AGSO

EXPLANATORY NOTES FOR A LANDSAT-5-TM IMAGE SERIES PROCESSED ACCORDING TO AN RGB DIRECTED PRINCIPAL COMPONENTS/BAND RATIO FORMULA, NORTHERN PILBARA CRATON, WESTERN AUSTRALIA

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RECORD 1997/20

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AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Executive Director: Neil Williams

ISSN: 1039-0073
ISBN: 0 642 25027 8

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SUMMARY

A series of 1:100 000 scale enhanced Landsat-5-Thematic Mapper images have been prepared for the north Pilbara Craton, based on the RGB pc2(4/3;5/7):5/4:1+7 formula. The set includes seven and one half Landsat-5-TM (185x185 km) scenes covering a total area of c. 240 000 km^2, divided into 46 1:100 000 sheet areas covering a total area of c. 115 000 km^2 and defined by longitudes 116°00-121°00E and latitudes 20°00-22°00S. Scenes include Dampier (path114row74), Yarraloola (p114r75), Roebourne (p113r74), Pyramid (p113r75), Port Hedland (p112r74), Marble Bar (p112r75), Nullagine (p111r75) and the southern part of Yarrie (p111r74). Griding of these images to the Australian Metric Grid (AMG), using between 10 and 23 control points for each Landsat scene, produced RMS errors of <50 metres and in some instances sub-pixel (<30 m) errors. The images are available in digital data in Ermapper bil (banded interleaved line) format and as hard copies.

These notes explain the principles underlying the selection of the directed principal components formula and outline the lithological correlations allowed by the image data. These notes are to be used in conjunction with the images as an aid to interpretation.

It is emphasised that the image data can not be regarded as an exclusive basis for geological and environmental mapping, but effective guides for the interpolation and extrapolation of field observations where accompanied by ground truthing, field and laboratory spectrometry and/or X-ray analysis of surface materials.

The north Pilbara Craton is one of the most complete and best exposed Archaean terrains in the world, and constitutes a magnificent laboratory for spectral studies. It is is endowed with a wide range of little weathered rock types, which are commonly little deformed and metamorphosed at lower to middle Greenschist facies. Multispectral studies of the Pilbara Craton are thus of interest also to those not directly involved in the study of this terrain, as well as applicable to regional geological and environmental mapping.

Introduction

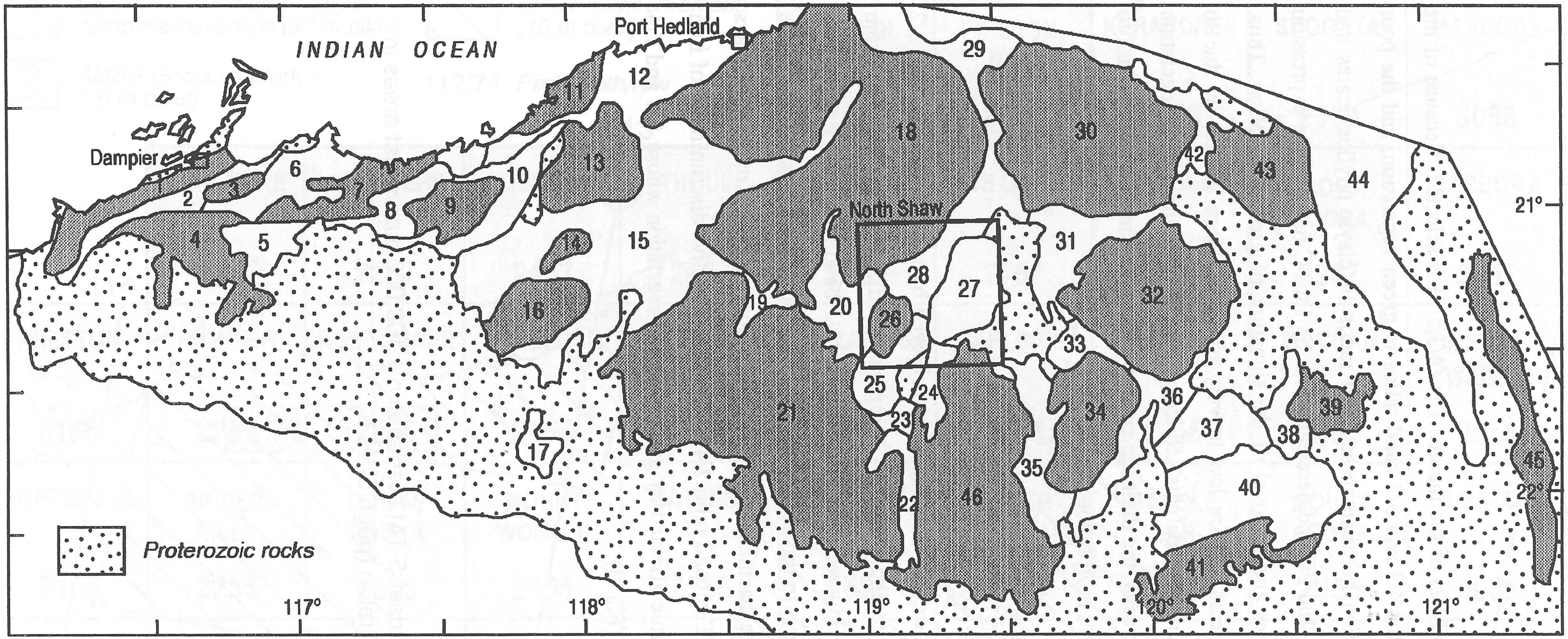
The northern part of the Pilbara Craton, Western Australia (Hickman, 1983) consists of an Archaean (3.5-2.7 Ga) greenstone-granite system overlain by outliers of the c. 2.7 Ga Fortescue Group of the Mount Bruce Supergroup (Fig. 1). As a part of systematic NGMA 1:100 000 scale mapping of this terrain by GSWA and AGSO, commenced in 1995, a study has been undertaken of Landsat-5-TM multispectral (7-band) visible, near-infra red and short wave infrared satellite scanner data (30x30 m pixel size). These notes accompany the release of digital and hard copy image products of a directed principal component image set designed according to the formula RGB pc2[4/3;5/7]:5/4:1+7. The coverage of these scenes and of 1:100 000 scale sheet areas is outlined in Figure 2. The application of multispectral image data to 1:100 000 NGMA mapping programs depends critically on the identification of consistent lithological correlations. The enhanced Landsat-5-TM multispectral images tested and correlated in the field are shown to provide a powerful tool for the interpolation and extrapolation of geological and environmental mapping. The good exposure under the arid conditions of the Pilbara region, north west Australia, combined with the abundance of relic lateritic weathering surfaces, allow effective correlations between multispectral sensor data, weathering products and original rock types. Consistent relationships are indicated between the enhanced image data and the ratios between clay minerals, iron oxides and quartz in weathering crusts, with implications for the composition of the underlying rocks.

Principal aims of the multispectral remote sensing study included (1) discrimination between tholeiitic basalts and komatiites; (2) identification of felsic volcanic and sedimentary rocks; (3) differentiation between extrusive and intrusive ultramafic units: (4) identification of alteration zones; (5) differentiation between granitoid phases in batholiths; (6) tracing of faults, shear zones and dykes; (7) identification of the composition and thereby the source of alluvial and creek bed deposits, including delineation of lateritic zones and calcrete deposits. Following tests of a range of alternative image processing methods under the arid conditions of inland Australia (Fraser and Green, 1987; Glikson, 1994; Glikson and Creasey, 1995) a directed principal components and band ratio method producing RGB pc2[4/3;5/7]:5/4:1+7 images was identified as particularly suitable for correlation of a wide range of surface material types as well as morphological/drainage features. Field tests of this method in the Pilbara were conducted during 1995-1996 and were assisted by an extensive geochemistry data base developed by AGSO and GSWA in previous investigations (Glikson and Hickman, 1981; Glikson et al., 1986a,1986b,1987). The geochemical data allow reliable correlations between the image data and the composition of rocks in the areas sampled. Further information regarding the processing methods and correlation of the Pilbara Landsat data is given in Glikson (1997a, 1997b).

Methodology

Landsat-5-TM RGB composite single-band images allow a fair approximation of the proportion of some of the main constituents of natural weathering surfaces. Thus, iron oxides are well expressed by high reflectance in band 7 and absorption in bands 1 and 2, green vegetation shows high reflectance in band 4 and absorption in band 3, and clays show strong reflectance in band 1 and absorption in band 7 (Fig. 3). However, single band images suffer from shadow and glare effects, namely low reflectance values in shaded areas and very high reflectance values in fireburn areas - with consequent loss of information significant to lithological correlations. Band ratios overcome this problem as they utilise the lower reflectance values in shaded areas. On the other hand, the loss of morphological definition in band ratio images render them difficult to use in the field. Both single band images and band ratio images suffer from superposition problems, for example high 5/7 band ratios apply to clay, green vegetation and dry vegetation. The application of directed principal component analysis overcomes some of these problems, allowing discriminations between materials with partly overlapping spectral patterns (Fraser and Green, 1987). The application of this method to the Pilbara image data was suggested by J.W. Creasey, supervisor, AGSO remote sensing laboratory. In the present study the following choices of RGB components were made in order to achieve maximum discrimination between weathering materials, as well as manifest the morphological features of the terrain:

Figure 1 - Geological sketch map of the northern Pilbara Craton, Western Australia, showing principal greenstone belts, granitic batholiths and patterned outcrops of the Proterozoic Fortescue Group (page 3). Outline of a 1:100 000 Sheet area (North Shaw).



16/WA/159

1 Dampier Batholith
2 Regal Belt
3 Karratha Granite
4 Chiratta Batholith
5 Sholl Belt
6 Roebourne Syncline
7 Harding Granite
8 Sherlock Belt
9 Caines Well Granite
10 Whim Creek Belt
11 Balla Balla Granite
12 Boodarie Belt
13 Portree Granite
14 Peawah Granodiorite
15 Mallina Synclinorium
16 Satirist Granite
17 Nunyerry Inlier
18 Carlindi Batholith
19 Wodgina Belt
20 Pilgangoora Syncline
21 Yule Batholith
22 Western Shaw Belt
23 Tambina Complex
24 North Shaw Belt
25 Soanesville Belt
26 Strelley Granite
27 North Pole Dome
28 Lalla Rookh Syncline
29 Goldsworthy Syncline
30 Muccan Batholith
31 Marble Bar Belt
32 Mount Edgar Batholith
33 Warrawoona Syncline
34 Corunna Downs Batholith
35 Coongan Syncline
36 Kelly Belt
37 McPhee Dome
38 Mount Elsie Belt
39 Yilgalong Granite
40 Mosquito Creek Synclinorium
41 Kurrana Batholith
42 Shay Gap Syncline
43 Warrawagine Batholith
44 Canning Basin
45 Gregory Granitic Complex
46 Shaw Batholith

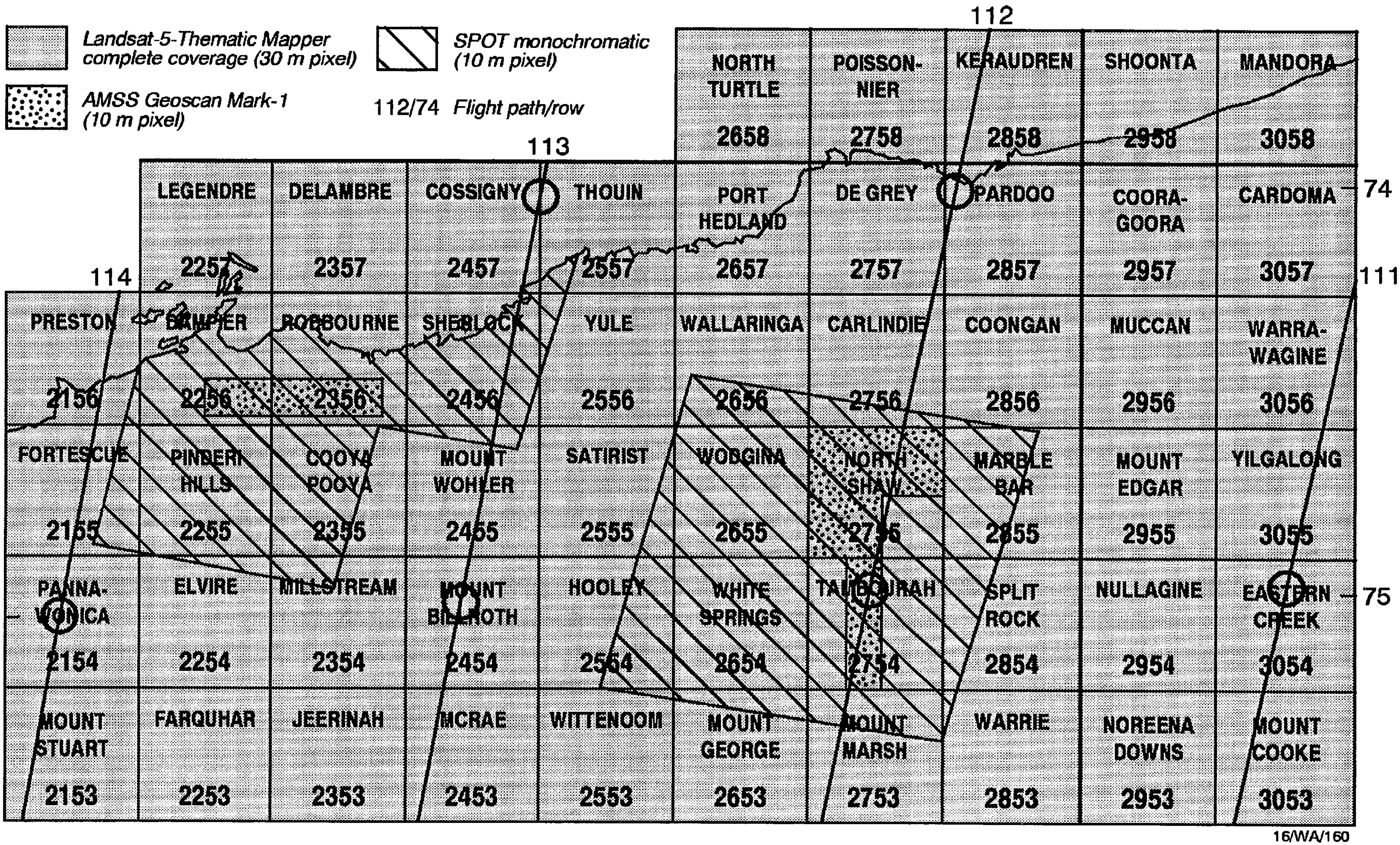
Red channel - pc2(4/3;5/7):

The 2nd principal component (PC2) of the merged file (4/3;5/7) is selected. Because of the generally good correlation of the 4/3 and 5/7 band ratios in green vegetation, and the poor correlation or lack of correlation between these band ratios in clays, phyllosilicates and carbonates, the selection of the 2nd PC and deselection of the 1st PC result in the expression of clay/phyllosilicates/carbonates and removal of the signature of green vegetation. Thus, gum tree-fringed drainage systems acquire low to very low reflectance values, ie. due to removal of the high 4/3 signature of Eucalypts. Since gum trees and other green vegetation almost invariably accompany creeks, the drainage system is markedly manifested by dark to black outlines, allowing excellent morphological controls.

Green channel - 5/4 band ratio:

The discrimination of iron oxide components is often achieved by reference to the high 3/2 and 3/1 band ratios of haematite and goethite - components difficult to discriminate from each other by Landsat-5-TM. However, the similarly high 3/1 band ratio of dry vegetation somewhat obscures this signature. In this study the 5/4 band ratio is chosen as representative of the role of iron oxide, since haematite - the normally dominant iron oxide - displays uniquely high 5/4 band ratios. The band ratio 7/4 is similarly effective discriminator of iron oxide. These band ratios are little affected by green and dry vegetation whose 5/4 and 7/4 band ratios are low to very low (Fig. 3).

Figure. 2 - Distribution of Landsat-5-TM scenes and 1:100 000 map sheet areas in the north Pilbara Craton (page 5).


Landsat-5-Thematic Mapper complete coverage (30 m pixel)
SPOT monochromatic (10 m pixel)
AMSS Geoscan Mark-1 (10 m pixel)
112/74 Flight path/row
112
113
114
111
74
75
NORTH TURTLE 2658
POISSON-NIER 2758
KERAUDREN 2858
SHOONTA 2958
MANDORA 3058
LEGENDRE 2257
DELAMBRE 2357
COSSIGNY 2457
THOUIN 2557
PORT HEDLAND 2657
DE GREY 2757
PARDOO 2857
COORA-GOORA 2957
CARDOMA 3057
PRESTON 2156
DAMPIER 2256
ROEBOURNE 2356
SHERLOCK 2456
YULE 2556
WALLARINGA 2656
CARLINDIE 2756
COONGAN 2856
MUCCAN 2956
WARRA-WAGINE 3056
FORTESCUE 2155
PINDERI HILLS 2255
COOYA POOYA 2355
MOUNT WOHLER 2455
SATIRIST 2555
WODGINA 2655
NORTH SHAW 2755
MARBLE BAR 2855
MOUNT EDGAR 2955
YILGALONG 3055
PANNA-WONICA 2154
ELVIRE 2254
MILLSTREAM 2354
MOUNT BILLROTH 2454
HOOLEY 2554
WHITE SPRINGS 2654
TAMBOURAH 2754
SPLIT ROCK 2854
NULLAGINE 2954
EASTERN CREEK 3054
MOUNT STUART 2153
FARQUHAR 2253
JEERINAH 2353
MCRAE 2453
WITTENOOM 2553
MOUNT GEORGE 2653
MOUNT MARSH 2753
WARRIE 2853
NOREENA DOWNS 2953
MOUNT COOKE 3053
16/WA/160

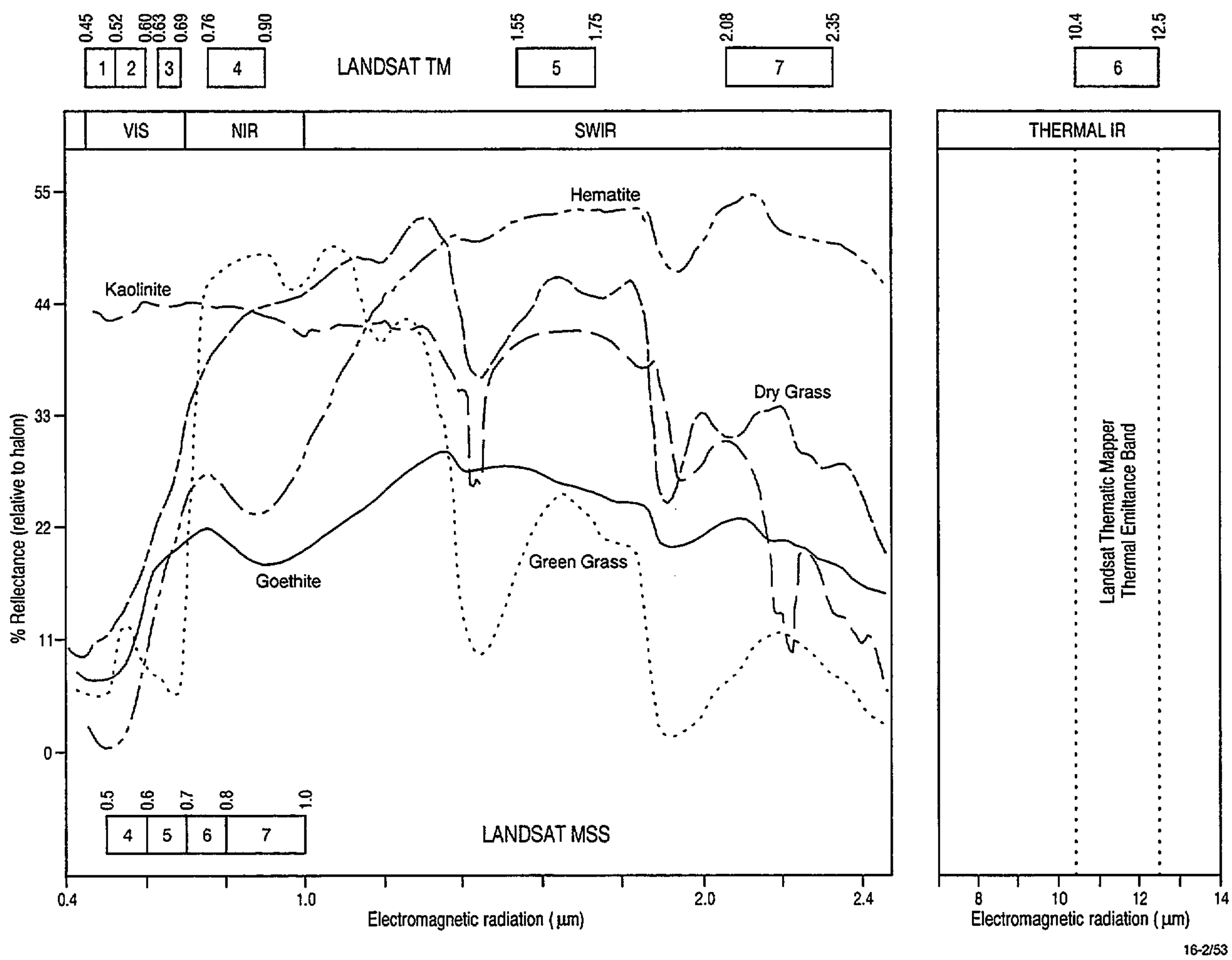
Blue channel - bands (1+7):

Materials yielding highest reflectance in all bands include quartz and silcrete. In particular, coarse grained quartz grains within granitoid rocks, and abraded clastic quartz in mature arenite and in alluvial sands in creek beds reflect strongly in all bands, as confirmed by field correlations. The sum of DN values of all bands can be used in this regard, but to conserve disc space bands 1 and 7 are combined. Note that combinations of bands on the low to mid part of the spectrum (1+2+3+4+5) will represent clay while the high ends of the spectrum (5+7) will be representative of iron oxides, respectively, rather than of quartz.

Throughout the Pilbara region outcrops are variously covered by dry spinifex and grass vegetation and in the more humid areas, particularly near to the coast, also by lichen. Depending on the density of the vegetation cover, the effect is to partially mask the rocks with the 5/7 band ratio signature of dry vegetation and to a lesser extent the 4/3 signature of green chlorophyll-rich vegetation. However, under the semi-arid conditions of the Pilbara a high proportion of rock weathering surfaces is normally exposed, allowing excellent spectral/lithological correlations. This is demonstrated by the expression of unique lithological signatures in the Landsat-5-TM spectra, including for example (1) the 5/4 band ratio which characterises iron oxides of laterites and weathered magnetite-rich gabbro, dolerite and pyroxenite, and is distinct from the spectral signature of spinifex and lichen vegetation, and (2) quartz-rich rock types such as granitoids whose strong reflectance is normally masked by vegetation signature only to a minor extent.

Consequently, RGB pc2(4/3; 5/7):5/4:1+7 images allow expression of four factors, namely clay, iron oxide, quartz and drainage patterns. Advantages of this method include (1) discrimination of visually sensitive red-green (clay-iron oxide) mixtures which, along with minor silica and carbonate, dominate weathering crusts and regolith materials in the Pilbara region; (2) good expression of drainage systems, and (3) the consequent direct lithological and morphological information allowed by these images. In the following, spectral/lithological correlations of individual rock types are considered.

Figure 3 - Laboratory measured reflectance spectra of kaolinite, hematite, goethite, green vegetation and dry vegetation relative to Halon (page 7).



0.45
0.52
0.60
0.63
0.69
0.76
0.90
1
2
3
4
LANDSAT TM
1.55
1.75
5
2.08
2.35
7
10.4
12.5
6
VIS
NIR
SWIR
THERMAL IR
Hematite
Kaolinite
Dry Grass
Goethite
Green Grass
% Reflectance (relative to halon)
55
44
33
22
11
0
0.5
0.6
0.7
0.8
1.0
4
5
6
7
LANDSAT MSS
0.4
1.0
2.0
2.4
Electromagnetic radiation (µm)
Landsat Thematic Mapper
Thermal Emittance Band
8
10
12
14
Electromagnetic radiation (µm)
16-2/53

Spectral-lithological correlations

In testing spectral-lithological correlations it must be borne in mind that this method is only effective when combined with other approaches - primarily detailed ground observations, identification of the mode of occurrence of surface materials and of the structural and textural patterns which characterise rock units. It is only then that spectral-lithological interpolations and extrapolations of field data come to there own. Ideally such correlations need to be examined using field spectrometers, while alternatives include X-ray and thin section studies of weathering crusts and their parental materials. The present correlations of RGB pc2(4/3;5/7):5/4:1+7 images are based solely on field and microscopic observations, indicating the following correlations:

Peridotite - Mg-hydrosilicate (chlorite, serpentine, talc, brucite)-rich weathering crusts show in crimson red. Where accompanied by vein quartz detritus (blue) the surface shows in shades of purple;

Pyroxenite - phyllosilicate and iron oxide-dominated weathering crusts show in green; *Gabbro* - iron oxide and clay-dominated weathering crusts show in green to light red, and thereby yellow;

High-Mg to peridotitic komatiitic volcanics - phyllosilicate-dominated weathering crusts show in deep crimson red;

Mafic volcanics - iron oxide-dominated (+ clay mix) weathering crusts show in light green with yellow and reddish tinges;

Doleritic dykes - show marked iron oxide-rich weathering crusts, expressed in green;

Felsic volcanics - clay to iron oxide-dominated weathering crusts show in mottled red to yellow tinged with green;

Feldspathic sandstones - similar to felsic volcanic signatures, but show different drainage patterns;

Granitoids - dominated by quartz and clay-rich arkose weathering, show in blue to purple. Blue is particularly marked in fireburn areas;

Banded iron formations - due to the universal interbanding of these rocks with siltstone units, and the abundance of flat lying silt-coated slabs around outcrops, banded iron formations surprisingly display dominant clay signature mixed with iron oxide;

Lateritic deposits - commonly occur as relic plateau and flat hill tops (mesa), displaying in deep apple green;

Alluvial mafic source-derived detritus and creek deposits - display iron oxide and clay signatures, showing in yellow to green;

Alluvial quartz-rich felsic source-derived detritus and creek bed sand - markedly represented in the blue. Major creeks display strongly in the blue forming corridors fringed by black, the latter representing the subtraction of the green vegetation signature of fringing Eucalypts.

Problems remain, for example the commonly strong but unexplained 5/7 band ratio signatures associated with chert units. Further field and laboratory spectrometric measurements should allow fine tuning of satellite and airborne multispectral correlations as one of the essential pre-requisites for the next generation of geoscience maps.

Acknowledgments

The preparation of the present image series would not have been possible had it not been for the assistance by John W. Creasey, AGSO remote sensing laboratory. I am grateful to Phil Bierwirth and John Wilford for reviews of this report and to Prame Chopra and Matt Peljo for useful hints. Matt Peljo and Penny Ursem undertook rectification/gridding of Landsat images to AMG coordinates. I thank Mitch Ratajkoski and Colin Johnson for designing the surrounds of the images, merging adjacent Landsat scenes and being instrumental with the final preparation of this material for release. I thank Arthur Hickman, Chris Kojan and Hugh Smithies of the Geological Survey of Western Australia for helpful feedback regarding the application of the Landsat imagery to 1:100 000 mapping in the Pilbara Craton.

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Appendix I - list of 1:100 000 image sheet areas

(arranged in west-to-east and north-to-south order)

Legendre 2257
Thouin 2557
Port Hedland 2657
De Grey 2757
Pardoo 2857
Preston 2156
Dampier 2256
Roebourne 2356
Sherlock 2456
Yule 2556
Wallaringa 2656
Carlindie 2756
Coongan 2856
Muccan 2956
Warrawagine 3056
Mardie 2055
Fortescue 2155
Pinderi Hills 2255
Cooya Pooya 2355
Mount Wohler 2455
Satirist 2555
Wodgina 2655
North Shaw 2755
Marble Bar 2855
Mount Edgar 2955
Yilgalong 3055
Yarraloola 2054
Pannawonica 2154
Ellvire 2254
Millstream 2354
Mount Billroth 2454
Hooley 2554
White Springs 2654
Tambourah 2754
Split Rock 2854
Nullalgine 2954
Eastern Creek 3054
Mount Stuart 2153
Farquhar 2253
Jeerinah 2353
McRae 2453
Wittenoom 2553
Mount George 2653
Mount Marsh 2753
Warrie 2853
Norcena Downs 2953