An AVIRIS Survey of Quaternary Surfaces Formed on Carbonate-Provenance Alluvium, Mojave Desert, Southern Nevada

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ABSTRACT

AVIRIS data acquired over Kyle Canyon (Nevada) are used in an attempt to discriminate Quaternary surfaces formed on carbonate-provenance alluvium and establish chronological sequences. Surface discrimination is based on increased albedo with age and mineralogical changes that can be inferred in great detail with AVIRIS high-spectral-resolution data. In order to do so, AVIRIS data were converted to reflectance using the radiative transfer modeling approach, combined with the extraction of total column abundance of precipitable water in the atmosphere from the AVIRIS data. Results show that the various surfaces can be easily identified and mapped in great detail on AVIRIS color composite and principal components images. All surfaces appear to present a clear carbonate absorption and the albedo seems to increase with age.

INTRODUCTION

1. Objectives

The purpose of this study is to investigate the use of high-spectral-resolution AVIRIS data for discrimination of Quaternary surfaces and attempt to establish chronological sequences based on their spectral characteristics. A previous analysis of Thematic Mapper (TM) data showed the utility of spectral information for the interpretation of Quaternary surfaces. Surface discrimination was based on increased albedo with age and mineralogical changes that were inferred from absorption differences for the TM bands. The increased spectral resolution of AVIRIS should allow detection of more subtle spectral differences between the different surfaces and within the surfaces. To extract this information, AVIRIS data need to be corrected to reflectance. A radiative transfer model approach has been used here, combined with the extraction of the total column abundance of precipitable water in the atmosphere from AVIRIS radiance data.

2. Description of the study area

The study area, Kyle Canyon, is located 25 km northwest of Las Vegas, Nevada (Figure 1). The Kyle Canyon alluvial fan is one of the largest fans flanking the east side of the Spring Mountains in southern Nevada. The bedrock of the source area consists of Cambrian to Triassic sedimentary strata, largely limestone and dolomite, with minor siltstone, sandstone, and chert.

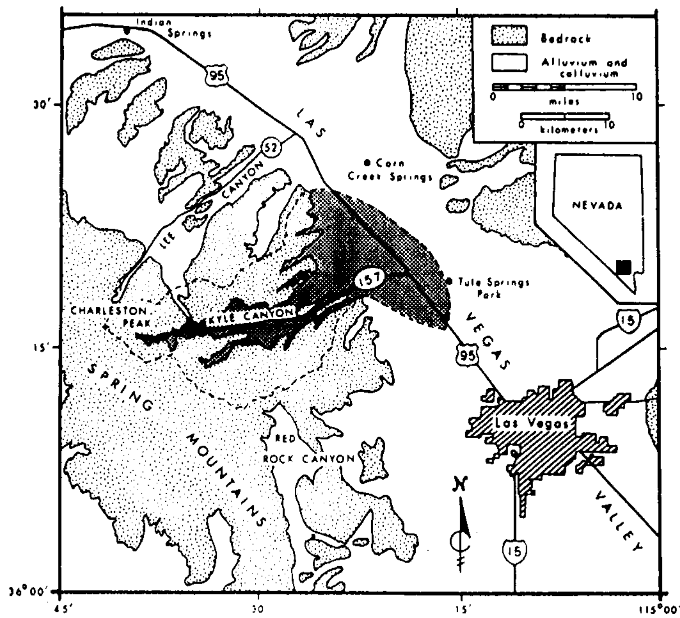


Figure 1. Location of the study area

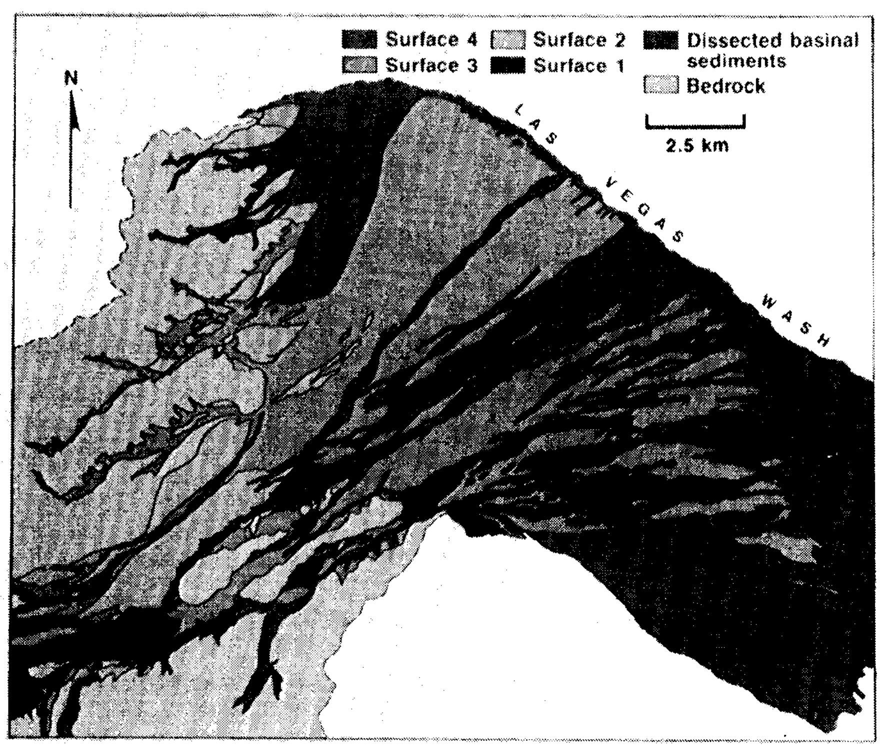


Figure 2. Simplified geomorphic map of the Kyle Canyon alluvial fan (after Chadwick et al., 1989) (see Slide 2)

Four main alluvial surfaces of different ages that can be distinguished by their surface properties and relative positions occur on the Kyle Canyon fan (Figure 2).

Surface 1, the oldest deposit, consists of rolling, dissected ballenas, and nowhere is the original depositional surface preserved. The deposit age, based on paleomagnetism of the associated pedogenic calcrete, is over 730.000 B. P., and the surface age is variable depending on erosion status (Sowers, 1985, 1986). It has a light-colored surface due to whitish calcrete fragments in the desert pavement. Desert pavement, well developed on ridge crests, is composed of extremely etched and pitted calcrete fragments and limestone clasts.

Surface 2 is moderately dissected, but remnants of the original depositional surface are preserved, giving it smooth local topography on interfluves that are separated by many steep-sided ravines. It has been dated at about 130.000 B.P. (Amundson et al., 1989b). It also has a light-colored surface due to whitish calcrete fragments, and the presence of secondary clay in the desert pavement. The desert pavement is similar to surface 1, being composed of etched and pitted limestone clasts and calcrete fragments; however, the soil B horizons are composed of greater amounts of smectite and palygorskite. These clays are exposed at the surface by the same turbation processes that expose the calcrete, usually fossorial mammals.

Surface 3 is slightly dissected with few drainages. It has a relatively smooth appearance due to the presence of quartz and iron-rich eolian dust that fills the intergrain areas of the alluvium. Its surface is time transgressive, dated between 5000 B.P. at the toe of the fan to 75.000 B.P. near the apex (Amundson et al, 1989a). Soils have strong calcic horizons, but pedogenic carbonate is seldom exposed at the surface. It is a dark-colored surface relative to surfaces 1 and 2 because of the lack of whitish calcrete fragments, the dominance of grey limestone in the desert pavement, and the accumulation of quartz and iron-rich fines in the interpavement areas.

Surface 4 is considered the modern surface, which includes the active channel and low terraces. It is dark colored, except in recently active channels where it is light. Soil development varies from none to weak carbonate accumulation. Pavement development is weak to none. This surface is composed of loose to slightly etched limestone clasts that are well sorted, and small amounts of eolian dust.

The morphology and the physical and chemical properties of soils on the Kyle Canyon fans indicate that five major processes are involved in their pedogenesis (Amundson et al, 1989b):

(1) formation of calcic horizons and calcrete;
(2) additions of eolian dust;
(3) translocation of clays;
(4) oxidation of iron;
(5) displacement and replacement of aluminosilicate grains, contributing to the formation of opaline or amorphous silica, palygorskite, and sepiolite.

The calcic horizons and calcrete of Kyle Canyon soils form by solution of calcite from eolian dust and the parent material and subsequent precipitation as clast coats and matrix cement.

Evolution of the carbonate-derived alluvium through a series of discrete stages of surface and soil properties suggests that we may be able to use multispectral imagery to identify significant properties at each stage. Identification of surfaces at specific evolutionary stages allows inferences regarding stability of Quaternary deposits in specific localities and, potentially, interpretations of climatic and tectonic influences on their stability.

WHAT IS KNOWN FROM THEMATIC MAPPER (TM)

Previous analysis of TM data over the area (Chadwick et al., 1989) showed (Figure 3):

(1) an increase in albedo as surface age increases;
(2) Surface 1 and 2 had greater absorption in band 7 because of increased amounts of clay and/or calcite;
(3) Surface 1 had greater iron absorption in band 4;

Those preliminary results point to the potential of AVIRIS data to:

(1) discriminate clays from carbonates;
(2) detect changes in depth of carbonate absorption features;
(3) identify specific minerals such as palygorskite or sepiolite;
(4) detect iron oxides absorption features.

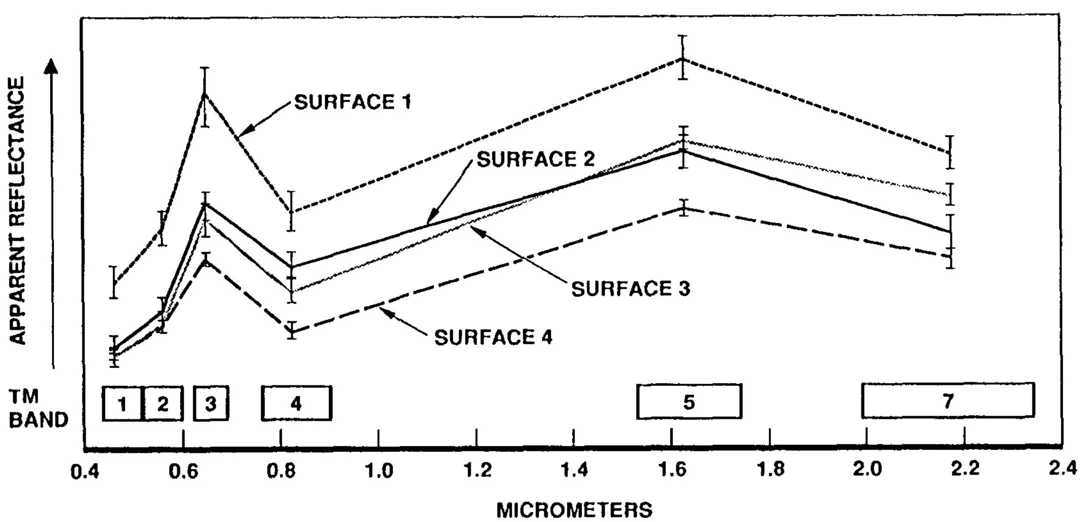


Figure 3.Thematic Mapper spectra of the various Quaternary surfaces (after Chadwick et al., 1989)

AVIRIS DATA ANALYSIS

1. Simple techniques

Color Composite interpretation

Analysis of a simple color composite (Figure 4) suggests the possibility of mapping with greater spatial detail, including possible subdivision of surfaces (e.g., Surface 3).

PCA (Figure 5)

Principal component analysis was performed on four AVIRIS bands to check the importance of spatial changes in the composition from surface-to-surface and internal to each surface. The results are similar to what was observed on the color composite.

Band ratios (Figure 6)

A simple band ratio approach was also used in an attempt to locate spatial distribution of various important minerals such as carbonates, gypsum, and clays.

Gypsum, based on a ratio to detect the 1.75-absorption feature, is detected in the paludal sediments exposed in the basin bottom at the toe of the alluvial fan.

Carbonate is spread almost evenly over the area, with the exception of surface 1 and the active part of the wash. This result is unexpected in view of the amount of calcrete exposed on surface 1.

Clays are mainly encountered on surfaces 1 and 2 and absent from surface 4.

2. Correction to reflectance

The second step in AVIRIS data analysis was to retrieve reflectance from the radiance data. The approach used to convert AVIRIS radiance data to reflectance is presented in more detail in these proceedings by van den Bosch and Alley. It consists of using the LOWTRAN 7 radiative transfer code to model the radiance at AVIRIS for the conditions of the flight and a constant background reflectance chosen by the user. This allows us to predict the atmospheric component in order to remove it to get to reflectance. The steps involved are as follows:

(1) LOWTRAN 7 is run for the conditions of flight using meteorological observations from ground stations for visibility and water from the radiosonde profile:

$$L_{tot} = L_{path} + L_{ground}$$

with $L_{ground} = L_{sun}\, t_1\, t_2\, r$

L_{tot} is the total radiance at AVIRIS

L_{path} is path radiance

L_{ground} is the ground reflected component with L_{sun} = solar radiance, t_1 and t_2 transmittance upward and downward and r ground reflectance as chosen by the user.

Figure 4. AVIRIS color composite
red: 2107.8 nm; green: 1022.5 nm; blue: 604.1 nm
(see Slide 3)

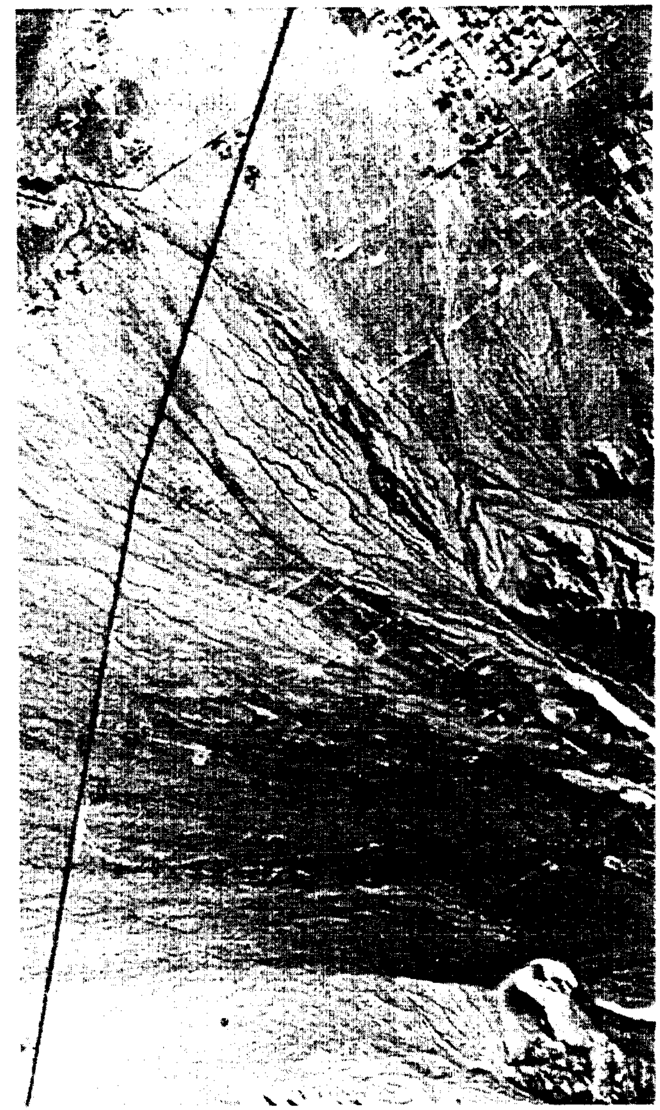


Figure 5. AVIRIS PC color composite
red: PC1; green: PC2; blue: PC3
(see Slide 4)

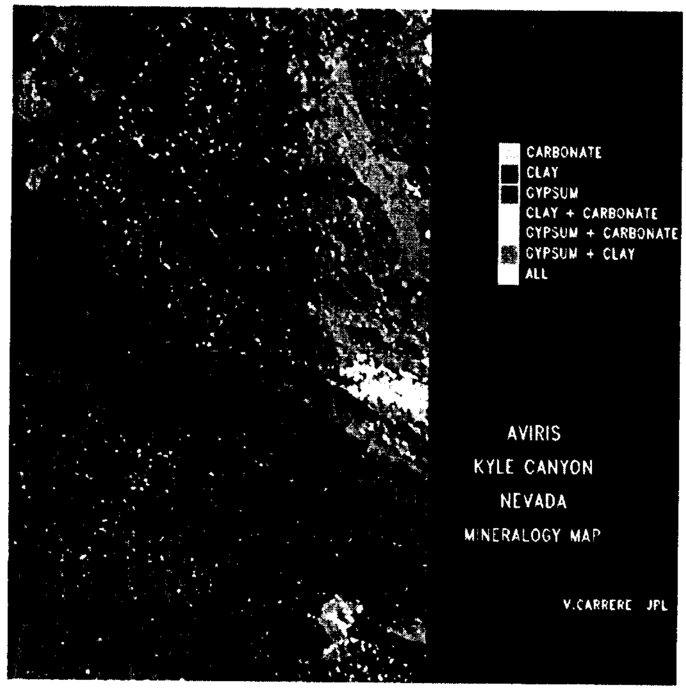


Figure 6. Mineralogy map of the Kyle Canyon fan obtained from combined band ratios (see Slide 5)

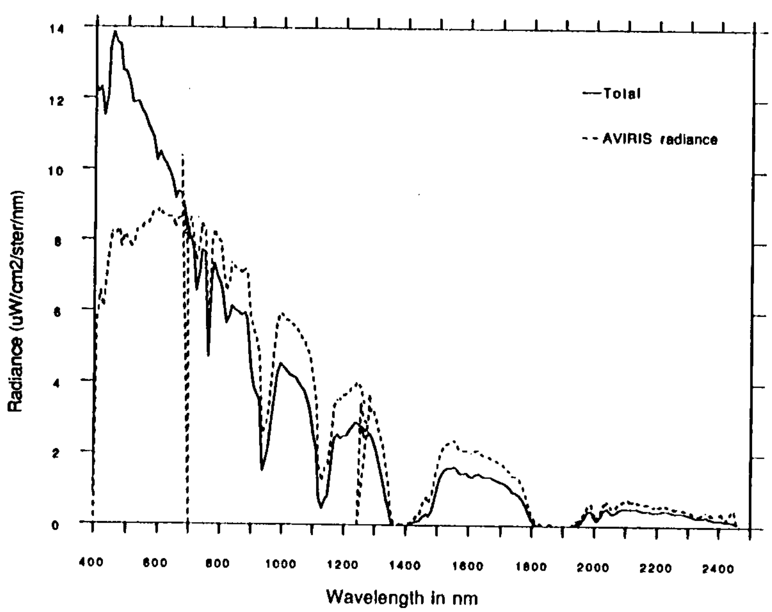


Figure 7. Radiance predicted by LOWTRAN using radiosonde data/AVIRIS radiance

$L_{sun}\ t_1\ t_2$ is the main unknown but can be retrieved from the LOWTRAN run since the background reflectance is known:

$$L_{sun}\ t_1\ t_2 = L_{ground}\ /\ r$$

(2) Reflectance can then be extracted from AVIRIS data using the following equation:

$$R_{AVIRIS} = (rad_{AVIRIS} - L_{path})\ r\ /\ L_{ground},$$

giving a gain and offset factor applicable to the entire scene (assuming the elevation does not change drastically, thus modifying the amount of water in the total column).

$$gain = r\ /\ L_{ground}$$
$$offset = -\ gain * L_{path}$$

In the first attempt, considering we did not have any ground support simultaneous with the overflight, we used atmospheric parameters obtained from the Las Vegas airport weather station and the Desert Rock test site at Yucca Flat, Nevada, both of these being within 50 km of our study area. The visibility, as estimated from the Las Vegas data, was of 80 km, and the total column abundance of water, as observed by the radiosonde launched at the Desert Rock test site, was of 1.162 g/cm^2.

Comparison between the AVIRIS radiance data and the radiance predicted by LOWTRAN (Figure 7) shows that the amount of water detected by the radiosonde was too large for our area. This was confirmed after correction to reflectance (Figure 8). All the atmospheric water bands were overcompensated for, appearing reversed on the spectra.

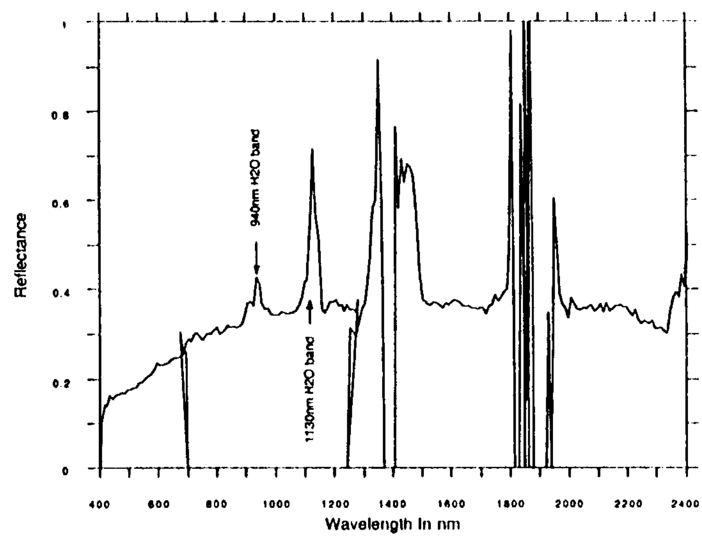


Figure 8. Reflectance obtained using radiosonde data

In a second attempt, we decided to use the information included in the AVIRIS radiance data. The technique used, known as Continuum Interpolated Band Ratio (CIBR) (Conel et al., 1988, Conel et al., 1989, Green et al., 1989), allows us to retrieve total column abundance of water using the 940-nm (or the 1130-nm) atmospheric water band (Figure 9). This estimate of the depth of the absorption feature is related to the amount of precipitable water through a curve of growth (Figure 10). This curve is obtained by running LOWTRAN 7 for the conditions of the flight, a constant background reflectance of 0.25, and increasing amounts of water ranging from 0 to 200%. The total radiances predicted by LOWTRAN are then convolved to AVIRIS bandpasses, CIBR is performed for each amount of water, and a file relating the amount of water to CIBR values is created.

Transects across and along the surfaces were extracted from this water map in order to investigate the range of changes in amount of atmospheric water over the study area. The average amount was found to be between 0.7 and 0.75 g/cm^2. This value was then used as input to LOWTRAN to retrieve reflectance. Figure 11 shows the result. One can notice that the atmospheric water bands are not perfectly compensated for. The 940-nm water band is undercompensated but the 1130 nm is slightly overcompensated. This points to a problem in the calibration file used to convert AVIRIS raw data to radiance, and confirms the sensitivity of this approach to selection of appropriate parameters such as radiance calibration and amount of water. The average value of 0.7 cm was kept as a best (although not perfect) estimate.

Results after correction to reflectance are shown in Figures 11 and 12. From these spectra, one can notice that:

(1) Every surface is dominated by carbonates, as expected and shown by the ratios;

(2) Surface 1 is the brightest because of the increased amount of pedogenic calcite;

(3) Surface 2 is darker, possibly because of the presence of quartz-rich eolian dust, lack of calcrete at the surface, and the presence of a broader feature between 2200 and 2350 nm (possibly due to increased quantities of secondary clay minerals at the surface);

(4) Surfaces 3 and 4 appear to have very similar spectral characteristics.

CONCLUSIONS

These preliminary results show that:

(1) Quaternary surfaces can be easily identified and mapped in greater detail on AVIRIS color composites than with a Thematic Mapper;

(2) Differences between surfaces derive from subtle spectral and spatial influences that are not obvious spectrally. This might be due to the fact that morphology and composition of soils on the same surface vary with elevation on the fan or a signal-to-noise ratio in the D spectrometer that is too low to allow discrimination of important mineral absorption features in the 2000- to

Figure 9: Continuum interpolated band ratio (CIBR)

CIBR = L / (0.5 * C1 + 0.5 * C2)

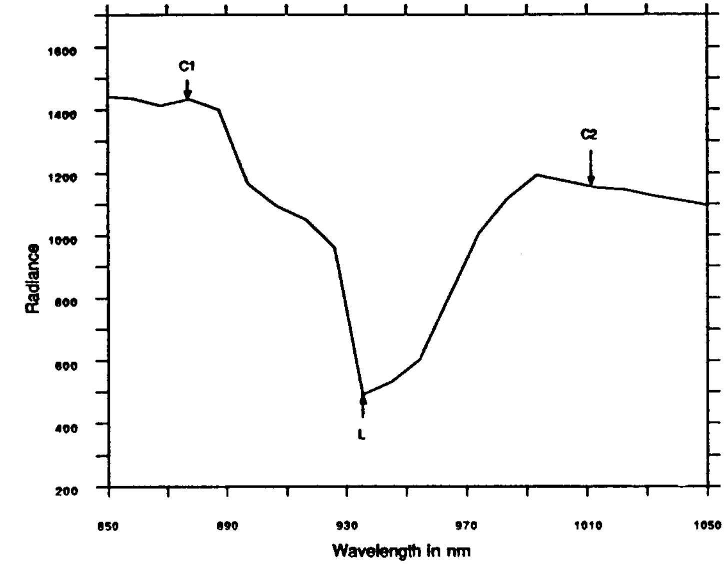


Figure 10: Curve of growth for the 940nm atmospheric water

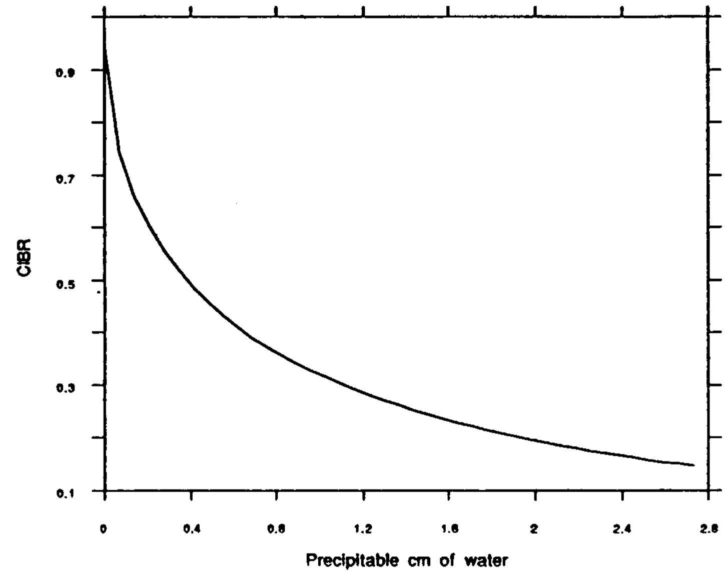


Figure 11: Average reflectance of the different surfaces

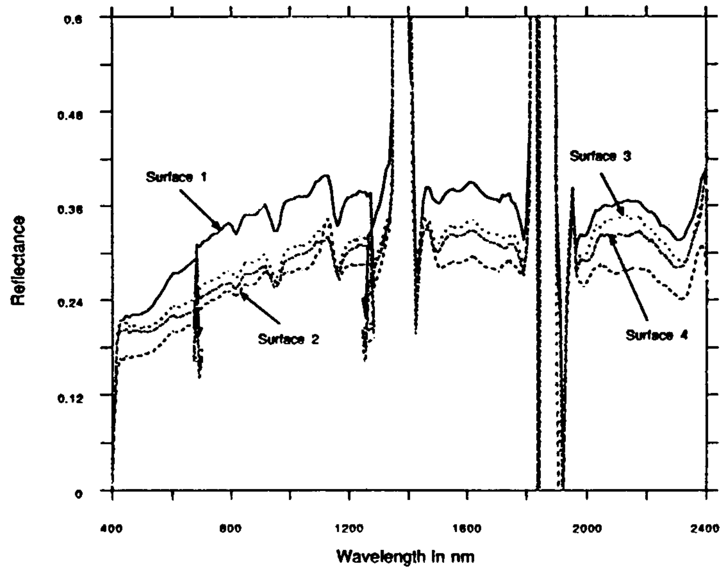
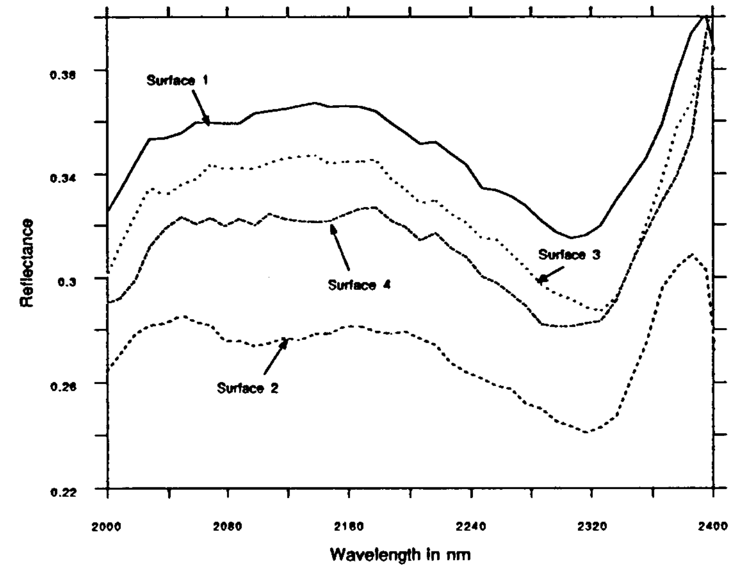


Figure 12: Average reflectance of the different surfaces between 2000 and 2400nm



2400-nm range. Poor signal to noise not withstanding, all the surfaces appear to present a clear carbonate absorption;

(3) As observed on Thematic Mapper data, the albedo seems to increase with age;

(4) A better calibration of AVIRIS data to radiance and a very good knowledge of the amount of water in the atmosphere is indispensable to be able to correct to reflectance. The CIBR approach has proven to be an easy and accurate way to retrieve the amount of precipitable water (Conel et al., 1990a, 1990b, Bruegge et al., 1990). Its combination with the radiative transfer modeling approach allows retrieval of reflectance from AVIRIS radiance data without the necessity of ground support at the time of the overflight.

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