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USE OF THE TM TASSELED CAP TRANSFORM FOR INTERPRETATION OF SPECTRAL CONTRASTS IN AN URBAN SCENE

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I. ABSTRACT

The TM Tasseled Cap transform has been applied to a Washington, DC scene to test its use as a means to carry out a physically-based analysis of urban landscapes from TM observations premised on a priori knowledge of land spectral radiance properties. The results show that urban spectral patterns are more diverse in TM data space than agricultural scenes but that the dimensions of the data as defined by the plane of vegetation and plane of soils in the Tasseled Cap transform still provide a rational explanation of the observed patterns. Presence of extensive forest cover and urban materials produces the observed diversity in the data space of the Washington, DC scene. For this scene the fourth TM tasseled cap dimension contains significant information which permits discrimination between urban materials and soils. Ground spectral measurements of soils and urban materials collected at the Goddard Space Flight Center show that TM band 1 measurements provide the primary source of contrast observed between soils and urban materials. The fourth dimension appears to be primarily sensitive to the redness of soils versus urban materials in the scene as a result of soils iron oxide content. The TM Tasseled Cap transform not only appears to provide a scene-invariant method to characterize the physical attributes of urban scenes but also has directed attention to new spectral information in the TM data which may be used to more thoroughly characterize urban landscapes.

II. INTRODUCTION

As part of a research effort being carried out at the Goddard Space Flight Center (GSFC) to develop automated numerical image analysis procedures, the authors are currently examining physically-based multispectral data transforms as a means to incorporate a priori knowledge of land radiance properties in the analysis process. Numerical analysis of Landsat observations has generally proceeded under the implicit assumption that no a priori information exists with which to explain the observed spectral patterns. This approach is costly in terms of both human and computer resources since for each new scene the relation between known land features and spectral patterns observed must be derived. This training phase dilemma in analysis is exacerbated with sensors such as Thematic Mapper because the dimensionality of the observations is considerable.

Research carried out, particularly during the last decade, on the spectral reflectance properties of land areas has shown that only a limited range of spectral band measurement combinations occur in the data space defined by Landsat multispectral sensors. The relative position of these spectral measurements in the data space may be related to specific physical phenomena on the ground. In general MSS observations may be characterized by two dimensions which are primarily related to variations in soil brightness and the amount of green vegetation present (Kauth and Thomas, 1976; Richardson and Wiegand, 1977). This information appears to be relatively scene-invariant once atmospheric effects and illumination conditions are taken into account (Christ and Cincone, 1983). Knowledge of these scene-invariant attributes of land spectral reflectance properties have been used to study vegetation activity over large areas of the global and over considerable time intervals with automated analysis techniques (Thompson and Wehmanen, 1979; Tucker, Townshend, and Goff, 1984).

Investigators at the Environmental Research Institute of Michigan have developed a physically-based transform of TM observations that extends the Landsat MSS Tasseled Cap transform developed by Kauth and Thomas (1976) to TM data observations (Christ, 1983; Christ and Ciccone, 1984). The basis of the Tasseled Cap transform is that soils reflectance patterns in the visible and near infrared are highly correlated and thus form a "line-of-soils" in the data space. Variations at right angles from the soils line forms a plane of measurements in the feature space which is related to the amount of photosynthetically active "green" vegetation present. With TM observations the ERIM investigators note that at least a third dimension is added to the data which forms a second plane in the data space and appears to be related to the "wetness" of soils present. They have shown that for three TM scenes from different regions in the United States the "greenness", "brightness" and "wetness" transforms of the TM data are scene invariant.

III. OBJECTIVE

To date, much of the research on physically based spectral transformations has emphazised analysis of agricultural data, the degree to which these insights may be applied in analysis of urbanized landscapes is uncertain. The objective of this study was to examine the utility of the TM Tasseled Cap transform as applied to TM data from an urban landscape. Crist and Cicone (1983) have shown that urban features and forest lie outside the portions of the transform data space defined by the "plane of vegetation," the "plane of soils," and the "transition zone" identified through analysis of agricultural observations. This suggests that TM observations contain spectral information not available in MSS data which may be useful in delineating urban landscapes. In addition, the the 30m IFOV of the TM more effectively resolves urban land patterns than previous satellite-based sensors.

IV. DATA AND METHODS

A 512 x 512 subset of the Washington, DC November 2, 1982 TM scene, centered on Springfield, Virginia, southwest of Washington, was used in the analysis. The land cover is predominantly suburban housing, with a mixture of forest, road networks, shopping malls, light industry, a golf course and a large bare soil area. The decidious trees were scenesent at this time, resulting in increased reflectance in the red spectral band of the TM data. The TM Tasseled Cap transform coefficients (Table 1) given by Christ (1983) were applied to the data to produce "brightness", "greenness", "wetness" and the fourth feature direction (as of yet unnamed). The fifth and sixth features were not examined in this study.

Low-altitude aerial photography of the region and field visits were used to identify the representative cover materials at selected sites. Pixels from these sites were visually located in the TM images and on scatterplots of the data in the Tasseled Cap feature dimensions. These results were compared with the patterns previously reported by Christ (1983).

Local ground spectra measurements of soils, concrete, composite roofs and asphalt were collected by a Barnes 12-1000 eight-band spectral radiometer (TM bands plus 1.15-1.30 μm) and a Spectron Engineering SE-590 spectrometer (240 contiguous spectra between .38 μm and 1.0 μm) were processed and analyzed. See the paper by Williams, Walthall, and Goward in these proceedings for a description of these instruments. These measurements were made at GSFC, some 20 miles from the study area, but given the consistency of soils and construction materials found throughout the Washington, DC region it is assumed that they are representative of materials encountered in the study area.

V. RESULTS AND DISCUSSION

A. GENERAL PATTERNS

The "brightness", "greenness", "wetness" patterns of the Washington, DC TM (Figs. 1-2a) in general correspond to those reported by Christ (1983) for TM scenes. The general distribution of cover materials in these feature dimensions (Figs. 1-2b) show that the plane of vegetation and plane of soils are not well developed due to the preponderance of mixed pixels in the scene. Therefore, many of the observations are located in the transition zone between bare soils and full vegetative cover (Figs. 2a and 2b). However the projection of the soils plane is represented by a line in the greenness/brightness plane, as predicted, parallel to the brightness direction in the greenness-brightness plot (Fig. 1b).

Forests are observed as low reflectors in the visible, and lower reflectors than herbaceous vegetation in the near infrared wavelengths. Forests therefore show up as relatively low brightness with moderate greenness which places them outside the portion of the feature space defined by the soils and vegetation planes. This region is referred to as the "badge-of-trees" by Crist and is is related to shadowing and the reflectance properties of woody portion of trees (Christ, 1983). The "badge-of-trees" stands out as the area of highest data density in this study site. Suburban streets and shadows show up at the extremities of the badge-of-trees as a result of mixed pixel observation of these sub-TM resolution features. Water observations occur at the lowest brightness and greenness positions but at the highest wetness values, as expected.

Construction material (i.e., roofs, interstate highway, parking lots) observations occur below the soils line in the greenness-brightness direction, predominantly above the vegetation line in the wetness-brightness direction and below the line of soils in the greenness-wetness direction.

To further evaluate the observed patterns, slices of the greenness, wetness dimensions were plotted for selected ranges of brightness. This revealed a V form structure in the plot with the apex of the V centered on the bare soil observations (Fig. 3). The upper arm of the V (higher greeness then at apex) extends from the bare soil measurements to the grass observations. This arm is the transition zone between the vegetation and soils planes that results from variable vegetation ground cover and shows that for this scene that the planes are not well developed due to the mixed pixels. This is not unexpected because the herbaceous vegetation present (grass) is regularly mowed and seldom reaches a condition of complete ground cover when compared to agricultural crops. The soils plane is not fully developed because soil properties and conditions are relatively uniform over the small study area.

The lower arm of the V (lower greenness than at apex) is somewhat puzzling. Christ noted that construction materials such as concrete should be the ultimate "dry" materials and thus show up at low wetness values. The plots show that this is not the case for the Washington D.C. test site. The lower arm extends from the soil observations to lower greenness but higher wetness for the roofs and parking lots of the larger commercial industrial structures in the area.

The fourth dimension of the TM Tasseled Cap transform presents additional evidence that urban scenes contain more spectral diversity than scenes of agricultural regions. Christ noted that there is a suggestion of additional information in the fourth dimension, but shows little variability in the fourth dimension of the soils and agricultural measurements. The fourth dimension of the Washington scene displays a marked pattern of spectral variability (Fig. 4a). Vegetation, soils, and water observations all display similar values in the fourth dimension, whereas urban material observations display marked different values (Fig. 4b). The transform coefficients used in the fourth dimension (Table 1) are heavily weighted on TM band 2 (.45 .52 um) and band 3 (.63 - .69 um) which suggests that the observed contrast occurs in these regions of the spectrum.

B. Urban Material Spectral Reflectance

Full evaluation of the possible contributions TM observations may make in urban analysis requires a physical explanation of the Washington D.C. observations. Only with this understanding is it possible to extrapolate the results derived here to other regions. Field measurments were made for soils, concrete, asphalt, gravel roofs, and other urban materials. These measurments confirm the contrasts observed by TM and have provided insights which suggest the physical mechanisms involved.

Barnes MMR measurments for asphalt, white rock gravel roofs. soils and a blue-green automobile roof are presented in Table 2. Note that in the case of the urban materials, only a small increse in reflectance occurs with increasing wavelength. The soils measurements show a sharp increase in the visible TM bands. The contrast between the blue and red bands (bands 1 and 3 respectively) is typically a factor of 2 for soils whereas the urban materials show contrasts of no more than 1.4 to 1. The SE590 spectrometer observations dramatically show these differences between soils and concrete (Fig. 5). Measurments for both materials decrease with decreasing wavelength but the soils decrease more rapidly developing a sharp constrast between the concrete and soil in the blue portion of the spectrum.

Studies conducted by Hunt and Salisbury (1970) have shown that minerals with high iron oxide content display an electron transition absorption band in the ultraviolet which expands into the visible spectrum, as the iron oxide content increases. Fresh concrete, produced from crushed rock, calcium carbonate and water has minimal concentrations of iron oxide. Asphalt reflectance is dominated by hydrocarbons which are strong absorbers throughout the TM spectrum. As the concrete weathers, the rock component of the material provides iron materials that form into iron oxides and increase the blue absorption of the material. Measurements carried out recently at GSFC for concrete of differing ages and soils of differing apparent redness show that the blue band absorption increases as the visual redness of the material increases. Since typical building materials have less iron oxide content than soils in the Washington region, the contrasts between urban materials and the soils are best observed in the fourth dimension. Note that the other materials in the scene including water, forest, grass, and shadows all have low reflectances in the blue and red bands and therefore produce low fourth dimension "redness" measurments.

These spectral contrasts between soils and construction materials produce the observed patterns. In the greenness direction the low values for urban materials occur because of the relative small difference in reflectance between the visible and near infrared. Differences in the wetness direction occur for the same reason. The differences between the Washington observations and those reported by Christ (1982) most likely occur because of differing soil types and conditions in the various locations studied. If the Washington, DC soils were particularly dry during the observation period they would produce lower wetness measures than the urban materials (i.e., the mid-IR measurements balance the other bands). When soils are wetter they would move in the direction of the urban wetness values.

The spectral contrasts provided by TM band 1 permit characterizing the redness of non-vegetated land surfaces. This redness appears to be related primarily to iron oxide content. Urban materials and soils in the Washington D.C. region can be readily distinguished in TM observations as a result of their constrast in redness.

VI. SUMMARY AND CONCLUSIONS

The spectral patterns displayed in this Washington, DC TM scene correspond to those observed by Christ for TM scenes for other regions of the United States. The Washington, DC scene shows only a small portion of the soils and vegetation planes defined from agricultural scenes, not a surprising result considering the predominance of trees and urban materials. The urban construction material reflectance patterns are particularly interesting because they suggest that TM observations may be used to characterize the magnitude of human alteration of land in urban regions.

The TM tasseled cap transformation does appear to provide a good means to explain land physical attributes of the Washington scene and thus suggests a direction by which a priori knowledge of landscape spectral patterns may be incorporated into numerical image analysis. However several limitations in this approach still need to be resolved. The transform as now configured is sensitive to atmospheric conditions, is sensor-dependent and may not necessarily extend to other regions of the globe. These limitations point toward current shortcomings in our knowledge of remotely sensed observations. In particular, further research is needed to better understand the physical basis for the seperability between urban materials and soils in the fourth dimension "redness". If, as hypothesized in the paper, the separability depends on iron oxide content, urban materials and soils would be inseperable in areas having soils with low iron oxide content. To validate the hypothesis, it will be necessary to apply the TM Tasseled Cap transform to other scenes having markedly lower or higher oxide concentrations than the Washington D.C. scene.

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BIOGRAPHICAL SKETCHES

Samuel N. Goward is a faculty member of the Geography Department, University of Maryland. He received a Ph.D. degree in physical geography from Indiana State University in 1979. He holds B.A. and M.A. degrees in geography from Boston University. Dr. Goward has been involved in remote sensing research for ten years. His primary interest is extraction of land physical measurements from remotely sensed observations. From 1978 to 1982 he served as co-principal investigator on cooperative research activities between the Geography Department, Columbia University and the NASA/Goddard Institute for Space Studies. He is currently principal investigator for cooperative research between the Geography Department, University of Maryland and the Earth Resources Branch, NASA/Goddard Space Flight Center.

Stephen Wharton was born in Cambridgeshire, England on 14 January 1956. He recieved a B.S. and M.S. in Forest Science from the Pennsylvania State University and a M.S. in Computer Science from the University of Maryland. Currently, he is working in the Earth Resources Branch of the Laboratory for Earth Sciences at the NASA Goddard Space Flight Center on various non-supervised classification algorithms for remotely sensed data.

Table 1. Thematic Mapper Tasseled Cap Coefficients

	TM Band					
Feature	1	2	3	4	5	7
Brightness	.3037	.2793	.4743	.5585	.5082	.1863
Greenness	-.2848	-.2435	-.5436	.7243	.0840	-.1800
Third	.1509	.1973	.3279	.3406	-.7112	-.4572
Fourth	-.8242	.0849	.4392	-.0580	.2012	-.2768
Fifth	-.3280	.0549	.1075	.1855	-.4357	.8085
Sixth	.1084	-.9022	.4120	.0573	-.0251	.0238

Table 2

Barnes MMR Measurements
for NASA/GSFC
(percentage reflectance to $BaSO_4$)

Subject	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7
Old Asphalt	7.50	8.12	8.59	9.23	11.33	13.11	12.65
New Asphalt	6.01	6.67	7.25	7.94	9.21	9.90	9.50
Gravel Roof	14.83	18.01	20.01	26.03	33.14	37.30	26.32
Gravel Roof	21.26	24.32	26.07	36.96	36.33	38.92	27.07
Asphalt	11.96	14.79	16.93	17.45	18.99	19.38	17.59
Asphalt	8.89	9.97	10.44	11.05	11.77	11.60	10.52
Car Top (blue)	15.66	15.49	12.55	13.59	17.35	16.87	15.84
Soil	17.26	28.67	41.64	46.75	57.47	58.09	54.49
Soil	19.92	30.37	40.05	44.99	54.77	55.86	52.87
Soil	20.24	30.69	40.71	45.46	54.45	51.47	52.39

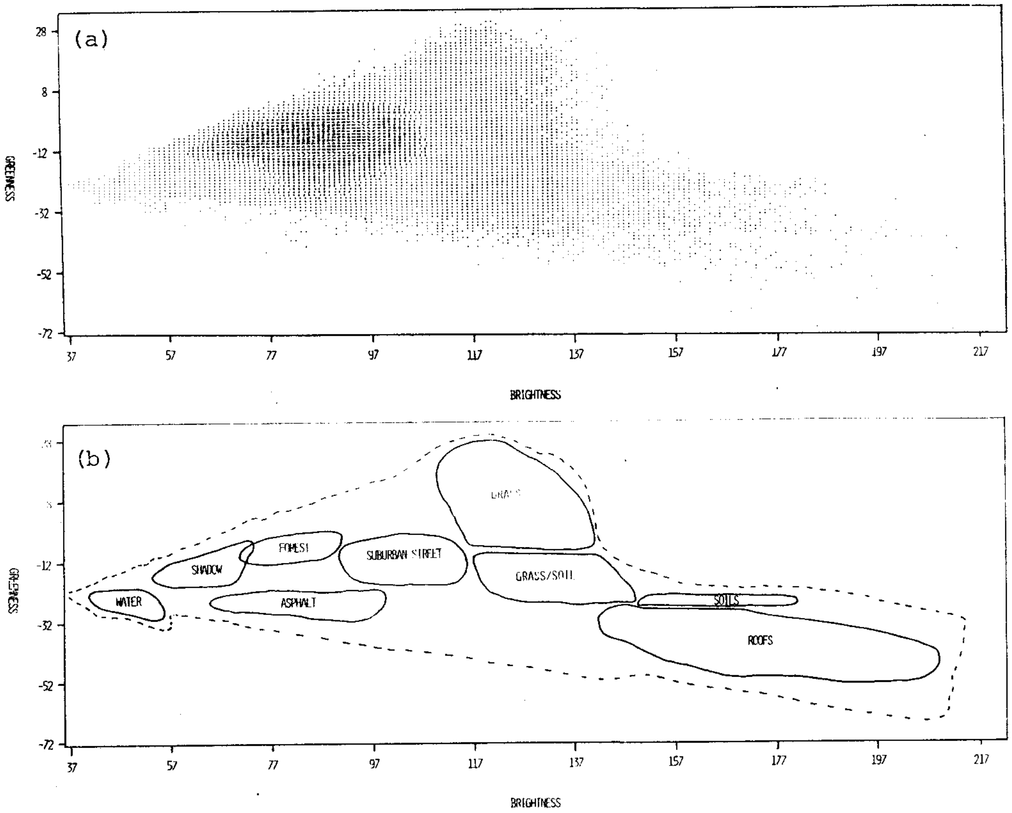

Fig. 1. (a) scatterplot of greenness-brightness dimensions of Washington subscene.
(b) general postion of surface features in greenness-brightness dimensions.

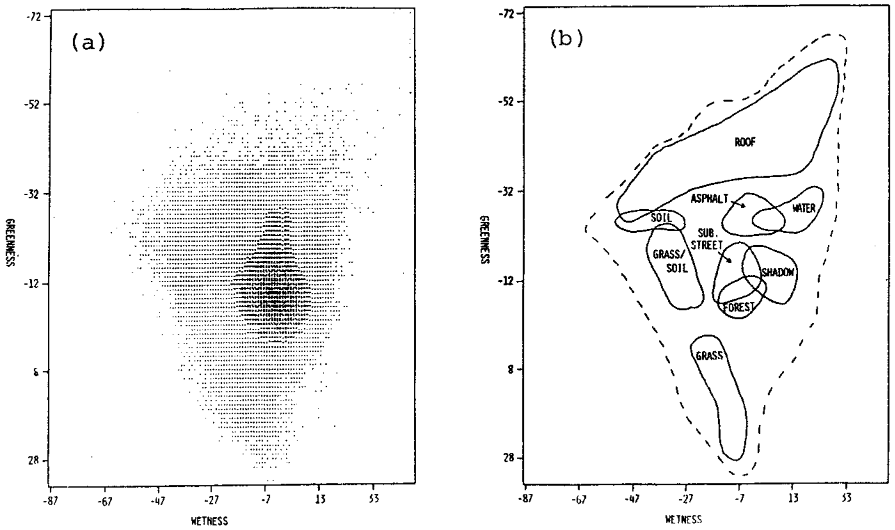

Fig. 2. (a) scatterplot of greenness-wetness dimensions of Washington subscene.
(b) general position of surface features in greenness-wetness dimensions.

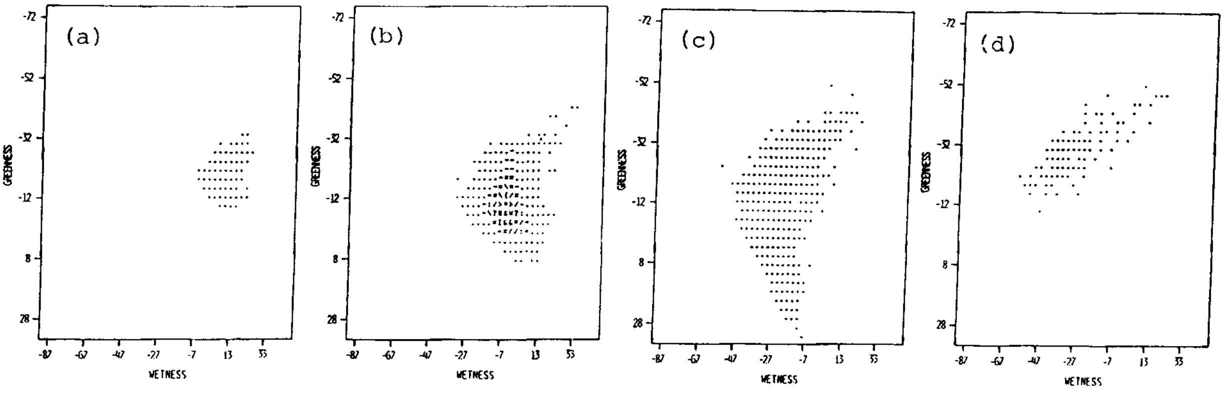

Fig. 3. five increment brightness slices of the greenness-wetness (a) 52-57 brightness (b) 82-87 brightness (c) 122-127 brightness (d) 152-157 brightness.

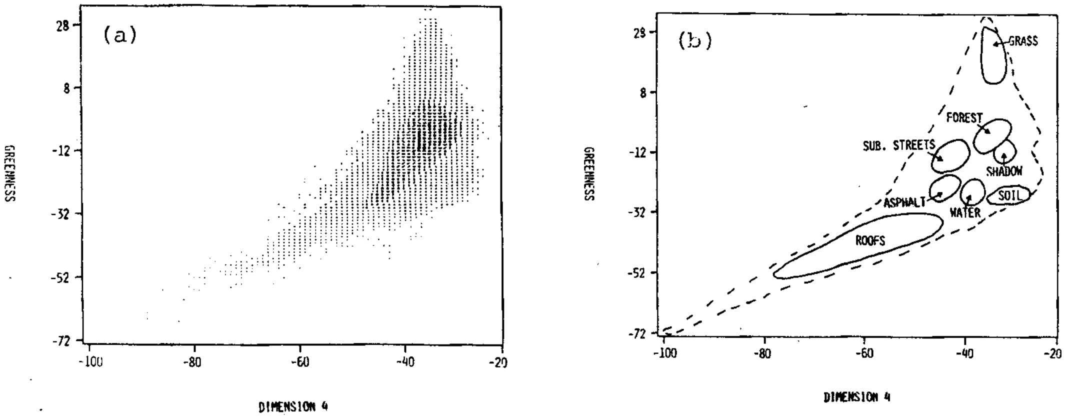

Fig. 4. (a) scatterplot of greeness-4th dimension for Washington subscene.
(b) general position of surface features in greenness-redness (4th) dimensions.

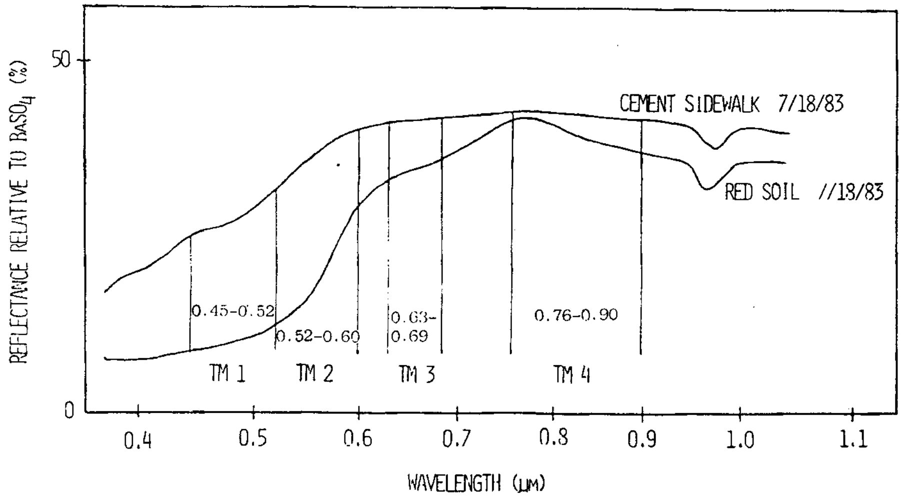

Fig. 5. SE spectrometer measurements of concrete and soil at the Goddard Space Flight Center.