LANDSAT Satellites - Historical

LANDSAT PROGRAM

The LANDSAT Program is the longest running exercise in the collection of multispectral digital data of the earth's surface from space. The program has operated continuously since LANDSAT 1 (then the Earth Resources Technology Satellite (ERTS) 1) was launched on July 23, 1972. More than 3 million images from the Multispectral Scanner System (MSS) on LANDSATs 1-5 have been acquired and stored at the National Satellite Land Remote Sensing Data Archive (NSLRDA) at EROS Data Centre (EDC), Sioux Falls, South Dakota and the LANDSAT international ground stations. The temporal extent of the collection, the characteristics and quantity of LANDSAT data, and the ability to collect new data directly comparable to that in the archive, make LANDSAT data a unique resource, one used extensively to address a broad range of issues in earth science, global change science, and monitoring and assessing land and coastal zone resources.

From E.J.Sheffner. The LANDSAT Program: Recent History and Prospects. Photogrametric Engineering and Remote Sensing. P.735 June 1994.

The data presented here on the historical aspects of the Landsat Program is a summary only and more details can be found on the web sites -

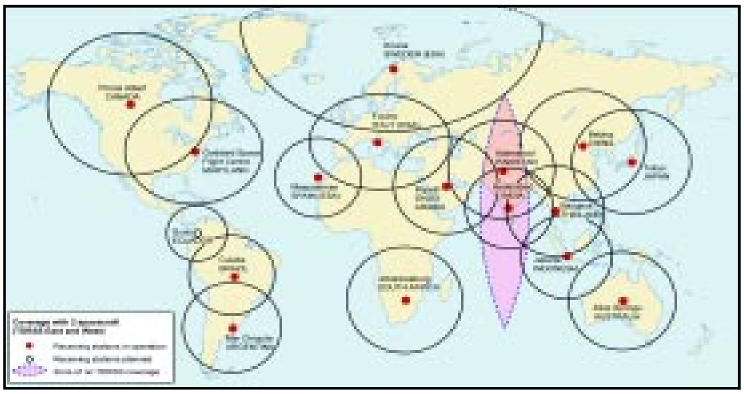
http://geo.arc.nasa.gov/esdstaff/landsat/lpsun.html
http://landsat7.isgs.gov

LANDSAT PLATFORMS

Six LANDSAT satellites have now been successfully launched commencing with LANDSAT 1 in July 1972. All platforms have operated from a repetitive, circular, sun-synchronous, near-polar orbit and on each day-side pass, scan a ground swath 185km wide beneath the satellite. The first three satellites carried the Multispectral Scanner (MSS) as the main imaging instrument with a Return Beam Vidicom (RBV) as a subsidiary. The paths of these satellites were inclined 99 degrees with an 18 day repeat cycle and an equatorial crossing of between 8:30 and 9:30am local time. LANDSATs 4 and 5 had the Thematic Mapper (TM) as the main sensor together with an MSS. They were inclined 98 degrees, had a repeat cycle of 16 days and an equatorial crossing between 9:30 and 9:45am local time.

LANDSAT 6 was unfortunately lost on launch in 1993 however LANDSAT 5 continued to provide good data until the launch of LANDSAT 7. This sensor was successfully launched in April 1999 and produced imagery within a few days of launch. Details of the satellite and its sensors are provided on Pages 13 and 14 of this brochure.

World Wide Ground Receiving Stations

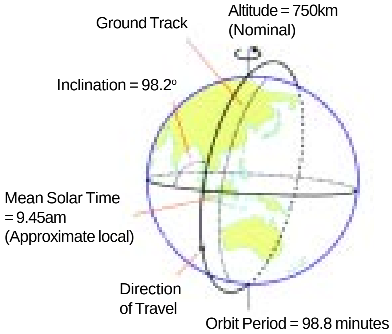


DATA RECEPTION

Data from LANDSATs 1-3 was either directly transmitted to ground stations or recorded onto onboard magnetic tapes for later transmission to ground stations in the US. LANDSATs 4 and 5 did not have onboard magnetic storage and were restricted to direct download or uplink via the Tracking and Data Relay Satellites (TDRSS). LANDSAT 7 has sufficient onboard solid state memory to store 100 scenes for playback over a US ground station as well as the capability for direct transmission to ground stations.

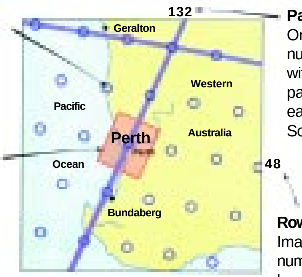
WORLDWIDE REFERENCE SYSTEM

Data from the LANDSAT satellites is collected in a continuous stream of data along a near vertical path as the satellite moves from north to south in a descending pass. Some thermal imagery has been collected in ascending night-time passes. The data is arbitrarily divided into nominal scenes which are about 24 seconds of spacecraft time apart, corresponding to a spacing of approximately 160km. The path/row designation is referred to as the LANDSAT Worldwide Reference System (WRS). The rows have been positioned in such a way that Row 60 coincides with the equator. This reference system is different for LANDSATs 1-3 and LANDSATs 4-7 because of the different altitudes and inclination angles of the satellites. This effects the spacing of the paths and LANDSATs 1-3 have 251 paths worldwide and LANDSATs 4-7 have 233 paths. Designation of the rows is similar for each group of satellites. A series of WRS path/row index maps is available world wide from the EROS Data Centre and these normally have the LANDSATs 1-3 WRS on one side and the LANDSATs 4-7 WRS on the other. The maps sheets are at 10 million scale and 26 are needed for global coverage. GEOIMAGE provides its clients with vector outlines of worldwide scenes in various GIS formats. LANDSAT path numbers increase from east to west while SPOT are the reverse.



Near polar sun synchronous orbit - LANDSAT 5 orbit pattern

The standard MSS and TM scenes from all the LANDSAT satellites have the same nominal ground coverage of 185km by 170km. Since the LANDSATs 1-3 had 251 paths compared to 233 of the later satellites, there was considerably more overlap between adjacent paths on the earlier satellites. For example there was 14% overlay at the equator on LANDSATs 1-3 and 7% on LANDSATs 4-7. At higher latitudes sidelap increases and when sidelap is greater than 50% (56 degrees for LANDSATs 1-3 and 58 degrees for LANDSATs 4-7) only alternate scenes are required for complete ground coverage. It is possible to view LANDSAT images stereoscopically in the overlay region and at latitudes of greater than 60 degrees, there is complete stereoscopic coverage. The quality of the viewing will be dependent on relief but the angle of capture varies from zero at the centre to a maximum of 8 degrees at the edges of the scenes.



Example of Worldwide Reference System (WRS)

LANDSAT Program Summary

System	Launch (End of Service)	Instrument	Resolution (metres)	Communication	Altitude (km)	Revisit Days	Equatorial Crossing	Paths	Data rate (Mbps)
LANDSAT 1	23 Jul 72 (6 Jan 78)	RBV MSS	80 80	Direct Downlink with Recorders	917	18	8:30 am	251	15
LANDSAT 2	22 Jan 75 (25 Feb 82)	RBV MSS	80 80	Direct Downlink with Recorders	917	18	9:00 am	251	15
LANDSAT 3	5 Mar 78 (31 Mar 83)	RBV MSS	30 80	Direct Downlink with Recorders	917	18	9:30 am	251	15
LANDSAT 4	16 Jul 82 (TM - Aug 93)	MSS TM	80 30	Direct Downlink TDRSS	705	16	9:45 am	233	85
LANDSAT 5	1 Mar 84	MSS TM	80 30	Direct Downlink TDRSS (Failed)	705	16	9:45 am	233	85
LANDSAT 6	5 Oct 93 (5 Oct 93)	ETM	15 PAN 30 MS	Direct Downlink with Recorders	705	16	10:00 am	233	85
LANDSAT 7	15 Apr 99	ETM+	15 PAN 30 MS	Direct Downlink Solid State Recorders	705	16	10:00 am	233	150

Landsat 7 was successfully launched on April 15, 1999 and is working well. The earth observing instrument on Landsat 7, the Enhanced Thematic Mapper Plus (ETM+), replicates the capabilities of the highly successful Thematic Mapper instruments on LANDSATs 4 and 5. Like these instruments the scanner operates at an altitude of 705km, has a swath width of 185km and a repeat cycle of 16days.The ETM+ also includes new features that make it a more versatile and efficient instrument for global change studies, land cover monitoring and assessment, and large area mapping than its design forebears. The primary new features on Landsat 7 are:

* a panchromatic band with 15m spatial resolution
* on board, full aperture, 5% absolute radiometric calibration
* a thermal IR channel with 60m spatial resolution

The instrument will be supported by a ground network that will receive ETM+ data via X-band direct downlink only at a data rate of 150 Mbps. The primary receiving station will be at the US Geological Survey's (USGS) EROS Data Centre (EDC) in Sioux Falls, South Dakota. Substantially cloud-free, land and coastal scenes will be acquired by EDC through real-time downlink, and by playback from an on-board, solid state, recording device(375Gb). The capacities of the satellite, instrument and ground system will be sufficient to allow for continuous acquisition of all substantially cloud free scenes at the primary receiving station. In addition, a worldwide network of receiving stations will be able to receive real-time, direct downlink of image data via X-band.

Each station will be able to receive data only for that part of the ETM+ ground track where the satellite is in sight of the receiving station.

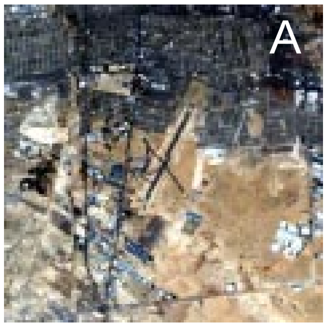
Landsat 7 Processing Levels

Landsat 7 data can be delivered to customers in three basic products depending on the level of processing that has been performed on the data.

Level 0 Reformatted (L0R)

The Level 0R product is reformatted, raw data. Reformatting includes shifting pixels by integer amounts to account for 1) the alternating forward-reverse scanning pattern of the ETM+ sensor, 2) the odd-even detector arrangement within each band, 3) the detector offsets inherent to the focal plan array engineering design. Pixels are neither resampled nor are they geometrically corrected or registered, i.e. the pixels are NOT aligned per scan line.

The sample image (A) shows a small city in an arid region. Note the airport in the center of the image with the crossing runways.The scans in this image have received a rudimentary alignment of each scan to a common starting point at the extreme left of the image (not shown). Visible scan misalignment is still quite easily noticed in the upper portions of both runways as well as the roads to their left. Although radiometric artifacts are not readily apparent in this sample any artifacts such as impulse noise, coherent noise, memory effects, etc. would still be in any L0R image.



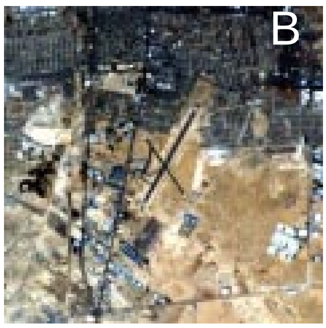
Level 1 Radiometrically Corrected (L1R)

The Level 1R product is a radiometrically corrected L0R product. This product 1) corrects detector artifacts such as coherent noise; 2) improves cosmetic artifacts such as banding, striping, and dropped lines or pixels; and 3) is calibrated to radiance units, i.e. color corrected, as integer values. Radiometric corrections are not reversible. Pixels are neither resampled nor are they geometrically corrected or registered, i.e. the pixels are NOT aligned per scan line.

Level 1 Geometrically Corrected (L1G)

The Level 1G product is radiometrically and geometrically corrected(systematic) to the user-specified parameters including output map projection, image orientation, pixel grid-cell size, and resampling kernal. The correction algorithms model the spacecraft and sensor using data generated by onboard computers during imaging. Sensor, focal plane, and detector alignment information provided by the Image Assessment System (IAS) in the Calibration Parameter File (CPF) is also used to improve the overall geometric fidelity. The resulting product is free from distortions related to the sensor (e.g., jitter, view angle effect), satellite (e.g., attitude deviations from nominal), and Earth (e.g., rotation, curvature). Residual error in the systematic L1G product is less than 250 metres (1 sigma) in flat areas at sea level. The systematic L1G correction process does not employ ground control or relief models to attain absolute geodetic accuracy. product is radiometrically and geometrically corrected(systematic) to the user-specified parameters including output map projection, image orientation, pixel grid-cell size, and resampling kernal. The correction algorithms model the spacecraft and sensor using data generated by onboard computers during imaging. Sensor, focal plane, and detector alignment information provided by the Image Assessment System (IAS) in the Calibration Parameter File (CPF) is also used to improve the overall geometric fidelity. The resulting product is free from distortions related to the sensor (e.g., jitter, view angle effect), satellite (e.g., attitude deviations from nominal), and Earth (e.g., rotation, curvature). Residual error in the systematic L1G product is less than 250 metres (1 sigma) in flat areas at sea level. The systematic L1G correction process does not employ ground control or relief models to attain absolute geodetic accuracy.

Note how resampling has aligned the scans in the example (B) making the runways and roads straight. Although this data has had radiometric corrections applied, it has been returned to 8-bit data.This product is the most correct product offered geometrically and geodetically.



LANDSAT Multispectral Scanner (MSS)

The MSS was the original sensor on LANDSAT 1 launched in 1972 and continued as the main sensor on LANDSATs 2-3. With the launch of LANDSAT 4 in 1982, it became subsidiary to the Thematic Mapper sensor and the last MSS sensor was on LANDSAT 5. The MSS instrument was turned off on LANDSAT 5 in December 1997.

The MSS instrument is an electromechanical scanning system which scans side to side during the passage of the satellite from north to south. Radiation from the earth's surface is directed to a set of six detectors in each of the four bandwidths, allowing six lines of data to be collected with each sweep of the mirror system. This radiation is converted into a digital signal in the range of zero to 63 or 127, which is then transmitted to the ground station.

The Instantaneous Field of View (IFOV) of the MSS sensor on LANDSATs 1-3 was 79 metres square, however oversampling of the data in the scan line direction resulted in data collected at approximately 57 metre centres. The approximate ground area of pixels of unprocessed data is therefore 57 metres by 79 metres. Similarly for LANDSATs 4-5, the approximate ground area of a pixel is 68 metres by 83 metres.

The four wavelength bands in the MSS sensor were referred to as bands 4 to 7 in LANDSATs 1-3 and bands 1 to 4 in LANDSATs 4-5, however the spectral regions remained the same and are described in the table. The only exception is LANDSAT 3 which had an 8th band in the thermal infrared region, however very little data is available from this band.

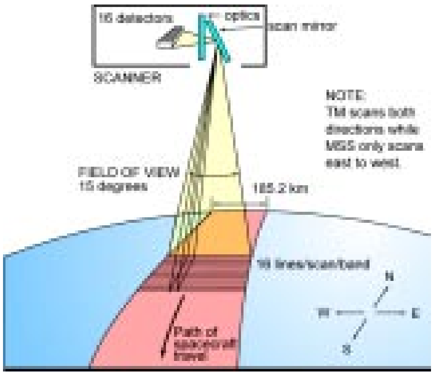
Worldwide LANDSAT MSS data collected in the period 1972 until the mid 1980s is an important set of data for global change analysis and although limited in resolution and bands (by todays standards) is unique in its coverage and availability.

Bands		Wavelength (um)	Applications
L 1-3	L 4-5		
4	1	0.5 to 0.6 (visible green)	emphasises movement of sediment-laden water and delineates areas of shallow water, such as shoals, reefs etc
5	2	0.6 to 0.7 (visible red)	emphasises cultural features, such as city areas. Also used for some vegetation types.
6	3	0.7 to 0.8 (near infrared)	emphasises vegetation, the boundary between land and water, and landforms.
7	4	0.8 to 1.1 (near infrared)	provides the best penetration of atmospheric haze, and also emphasises vegetation, the boundary between land and water, and landforms.
8*		10.41 to 12.6 (thermal)	emphasises temperature variations.

* only on LANDSAT 3

LANDSAT Thematic Mapper

The Thematic Mapper (TM) scanner which first appeared on LANDSAT 4 in 1982 was designed to provide improved spectral and spatial resolution over the MSS instrument. The basic mode of operation is similar, however the use of more sensitive detectors, better optics and a lower orbit has enabled the collection of radiation in 7 spectral bands, with improved ground resolution, and with data quantised to 256 intensity levels. Data is collected using banks of 16 detectors in each band and 16 lines of data are collected during both the forward and backward sweeps of the oscillating mirror system.



Mirror scanning system ▲ LANDSAT TM

Reception of TM data in Australia commenced in August 1986 when an AMIRA sponsored project involving mining companies, CSIRO and ACRES upgraded the receiving station at Alice Springs. Intermittent reception under the AMIRA project was replaced by continuous reception by ACRES in 1987 and a full upgrade of the receiving station was completed in 1989. TM reception from Alice Springs covers the whole of Australia and north to Papua New Guinea. The north coast of PNG is the limit of reception from Alice Springs, and only occasionally is useable data acquired this far north.

The geometry of TM scenes is similar to MSS. Each full scene covers an area of approximately 185km EW by 170km NS. Pixel size in bands 1 to 5 and band 7 is 30m and 120m in band 6 (60m in LANDSAT 7). LANDSAT 7 also has a 15m panchromatic band that can be used to sharpen the other bands (See Page 33). TM scenes are designated by the same Worldwide Reference System (WRS) as MSS data from the LANDSATs 4-5. Scene centres may be moved along the satellite path to better cover an area of interest, but cannot be moved across track edges. Allowing for the differences in orbit parameters and scanning optics, geometric processing of TM data is similar to MSS.

The wavelengths of sensors on the MSS instrument were specifically selected for agricultural purposes, i.e. to highlight vegetation differences. For TM these broad vegetation bands were subdivided to provide more discrimination, but an additional sensor at 2.2 um was included to provide geological information. The TM bands, the materials that influence their spectral response, and some examples of typical reflectance curves are shown in the table and figure on this page.

▼ Thematic Mapper Wavelengths

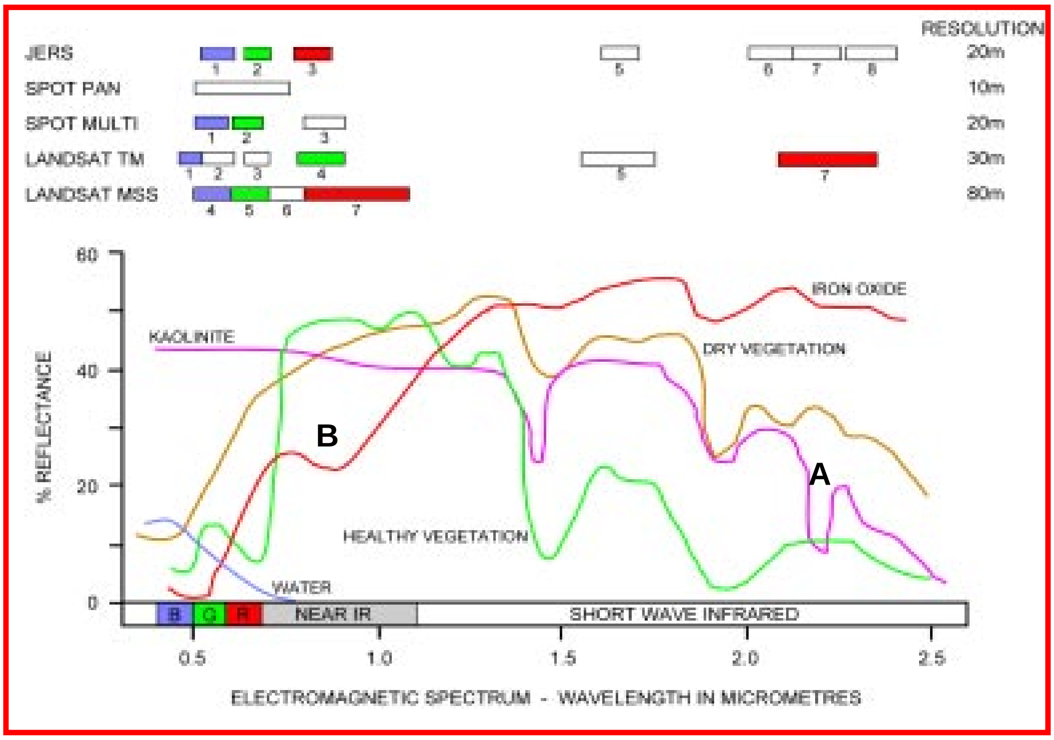
Band Number	Wavelength (um)	Applications
1	0.45 - 0.52 (visible blue)	coastal water mapping, differentiation of soil from vegetation, has poor penetration through haze
2	0.52 - 0.60 (visible green)	vegetation vigour assessment
3	0.63 - 0.69 (visible red)	vegetation discrimination, also has high iron oxide reflectivity
4	0.76 - 0.90 (near infrared)	determining biomass content and delineation of water bodies
5	1.55 - 1.75 (middle infrared)	vegetation and soil moisture content, differentiation of cloud from snow
6	10.40 - 12.50 (thermal infrared)	vegetation heat stress analysis, soil moisture discrimination, thermal mapping, has limited use as a large percentage of thermal radiation in daytime is reflected
7	2.08 - 2.35 (middle infrared)	discrimination of rock types and hydrothermal clay mapping
8*	0.52 - 0.90 (v.g. - near ir)	textural detail

* Pan band only on Landsat 7

Because the data is stored digitally and amenable to digital image processing and analysis techniques, a vast array of "algorithms" exist that have been developed to highlight specific features in TM data. Remote sensing texts and research journals are a rich source of these solutions to everyday problems. However, a word of caution. Experience has shown that what works in one circumstance may not work in another. The reason for this lies in the fact that natural systems are extremely complex. The response from a single TM pixel is the result of the interaction of naturally occurring illumination of all the materials on the surface within a 30m square area. This includes vegetation, leaf litter, varying soils and rocks, varying moisture contents, and a shadow component. What is represented in an image is a summation over a large number of pixels of all these effects, and will be dominated by the major surface components. Thus for geologists trying to differentiate rock units, vegetation can be considered as interference and its effects are often poorly documented in geological literature.

Image processing techniques for the enhancement of LANDSAT Thematic Mapper (TM) imagery for geological applications can be divided into spatial and spectral. Spatial filtering to enhance directional and edge information in imagery is a valid technique in the visualisation and interpretation of structural features but will not be considered further here. Spectral processing involves enhancing the interrelationship between the different spectral bands in an image and the major types of processing, contrast enhancement, principal component images and band ratios as well as the LSFIT technique, are described on Page 15.

Image processing techniques for natural resource assessment usually involve such techniques as unsupervised and supervised classification, change images and calculation of indices such as the NDVI vegetation index.



◄ Spectral Reflectance Curves for common cover types with wavelength bands of the main remote sensing satellites. This diagram shows the extension of the spectral curves graph on Page 3 to cover the mid-infrared part of the spectrum. Note the absorption in the kaolinite spectra in the area corresponding to TM band 7 (A). Most "clay" minerals have an absorption in this area although the shape of the spectra varies and the feature can be used to predict the presence of clay minerals using a 5/7 band ratio or the LSFIT technique described on Page 15. Note that iron oxides have an absorption high in the area corresponding to TM band 4 (B), and this characteristic is highlighted in a 7/4 or 5/4 ratio.

CONTRAST ENHANCEMENT

With six reflectance spectral bands, it is possible to make a total of 120 different 3 band colour composite images from a TM image. From a practical viewpoint however, the first three visible bands are very highly correlated as are bands 5 and 7 so the number of significantly different 3 band combinations reduces to a few. The main ones being:-

Bands147 or 247 in BGR simulated natural colour with the visible blue in blue, vegetation in green and iron oxides in red. This band combination usually has the least correlation between bands.

Bands 345 in BGR is usually preferred for vegetation studies.

Bands 123 in BGR is a natural colour image and although the bands are very highly correlated often shows a remarkable amount of detail.

Bands 457 in BGR incorporates all the infrared bands and is useful in areas affected by haze.

Of course, the selection of the bands is only the first step and the selection of the type of histogram modification is just as important. This is especially so in the case of a bimodal histogram where separate enhancements may be necessary to give maximum information e.g. in a greenstone terrain with very bright granitic and very dark greenstone areas. Region of interest contrast stretching may be required where the image area used in the histogram generation is restricted to the immediate area of interest e.g. over a particular rocktype, so that the resulting contrast modification is maximised to show that particular rocktype.

PRINCIPAL COMPONENT IMAGES

Principal component analysis has been used in several ways to enhance imagery. For example, the first three principal components can be displayed as an RGB composite.This shows the majority of the information content of a six band image as three bands and is of limited usefulness because the resulting colours cannot easily be related to the original bands. The first principal component can be regarded as the albedo and is often displayed in greyscale, either by itself or as a backdrop for mineral or thematic maps. A variation on PC enhancement is the decorrelation stretch where an original three band image is taken into PC space, the variance of these bands increased and then transformed back into normal colour space. This has the effect of saturating or increasing the colour information in a normal three band colour composite. Directed principal component analysis has also been used to enhance iron and clays in an image using a technique now referred to as the "Crosta Technique". This technique is described with references at http://www.ermapper.com/forum_new/emuf3-3.htm

BAND RATIOS

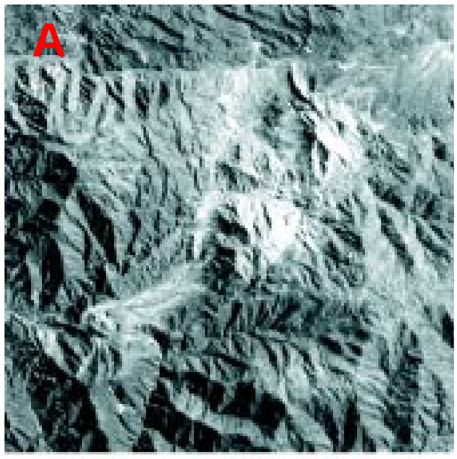
Ratios of spectral bands are commonly used because they highlight the spectral differences between materials, at the same time decreasing the variations in surface brightness due to topography. For example, the ratio of bands 3/1 is often used to highlight iron oxide and 5/7 is used to highlight clays. Before ratios are calculated it is important to remove the effects caused by scattering of light in the atmosphere from each band. This effect which is highest in band 1 decreases to an almost negligible values in bands 5 and 7. Theoretically the atmospheric effect would be the reflectance value in the image from a black body reflector on the earth's surface. This might be expected to be the minimum value in any band however there may be noise in the image well below this value. The best method of estimating the value is to examine the histogram and select the value where the back slope of the band's histogram intersects the zero reflectance. Use these values in the ratio and examine the image produced. If there is still topographic detail visible in the image slightly modify the subtraction values until it disappears. When there is minimal slope information visible in the image, you will know that the atmospheric corrections are correct. Ratios tend to highlight the noise in an image and this can be minimised using a median filter.

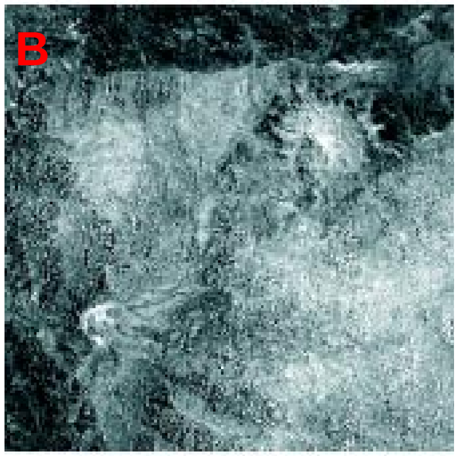
LSFIT

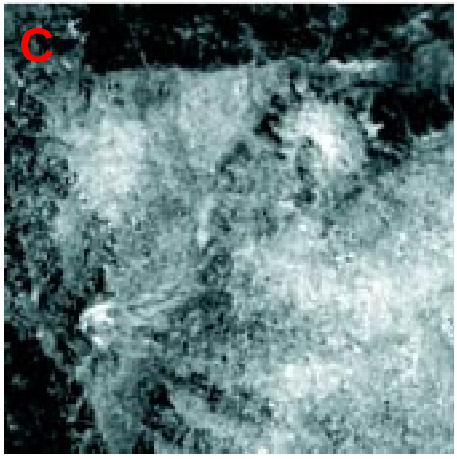
Most clay minerals have an absorption feature in the area covered by LANDSAT TM Band 7. Many techniques have been developed to highlight this effect and thus enable identification of areas of clay alteration indicative of mineralisation. The LSFIT technique developed by the Australian CSIRO is a linear regression technique that compares the predicted band 7 with the actual band 7 to identify areas of anomalously high absorption and hence infer the presence of clays.

SUMMARY

The above techniques are generally very important in providing information on the rock types and possible alteration from TM imagery prior to field visits. It is however important that the spectral techniques be applied properly and that common sense is used in their interpretation. For example, techniques that try to predict clays may also highlight water and snow as well as defining all playas with thin coatings of clay. For this reason, it is important to interpret such images in conjunction with a standard colour composite image of the same area.







FIGURES.

A.Band ratio 3/1 with no atmospheric corrections

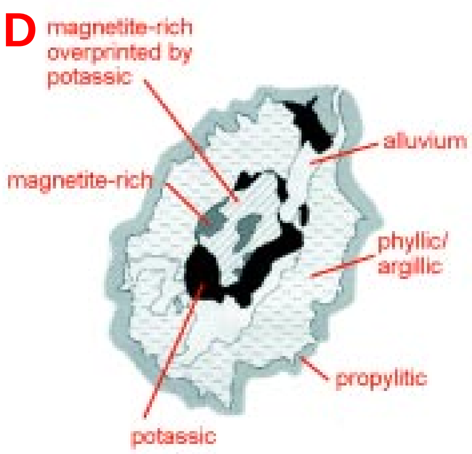
B.Band ratio 3/1 with correct atmospheric corrections

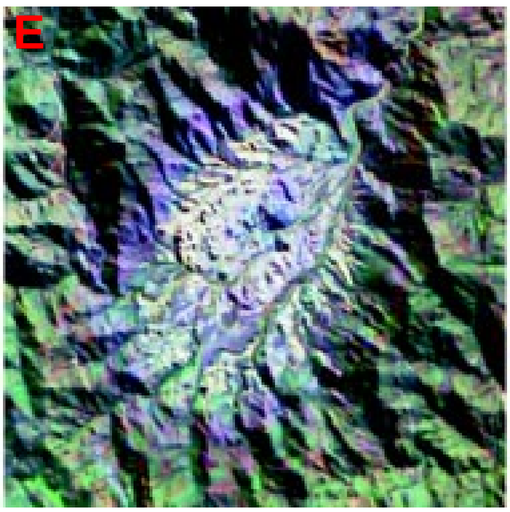
C.Band ratio 3/1 with a median filter applied

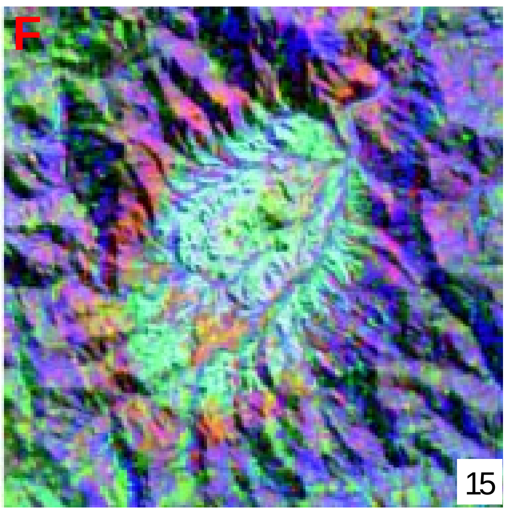
D Alumbrera alteration 1:50 000 scale from Sasso and Clark, SEM Newsletter.

E Band 147 in BGR sharpened with Spot Pan

F. LSFIT B7, 7/4,3/1 in RGB sharpened with Spot Pan.

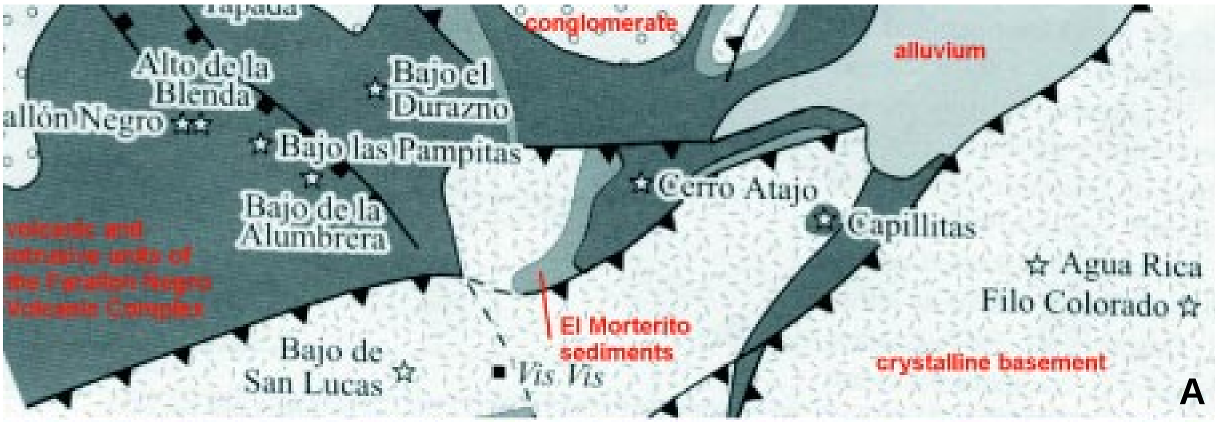




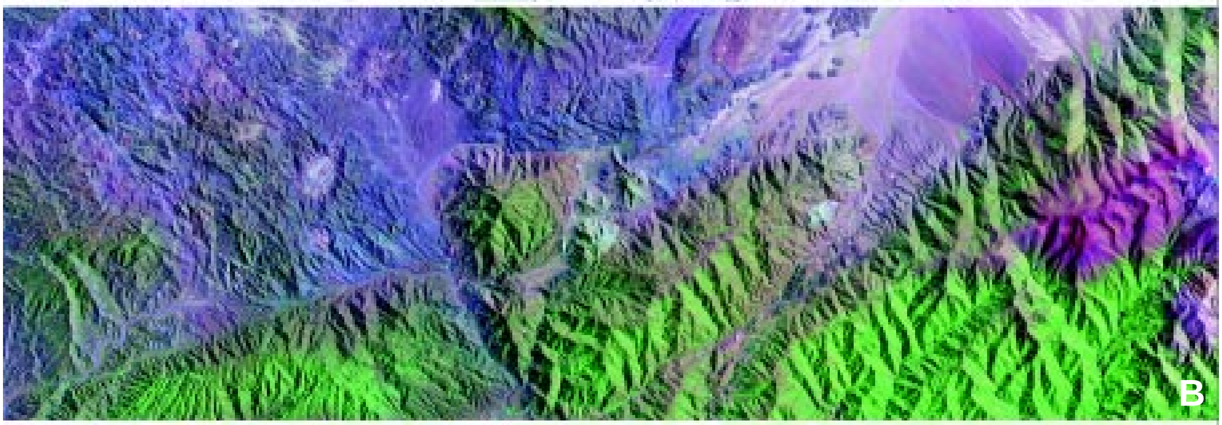


LANDSAT TM - Spectral Processing Alumbrera Area, Argentina

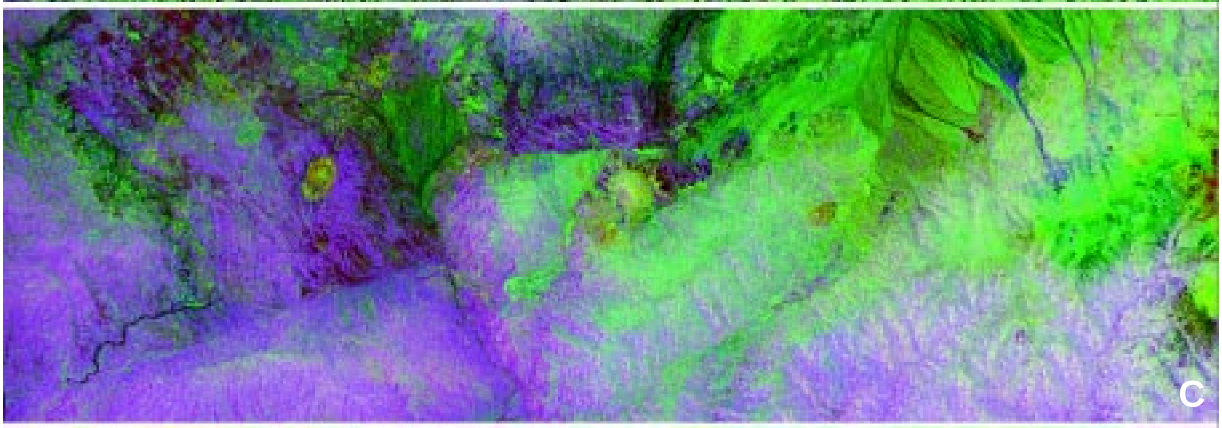
This example of spectral processing of LANDSAT Thematic Mapper imagery over the Alumbrera copper-gold porphyry and associated deposits its emphasises the need to process several types of spectral imagery to maximise the information that can be obtained from the imagery.



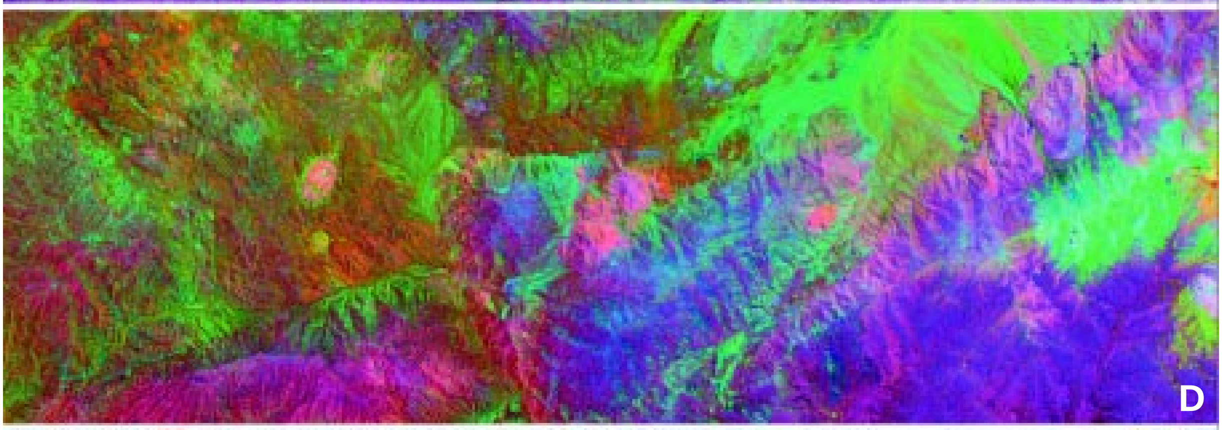
A. Simplified geological maps of the Farallon Negro Region with the location of ore deposits and important prospects. From Sassa, A.M. and Clark, A.H., SEG Newsletter July 1998. Approximate scale is 1:400 000.



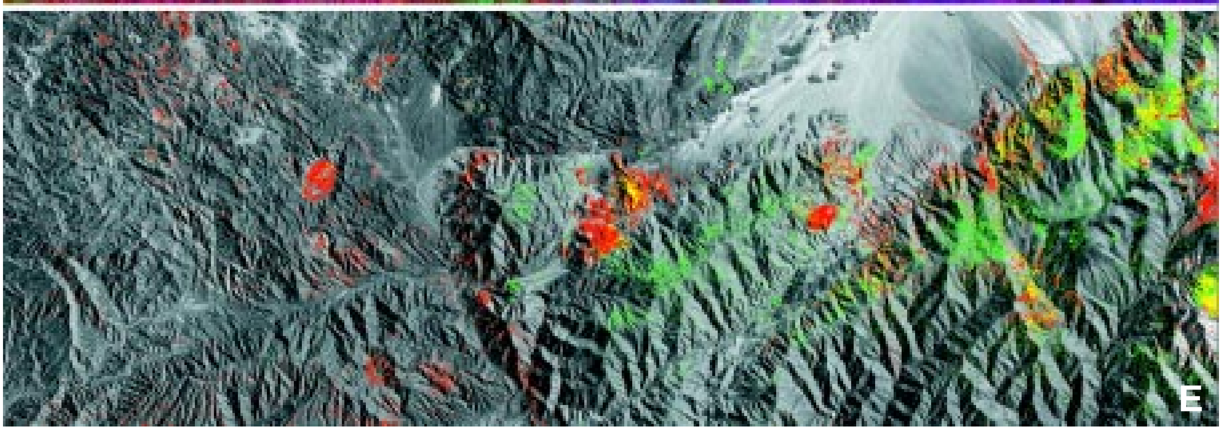
B. LANDSAT Thematic Mapper image. Path 231 Row 79 Date 28-Feb-1985 Bands 7 4 1 in RGB. Note the variability in the vegetation which produces a bi-modal histogram.



C. Abram's Ratio. Bands 5/7 in Red, 3/1 in Green and 4/3 in Blue. The ratio 3/2 is commonly used in the green channel and may be more useful when there is high level of noise or atmospherics in band 1. In this enhancement, healthy vegetation and clays will have a high 5/7 ratios but vegetation should have a high 4/3 ratio and therefore will be shown in shades of magenta. Clays should either be red or yellow if there is also high iron.



D. Modified Crippen's Ratio. LSFIT in red, 7/4 in green, 3/1 in blue. Based on Crippen's ratio which has 5/7, 5/4, 3/1 in RGB. Clay prediction in red, ferrous iron (jarosite etc) in green and ferric iron (haematite etc) in blue.



E. Crosta Predictions. High predicted clay in red, high predicted iron oxide in green on a PC1 albedo greyscale image. A similar image would have been obtained by substituting an LSFIT band 7 in red and a 3/1 ration in green.