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# Habitat ecology of southern African quartz fields: studies on the thermal properties near the ground

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## Abstract

Desert pavements of white quartz stones (quartz fields) represent azonal habitats in several arid regions of southern Africa. The vegetation of these quartz fields is characterised by dwarf and highly succulent growth forms which contrast strongly with the shrubby vegetation of the surroundings. Incoming and reflected global solar radiation, air temperature near the ground, soil-surface temperatures and leaf-surface temperatures of dwarf plants were determined under natural habitat conditions inside and outside of the quartz fields. Surface temperatures of quartz and shale stones were compared. The study was conducted in the Knersvlakte and the Little Karoo (Succulent-Karoo Biome), South Africa. The daily maximum temperatures of the air near the ground of quartz fields was several degrees lower than the air near the ground of neighbouring soils without quartz cover. Maximum soil-surface temperatures of the quartz fields, however, were only lower in summer. Accordingly, the leave surfaces of dwarf plants (Aizoaceae) growing inside quartz fields were up to 3 K cooler than identical plants outside the quartz fields. The lower maximum temperatures is associated with an about 5% higher reflection of quartz fields compared to neighbouring soils without quartz cover. At night, the minimum temperatures of the air near the ground and the soil surface temperatures on quartz fields were above those of soils without quartz cover. The nocturnal surface temperatures of quartz stones did not differ considerably from that of shale and often ranged above the temperatures and dew-point of the ambient air. Consequently, the relatively cooler quartz fields seem to provide less adverse growing conditions for plants near the ground compared to surrounding soils without quartz cover.

## Introduction

### *The quartz fields*

Quartz fields in the arid part of southern Africa represent a unique, azonal habitat type. They are characterised by a dense layer of white, angular quartz stones on the soil surface. The vegetation of these quartz fields differs considerably from its surroundings by a particular species composition and the dominance of dwarf and ground level growth forms (Figure 1) (Schmiedel and Jürgens 1999, 2002) with low height and low cover values (Figure 2).

Quartz fields are clustered into six regions in arid to semi-arid southern Africa (Schmiedel 2002) (Figure 3). The Knersvlakte, Riethuis-Wallekraal area, Richtersveld and Little Karoo fall within the Succulent-Karoo Region *sensu* Jürgens (1991) of the Greater Cape Flora, which is botanically defined by a high number of species of Aizoaceae *sensu* Bittrich and Hartmann (1988) and a strong dominance of leaf-succulent growth forms (Milton et al. 1997). The Region is ecologically characterised by a relatively mild temperature regime and highly predictable winter rainfall (Hoffman and Cowling 1987; Cowling et al. 1999). The Warmbad and Pofadder region are part of the Nama-Karoo Region of the Palaeotropis (Jürgens


*Figure 1.* Dwarf growth *Argyroderma pearsonii* (Aizoaceae), a leaf-succulent dwarf shrub from the quartz fields of the Knersvlakte, South Africa.

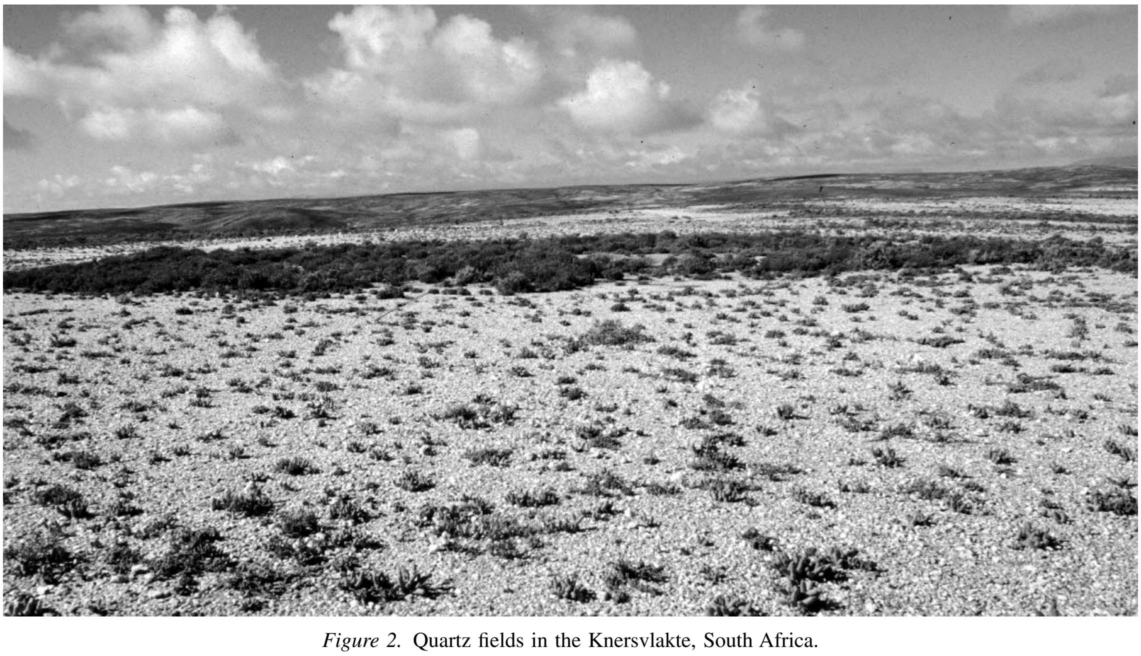

*Figure 2.* Quartz fields in the Knersvlakte, South Africa.

1991) and are located in the summer rainfall region (rainfall peaks occur in late summer) (Figure 4). The vegetation in the Nama-Karoo Region is dominated by grass and non-succulent dwarf shrubs (Palmer and Hoffman 1997).

Although part of a different floral region, the quartz-field vegetation in the Nama-Karoo Region comprises the same growth form composition as in the Succulent-Karoo Region. Each region where quartz fields occur has a quartz-field flora of its own, comprising a high number of endemics (Schmiedel

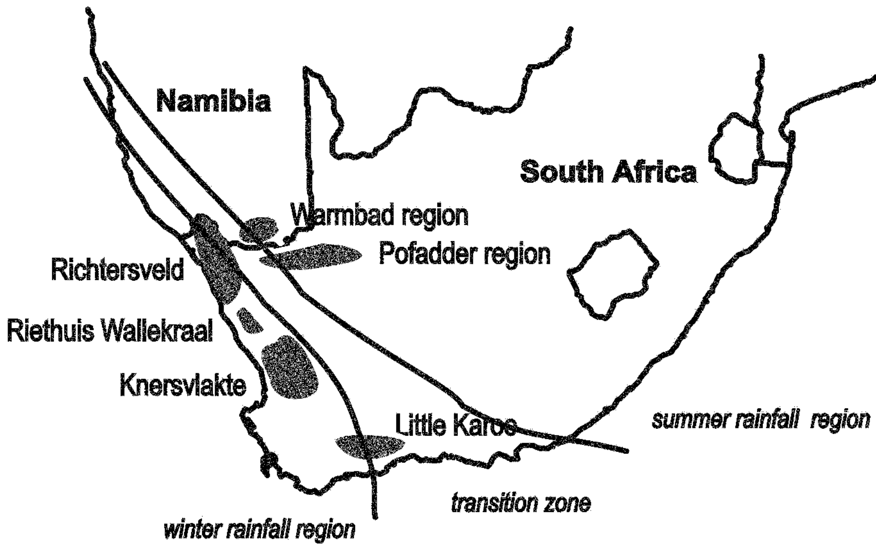


*Figure 3.* Geographical distribution of regions with frequent occurrence of quartz fields in southern Africa.

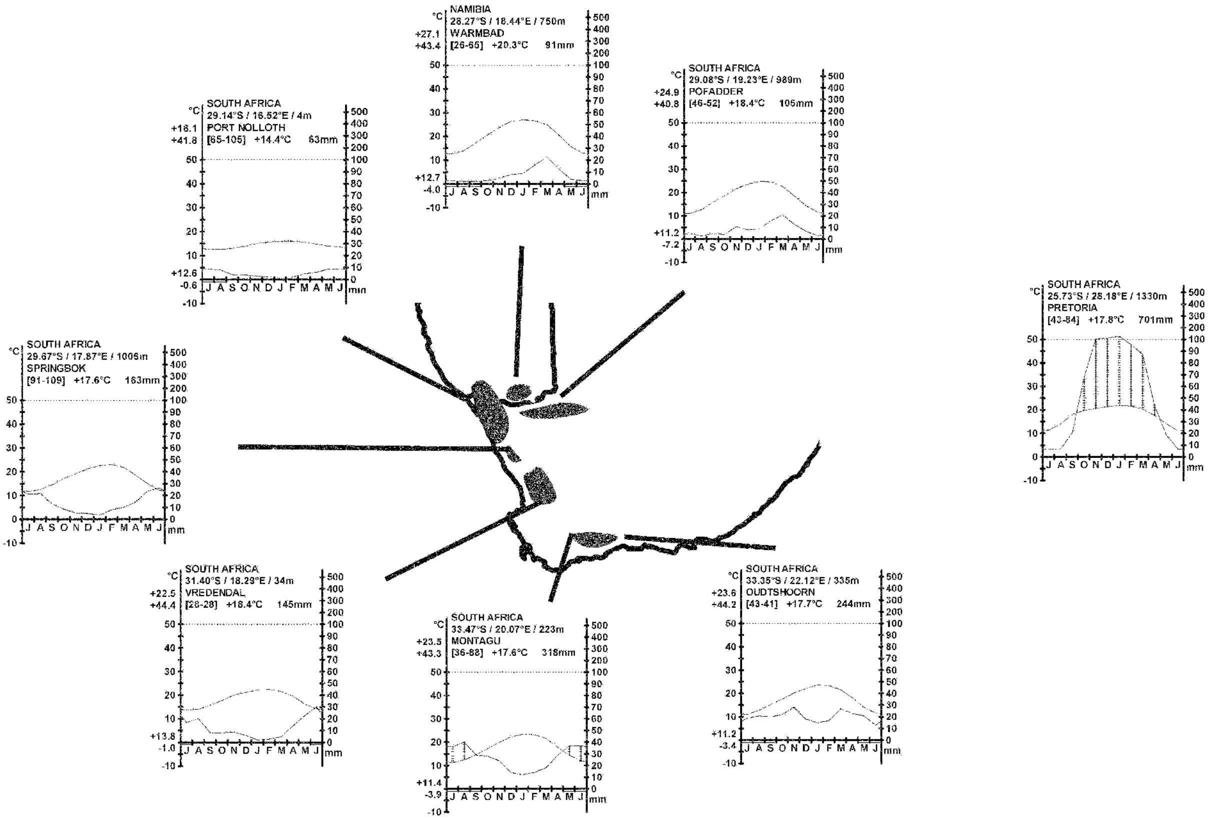


*Figure 4.* Climate diagrams for selected weather stations in areas with high frequency of quartz fields and in Pretoria.

2002). The high similarity in growth form composition in various regions supplied by taxa of different lineages has been interpreted as a result of convergent evolution (Jürgens 1986; Schmiedel and Jürgens 1999).

A strong influence of chemical and physical soil features on the growth form composition of the vegetation has been shown for the quartz-field vegetation of two different regions, Little Karoo and Knersvlakte, both Succulent-Karoo Region (Schmiedel and Jürgens 1999, 2002).

*The thermal properties on quartz fields*

Due to the glaring and dazzling appearance of the white quartz cover on clear and bright days, several authors and local laymen consider the hypothesis that quartz fields provide particular microclimatic conditions regarding radiation and temperature (Vogel 1955; Hartmann 1981; Jürgens 1986). However, to-date very few studies on the microclimate of quartz fields have been conducted. von Willert et al. (1995) compare the reflectivity of a quartz stone with brown shale and red desert soil and did not detect a higher reflection by the quartz stone compared to the other surfaces. The same authors investigated the thermal properties inside and outside quartz fields during a late summer day (March 1977) in the Knersvlakte. The course of the temperature during the year and the thermal impact on dwarf plants inside and outside of quartz fields has not yet been studied.

More attention has been paid to submerged growth forms which are typical for several quartz-field taxa as well as *Lithops* N.E. Brown (Aizoaceae, so called ″living stones″). Eller and Nipkow (1983) and Eller and Grobbelaar (1986), Nobel (1989), Turner and Picker (1993) studied the ecological advantage of *Lithops* plants with respect to thermal properties and water relation under controlled and natural conditions with controversial results. According to Eller and Nipkow (1983) and Eller and Grobbelaar (1986) the embedded growth form has no positive effect on the thermal properties of the plant and can merely be interpreted as a structural adaptation to reduce transpiratory water-loss as has been shown by Eller and Ruess (1982) or even as a mechanism to protect the plant from browsing and trampling by larger herbivores. Turner and Picker (1993), in return, show evidence that the temperatures of submerged leaves and surrounding soils are strongly coupled which result in a heat flux from the leaf to the lower soil. This, however, denies the existence of isolation caused by the old leaves which in natural habitat provide several layers of dry, papery sheaths around the new leaves. Eller (1982) investigated the direct solar radiation absorbed by *Argyroderma pearsonii* (N.E. Brown) Schwantes (Aizoaceae), a species restricted to quartz fields of the Knersvlakte, during the growing (winter) and dry period (summer). In summer the increase of radiation absorbed by old *Argyroderma* leaves was lower than the increase of the impinging solar radiation in comparison to winter conditions.

The present study aims at a comparative analysis of the balance of solar global radiation and thermal conditions near the ground of soils with and without quartz cover. Therefore, the data were analysed and interpreted in a comparative way (quartz fields vs. neighbouring soils without quartz cover).

The study was based on the following hypotheses: Due to the strong visible reflection, quartz fields have a higher reflectivity of solar global radiation than neighbouring soils without quartz cover. The high reflectivity of the quartz fields reduces the temperatures near the ground and thus the leaf surface temperatures of dwarf plants. This may have a positive effect on the dew/fog trapping of the quartz stones. Thermal conditions near the ground on quartz fields are similar in distant areas. They play an important role for the growing conditions and thus growth form composition on the quartz fields in southern Africa.

Thus, the scope of this paper was neither to conduct a comprehensive microclimatic assessment nor to determine the non-radiation energy balance and the absolute temperature values. Also, the applied instrumental set-up and the relatively long intervals of integrated values (20–30 min) were not suitable for that.

## Methods

*Study area*

The measurements were conducted in the Knersvlakte (30°45′–31°40′ S, 18°15′–19°00′ E) and Little Karoo (33°25′–55′ S, 20°10′–22°30′ E), which form part of the Succulent-Karoo Region. They are characterised by a high density of quartz fields. The Knersvlakte, the most southern part of the Namaqualand (Cowling et al. 1999), is a gently undulated plain bordered by the Atlantic Ocean in the west, the Olifants River Valley in the south, the steep scarp of the Cape Folded Belt in the east and granitic-gneiss uplands in the north (see Cowling et al. (1999)). The area is underlain by shales, phyllites and limestones of the Nama Group and is streaked by numerous quartzveins.Theregionalweatherconditioninthe Knersvlakte is mild in winter and hot in summer: maximum temperatures of > 40 °C have been detected for Vredendal, the only weather station of the Knersvlakte (Figure 4). Vredendal, however, is located at the southwestern corner of the Knersvlakte near the coast (30 km inland). In the central Knersvlakte, the temperatures during summer are typically more extreme. The Knersvlakte receives a reliable winter rainfall (May–August) of 100 to 175 mm/a (Weather Bureau 1988, Figure 4). Phytogeographically, the region forms part of the Namaqualand Namib Domain *sensu* Jürgens (1991) of the Succulent-Karoo Region.

The Little Karoo consists of a series of intermontane valleys, bounded on all sides by the east-west trending anticlines of the Cape Folded Belt. These mountains impede the penetration of both winter frontal rains as well as post frontal rains derived from the warm Indian Ocean to the south (Desmet and Cowling 1999). The predominant bottomland rocks comprise Bokkeveld group shales, softer sediments within the Cape Soupergroup. Quartz veins and associated quartz patches are concentrated in the western sector of the Little Karoo. No weather station is located in the vicinity. The data from the nearest weather stations (Montagu and Oudtshoorn) are shown in Figure 4. The temperature regime of the western sector of the Little Karoo is similar to that of the Knersvlakte. The winters are mild and without severe frost, the summers are hot and dry. The annual rainfall in the vicinity of the study area is about 200 mm/a (Weather Bureau 1988) and seasonality is less pronounced than in the Knersvlakte – the rainy season extends from March to November. The Little Karoo forms part the Southern Karoo Domain *sensu* Jürgens (1991) of the Succulent-Karoo Region.

*Data collection*

Measurements of incoming global solar radiation (pyranometer sensor based on thermocouples, WMO second class, 305–2800 nm, ecoTech Bonn/Germany) and reflected radiation of soils with and without quartz cover (same pyranometer sensor, directing towards the ground) were conducted in the Knersvlakte (Quaggas Kop, 31°24′ S, 18°38′ E) in spring 1996 for 56 days (August 28–October 21 1996). The actual values were measured by a data logger in a 1 sec interval and recorded in 30 min intervals.

The temperatures near the ground and the weather data were collected nearly continuously between 1996 and 2000. An automatic weather station (ecoTech Bonn) gathered air temperature and relative humidity at 2 m (combined Pt 100 and capacitive sensor, ecoTech Bonn). The data recording interval was 20 or 30 min, the actual values were determined.

The temperature measurements near the ground were conducted on level, adjacent sites with and without quartz cover: Air temperature and relative humidity (not-ventilated, combined Pt1000 and capacitive sensor shaded by a sinter cap, T/rF-Kombi-Geber, ecoTech Bonn) at 10 mm, soil surface temperature (Pt100 sensor, 4 × 8 mm, covered by dust, ecoTech Bonn), temperatures at 3 mm soil depth (Pt100 sensors, 4 × 8 mm, ecoTech Bonn), and leaf surface temperatures of *G. cryptopodium* (Kensit) Bolus and *Argyroderma pearsonii* (N.E. Brown) Schwantes, both Aizoaceae, growing either inside or outside the quartz fields (nickel-chromium/nickel-aluminium thermocouples (Fa. Driesen & Kern, Bad Bramstedt/ Germany) vertically applied into the epidermis of the flat leaf tips, four individuals were measured per species and habitat type). Both species were chosen because of their flat leaf-tips which enable a vertical application of the sensors on a horizontal surface and thus differences in temperature caused by different exposure to the sun have been avoided. They represent characteristic dwarf growth forms of the endemic quartz field flora (Schmiedel and Jürgens 1999). The measurements have been conducted intermittently. Measurements of surface temperatures of quartz and shale, about 40 mm in diameter (nickel-chromium/ nickel-aluminium thermocouples). The wires of the thermocouples were held by small stands.

The interpretation of the presented data was based on the evaluation of the nearly continuous series of measurements. For this study, main focus was put on the differences of summer and winter temperatures, as two extremes of climatic conditions. The thermal characteristic features of the quartz fields and neighbouring soils without quartz cover are therefore shown on the basis of representative summer and winter days.

## Results

*Radiation*

In spring 1996, the incoming maximum global solar radiation in the Knersvlakte was about 900 W/m$^2$ (Figure 5). On some exceptional days the global solar radiation rose to 1100 W/m$^2$. Quartz fields and soils without quartz cover reflected about 300 W/m$^2$ or 30 to 40% of the incoming global solar radiation. The net

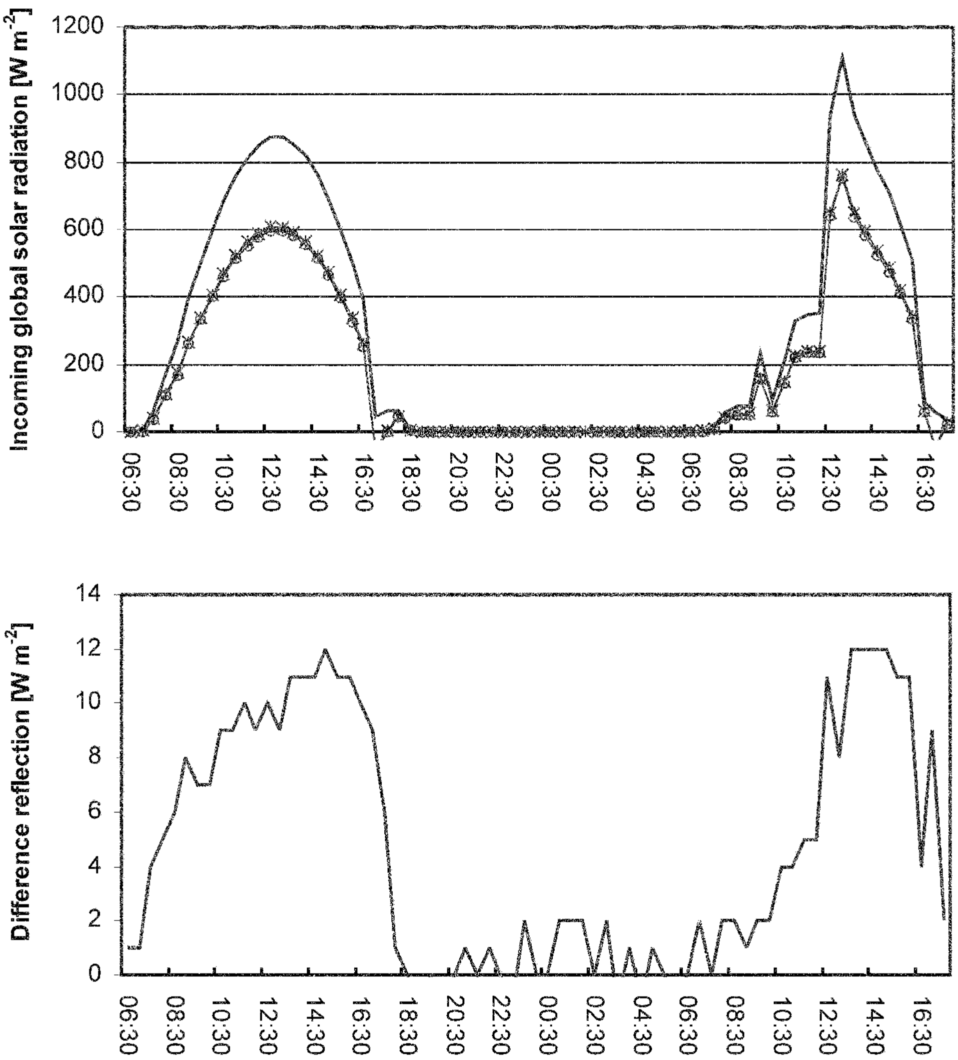


*Figure 5.* Above: Incoming global solar radiation (305–2800 nm) (continuous line), net radiation on soils with (line with circles) and without (line with crosses) quartz cover. Below: Difference between reflected solar radiation (305–2800 nm) of quartz fields and of soils without quartz cover (quartz fields — soils without quartz cover). Knersvlakte, September 1–2, 1996.

radiation on soils with and without quartz cover was between 600 and 800 W/m$^2$.

Quartz fields had a higher reflectivity than soils without quartz (Figure 5). The daily maximum difference between the net radiation inside and outside the quartz fields was between 10 and 15 W/m$^2$, i.e. 1.5% of the global solar radiation and about 15% higher reflection of global solar radiation by quartz fields than neighbouring soils without quartz cover. A Wilcox-test revealed that the difference of the daily maximum reflection of the two soil types was consistent for 56 days and highly significant ($z = -6.506$, $p < 0.000$, two-sided).

*Air temperature near the ground*

Figures 6 and 7 show the air temperature at 10 mm above soil surface measured in the Knersvlakte on quartz fields and on neighbouring soils without quartz cover compared with the air temperatures at 2 m during a representative day in winter (Figure 6) or summer (Figure 7), respectively. In winter and in summer the temperatures of the air near the ground on quartz fields was below that of the neighbouring soils without quartz cover. The maximum differences, measured during the hottest time of the day between noon and 2 p.m., was up to 5 K in winter and 8 K in summer. During night the air temperature near the ground of both soil types differed only by about 1 K.

*Soil surface temperature*

In winter the daily maximum surface temperatures of both soil types (Figure 6B, 6C) were about 10 K lower than the air temperatures near the ground. The surface temperatures were only about 5 K above the air temperatures at 2 m. In summer (Figure 7B, 7C) the surfaces of both soil types reached temperatures close to those of the air near the ground. In winter, soil surfaces with quartz cover had higher daily maximum temperatures than those without quartz cover. The differences was at about 4 K. In summer the relationship was typically inverse: the daily maximum temperatures on soil surface of quartz fields were up to 4 K lower than those of soils without quartz cover. In summer and in winter, the maximum differences occurred during the hottest time of the day, i.e., between noon and 2 p.m.

*Leaf surface temperature*

Measurements in the Knersvlakte of leaf-surface temperature of *Argyroderma pearsonii* growing inside and outside of quartz fields (Figures 6D and 7D) showed maximum temperatures of more than 60 °C (55 °C in Figure 7D) during the summer months. The daily maximum temperatures during winter were considerably lower and seldom exceeded 35 °C (compare Figure 6D).

During summer and winter, the *Argyroderma* plants growing on quartz fields showed lower maximum surface temperatures of the leaves than plants growing outside quartz fields. Highest differences of 3 to 5 K (3 K on September 8, 1998, Figure 6D) were determined for relatively warm winter and spring days. The measurements carried out in mid- and late summer showed minor differences only (on most days < 1 K) (2 K on December 28, 1999, Figure 7D).

In agreement with the studies in the Knersvlakte, measurements on *Gibbaeum cryptopodium* growing inside and outside the quartz fields of the Little Karoo (Figure 8) showed similar results: During late summer (March 14, 1998), the *G. cryptopodium* plants on quartz fields had lower daily maximum temperatures than the specimens on the neighbouring soils without quartz cover.

*Surface temperatures of a quartz stone*

Comparative measurements of the surface temperatures of a quartz stone and of a brown shale stone in the Little Karoo in September 1995 showed almost identical temperatures for both stones during night but lower maximum temperatures of the quartz stone during daytime (Figure 9). The strongest differences of up to 4 K were determined when both stones reached high maximum temperatures (September 18, 1995). The nocturnal dew-point temperatures varied strongly and were either above or below the temperature of the ambient air. However, for the period of time where the measurements were conducted, it stayed below the surface temperatures of both stones.

## Discussion

*Radiation*

The measurements revealed an impinging global solar radiation (305–2800 nm) of about 950 to 1100 $W/m^2$. The reflected radiation on quartz fields had a consistently higher maximum than neighbouring soils without quartz cover.

The maximum global solar radiation of about 900 to 1100 $W/m^2$ is in line with the value of 950–1200 $W/m^2$ given for deserts by von Willert et al. (1992). The higher reflection by quartz fields seems to contrast with the results by von Willert et al. (1992), who determined the optical properties in the wavelength range between 300 and 1300 nm of a quartz stone from the southern African quartz fields. They show that the reflectivity of the quartz stone in the visible spectrum (300–700 nm) is far higher than the reflectivity of a brown shale stone but does not differ considerably from that of red desert soil. Whereas in the range of wavelength of the near infrared radiation (750–1350 nm) the quartz stone reflects about half as much as red desert soil and brown shale. Due to the lower reflectivity on quartz fields, von Willert et al. (1992) assume that the radiation input on the plant by solar radiation reflected from the soils is reduced for plants growing on quartz fields compared to those that grow on red desert soils.

The data given by von Willert et al. (1992) are hard to compare with the data gathered in this study:

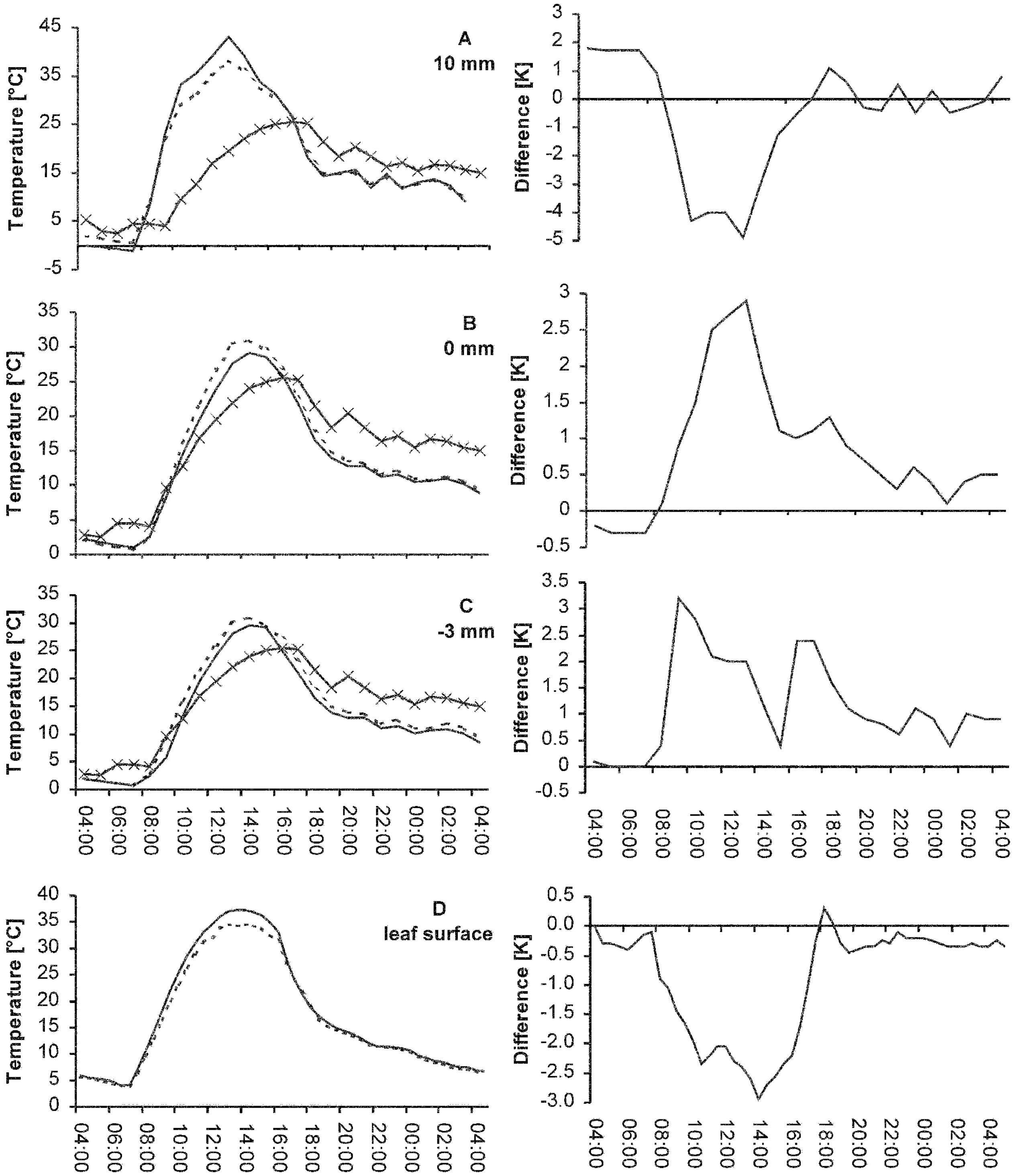


*Figure 6.* Left: Temperatures (A) of air at 10 mm, (B) of soil surfaces, (C) at 3 mm soil depth, and (D) of leaf surfaces of *Argyroderma pearsonii* plants (medians of 4 individuals each) on soils with (dotted line) and without quartz cover (continuous line) compared to the air temperature at 2 m (line with crosses) in the Knersvlakte on representative winter days (August 8, 1998, A–C, September 8, 1998, D). Right: Temperature differences (quartz fields — soils without quartz cover).

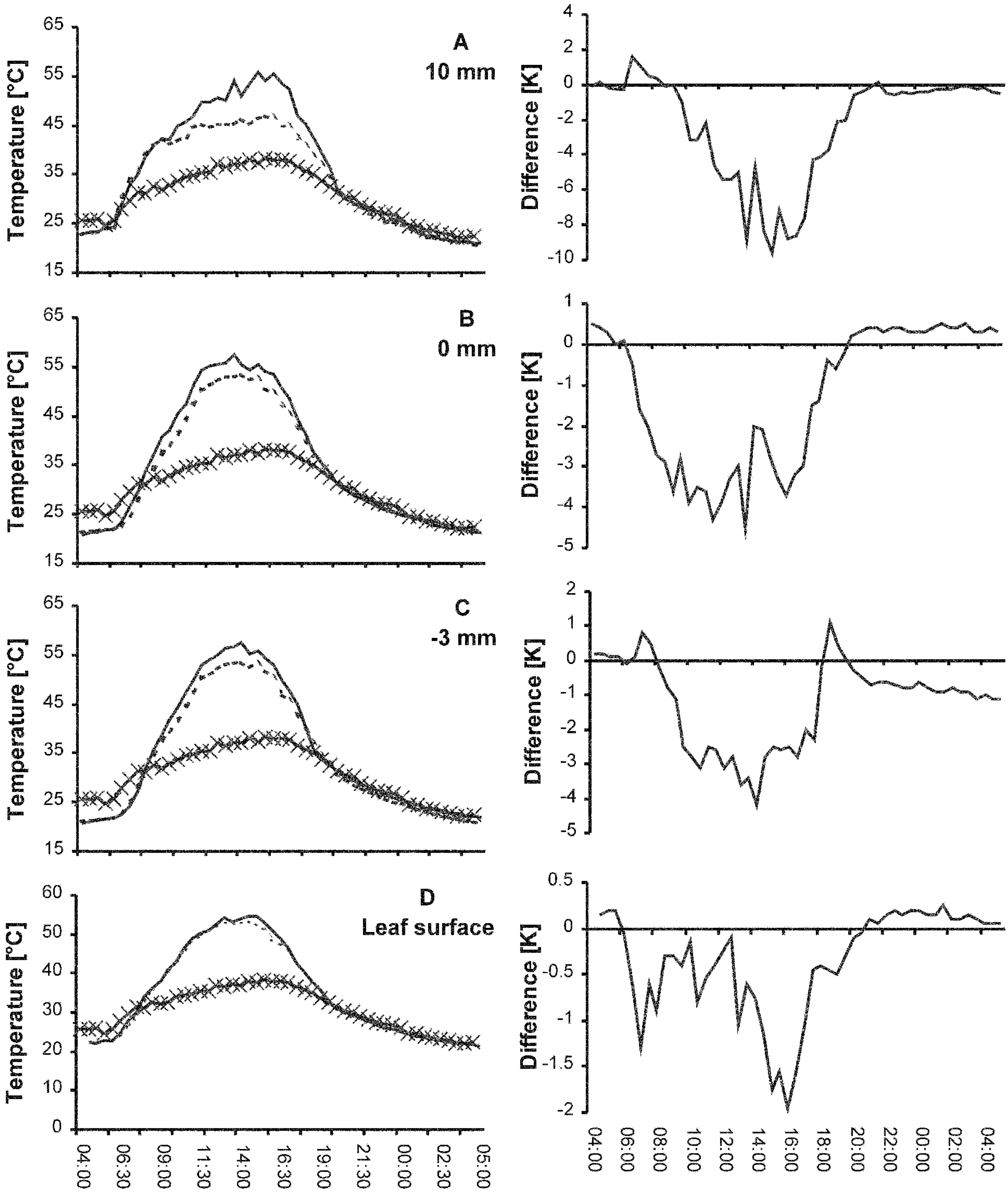


*Figure 7.* Left: Temperatures (A) of air at 10 mm, (B) of soil surfaces, (C) at 3 mm soil depth and (D) of leaf surfaces of *Argyroderma pearsonii* plants (medians of 4 individuals each) on soils with (dotted line) and without quartz cover (continuous line) compared to the air temperature at 2 m (line with crosses) in the Knersvlakte at a representative summer day (December 28, 1999). Right: Temperature differences (quartz fields — soils without quartz cover).

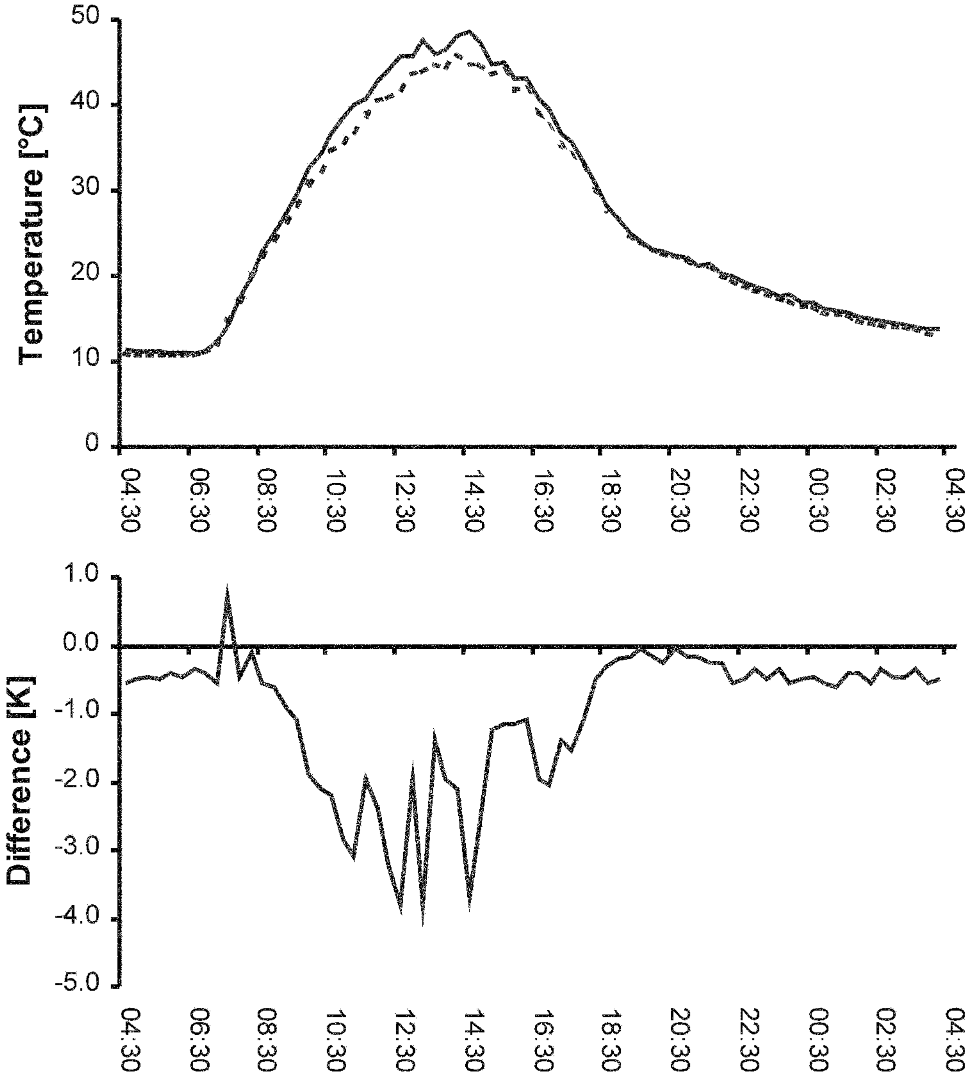


*Figure 8.* Left: Leaf surface temperatures of *Gibbaeum cryptopodium* plants (medians of 4 individuals each) growing inside (dotted line) and outside (continuous line) of quartz fields. Little Karoo, March 14, 1998. Right: Temperature differences (quartz fields — soils without quartz cover).

the soil without quartz cover in the present study derived from weathered phyllite and was neither brown shale nor red desert soil. Furthermore, the spectrum measured was broader (305–2800 nm) than that employed by von Willert et al. (300–1350 nm) and the present study did not differentiate between different ranges of wavelength as was done by von Willert et al. However, the results by von Willert et al. that quartz fields have a similar reflectivity for visible radiation as red desert soil seem to contradict the dazzling shine of the white quartz fields which indicate high reflectivity of the quartz fields in the visible spectrum. Maybe, this seeming contradiction has methodical reasons. Since von Willert et al. (1992) measurements were carried out on a single stone in an integrating sphere (von Willert et al. 1995), they may not represent the situation *in situ*. The reflectivity of a dense layer of quartz stones may differ from that of a single stone because of multiple reflection of neighbouring stones (von Willert pers. comm.).

The measurements of radiation properties of quartz fields within this study were restricted to a short period during spring (September and October 1996). Future measurements of global and reflected radiation

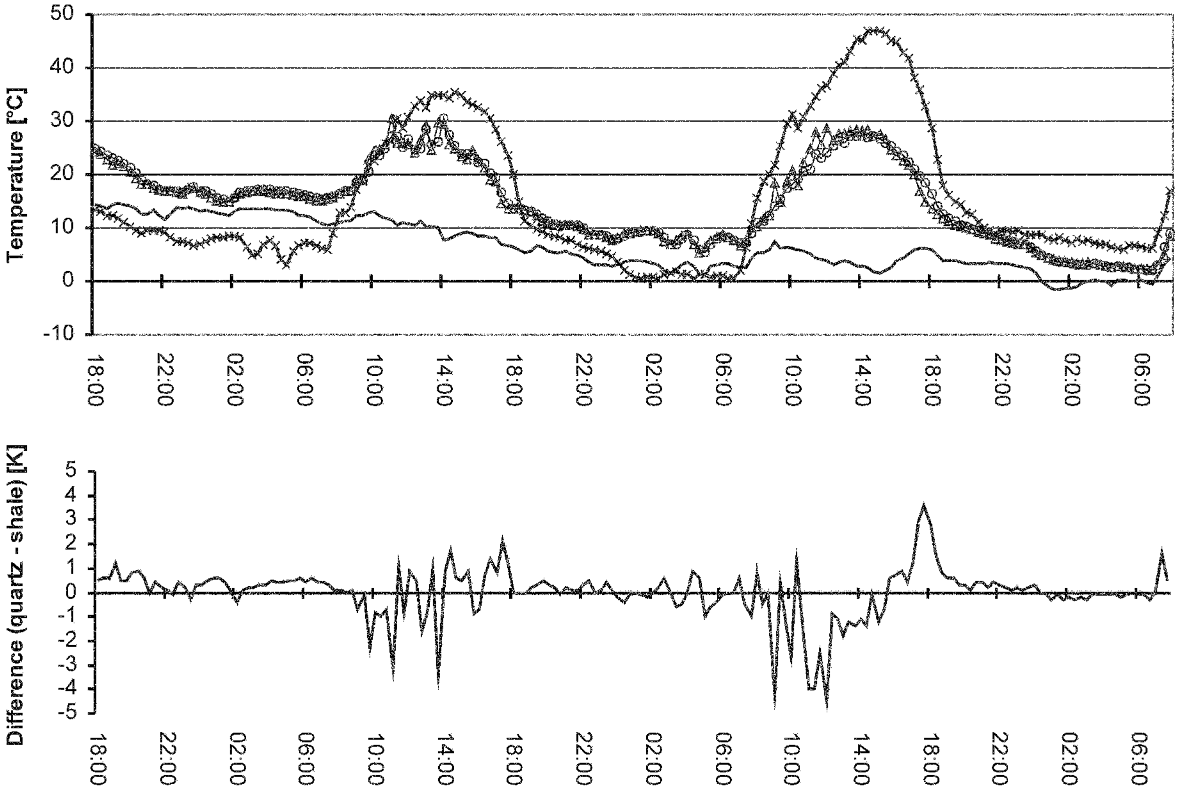


*Figure 9.* Above: In situ surface temperatures of a brown shale stone (line with triangles), a quartz stone (line with circles), temperatures of the ambient air (10 mm) (line with crosses), dew-point temperature of the ambient air (10 mm) (continuous). Below: Temperature differences between quartz and shale stone (quartz fields — soils without quartz cover). Little Karoo, September 16–19, 1995.

should differentiate between visible and the sun's infrared radiation and should be carried out during summer and winter time and under different weather conditions, i.e., clear, cloudy, and overcast sky.

*The thermal regime on quartz fields*

During hot summer days, the daily maximum temperatures of the air near the ground in the study area may exceed 60 °C. These temperatures surpass the air temperature at 2 m by up to 20 °C. Quartz fields have considerably lower maximum air temperatures (differences of up to 10 K) than neighbouring soils without quartz cover for most days of the year. The maximum temperatures of the soil surface of quartz fields are lower only during the hot season whereas the relationship is inverse during winter. Due to the thermal conductivity of the unventilated sinter caps, the absolute values of the measurements of air temperature measurements near the ground might not be reliable. However, the use of identical sensors and the identical set-up ensure the comparability of the temperature values.

The results are in line with the only comparative studies of surface temperature of soils with and without quartz cover during a summer day (5 March 1977) in the Knersvlakte carried out by von Willert et al. (1992): The soil surface of the quartz field showed a far lower maximum temperature (about 40 °C) than the soil surface with quartz cover (about 48 °C).

The relatively lower temperatures may be partly attributed to the higher reflection of the quartz fields as has been determined in the present study. Besides reflectivity, heat capacity, heat conductivity and evaporation influence the energy budget of a body. Since the determination of the energy budget of the quartz fields was not in the scope of this study, the latter three variables have not been determined.

The daily maximum temperatures of soil surfaces in warm deserts (Nobel et al. 1986) can even reach the high heat tolerance of some desert plants (e.g., > 60 °C for *Haworthia* Duval and *Lithops* N.E. Brown, Nobel (1989)). This may particularly apply for seedlings (Nobel 1984) and dwarf plants which live near the ground and – if not shaded by surrounding plants or rocks – are fully subject to these temperatures.

Quartz fields seem to be the only habitat type in southern Africa where dwarf growth forms occur exclusively and in high densities on level and open (i.e. not shaded) sites. Shrubby growth forms only occur with very low abundance (Schmiedel and Jürgens 1999, 2002) and, consequently, shade provided by such plants is rare.

Therefore, the relatively lower maximum temperatures on quartz fields can possibly be relevant for the survival of dwarf plants near the ground. This presumption can be supported by the lower maximum temperatures of the leaf surface of dwarf plants growing inside compared to the same species growing outside the quartz fields.

Beside the present study, no data have been published yet on leaf surface temperatures of comparable plants inside and outside of quartz fields. von Willert et al. (1992) compare the leaf surface temperature of a dwarf *Argyroderma* plant inside quartz fields with that of a shrubby *Ruschia* Schwantes (Aizoaceae) plant outside quartz fields. They show that the leaf-surface temperatures of the latter exceed that of the ambient air by > 10 K thus reaching surface temperatures of > 45 °C, whereas the leaf-surface temperature of the *Argyroderma* plant was close to that of the ambient air (about 35 °C). This data does not properly compare the thermal conditions of dwarf plants inside and outside the quartz fields, since the comparison refers to different growth forms which were measured at different heights above soil surface.

*Water supply*

The nocturnal surface temperature of a quartz stone and a brown shale stone in the Little Karoo showed no particular differences. Based on these thermal data (which did not take into account the wind as an additional factor influencing the precipitation of fog and dew), quartz stones do not seem to provide a better source for additional water supply by dew than other desert pavements. However, in comparison to soils without stone cover, desert pavements can generally be considered as having a positive effect on water supply due to an decrease of runoff and evaporation and an increased surface area which allow higher precipitation of dew and fog. On quartz fields these properties of desert pavements result in the occurrence of green algae and cyanobacteria underneath the semi-translucent quartz stones (Vogel 1955; Büdel and Wessels 1991; Rumrich et al. 1989, 1992). It seems to be likely that shallow rooting dwarf succulents or cryptogams can benefit from such a small but reliable water supply.

This additional water supply together with the relatively milder thermal regime of desert pavements might also facilitate the occurrence of dwarf succulents on quartz fields even outside the proper winter-rainfall area (i.e., the Warmbad and Pofadder regions): The predictable, additional water supply by dewfall possibly replaces the predictable winter rainfall in the summer rainfall area. This hypothesis, however, needs to be proven by measurements of the relative humidity of soils inside and outside the various desert pavements under different ranges of temperatures (summer and winter) and weather conditions.

*The possible impact of the microclimate on the vegetation of the quartz fields*

Unshaded dwarf growth forms in warm deserts are exposed to extremely high air temperatures near the ground. This is also true for the inhabitants of the quartz fields. However, quartz fields provide relatively lower maximum air temperatures than surrounding soils. This results in lower maximum temperatures of the plants compared to similar plants growing outside quartz fields. These relatively less adverse growing conditions for dwarf plants on quartz fields cannot explain the dwarfism of their inhabitants since even on quartz fields, the maximum air temperatures near the ground are still far above the maximum air temperatures in 2 m. Rather the dwarfism within the quartz-field vegetation seems to be controlled by soil chemical and physical soil conditions (Schmiedel and Jürgens 1999, 2002; Schmiedel 2002), but the less extreme microclimatic conditions on quartz fields might reduce the heat stress of the dwarf plants on quartz fields relative to other habitats and therefore allow the plants to occur on such an open and exposed habitat. Nothing is known about the phyto-physiological effect (regarding thermal stress and water budget) of the milder microclimate on quartz fields. Such studies would contribute considerably to the understanding of the habitat ecology of quartz fields and support the hypothesis given above.

However, in southern Africa dwarf growth forms are not restricted to quartz fields. Numerous species (e.g. *Crassula* L. and *Conophytum* N.E. Brown species) are specialised on rocky habitats, e.g. outcrops and soil pockets in rock crevices (Hammer 1993, 2002). Until now little is known about their thermal properties. But in contrast to open and plain habitats like quartz fields, rocky habitats may provide shade due to surrounding rocks for at least parts of the day. Such shade combined with a clear sky (open shade) can result in a negative net thermal radiation flux, i.e., energy loss by the plant (von Willert et al. 1992).

Until now the measurements were restricted to quartz fields of the winter-rainfall region. Here the quartz-field vegetation and flora reaches its highest diversity (Schmiedel 2002). However, in order to understand the habitat ecology of the southern African quartz fields in general, similar measurements under summer rainfall conditions were necessary.

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