14 Polarization Pattern of a Fata Morgana: Why Aquatic Insects are not Attracted by Mirages?

It is a well-known phenomenon that on hot days mirages, called also Fata Morgana, may appear on roads. Such mirages are also seen on hot plains. There seems to be a pool of shiny water in the distance, which dissolves on approach. The sky, different landmarks and objects are mirrored in this ”pool”. In addition, the chaotic vibration of a mirage due to the turbulent flows of hot air imitates the wind-generated undulation of a water surface. Water insects, however, do not detect water on the basis of its brightness and colour but by means of the horizontal polarization of reflected light. Hence, the question arises, whether mirages can deceive water-seeking polarotactic insects.

To answer this question, Horváth et al. (1997) investigated and compared the polarizational characteristics of a mirage and a real water surface. They studied a mirage on a sunny hot day under clear sky conditions in the Tunisian desert within a salt pan. As at the study site the salt pan was totally dried out, a beautiful mirage could be observed near the horizon. The polarization pattern of the mirage and the landscape was measured by video polarimetry (Horváth and Varjú 1997). In addition, the reflection-polarization pattern of the surface of a sea was measured by video polarimetry on a sunny day under clear sky on the beach of Maharés in central Tunisia. Both the mirage and the sea were seen near the horizon at a great distance from the observer. Thus, the direction of view of the video camera recorder was always horizontal.

Figure 14.1A provides a view of a salt pan landscape over which a mirage has developed. The top half of the landscape is covered by clear sky. The darker, cone-shaped band in the middle of the picture is a mountain and its mirror image. The height of the mountain decreases gradually from right to left. Below the mountain the shiny, water-mimicking region is the sky's mirage merging into the sky at the left-hand side. Note that as the mirror-effect of a mirage is optically equivalent to total reflection of light, the horizontal area of the sky's mirage appears as bright as the sky itself. Thus, due to the mirage of the sky the mountain seems to be elevated above the apparent horizon, i.e. above the sandy bottom of the salt pan.

Figures 14.1B and 14.1C represent the spatial distributions of the degree of linear polarization p and angle of polarization α occurring within the same areas of the landscape as in Fig. 14.1A. The light reflected from the sandy bottom of the salt pan is slightly polarized. The skylight is partially polarized with $\alpha \approx 120^o$, measured clockwise from the vertical. Since the light from the sky and the sky's mirage coincide in their p and α, there is no contrast between the sky and its mirage. In Fig. 14.2A histograms of α and p are shown for the rectangular area outlined in Figs. 14.1A-C. This area includes part of the sky and its mirage. As these histograms have only single peaks, there are no differences in the mean α- and p-values between the sky and its mirage.

Figures 14.1D, E and F provide the picture as well as the p- and α-patterns of another type of landscape, the muddy beach near the village of Maharés. The top half of the landscape as shown in Fig. 14.1D is occupied by clear sky. The darker band in the middle represents the sea. Note the undulating surface of the sea and, at the horizon, the two sailing boats with their vertical yards. There is a sharp brightness contrast between the sea and the sky. Similarly sharp contrast occurs in the maps of p and α in Figs.14.1E and F. The light reflected from the sea surface is partially horizontally polarized with an average $p = 19\%$. This low p is due to the small angle between the sea surface and the line of sight. The light coming from the clear sky is partially linearly polarized. At the time of day at which the measurement was performed $p \approx 8\%$ of the skylight near the horizon was even lower than that of light reflected from the sea surface. α in the strip of sky shown here is about 125°. Figure 14.2B depicts quantitative data about α and p as measured for the rectangular area demarcated in Figs. 14.1D-F. In these histograms the double peaks again illustrate the polarization contrast between sky and sea.

These video-polarimetric measurements make it quite clear that there are significant differences between the polarizational characteristics of water-imitating mirages and real water surfaces. Flat water surfaces reflect usually more or less horizontally polarized light, while undulating water surfaces reflect light, the E-vector of which is perpendicular to the line between the point of reflection and the sun. The p of reflected light depends upon the direction of view and the undulation of the surface. If the water surface is far away from the observer, p is relatively low due to the grazing direction of view. If the horizon is defined by the border between the water surface and the sky, there is, in general, a high polarization contrast between water and sky in both p and α (Figs. 14.1D-F). The reason for this is that due to its reflection from water surfaces skylight gets repolarized (Fig. 14.3A).

On the other hand, in the desert landscape there are no contrasts of brightness, p and α between the sky and its mirage (Figs. 14.1A-C). Mirages are not usual reflections but are formed by gradual refraction and a total reflection of light (Fig. 14.3B). Fata Morganas are generated above hot plains. The nearer to the ground, the warmer the air and the smaller its index of refraction. Thus, the direction of grazing rays of light gradually changes to such an extent that the rays do not reach the ground, but after total reflection they are deflected upward (Fig. 14.3B). This gradual deflection provides an observer with the same impression as mirroring does. Such gradual refractions and total reflection of light do not change the polarization (Können 1985). This can be seen in Fig. 14.1. In comparison, if unpolarized incident light is reflected from a flat water surface under angles of incidence larger than 89.4°, p of horizontally polarized reflected light is not higher than about 2% (Guenther 1990). However, if one approaches the water surface, the p of reflected light increases abruptly as the angle of observation approaches the Brewster angle. In contrast, a mirage can never be reached by an observer, so that the direction of observation remains always the same, i.e. nearly horizontal.

Contrary to the calculated $p \approx 2\%$ of light reflected from a distant, flat water surface, p of light reflected from the sea surface in Fig. 14.2B is on average 19% and reaches a maximum of about 40%. The reason for this difference is twofold: On the one hand, the incident skylight is partially polarized ($p \approx 8\%$). On the other hand, due to wind the sea surface is undulating. Thus, the average angle of incidence of skylight reflected from the wavy water surface is lower than for an ideally flat, exactly horizontal water surface. As the angle of incidence gets smaller than 90^o, p of reflected light increases. In the case of unpolarized incident light the observed average and maximum p of reflected light (19% and 40%, respectively) indicates that the average and maximum angles of incidence are 84^o and 77^o, respectively.

Water insects detect water surfaces polarotactically, that is, by means of the horizontally polarized reflected light, rather than phototactically, that is, by means of the intensity of reflected light. Horváth et al. (1997) proposed that Fata Morganas can imitate water surfaces only for those animals, whose visual system is polarization-blind, but sensitive to brightness and colour differences. A polarization-sensitive water-seeking insect is able to detect the polarizational characteristics of a mirage. Since these characteristics differ considerably from those of real water surfaces, these animals cannot be deceived by and attracted to Fata Morganas.

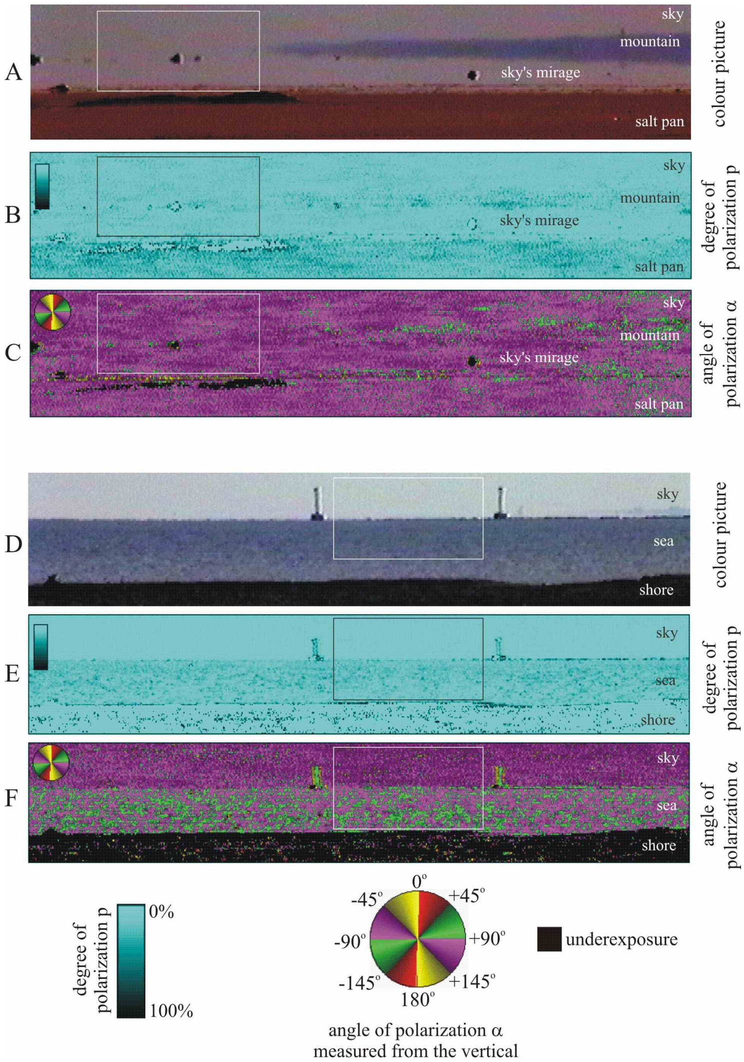

Fig. 14.1. A: Colour picture of a mirage occurring above a desert landscape, the salt pan Chott el Djerid in southern Tunisia. The dark cone-shaped band in the middle right is a mountain, tapering to the left. Below the mountain, the shiny stripe represents the mirage of the sky which merges in the real sky on the left. The lower half of the picture is occupied by the sandy floor of the salt pan. The vertical angular extension of the landscape shown is about 1.5°. The areas demarcated with rectangular windows represent the regions, for which the histograms of the degree p and angle α of linear polarization are given in Fig. 14.2. B, C: Spatial distribution of p and α of the landscape portrayed in A and measured by video polarimetry at 550 nm. D-F: Same as A-C, but now for a seaside landscape near Maharés, Tunisia. The uppermost part of the picture is filled with clear sky, the middle part is occupied by the sea and the lowermost part by the shore. (After Fig. 1 of Horváth et al., 1997, p. 301).

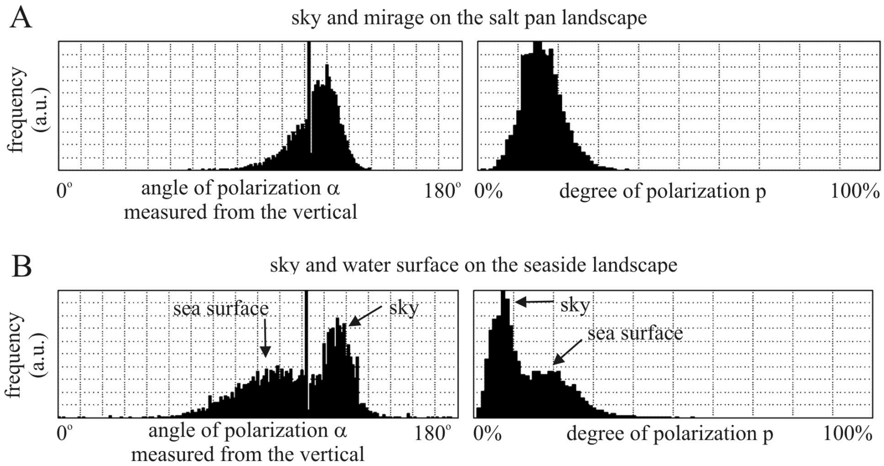

Fig. 14.2. Histograms (frequency in arbitrary units) of the angle of polarization α and the degree of linear polarization p computed for the areas demarcated with rectangular windows in Fig. 14.1. A: Mirage occurring above the desert plain of the salt pan. B: Seaside landscape at Maharés. (After Fig. 2 of Horváth et al., 1997, p. 302).

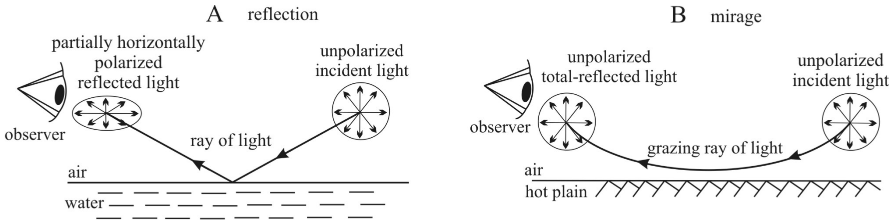

Fig. 14.3. A: Unpolarized incident light becomes partially horizontally linearly polarized when reflected from a water surface. B: Formation of a mirage above a hot plain, where the air temperature decreases exponentially as height above ground increases. As a consequence, the refractive index of air increases abruptly with height above ground, and grazing rays of light refract and after total reflection bend gradually into the eye of the observer. This gradual refraction and the total reflection do not alter the polarization of light. The inset figures represent polarization ellipses. The E-vector orientations are shown by double-headed arrows. (After Fig. 3 of Horváth et al., 1997, p. 302).