CLASSIFICATION OF A LANDSAT-TM IMAGE WITH THE SPECTRAL MIXTURE ANALYSIS UNDER THE APPLICATION OF FIELD SPECTROSCOPY

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Abstract: *A LANDSAT-TM-5 image from a desert area was classified with the spectral mixture analysis. The endmember for the spectral unmixing were selected by means of field spectroscopy. By this approach 98% of the image could be classified with an average rms of 0.7%. The results of the linear unmixing were confirmed by ground truth data.*

Kurzfassung: *Ein LANDSAT-TM-5-Bild aus der Libyschen Wüste wurde mit der Linearen Entmischung klassifiziert. Die Endmember für die Entmischung wurden aus der Analyse von Feldspektrometer-Messungen ausgewählt. Mit dieser Methode konnten 98 % des Bildes mit einem durchschnittlichen RMS von 0.7% klassifiziert werden. Die Ergebnisse wurden anhand von Geländedaten überprüft.*

1 INTRODUCTION

Field spectroscopy and LANDSAT-TM-5 are two remote sensing systems which cover the same wavelength range from 0.4 to 2.4µm, however, they differ in the spatial and spectral resolution. In this study a LANDSAT-TM-5 image was classified with the spectral mixture analysis and field spectra were used for the selection of the endmembers. Their high resolution of 2 - 6nm is usefull for determining very small differences in the spectral signatures of the surfaces.

This combination of datas was applied to the characterization of bare soil surfaces particularly for loose sediments. The study area was *Wadi Rayan* southwest of Cairo in the Libyan desert. It is an escarpment surrounded by pediments. A broad dune belt covers the center of the study area and several longitudinal dunes are located between the escarpments. Allmost all surfaces are covered by weathered material. The bedrock is limestone (mainly marine) full of the leading fossil *Nummulite*. In between there are layers of clay, sand and flint. A detailled ground check was carried out in October 1993 and 96 spectra of the soil surfaces were acquired using a SIRIS spectrometer. The LANDSAT-TM image was acquired on 20.9.1993. The direct comparison of the data (spectrometer and LANDSAT-TM) requires conversion of the data into absolute reflectance. Therefore, the processing of the LANDSAT-TM image includes an atmospheric correction by the radiative transfer code LOWTRAN-7 and a correction of the adjacency effects by a weighted filterbox (BACH & MAUSER, 1994). For the field spectra there is no influence of the atmosphere due to the acquisition method.

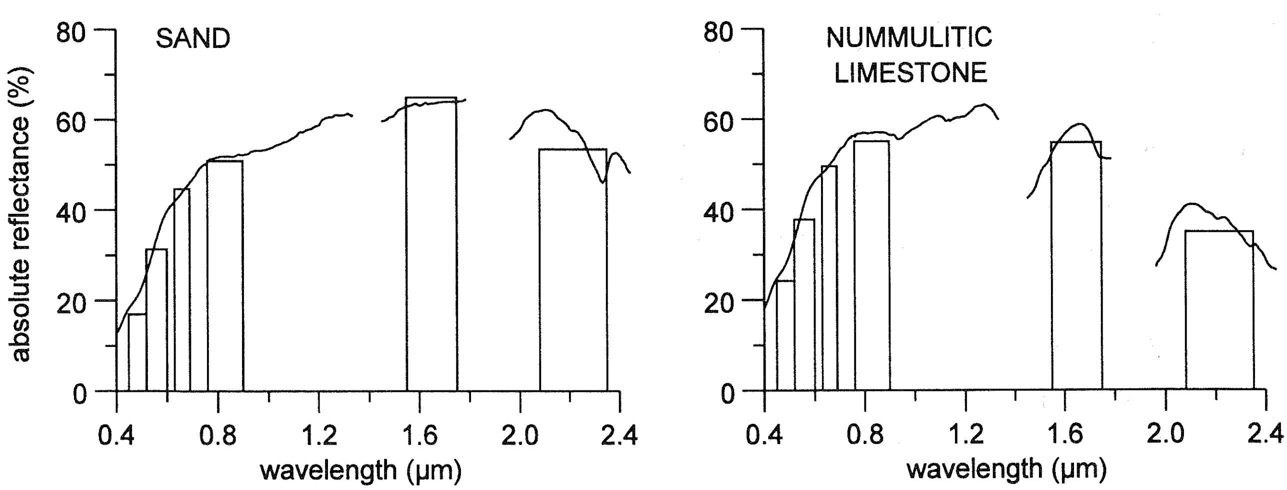

Fig. 1: Comparison of the measured field spectra with the calibrated data of the LANDSAT-TM bands 1 - 5 and 7 from the surrounding of the selected spots

A comparison of both sets of data after the conversion into absolute reflectance shows that the spectral signatures obtained from the field measurements and the corresponding signatures of the LANDSAT-TM fits well. As an example Fig. 1 shows the comparison for sand and nummulitic limestone.

After this step the spectral signature of the selected endmembers in the LANDSAT-TM image had to be determined. Finally, the spectral unmixing was carried out. In Fig. 2 the sequence of all steps for the processing of the data is shown.

2 SPECTRAL MIXTURE ANALYSIS

This method has been described in HILL (1994), SABOL et al. (1992) and SMITH et al. (1990). The spectral signature of a pixel arises from the weighted sum of the individual components of its surface. The unknown quantities Fj (Eq. 1) are determined by a least-square method.

$$R_i = \sum_{J=1}^{n} F_j * RE_{ij} + \varepsilon_i$$

with the condition

$$\sum_{j=1}^{n} F_j = 1 \qquad (1)$$

F_j = *fraction of the endmember* ***j***
R_i = *reflectance of the mixed spectrum in band* ***i***
RE_{ij} = *reflectance of the endmember* **j** *in band* **i**
ε_i = *residual error in band* **i**

The rms (Eq. 2) provides the difference between the measured and the modelled spectrum. The rms should be in the range of the noise level, in case of the processed LANDSAT-TM image it is 0.56% absolute reflectance.

$$rms = \sqrt{\frac{\sum_{j=1}^{n} (R_j - R'_j)^2}{n}} \qquad (2)$$

R_j = *modelled reflectance*
R'_j = *measured reflectance*
n = *number of bands*

To compensate differences in brightness due to surface roughness and artefacts of the relief shadow had to be included as an endmember. Since there is no spectral information in this endmember the fractions of all other endmembers have to be normalized (to unity, without the fraction of shadow (Eq. 3 and 4)).

$$f = 1 / (1 - F_s) \qquad (3)$$

F_s = *fraction of the endmember SHADOW*

$$\sum_{J=1}^{(n-1)} F_j * f = 1 \qquad (4)$$

f = *normalization factor*
F_j = *fraction of endmember* **j**

For the spectral unmixing of the LANDSAT-TM image fitting of experimental data was performed for all combinations of endmembers. The combination with the lowest rms was selected for the final result. A pixel was classified as unmixed if the rms was <2%. This value is about three times the noise level.

As the final result of the unmixing the fractions of the individual endmembers and the rms were obtained for every pixel in the image.

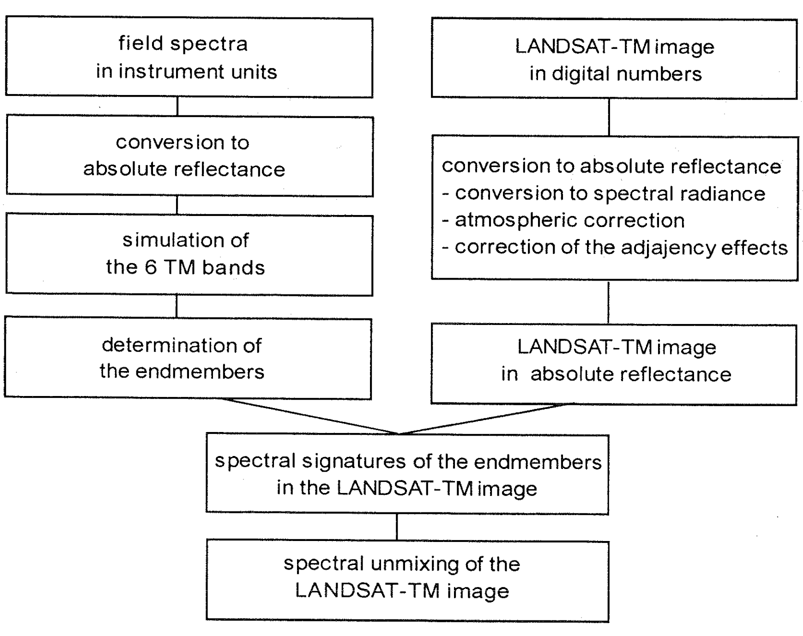

Fig. 2: Single steps for the processing of the two data sets

3 SELECTION OF THE ENDMEMBERS

The analysis of the field spectra provides four endmembers which represent the major substrate types of the study area: **sand**, **stone pavement** with flintstones, **nummulite-covered surfaces** and gypsum containing **nummulitic limestone** (Fig. 3, left). These endmembers have small differences in their spectral signature. Sand mainly consists of SiO_2 that shows no absorption bands and an increasing reflectance up to 2μm wavelength. The spectral signature of the sand shows weak bands from ferric ions (0.45, 0.6, 0.9μm) and the deep band of calcite at 2.3μm. The spectrum of the stone pavement consisting of sand and flintstones has the weak ferric ion bands from the sand and an overlapping band from opal and calcite at 2.3μm. The nummulite-covered surfaces are very bright. They have weak ferric ion bands and a strong band due to the large calcite content. The nummulitic limestone also shows these bands and in addition strong bands from gypsum at 1.5, 1.8μm and in the range from 2.0 to 2.4μm.

Convolution of the spectra with the sensor response function of the LANDSAT-TM (Fig. 3, right) shows that the spectral differences of the endmembers are preserved in the broad TM bands (TM1-TM5 and TM7). In the spectrum of sand reflectance increases up to TM5 and decreases for TM7. The reflectance of the stone pavement increases more strongly up to TM5 and decreases strongly to TM7. The nummulite-covered surfaces show the largest reflectance and the largest decrease from TM5 to TM7. The nummulitic limestone is the only endmember for which reflectance decreases form TM4 to TM5 and further on to TM7.

For the spectral unmixing TM spectra were determined for every endmember by selecting pixels in the TM image in the neighborhood of the field spectrometer measurements (EIBL, 1995).

4 RESULTS

Water surfaces and vegetation areas were masked in the image. The results of the spectral unmixing are shown in Fig. 4 to 6. Four selected areas were checked by ground truth. In these areas field spectroscopy data were acquired. The spectral unmixing yielded plausible results for the surface fractions of these areas.

In the following we show half-tone images corresponding to the fraction of the various endmembers. The fraction of shadow (Fig. 4) arises due to the relief and the surface roughness. On average the four endmembers have a slightly too small reflectance. Therefore, the fraction of shadow lies between -2 and -11%. Strongly negative fractions of shadow indicate areas which are overexposed due to their particular arrangement with respect to the incident sun light. These are dunes and slopes or surfaces with very small surface roughness, e.g. nummulite-covered areas. If shadow appears over extended areas it is due to the surface roughness. If shadow appears as a line contrast it comes from large variations in the relief.

Sand has the largest fractions in the whole image (Fig. 5). Dune belts and individual longitudinal dunes between the escarpments yield nearly 100% of sand. Along the slopes thin ribbons are observed with a 60 - 100% sand fraction. These ribbons arise due to an increased deposition of sand at the foot of the slope. Sand is also contained in most other pixels, however, with significantly smaller fractions.

Areas with large fractions of stone pavement (Fig. 6, top) are found predominantly on top of the escarpments because the flint horizons occur in the younger layers. Areas with a small fraction of stone pavement appear at the pediments in combination with nummulite-covered surfaces.

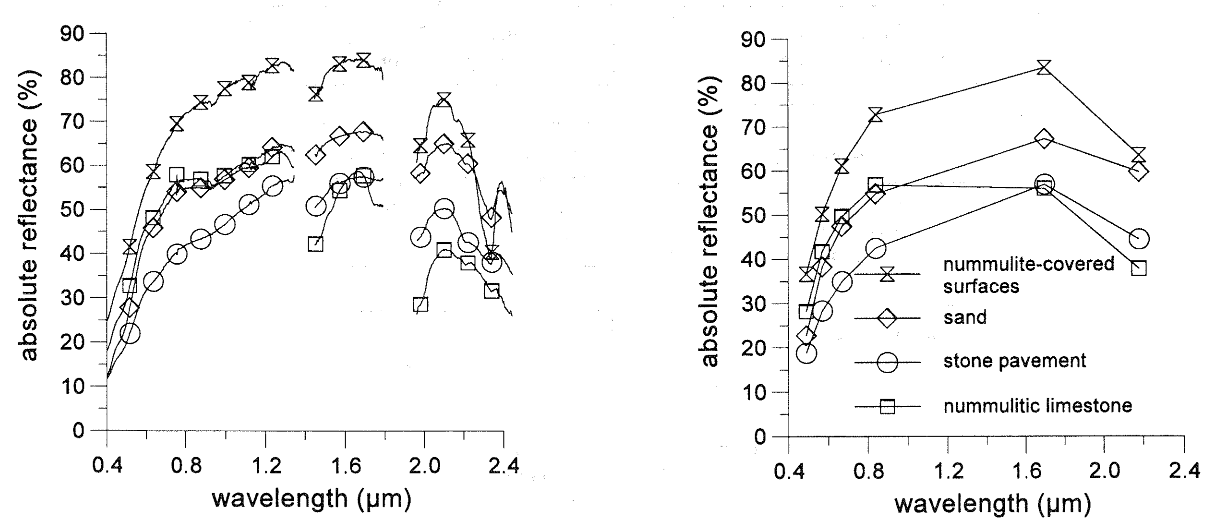

Fig. 3: Spectra (left) of the major substrate types and their TM simulations in the LANDSAT-TM band 1-5 and 7 (right)

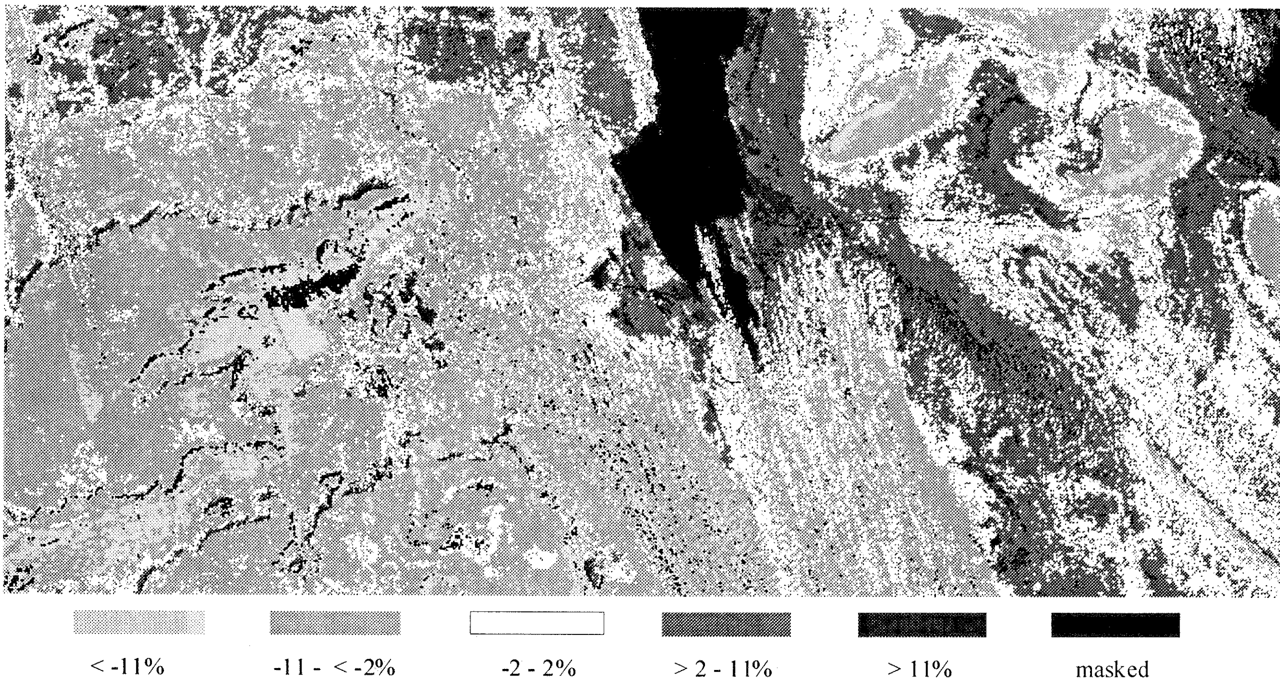

Fig. 4: Fractions of the endmember SHADOW

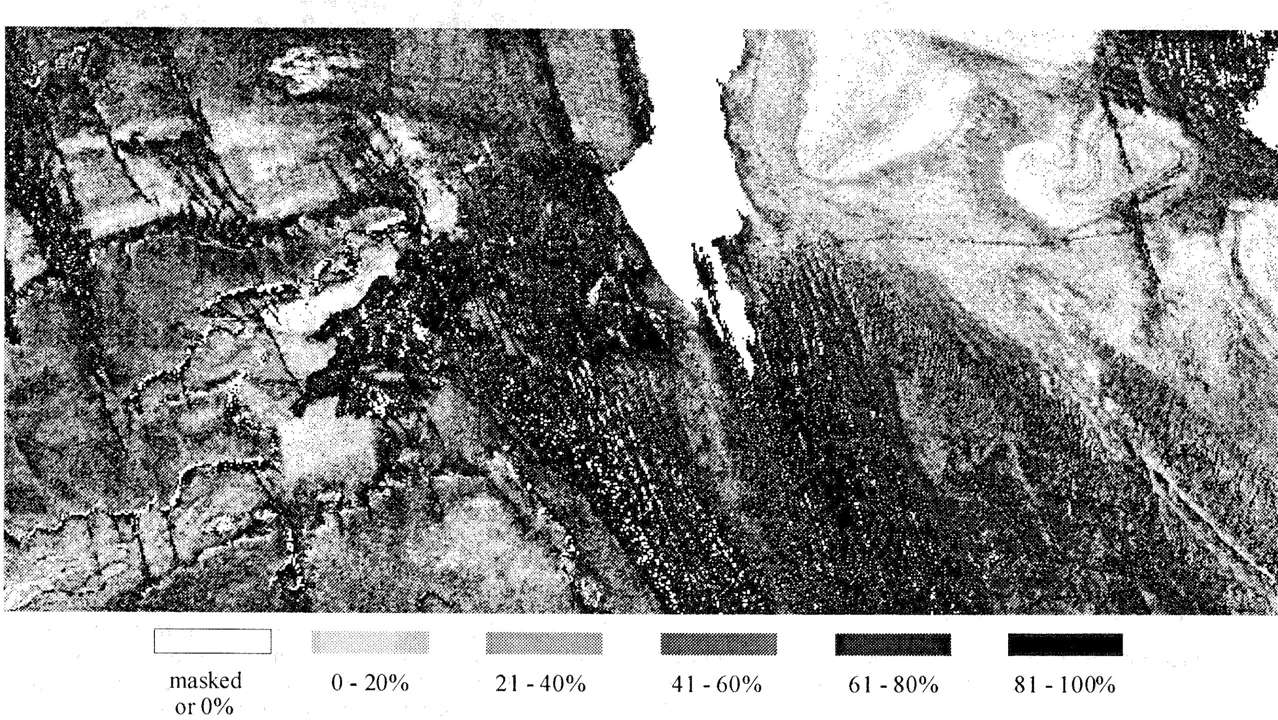

Fig. 5: Fractions of the endmember SAND

Because sand is an individual endmember but occurs also in the stone pavement the obtained fractions can be explained in two manners: (i) the endmembers occur as seperated areas or (ii) the stone pavement has a small coverage with flintstones. In the southeast of the image is a plateau that drains to the northeast. The drainage channels are filled with sand and some flintstones. These areas show a large percentage of sand and a small fraction of stone pavement. In the areas between the channels there is more or less dense stone pavement. The pixels in these areas are unmixed as sand and stone pavement and the fraction of stone pavement varies between 40 and 80%.

The nummulite-covered surfaces (Fig. 6, bottom) lie predominantly east of the lake. These areas are pediments along the *Inselberge* covered by nummulites of the bedrock. With respect to this endmember the spectral unmixing is not unambigous and the areas could be nummulitic limestone without gypsum. The investigation of a specimen from nummulitic limestone by x-ray diffraction showed that nummulitic limestone does not necessarily contain gypsum.

Areas with a large fraction of gypsum containing nummulitic limestone are rarely observed.

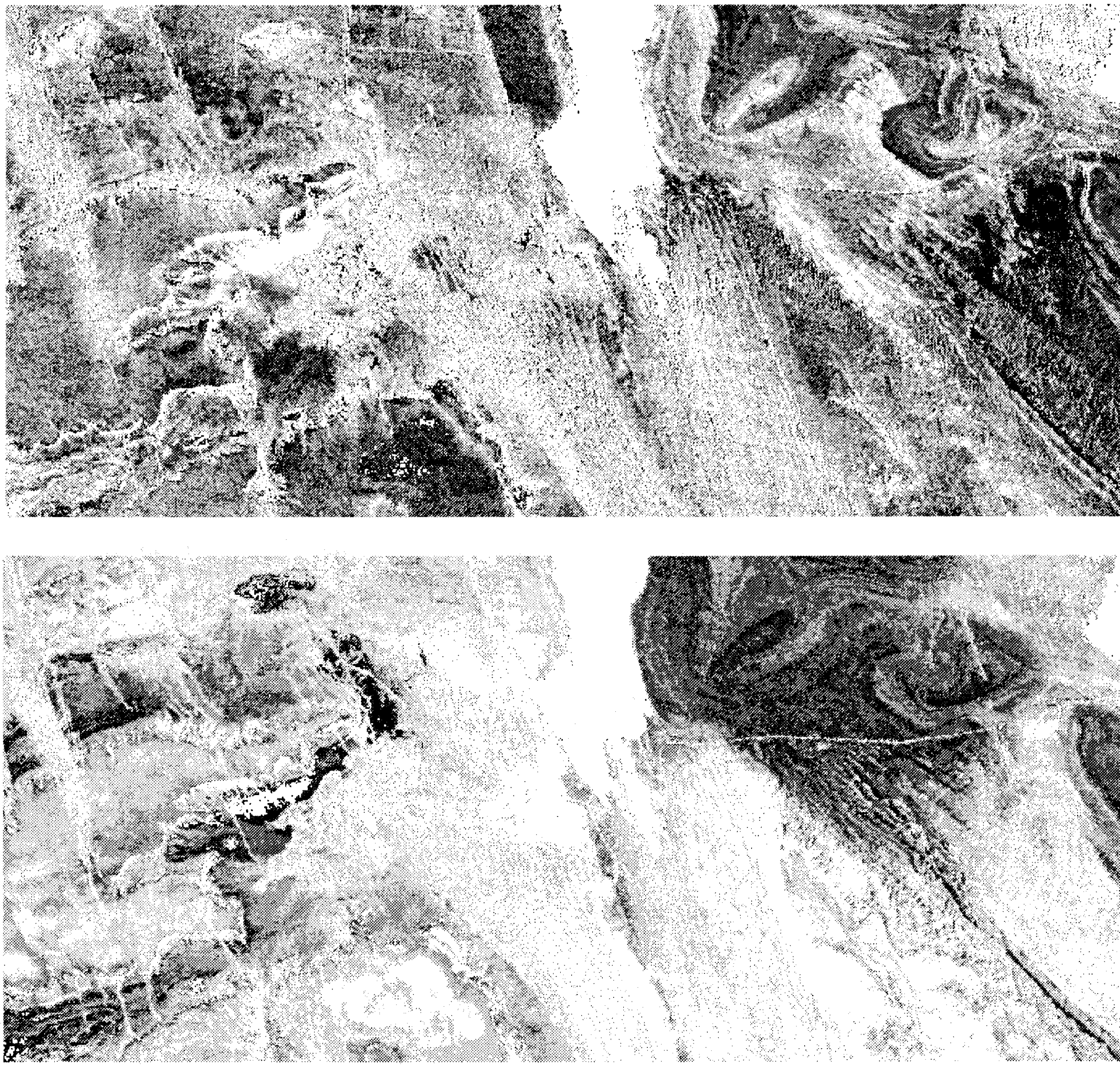

Fig. 6: Fractions of the endmember STONE PAVEMENT (top) and NUMMULITE-COVERED SURFACES (bottom) (caption see Fig. 5)

By the applied method 98% of the pixels in the study area could be unmixed with a rms <2% (Fig. 7).

The average rms of the whole image was 0.7%, i.e. slightly larger then the noise level of 0.56%. Pixels with a large rms occur mainly in the surrounding of the dunes and along the slopes. In these areas the intensity of the incoming sunlight varies due to the relief.

5 CONCLUSIONS

The spectral mixture analysis provides a fractional classification of the LANDSAT-TM image for bare soil surfaces in the study area. The application of the field spectroscopy was important for the determination of the endmembers and makes it possible to keep their number as small as possible. The spatial resolution of the LANDSAT-TM demands as an endmember *shadow*. the fraction of shadow provides information about the relief and the surface roughness.

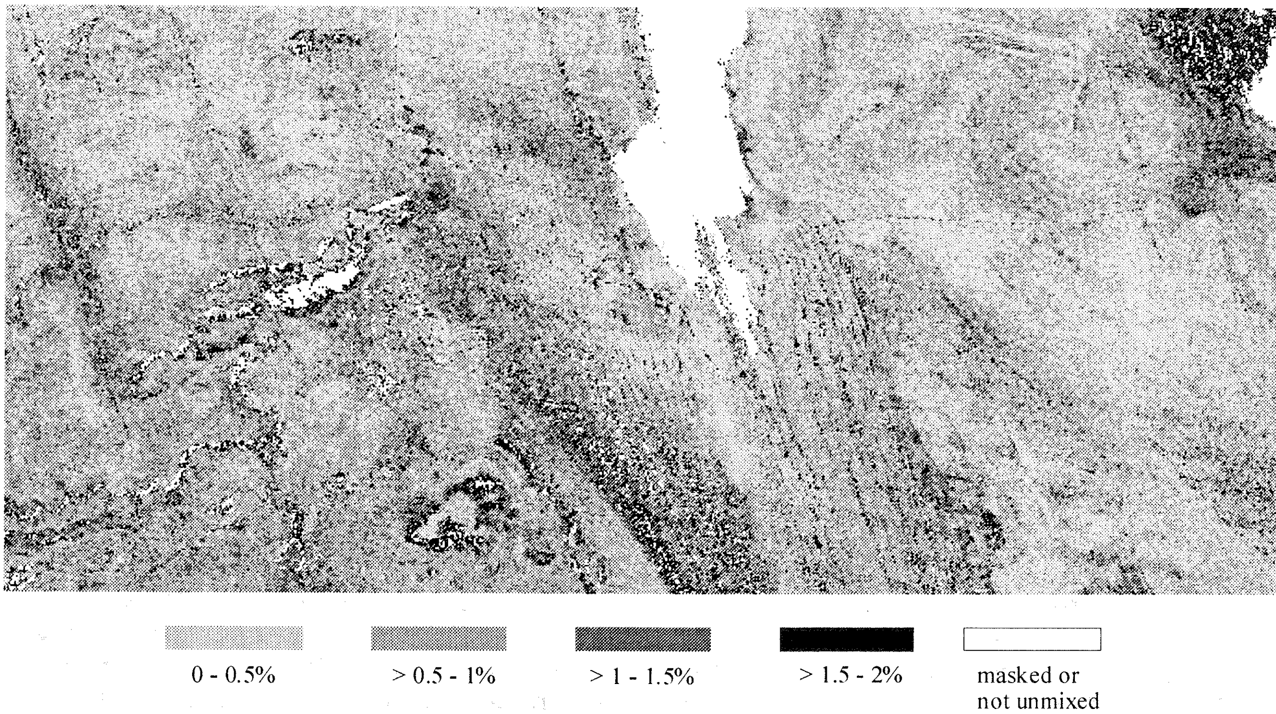

Fig. 7: Rms for every classified pixel

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