 7, 8 and 33 (Plate 16). Although specimens from both occurrences are classified as Helichrysum leptolepis, only the specimens illustrated in Plate 16 will grow in soils with a high copper content. Compared with those from the cutout over the ore body, which have numerous branching stems, these are very small, have one single stem and only two or three small leaves. It is possible that they germinated successfully in soils with above background but relatively low copper levels, but did not flourish owing to an insufficient supply of this metal consequently remaining small.

b. The search for additional areas of mineralization

In the search for additional areas of mineralization attention was focussed initially on the farms Avro, Klein Nauas, Tsams and Versailles where geochemical anomalies had been located as a result of the survey undertaken by E.W.B. Miller and Associates. Later, claims by a farmer that he had found malachite chips in a borehole on the farm Sukses prompted investigations on this farm.

The farm Avro is located in an area of alternating sand dunes and "straate". The geochemical anomalies located by E.W.B. Miller and Associates occurred in alluvium in the "straate" (Fig. 3, Line C). As a first step, in order to ascertain whether they were merely surface phenomena in transported material, pits were dug and profile samples collected for geochemical analysis (Plate 28). When the results, showing copper values decreasing with depth, confirmed this to be the case, no plant sampling was undertaken.

The geochemical anomalies (Fig. 3, Line 1) on the farms Klein Nauas and Tsams occurred on flat plains associated with sheetwash and a series of small streams terminating in poorly developed pans. Here a few small specimens of <u>Helichrysum leptolepis</u> were scattered over a wide area. It was initially suspected that this anomaly was a result of transported metals in the soil, and this was confirmed by wagon drill holes which proved that there was no increase in metal content of the soil with depth. Accordingly no further geobotanical work was carried out in the area.

On the farm Versailles the geochemical anomalies all occurred in thick, fine-grained micaceous alluvium in the delta of the Schaf River (Fig. 3, Line 5). No geobotanical anomalies were present. Analysis of profile soil samples taken in a series of pits showed that the anomalies did not persist in depth and it was concluded that they were transported.

The borehole on the farm Sukses from which malachite chips were claimed to have been found is located in a "straat" between closely spaced sand dunes, and near an area where the geochemical survey

Plate 27: Eragrostis denudata grass occupying an area devoid of trees and shrubs on transect 12 on the farm Sib. (Ref. MMC/SWA 20/25)

Plate 28: Portion of the farm Avro showing the location of a prospecting pit in an area of thick alluvium. In the background is a sand dune carrying Acacia giraffae and Boscia albitrunca trees. (Ref. MMC/SWA 21/20)

of E.W.B. Miller and Associates found copper anomalies in stream sediment samples (Fig. 3, Line D). The "straat" is covered with thick micaceous alluvium veneered by a thin cover of windblown sand (Plate 10). The sand dunes and "straate" in the vicinity are orientated at a right angle to the inferred strike of the concealed geology. Two transects, 21 and 22, were therefore located within the "straate" and parallel to the dunes (Fig. 44) in order to sample the area with the least overburden in an attempt to find mineralized bedrock. The shrubs Phaeoptilum spinosum, Rhigozum trichotomum and the tree Acacia giraffae were sampled at 20 metre intervals wherever possible; soil samples were also taken at 20 metre intervals and the -270 mesh fraction analysed. Neither plant nor soil samples showed anomalous values. After further investigation it was concluded that the country bedrock was Karroo lava and the so-called "malachite" chips were in fact fragments of zeolites.

Analysis of profile soil samples from pits put down on the remaining geochemical anomalies on Line D (Fig. 3), and also those on Lines C and E on the farms Avro and Wilderness respectively, all indicated that these anomalies were of a transported origin.

The investigations undertaken indicated that all the geochemical anomalies located by E.W.B. Miller and Associates on the farms Avro, Klein Nauas, Tsams, Versailles, Sukses and Wilderness (Fig. 3) were of a transported origin with the likely source of the mineralization in the Kharubeam Hills area to the north, where some copper occurrences were already known. Attention, therefore, was directed to geobotanical, biogeochemical and geochemical investigations in that area. These form the subject of Part III of this thesis.

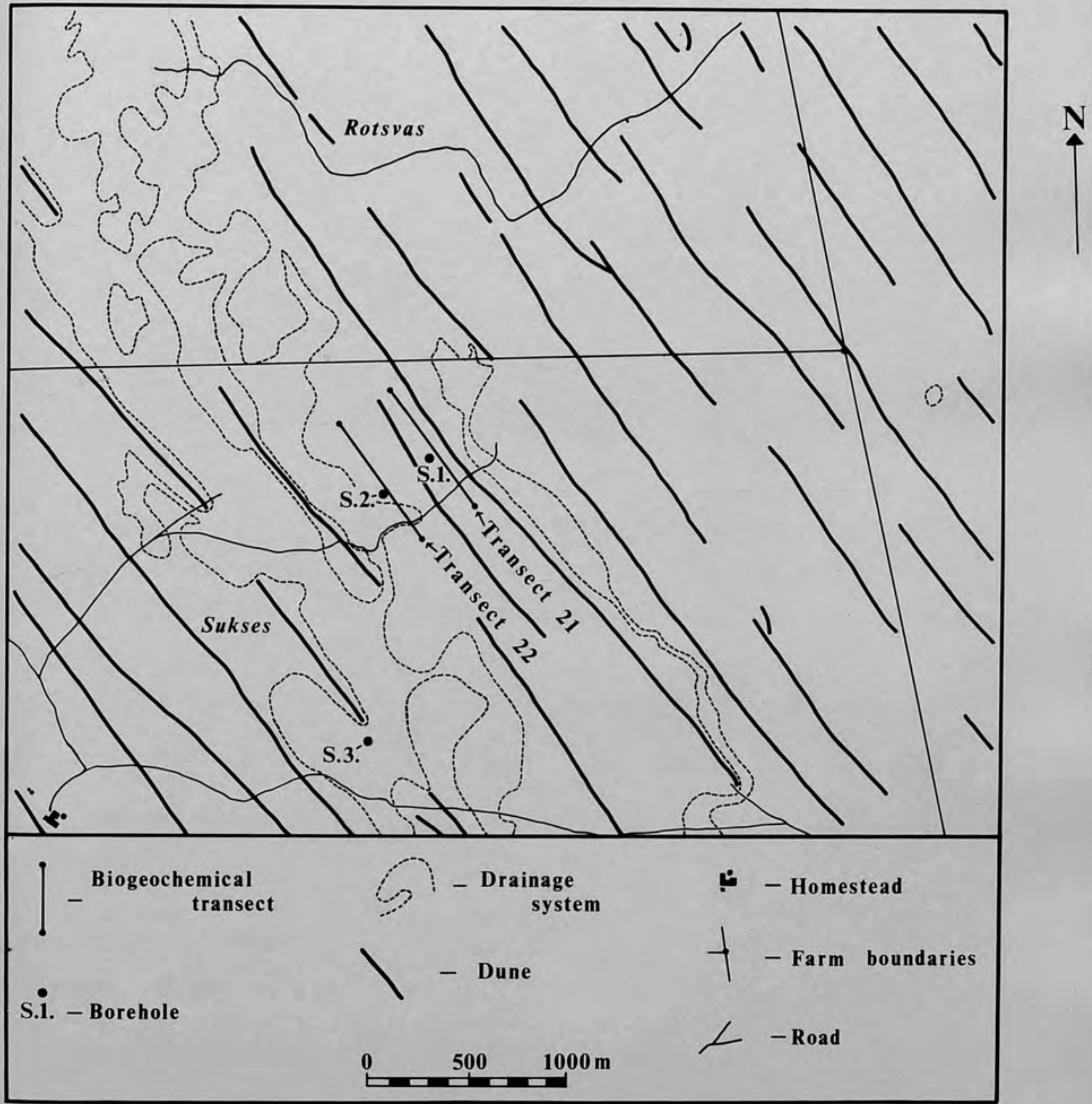


Fig.44: Location of biogeochemical / geochemical transects on the farm Sukses

P A R T III

Chapter 9

THE KHARUBEAM HILLS AREA

The physical background

The Kharubeam Hills area, north of the Sib area, contrasts sharply with the latter both in its geology and physique and in the character of its vegetation and supporting soils. Basically these differences derive from the geology.

Geology

The Kharubeam Hills area is underlain by rocks of the Dordabis, Tsumis and Nama Systems (Fig. 7). Outcrops of these rocks occur on the farms Mertens, Gravenstein, Wiese, Hexen Kessel, Girib Ost, Tigerpforte and Compromise (Figs. 4 and 7).

The lowermost member of the Dordabis System, namely the Opdam formation, outcrops on the farms Wiese, Mertens and Hexen Kessel (Fig. 7) where, in consequence of its relatively weak resistance to erosion which is aided by intense fracturing, it forms the valleys between the hills of more resistant Skumok and Doornpoort rocks (Plate 29).

The Opdam formation comprises three lithological divisions (Schalk 1961), all of which are represented

Plate 29: View south-east across plain in valley between the Kharubeam Hills. The plain is formed by erosion of the less resistant Opdam lavas. The centre of the photograph shows the hill on the farm Hexen Kessel formed by effusive quartz porphyry. The foreground shows hills of quartz porphyry supporting a low tree and shrub savanna characterized by _Acacia senegal_ and _Combretum apiculatum_ trees. (Ref. MMC/SWA 49/34 - 36)

in the study area. They are:-

Lower: Basal conglomerate followed by a boulder conglomerate associated with sporadic flows of basaltic lava

Central: Mafic and felsic lavas with interbedded quartzites and phyllites

Upper: Quartzite and basaltic lavas

The degree of metamorphism is relatively low and interbedded sediments have been altered locally to epidotic metaquartzite and sericitic phyllite. The mafic lavas have been altered to chlorite-epidote rocks.

The coarse boulder conglomerate of the lower division, common on Wiese, Mertens and Hexen Kessel, and the thick basaltic lavas, phyllitic and sericitic quartzites are interbedded. The amygdaloidal lavas of the central division are basaltic to andesitic in composition. The amygdales may be filled with quartz, calcite, epidote and chlorite. The metaquartzites in this sequence are dense, very hard and fine-grained with colours varying from light grey to yellowish or greenish, depending on epidote content. An interbedded purplish slate is also encountered in the higher portions of the sequence.

The Opdam formation is unconformably overlain by the Skumok formation, but this contact is well defined only in the Dordabis area. In the study area the Skumok formation generally occurs as intrusive sills in the Opdam lavas and at the base of the overlying Doornpoort formation.

After a quiet period of sedimentation, during which the upper quartzites and slates of the Opdam formation were deposited, a general uplift of the basin occurred. This was accompanied by intense fracturing and faulting and renewed volcanic activity which led to the outpouring of large masses of porphyry, rhyolite and granophyre and subsequent intrusion into the Opdam rocks. When this activity stopped, sedimentation was resumed and the rocks of the Doornpoort were laid down. During the early deposition period, however, renewed outpourings of lava and porphyry (of Skumok age) resulted in numerous small sills being formed at the base of the Doornpoort formation. In the outcrops of the bedded or foliated rocks on Wiese and Mertens, the porphyry is usually intruded parallel to these rocks (Plate 30).

The effusive quartz porphyry, which is purplish-grey in colour, consists mainly of quartz feldspar, and phenocrysts of orthoclase and microcline are common. On Hexen Kessel this porphyry forms a large, conspicuous hill rising from the valley floor which is underlain by Opdam lavas (Plate 29). At the base of the porphyry on Mertens and Wiese there is a volcanic agglomerate which consists of rounded lava "bombs" embedded in a porphyritic matrix (Plate 31). A rhyolitic lava which is vesicular with frequent pyroclastic lenses is also present. Even contorted banding produces the characteristic flow lines.

Felsic lavas containing phenocrysts of quartz and feldspar are found interbedded with the Opdam lavas on Mertens, Wiese and Hexen Kessel, while there is evidence of the intrusion of granophyre in early Skumok times on the farm Mertens. This rock is reddish in colour and contains scattered feldspar phenocrysts. Conglomerates and intrusive granites also form part of the Skumok formation.

The Skumok and Opdam formations are overlain by the Doornpoort formation of Schalk (1961) and Martin (1965). This consists of quartzites, slates, interbedded calcareous quartzites, conglomerates and sedimentary breccias. In the study area the rocks, being resistant to erosion, form a range of hills - the Kharubeam Hills (Figs. 5 and 7).

Plate 30: Prominent outcrop (foreground) formed by effusive porphyry intruded parallel to bedded and foliated country rock of Opdam lavas. View north-east on the farm Mertens. (Ref. MMC/SWA 50/8 - 9)

Plate 31: Volcanic agglomerate consisting of rounded lava "bombs" embedded in a porphyritic matrix at the base of the porphyry on transect 1, Mertens. (Ref. MMC/SWA 48/34a)

The Doornpoort succession begins with a coarse sedimentary breccia followed by a well sorted conglomerate carrying well rounded pebbles, examples of which are seen on Wiese and Hexen Kessel. Pebbles of Opdam lava and fragments of fine-grained Skumok porphyry are common in the breccia. Purplish-grey quartzites alternating with red slates are common above the conglomerate. The quartzite is hard, feldspathic, virtually free from pebbles and reddish-brown in colour. Interbedded with the quartzites are slates and calcareous quartzites. Ripple marks and clay pellets are common, indicating deposition in shallow water.

While Schalk (1961) and Martin (1965) include the Doornpoort formation in the Dordabis System, Handley (1965) includes it in his classification of the Tsumis System. The description given by Handley of the Basal conglomerate and quartzite and the Tsumis A and B stages conforms to that of the Doornpoort formation given above, and it can be concluded that the rocks described are the same formation or stage (Fig. 7).

It appears that the calcareous quartzite stage (Tsumis B) is absent in the study area, as the Basal conglomerate and Tsumis A stage (≡ Doornpoort) is overlain with a major unconformity on Girib Ost by the Tsumis C stage. These rocks were originally classified as Kamtsas quartzite, but are now considered to be Tsumis C quartzites, and conform to the description given in Chapter 4 for the Sib area.

A syncline formed by the rocks of the Tsumis C stage, which outcrop on Girib Ost, Tigerpforte and Compromise, is filled with sediments belonging to the Buschmannsklippe formation of the Nama System (Fig. 7). Although a discordance is observed between the Tsumis and Nama Systems, it appears that the two systems were folded together.

All the members of the Dordabis System appear to have been folded before the deposition of the Tsumis sediments, and on Mertens, Wiese and Hexen Kessel the steeply dipping lavas and interbedded metasediments outcrop on the flanks of an anticline.

The main ore bearing rock in the Kharubeam Hills area is a fine-grained, massive, mafic Opdam lava, which is highly epidotized and contains amygdales filled with quartz and calcite together with epidote. The mineralization takes the form of disseminated malachite together with chalcocite and native copper. The amygdales often contain malachite or cuprite. An assay of a sample of mineralized lava from 00 point on transect 1, Mertens, gave the following values:-

% Cu	% Fe	ppm Zn	ppm Pb
9.71	0.46	15	5

Where this amygdaloidal Opdam lava shows no copper mineralization, specularite/haematite is often observed and the rock is a reddish colour where weathered (see footnote).

Structure of the mineralized horizon on Mertens

The lavas and associated metavolcanics, metasediments and porphyries generally dip to the south and thus form the southern limb of an anticline in the area. The dip, however, varies locally and at 00 point it is recorded at an angle of -60° to the south. At a point 100 metres to the west of 00 point the dip is almost vertical.

The mineralized horizon increases slightly in thickness below the surface at 00 point. At

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Information based on mineralogical and petrological studies of trench samples from Mertens by Anhaeuser and Button (1969).

surface it is 1.2 metres in width, while at a point 20 metres below surface (vertical depth) the width increases to 1.5 metres (data from wagon drill holes).

Physiography and Geomorphology

The Kharubeam Hills, a series of mainly longitudinal hills and kopjes running in a NE - SW direction (Fig. 5), form the major relief feature of the area. On the northern side they are flanked by plains covered by windblown Kalahari sand which exhibit linear dunes of a low stature. To the east and to the west of the Kharubeam Hills there are extensive flat plains traversed by parallel linear sand dunes which provide striking relief features, for example on the farm Strife where the dunes run in a NW - SE direction and may be 100 to 300 metres apart and up to 30 metres in height (Plate 32).

The Kharubeam Hills are built of those rocks of the Dordabis and Tsumis Systems which are resistant to erosion. The valleys in the Kharubeam Hills on the farms Mertens, Wiese, Hexen Kessel and Girib Ost have been fashioned by the erosion of the less resistant and intensely fractured Opdam lavas of the Dordabis System, while differential erosion over rocks of varying resistance has been partly responsible for minor relief features within these valleys. The floors of the valleys are slightly undulating, the relief being provided by calcrete and effusive porphyries which form low ridges, while on the farm Hexen Kessel this effusive porphyry forms the large hill described in the section on the geology of this area. The synclinal basin flanked by outcropping Tsumis C rocks on the farms Girib Ost, Tigerpforte and Compromise is

Plate 32: View south-east from the apex of a sand dune on the farm Strife showing the linear sand dune formation with the "straate" between the dunes. The "straate" are occupied mainly by Phaeoptilum spinosum, Acacia mellifera and Rhigozum trichotomum shrubs while the dunes exhibit a growth of Boscia albitrunca, small Acacia giraffae and Acacia haematoxylon trees. (Ref. MMC/SWA 49/30 - 32)

remarkably flat. Its level surface, however, is interrupted by linear sand dunes some of which are parallel while others converge towards the water gap, the Klein Nauas or Tiger poort, cut by the strong flowing waters of an earlier river system. Calcrete deposits also form low ridges where the sand cover is thin or absent in the basin.

The main drainage in the area is provided by the Schaf River (Fig. 5) which, following the upwarp in the Khomas axis, carved a deep poort through the Kharubeam Hills on the farm Wiese (Plate 5). A series of less spectacular poorts occur on Wiese, Mertens, Girib Ost and Tigerpforte. Runoff from the high ground is considerable, and on Mertens, Wiese and Hexen Kessel in particular, deep channels have been cut in the Opdam lavas by strong flowing streams. The drainage pattern is dendritic and pans are generally absent (Fig. 5). On the farms Girib Ost, Tigerpforte and Compromise the runoff from the hills is also considerable, but on the sand covered basin floor the stream courses end in internal drainage systems characterized by numerous pans between the dunes (Fig. 5). After the rains, however, a major stream occupies the Klein Nauas or Tiger poort on Tigerpforte.

On the farms Strife and Gravenstein the drainage is entirely internal and consists of a series of interconnecting pans lying between the linear sand dunes. Here differences in relief are the result of wind action.

The physiography of the area has been greatly influenced by geomorphological processes operating during successive wet and dry periods, probably during late Cretaceous and early Tertiary times. In the past, great changes have been brought about by a single flood. In the 1933/34 rainy season, for example, when ± 1000 mm of rain fell over a 96 hour period, the Schaf River came down in flood. It was prevented from flowing through its poort in the Kharubeam Hills by a sand dune built up during previous dry years. Consequently the river broke its banks and the floodwaters ran to the south-west, north of the range of hills on Wiese and Hexen Kessel, and also across Mertens, before breaking through the range in a poort on Gravenstein. The floodwaters carried an enormous amount of silt and sand, which was deposited adjacent to the river and in the low lying areas covered by the floodwaters. Eventually the impeding sand dune was swept away, and the river flowed onto the plains south of the hills and deposited vast amounts of alluvium. These alluvial deposits, together with those of subsequent lesser floods, have depths of up to 25 metres in places, and effectively mask the underlying bedrock in the low lying areas within and south of the Kharubeam Hills.

The extent and nature of the superficial deposits in the Kharubeam Hills area has resulted in the development of vegetation patterns unrelated to the local bedrock.

Overburden and Soils

The overburden and soils in the Mertens, Wiese, Hexen Kessel and Girib Ost areas were mapped using aerial photographs and ground reconnaissance. They were found to be extremely varied but could be grouped into 10 categories (Fig. 45).

The skeletal, grey to reddish-brown, fine to medium-grained soils which mantle the flat floored valleys may be derived from sub-outcropping bedrock or from water transported material and/or windblown sand. They vary in thickness from a few centimetres to about 2 metres. These soils are immature and show no profile development.

Over a large part of the area characterized by these soils, calcrete either outcrops or occurs

KEY : Fig.45

1. Skeletal, grey to reddish-brown, fine to medium-grained soils derived from sub-outcropping bedrock or from water transported and/or windblown sand
2. Skeletal, fine to medium-grained, brown soils
3. Windblown, medium to coarse-grained, red Kalahari sand
4. Grey to light brown, fine to medium-grained, micaceous alluvium
5. Light brown, fine to medium-grained, non-micaceous alluvium
6. Shallow veneer of windblown Kalahari sand overlying fine to medium-grained micaceous alluvium
7. Fine to medium-grained, micaceous alluvium overlain by dunes of buff coloured, medium to coarse-grained sand
8. Beige coloured, medium to coarse-grained sand
9. Beige coloured, coarse- grained sand
10. Greyish-brown, fine-grained silt

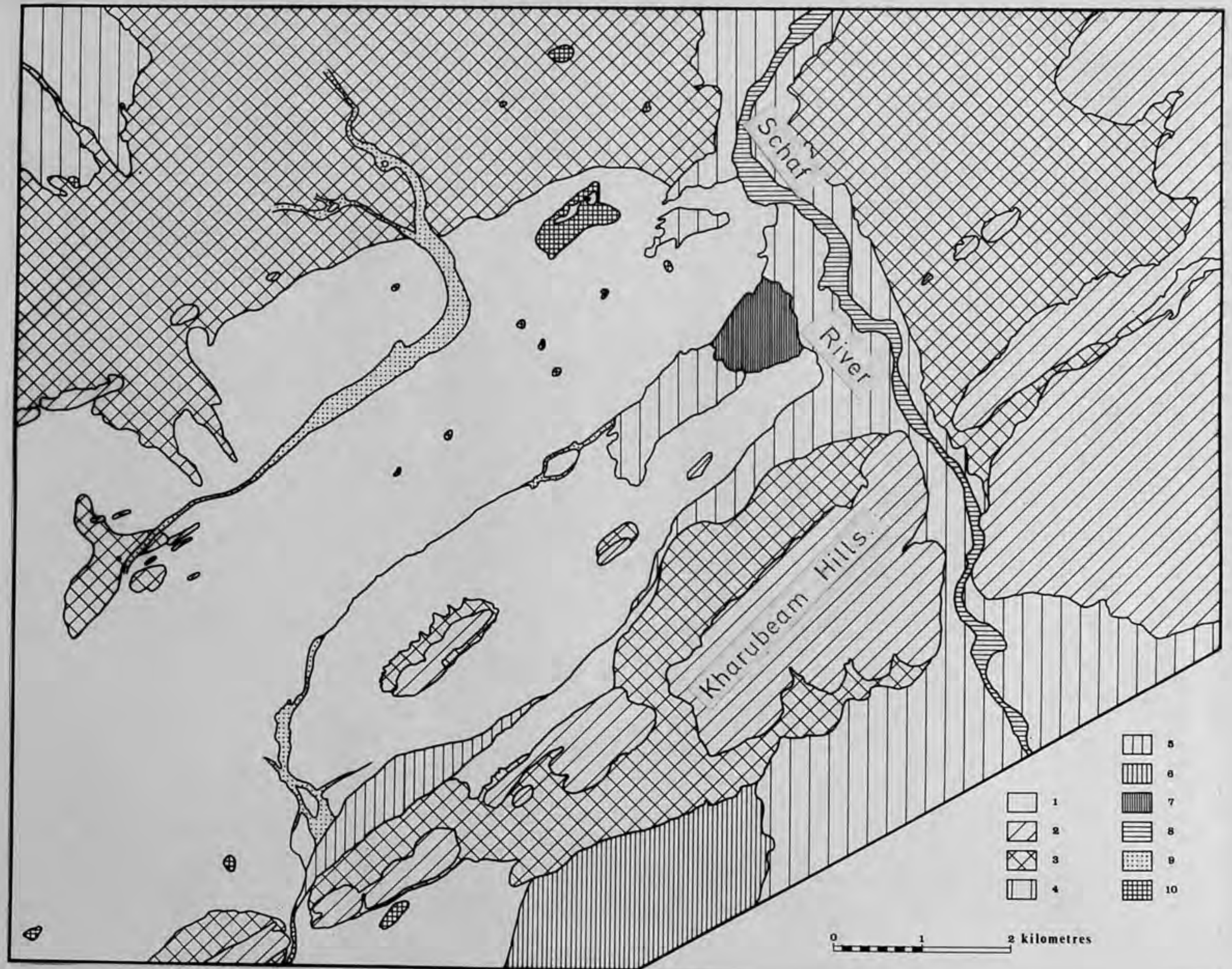


Fig.45: Overburden and soils on portions of the farms Mertens, Wiese, Hexen Kessel, Gravenstein and Girib Ost in the Kharubeam Hills area (for location map see Fig.48)

beneath varying thicknesses of overburden. On Wiese it reaches a thickness of 4 metres.

On Mertens lateritic material occurs, which consists of small to medium rounded pebbles of quartz and quartzite, semi-compacted and exhibiting iron staining. Over a large portion of this area a surface layer of scattered, subangular quartz pebbles is found, the pebbles being derived from the erosion of quartz veins which are common in the area.

Skeletal, fine to medium-grained brown soils cover the rocky slopes of the Kharubeam Hills. They vary in thickness from 5 to 15 cms. The flanks of these hills may be mantled by red, medium to coarse-grained, windblown Kalahari sand. To the east of the Schaf River and in the northern area of Mertens this sand covers the plains and also forms linear, semi-fossilized dunes. Thicknesses of 10 to 15 metres have been recorded and no profile development is evident.

The plains bordering the Schaf River are covered by grey to light brown, fine to medium-grained, micaceous alluvium which varies in thickness from a few centimetres to 5 metres and shows no evidence of profile development. The major portion of this layer was deposited during the 1933/34 flood, but has been added to by recent floods.

Close to the southern boundary of Mertens a layer of light brown, fine to medium-grained, non-micaceous alluvium, averaging 2 metres in thickness was deposited, mainly by the 1933/34 flood.

South of the Kharubeam Hills and west of the Schaf River delta is an area covered by fine to medium-grained, micaceous alluvium which reaches depths of 10 to 20 metres and lacks profile development. This in turn is overlain by a shallow veneer of windblown Kalahari sand.

To the north of the poort on Wiese and to the immediate west of the Schaf River is an area covered by fine to medium-grained micaceous alluvium with depths of up to 3 metres. Covering this alluvium is a series of small dunes of buff coloured, medium to coarse-grained sand, 3 - 4 metres in height.

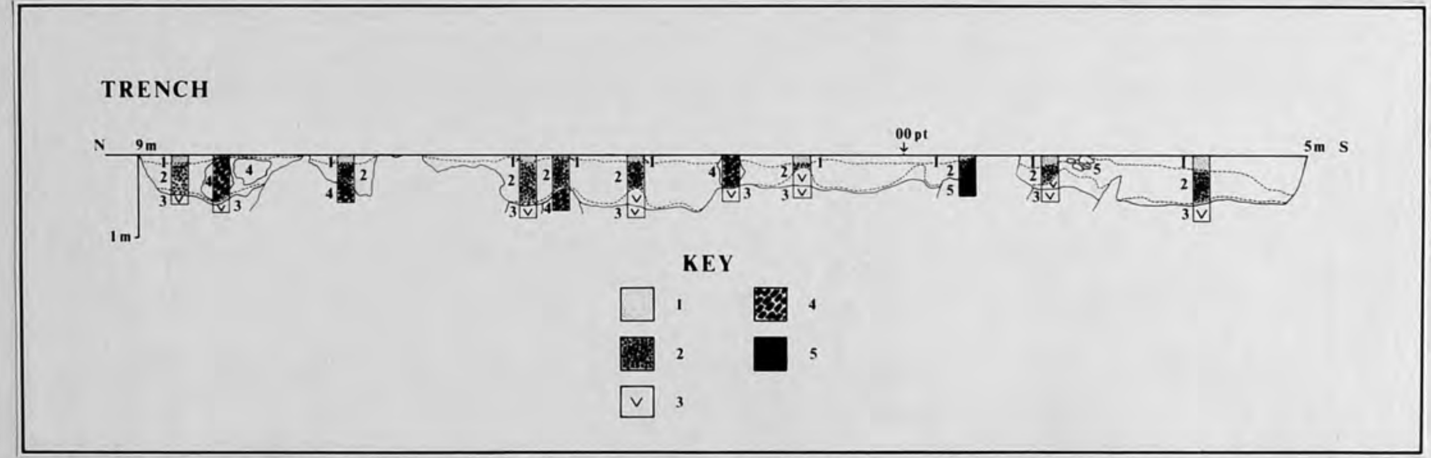
The bed of the Schaf River is covered by beige coloured, medium to coarse-grained sand while old stream courses in the northern parts of Mertens and Wiese contain beige coloured, coarse-grained sand. Pans in the area generally contain greyish-brown, fine-grained silt of which a depth of 1.5 metres was recorded in a pan on Wiese.

At the base of most of the steep hills in the area, colluvial deposits are found. They consist of semi-rounded to angular fragments of quartzite and lava from the hills and are often mixed with windblown Kalahari sand.

Soil profiles associated with the mineralized horizon on Mertens

A trench, running from 9 metres N to 5 metres S on transect 1, Mertens, was dug in order to study the overburden and soil types associated with the mineralized horizon. From the profile diagram (Fig. 46) it is evident that the transported overburden is very thin and does not exceed a thickness of 70 cms. The windblown sand reaches a maximum thickness of 50 cms at 5 metres S and the gravel, where present, varies in thickness from a few centimetres to 60 cms at 2.75 metres N. Both the windblown sand and gravel show a complete lack of sorting and profile differentiation.

The hard, highly epidotized, mafic lavas are more resistant to erosion than the soft, sheared, mostly non-epidotized lavas and thus form prominent subsurface ridges or outcrops, while the softer material forms shallow depressions. The depressions



1. Fine to medium-grained windblown sand, containing 10 - 15% angular to subangular vein quartz pebbles (1 - 2 cms diameter).
2. Coarse gravel consisting of 95% subangular to rounded vein quartz pebbles in a fine to medium-grained sandy matrix. Angular fragments of dark coloured, fine-grained, weathered, epidotized Opdam lava (10 - 15 cms diameter) constitute the remaining 5%
3. Greyish to bluish-green, soft, fine-grained, massive Opdam lava (possibly some tufaceous material). Epidote content variable but if present is in the form of amygdaloidal fillings. Sericite streaking and chlorite patches lend a mottled appearance to the rock. Varying degrees of shearing.
4. Hard, fine-grained, massive, mafic Opdam lava. Epidote is common and the rock is black where the epidote is absent. Quartz and calcite are common amygdaloidal fillings together with epidote. Specularite/haematite observed in places and the weathered rock is a reddish colour.
5. Hard, fine-grained, massive, mafic Opdam lava. Quartz veins and amygdales (filled with quartz, calcite and epidote) are common. Disseminated malachite, chalcocite and native copper occur, and amygdales are often filled with malachite or contain cuprite.

Fig.46: Profiles through the soil, overburden and weathered bedrock exposed along a trench dug on transect 1, Mertens

contain large boulders of weathered highly epidotized lava which have been eroded from outcrops in the area.

Although the soft sheared lavas weather relatively easily, there is no indication of major profile development. Generally the contact between bedrock and overburden types is very sharply defined.

Vegetation

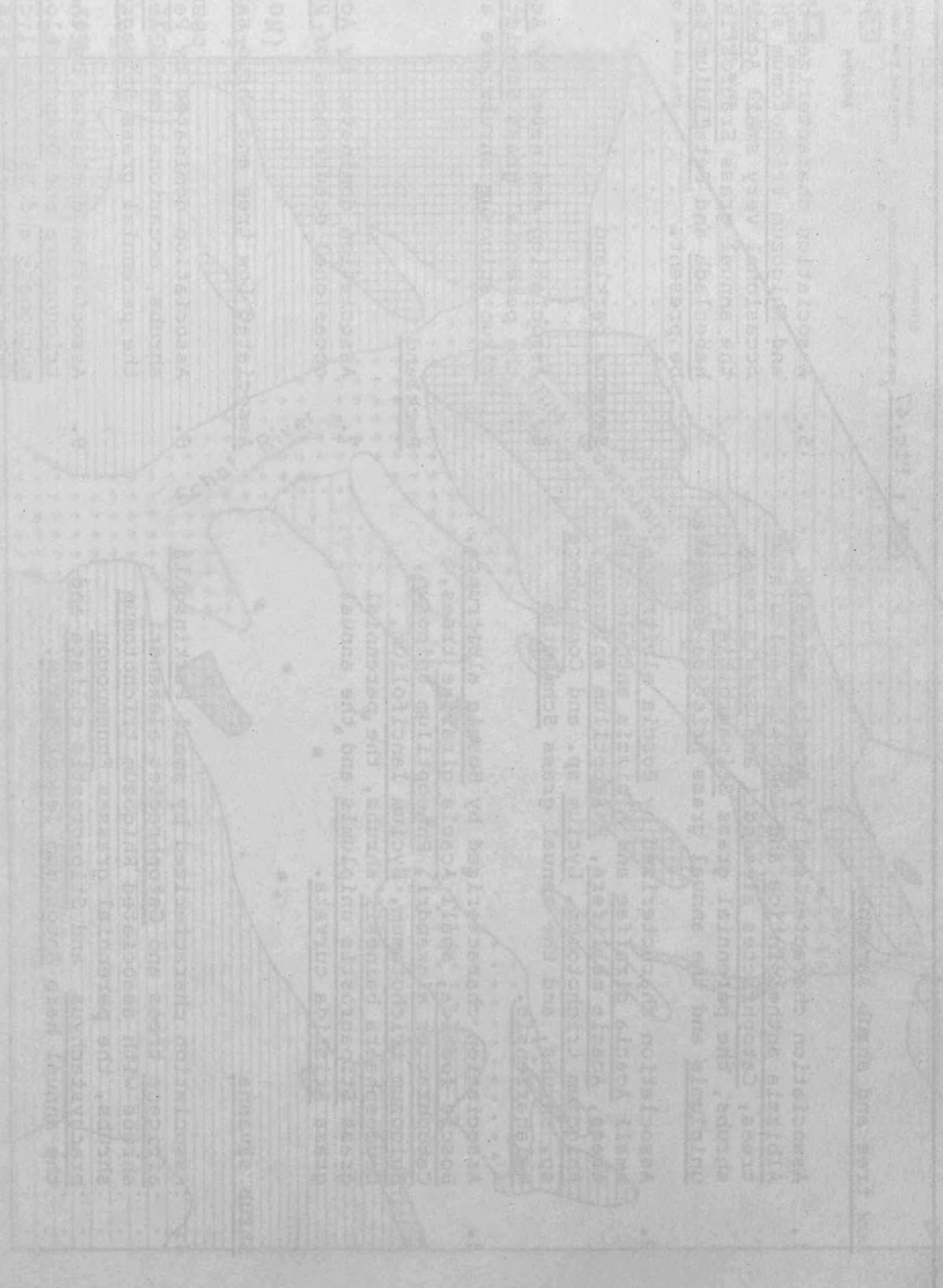
A study of the vegetation in the Mertens, Wiese, Hexen Kessel and Girib Ost areas was made by the use of aerial photographs and a ground reconnaissance survey. These investigations showed that the vegetation in the Kharubeam Hills area comprises the following physiognomic units:-

Low tree and shrub savanna
Shrub savanna
Savanna parkland
Parkland
Associated low tree and shrub savanna - Savanna grassland.

Within each of these units a number of vegetation associations may be recognized (Fig. 47).

Within the low tree and shrub savanna an association characterized by Acacia senegal, Albizzia anthelmintica and Combretum apiculatum trees, Catophractes alexandri and Grewia tenax shrubs, the perennial grass Stipagrostis uniplumis and the annual grass Aristida congesta is found on the skeletal soils on the rock strewn slopes of the hills formed by quartzites and quartz porphyries. The trees and shrubs are sparse and ground vegetation is almost non-existent (Plate 29).

By contrast, where windblown Kalahari sand


Schar River

KEY : Fig.47

Low tree and shrub savanna

1. Association characterized by *Acacia senegal*, *Albizzia anthelmintica* and *Combretum apiculatum* trees, *Catophractes alexandri* and *Grewia tenax* shrubs, the perennial grass *Stipagrostis uniplumis* and the annual grass *Aristida congesta*.

2. Association characterized by *Boscia albitrunca*, small *Acacia giraffae* and *Albizzia anthelmintica* trees, *Acacia mellifera*, *Phaeoptilum spinosum*, *Rhigozum trichotomum*, *Lycium* sp. and *Commiphora* sp. shrubs, and the annual grass *Schmidtia kalahariensis*.

3. Association characterized by *Boscia albitrunca*, *Boscia foetida*, small *Acacia giraffae* trees, *Catophractes alexandri*, *Phaeoptilum spinosum*, *Rhigozum trichotomum*, *Lycium lancifolium*, *Leucosphaera bainesii* shrubs, the perennial grass *Stipagrostis uniplumis* and the annual grass *Aristida curvata*.

Shrub savanna

4. Association characterized by small *Parkinsonia africana* trees and *Catophractes alexandri* shrubs with associated *Rhigozum trichotomum* shrubs, the perennial grasses *Enneapogon brachystachyus* and *Stipagrostis ciliata* and the annual herb *Aptosimum leucorrhizum*.

5. Association characterized by *Phaeoptilum spinosum* and *Rhigozum trichotomum* shrubs associated with occasional very small *Acacia giraffae* trees and the annual grass *Eragrostis trichophora*, while *Acacia hebeclada* and *Petalidium parvifolium* shrubs may also be present.

Savanna parkland

6. Association dominated by *Acacia giraffae* trees and the perennial grass *Schmidtia kalahariensis*. *Phaeoptilum spinosum* shrubs are also present occasionally.

Parkland

7. Association dominated by *Acacia giraffae* trees with occasional occurrences of *Phaeoptilum spinosum* shrubs.

Associated Low tree and shrub savanna - Savanna grassland

8. Association dominated by *Petalidium parvifolium* shrubs, occasional small *Acacia giraffae* trees and the perennial grass *Stipagrostis uniplumis*.

9. Association dominated by the annual grass *Eragrostis trichophora* and *Diandrochloa pusilla* with *Ziziphus mucronata* and *Diospyros lycioides* trees and *Acacia hebeclada* shrubs around the peripheries.

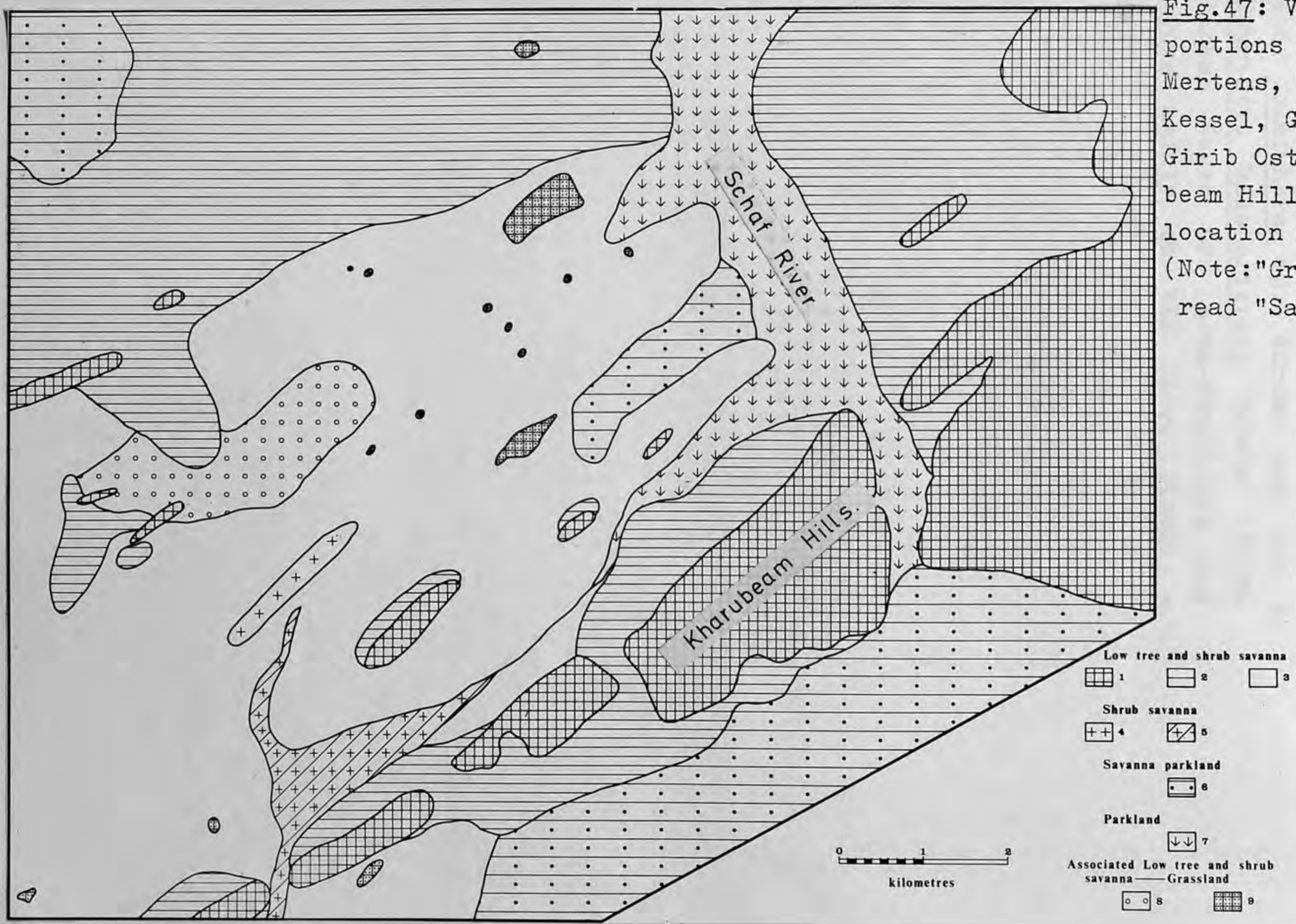


Fig.47: Vegetation on portions of the farms Mertens, Wiese, Hexen Kessel, Gravenstein and Girib Ost in the Kharubeam Hills area (for location map see Fig.48) (Note:"Grassland" should read "Savanna grassland")

mantles the flanks of the hills or forms linear dunes, a low tree and shrub savanna characterized by Boscia albitrunca, small Acacia giraffae and Albizzia anthelmintica trees, Acacia mellifera, Phaeoptilum spinosum, Rhigozum trichotomum, Lycium sp. and Commiphora sp. shrubs and the annual grass Schmidtia kalahariensis occurs (Plate 33). The linear dunes are semi-fossilized and the vegetation grows mainly on the lower slopes with the apices normally remaining bare.

A low tree and shrub savanna characterized by Boscia albitrunca, Boscia foetida and small Acacia giraffae trees, Catophractes alexandri, Phaeoptilum spinosum, Rhigozum trichotomum, Lycium lancifolium and Leucosphaera bainesii shrubs, the perennial grass Stipagrostis uniplumis and the annual grass Aristida curvata occupies the skeletal soils of plains underlain by weathered lavas and metasediments. The trees are scattered and the shrubs constitute the major part of the association. Ground vegetation forms less than 10% of the total vegetation cover (Plate 34).

Where a very thin layer of sand covers calcrete rises, a shrub savanna characterized by small Parkinsonia africana trees and Catophractes alexandri shrubs with associated Rhigozum trichotomum shrubs, the perennial grasses Enneapogon brachystachyus and Stipagrostis ciliata and the annual herb Aptosimum leucorrhizum is recognized.

A shrub savanna also occurs where non-micaceous alluvium was deposited during the 1933/34 floods. This association is characterized by Phaeoptilum spinosum and Rhigozum trichotomum shrubs, associated with occasional small Acacia giraffae trees and the annual grass Eragrostis trichophora. Acacia hebeclada and Petalidium parvifolium shrubs may also be present.

A savanna parkland dominated by Acacia giraffae trees and the perennial grass Schmidtia kalahariensis

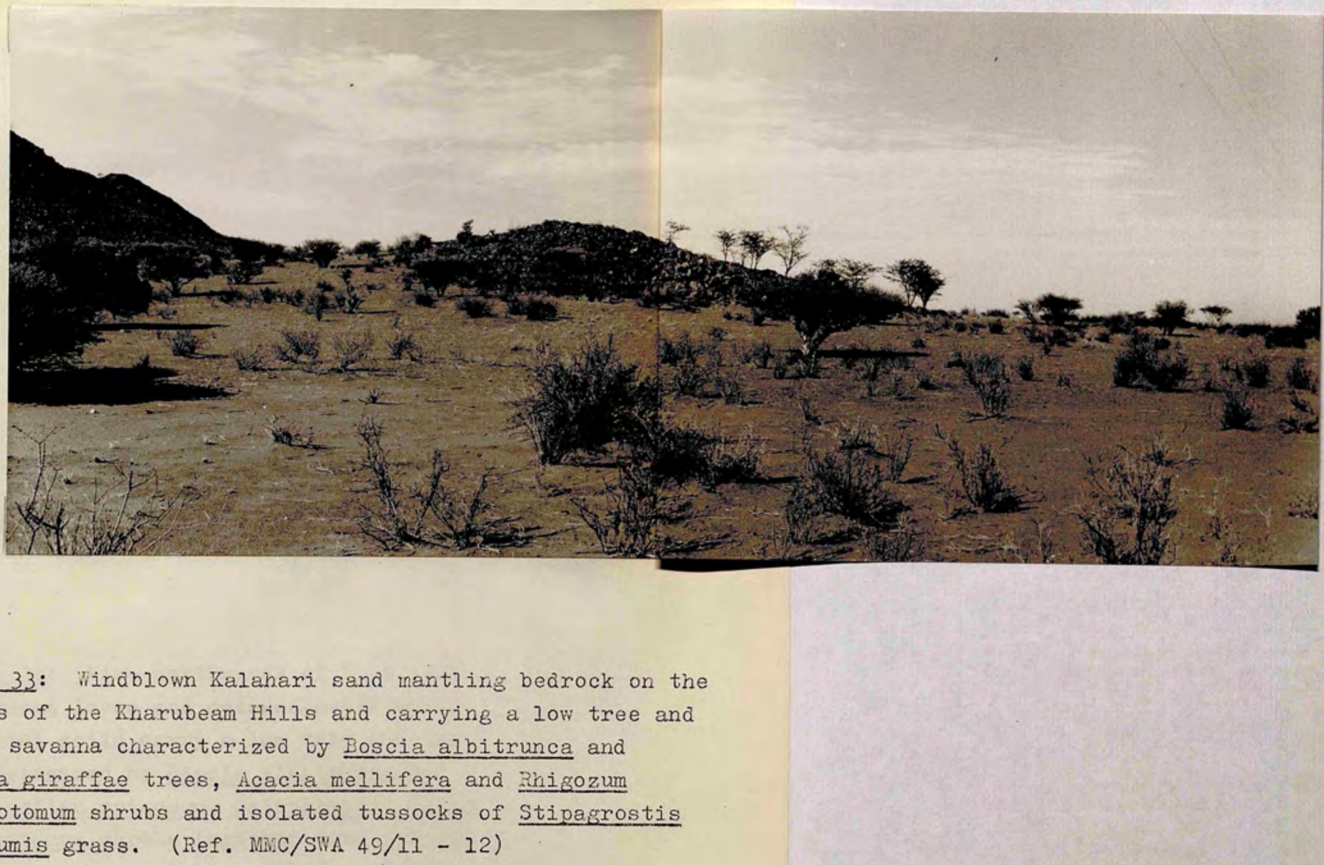


Plate 33: Windblown Kalahari sand mantling bedrock on the flanks of the Kharubeam Hills and carrying a low tree and shrub savanna characterized by Boscia albitrunca and Acacia giraffae trees, Acacia mellifera and Rhigozum trichotomum shrubs and isolated tussocks of Stipagrostis uniplumis grass. (Ref. MMC/SWA 49/11 - 12)

Plate 34: View northwards of flat plain underlain by weathered lavas and metasediments on the farm Wiese. The skeletal soils carry a low tree and shrub savanna characterized by Boscia albitrunca and Boscia foetida trees, Phaeoptilum spinosum, Catophractes alexandri and Rhigozum trichotomum shrubs together with the perennial grass Stipagrostis uniplumis. (Ref. MMC/SWA 50/18)

occupies the micaceous alluvium in the Schaf River delta and other areas of micaceous alluvial deposits.

Where a micaceous alluvium flanks the Schaf River, to the north of the poort on Wiese, a parkland dominated by Acacia giraffae trees occurs. Occasionally Phaeoptilum spinosum shrubs occur (Plate 35).

An associated low tree and shrub savanna - savanna grassland dominated by Petalidium parvifolium shrubs, occasional small Acacia giraffae trees and the perennial grass Stipagrostis uniplumis covers the stretches of silt and sand in wide stream courses. This physiognomic unit is also recognized in the cover of the silts and silty loams of pans in the area and is dominated by the annual grasses Eragrostis trichophora and Diandrochloa pusilla with Ziziphus mucronata and Diospyros lycioides trees with Acacia hebeclada shrubs on the peripheri.

The vegetation on the farms Strife and Gravenstein, to the south-west of the area covered by Fig. 47, falls into the low tree and shrub category. The vegetation on the linear sand dunes is dominated by Boscia albitrunca and small Acacia giraffae and Acacia haematoxylon trees, Phaeoptilum spinosum and Rhigozum trichotomum shrubs on the lower flanks of the dunes, the annual grass Schmidtia kalahariensis and the annual ground herbs Helichrysum argyrosphaerium and Tribulus zeyheri (Plate 32).

The "straate" between the dunes are dominated by the shrubs Rhigozum trichotomum and Phaeoptilum spinosum together with large Acacia giraffae and Boscia albitrunca trees and the annual grass Eragrostis trichophora.

From the use of aerial photographs and ground mapping it is evident that over the greater part of the area the vegetation follows very closely the various overburden and soil types outlined earlier.

Plate 35: Alluvial plain north of the Schaf River poort in the Knarubeam Hills. The parkland vegetation is dominated by *Acacia giraffae* trees with occasional *Phaeoptilum spinosum* shrubs. (Ref. MMC/SWA 50/34 - 36)

Bedrock outcrop forms 5 - 10% of the area and consequently some lineation is observed in the vegetation cover in those areas with very shallow or non-existent transported material. It can be concluded that, in general, the controlling factor for the vegetation is the soil type and, to a much lesser extent, the bedrock geology.

Chapter 10

THE KHARUBEAM HILLS AREA

The biogeographical/geobotanical investigations

The biogeographical/geobotanical investigations in the Kharubeam Hills area were prompted by the discovery of copper mineralization in amygdaloidal Opdam lava on the geochemical anomaly on Line 6 on the farm Mertens (Fig. 3) by Anglo Vaal geologists. The mineralized lava, with a total strike length of 400 metres, was later found to extend on to the farm Hexen Kessel.

Initial ground reconnaissance coupled with a study of aerial photographs suggested that there were no anomalous plant communities or indicator species associated with the mineralized horizon. Nevertheless, as the copper mineralization on Mertens was associated with a different rock type to that on Sib, geobotanical investigations were undertaken in order to ascertain what effect this mineralization had on the associated soils and vegetation. The methods followed in these investigations were the same as those outlined in Chapter 5.

A transect (transect 1, Fig. 48) was orientated to cross the mineralized horizon on Mertens. Soil samples were collected at 10 metre intervals at a depth of 10 cms and analysed by the acid leaching method followed by atomic absorption spectrophotometry.

The data obtained revealed an absence of any specific indicator species among the ground vegetation recorded (Fig. 49). _Fimbristylis exilis_ occurred at 100 N, but this occurrence did not coincide with

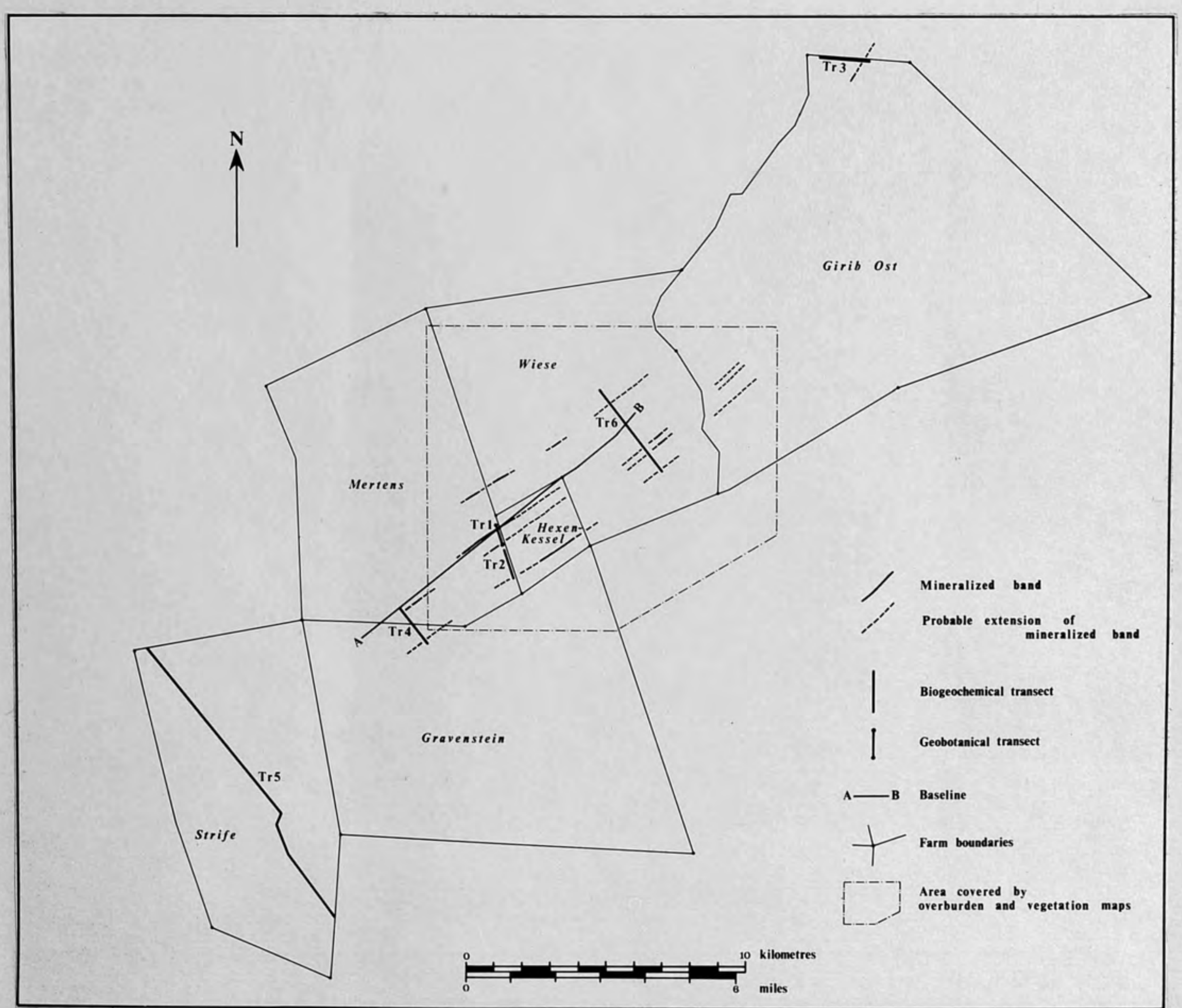


Fig.48: Location of transects 1 - 6, mineralized bands, probable extensions of mineralized bands and also the area covered by the overburden and soils map (Fig.45) and the vegetation map (Fig.47) in the Kharubeam Hills area

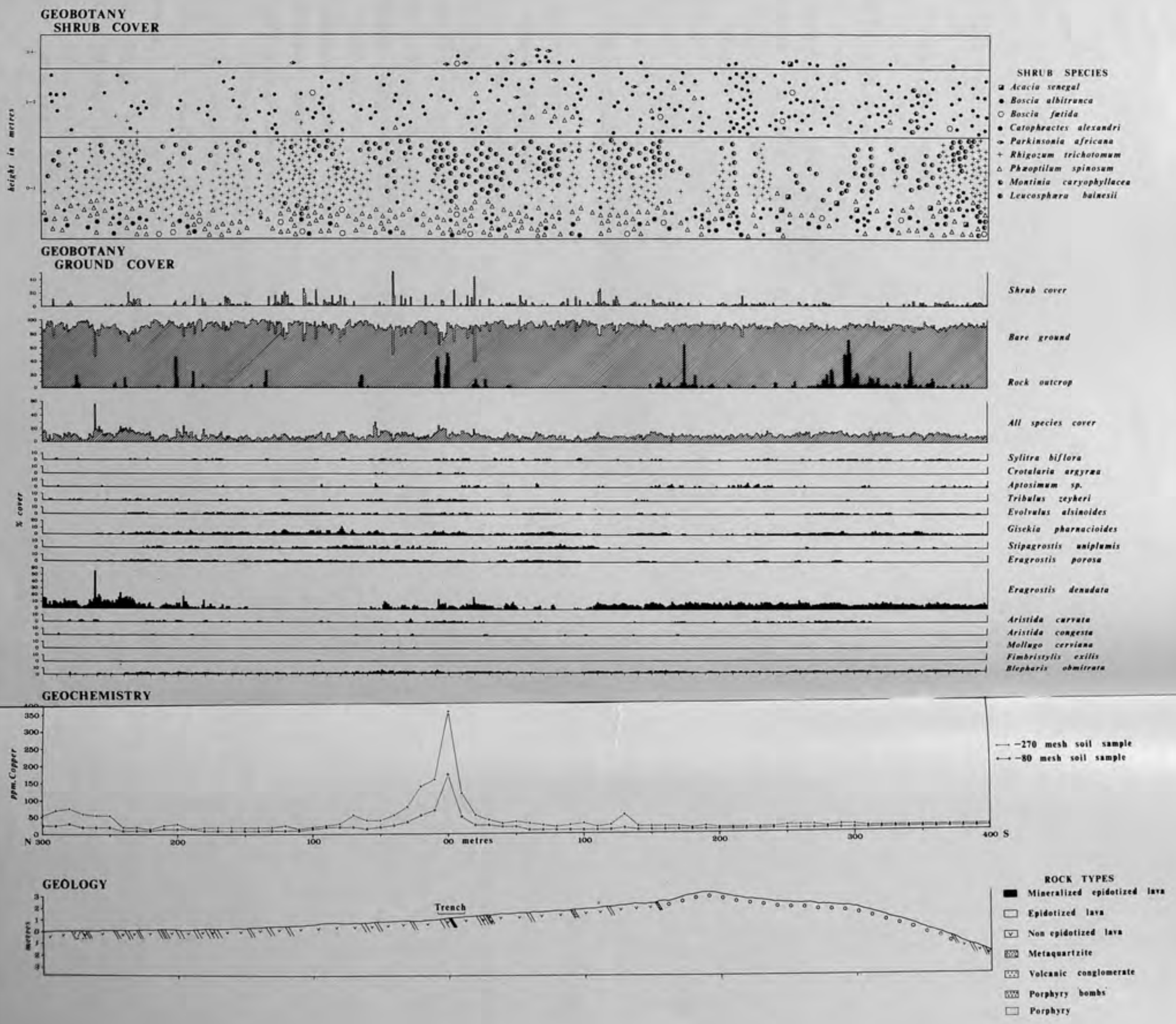


Fig.49: Transect 1 across the mineralized zone on the farm Mertens showing the relationship between the distribution of plant species and the geochemistry, relief and geology

the copper mineralization. Most species were evenly distributed and no significant changes occurred over the zone where the copper value in the -270 mesh fraction of the surface soil reaches 360 ppm. Between 220 and 270 N there was a concentration of Eragrostis denudata but this coincided with a small stream channel and was probably associated with increased moisture in the soil. Overall there was little difference in the composition of the ground vegetation over the lavas, metavolcanics, metasediments and porphyries.

Similarly the investigation revealed little difference in the composition of the tree and shrub layers, individual plants being relatively evenly distributed and of similar height throughout the area on the line. Some increase in the number of Acacia senegal trees over the porphyry was apparent, and an unexplained concentration of Parkinsonia africana trees occurred between 50 and 90 S.

Throughout the area the cover of trees, shrubs and ground species was very sparse. Bare ground averaged 90% and there were considerable areas of rock outcrop (Plate 36). Geological mapping and reconnaissance disclosed further bands of outcropping mineralized lavas and quartz veins on Mertens, Wiese and Hexen Kessel (Fig. 48 and Plates 37 and 38). Again the known indicator species of the Sib area were absent from these areas, and there were no significant changes in the vegetation either over the different bedrock units or over the mineralized zone. No reason for this was immediately apparent. The higher calcium content of the bedrock, by importing a higher base status to the soils weathered therefrom, may be important since high calcium levels counter high copper levels. The results of these investigations suggested that geobotany offered little promise in this particular environment and accordingly further studies were not pursued.

Plate 36: Vegetation associated with the mineralization in the vicinity of transect 1, Mertens and comprising Boscia albitrunca trees, Catophractes alexandri and Rhigozum trichotomum shrubs together with the woody herb Blepharis obmitrata and the perennial grass Stipagrostis uniplumis. Outcrop in the foreground is of mineralized Opdam lava. (Ref. MMC/SWA 20/30)

Plate 37: Mineralized Opdam lava outcropping through a cover of wind and water transported material on the farm Wiese. Vegetation of Phaeoptilum spinosum, Acacia mellifera, Catophractes alexandri and Rhigozum trichotomum shrubs and Boscia albitrunca trees. (Ref. MMC/SWA 50/17)

Plate 38: Mineralized Opdam lava outcropping through a cover of wind and water transported material on the western boundary of the farm Wiese. Vegetation of Phaeoptilum spinosum, Catophractes alexandri and Rhigozum trichotomum shrubs and Parkinsonia africana trees.
(Ref. MMC/SWA 50/10)

Chapter 11

THE KHARUBEAM HILLS AREA

The geochemical investigations

Although the geochemical investigations in the Sib area established background and anomalous copper levels in the soil it was decided that additional orientation studies should be carried out in the Kharubeam Hills area. This was due to the fact that the rock types of the Kharubeam Hills area differed from those of the Sib area, and consequently there might be changes in both the background and anomalous copper levels in the soils which in turn might possibly have differing effects on the vegetation of the area.

The orientation studies consisted of investigations to establish the mesh size fraction of the soil samples most likely to outline geochemical anomalies in this environment and also to ascertain the most suitable procedure for extraction of copper from the samples for analytical purposes.

Orientation geochemical studies

To establish which mesh fraction contained the most copper, two bulk samples were collected on transect 1, Mertens. One was collected in the anomalous zone at 00 point while the other was collected in the background zone at 200 N (Table 11). The technique applied to each sample is the same as that outlined in Chapter 6 for the bulk samples collected on transect 33, Sib.

Table 11: Mesh fraction content of bulk soil samples and copper content of each fraction. Transect 1, Mertens

Sample	Microns	Mesh fraction	Weight(g)	% of total sample	ppm Cu
200 N	490	-35	407.7	77.50	15
(Wt. 525.7 g)	250	-60	285.0	54.20	15
	170	-80	231.8	44.00	15
	125	-120	115.8	22.00	20
	74	-200	72.0	13.60	30
	53	-270	25.1	4.77	40
00	490	-35	410.5	77.80	180
(Wt. 527.6 g)	250	-60	307.5	58.30	210
	170	-80	243.7	46.10	215
	125	-120	119.7	22.70	250
	74	-200	75.4	14.30	340
	53	-270	27.4	5.20	450

The percentage (of total sample) was plotted against aperture size (microns) in order to establish the particle size distribution within each sample. The resultant graph (Fig. 22) shows that the finer fractions, which contain the clay particles, constitute 5% or less of each sample. Compared to the bulk samples collected on Sib (Table 6), the fine fractions (i.e. 53 microns or less) of the Mertens samples constitute a slightly greater part of each sample. The copper content of each mesh fraction was plotted against aperture size (microns), and from Fig. 22 it is seen that the coarser fractions of the samples (i.e. $>$ 170 microns) contained less copper than the fine fractions (i.e. $<$ 170 microns). As for the Sib results, the finest fraction analysed, i.e. 53 microns and less, gave the highest copper values. Similarly, from the results of this investigation, it is obvious that the copper adheres to the clay particles contained in the -270 mesh fraction (53 microns and less), and that this mesh fraction remains more suitable than the -80 mesh fraction for geochemical analysis in the Kharubeam Hills area. Although the peak copper value over the mineralization on Mertens is lower than that over the mineralization on Sib, the background copper values on Mertens appear to be slightly higher than background copper values on Sib, but no conclusions can be drawn as only two bulk samples were collected from each area.

As a result of the change of rock type between the Sib and Kharubeam Hills areas, studies were undertaken to establish the most suitable method for extracting the copper from the soil samples for detailed exploration purposes in the latter area. Three methods were investigated and these comprised acid leaching and the Stanton method of total copper extraction both followed by analysis by atomic absorption spectrophotometry, and the cold extraction method followed by colorimetric determination of copper content (see Appendix to Chapter 6). For this purpose soil samples collected at 20 metre intervals along transect 1, Mertens, and sieved to the -80 mesh fraction, were used.

The results showed that, as for the Sib investigations (Chapter 6), higher values were obtained by using the Stanton method (Fig. 24) in preference to acid leaching followed by atomic absorption spectrophotometry (Fig. 49), and that the values obtained from the latter were similar to those obtained from the cold extraction followed by colorimetric determination (Fig. 24). However, from Figs. 24 and 49 it is evident that while the Stanton and cold extraction methods show peak values of 5 and 8 times the background values respectively, the acid leaching method shows a peak value of 17 times the background value. This fact, together with the fact that the acid leaching method extracts approximately 88% of the total copper from the soil and is relatively simple in preparation, suggested that the acid leaching method followed by atomic absorption spectrophotometry was the most suitable analytical method for the geochemical work in the Kharubeam Hills area.

Due to the time factor, a detailed geochemical grid was not laid out across the zone of mineralization on Mertens, but soil samples were collected together with plant samples on the regional biogeochemical survey outlined in Chapter 13.

The only detailed geochemical investigation undertaken over the mineralized zone on Mertens was the work on transect 1. Soil samples were collected at 10 metre intervals at a depth of 10 cms along this line, and after being sieved to the -80 and -270 mesh fractions, were analysed for copper using the acid leaching method followed by atomic absorption spectrophotometry as outlined in the Appendix to Chapter 6. The resultant graph (Fig. 49) showed the expected increase in copper content of the soils over the mineralized horizon and also the following significant features:-

1. A pronounced surface slope from south to north and its accompanying drainage system has resulted in uneven dispersion of copper ions originating from the mineralized horizon. Consequently the copper content of the soils collected up to 70 N of the mineralized band is high.

2. Slightly higher copper levels in both the -80 and -270 mesh fractions in soil samples collected between 240 and 300 N may be due to a slight increase in the copper content of the volcanic conglomerate although no macroscopic mineralization was observed.

The soil samples collected at 20 metre intervals on transect 1, Mertens, were also measured for pH, and values ranging from 5.0 to 6.2 were recorded (Fig. 29). These values are similar to those obtained on transect 33, Sib, and generally fall within the optimum range (5.5 - 7.0) for absorption of metals by plants. The pH values are generally lower in soils over the quartz porphyry than in soils over the lavas, metavolcanics and metasediments.

As in the Sib area, the overburden is thin over the mineralization on Mertens and geochemistry proved successful in delineating the mineralized band, but elsewhere in the Kharubeam Hills area the extent and depth of the overburden is considerable. For this reason geochemistry was used as an exploration technique, but only as an aid to the geobotanical/biogeochemical investigations.

Chapter 12

THE KHARUBEAM HILLS AREA

The biogeochemical investigations

As the biogeographical/geobotanical investigations failed to reveal the presence of any specific indicator species or anomalous plant assemblage over the copper mineralization on the farm Mertens, possibly as a result of the different geological environment and the fact that copper in the soil might be in a form not readily available to the plants, biogeochemical investigations were undertaken. These investigations were aimed at establishing the physiological relationships between the plants and the soils in which they grow and also at an assessment of the value of the technique in the type of environment characteristic of the Kharubeam Hills. Additionally, the biogeochemical investigations were aimed at the delineation of known mineralization and the location of new areas of mineralization.

In an attempt to ascertain the behaviour of species characteristic of the area in respect of mineral uptake, samples of all the tree and shrub species occurring along transect 1, Mertens, were collected and analysed for copper by the dry ashing method followed by atomic absorption spectrophotometry as outlined in the Appendix to Chapter 7. Soil samples were collected at a depth of 10 cms at 10 metre intervals, and the -80 and -270 mesh fractions were analysed for copper by the acid leaching method followed by atomic absorption spectrophotometry. The analytical results of the three most common species sampled are tabulated in the Appendix to the thesis. The results are given in Fig. 50.

Of the species sampled, <u>Phaeoptilum spinosum</u> can be seen to take up and retain in its leaves and twigs more copper than the other species. Expressed on a dry weight basis the leaves and twigs of this species have background values of ± 5 and ± 6 ppm respectively. The peak values obtained over the mineralized bedrock are 87 ppm and 29 ppm respectively. Therefore the peak value obtained by the leaves over the mineralized zone represents an approximate increase of 17 times the background value, while the peak value obtained by the twigs represents an approximate increase of 5 times the background value. These results compare favourably with those obtained for the same species on transect 33, Sib.

It is also evident that the analysis of the leaves of <u>Phaeoptilum spinosum</u> provide a greater contrast between anomalous and background zones than do the twigs. Along the total length of the transect, the copper levels in the plant tissues reflect very accurately those in the soils. It is also evident that the high value obtained in the leaf sample of this species collected 1 metre S of 00 point suggests that the plant is rooting in the weathered zone of the mineralized band where it is dipping to the south.

Due to relief and drainage causing dispersion of copper in the surface soil to the north of the mineralized bedrock, and thus creating a wide geochemical anomaly, it is evident that the anomaly obtained by the analysis of <u>Phaeoptilum spinosum</u> samples is narrow and therefore represents a more accurate reflection of the actual width of the mineralized horizon.

As for the Sib area, the analysis of <u>Phaeoptilum spinosum</u> samples in the Mertens area shows that the species takes up relatively large amounts of

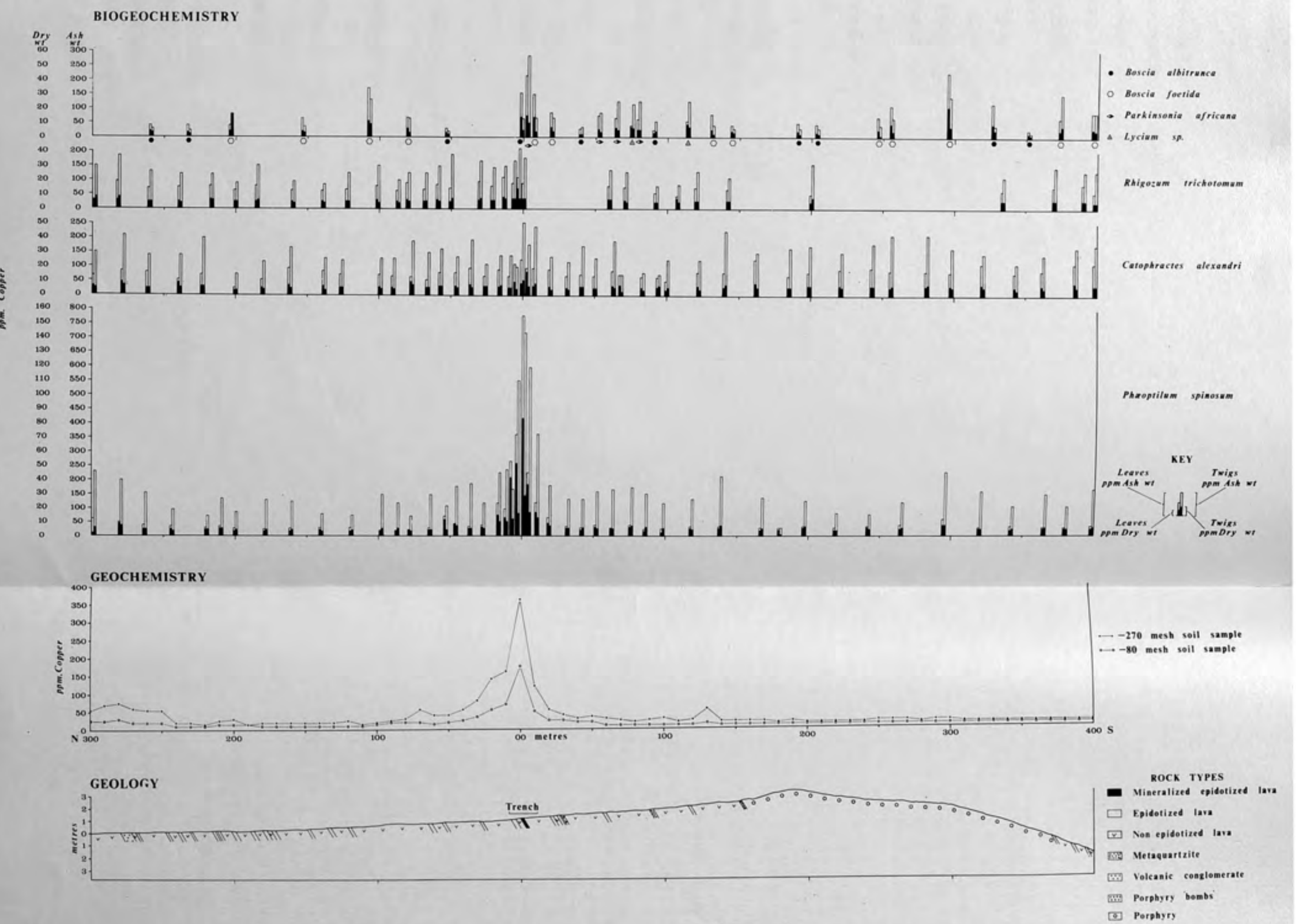


Fig.50: Transect 1 across the mineralized zone on the farm Mertens showing the copper content of the listed species together with the geochemistry, relief and geology

copper which are closely related to bedrock, and this species therefore offers promise in biogeochemical investigations in the Kharubeam Hills area.

The analysis of the leaf and twig samples of Rhigozum trichotomum reveals slightly higher levels of copper content of the tissues over the mineralized zone (Fig. 50). The leaves and twigs, expressed on a dry weight basis, both show background values of ± 5 ppm. The peak values obtained over mineralized bedrock are 14 ppm and 7 ppm respectively. This represents an approximate increase of 3 times the background value for the leaves and an approximate increase of 1.4 times the background value for the twigs. Overall the results suggested that Rhigozum trichotomum was less effective than Phaeoptilum spinosum as a sampling species, a fact which could be attributed to the difference in rooting habit.

The analysis of the leaves and twigs of Catophractes alexandri yielded results which were very similar to those obtained on transect 33, Sib. The copper values were slightly higher over the mineralized zone but they fluctuated in the background area. The leaves and twigs, expressed on a dry weight basis, both gave background values of ± 5 ppm. Peak values obtained by the leaves and twigs over the mineralization were 16 ppm and 10 ppm respectively. These peak values therefore represent an approximate increase of 3 times the background value for the leaves and an approximate increase of 2 times the background value for the twigs. As for the Sib area, Catophractes alexandri offered little promise for further biogeochemical investigations.

The trees Boscia albitrunca, Boscia foetida and Parkinsonia africana, and the shrub Lycium lancifolium were sampled wherever they occurred on the transect line, but as they were infrequent few samples could be collected and the results must be treated with caution.

Only ten samples of Boscia albitrunca could be collected for analysis (Fig. 50). The individual analyses show an uptake of copper in the plant tissues over the zone of mineralization which is more marked than that on Sib. This is probably due to the fact that the specimens sampled on Mertens were mature trees. Unfortunately, in the Kharubeam Hills area, Boscia albitrunca occurs too infrequently to be a useful species for routine sampling purposes.

Difficulties were experienced in the ashing of the Boscia foetida samples. Consequently erratic results were obtained in the analyses and comment is precluded.

Like those of Boscia albitrunca, the samples of Parkinsonia africana collected over the copper bearing horizon contained significantly more copper than those collected in background areas (Fig. 50). The ratio between peak copper values and background copper values in the plant tissues over anomalous and background zones for the four trees sampled was relatively high. The usefulness of this species for routine sampling purposes, however, is reduced by the infrequency of its occurrence.

As only two plants of the shrub Lycium lancifolium were sampled, no comments are possible regarding its use for routine biogeochemical sampling.

To establish the range of copper uptake of Phaeoptilum spinosum, Rhigozum trichotomum and Catophractes alexandri, graphs were prepared showing the relationships between copper content per ash weight and copper content per dry weight in the leaves and twigs of each sample. For this purpose the analyses of samples collected along transect 1, Mertens, were used. The scattergrams (Fig. 51), showing the copper content expressed per

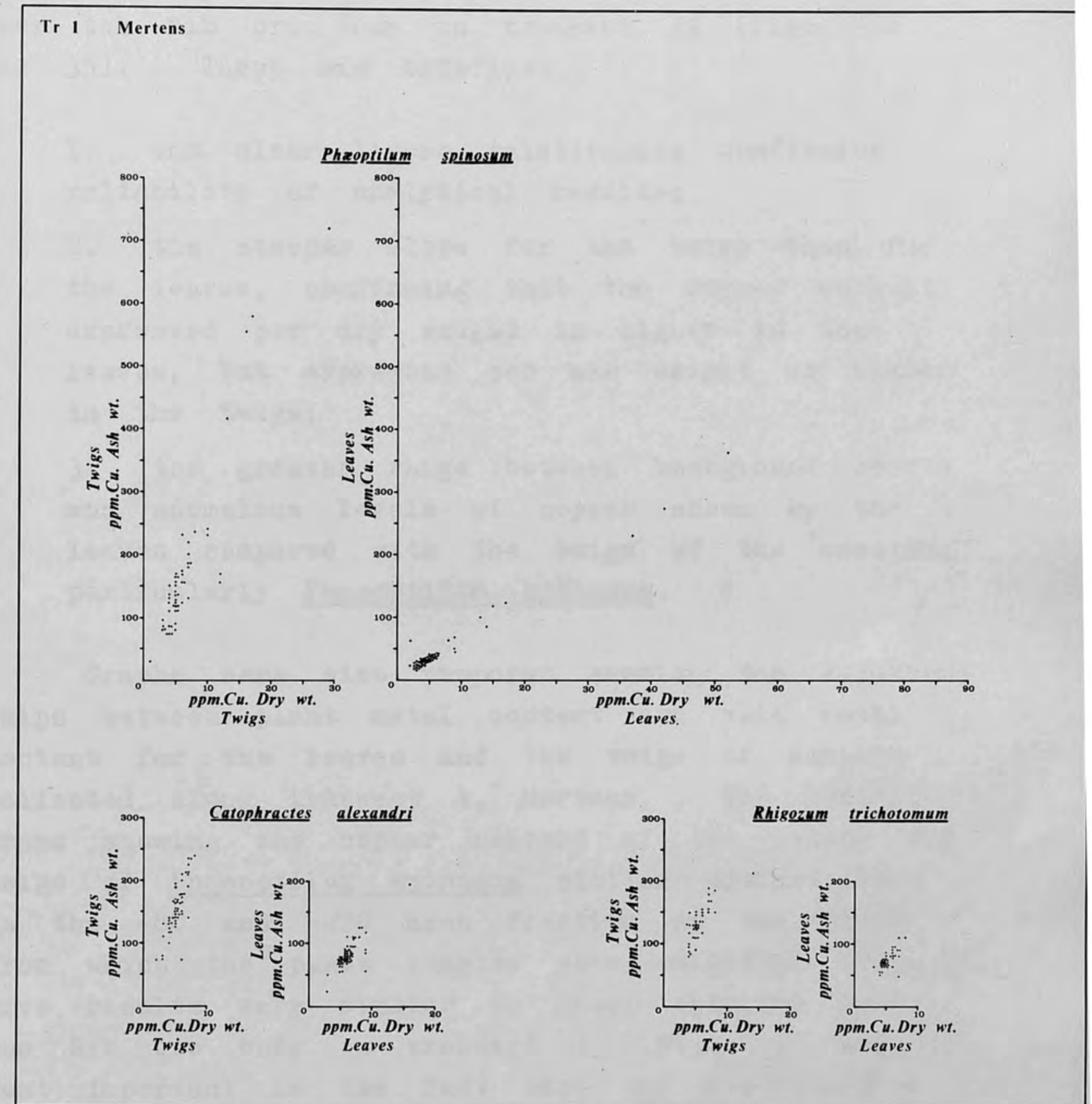


Fig.51: The relationship between the copper content expressed per dry weight of sample and that expressed per ash weight of sample in the leaves and twigs of Phaeoptilum spinosum, Catophractes alexandri and Rhigozum trichotomum collected along transect 1, Mertens

dry weight of sample plotted against the copper content expressed per ash weight of sample for the leaves and twigs of all three samples, reveal, in all three cases, similar results to those obtained over the Sib ore body on transect 33 (Figs. 34 and 35). These are briefly:-

1. the clear linear relationship confirming reliability of analytical results;

2. the steeper slope for the twigs than for the leaves, confirming that the copper content expressed per dry weight is higher in the leaves, but expressed per ash weight is higher in the twigs;

3. the greater range between background levels and anomalous levels of copper shown by the leaves compared with the twigs of the species, particularly Phaeoptilum spinosum.

Graphs were also prepared showing the relationships between plant metal content and soil metal content for the leaves and the twigs of samples collected along transect 1, Mertens. The scattergrams showing the copper content of the leaves and twigs of Phaeoptilum spinosum plotted against that in the -80 and -270 mesh fraction of the soils from which the plant samples were collected (Fig. 52), give results very similar to those obtained over the Sib ore body on transect 33 (Figs. 36 and 37). Most important is the fact that the relationships are linear. However these are more obvious when the plant metal content is expressed on the ash weight basis, but a similar pattern would have emerged had a larger scale been used for plotting the plant metal content on a dry weight basis. The conclusions, therefore, remain the same as those outlined for transect 33, Sib.

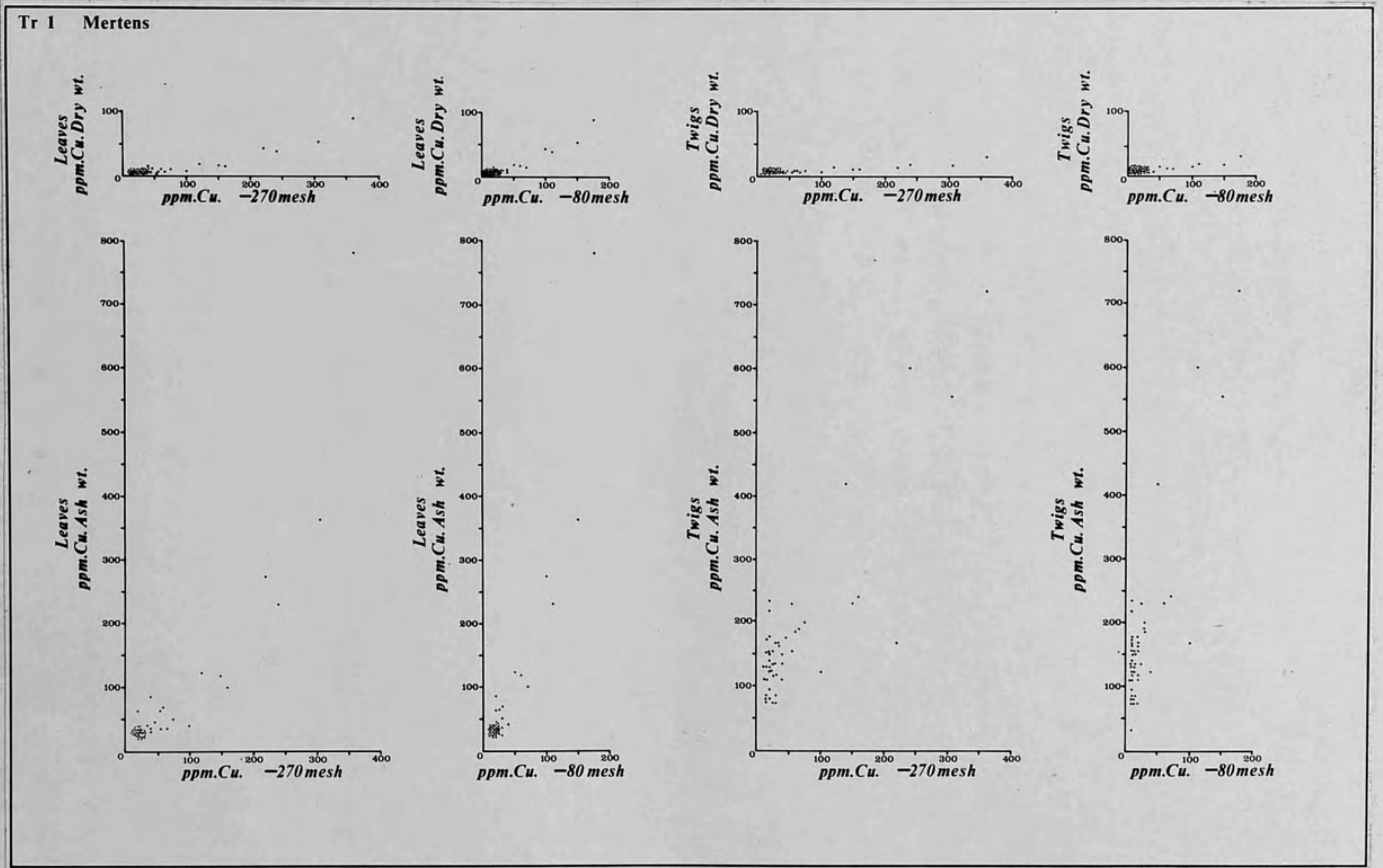


Fig. 52: The relationship between the copper content of the leaves and twigs of *Phaeoptilum spinosum* sampled along transect 1, Mertens, and the content of the -80 and -270 mesh fractions of the soil sampled at 10cms at 10 metre intervals

Iron content of plants

Due to the fact that high levels of toxic metals in the soils may depress the uptake of iron by plants, thereby causing chloritic symptoms, the plants growing along transect 1, Mertens, together with the soils, were analysed for their iron content. This was done to establish whether any relationship existed between the iron content of the soils and that of the plants in this area. Similar to the investigation carried out on transect 33, Sib, (Fig. 39), the results were inconclusive as the analytical values were very erratic (Fig. 53). However a general increase in the iron content of the soil in both the -80 and -270 mesh fractions, between 150 and 300 N on the transect line, does appear to be reflected in the plant analyses when expressed on a dry weight basis. The origin of the increased iron content of the soil in this zone appears to be a lateritic horizon at a depth of 0.5 metres.

Investigation of the rooting systems of selected shrub species

In order to confirm the findings of a root system survey carried out on Sib and described in Chapter 7, the root systems of Phaeoptilum spinosum, Catophractes alexandri and Rhigozum trichotomum were exposed on Mertens and measured. The results were very similar to those on Sib and confirm that Phaeoptilum spinosum has a well developed taproot system, while Catophractes alexandri and Rhigozum trichotomum have lateral root systems. The relatively good results obtained in the biogeochemical survey on transect 1, Mertens, by Phaeoptilum spinosum may well be explained by the ability of its well developed tap root system to penetrate the zone of weathered bedrock where metals are readily absorbed if the bedrock is mineralized and lies in the ground water zone. As in the Sib area, the lateral root systems of Catophractes alexandri and Rhigozum trichotomum may explain the relatively low levels of copper in their tissues over the mineralized horizon on transect 1, Mertens, and the resulting poor contrast between background and peak anomalous values.

The selection of species suitable for biogeochemical investigations

The results of the biogeochemical investigations carried out on the farm Mertens confirm those obtained on the farm Sib, and suggest that the uptake of minerals from the soil by plants is influenced by the same factors in both areas.

Of the species sampled, Phaeoptilum spinosum is the most suitable for regional biogeochemical investigations since it has a high ratio between peak copper values and background copper values in the plant tissues over anomalous and background zones, a deep tap root system and occurs frequently in the area.

Boscia albitrunca and Parkinsonia africana both have penetrating tap roots and relatively high ratios between peak and background copper values in their tissues over anomalous and background zones, but their frequency of occurrence limits their use in regional biogeochemical investigations.

Catophractes alexandri and Rhigozum trichotomum both occur frequently, but they have lateral root systems and low ratios between peak and background copper values in their tissues over anomalous and background zones.

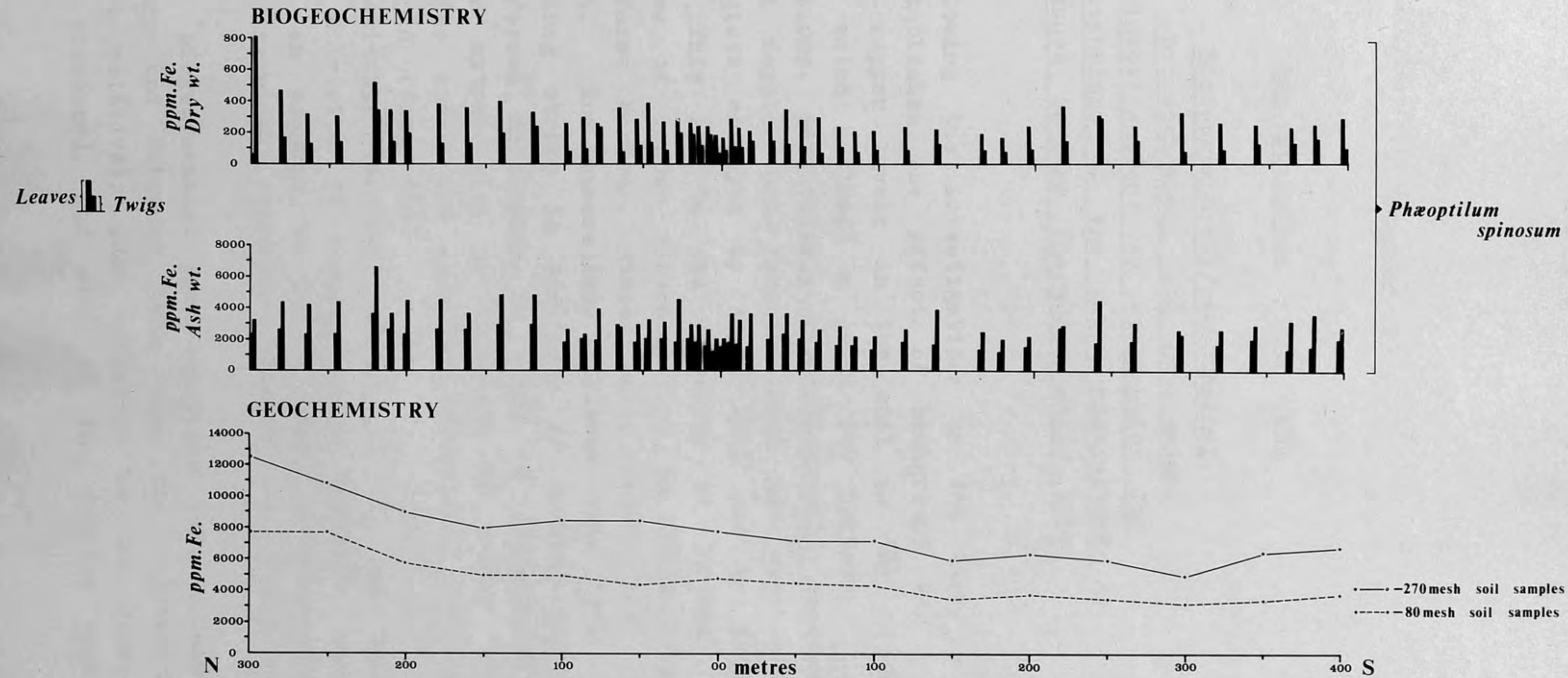


Fig.53: The iron content of the leaves and twigs of Phaeoptilum spinosum sampled along transect 1, Mertens, and that of the -80 and -270 mesh fractions of soils sampled at 10cms at 50 metre intervals

Chapter 13

THE KHARUBEAM HILLS AREA

Biogeographical/geobotanical, biogeochemical and geochemical investigations in exploration for extensions of the known mineralized zones in the Kharubeam Hills area

Following the investigations on the farm Mertens, which established the effect of background and anomalous copper levels in the soil on the vegetation and which outlined a guide for further investigations, particularly biogeochemistry, regional geological mapping and reconnaissance was undertaken by geologists employed by Anglo Vaal and by the author. This led to the discovery of further occurrences of copper mineralization in Opdam lavas on the farms Mertens, Wiese, Hexen Kessel and Girib Ost. The mineralized horizons were then traced along strike in the area of outcrop and their inferred extensions in areas of transported overburden extrapolated by reference to marker horizons. The known and inferred mineralized horizons were mapped (Fig. 48).

A suitably located baseline (A - B) was marked out and a series of biogeochemical transects was sited in an attempt to locate possible extensions of the mineralized horizons beneath the overburden (Fig. 48).

The biogeochemical investigations were undertaken in January and February 1970, when the vegetation was in a relatively poor condition as the rains had not commenced, and many of the species were leafless. As a result only twig samples of *Phaeoptilum spinosum* were collected. Where possible these were taken at 10 or 20 metre intervals, but where the species occurred infrequently samples were taken wherever the plant occurred along the transect line. Soil samples were taken at 10 cms at each plant sampling site, and the -270 mesh fraction analysed by the acid leaching method followed by atomic absorption spectrophotometry as outlined in the Appendix to Chapter 6.

Plant samples were analysed in the Bedford College laboratories by the dry ashing method followed by atomic absorption spectrophotometry, and repeat analyses were carried out on split samples in the Anglo Vaal laboratories using the acid leaching method followed by atomic absorption spectrophotometry (Appendix to Chapter 7).

The biogeochemical investigations on the farms Mertens, Gravenstein, Wiese, Girib Ost and Strife

Three transects were undertaken in an attempt to locate zones of copper mineralization on the farms Mertens, Gravenstein and Wiese. The first of these, transect 2, investigated the area covered by alluvium deposited during the 1933/34 flood with the objective of locating the southern-most band of mineralization on Hexen Kessel (Fig. 48). It produced discouraging results (Fig. 54). Somewhat erratic copper values were found in the soils throughout the transect while the levels in the plant samples were generally low. As the depth of the alluvium was only between 1 and 3 metres it was concluded that the higher copper values in the soil were related to transported material and not to concealed bedrock.

A second transect, transect 4, was sited to the south-west of transect 2, in an attempt to

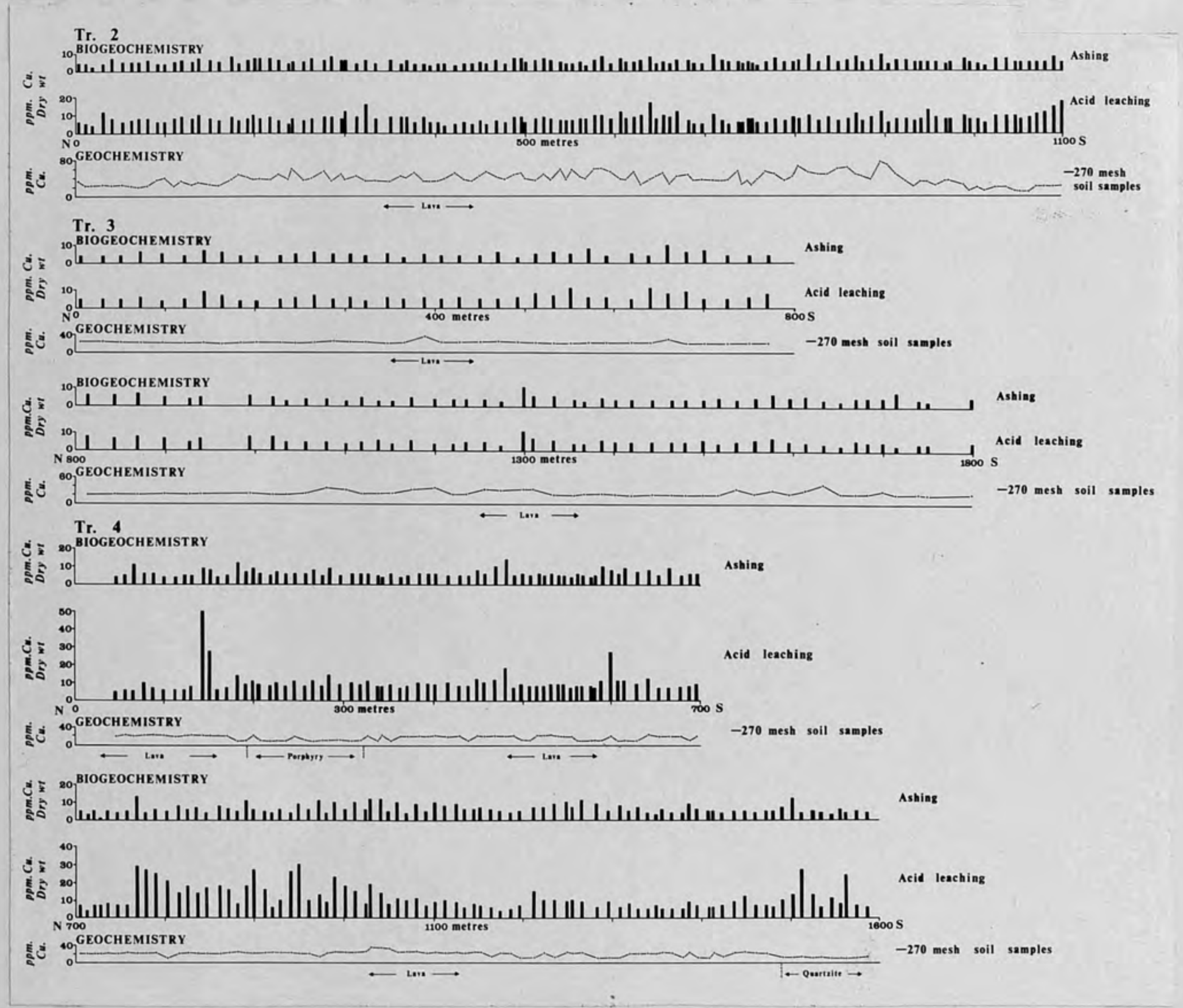


Fig.54: The copper content of plant samples collected along transects 2, 3 and 4 in the Kharubeam Hills area together with that of the -270 mesh fraction of the soils sampled at 10cms at the same sites

locate an extension of the southern-most mineralized horizon on the farm Hexen Kessel which had already been uncovered on the road running parallel to the Mertens - Gravenstein boundary fence. The transect, which was aligned roughly parallel to transect 2, was extended in a north-westerly direction to the baseline with the aim of locating a possible extension of another mineralized band already known to run parallel to, and immediately south of, the baseline (Fig. 48).

The results (Fig. 54) of the analyses of the samples collected along transect 4 posed problems. Analyses of the plant samples following acid leaching indicated highly anomalous levels of copper at 140 S and 150 S and also at 600 S. These values were repeated on re-analysis. They were not obtained, however, when the samples were analysed following dry ashing procedures. Analysis of the soil samples yielded only low background copper levels. Uncertainty over the results, and the possibility that the plants might be detecting copper mineralization in concealed bedrock, prompted trenching along the line between 142 S and 158 S from origin (Fig. 55). This trench exposed weathered Opdam lava at a depth of one metre which showed no visible evidence of mineralization. The section also revealed a depth of 1.9 metres of windblown sand at 14 S. The root systems of *Phaeoptilum spinosum*, *Rhigozum trichotomum* and *Petalidium parvifolium* were also exposed.

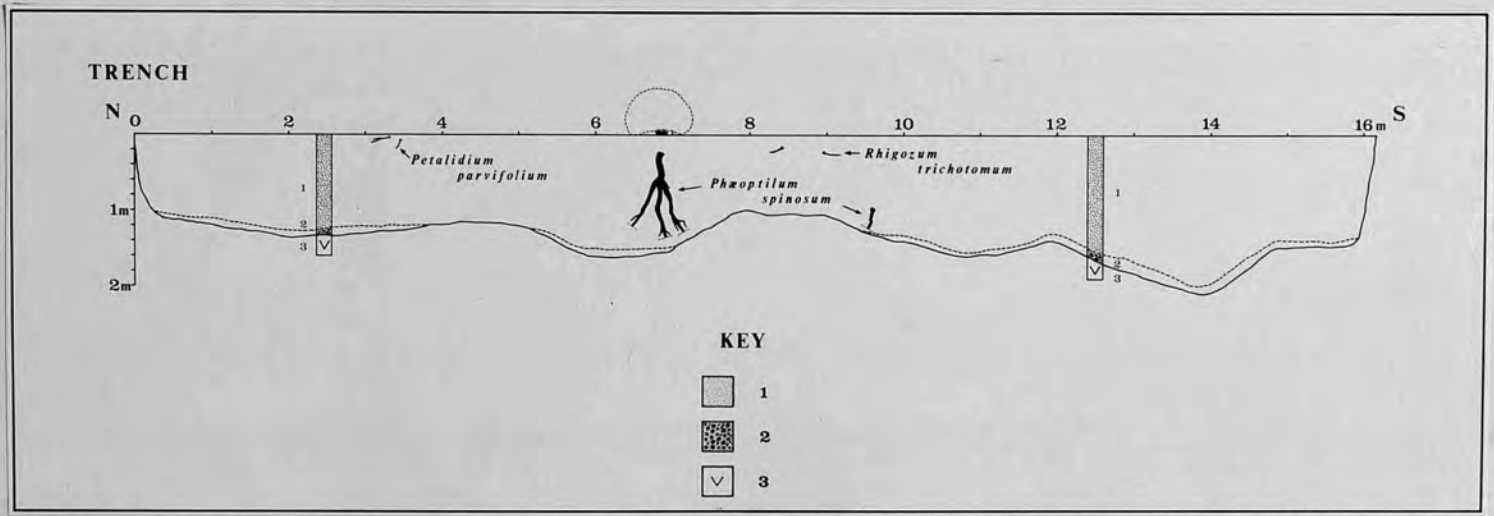
A third transect, transect 6, was then run approximately parallel to transects 1 and 2 and some six kilometres to the north-east of them on the farm Wiese (Fig. 48). The object was to locate possible extensions of the mineralized horizons in the Opdam lavas which alternate with bands of effusive porphyry. In this area the easily weathering lavas form depressions filled with some 1 to 4 metres of alluvium, whereas the porphyries outcrop in a succession of low but prominent ridges. The analytical results (Fig. 56) revealed the absence of any significant geochemical anomalies. The variations in the copper values may be related directly to the geology, with higher values over the areas of alluvium.

The analysis of the plant samples suggested possibly anomalous copper levels at 1900 S, 2780 S and 3155 S. These occurred when the samples were analysed following both the dry ashing and acid leaching methods. Pits dug on these anomalies failed to reveal any bedrock mineralization.

A further transect, transect 3, was sited some sixteen kilometres to the north-east of transect 6, on the boundary of the farm Girib Ost (Fig. 48). This transect was sited in an attempt to locate an extension to a mineralized horizon approximately 800 metres south of the northern boundary of the farm Girib Ost. Here bedrock is buried under 0.5 to 1 metre of mixed colluvium and skeletal soil on the steep side of a hill. No anomalous copper values were obtained from the plant and soil samples (Fig. 54).

Finally, transect 5 was run on the farm Strife some eight kilometres south-west of transect 4 (Fig. 48). This was twelve kilometres in length and was located in a "straat" between, and parallel to, the linear dunes. The thickness of the alluvium in the "straat" between the dunes was unknown, but it was hoped that biogeochemical investigations might locate any mineralization which might be present as an extension of the copper bearing horizon on the farms Mertens and Hexen Kessel and which here would be buried beneath the alluvium.

The analysis of plant and soil samples collected along this line yielded what appeared to be significant coincident biogeochemical and geochemical copper anomalies between 11400 and 11500 metres SE from origin (Fig. 56). Maximum values of 65 ppm copper were obtained in the -270 mesh fraction of the soil



1. Fine to medium-grained windblown sand, containing 10 - 15% angular to subangular vein quartz pebbles (1 - 2 cms diameter).

2. Coarse gravel consisting of 95% subangular to rounded vein quartz pebbles in a fine to medium-grained sandy matrix. Angular fragments of dark coloured, fine-grained, weathered, epidotized Opdam lava (10 - 15 cms diameter) constitute the remaining 5%.

3. Greyish to bluish-green, soft, fine-grained, massive Opdam lava (possibly some tufaceous material). Epidote content variable but if present is in the form of amygdaloidal fillings. Sericite streaking and chlorite patches lend a mottled appearance. Varying degrees of shearing.

Fig.55: Profiles through the soil, overburden and weathered bedrock together with the root systems of Phaeoptilum spinosum, Rhigozum trichotomum and Petalidium parvifolium exposed in a trench dug on transect 4, Mertens

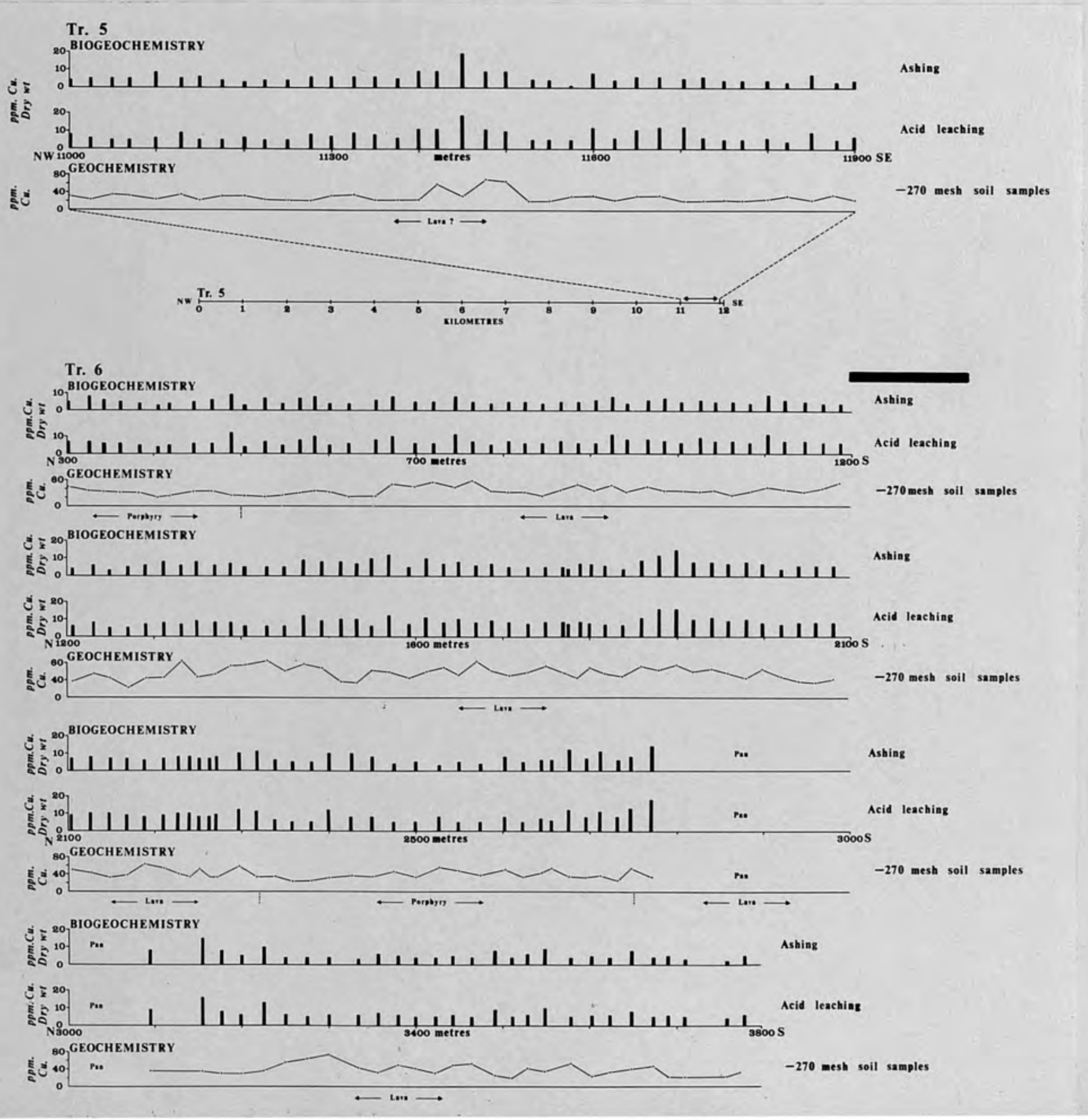


Fig.56: The copper content of plant samples collected along transects 5 and 6 in the Kharubeam Hills area together with that of the -270 mesh fraction of the soils sampled at 10cms at the same sites

sampled at 11475 metres SE, and 20 ppm copper in the twigs of Phaeoptilum spinosum collected at 11450 metres SE. Anomalous copper values in the twigs of the sample were obtained by analysis following both the dry ashing and acid leaching procedures. The information regarding this anomaly was passed on to the geologists employed by Anglo Vaal, but unfortunately, so far as the author is aware, it was not investigated by trenching or drilling.

With the possible exception of the biogeochemical/geochemical anomaly located on transect 5, the lack of success in locating mineralization may be attributed to the fact that mineralization in the lavas tends to occur in lenses of restricted or discontinuous development. From areas of known mineralization it has been ascertained that these lenses vary from a few metres to a maximum of 500 metres in extent. Frequently the mineralization is associated with vein quartz.

Only a small number of transects were undertaken and on these sampling was undertaken at 10 to 25 metre intervals. The transects may have been located across areas of barren bedrock and thereby have missed areas containing copper bearing lenses.

The results obtained along transect 5 suggest that biogeochemical investigations may be successful in locating mineralized bedrock beneath a deep cover of alluvium and it is particularly disappointing that the results could not be verified by follow-up drilling.

PART IV

Chapter 14

CONCLUSIONS

The investigations described in the preceding chapters have shown significant relationships between the distribution of vegetation associations and plant communities and environmental conditions, and have permitted an assessment of the role of biogeography/ geobotany, biogeochemistry and geochemistry in exploration for copper ores in areas where bedrock outcrops and where it is concealed beneath transported overburden. The results of the investigations may now be summarised.

The relationships between vegetation distribution and the physical environment

In the first place, the investigations have shown that distinctive vegetation associations characterize areas with particular types of soils and overburden. Secondly, they have shown that in areas of near surface bedrock different associations distinguish lithologically distinct geological units.

Within the vegetation associations individual plant species occur within a given range of copper levels in the soils at rooting depth. Where toxic conditions occur only specific indicator species may be present and under excessive conditions even these may be absent and the ground may be bare.

The small shrub Helichrysum leptolepis, already established as a copper indicator plant in the Witvlei area east of Windhoek, grows only in soils of which copper levels of 100 ppm and 200 ppm are found in the -80 and -270 mesh fractions respectively. This species occurs along with Fimbristylis exilis over the copper bearing tilloid on the farm Sib, where it constitutes a distinctive geobotanical anomaly marked by the absence of the characteristic species of the background vegetation. In other parts of the Gamma concession Helichrysum leptolepis may germinate in soils containing less than 100 ppm and 200 ppm copper in the -80 and -270 mesh fractions respectively. These plants, however, will not flourish but will die or remain stunted in growth. Both in the vicinity of the Sib geobotanical anomaly and in other areas within the concession, the annual grass Aristida congesta grows in soils containing relatively high levels of copper. This plant is a hardy pioneer and has a high tolerance range.

In the Kharubeam Hills area no indicator species were present in the areas where copper mineralization occurs in lavas on the farms Mertens, Wiese, Hexen Kessel and Girib Ost. The investigations failed to provide a conclusive reason for this.

Generally speaking, the investigations led to the conclusion that the extent of transported overburden masked the relationships between vegetation associations and bedrock geology, and hence limited the use of geobotany as a prospecting tool in the Gamma concession which could be regarded as characteristic of the western fringes of the Kalahari. Here biogeochemical techniques offered greater promise in mineral exploration.

An assessment of the role of geobotany, biogeochemistry and geochemistry in mineral exploration on the western fringes of the Kalahari

The location of known copper mineralization on the farms Sib and Mertens within the Gamma concession permits an assessment of the role of geobotany in mineral exploration in an environment characteristic of the western fringes of the Kalahari.

The studies have shown that biogeographical/geobotanical investigations involving a combination of aerial photograph interpretation and field surveys may be used on a regional basis to assist in the mapping of soils, overburden and bedrock geology and to delineate target areas of anomalous vegetation for detailed work. The initial reconnaissance investigations must be undertaken by personnel with geographical and botanical training but they can be carried out rapidly and relatively cheaply. Once the plant species have been identified, the detailed follow-up investigations can be performed by suitably trained field assistants.

Within the Gamma concession area, the application of biogeography/geobotany is complicated by the complex physiography which is the legacy of several geomorphological cycles operating under changing climatic conditions in the past. Consequently detailed geomorphological investigations are prerequisite before biogeography/geobotany can be widely applied to prospecting in an environment characteristic of the western fringes of the Kalahari. These remarks, however, are equally valid for other exploration techniques.

The geochemical investigations have confirmed the value of the technique in areas of near surface bedrock but have also revealed its limitations in areas of transported overburden in this particular environment.

Most important, the investigations established the value of biogeochemistry, both in areas of near surface bedrock and in those where there are considerable thicknesses of water borne and wind transported overburden. Indeed the investigations suggested that biogeochemistry had advantages over geochemistry in areas where transported overburden concealed bedrock. One widely distributed, deep rooting shrub species, Phaeoptilum spinosum, was found to be a particularly useful species for biogeochemical sampling. Over the area as a whole the main constraint on the use of biogeochemistry as a prospecting tool is the sparsity of the vegetation cover and the infrequent occurrence of the deeper rooting species. As was the case with geobotany, orientation biogeochemical investigations must be undertaken by personnel with geographical and botanical training, but routine sampling and follow-up investigations may be carried out by trained field assistants.

The overall exploration programme in the Gamma concession area suggested that such copper mineralization as was found was either of low grade, as on the farm Sib where it occurs in a tilloid, or of a higher grade but of sporadic lens-like occurrences as in the Opdam lavas on the farms Mertens, Wiese, Hexen Kessel and Girib Ost. Such mineralization is difficult to detect by any technique and the fact that it was found during the geobotanical, biogeochemical and geochemical investigations is testimony to their value in an environment characteristic of the western fringes of the Kalahari.

APPENDIX

I : The role of copper in plant physiology

Biogeochemical investigations examine the direct relationship between the chemical composition of plants and that of the soil in which they grow. In order to understand the results obtained from analysis of plant tissues, it is necessary to understand the basic plant physiology.

Most plants contain the following ten macro-nutrient elements (C, H, O, N, P, S, K, Ca, Mg, Fe) and five micro-nutrient elements (B, Mn, Zn, Cu, Mo) amongst others. These macro-nutrient elements are mainly constituents of proteins, cell walls or mechanical structures, while the micro-nutrient elements are primarily catalytic and generally do not have any structural function.

Copper is an essential micro-element for all plants, and serves a physiological function common to all living cells. Several plant enzymes such as polyphenol or catechol oxidase, tyrosinase, laccase and ascorbic acid oxidase, contain copper. These enzymes are concentrated in the chloroplasts of green leaves and bring about the oxidation of organic compounds by means of molecular oxygen during the primary light reaction of photosynthesis. There is also evidence that copper is concerned with the oxidation of iron in the plant.

Plants require only very small amounts of copper but if insufficient is available in soluble form, deficiency symptoms develop and death may result. Excessive concentrations of available copper can be highly toxic and may cause death or prevent germination of many species (Stiles 1961).

Most plant species have some regulating mechanism which controls the uptake of copper into their tissues, but some may concentrate copper far in excess of their normal physiological needs (Marston 1952).

The uptake of nutrients in plants with special reference to copper

The roots of plants are powerful sampling mechanisms and collect aqueous solutions from a large volume of moist ground below surface. These solutions form a source of inorganic salts that are absorbed and ultimately deposited in the upper parts of the plant. Biogeochemistry detects only those metals capable of moving in solution.

Copper occurs in the soil with Fe, Mn and Zn as cations which form insoluble salts such as sulphate, chloride, carbonate and phosphate. For absorption by plants, copper must be in a soluble form in the soil moisture and in a readily exchangeable form. Available copper consists of ions that are either dissolved in the soil moisture or adsorbed on the clay minerals in a readily exchangeable form. The exchangeable copper, however, may be strongly adsorbed by organic matter, thereby forming stable complex compounds in which form it in non-exchangeable. Biogeochemical responses are related to such variables as soil pH, exchange capacity and complex factors controlling metal mobility in this environment.

Some ions may be passively absorbed, i.e. free diffusion occurs across a membrane to give equilibrium with no metabolic energy involved. Most ions, however, are actively absorbed and both anions and cations can be absorbed against concentration gradients. The transport of ions into root cells takes place with the possible aid of a carrier compound or molecule present in the cell membrane. The compound or molecule forms a loose specific binding with the ions, and the entire complex moves across the cell membrane to dissociate on the inside of the cell, resulting in the release of the ions. Some of the nutrient ions entering the root will remain in the root cells while the majority are transported to the aerial portions of the plant.

The amount of copper absorbed by plants increases in relation to the amount in the rooting medium, but is greatly affected by the pH of the soil in the vicinity of the root hairs. The high concentration of H^+ ions in the immediate vicinity of the roots results in some of the metal bound to the lattice of soil minerals being released and extracted over and above what is readily exchangeable (Jacobsen 1959); this may be the decisive factor in different levels of uptake by different plant species. Previous studies have shown that the optimum availability pH range for copper is 5.5 to 7.0.

An investigation of the availability to plants of copper adsorbed on the surface of lime particles in soil systems has suggested that some decrease occurs with the application of lime (up to 5%) but that increased lime applications do not reduce copper availability significantly (Brown and Jurinak 1963). It thus appears that copper remains available to plants in areas of increased lime content of the soil. This was confirmed by the investigations described in Chapter 7.

II : Tables of analytical results

The results of the analyses of samples of *Phaeoptilum spinosum*, *Acacia mellifera*, *Boscia albitrunca*, *Rhigozum trichotomum*, *Catophractes alexandri* and *Petalidium parvifolium* on transect 33, Sib and those of *Phaeoptilum spinosum*, *Rhigozum trichotomum* and *Catophractes alexandri* on transect 1, Mertens are tabulated on pages 238 to 261.

The plant samples comprised unmilled material and were analysed by the dry ashing / acid digestion method followed by atomic absorption spectrophotometry. The soil samples were analysed by the acid leaching method followed by atomic absorption spectrophotometry. All the analyses listed in the tables were carried out in the Bedford College laboratories.

Abbreviations

L	=	leaves
T	=	twigs
fr.	=	fraction
min.	=	mineralized

Phaeoptilum spinosum - Analyses of plant and soil samples from transect 33, Sib.

Sample no.	Collection Site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4032	23N	L	14.39	460	66	115	140	
		T	1.86	520	10			
4033	30N	L	13.08	505	66	115	285	
		T	3.36	680	22			
4034	40N	L	17.23	440	75	105	285	
		T	2.73	550	15			
4035	50N	L	15.65	125	20	95	233	
		T	2,81	420	12			
4036	60N	L	17.57	70	12	30	100	
		T	3.72	353	13			↑
4037	70N	L	17.24	80	13	20	40	
		T	3.98	268	10			
4038	83N	L	16.70	80	13	30	40	Quartzites
		T	3.90	309	12			
4039	88N	L	19.16	35	6	10	20	
		T	3.47	170	6			↓
4040	100N	L	16.45	35	5	10	20	
		T	3.49	150	5			
4041	110N	L	16.79	35	5	20	30	
		T	3.49	194	6			
4042	140N	L	15.69	52	8	20	40	
		T	3.88	165	6			
4043	160N	L	17.39	46	7	10	20	
		T	2.55	160	4			
4044	176N	L	15.76	46	7	10	10	
		T	3.32	210	7			
4045	200N	L	15.99	30	5	10	10	
		T	3.49	138	5			
4046	220N	L	15.83	25	4	10	20	
		T	4.33	86	4			
4047	240N	L	15.17	35	5	10	10	
		T	5.90	80	5			
4178	3S	L	13.95	312	43	95	153	Mineralized tilloid
		T	3.47	375	13			

Phaeoptilum spinosum - Analyses of plant and soil samples from transect 33, Sib.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant) per ash wt.	ppm Cu (plant) per dry wt.	ppm Cu (soil) -80 mesh fr.	ppm Cu (soil) -270 mesh fr.	Rock type
4179	9S	L	14.74	370	54	140	440	Mineralized tilloid
		T	2.49	480	11			
4180	20S	L	15.26	280	42	225	340	
		T	3.57	670	23			
4181	30S	L	15.67	330	51	280	700	
		T	4.38	470	20			
4182	36S	L	17.30	335	57	225	450	
		T	3.97	443	17			
4183	50S	L	17.90	610	109	215	467	
		T	3.75	393	14			
4184	93S	L	15.38	443	68	225	510	
		T	5.60	540	30			
4185	100S	L	17.36	415	72	335	678	
		T	5.34	430	22			
4186	116S	L	19.15	160	30	170	377	
		T	3.95	345	13			
4187	134S	L	15.90	380	60	150	387	
		T	5.04	455	22			
4188	160S	L	17.26	268	46	115	285	Quartzites
		T	4.92	255	12			
4189	173S	L	15.35	470	72	130	285	
		T	4.31	490	21			
4190	190S	L	16.22	312	50	95	233	
		T	4.84	380	18			
4191	201S	L	19.28	98	18	105	240	
		T	5.05	268	13			
4192	220S	L	19.01	170	32	75	187	
		T	5.03	233	11			
4193	244S	L	17.74	145	25	40	87	
		T	3.61	250	9			
4194	265S	L	18.18	90	16	20	40	
		T	3.70	230	8			
4195	280S	L	14.29	90	12	20	20	
		T	3.43	228	7			

Phaeoptilum spinosum - Analyses of plant and soil samples from transect 33, Sib.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4196	300S	L	15.61	58	9	20	50	
		T	3.93	188	7			
4197	320S	L	18.47	125	23	20	40	↑
		T	3.81	255	9			
4198	340S	L	18.69	46	8	20	40	
		T	4.36	160	6			
4199	356S	L	17.44	218	38	20	50	Quartzites
		T	4.27	134	5			
4200	378S	L	18.56	105	19	10	30	↓
		T	3.82	240	9			
4201	400S	L	15.26	46	7	10	20	
		T	3.61	125	4			

Acacia mellifera - Analyses of plant and soil samples from transect 33, Sib.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4081	15N	L	8.24	280	23	150	177	Mineralized tilloid
		T	4.41	375	16			
4082	20N	L	8.32	200	16	115	140	
		T	4.15	318	13			
4083	30N	L	9.46	115	10	115	285	Quartzites
		T	5.44	280	15			
4084	40N	L	8.58	145	12	105	285	
		T	5.22	156	8			
4085	54N	L	9.59	98	9	95	233	
		T	5.34	156	8			
4086	61N	L	9.07	75	6	30	100	
		T	5.40	86	4			
4087	68N	L	9.67	80	7	20	40	
		T	5.84	80	4			
4088	80N	L	7.93	110	8	30	40	
		T	4.00	63	2			
4089	94N	L	8.60	86	7	10	20	
		T	5.63	75	4			
4090	100N	L	7.81	70	5	10	20	
		T	4.48	125	5			
4091	120N	L	8.41	86	1	30	20	
		T	4.35	138	6			
4092	140N	L	8.42	86	7	20	40	
		T	4.71	86	4			
4093	160N	L	6.75	80	5	10	20	
		T	3.67	63	2			
4094	180N	L	7.17	125	8	10	10	
		T	4.03	90	3			
4095	195N	L	8.53	86	7	10	10	
		T	4.81	134	6			
4096	220N	L	9.01	80	7	10	20	
		T	4.26	90	3			
4097	240N	L	7.81	75	5	10	10	
		T	5.55	80	4			

Acacia mellifera - Analyses of plant and soil samples from transect 33, Sib.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4250	3S	L	9.16	205	18	95	153	Mineralized tilloid
		T	4.04	233	9			
4251	8S	L	9.74	200	19	140	440	
		T	5.16	240	12			
4252	19S	L	5.73	156	8	225	340	
		T	5.12	175	8			
4253	30S	L	8.32	115	9	280	700	
		T	6.18	160	9			
4254	40S	L	9.64	134	12	225	450	
		T	4.05	275	11			
4255	49S	L	8.53	218	18	215	467	
		T	4.97	353	17			
4256	74S	L	8.80	160	14	280	550	
		T	3.95	310	12			
4257	79S	L	9.18	233	21	180	433	
		T	5.04	312	15			
4258	88S	L	8.68	165	14	225	510	
		T	5.01	245	12			
4259	108S	L	10.56	150	15	245	500	
		T	5.71	120	6			
4260	125S	L	8.22	174	14	160	382	
		T	5.26	255	13			
4261	144S	L	9.05	188	17	170	377	
		T	6.14	165	10			
4262	152S	L	8.45	174	14	140	340	
		T	5.29	165	8			
4263	163S	L	9.11	110	10	115	285	Quartzites
		T	5.43	138	7			
4264	170S	L	8.61	110	9	130	285	
		T	5.29	105	5			
4265	180S	L	9.26	80	7	150	340	
		T	4.68	75	3			

Acacia mellifera - Analyses of plant and soil samples from transect 33, Sib.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant) per ash wt.	ppm Cu (plant) per dry wt.	ppm Cu (soil) -80 mesh fr.	ppm Cu (soil) -270 mesh fr.	Rock type
4266	194S	L	10.90	70	7	95	233	
		T	6.39	86	5			
4267	215S	L	9.30	105	9	105	240	
		T	4.74	110	5			
4268	235S	L	8.45	80	6	40	94	
		T	5.19	70	3			
4269	255S	L	8.24	145	10	20	45	↑
		T	4.62	110	5			
4270	280S	L	8.07	90	7	20	20	Quartzites
		T	5.13	63	3			
4271	307S	L	8.44	90	7	20	50	
		T	6.37	70	4			
4272	320S	L	8.09	150	12	20	40	↓
		T	4.91	75	3			
4273	338S	L	8.92	90	8	20	40	
		T	4.84	110	5			
4274	360S	L	9.82	80	7	20	50	
		T	4.95	70	3			
4275	383S	L	8.60	105	9	10	30	
		T	5.09	75	3			
4276	399S	L	8.02	115	9	10	20	
		T	4.07	86	3			

Boscia albitrunca - Analyses of plant and soil samples from transect 33, Sib.								
Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4051	16N	L	12.67	90	11	150	177	Min. tilloid
		T	5.18	120	6			——20 N——
4052	21N	L	8.88	156	14	115	140	
		T	4.63	110	5			
4053	30N	L	11.69	110	13	115	285	
		T	5.40	90	5			
4054	37N	L	9.91	80	8	105	285	
		T	16.18	86	14			
4055	50N	L	11.24	110	12	95	233	
		T	5.15	138	7			
4056	63N	L	9.78	58	6	30	100	
		T	6.09	70	4			↑
4057	71N	L	11.46	58	7	20	40	
		T	6.18	90	5			
4058	90N	L	8.04	63	5	10	20	Quartzites
		T	7.75	115	8			
4059	100N	L	11.83	52	6	10	20	↓
		T	4.63	115	5			
4060	111N	L	9.40	38	3	20	30	
		T	5.70	52	2			
4061	142N	L	4.53	58	2	20	40	
		T	3.31	63	2			
4062	157N	L	9.21	58	5	10	20	
		T	5.29	63	3			
4063	185N	L	9.02	35	3	10	10	
		T	3.40	86	2			
4064	206N	L	12.41	30	3	10	10	
		T	5.96	38	2			
4065	225N	L	8.41	46	3	10	10	
		T	4.60	70	3			
4066	244N	L	8.59	35	3	10	10	
		T	4.15	70	2			

Boscia albitrunca - Analyses of plant and soil samples from transect 33, Sib.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4207	3S	L	8.87	120	10	95	153	
		T	4.71	165	7			
4209	18S	L	9.30	174	16	225	340	↑
		T	4.91	134	6			
4210	25S	L	11.44	120	13	280	700	
		T	7.13	110	7			
4211	40S	L	11.59	120	13	225	450	Mineralized
		T	5.72	150	8			
4212	48S	L	8.39	160	13	215	467	tilloid
		T	4.90	150	7			
4213	75S	L	10.04	150	15	230	490	↓
		T	4.54	188	8			
4214	135S	L	7.74	194	15	160	382	
		T	5.09	138	7			
4215	145S	L	8.26	174	14	155	362	
		T	5.50	105	5			— — 150 S — —
4216	170S	L	10.37	134	13	130	285	
		T	7.40	75	5			
4217	201S	L	15.06	80	12	105	240	
		T	4.67	80	3			
4218	247S	L	7.76	63	4	20	50	
		T	5.34	70	3			
4219	260S	L	7.51	70	5	20	40	↑
		T	3.86	63	2			
4220	280S	L	10.09	150	15	20	20	Quartzites
		T	7.01	80	5			
4221	304S	L	8.07	63	5	20	50	↓
		T	7.86	38	2			
4222	320S	L	10.84	52	5	20	40	
		T	5.02	115	5			
4223	347S	L	11.44	90	10	20	50	
		T	4.76	80	3			

Rhigozum trichotomum - Analyses of plant and soil samples from transect 33, Sib.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant) per ash wt.	ppm Cu (plant) per dry wt.	ppm Cu (soil) -80 mesh fr.	ppm Cu (soil) -270 mesh fr.	Rock type
4070	15N	L	6.15	470	28	150	177	Mineralized tilloid
		T	3.40	353	12			
4071	21N	L	5.58	290	16	115	140	
		T	3.36	318	10			
4072	32N	L	7.64	134	10	115	285	Quartzites
		T	4.29	150	6			
4073	40N	L	6.53	160	10	105	285	
		T	3.89	200	7			
4074	53N	L	6.81	134	9	95	233	
		T	3.78	150	5			
4075	70N	L	6.56	115	7	20	40	
		T	4.09	160	6			
4076	81N	L	7.03	120	8	30	40	
		T	4.01	188	7			
4077	120N	L	5.62	138	7	30	20	
		T	3.36	218	7			
4078	210N	L	6.67	110	7	10	10	
		T	4.13	160	6			
4079	232N	L	7.72	105	8	10	10	
		T	4.19	125	5			
4080	242N	L	6.23	110	6	10	10	
		T	5.35	115	6			
4227	3S	L	9.13	300	27	95	153	Mineralized tilloid
		T	3.41	358	12			
4228	13S	L	5.94	188	11	140	440	
		T	4.74	200	9			
4229	22S	L	8.42	170	14	225	340	
		T	4.88	194	9			
4230	32S	L	6.42	175	11	280	700	
		T	3.83	205	7			
4231	40S	L	7.76	250	19	225	450	
		T	3.39	218	7			
4232	46S	L	6.19	308	19	215	467	
		T	3.93	245	9			

<u>Rhigozum trichotomum</u> - Analyses of plant and soil samples from transect 33, Sib.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4233	75S	L	9.10	365	33	280	550	
		T	3.25	257	8			
4234	85S	L	7.14	245	17	180	433	
		T	4.39	228	10			
4235	90S	L	6.51	220	14	225	510	
		T	5.47	160	8			
4236	99S	L	8.01	188	15	335	678	↑ Mineralized tilloid ↓
		T	4.54	188	8			
4237	107S	L	8.53	218	18	245	500	
		T	3.26	228	7			
4238	113S	L	8.21	194	15	210	435	
		T	3.24	160	5			
4239	123S	L	7.27	200	14	170	377	
		T	9.03	188	16			
4240	130S	L	8.18	210	17	150	387	
		T	9.98	175	17			
4241	138S	L	7.44	220	16	170	377	
		T	4.75	205	9			
4242	147S	L	6.55	260	17	140	340	
		T	3.52	220	7			
4243	170S	L	4.40	280	12	130	285	
		T	3.62	218	7			
4244	190S	L	5.44	174	9	95	233	
		T	4.59	125	5			
4245	213S	L	6.54	205	13	105	240	
		T	3.56	228	8			
4246	253S	L	7.32	165	12	20	50	↑ Quartzites ↓
		T	3.90	250	9			
4247	289S	L	5.41	134	7	20	20	
		T	4.14	194	8			
4248	350S	L	5.42	170	9	20	50	
		T	5.35	86	4			
4249	380S	L	6.04	220	13	10	30	
		T	3.79	250	9			

Catophractes alexandri - Analyses of plant and soil samples from transect 33, Sib.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4012	15N	L	5.77	268	15	135	160	Min. tilloid
		T	2.88	318	10			
4013	20N	L	7.63	170	12	115	140	Quartzites
		T	3.90	275	11			
4014	30N	L	6.88	218	14	115	285	
		T	3.09	240	7			
4015	45N	L	5.46	260	14	100	255	
		T	2.85	340	10			
4016	50N	L	5.85	228	13	105	285	
		T	3.10	330	10			
4017	60N	L	7.04	188	13	30	100	
		T	3.14	175	6			
4018	78N	L	8.04	156	12	30	40	
		T	3.40	165	5			
4019	90N	L	6.46	110	7	10	20	
		T	2.85	115	3			
4020	100N	L	6.01	150	9	10	20	
		T	3.40	138	4			
4021	125N	L	7.90	150	11	20	20	
		T	3.57	170	6			
4022	140N	L	5.67	160	9	20	40	
		T	2.99	218	6			
4023	160N	L	6.61	138	9	10	20	
		T	3.85	150	5			
4024	180N	L	7.93	105	8	10	10	
		T	4.43	110	5			
4025	200N	L	6.41	125	8	10	10	
		T	3.24	174	5			
4026	223N	L	7.04	120	8	10	20	
		T	4.90	86	4			
4027	230N	L	6.34	134	8	10	10	
		T	4.08	165	6			
4028	250N	L	6.82	134	9	10	20	
		T	2.63	218	6			

<u>Catophractes alexandri</u> - Analyses of plant and soil samples from transect 33, Sib.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4148	12S	L	6.27	174	10	140	440	
		T	4.95	210	10			
4149	16S	L	6.64	235	15	180	390	
		T	4.10	250	10			
4150	24S	L	6.34	205	12	225	340	
		T	3.81	243	9			
4151	32S	L	6.23	170	10	280	700	↑
		T	3.83	260	9			
4152	40S	L	7.50	188	14	225	450	
		T	7.99	210	16			
4153	49S	L	7.21	235	16	215	467	Mineralized tilloid
		T	4.98	290	14			
4154	80S	L	7.01	235	16	180	433	
		T	3.70	318	11			
4155	90S	L	6.48	165	10	225	510	↓
		T	5.07	156	7			
4156	120S	L	8.81	194	17	170	377	
		T	4.92	200	9			
4157	130S	L	6.38	218	13	150	387	
		T	8.75	160	14			
4158	140S	L	7.60	235	17	140	377	
		T	3.84	240	9			
4159	150S	L	6.01	200	12	140	340	
		T	3.22	304	9			
4160	160S	L	6.26	218	13	115	285	
		T	3.74	222	8			
4161	180S	L	7.92	138	10	150	340	↑
		T	4.64	150	6			
4162	205S	L	7.70	138	10	105	240	
		T	4.89	194	9			
4163	230S	L	5.94	170	10	40	100	Quartzites
		T	3.69	150	5			
4164	240S	L	6.55	175	11	40	87	↓
		T	4.20	165	6			

Catophractes alexandri - Analyses of plant and soil samples from transect 33, Sib.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4165	260S	L	8.17	138	11	20	40	
		T	3.44	160	5			
4166	275S	L	5.92	145	8	20	25	
		T	2.92	200	5			↑
4167	292S	L	7.05	160	11	20	20	
		T	3.88	156	6			
4168	311S	L	7.06	150	10	20	50	Quartzites
		T	3.16	160	5			
4169	340S	L	8.10	138	11	20	40	
		T	4.02	156	6			↓
4170	370S	L	6.61	125	8	10	30	
		T	3.62	170	6			
4171	382S	L	6.60	120	7	10	30	
		T	3.86	138	5			
4172	400S	L	5.51	145	7	10	20	
		T	3.07	174	5			

Petalidium parvifolium - Analyses of plant and soil samples from transect 33, Sib.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
3991	14N	L	14.16	115	16	150	177	
		T	7.26	188	13			
3992	19N	L	14.84	98	14	115	140	
		T	8.65	194	16			
3993	28N	L	17.53	98	17	115	285	
		T	7.59	105	8			
3994	39N	L	17.67	75	13	105	285	
		T	8.86	120	10			
3995	50N	L	18.11	90	16	95	233	
		T	8.90	110	10			
3996	60N	L	5.20	86	5	30	100	↑
		T	5.05	175	9			
3997	73N	L	20.08	80	16	20	40	
		T	7.45	115	8			Quartzites
3998	80N	L	15.05	80	12	30	40	
		T	7.58	115	8			
3999	90N	L	16.13	63	10	10	20	↓
		T	6.75	80	5			
4000	105N	L	18.91	38	7	10	20	
		T	9.06	70	6			
4001	120N	L	12.64	80	10	30	20	
		T	7.32	150	11			
4002	140N	L	17.44	58	10	20	40	
		T	6.12	90	5			
4003	160N	L	13.98	63	8	10	20	
		T	5.83	110	6			
4005	180N	L	16.95	46	7	10	10	
		T	5.49	120	6			
4006	205N	L	17.59	46	8	10	10	
		T	8.38	70	5			
4007	228N	L	16.24	52	8	10	20	
		T	5.41	75	4			
4008	235N	L	16.58	38	6	10	10	
		T	7.04	86	6			

Petalidium parvifolium - Analyses of plant and soil samples from transect 33, Sib.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4116	6S	L	14.69	110	16	95	153	
		T	4.95	218	10			
4117	11S	L	16.54	125	20	140	440	
		T	8.59	174	14			
4118	21S	L	19.52	86	16	225	340	
		T	8.45	160	13			
4119	32S	L	18.43	115	21	280	700	
		T	6.48	165	10			
4120	40S	L	18.48	90	16	225	450	
		T	7.49	188	14			↑
4121	48S	L	19.34	98	18	215	467	
		T	6.85	115	7			
4122	80S	L	15.69	125	19	180	433	Mineralized tilloid
		T	5.90	235	13			
4123	90S	L	17.21	90	15	225	570	
		T	5.90	175	10			
4124	100S	L	19.22	115	22	335	678	↓
		T	8.37	188	15			
4125	113S	L	19.82	75	14	245	500	
		T	10.25	175	17			
4126	124S	L	17.09	98	16	170	377	
		T	7.73	174	13			
4127	130S	L	16.34	70	11	150	387	
		T	8.58	110	9			
4128	139S	L	15.65	115	17	170	377	
		T	6.25	174	10			
4129	150S	L	14.77	120	17	140	340	
		T	5.60	194	10			
4130	160S	L	16.76	90	15	115	285	↑
		T	6.79	228	15			
4131	183S	L	15.12	80	12	150	340	Quartzites
		T	3.07	110	3			
4132	200S	L	17.42	58	10	105	240	↓
		T	8.43	105	8			

Petalidium parvifolium - Analyses of plant and soil samples from transect 33, Sib.								
Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4133	218S	L	21.76	70	15	75	187	↑ Quartzites ↓
		T	7.01	120	8			
4134	239S	L	4.01	75	3	40	87	
		T	5.40	110	5			
4135	260S	L	17.55	52	9	20	40	
		T	7.21	120	8			
4136	280S	L	16.08	75	12	20	20	
		T	6.88	125	8			
4137	302S	L	21.12	58	12	20	50	
		T	7.72	86	6			
4138	324S	L	12.10	110	13	20	40	
		T	4.70	125	5			
4139	340S	L	14.78	63	9	20	40	
		T	7.24	110	7			
4140	360S	L	18.51	70	12	20	50	
		T	6.81	138	9			
4141	379S	L	23.96	52	12	10	30	
		T	6.89	110	7			
4142	400S	L	17.27	58	10	10	20	
		T	8.78	90	7			

<u>Phaeoptilum spinosum</u> - Analyses of plant and soil samples from transect 1, Mertens.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4307	3N	L	14.40	363	52	120	260	Min. lava
		T	3.04	555	16			
4308	7N	L	15.49	273	42	120	270	↑
		T	7.02	168	12			
4309	11N	L	13.16	100	13	70	160	
		T	3.96	240	10			
4310	16N	L	12.73	118	15	55	140	
		T	4.42	230	10			
4311	27N	L	16.02	40	6	35	80	
		T	4.34	123	5			
4312	36N	L	13.11	35	5	25	55	
		T	2.81	190	5			
4313	46N	L	19.25	45	9	20	40	Epidotized and non-epidotized lavas
		T	4.21	178	7			
4314	53N	L	15.90	85	14	20	40	
		T	4.07	110	4			
4315	64N	L	12.18	30	4	15	40	
		T	2.87	150	4			
4316	78N	L	13.60	23	3	20	30	↓
		T	5.99	73	4			
4317	87N	L	14.92	20	3	20	25	
		T	4.10	118	5			
4318	98N	L	13.92	20	3	15	20	
		T	3.01	150	5			
4319	119N	L	11.23	30	3	10	25	
		T	4.92	73	4			
4320	140N	L	13.57	30	4	10	20	
		T	3.97	80	3			
4321	161N	L	13.66	23	3	10	20	
		T	3.61	123	4			
4322	179N	L	14.54	23	3	10	20	
		T	2.86	130	4			
4323	200N	L	14.74	23	3	15	30	
		T	4.55	85	4			

Phaeoptilum spinosum - Analyses of plant and soil samples from transect 1, Mertens.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4324	210N	L	13.13	35	5	15	25	↑
		T	3.84	135	5			
4325	220N	L	14.35	30	4	10	15	Epidotized and
		T	5.15	73	4			non-epidotized
4326	244N	L	13.08	35	5	10	20	lavas with a
		T	3.09	95	3			
4327	263N	L	13.69	35	5	20	55	volcanic conglom-
		T	3.08	155	5			
4328	280N	L	17.90	50	9	30	75	erate at 275 N
		T	3.74	200	7			
4329	300N	L	2.46	63	2	25	55	↓
		T	25.22	230	6			
4381	2S	L	11.09	780	87	175	360	Mineralized lava
		T	4.04	720	29			
4382	5S	L	16.27	230	37	110	240	
		T	2.88	600	17			
4383	11S	L	13.81	123	17	50	120	
		T	3.20	418	13			
4384	19S	L	13.74	68	9	25	55	↑
		T	3.93	185	7			
4385	32S	L	13.33	35	5	25	40	Epidotized and
		T	3.95	135	5			
4386	42S	L	14.58	30	4	20	30	non-epidotized
		T	3.42	168	6			lavas with
4387	52S	L	13.80	40	6	20	35	volcanic conglom-
		T	3.33	163	5			
4388	635	L	16.36	30	5	10	30	erate and
		T	2.72	168	5			metaquartzite
4389	76S	L	14.33	40	6	10	20	
		T	3.70	178	7			
4390	86S	L	12.16	23	3	10	25	↓
		T	3.68	155	6			
4391	98S	L	8.17	23	2	10	30	
		T	4.08	118	5			

Phaeoptilum spinosum - Analyses of plant and soil samples from transect 1, Mertens.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant) per ash wt.	ppm Cu (plant) per dry wt.	ppm Cu (soil) -80 mesh fr.	ppm Cu (soil) -270 mesh fr.	Rock type
4392	118S	L	12.96	35	5	10	25	↓
		T	3.27	135	4			
4393	138S	L	13.35	35	5	10	20	
		T	3.29	218	7			— — 150 S — —
4394	167S	L	14.11	30	4	10	20	
		T	3.64	140	5			
4395	180S	L	13.49	30	4	10	15	↑
		T	3.73	30	1			
4396	197S	L	15.81	35	6	10	15	
		T	5.07	130	7			Quartz-feldspar
4397	219S	L	13.30	30	4	10	15	porphyry
		T	5.05	85	4			
4398	242S	L	16.98	35	6	10	15	↓
		T	6.44	80	5			
4399	265S	L	12.52	40	5	10	20	
		T	4.72	123	6			
4400	295S	L	12.38	63	8	10	20	
		T	3.39	235	8			
4401	320S	L	15.71	30	5	10	15	
		T	3.26	163	5			
4402	342S	L	12.27	35	4	10	15	
		T	4.41	110	5			
4403	365S	L	16.51	30	5	10	15	
		T	4.07	155	6			— — 370 S — —
4404	380S	L	16.26	30	5	10	15	
		T	4.21	110	5			Epidotized and
4405	398S	L	14.14	35	5	10	15	non-epidotized
		T	3.53	173	6			lavas

Rhigozum trichotomum - Analyses of plant and soil samples from transect 1, Mertens.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4352	4N	L	6.51	110	7	120	260	Min. lava
		T	7.31	90	7			
4353	5N	L	6.72	213	14	120	260	
		T	4.18	168	7			
4354	13N	L	7.25	110	8	70	160	
		T	4.34	150	7			
4355	21N	L	6.92	80	6	55	140	↑
		T	4.17	145	6			
4356	30N	L	6.06	95	6	35	80	
		T	3.89	168	7			
4357	50N	L	7.18	73	5	20	40	Epidotized and non-epidotized
		T	3.62	190	7			
4358	59N	L	7.31	85	6	15	40	lavas with a
		T	3.50	150	5			
4359	68N	L	7.93	68	5	20	55	volcanic conglomerate
		T	4.08	123	5			
4360	80N	L	6.24	90	6	20	30	at 275 N
		T	3.80	125	5			
4361	87N	L	7.64	63	5	20	25	↓
		T	4.15	100	4			
4362	101N	L	7.32	80	6	15	20	
		T	2.72	150	4			
4363	122N	L	7.36	68	5	10	25	
		T	3.95	125	5			
4364	139N	L	7.46	63	5	10	20	
		T	4.72	85	4			
4365	160N	L	7.48	65	5	10	20	
		T	4.25	95	4			
4366	185N	L	6.18	80	5	10	20	
		T	4.00	150	6			
4367	200N	L	8.00	63	5	15	30	
		T	5.84	90	5			
4368	217N	L	8.36	80	7	10	15	
		T	4.79	118	6			

Rhigozum trichotomum - Analyses of plant and soil samples from transect 1, Mertens.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant) per ash wt.	ppm Cu (plant) per dry wt.	ppm Cu (soil) -80 mesh fr.	ppm Cu (soil) -270 mesh fr.	Rock type
4369	239N	L	6.33	73	5	10	20	↓
		T	3.67	118	4			
4370	260N	L	7.19	73	5	20	55	
		T	4.03	130	5			
4371	282N	L	6.30	95	6	30	75	
		T	4.09	185	8			
4372	300N	L	8.82	63	6	25	55	
		T	4.16	150	8			
4442	1S	L	8.23	90	7	175	360	Min. lava
		T	4.21	178	7			
4443	60S	L	7.33	80	6	10	30	
		T	4.26	135	6			Epidotized and
4444	71S	L	6.43	73	5	10	25	non-epidotized
		T	2.95	130	4			
4445	92S	L	7.05	55	4	10	25	lavas with
		T	5.04	80	4			
4446	107S	L	8.21	45	7	10	20	volcanic conglomerate and
		T	4.33	85	4			
4447	120S	L	7.16	73	5	10	25	metaquartzite
		T	3.59	130	5			
4448	142S	L	7.76	68	5	10	20	
		T	4.49	110	5			150 S
4449	200S	L	7.47	50	4	10	15	
		T	4.43	155	7			Quartz-feldspar
4450	334S	L	7.47	63	5	10	15	
		T	4.34	110	5			porphyry
4451	370S	L	6.35	73	5	10	15	
		T	3.72	145	5			
4452	391S	L	5.97	85	5	10	15	
		T	3.86	130	5			
4453	400S	L	7.34	55	4	10	15	As for samples 4443 - 4448
		T	3.35	130	4			

Catophractes alexandri - Analyses of plant and soil samples from transect 1, Mertens.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4330	00	L	6.49	125	8	175	360	Min. lava
		T	3.76	255	10			
4331	5N	L	7.53	118	9	120	260	---- 4 N ----
		T	3.52	100	4			
4332	9N	L	7.92	68	5	70	160	
		T	3.40	140	5			
4333	16N	L	7.43	85	6	55	140	↑
		T	4.83	140	7			
4334	26N	L	8.65	68	6	35	80	Epidotized and
		T	3.01	210	6			
4335	36N	L	6.96	95	7	25	55	non-epidotized
		T	2.76	195	5			
4336	46N	L	7.33	80	6	20	40	lavas with a
		T	4.00	135	5			
4337	57N	L	7.48	80	6	15	40	volcanic conglomerate at 275 N
		T	3.56	163	6			
4338	66N	L	8.80	55	5	20	55	↓
		T	3.43	150	5			
4339	77N	L	10.14	90	9	20	30	
		T	3.62	190	7			
4340	90N	L	7.65	68	5	20	25	
		T	3.19	130	4			
4341	99N	L	7.44	73	5	15	20	
		T	2.95	130	4			
4342	126N	L	7.39	73	5	10	25	
		T	3.00	163	5			
4343	138N	L	6.99	80	6	10	20	
		T	2.66	130	3			
4344	162N	L	7.36	95	7	10	20	
		T	3.17	168	5			
4345	181N	L	8.22	55	5	10	20	
		T	3.79	118	4			
4346	200N	L	14.79	23	3	15	30	
		T	4.01	73	3			

Catophractes alexandri - Analyses of plant and soil samples from transect 1, Mertens.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4347	223N	L	7.85	73	6	10	15	
		T	3.18	200	6			
4348	239N	L	17.02	55	9	10	20	
		T	3.55	140	5			↓
4349	261N	L	6.64	80	5	20	55	
		T	3.32	140	5			
4350	279N	L	10.06	85	9	30	75	
		T	3.21	213	7			
4351	300N	L	8.77	73	6	25	55	
		T	3.53	150	5			
4411	2S	L	17.08	95	16	175	360	Min. lava
		T	3.35	178	6			
4412	8S	L	6.39	95	6	50	120	↑
		T	3.17	240	8			
4413	19S	L	7.00	90	6	25	55	
		T	2.94	135	4			Epidotized and
4414	31S	L	7.32	68	5	25	40	non-epidotized
		T	3.55	118	4			lavas with
4415	41S	L	7.73	73	6	20	30	volcanic conglom-
		T	3.44	178	6			erate and
4416	50S	L	7.42	68	5	20	35	metaquartzite
		T	3.93	130	5			↓
4417	63S	L	7.06	85	6	10	30	
		T	2.89	190	5			
4418	68S	L	9.09	73	7	10	25	
		T	3.42	73	2			
4419	83S	L	7.61	63	5	10	20	
		T	3.73	80	3			
4420	94S	L	7.90	63	5	10	25	
		T	7.90	73	6			
4421	100S	L	6.98	50	3	10	30	
		T	3.73	125	5			
4422	122S	L	7.09	80	6	10	25	
		T	3.02	123	4			

Catophractes alexandri - Analyses of plant and soil samples from transect 1, Mertens.

Sample no.	Collection site	Part of plant	% ash	ppm Cu (plant)		ppm Cu (soil)		Rock type
				per ash wt.	per dry wt.	-80 mesh fr.	-270 mesh fr.	
4423	140S	L	6.61	80	5	10	20	
		T	2.98	225	7			
4424	162S	L	6.01	125	8	10	20	--- 150 S ---
		T	3.15	150	5			
4425	185S	L	7.77	68	5	10	15	
		T	3.31	165	5			
4426	199S	L	7.60	80	6	10	15	↑
		T	3.44	173	6			
4427	221S	L	6.93	90	6	10	15	
		T	3.52	150	5			
4428	243S	L	7.14	90	6	10	15	Quartz-feldspar porphyry
		T	3.29	178	6			
4429	261S	L	6.97	85	6	10	20	
		T	3.25	213	7			
4430	281S	L	7.29	85	6	10	15	↓
		T	3.24	210	7			
4431	298S	L	7.03	80	6	10	20	
		T	3.09	165	5			
4432	320S	L	6.32	110	7	10	15	
		T	3.46	146	5			
4433	343S	L	6.85	73	5	10	15	
		T	3.18	110	3			
4434	362S	L	6.61	85	6	10	15	
		T	3.21	140	4			
4435	385S	L	6.92	110	8	10	15	--- 370 S ---
		T	3.01	165	5			
4436	398S	L	5.41	110	6	10	15	As for samples 4412 - 4423
		T	3.51	173	6			

III : List of plants

Species marked * are not mentioned in the text and are mainly rarely occurring annuals. A few perennials of little significance are also listed.

	Specimen number
ACANTHACEAE	
Blepharis obmitrata C.B.Cl.	3628
Petalidium parvifolium Nees.	3635
AMARANTHACEAE	
Hermbstaedtia odorata (Burch.) T.Cooke.*	3636
Leucosphaera bainesii (Gilg.) C.B.Cl.	3625
Nelsia quadrangula (Engl.) Schinz.*	3593
AMARYLLIDACEAE	
Nerine laticoma (Ker.) Dur. & Schinz.*	3637
ASCLEPIADACEAE	
Caralluma lugardii N.E.Br.*	3613
BIGNONIACEAE	
Catophractes alexandri D.Don.	3580
Rhigozum trichotomum Burch.	3516
BORAGINACEAE	
Ehretia rigida (Thunb.) Druce.	3643
BURSERACEAE	
Commiphora pyracanthoides Engl.	3656
Commiphora sp.	3659

CAPPARIDACEAE

Boscia albitrunca (Burch.) Gilg. et Binn.	3638
Boscia foetida Schinz.	3624
Cleome kalahariensis (Schinz.) Gilg. et Binn.*	3594
Cleome rubella Burch.*	3606a

COMBRETACEAE

Combretum apiculatum Sond.	3657

COMPOSITAE

Dicoma capensis Less.	3639
Helichrysum argyrosphaerium DC.	3640
Helichrysum leptolepis DC.	3641
Hirpicium gorterioides (Oliv. & Hiern.) Roessler subsp. gorterioides*	3585

CONVOLVULACEAE

Evolvulus alsinoides (L.) L.	3658

CUCURBITACEAE

Coccinea rehmannii Cogn. *	3517
Cucumis africanus L.f.*	3620

CYPERACEAE

Fimbristylis exilis Roem. & Schult. ex hispidula Kunth.	3615

EBENACEAE

Diospyros lycioides Desf. subsp. lycioides	3575

EUPHORBIACEAE

Euphorbia inequilaterans Sond.*	3655

FICOIDEAE

Gisekia pharnacioides L.	3608
Limeum viscosum (Gay.) Fenzl. subsp. viscosum	3610
Mollugo cerviana (L.) Ser.	3614/3350
Semonvillea fenestrata Fenzl.*	3587
Tetragonia fruticosa L.*	3617

GRAMINEAE

Anthephora pubescens Nees.	3634
Aristida congesta Roem. & Schult. subsp. barbicollis (Trin. & Rupr.) De Wint.	3596
Aristida curvata (Nees.) Trin. & Rupr.	3623
Aristida meridionalis Henr.*	3618
Asthenatherum glaucum (Nees.) Nevski var. lasiophyllum (Pilg.) Conert.	3520
Asthenatherum glaucum (Nees.) Nevski var. glaucum	3576
Cenchrus ciliaris L.*	3597
Chloris virgata Sw.*	3592
Diandrochloa pusilla (Hack.) de Wint.	3644
Enneapogon brachystachyus (Jaub. & Spach.) Stapf.	3598
Eragrostis denudata Hack. ex Schinz.	3582
Eragrostis porosa Nees.	3599
Eragrostis trichophora Coss. & Dur.	3354
Fingerhuthia africana Lehm.*	3584
Pogonarthria flechii (Hack.) Hack.	3621
Rhynchelytrum repens (Willd.) C.E.Hubb	3591
Schmidtia kalahariensis Stent.	3351/3595
Stipagrostis ciliata (Desf.) de Wint. var. capensis (Trin. & Rupr.) de Wint.	3622
Stipagrostis namaquensis (Nees.) de Wint.	3519
Stipagrostis uniplumis (Licht.) de Wint. var. uniplumis	3355
Triraphis ramosissima Hack. ex Schinz.*	3626

IRIDACEAE

<u>Ferraria glutinosa</u> (Bak.) Rendle.*	3619

LABIATAE

<u>Ocimum americanum</u> Linn. 3586

LEGUMINOSAE

<u>Acacia giraffae</u> Willd. 3646
<u>Acacia haematoxylon</u> Willd. 3361
<u>Acacia hebeclada</u> DC. 3648
<u>Acacia karroo</u> Hayne. 3647
<u>Acacia mellifera</u> (Vahl.) Benth. subsp. <u>detinens</u> (Burch.) Brennan. 3650
<u>Acacia senegal</u> (L.) Willd. var. <u>rostrata</u> Brennan. 3627
<u>Albizzia anthelmintica</u> Brongn. 3645
<u>Cassia italica</u> Lam. ex Steud. subsp. <u>arachoides</u> (Burch.) Brennan. 3581
<u>Crotalaria argyraea</u> Welw. ex Baker 3603
<u>Dichrostachys cinerea</u> (L.) Wight. & Arn. subsp. <u>africana</u> Brennan & Brummit. var. <u>africana</u> Sens. lat.* 3649
<u>Hoffmanseggia lactea</u> Schinz.* 3604
<u>Indigofera alternans</u> DC.* 3602
<u>Parkinsonia africana</u> Sond. 3573
<u>Sylitra biflora</u> E. Mey. 3612
<u>Tephrosia dregeana</u> E. Mey.* 3607

LILIACEAE

<u>Dipcadi bakerianum</u> Bol. * 3583
<u>Eriospermum luteorubrum</u> Bak. * 3589
<u>Ornithoglossum viride</u> (L.f.) Ait. * 3605

MALVACEAE

<u>Hibiscus micranthus</u> L. (cf. <u>micranthus</u>)* 3579/3633

NYCTAGINACEAE

<u>Phaeoptilum spinosum</u> Radlk. 3652

ONAGRARIEAE

Montinia caryophyllacea Thunb.	3651

PEDALIACEAE

Sesamum triphyllum Welw. ex Asch. *	3611

POLYGONACEAE

Oxygonum alatum Burch.*	3590

RHAMNACEAE

Ziziphus mucronata Willd.	3653

SCROPHULARIACEAE

Aptosimum leucorrhizum (E. Mey.) Phill.	3601
Aptosimum lineare Marl. et Engl.*	3609
Walafrida cf. densiflora Rolfe. *	3588

SOLANACEAE

Lycium lancifolium Damm.	3616
Lycium sp.	3660

TILIACEAE

Corchorus asplenifolius Burch.	3600
Grewia flava DC.	3572
Grewia tenax (Forsk.) Fiori.	3632

VAHLIACEAE

Vahlia capensis Thunb. *	3577

VERBENACEAE

Chascanum pinnatifidum E. Mey. *	3654

ZYGOPHYLLACEAE

Fagonia minutistipula Engl. *	3578
Tribulus zeyheri Sond.	3518

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