2. AIMS OF THE STUDY

As a contribution to the aims of BIOTA, the following was to be accomplished with this study:

Description and preliminary mapping of the vegetation of a section of the southern African BIOTA Transect (Figure 2), from the watershed between the Omuramba-Omatako and Swakop-river catchment areas to the dairy farm Rietfontein east of Otavi. The length of this transect section is roughly 320 km.

The aims of the transect vegetation map and its data, which is to serve as baseline data for the BIOTA project and especially its envisaged monitoring activities are:

- Documentation and description of the spatial changes in phytodiversity along the transect, paying attention to life forms (strategy-types), structure (height/layers of different life forms) and floristic components (phylogenetic diversity) as they change with changing abiotic conditions (e.g. rainfall gradient).
- Analysis of the importance of environmental features for the change in phytodiversity.
- Identification of plateau-phases and discontinuities along the transect.

3. PROBLEM ANALYSIS

Surveying a large tract of land can be incredibly time-consuming; the fieldworker is often confronted with the dilemma of surveying enough points to be representative of a vegetation type, as well as the question where to put these points to ensure that the different vegetation types can be correctly delimited. The time-frame set for the description of the plant communities along the transect is 2 years, while during those 2 years vegetation can only be successfully sampled during a 3-4 month rainy season, when plants are in full growth, flower and fruit, and thus can be positively identified.

Some key questions are:

- Can satellite imagery be used to give an adequate initial stratification of the study area, to ensure that sampling units are spread evenly over the potential plant communities?
- How well will the communities identified by classification of data correspond to plant communities identified on the satellite map?

It is hypothesised that on a smaller scale (1: 250 000 or less) phytodiversity follows a zonation roughly corresponding to the gradient of the mean annual rainfall.

- How important is this gradient compared to other environmental gradients likely to be found along the transect, e.g. soil types?

4. LOCATION OF THE STUDY AREA

The study area, forming part of the Biota Transect (Figure 1) is located in the Otjozondupa Region, Namibia, roughly following the main road between Okahandja, Otjiwarongo, Otavi and Grootfontein.

The watershed between the Swakop River and Omuramba-Omatako catchments has been taken as the southern boundary of the study area, at roughly 21°45'00" S. The decision for this southern boundary was based on the considerate differences in local topography: south of the divide the central plateau consists of strongly dissected inselberg plains with a slope range of 8-15%, while landforms of the transect area to the north of the divide consist largely of alluvial and inselberg plains, interrupted by few large inselbergs as well as the Omuramba-Omatako with its smaller tributaries. The most conspicuous inselbergs of the study area are, from south to north, Matador, Omatako Mountains, Omboroko Mountains, with the Elefantenberg on the northern boundary of the study area. Elefantenberg is situated south of Otavi, at about 19°45'00"S and forms the southern limit of the dolomite outcrops and mountain ridges of the Otavi area, which were avoided in this study. However, at this point the transect was extended east to Rietfontein, at about 17°45'00"E (Figure 2).

The average height of the study area, excluding the inselbergs, is about 1000 m to 1700 m above sea level.

The width of the transect surveyed was kept at more or less at 30 km but boundaries were not strictly fixed, as it was envisaged that with the aid of remote sensing technology the vegetation map could potentially be drawn for an area extending beyond these 30 km.

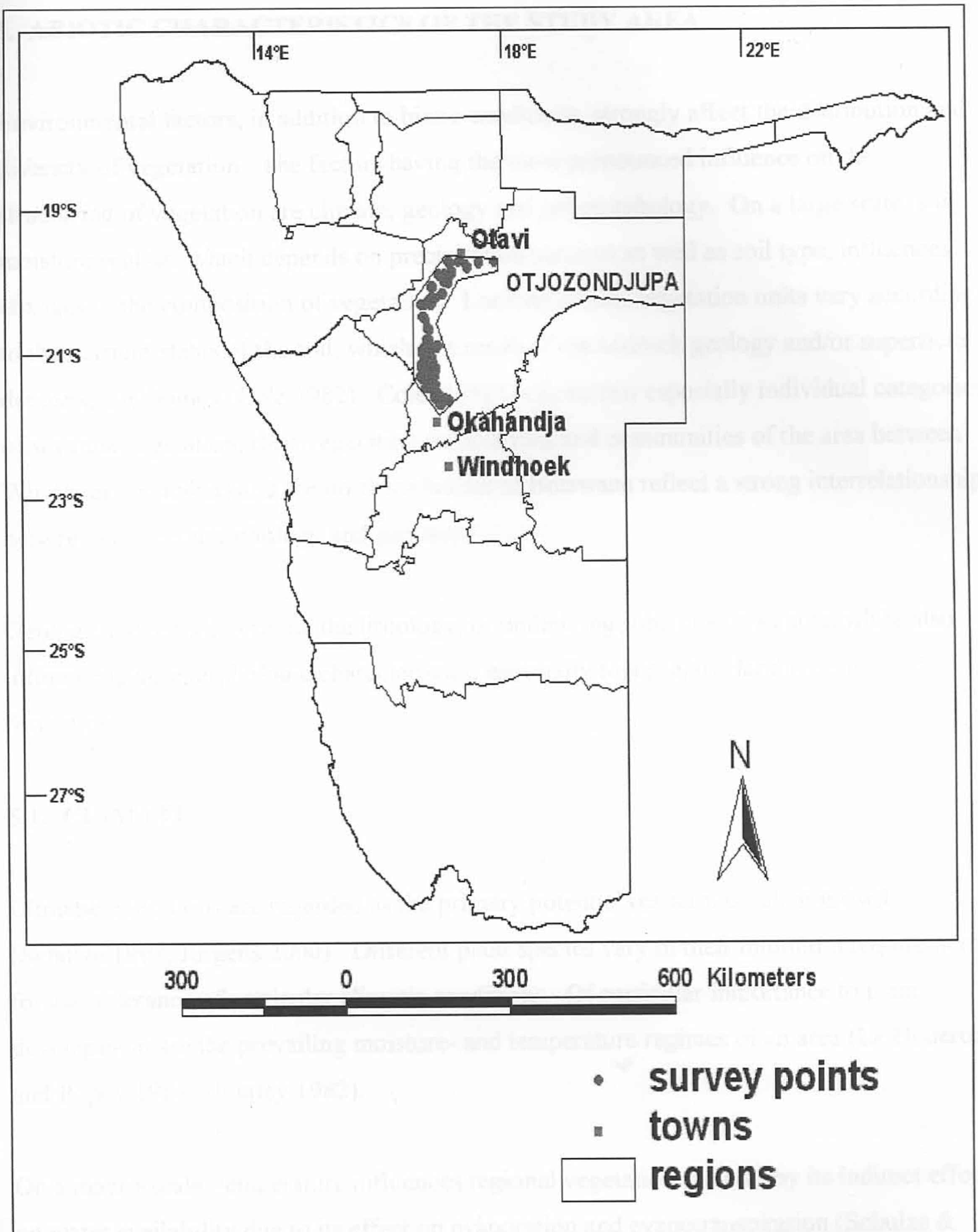


Figure 2: Location of the Study Area, which covers the part of the BIOTA Transect from 40km north of Okahandja to 20 km south of Otavi, then turning east up to the farm Rietfontein.

5. ABIOTIC CHARACTERISTICS OF THE STUDY AREA

Environmental factors, in addition to biotic conditions, strongly affect the distribution and diversity of vegetation. The factors having the most pronounced influence on the structuring of vegetation are climate, geology and geomorphology. On a large scale, soil moisture regime, which depends on precipitation patterns as well as soil type, influences changes in the composition of vegetation. Looking closer, vegetation units vary according to the nutrient status of the soil, which is a result of the bedrock geology and/or superficial deposits, e.g. humus (Cole 1982). Cole (1982) noticed that especially individual categories of savanna vegetation, their vegetation associations and communities of the area between Windhoek (Namibia) and the northern border of Botswana reflect a strong interrelationship between soil, geomorphology and geology.

Geological events determine the lithology, or underlying substrate of an area, while also influencing geomorphologic characteristics, especially topography, land type and soil formation.

5.1. CLIMATE

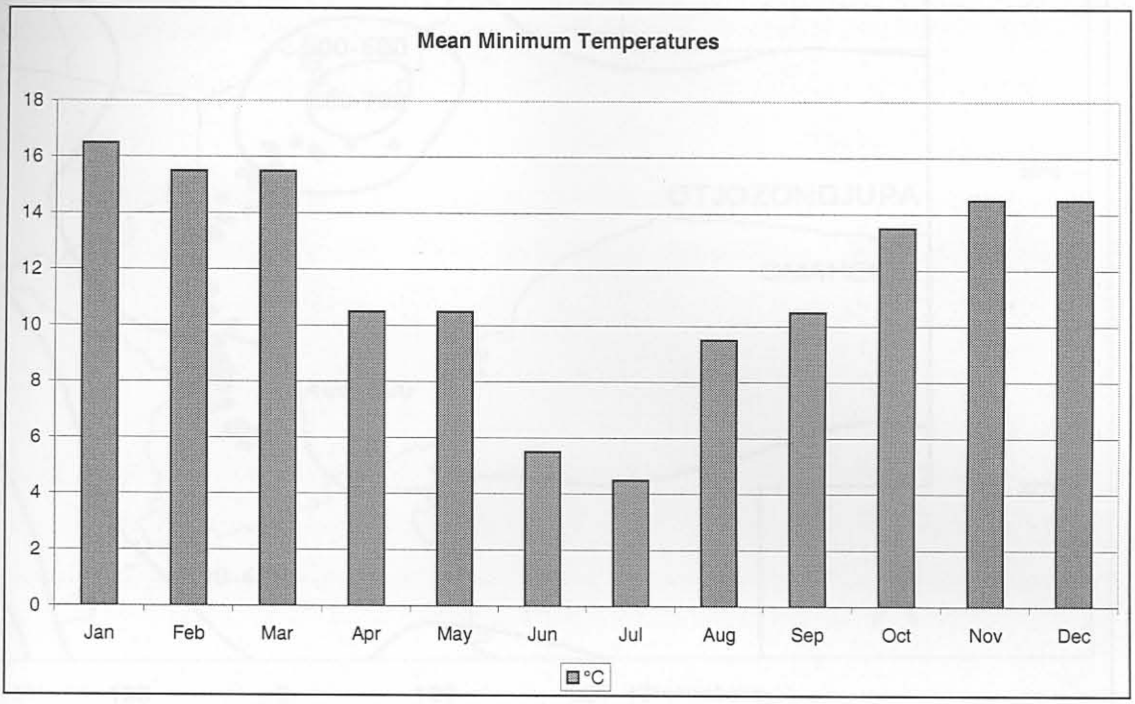
Climatic conditions are regarded as the primary potential restraint on plant growth (Schulze 1997, Jürgens 2000). Different plant species vary in their minimum requirements for and tolerance of particular climatic conditions. Of particular importance to plant development are the prevailing moisture- and temperature regimes of an area (Le Houerou and Popov 1981, Huntley 1982).

On a macro-scale, temperature influences regional vegetation patterns by its indirect effect on water availability due to its effect on evaporation and evapotranspiration (Schulze & McGee 1978). On a meso- and micro-scale, plant diversity has evolved to and is influenced by temperature effects on plant metabolism and thus temperature influences growth-, reproduction- as well as germination rates. Rutherford and Westfall (1994) and Schulze (1997) observed that savannas are in general absent from high rainfall areas (mean annual rainfall above 235 mm) with low winter temperature minima, while arid savannas are still being present in low rainfall areas with relatively severe winter frosts (Huntley 1982). The study area falls entirely within an arid eco-climatic zone with occasional frosts

(Werger & Coetzee 1978, Le Houerou and Popov 1981). Le Houerou and Popov (1981) define eco-climatic zones based on their characteristic annual distribution and amount of precipitation and temperatures, and especially take the occurrence of frost into consideration. Many plants have evolved some form of physical and biological mechanism to avoid frost-damage, but none of these will provide complete protection against below zero temperatures. An air temperature of 3-4°C is already considered low enough for light frosts to occur. Critical temperature indices such as winter minima, which also indicate the occurrence of frost, and summer maxima are thus the most useful parameters in studying plant distribution, rather than e.g. mean annual temperatures (Schulze 1997).

For southern Africa, mean daily minimum temperatures characteristic for winter are represented by July-temperatures. These temperatures range from 7-8 °C over the southern and central parts and 3-6 °C in the north-eastern part of the study area. Similarly, maximum temperatures recorded during January are taken as representative of the mean daily summer maximum temperatures, ranging from 28-30 °C for the study area (Figure 3) (Schulze & McGee 1998, AEZ 2001).

The savanna biome occurs in regions with a relatively long summer, an arid savanna experiencing about seven (or more) dry months (Huntley 1982, Rutherford & Westfall 1994, AEZ 2001). The study area receives primarily summer rainfall, with a Summer Aridity Index of 3.7 to 3.8 (Rutherford & Westfall 1994, Irish 1994). Average long-term annual rainfall gradually increases in a north-north-easterly direction over the study area (Figure 4). Local variations occur especially east of Otavi with a markedly higher rainfall than surrounding areas due to the mountain ridges found there. The bulk of the annual precipitation occurs within 4 months (Figure 5), greatly affecting annual and seasonal soil moisture balances which have a more pronounced influence on phytogeographic divisions than gross precipitation alone (Schulze 1997, AEZ 2001).



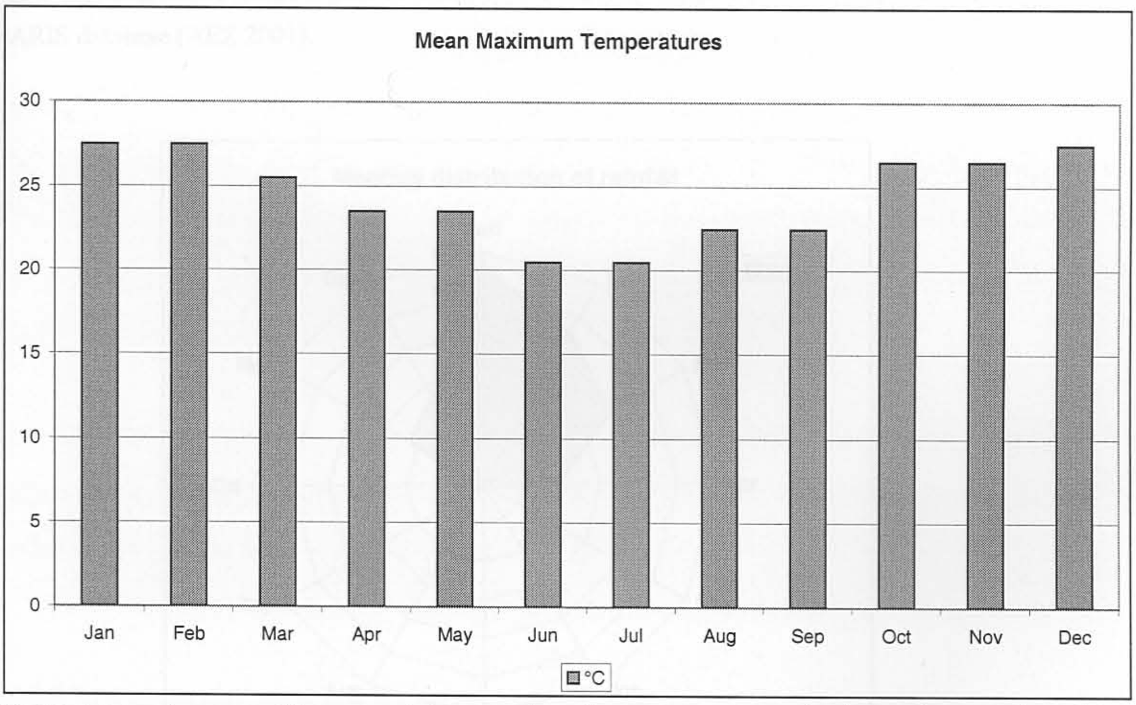


Figure 3: Long-term monthly mean minimum and maximum temperatures for the study area, adapted from the AEZ database (2001).

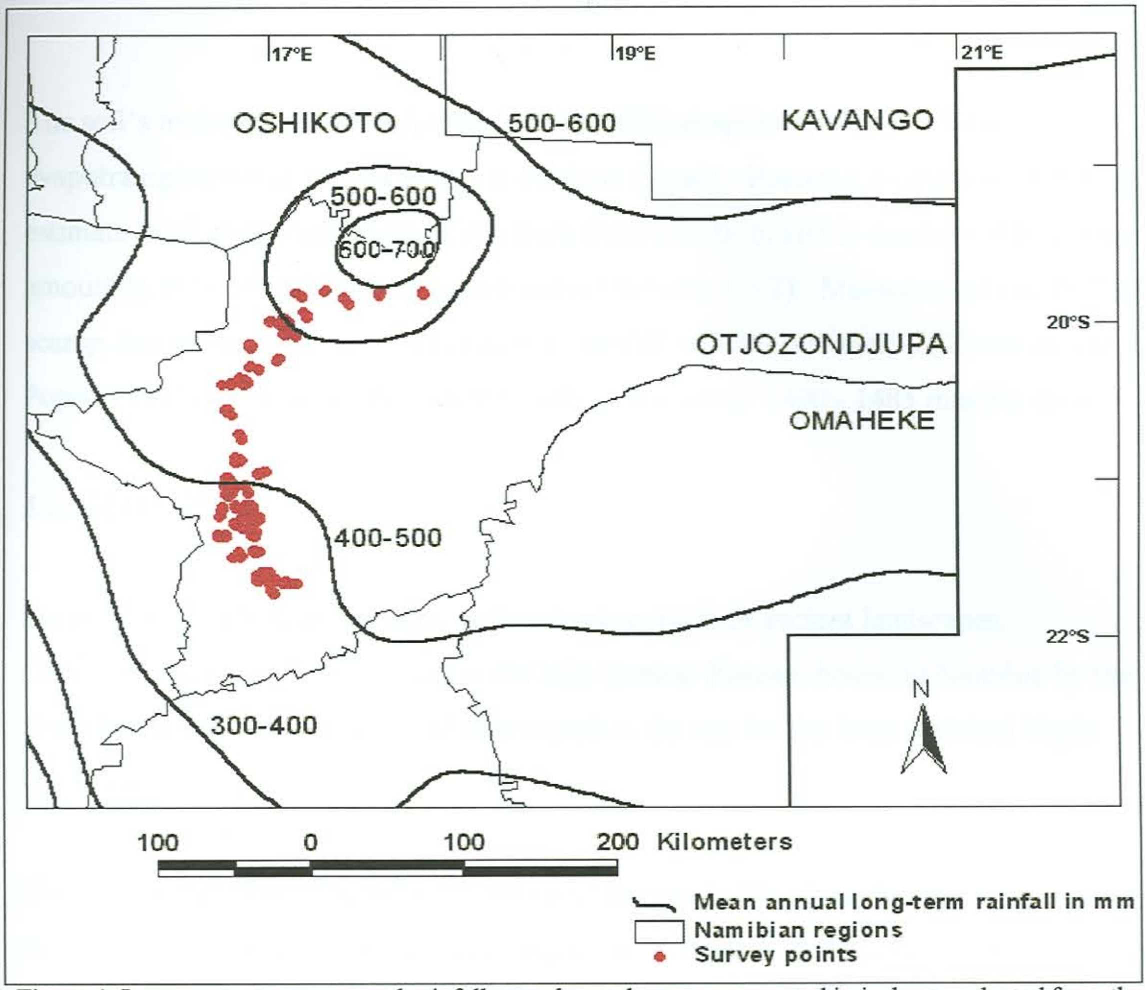


Figure 4: Long-term average annual rainfall over the study area represented in isohyets, adapted from the NARIS database (AEZ 2001).

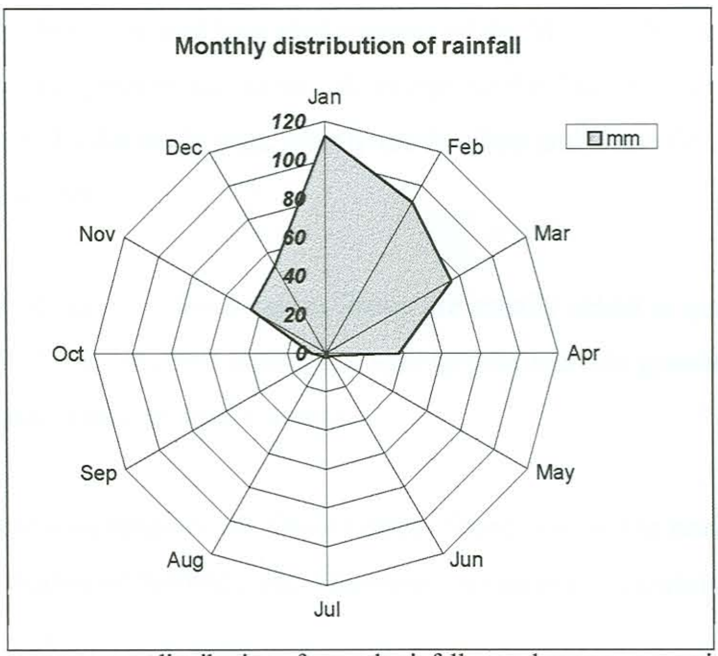


Figure 5: Long-term average distribution of annual rainfall over the year as experienced in the study area, adapted from the NARIS database (AEZ 2001).

The soil's moisture regime is further influenced by evaporation losses - both evapotranspiration as well as evaporation from the soil. Potential evaporation (PET) is an estimate of all evaporative loss of moisture from a surface, and in southern Africa may amount to 91% of mean annual precipitation (Schulze 1997). Measurements of PET are scarce, but compared to an average annual rainfall of 300 - 600 mm, Le Houerou and Popov (1981) estimate the PET of the study area at about 1490 - 1485 mm per annum.

5.2. GEOLOGY

Large parts of Africa are covered with extensive tracts of ancient landscapes. Characteristic for southern Africa is the high Central Plateau, bound in Namibia by the Great Escarpment in the west and interrupted in the east by the large Kalahari Basin (Partridge 1997).

The Geological Map of Namibia (Geological Survey 1980), describes the study area as consisting of the Karoo- and Damara Sequences as well as the Kalahari-Group (Figure 6).

The Damara Sequence, consisting of a succession of mainly sedimentary layers deposited during the late Protozoic to early Cambrian (see Table 1 below), is divided into the central and southern areas. The southern area consists of the Mulden, Swakop and Nosib Groups. The northern area is essentially identical, excepting the Otavi Group in place of the Swakop Group. In the study area, mostly the Swakop and Otavi Groups of the Damara Sequence are found.

Undifferentiated layers in the Swakop Group are usually schist or quartzite. However, the largest area of this group here consists of syn- to post-tectonic granites, sometimes with the inclusion of gneiss and/or quartz diorite.

The undifferentiated strata of the Otavi Group, found only in the northern part of the study area, consist mainly of dolomite and limestone, occasionally quartzites occur.

The main agent exposing the ancient Damara Sequence was erosion during the African Planation, which was a direct result of the break-up of Gondwanaland during the late Jurassic to early Cretaceous.

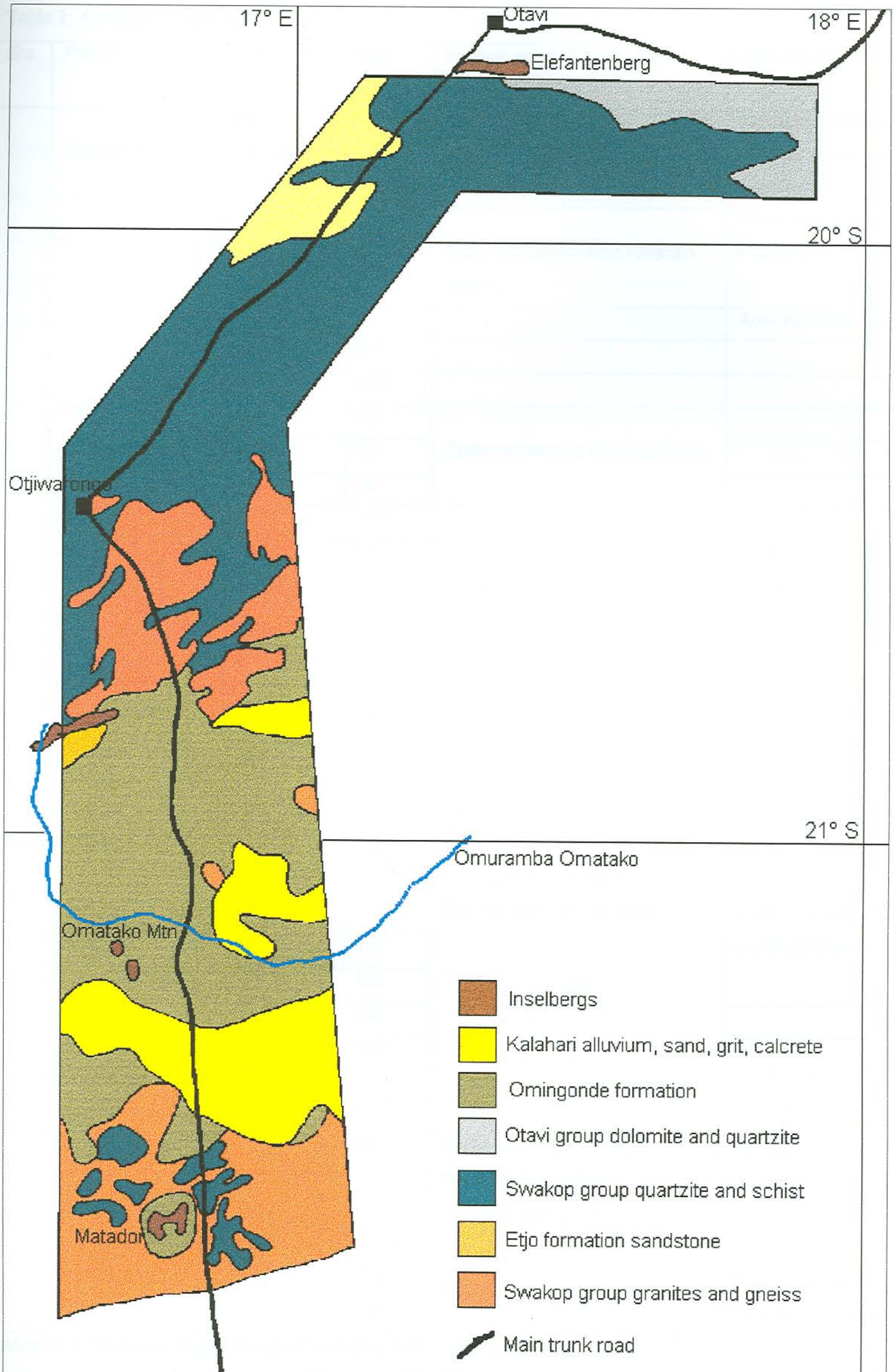


Figure 6: Diagrammatic representation of the main geological strata found in the study area, adapted from the Geological Map of Namibia (Geological Survey 1980)

Table 1: Geological Timescale

Era	*Period*	*Epoch*	*Age (M yr.)*	*Isotopic ages of geological strata*	*Major incidents*
		Holocene	0.01		Formation of present-day biomes, *Homo sapiens* appears
	Quarternary	Pleistocene			
			2		*Homo erectus* appears
		Pliocene	2.8	Sand-deposition onto Kalahari Basin	Pliocene cooling
		Miocene	4		*Australopithecus* appears
			5.1		
		Oligocene	24.6		
	Tertiary		32		
		Eocene	38	Sedimentation of Kalahari Basin	
			39		
		Palaeocene	54.9		
			65		Continents ± arrive at present-day position Dinosaurs die out
	Cretaceous		120		African Planation
			140		break-up of Gondwana-land, seed plants appear
	Jurassic		195	Formation of Karoo Sequence with	Formation of Laurasia and Gondwana
	Triassic		250	Ecca subgroup Omingonde Formation Etjo Sandstone Formation	Existence of the Pangea supercontinent
	Permian		285		
	Carboniferous		350		
	Devonian		405		
	Silurian		440		
	Ordovician		500		
	Cambrian		570		
	Pre-Cambrian (Protozoic)	Namibium	650	Swakop & Otavi Group of the Damara Sequence	
			920	Damara Sequence	
			1160		
			3500		First life-forms appear
			4500		formation of the earth

adapted from the Geological Map of Namibia (1980) and Gleich *et al.* (2000).

Also found in the study area is the Ecca Group of the Karoo Sequence. The Karoo Sequence was formed when, over 200 M yr. ago, much of southern Africa was a vast inland sea subject to sedimentation from surrounding area. The Ecca Group was formed during a period of global warming, characterized by periodic heavy rainfalls and flooding, leading to increased sedimentation of the Karoo-inland sea (King 1978). The Omingonde Formation of the Ecca Group typically consists of red mudstone, siltstone, sandstone or grit. Occasionally sills and dykes of dolerite, surrounded by aeolian sandstone of the Etjo Formation are found - the Omatako mountains are an example (Geological Survey 1980).

The Kalahari Basin has been a principal focus of continental sedimentation since the late Cretaceous, which continued into the quaternary. Accumulation of the red sands of the Kalahari probably only occurred as a result of drier climatic conditions during the Pliocene cooling (2.8 M yr.) (King 1978, Cole 1982, Geological Survey 1980, Partridge 1997). In Namibia, the Kalahari Group consists of alluvium, sand, gravel and smaller patches of surface calcrete. Typically, due to its inundation history, underneath the sandy layers is a calcareous layer, at places exceeding 10m thickness, which make it some of the thickest calcareous crusts in the world (Blümel 1982). This crust partially covers the older Omingonde Formation of the Karoo Sequence.

5.3. SOILS

Soils are the product of their environment, i.e. their formation is influenced by climate, lithology, topography as well as fauna and flora. In arid climates, more water evaporates than precipitates, leading to much reduced chemical weathering (compared e.g. to Europe) because solutes from weathering processed are accumulated rather than leached out. However, sandy soils in arid climates may undergo acidification when minerals and ions are washed out by strong, infrequent rainfall events (Scheffer & Schachtschabel 2002). Another, relatively recent factor, which cannot be ignored are land use practices which may preserve soils or lead to their degradation (Heine 1995).

The majority of Namibian soils are either Lithosols (*lithos* meaning rock or stone), weakly developed soils and further inland Arenosols (sandy soils). Calcareous sediments as well as calcrete crusts are further widely distributed in Namibia (Geological Survey 1980, Blümel & Eitel 1994, Heine 1995), forming a relatively impermeable subsurface pan horizons of cemented calcrete in the Kalahari (Tinley 1982).

Apart from the geological nature of soils, surface texture of soil is an important determinant of the soil water regime. Surface texture determines the level of water infiltration into the soil, as well as the amount of water remaining in the soil after rains and subsequent evaporation. In arid to semi-arid areas, clays or fine-textured soils are regarded as the most xeric substrates (further influenced by the presence or absence of pan horizons and their depth), while sands or coarser textured topsoils in general show a greater water retention ability (Alizai & Hulbert 1970, Tinley 1982, Scheffer & Schachtschabel 2002). In a study on soil water regimes in a shortgrass steppe, Dodd and Lauenroth (1997) established that sites with loamy sand had more a higher soil moisture content than sandy clay loams and sandy clays. In the latter, the bulk of the moisture only penetrated to the upper soil layers (about 30 cm), while water was able to infiltrate to a depth of about 100 cm on loamy sand sites. These soil moisture reserves were then much less susceptible to evaporative loss as the soil heats up during the day.

Based on Scheffer & Schachtschabel 2002, FAO Guidelines for Soil Description (FAO 1990) and the Soil Map of Namibia (AEZ 2001) the soils of the study area can be described as follows (note that soil colour descriptions are the colours of soils when wet):

Leptic Regosols are found mainly on the footslopes of hills and ridges on hard Damara limestone. These coarse to moderately coarse soils are shallow to moderately deep and in general well drained. The surface layer consists of loamy sand to loam of a dark grey to dark red colour. The limited depth of these soils limits plant rooting depth, while further constraining plant growth due to its low water-holding capacity.

Haplic Regosols are very deep with common to many coarse fragments and in general good drainage. The surface layer consists of loamy sand to sandy loam with quartz fragments, while the colour ranges from brown to yellowish red.

Chromic Cambisols are relatively old soils, having formed when the loamy soluble remains of limestone or dolomite have aggregated to a thickness exceeding 10 - 30 cm. Iron oxides are often present, leading to the reddish to brownish colours of these soils. The genesis of these soils is often associated with warmer, moister climates during the tertiary. These soils are thus comparatively very deep and well drained. The surface layer consists of coarse to moderately coarse loamy sand to sandy clay loam with a very dark greyish brown to dusky red colour. These soils have a moderate to high water holding capacity. When dry, the topsoil may become very hard, making it a generally difficult soil to work with.

Leptic-Chromic Cambisols are moderately deep to deep and well drained. The surface layer consists of loamy sand to sandy clay loam with a very dark greyish brown to dusky red colour. Texture varies from moderately coarse to moderately fine with occasionally few rock fragments. Water holding capacity of these soils is moderate.

Petric Calcisols are often found on hard Damara limestone, and are consequently very shallow and well drained. The surface layer consists of loamy sand to loam and is very dark grey to brown. The soils texture is moderately coarse to medium without rock fragments. Water holding capacity of these soils is very low.

Haplic Calcisols are very deep and well drained. The surface layer consists of coarse to moderately fine-textured sandy loam to silty loam with a very dark grey to dark yellowish brown colour. The underlying material often has accumulations of hard and soft nodules, resulting in a calcic horizon. Water holding capacity is moderate.

Lithic Leptosols are weakly developed soils, derived from and found on top of bedrock, here hard limestone outcrops, ridges or hills of the Damara sequence. These soils are very shallow (2-20 cm) and well drained, drying out relatively quickly. The surface layer consists of loamy sand to sandy clay loam and is dark greyish brown to dark reddish brown. Some humus may have accumulated, but is not significantly decomposed. Often these soils are relatively steep, which adds to their poor water holding capacity and makes them prone to erosion.

Mollic Leptosols are somewhat more developed than lithic Leptosols, with usually a richer component of humus and thus also nutrients. They are found on a bedrock of Damara limestone, are very shallow and well drained. The surface layer consists of coarse to moderately coarse loamy sand to sandy loam and are black to very dark brown. Water holding capacity is low.

Ferralic Arenosols are sands derived from aeolian deposits. They are very deep and somewhat excessively drained, with a typically poorly developed profile. The surface layer consist of coarse sand with a dark grey to reddish brown colour. Water holding capacity of these soils is low.

Arenic Fluvisols are typical for the omurambas (shallow, slow flowing water channels which are only seasonally filled) and river depressions of the Kalahari Region. These soils are weakly developed, derived from alluvial deposits, very deep and moderately to well drained. The soil surface consists of sand to loamy sand with a very dark grey to brown colour. Water holding capacity of these soils is low to moderate.

Specific soil types are hardly continuous over a large area, and may change within relative short distances. It can thus be anticipated that it is unrealistic to map singular soil types, rather, the Soil Map of Namibia has attempted to map the characteristic combinations of soils for a given map unit. These units for the study area (Figure 7) are:

CKf2: leptic Regosols with leptic-skeletic Regosols and leptic-chromic Cambisols as minor inclusions
CKg1: chromic Cambisols with leptic Regosols and petric Calcisols
CKh1: rock outcrops with lithic Leptosols
CKl1: mollic Leptosols with petric Calcisols
CLg1: leptic Regosols with haplic Regosols and petric Calcisols
CLh1: rock outcrops & lithic Leptosols Complex
CLl1: chromic Cambisols with leptic-chromic Cambisols and petric Calcisols as minor inclusions
CLl2: chromic Cambisols with leptic-chromic Cambisols
CLl3: petric Calcisols & leptic-chromic Cambisols Complex
KDf1: ferralic Arenosols & arenic Fluvisols & haplic Calcisols Association
KFv1: arenic Fluvisols and haplic Calcisols
KFv5: fluvic Cambisols & haplic Fluvisols & ferralic Arenosols Complex

KSd1: ferralic Arenosols

The occurrence of arid savannas in southern Africa is closely related to the distribution of calcareous soils (Huntley 1982), thus these soils deserve further mention. As mentioned earlier, they are widely distributed in Namibia and typical for arid climates. As calcareous soils, all soils containing free calcium carbonate ($CaCO_3$) or calcium-magnesium carbonate are referred to. They are not restricted to any particular type of substratum, but are rather the result of aeolian material (loess), which was generated and transported during various climatic phases (Scheffer & Schachtschabel 2002). To generate calcrete itself, any loose sufficiently permeable material will suffice should it be capable of absorbing $CaCO_3$ from descending infiltration facilitated by e.g. rainfall events (Blümel 1982). The actual formation of calcrete is a rather complex process (described by Blümel 1982). However, the final stages of calcrete formation may have an enormous impact on the vegetation. Erosion of the topsoil exposes the calcic horizon, which had formed during past decades, which then enables the re-solution and surface-cementation of Ca. Runoff water may further aid the deposition of the very fine Ca grains into voids or pores on the soil surface, so creating a lamellar soil surface. This surface becomes relatively impermeable to water-infiltration (Blümel 1982), which creates a rather arid soil environment for vegetation. These soils may be responsible for the occurrence of "marginal savannas" as described by Irish (1994) within the savanna biome, whose distribution cannot be ascribed to climatic conditions alone.

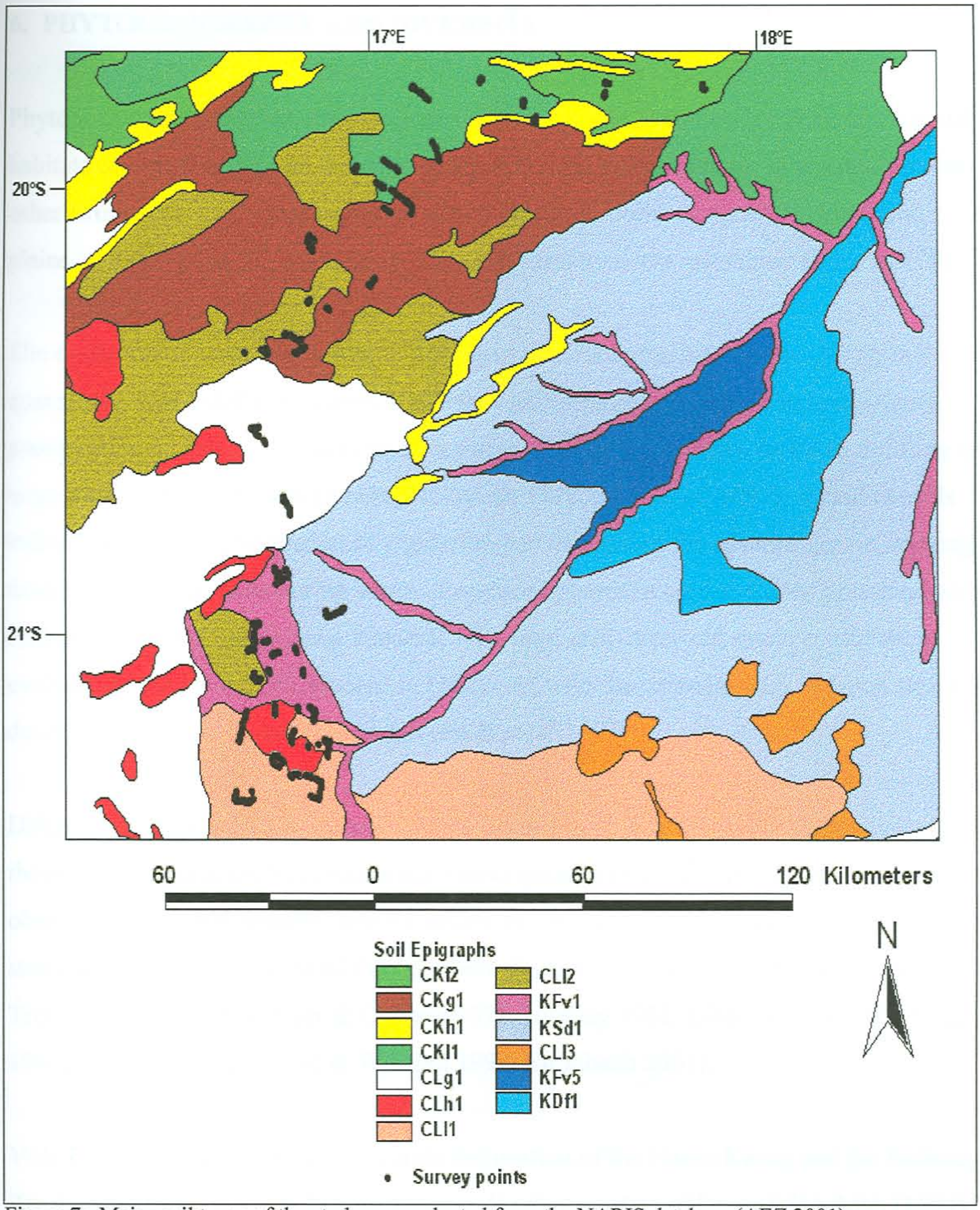


Figure 7: Major soil types of the study area, adapted from the NARIS database (AEZ 2001).