Bothalia 20,2: 233–240 (1990)

# The vegetation of the north-western Orange Free State, South Africa. 1. Physical environment

M.S. KOOIJ*, G.J. BREDENKAMP* and G.K. THERON*

**Keywords**: climate, geology, habitat, land types, physiography, soil, western Grassland Biome

ABSTRACT

The physiography, geology, soil, land types and climate of the north-western Orange Free State are described. The description provides a contextual framework for the subsequent vegetation classification.

UITTREKSEL

Die fisiografie, geologie, grond, landtipes en klimaat van die noordwestelike Oranje-Vrystaat word beskryf. Die beskrywing verskaf 'n gekoördineerde raamwerk vir die daaropvolgende plantegroeiklassifikasie.

## INTRODUCTION

The north-western part of the Orange Free State is one of the most important agricultural regions in South Africa. The study area represents the south-western part of the Highveld Agricultural Region. This region produces 80% of the maize, 75% of the grain sorghum and 65% of the sunflower seed output of the Republic of South Africa (Scheepers 1975). This part of the Grassland Biome also renders a large part of the Republic's animal products (Scheepers 1975; Mentis & Huntley 1982). Most of the land has been ploughed, mainly for maize cultivation. The remaining natural vegetation is restricted to non-arable shallow or rocky soils, vertic clays in bottomland situations, seasonally waterlogged vleys and along drainage lines. The vegetation is often overgrazed by sheep and cattle.

Little is known about the vegetation of the north-western Orange Free State. The relevance of plant ecological studies to land use planning and management is well documented (Edwards 1967; Walker 1976; Bredenkamp & Theron 1978; Muller 1983). A more detailed classification of vegetation than that of Acocks (1988) is necessary to meet the present needs for regional and subregional planning (Deall, Scheepers & Schutz 1989). It was therefore necessary to identify, classify and map the vegetation in order to permit efficient land use planning and also the compilation of management programmes for optimal utilisation, without the degradation of vegetation. In this account the fundamental physical environment of the study area is described.

## STUDY AREA

The study area represents the western parts of the 2726 Kroonstad map (1 :250 000). The area is situated between 26°00′ and 27°23′ E longitude and 27°00′ and 28°00′ S latitude. Towns situated in the study area are Kroonstad, Welkom, Bothaville, Hennenman, Viljoenskroon, Vredefort and Wesselsbron (Figure 1). The area covers approximately 1 437 000 ha and about 1 365 000 ha is available for agriculture (Land Type Survey Staff 1984).

* Department of Botany, University of Pretoria, 0002, Pretoria.
MS. received: 1989.09.07.

## GEOLOGY

The geology of the study area is presented in Figure 2.

### *Archaic granite*

Old Archaic granites are exposed in the vicinity of Vredefort where they form the central part of the Vredefort Dome. The round or castle-like koppies of stacked granite blocks are typical of this area. These granites occur only in the extreme north-eastern part of the study area. They are grey-white in colour and consist of quartz, potassium feldspar, plagioclase and biotite. The Archaic granite weathers to form a coarse, sandy soil of the Glenrosa Form in the uplands, and the Valsrivier and Sterkspruit Forms in the lowlands (Harmse 1967).

### *Witwatersrand Supergroup*

Rocks of the Witwatersrand Supergroup are exposed in a small part of the study area. They occur adjacent to the Archaic granites and, together with the Ventersdorp Supergroup, represent the outer rim of the Vredefort Dome.

The Witwatersrand Supergroup is of great economical value, seeing that it is the source of gold-bearing ore in South Africa. The Supergroup consists of alternating groups of quartzite and shale or slate. The gold ore is situated in fine layers in conglomerate. The resistance to erosion of the various rock types differs greatly. Quartzite is very resistant and therefore forms predominant parallel ridges. It gives rise to coarse sandy shallow lithosols (< 300 mm) and regosols represented by the Mispah Form (Harmse 1967). The softer shale and slate weather easily to form the valleys between the quartzite ridges. The shale and slate erode to form dark clayey soils.

### *Ventersdorp Supergroup*

This Supergroup is represented by outcrops along the Vaal River and the adjacent outer layers of the Vredefort Dome. A few outcrops are also found near Odendaalsrus.

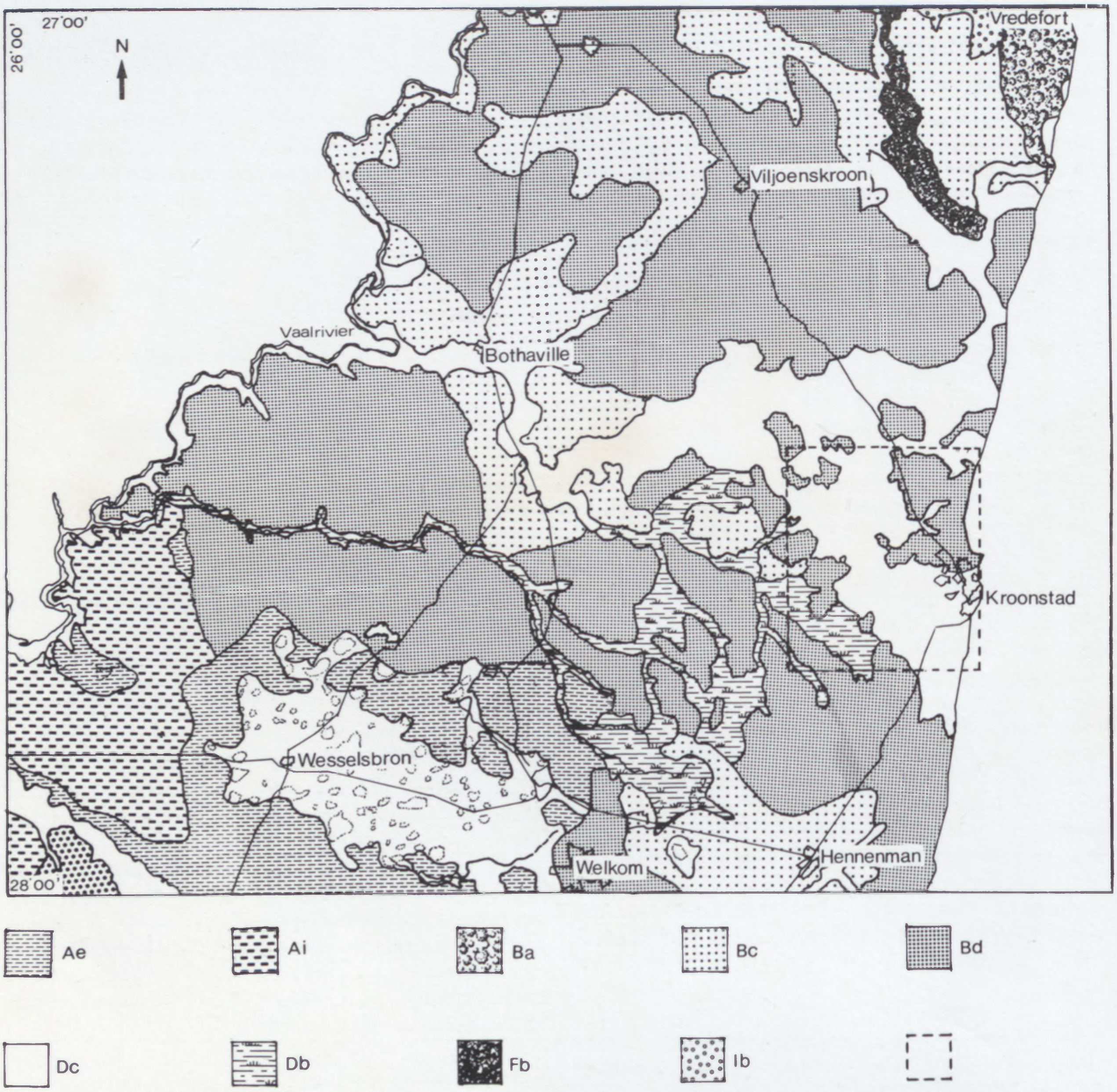


FIGURE 1.—The distribution of the different land types in the study area (Land Type Survey Staff 1984). Ae; Ai; Ba; Bc; Bd; Db; Dc; Fb; Ib; hatched square is portion studied by Scheepers (1975), around Kroonstad.

The lavas of the Ventersdorp Supergroup cover the Witwatersrand Supergroup. The Ventersdorp Supergroup consists of dark blue-grey Andesitic lava with round amygdaloids. The Andesitic lava consists of plagioclase and pyroxene which weather easily, resulting in a flat landscape with dark-coloured vertic soils with a high intrinsic fertility. This Supergroup is often covered with recent sand deposits.

*Transvaal Sequence*

Rocks of this Sequence are restricted to a small part in the north of the study area. It occurs between the Ventersdorp Supergroup outcrops adjacent to the Vaal River and the Vredefort Dome (Figure 2). Two groups can be identified in this Sequence namely the Chuniespoort Group and the Pretoria Group.

Chuniespoort Group

This Group is situated between the Pretoria Group and the Ventersdorp lavas. It is represented by the Malmani Subgroup, previously known as the Dolomite Series. It consists mainly of dolomitic limestone and chert. Other minerals such as calcite and dolomite may be present. The rocks are also rich in iron and magnesium (Truswell 1977). Chert is a hard, extremely compact, dull to semi-vitreous cryptocrystalline rock, consisting dominantly of cryptocrystalline silica (Harmse *et al.* 1984). These rocks were formed during a chemical deposition of silica in water (Kruger 1971). Dolomite and chert are both resistant to weathering. The result is a flat landscape with exposed dolomite and chert outcrops. The soils of this area are mostly very shallow and rocky, repesenting the Mispah, Glenrosa and shallow Hutton soil forms.

Pretoria Group

Within the study area this group is limited to a small area north of Viljoenskroon. It consists mainly of quartzite and shale. Igneous rock occurs regularly and two types are distinguished, namely Ongeluks lava that consists of a dark green to grey Andesitic lava with quartz amygdaloids and intrusive diabase plates. The soils derived from the shale, lavas and diabase are usually clayey and of the Bonheim, Arcadia or Rensburg Forms, whereas the sandy soils derived from the quartzite are mostly of the Mispah, Glenrosa and Hutton Forms.

*Karoo Sequence*

This Sequence occupies about 80% of the study area. It comprises a thick shale layer, mudstone and sandstone with tillite at the base and basaltic lava as a canopy. These strata were not disturbed by earth movements. Four groups can be distinguished, but only two of the four occur in the study area, namely the Ecca and the Beaufort Groups.

Ecca Group

Sediments of this Group are approximately 200–300 m thick. A considerable amount of fossils can be found in the sediments of this group. The Group can be subdivided into three subdivisions, namely the Lower Stage, consisting of soft dark blue shales; the Middle Stage, consisting of grit, shale and coal and the Upper Stage, consisting of soft, dark shale, usually covered with recent aeolian sand deposits.

The grit and sandstone are resistant to weathering and form low hills and escarpments. These sediments are usually covered with recent, deep, fine aeolian sands.

Beaufort Group

The Beaufort Group covers the south-eastern part of the study area. The sediments are a sequence of shale and mudstone with interbedded lenticular sandstone (Truswell 1977).

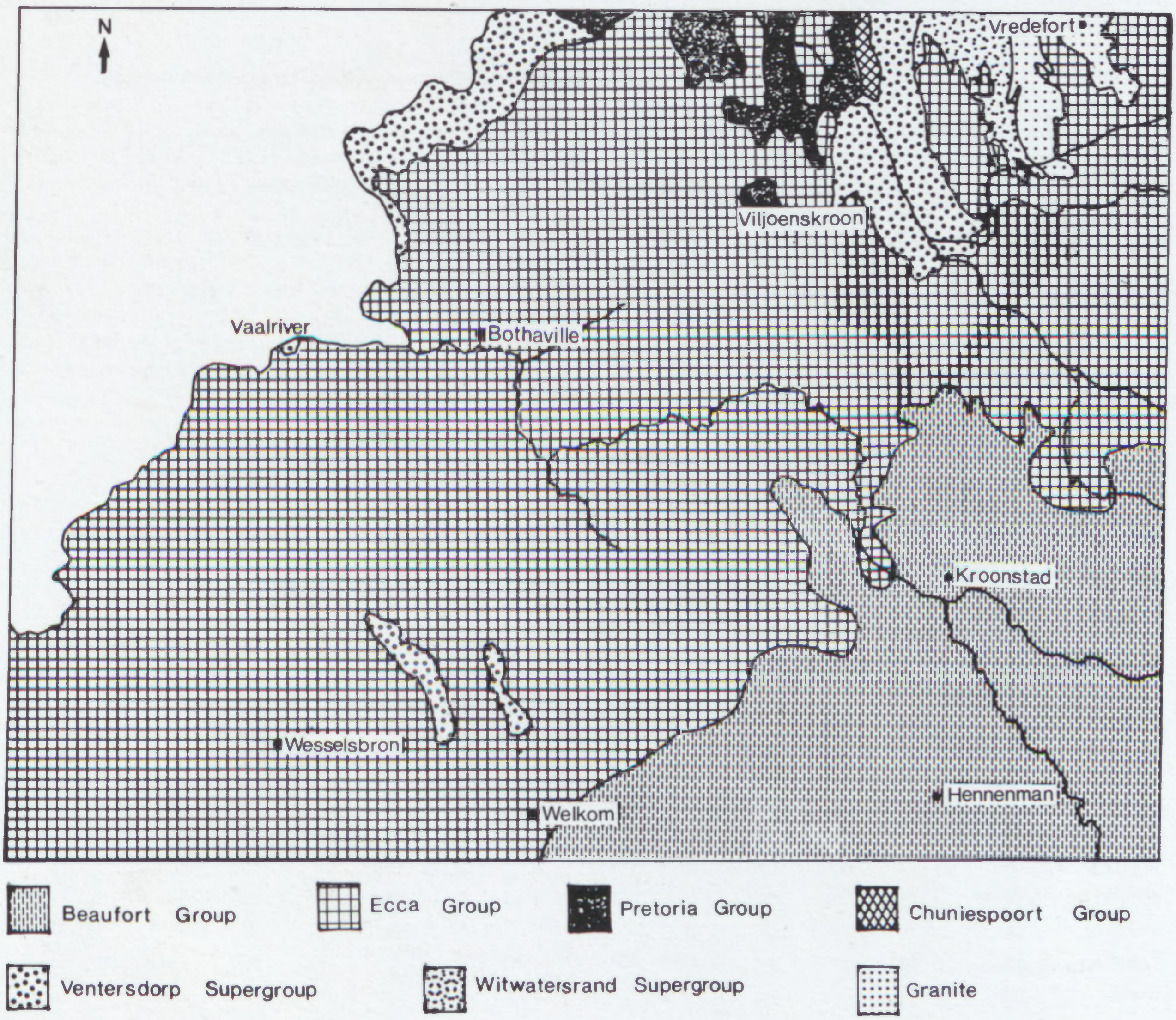


FIGURE 2.—The geology of the study area (Harmse 1967). Karoo Sequence: Beaufort Group: shale, mudstone arenaceous shale immature sandstone, extensively invaded by dolerite dykes and sheets; Ecca Group: shale and mudstone (carbonaceous and calcareous), immature sandstone and coal seams, extensively invaded by dolerite sheets and dykes. Transvaal Sequence: Pretoria Group: quartzite, banded ironestone, subordinate shale and lava; Chuniespoort Group: dolomitic limestone, chert, thin band of quartzite and conglomerate at the base. Ventersdorp Supergroup: andesitic lava, agglomerates and tuffaceous sediments. Witwatersrand Supergroup: quartzite, conglomerate shale, lava, slate and tillite. Granite.

The Karoo sandstone is soft and easily weathered to form a variety of deep, red to yellow sandy soils. On the other hand mudstone, shale and dolerite weather rapidly to give rise to both sedentary and colluvial, base-rich, dark, margalitic clays.

*Recent deposits*

Aeolian sand

The colour of the aeolian sand of the north-western Orange Free State varies from red to grey. The colours are a result of a fine layer of iron oxide that covers the quartz and feldspar grains (Harmse 1967). The only difference between the sands of the Kalahari area and the north-western Orange Free State is that the sands of the latter are covered with dense vegetation and that no prominent dunes occur.

## PHYSIOGRAPHY

The study area forms part of the Highveld inland plateau region and consists of smoothly plained or gently rolling land surfaces of the Tertiary and Miocene age (Mentis & Huntley 1982).

The monotonous soft rolling landscape on Karoo sediments is situated between 1 200 and 1 400 m above sea level. This physiographic unit stretches from the Vaal River south-eastwards to Theunissen and Ventersburg. Ventersdorp lavas are responsible for the formation of round hills whereas the uplands and mesas of Karoo dolerite are formed by relics of Tertiary erosion surfaces. Erosion within this physiographic unit is responsible for the formation of peneplains with vertic, impermeable, argillic soils of the Ecca Group. These clay peneplains are usually unsuitable for agronomy.

In areas covered with aeolian sand, most of the surface characteristics have been destroyed and therefore only an undulating landscape is visible. The presence of *Acacia karroo* is often the only indication of the existence of the dolerite sills. In the waterlogged areas of this landscape pans are a prominent characteristic. The pans can be subdivided according to their size and age.

The occurrence of large pans is restricted to clay flats situated on argillic sediment of the Upper Ecca. The form of the pans is uneven. These pans have an inflow but no outlet, and therefore the drainage is internal. The pan floors consist of dark waterlogged alkaline soils. During desiccation these soils form block fragments with gypsum crystals. A sparse vegetation may cover the pan floor.

Small pans are situated on the grey sands with a high water table. Iron and lime concretions occur frequently on the pan floors. No vegetation is found on the floors of these pans.

In the northern parts of the study area the gently undulating landscape of the Vredefort Dome occurs. Rocky hills and ridges of quartzite, shale and lavas of the Witwatersrand Supergroup and Transvaal Sequence form the rim of the Vredefort Dome. This landscape is steeply dissected and the Vaal River cuts deeply through the rocky ridges.

*Drainage*

The study area is situated in the catchment area of the Vaal River. Drainage occurs along the Vaal, Renoster and Vals Rivers and their tributaries, as well as flushes and seepages into pans. The Karoo Sequence is deeply incised by these rivers, gradually flattening towards the south-east.

Due to the gradual slopes in the area, erosion is restricted to rivers and flushes. No marshy areas are formed in the aeolian sand with a high permeability, but the clayey flats usually form marshy areas during the rainy season. This gives rise to the formation of the large pans which are responsible for the internal drainage of the area (Harmse 1967).

## LAND TYPES AND SOILS

A land type denotes an area that can be shown on a 1:250 000 scale map and displays a marked degree of

TABLE 1.—The mean monthly rainfall for weather stations in the study area

| Period | Station | Month | | | | | | | | | | | | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Av. |
| # 1951/84 | B | 99 | 83 | 72 | 52 | 20 | 7 | 6 | 8 | 17 | 52 | 73 | 75 | 564 |
| + 1987/88 | B | 33 | 158 | 45 | 81 | 9 | 2 | 4 | 13 | 57 | 118 | 71 | ** | |
| + 1987/88 | H | 74 | 67 | 160 | 69 | ** | 4 | 4 | 18 | 108 | 155 | 141 | 49 | |
| # 1951/84 | K | 105 | 83 | 82 | 53 | 23 | 6 | 8 | 12 | 25 | 66 | 74 | 74 | 611 |
| + 1987/88 | K | 57 | 85 | 146 | 88 | 8 | 6 | 2 | 16 | 108 | 91 | 100 | ** | |
| # 1974/84 | P | 91 | 70 | 59 | 44 | 13 | 5 | 7 | 15 | 26 | 54 | 63 | 56 | 503 |
| + 1987/88 | P | ** | 108 | 106 | 49 | 7 | 4 | 3 | 18 | 85 | 93 | 82 | ** | |
| + 1987/88 | Vk | 69 | 101 | 104 | 82 | ** | 4 | 2 | 10 | ** | 95 | 104 | 149 | |
| + 1987/88 | Vf | ** | 53 | 115 | 57 | 7 | 7 | 0 | 10 | 100 | 121 | 65 | 107 | |
| # 1955/78 | W | 99 | 67 | 67 | 49 | 23 | 8 | 7 | 5 | 17 | 49 | 63 | 72 | 526 |
| + 1987/88 | W | 35 | 148 | 122 | 61 | 10 | 6 | 4 | 16 | ** | 99 | 84 | 98 | |

B, Balkfontein-Bothaville No. 0399/894 4; H, Hennenman Police Station No. 0365/058 4; K, Kroonstad Municipality No. 0365/430 8; P, Plessisdraai-Hoopstad No. 0363/239 5; Vk, Viljoenskroon Municipality No. 0400/792 9; Vf, Vredefort School No. 0437/660 7; W, Welkom No. 0364/300 1; **, Unreliable data; #, Weather Bureau 1986; +, Weather Bureau 1989.

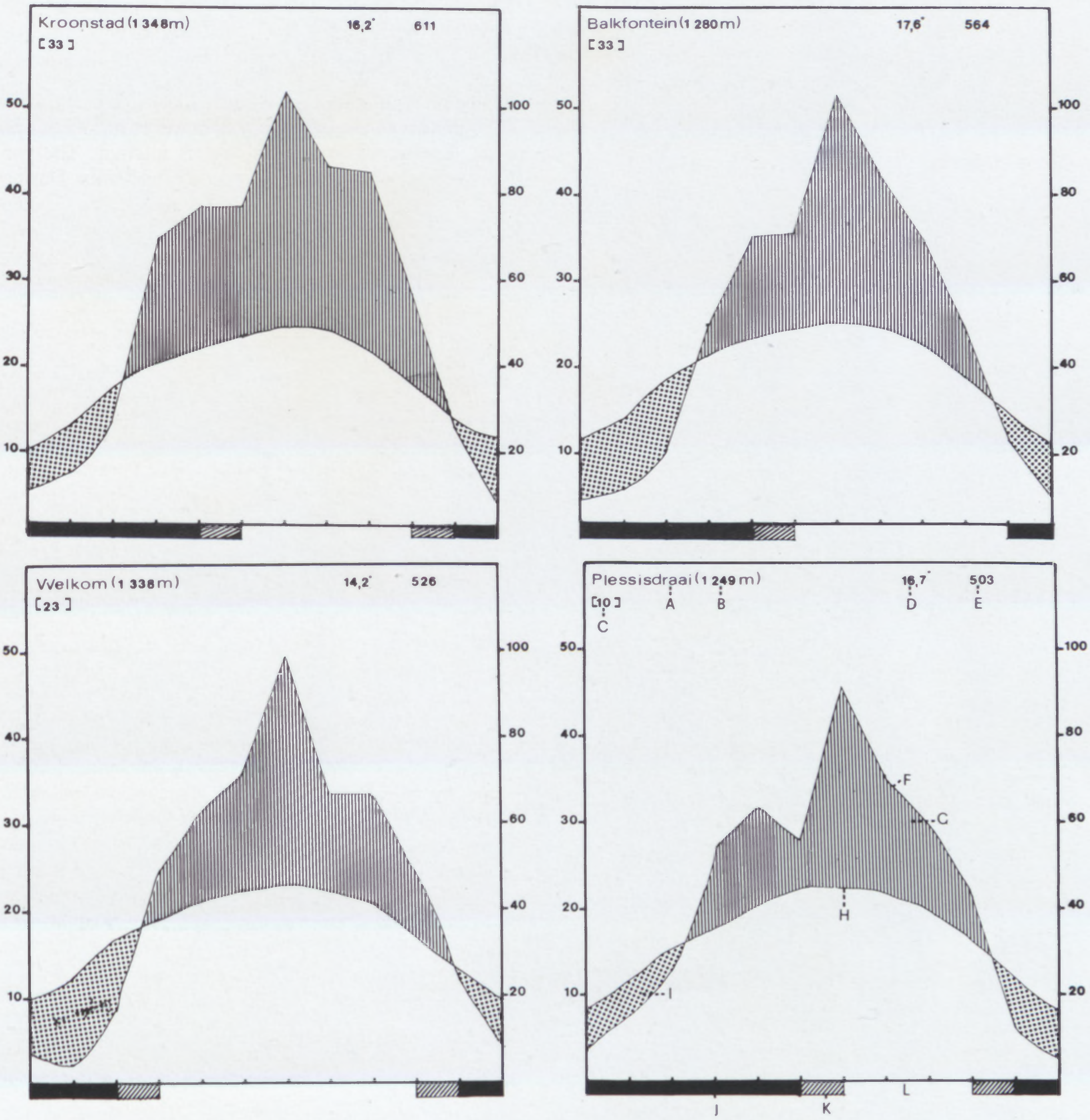


FIGURE 3.—Climatic diagrams for the study area. A, station; B, height above sea level; C, duration of observations in years (indicates precipitation); D, mean annual temperature in °C; E, mean annual precipitation in mm; F, mean monthly precipitation; G, wet period; H, mean monthly temperature; I, dry period; J, cold season (months with mean daily minimum below 0°C); K, months with absolute minimum below 0°C; L, frost-free period (Larcher 1975).

uniformity with respect to terrain form, soil pattern and climate. One land type differs from another in terms of one or more of the following: terrain form, soil pattern or climate (Land Type Survey Staff 1984).

Five different land types are distinguished in the study area, namely the A, B, D, F and I land types (Figure 1). Each of these land types can be further subdivided. They are discussed in detail in Land Type Survey Staff (1984) and in the following papers: A land type (Kooij *et al.* 1990c), B land type (Kooij *et al.* 1990b), D land type (Kooij *et al.* 1990a) and the Fb, Ib and Ba land types (Kooij *et al.* 1990d). Nomenclature of soil forms follows MacVicar *et al.* (1977).

## CLIMATE

The study area is situated in the H climate zone of the Highveld region, according to the classification of the Weather Bureau (1986). This region is characterised by thunderstorms during the summer months. The winter months are arid and cold.

### *Precipitation*

Soil moisture is derived from precipitation mainly in the form of rainfall, and to a lesser degree from mist, dew, hail and snow (Deall, Scheepers & Schutz 1989).

Rainfall: the mean monthly rainfall for Balkfontein (33 yrs), Kroonstad (33 yrs), Plessisdraai (10 yrs) and

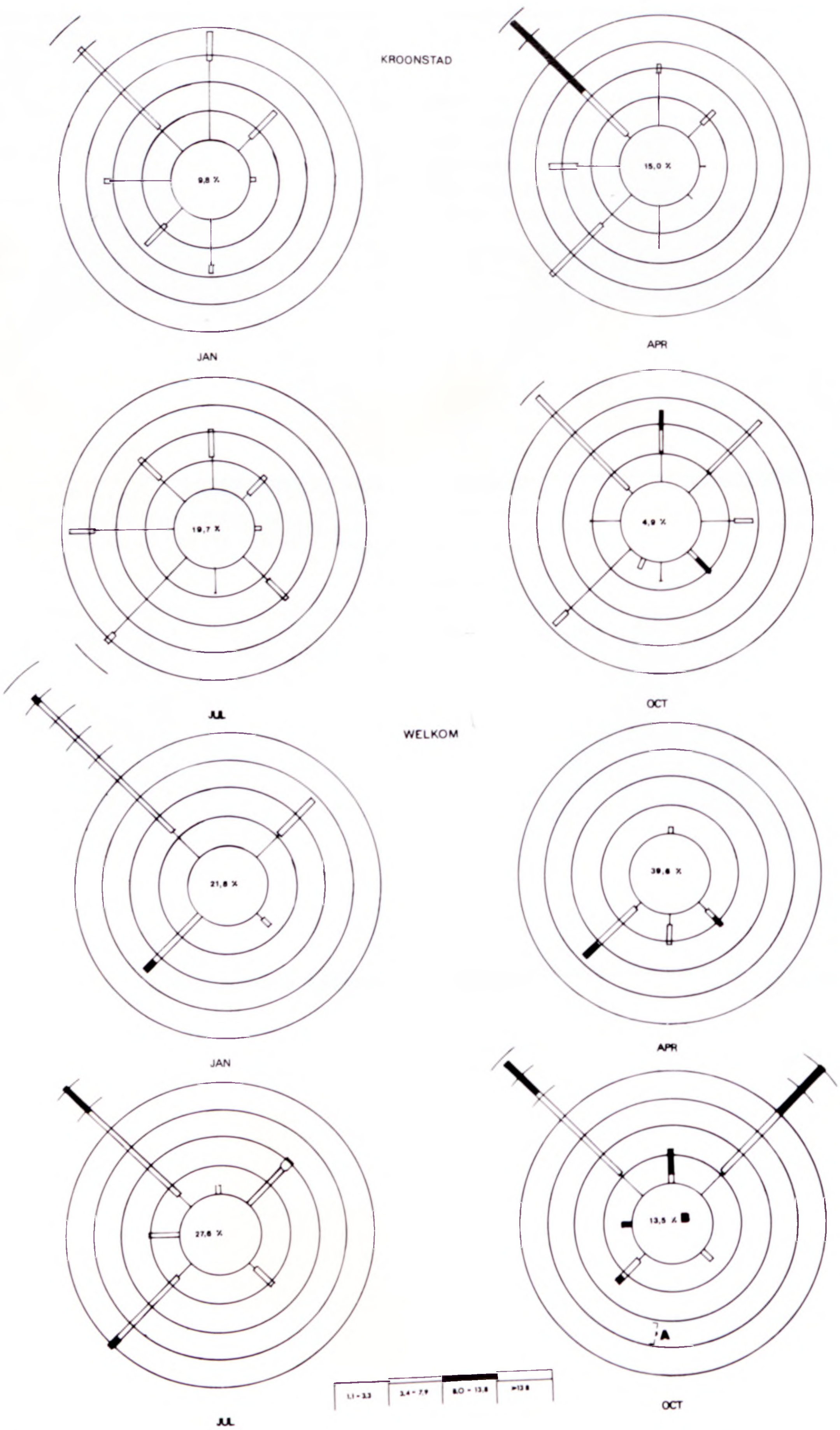


FIGURE 4.—Wind roses for two weather stations in the study area, representing wind directions and speed intervals (m/s) for January, April, July and October (Weather Bureau 1988). A, 5% frequency intervals; B, percentage of calm in circle.

TABLE 2.—The monthly number of days with frost

| Month | Weather station | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Plessisdraai | | Balkfontein | | Welkom | | Kroonstad | |
| | 1987 | 1988 | 1987 | 1988 | 1987 | 1988 | 1987 | 1988 |
| Jan. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Feb. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mar. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Apr. | 0 | 4 | 0 | 0 | 0 | 1 | 0 | 5 |
| May | 15 | 7 | 8 | 5 | 4 | 3 | 12 | 8 |
| Jun. | 27 | 16 | 23 | 21 | 14 | 17 | 27 | 25 |
| Jul. | 29 | 27 | 27 | 23 | 25 | 20 | 29 | 27 |
| Aug. | 21 | 15 | 12 | 13 | 6 | 6 | 14 | 17 |
| Sep. | 0 | 3 | 0 | 0 | 0 | 1 | 0 | 3 |
| Oct. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nov. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dec. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The occurrence of frost is taken as days with a minimum temperature of ≤2,5°C (Weather Bureau 1989).

Welkom (23 yrs) is presented in Table 1 and Figure 3 (Weather Bureau 1986). Mean monthly rainfall figures for a number of stations in the study area for the years 1987/1988, are given in Table 1 (Weather Bureau 1989). Table 1 indicates the above average rainfall of the two years (1987–1988) in which the vegetation study took place. The study area clearly falls within the summer rainfall zone, with most of the precipitation from October to March. Annual totals average 611 mm at Kroonstad in the eastern parts and 503 mm at Plessisdraai in the west. The rainfall also increases from south to north, with an average of 526 mm at Welkom in the south and an average of 611 mm at Kroonstad in the north. Thunderstorms are often violent and associated with strong south-westerly gusting winds and hail.

Frost is defined by the Weather Bureau as days with a minimum temperature of 2,5°C and lower. Frost can be expected from April to September in the study area (Table 2).

Snow: due to the dryness of the winter, snow does not often occur. Snowfalls were, however, recorded during June and July in the study area in 1987 and 1988.

*Temperature*

Temperature alone may not be a significant factor in determining major regional vegetation formations, it does however, play a part in the determination of floristic variations on a meso- and micro-scale (Schulze & McGee

TABLE 3.—The mean monthly maximum and minimum temperature (°C) for four weather stations in the study area

| Year | Month | Weather stations | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Balkfontein | | Kroonstad | | Plessisdraai | | Welkom | |
| | | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. |
| 1951/84 | Jan. | 30,2 | 16,7 | 29,5 | 15,8 | 30,4 | 15,5 | 29,4 | 16,6 |
| | Feb. | 29,3 | 16,2 | 28,5 | 15,4 | 29,8 | 15,7 | 28,4 | 16,1 |
| | Mar. | 27,9 | 14,2 | 26,9 | 13,2 | 27,7 | 12,7 | 27,0 | 14,7 |
| | Apr. | 24,8 | 9,7 | 23,9 | 8,6 | 25,3 | 7,9 | 23,2 | 10,6 |
| | May | 21,8 | 4,8 | 20,9 | 3,5 | 21,7 | 2,6 | 20,1 | 5,7 |
| | Jun. | 18,8 | 0,8 | 18,0 | −0,7 | 18,6 | −1,5 | 17,2 | 2,3 |
| | Jul. | 19,4 | 0,7 | 18,6 | −0,7 | 19,2 | −1,2 | 17,9 | 2,4 |
| | Aug. | 22,2 | 2,5 | 21,3 | 1,6 | 21,6 | 1,3 | 20,6 | 4,1 |
| | Sep. | 26,1 | 7,8 | 25,0 | 6,6 | 25,6 | 6,3 | 25,1 | 8,8 |
| | Oct. | 27,7 | 11,4 | 26,8 | 10,8 | 27,4 | 9,3 | 26,6 | 11,7 |
| | Nov. | 28,9 | 13,9 | 27,9 | 12,9 | 29,4 | 12,1 | 27,9 | 14,0 |
| | Dec. | 30,1 | 15,5 | 29,1 | 14,7 | 30,8 | 14,1 | 29,3 | 15,5 |
| | Av. | 25,6 | 9,5 | 24,7 | 8,4 | 25,6 | 7,9 | 24,3 | 10,2 |
| 1987/88 | Jan. | 33,1 | 17,6 | 31,8 | 16,4 | 34,2 | 15,9 | 32,8 | 16,6 |
| | Feb. | 30,1 | 18,1 | 29,6 | 17,1 | 30,6 | 17,3 | 29,5 | 17,3 |
| | Mar. | 28,4 | 15,6 | 27,7 | 14,5 | 28,3 | 14,5 | 27,5 | 14,9 |
| | Apr. | 25,6 | 11,9 | 24,6 | 10,5 | 25,4 | 10,0 | 24,5 | 11,2 |
| | May | 23,6 | 5,4 | 22,7 | 3,9 | 23,5 | 3,7 | 22,7 | 6,4 |
| | Jun. | 18,2 | 5,5 | 17,1 | −4,1 | 17,8 | −4,0 | 16,8 | 1,3 |
| | Jul. | 19,7 | −0,1 | 18,7 | −2,0 | 19,1 | −2,5 | 18,1 | 4,0 |
| | Aug. | 22,3 | 3,9 | 21,3 | 2,3 | 21,9 | 1,6 | 20,8 | 4,9 |
| | Sep. | 24,0 | 9,2 | 22,8 | 8,1 | 23,4 | 10,5 | 22,1 | 12,9 |
| | Oct. | 26,3 | 11,9 | 24,9 | 10,8 | 26,2 | 9,9 | 24,9 | 10,9 |
| | Nov. | 28,7 | 15,3 | 27,5 | 13,8 | 28,9 | 13,6 | 27,5 | 14,2 |
| | Dec. | 31,4 | 17,6 | 28,5 | 15,1 | 30,4 | 14,8 | 28,8 | 14,9 |

TABLE 4.—The extreme temperatures (°C) recorded at four weather stations in the study area

| Station | Temperature | | | |
|---|---|---|---|---|
| | Date | Max. | Date | Min. |
| Plessisdraai | 83-02-26 | 39,0 | 77-08-05 | −9,8 |
| Balkfontein | 81-01-12 | 39,5 | 74-08-01 | −8,8 |
| Welkom | 73-01-18 | 38,3 | 75-07-23 | −7,2 |
| Kroonstad | 73-01-19 | 39,6 | 75-07-23 | −8,7 |

1978). Such variations result from differential effects of temperature on plant growth rates, seed germination, seedling survival and flowering phenology (Deall *et al.* 1989). The average temperature is given in Figure 3 and the mean monthly maximum and minimum temperatures of the Plessisdraai, Welkom, Balkfontein and Kroonstad weather stations are represented in Table 3. There are no big differences between the maximum and minimum temperatures recorded at the different weather stations. The extreme maximum and minimum temperatures recorded at the four stations are represented in Table 4 (Weather Bureau 1986).

### *Wind*

Wind directions and velocities for the Welkom and Kroonstad weather stations are represented in Figure 4. The calmest days occur during May, June and July, whereas August and September are the windiest months (Weather Bureau 1989).

## CONCLUSION

A knowledge of the physical environment of the study area is necessary for the understanding and ecological interpretation of the abstract plant communities identified during a phytosociological survey. Environmental attributes largely determine the distribution of plant species and plant communities. These differences in distribution patterns make the classification of vegetation into ecological zones possible.

## ACKNOWLEDGEMENT

This research was financially supported by the Foundation for Research Development, CSIR.

## REFERENCES

ACOCKS, J.P.H. 1988. Veld types of South Africa, 3rd edn. *Memoirs of the Botanical Survey of South Africa* No. 57: 1–146.

BREDENKAMP, G.J. & THERON, G.K. 1978. A synecological account of the Suikerbosrand Nature Reserve. I. The phytosociology of the Witwatersrand geological system. *Bothalia* 12: 513–529.

DEALL, G.B., SCHEEPERS, J.C. & SCHUTZ, C.J. 1989. The vegetation ecology of the Eastern Transvaal Escarpment in the Sabie area. 1. Physical environment. *Bothalia* 19: 53–67.

EDWARDS, D. 1967. A plant ecological survey of the Tugela Basin. *Memoirs of the Botanical Survey of South Africa* No. 36: 1–285.

HARMSE, H.J. VON M. 1967. *Soil genesis in the Highveld Region of South Africa*. D.Sc. dissertation, Rijks University, Utrecht.

HARMSE, H.J. VON M., VAN DER WATT, H.v.H., VAN ROOYEN, T.H. & BURGER, R.D.U.T. 1984. *Glossary of soil science terms*. The Soil Science Society of South Africa, Pretoria.

KOOIJ, M.S., BREDENKAMP, G.J. & THERON, G.K. 1990a. The vegetation of the north-western Orange Free State, South Africa. 2. The D land type. *Bothalia* 20: 241–248.

KOOIJ, M.S., BREDENKAMP, G.J. & THERON, G.K. 1990b. Classification of the vegetation of the B land type in the north-western Orange Free State. *South African Journal of Botany* 56: 309–318.

KOOIJ, M.S., BREDENKAMP, G.J. & THERON, G.K. 1990c. The vegetation of the deep sandy soils of the A land type in the north-western Orange Free State, South Africa. *Botanical Bulletin of Academia Sinica* 31. In press.

KOOIJ, M.S., BREDENKAMP, G.J. & THERON, G.K. 1990d. The plant communities of the hills and ridges in the north-western Orange Free State, South Africa. *Botanical Bulletin of Academia Sinica* 31. In press.

KRUGER, J.A. 1971. *'n Ekologiese ondersoek van die plantegroei van die plaas Somerville 53 en omgewing (Dist. Ventersdorp), met besondere aandag aan die bodemkundige aspek*. M.Sc. thesis, Potchefstroom University for Christian Higher Education, Potchefstroom.

LAND TYPE SURVEY STAFF 1984. Land types of the maps 2626 Wesrand, 2726 Kroonstad. *Memoirs on the Agricultural Natural Resources of South Africa* No.4: 1–441.

LARCHER, W. 1975. *Physiological plant ecology*. Springer-Verlag, Berlin.

MACVICAR, C.N., LOXTON, R.F., LAMBRECHTS, J.J.N., LE ROUX, J., DE VILLIERS, J.M., VERSTER, E., MERRYWEATHER, F.R., VAN ROOYEN, T.H. & HARMSE, H.J. VON M. 1977. *Soil classification, a binomial system for South Africa*. Department of Agricultural Technical Services, Pretoria.

MENTIS, M.T. & HUNTLEY, B.J. 1982. *A description of the Grassland Biome Project*. Co-operative Scientific Programme, Council for Scientific and Industrial Research. Report No. 62. Graphic Arts Division of the CSIR, Pretoria.

MULLER, T. 1983. A case for a vegetation survey in a developing country based on Zimbabwe. *Bothalia* 14: 721–723.

RUTHERFORD, M.C. & WESTFALL, R.H. 1986. Biomes of southern Africa—an objective categorization. *Memoirs of the Botanical Survey of South Africa* No. 54: 1–97.

SCHULZE, R.E. & McGEE, O.S. 1978. Climatic indices and classification in relation to the biography of southern Africa. In M.J.A. Werger, *Biogeography and ecology of southern Africa*: 19–52. Junk, The Hague.

TRUSWELL, J.F. 1977. *The geological evolution of South Africa*. Purnell, London.

SCHEEPERS, J.C. 1975. *The plant ecology of the Kroonstad and Bethlehem areas of the Highveld Agricultural Region*. D.Sc. dissertation, University of Pretoria.

WALKER, B.H. 1976. An approach to the monitoring of changes in the composition and utilization of woodland and savanna vegetation. *South African Journal of Wildlife Resource Management* 6: 1–32.

WEATHER BUREAU 1986. *Climate of South Africa. Climate statistics up to 1984*. Government Printer, Pretoria.

WEATHER BUREAU 1988. *Climate of South Africa. Part 12. Surface Winds*. Government Printer, Pretoria.

WEATHER BUREAU 1989. *Climatological data for 1987–1989 for the Balkfontein, Plessisdraai, Kroonstad and Welkom weather stations*. Computer printout, Weather Bureau. Pretoria.