# 4 REMOTE SENSING

A variety of remote sensing techniques were applied to the study area in order to obtain further information on the relationship between neotectonic activity, basement structure and surface landforms. Data obtained from PIRSA included gravimetric, Total Magnetic Intensity and radiometric data. Satellite data was analysed for Landsat 5 TM, ASTER and JERS-1 SAR.

## 4.1 GRAVIMETRIC DATA

The gravimetric data can be used to interpret the structural arrangement of the underlying basement in the study area (Figure 4.1). High gravimetric levels are associated with granitic bodies and Proterozoic basement, whereas low gravimetric levels are associated with sedimentary basins. These gravity features represent the underlying structure of the region that influences overlying cover development. Sedimentary basins flank the gravimetric high associated with the Davenport Ranges (Figure 4.1). The Proterozoic rocks associated with this high are a spur branching off the northern Flinders Ranges. This ridge of Proterozoic sediment is generally fault-bounded on the eastern side throughout the Flinders Ranges (Drexel & Preiss, 1995) and this is reflected in the study area by the position of the Lake Eyre Fault along the margin between gravimetric high zones to the south and west and gravimetric low zones to the north and east (Figure 4.1).

Two obvious features are the large gravimetric low in the northwest corner associated with the Warburton Basin and the large gravimetric high in the southeast interpreted as a granitoid body (Figure 4.1). A subtler feature is the apparent offset between the two major gravimetric highs in the image. This may represent true fault displacement between the basement blocks but is conservatively interpreted here as a zone of structural weakness that forms a major lineament in the region (Figure 4.1). Additionally it is of note that the Neales Fan is bounded by the structural features outlined above, but does not possess a very low gravimetric signal suggesting that it does not have a thick sedimentary succession covering it (Figure 4.1).

## 4.2 MAGNETIC DATA

The interpretation of Total Magnetic Intensity data reveals the structural grain of the region; that is, the position and alignment of basement structural features that form boundaries, such as faults and dykes. Figure 4.2 shows the Total Magnetic Intensity with a sunshade filter. This helps to identify basement lineaments by exaggerating their ‘shadow’ (Earth Resources Mapping Inc., 2003). Two clear trends emerge, a southeast-northwest trend and a northeast-southwest trend. These lineaments are interpreted to represent basement faults. Southeast-northwest trends align with observed surface faults such as the Lake Eyre Fault and the Levi and Mt. Margaret Faults at the base of the Davenport Ranges. Northeast-southwest trends do not align with observed surface faults but do align with Palaeoproterozoic amphibolite dykes and with an interpreted transcurrent fault present on the Warrina mapsheet structural sketch (Rogers & Freeman, 1996). The transcurrent fault is interpreted along the zone of gravimetric disruption identified above.

## 4.3 RADIOMETRIC DATA

Radiometric surveys have been performed in only small portions of the study area. In the north of the region thorium is strongly associated with sandy streams while potassium and uranium are associated with the interfluves. Sand dunes appear to possess a high uranium gamma count. Notably, the small portion of the Neales Fan evident on this dataset appears extremely mixed.

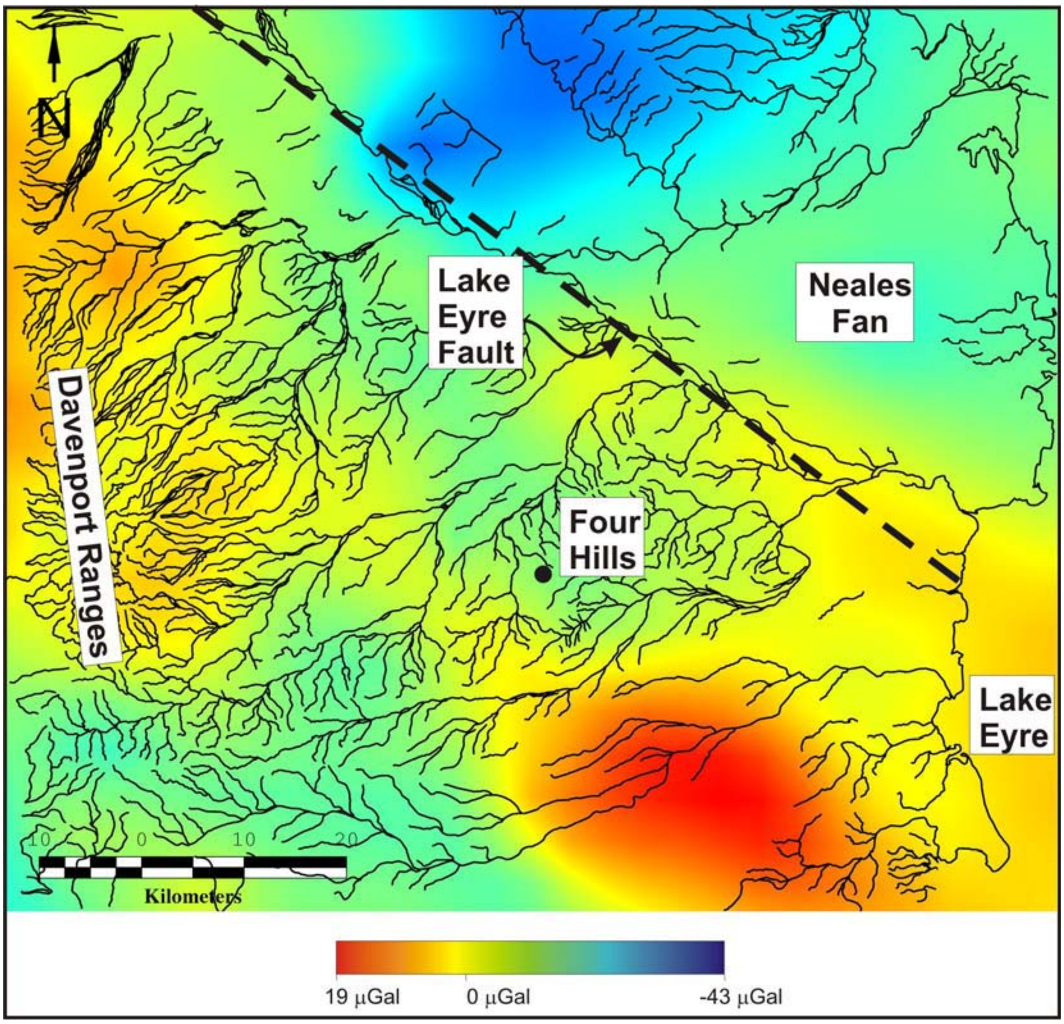

**Figure 4.1: Gravimetric imagery showing broad arrangement of basement structure. High gravimetric levels are associated with granitic bodies and Proterozoic basement, low gravimetric levels are associated with sedimentary basins. The basement structure appears to control the alignment and distribution of streams in the study area.**

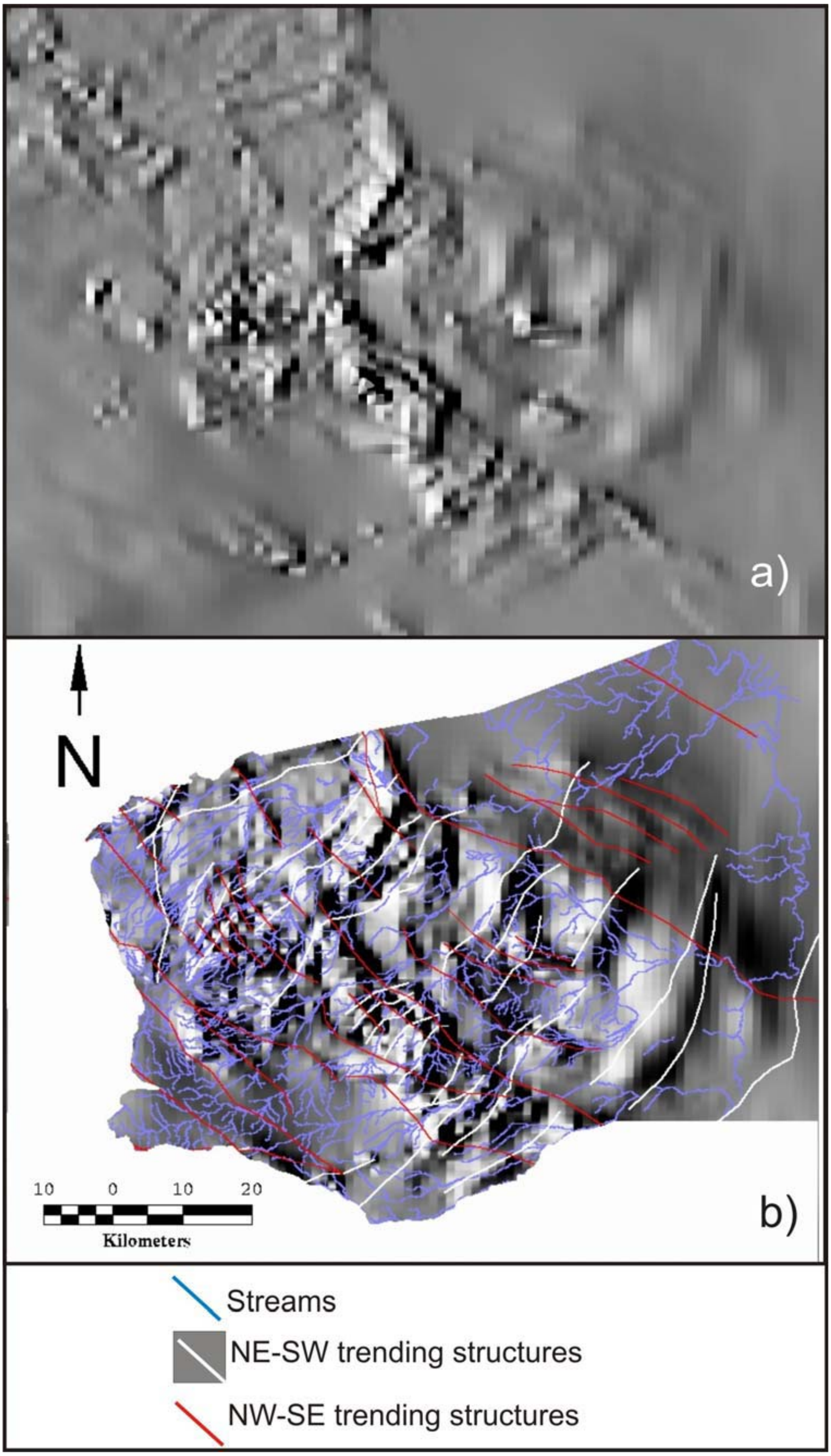

**Figure 4.2: Total Magnetic Intensity image displayed as (a) greyscale image with sun-shading. (b) Interpreted basement structural lineaments identified and displayed as red (NW-SE) and white (NE-SW) lines. Streams are shown in blue.**

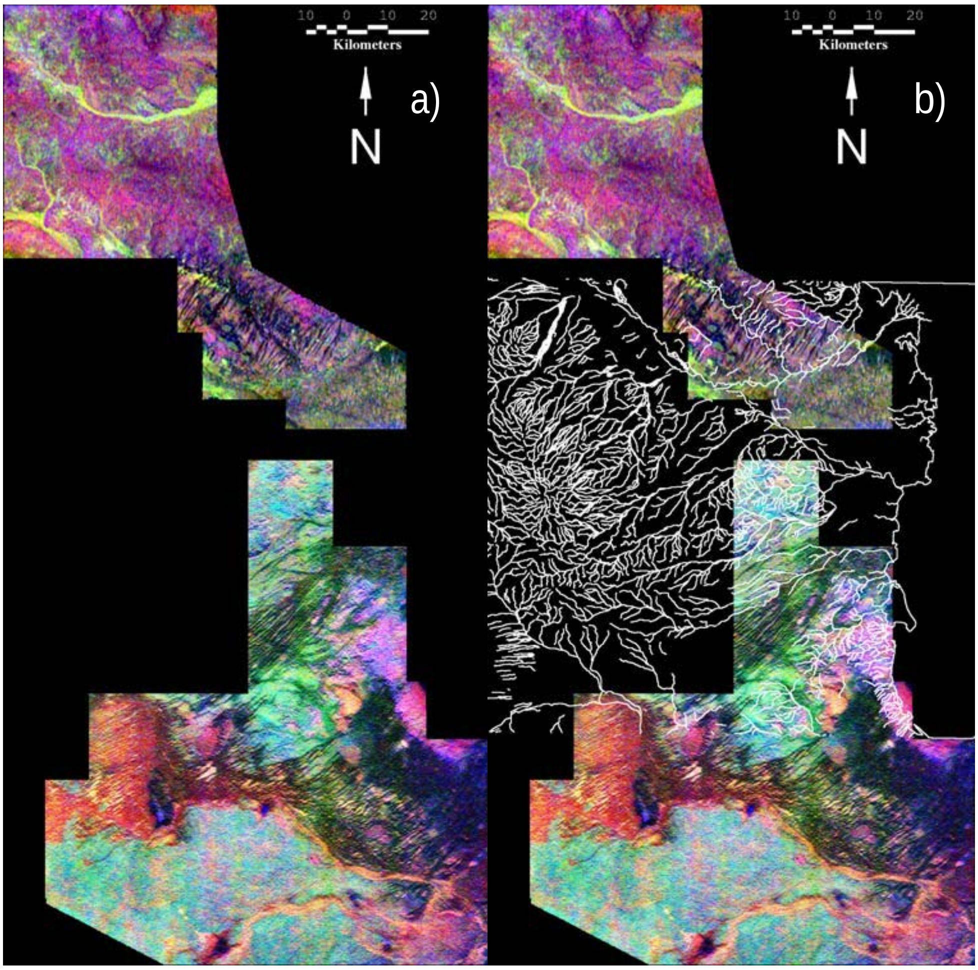

**Figure 4.3: (a) Radiometric imagery mosaic of surveys conducted within the study area showing potassium, thorium and uranium distribution in the landscape for exploration leases investigated in the region; potassium in red, thorium in green and uranium in blue. (b) Streams displayed in white for reference.**

The southern dataset shows a similar association on interfluves indicating a mixture of potassium and uranium. Sand dunes may be divided into a western potassium-rich unit and an eastern uranium-rich unit. A mixture of potassium and thorium dominates stream content. Highly ferruginised and silicified sediments are evident as areas high in potassium and uranium. It is probable that the uranium gamma count on interfluves is derived from heavy minerals and silica related to desert varnish coatings, silcrete and sand dunes. Potassium and thorium distribution is associated with clays and stream sands.

## 4.4 BASEMENT STRUCTURAL INTERPRETATION

The gravimetric, magnetic and radiometric datasets were used to interpret the structure of the basement. The underlying basement is composed of simple structural elements. A spur of Proterozoic sediments of the Adelaide Geosyncline dominates the study area, trending northwest-southeast. These are faulted against the rocks of the Gawler Craton. The Warburton Basin to the north of the Neales River and the adjacent Neales Fan, to the south, are crossed by northeast and northwest trending lineaments that are interpreted as faults (Rogers & Freeman, 1993). These appear to control the alignment and distribution of streams.

## 4.5 LANDSAT 5 TM

At a regional scale, landform mapping is often best carried out via satellite remote sensing. The breadth of coverage and sensitivity to changes in spectral response reflecting chemical variability make satellite-borne systems extremely useful in assessing the land surface. Of these Landsat is perhaps the most widely used because of its long and successful programme and broad range of applications. Details on the analysis of Landsat5TM data conducted for this study are in Chapter 2.2.1.

### 4.5.1 False Colour Composites

Specific combinations of bands were examined for their known response associated with different features.
Fals Colour Composites (FCCs) examined included:

- RGB321 (natural colour)
- RGB741
- RGB532
- RGB573
- RGB754

RGB321

RGB321 (Figure 4.5) displays the image as a natural colour image, or as close to natural colour as bandwidths allow. It may be interpreted in a manner similar to traditional aerial photography and shows readily identifiable landforms such as channels, sand dunes, lakes and claypans, and the Proterozoic sediments exposed in the Davenport Ranges. Bright areas near the centre of the image are evaporitic deposits associated with mound springs.

RGB741

The RGB741 image (Figure 4.6) identifies a range of features. Of these features, band 7 highlights areas of bedrock exposure and band 4 highlights clay and can be seen illuminating channels and claypans across the surface of the Neales Fan (Figure 4.7). The halite formed on the surface of Lake Eyre and around mound springs is evident as white to pale blue.

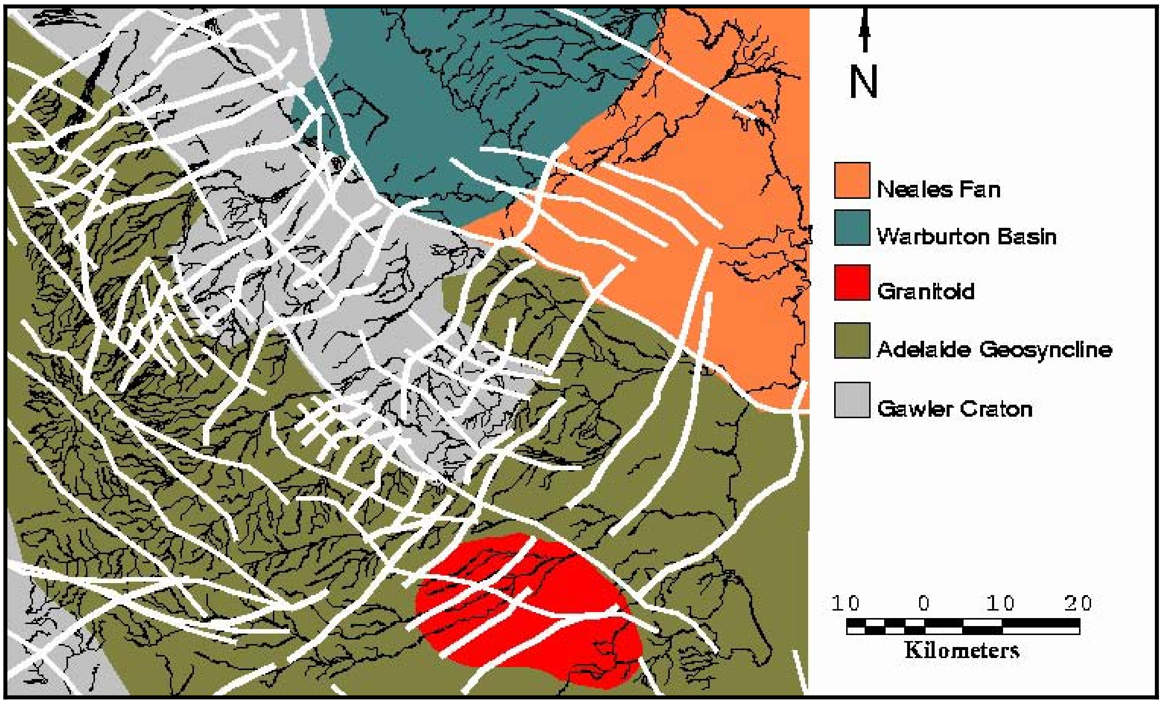

**Figure 4.4: Structural interpretation of geophysical data showing the broad arrangement of basement structures. Interpreted basement structural lineaments are identified and displayed as white lines. It appears that the basement structure controls the alignment and distribution of streams in the study area.**

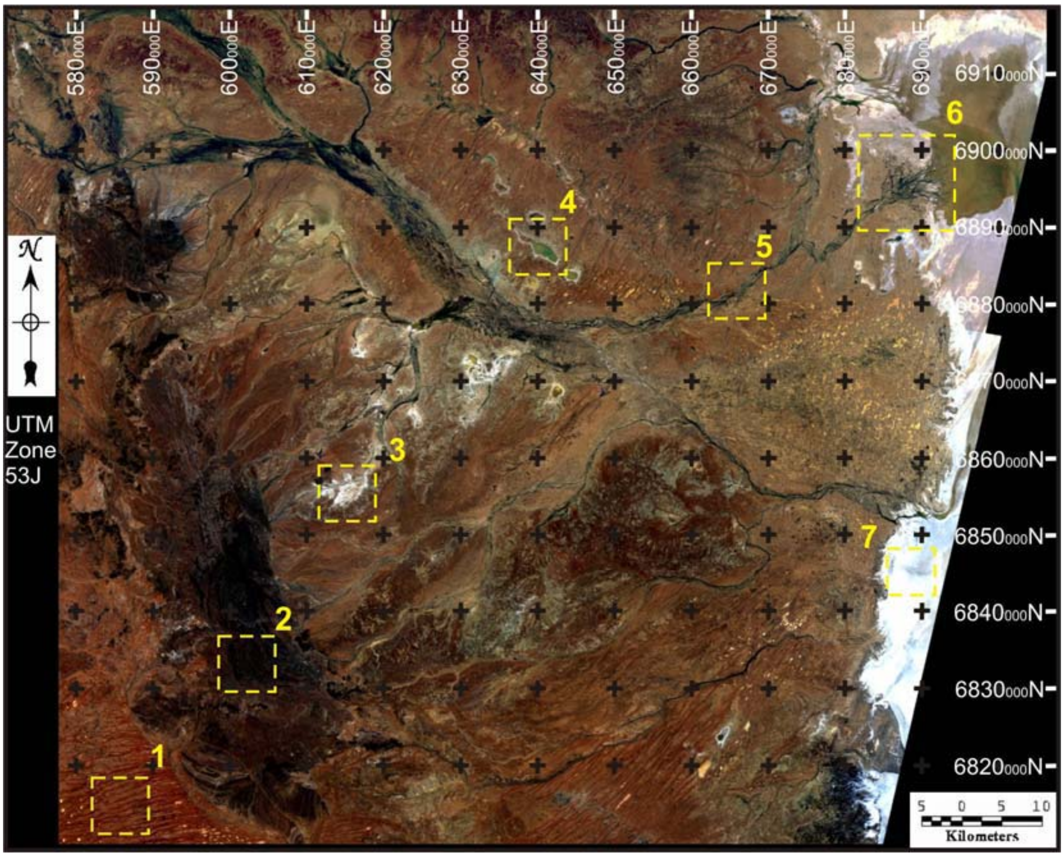

Figure 4.5: Landsat5 TM RGB321 natural colour image displaying identifiable landforms including: 1. sand dunes; 2. ranges; 3. mound springs; 4. claypans; 5. channels; 6. terminal splay complexes, and; 7. lakes.

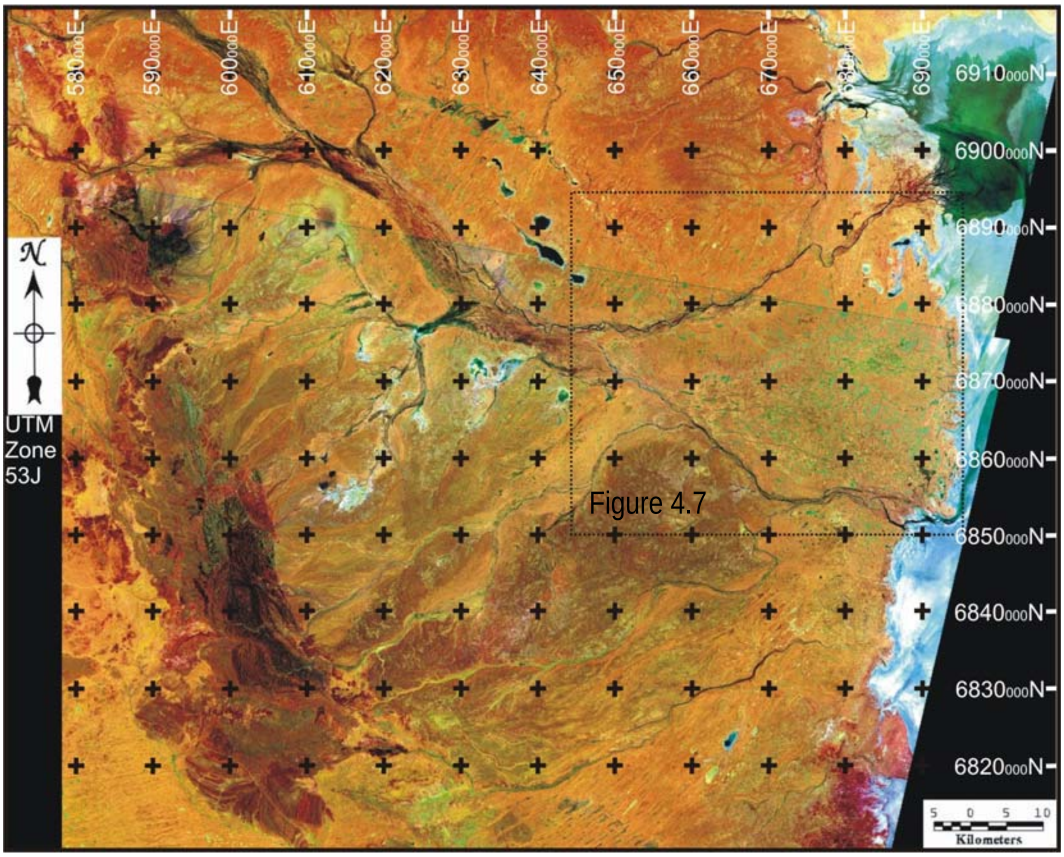

**Figure 4.6: Landsat 5 TM False Colour Composite image RGB741 showing areas of bedrock highlighted by band 7 in red, and clays highlighted by band 4 in green. The dark orange area in the north of the image is a plain covered by heavily desert-varnished silcrete gibber. Alluvial fans flank the base of the Davenport Ranges and are composed of quartz sandstone, except in the south where they consist of well-rounded, poorly sorted mixed clastic sediments that grade into heavily desert-varnished silcrete gibber. Mound springs and associated streams can be seen as pale patches eroding into the flanks of the alluvial fans near the centre of the image.**

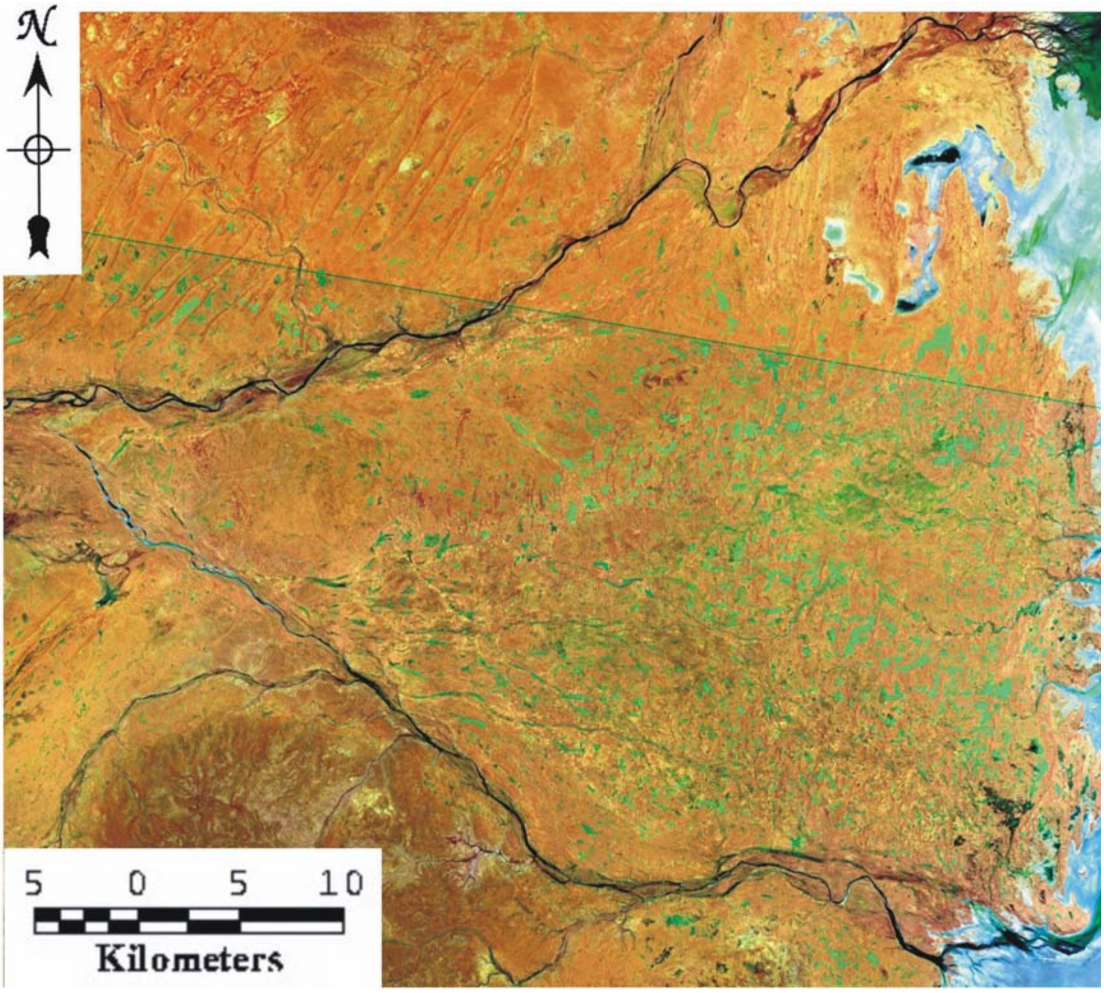

Figure 4.7: Detail Landsat5 TM False Colour Composite Image RGB741 (dashed box Figure 4.6) showing distribution of clay sediments across the surface of the Neales Fan. Claypans are absent along the northern third of the Neales Fan. Claypans populate the middle third of the Neales Fan and form two arms that may represent mud-plugs residing in palaeochannels.

RGB532

The RGB532 image (Figure 4.8) highlights the bedrock of the Davenport Ranges and alluvial fans adjacent to the ranges. Large areas dominated by dunes are clearly distinguished to the south, along the bottom of the image. Two darker areas corresponding to surfaces covered by pebble lags can be seen in the southern half and north of the image. Pale blue highlights areas of clay and evaporites. Escarpments and eroded surfaces of Mesozoic sediment are indicated by a pale purple-blue that is particularly evident along the northern bank of the Neales River, in the Four Hills area and around Hawker Springs. These areas are associated with gypsum-rich colluvium derived from Mesozoic sediments.

RGB573

The combination of RGB573 (Figure 4.9) allows discrimination between the alluvial sediments. In the northwestern quadrant of the image a conspicuous pale yellow band stretches from behind the ranges towards the Neales River, adjacent to Lambing Creek. This pale band is associated with Algebuckina Sandstone within the ranges and with modern alluvium away from the ranges. Field observations at the foot of this alluvial deposit indicate that it is largely composed of rounded white quartz clasts. It is probable that these clasts are derived from the Algebuckina Sandstone. These clasts would have been rounded by alluvial action prior to sedimentary incorporation. A similar pale streak occurs along George Creek and this area is also associated with alluvial sediments and rounded white quartz clasts (Figure 4.10).

RGB754

RGB754 (Figure 4.11) displays similar responses to the previous FCC band combinations and again highlights most of the observed features. It provides discrimination between different surface lag units possibly on the basis of different degrees of desert varnish; with older relict land surfaces evident as darker patches away from the ranges and younger less varnished lags evident as pale green patches. On the eastern flank of the Davenport Ranges this discrimination reveals the relationship between older Pleistocene alluvial fan surfaces and the younger modern alluvial system that is eroding back into the degraded remnants of the Pleistocene landforms. Also a strong distinction is made between the darker relict sediments of the Four Hills area and the Pleistocene alluvial fan units particularly to the east of Hawker Springs where a sharp north-south boundary delineates the two features. This boundary is coincident with a change in elevation and is interpreted as a fault.

### 4.5.2 Band Ratios

Band 3/1

Hematite is reflective in Landsat 5 TM Band 3 and is dark in Bands 1 and 2, so ratios of 3/1 and 3/2 reveal the presence of ferric material in the landscape (Figure 4.12). Areas of high ferric ratio response are associated with dunes and dunefields, probably due to the presence of hematite coatings on grains that impart the red colour to the desert sands in this region. It is of note that these dunes are of longitudinal type and extend along a northeast-southwest axis displaying a strong response. Those dunes located on the Neales Fan with a north-south trend display little response in either of these ratios suggesting that they do not contain ferric material. Other areas that display a strong response in these ratios are those covered by silcrete gibber plains with a strong desert varnish.

**Figure 4.8: Landsat 5 TM False Colour Composite image RGB532 showing large areas dominated by dunes and the effects of erosion on Mesozoic sediments in pale purple-blue associated with gypsum-rich colluvium and gypsite capped escarpments.**

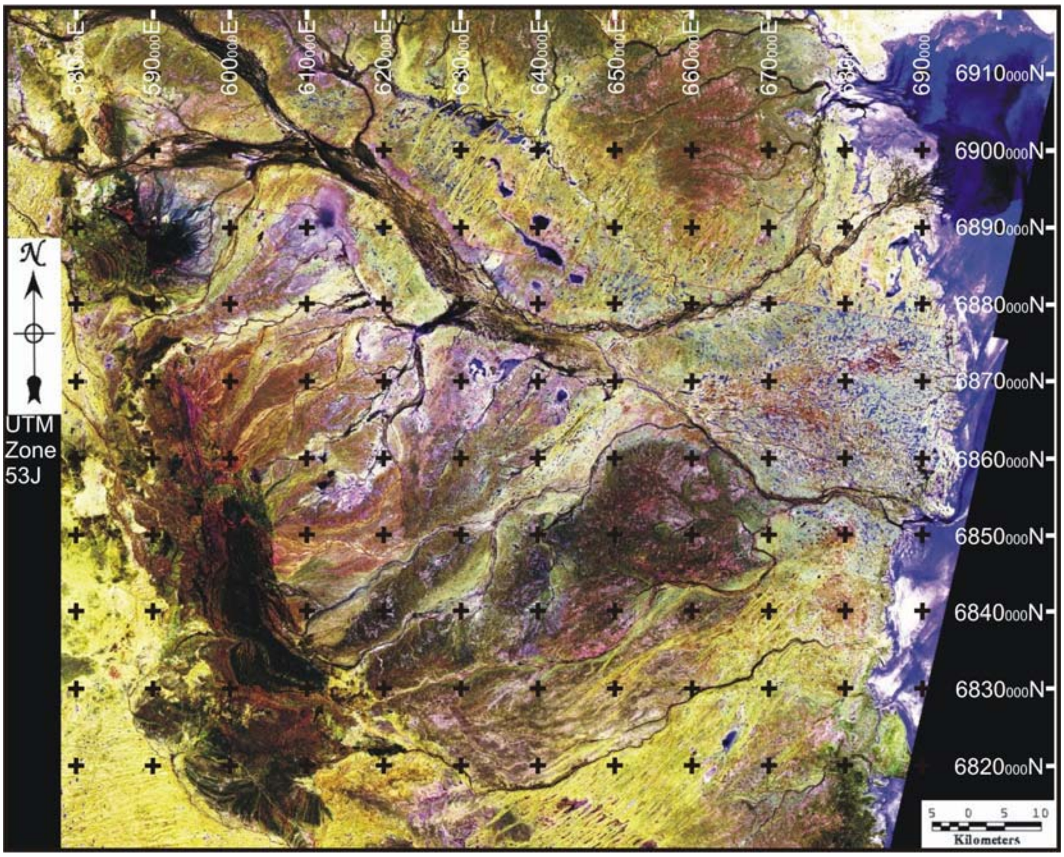

**Figure 4.9: Landsat 5 TM False Colour Composite image RGB573 showing the delimitation of alluvial units. Reworked Jurassic fluvial sands are conspicuous as pale yellow bands carried by modern alluvial systems from the northern and southern ends of the Davenport Ranges.**

**Figure 4.10: Detail of a pebble lag composed almost entirely of rounded quartz clasts derived from reworked fluvial Jurassic Algebuckina Sandstone. Scale= 10 cm. (0619941E 6828652N).**

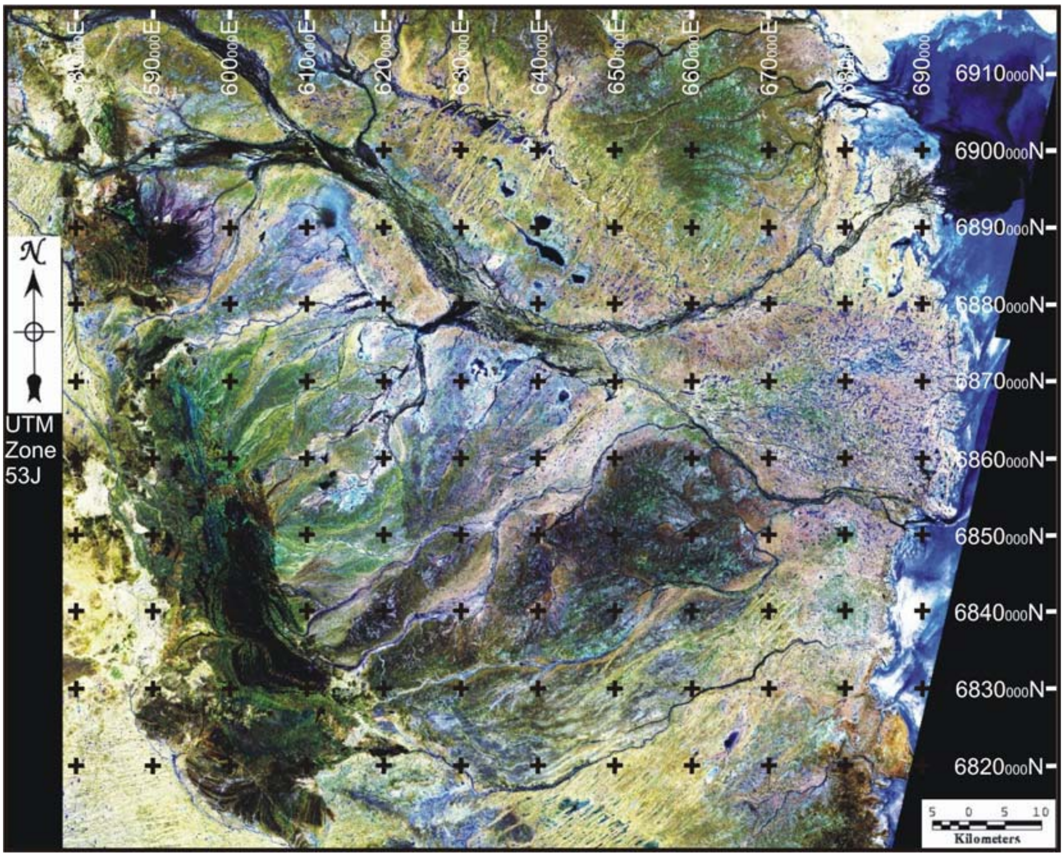

Figure 4.11: Landsat 5 TM False Colour Composite image RGB754 showing differences in the spectral response of surface lag units probably reflecting different degrees of desert varnish coatings.

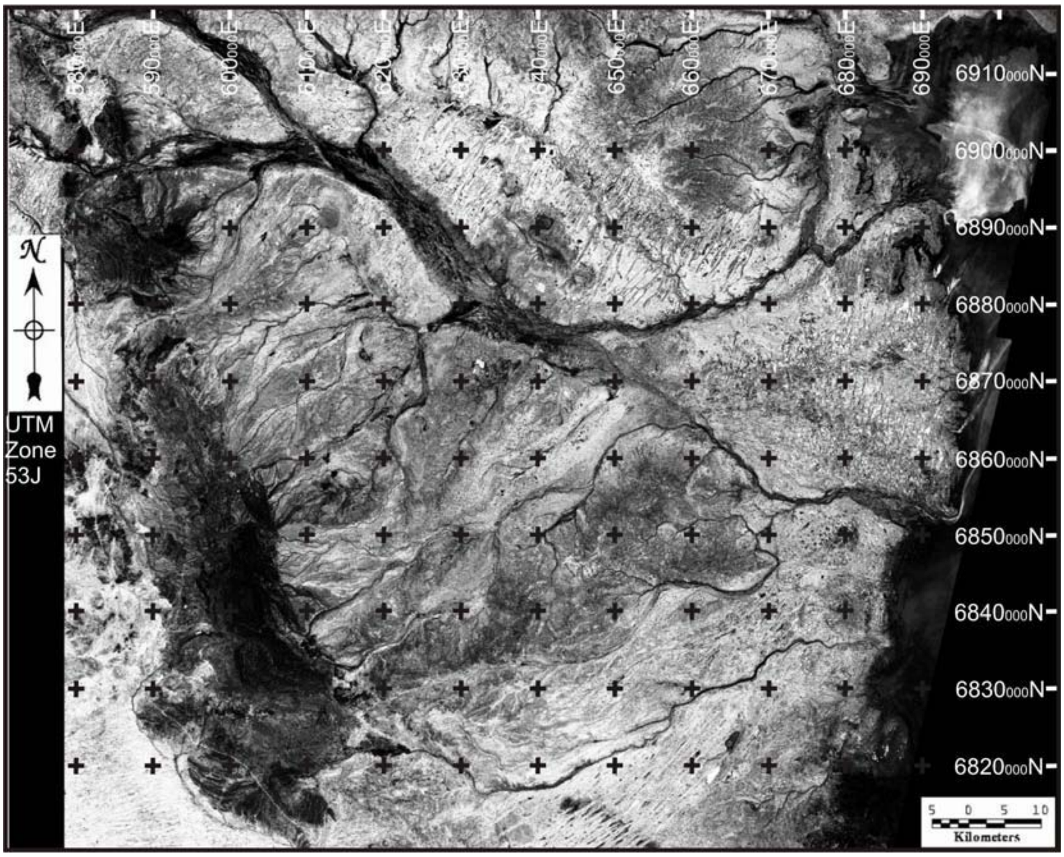

**Figure 4.12: Landsat 5 TM band ratio image Bands 3/1 showing the presence of iron oxides in the landscape. Sand dunes show a high response due to the presence of hematite grains that impart the red colour to dunes in this region. Alluvial fans and gibber plain surfaces show a high response due to the heavy desert varnish that coats the clasts composing these sediments. This varnish is deep red in colour and is likely to contain iron oxides. Sand dunes on the Neales Fan are not illuminated by this ratio and are unlikely to contain iron, suggesting a different source of origin to those dunes of the surrounding region.**

Band 7/5

Clay minerals display a high reflectance in Band 5 and absorption in Band 7, hence the ratio of Bands 7/5 reveals the likelihood of clay mineral abundance as bright areas (Figure 4.13). From the image, it is clear that clay minerals are located in stream channels, playas and smaller depositional depressions. There is also an indication that within the Davenport Ranges there is a mineral that posseses a similar spectral response to clay and appears to be associated with shale bands present within the Skillogalee Dolomite Formation.

False Colour Composite Ratios

A further means of examining Landsat TM data is through combinations of ratios represented as a FCC image. Figure 4.14 is a representation of RGB 3/1, 5/4, 5/7 and is designed to highlight iron, silica and aluminium hydroxides respectively. The three ratios separate the region into distinct areas. Red is evident on surfaces covered by gibber plains and alluvial overbank sediments. Green, representing silica, is associated with outcrops of Palaeozoic sediment in the Davenport Ranges and aeolian sands. Blue is associated with evaporitic and fine-grained sediment confined to watercourses and playas as well as occurring in the Skillogalee Dolomite synclinal core. Other blue areas highlight zones of colluvial sediments overlying Palaeozoic sediments.

Of interest are two regions of apparent silica-rich deposits. The first of these occurs in the Neales River downstream of a section with a strong clay response, suggesting a sandier reach in the river. This reach is also associated with a change in style of river plan morphology. The river alters from a braided or anabranching system to a sinuous one at precisely the point that the Umbum Creek overflow is located (Figure 4.14).

The second area of interest occurs between Sunny and George Creeks (Figure 4.14). Here a strong silica signal can be seen dispersed across the interfluve. The morphology is suggestive of an alluvial fan that has been degraded and the sediments dispersed downstream. Upstream of this location are outcrops of Algebuckina Sandstone, a Jurassic fluvial sandstone that is being exhumed and its sand-rich sediment redistributed down slope.

### 4.5.3 Landsat Summary

The association of certain chemical compositions with landforms was noted. Particularly the association of silica with bedrock and sand dunes, iron with sand dunes and relict gibber plains and clay with channels and playas. Sand dunes formed across the Neales Fan are low in iron oxide content.

From the cross-cutting relationships interpreted from the satellite imagery there appears to be older relict surfaces that are truncated by younger surfaces. These can be distinguished from each other by differences in colour, probably as a result of different degrees of desert varnish. Reworked fluvial sediments are being redeposited and ephemeral channels exist across the surface of the Neales Fan.

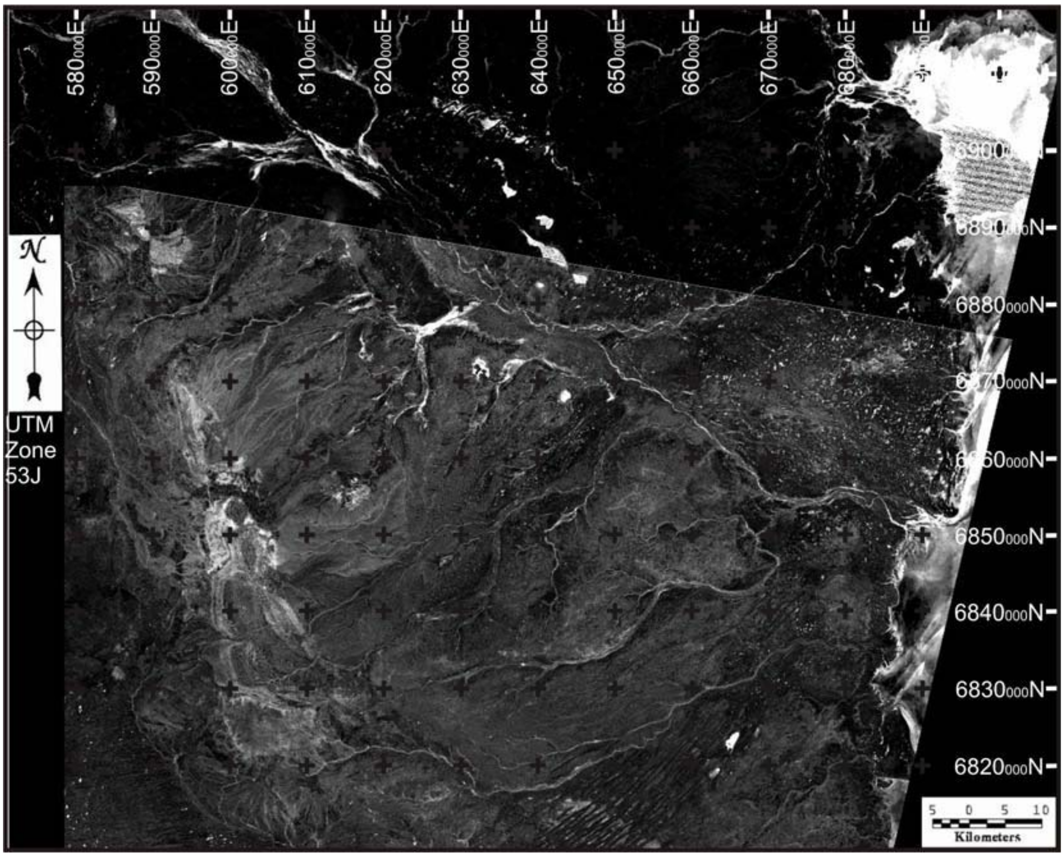

Figure 4.13: Landsat 5 TM band ratio image Bands 7/5 showing the presence of clay-forming minerals in the landscape as bright areas. These are associated here with stream channels, claypans and depositional depressions. There is also a geological unit in the Davenport Ranges that possesses a strong clay signature.

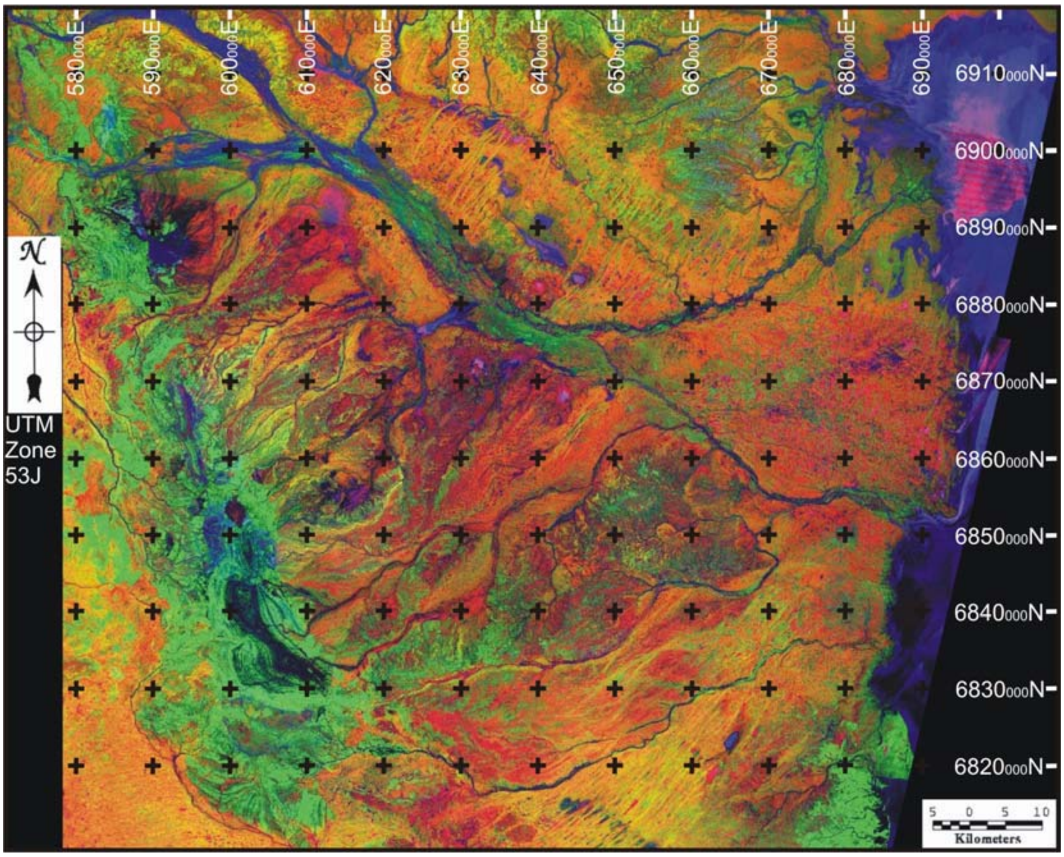

**Figure 4.14: Landsat 5 TM False Colour Composite of Band Ratios RGB3/1, 5/4, 5/7 designed to highlight iron (in red), silica (in green) and aluminium hydroxides (in blue). Silica- and aluminium hydroxide- rich rocks form the ranges and dominate the streams. Dunefields are dominated by iron and silica whereas dunes on the Neales Fan are dominated only by silica. Gibber plains covered by silcrete have a high silica response and appear as green. Floodouts are associated with aluminium hydroxides.**

## 4.6 ASTER IMAGE ANALYSIS

Three ASTER scenes were chosen for analysis (Figure 4.15) and referred to here by the major features visible in each data granule: Hawker Springs, Neales Fan and Sunny Creek. Each scene was analysed for Endmember Extraction, Rowan's Ratios and Spectral Indices, and for Supervised Classification (see Chapter 2.2.2 for methodology.)

### 4.6.1 Hawker Springs

#### Endmember Extraction

The Hawker Springs area encompasses the Davenport Ranges and the Neales River. There are several metamorphic inliers and mound springs within this scene. A band of cloud extends from the northwest to the southeast across the scene. This results in the presence of several artefacts within the scene across this strip (Figure 4.16).

The Non-Negative Principal Component Analysis image (Figure 4.16) highlights the separation of landscape units. Areas of clays and evaporites are highlighted by the magenta endmember. These are commonly associated with erosional exposure of the underlying Mesozoic sediments. The orange-yellow endmember is identified with alluvial fans fringing the Davenport Ranges. Colluvial rises mantled with a lag composed of debris-flow or alluvial material extends from the southern Davenport Ranges towards the Neales River. These are delimited by the green-yellow endmember. The plain green endmember is associated with erosional colluvial plains that are mantled with longitudinal dunes.

Most alluvial channels flow from the topographic high of the Davenport Ranges to the lowland Neales River (Figure 4.16). Other alluvial channels originate at mound springs and these are incising into the landscape, forming alluvial erosional depressions. This creates an escarpment fringed by colluvial slopes and incised by drainage channels.

The Independent Component Analysis image (Figure 4.17) shows a similar breakdown of landscape units although it displays more definition between units. Orange and magenta endmembers highlight areas of erosion often associated with underlying Mesozoic sediments. The difference between endmembers may be associated with changes to the chemistry of the underlying Mesozoic units as they pass from deep marine sediments to shallow marine sediments. The red endmember highlights clays and evaporates associated with mound springs, floodouts and claypans. The pale blue endmember highlights degraded Pleistocene alluvial fans fringing the Davenport Ranges. Relict colluvial plains dominated by heavily desert-varnished silcrete lags can be identified by the dark blue endmember and the green endmember is associated with Algebuckina Sandstone, reworked Algebuckina sands and other quartz sands.

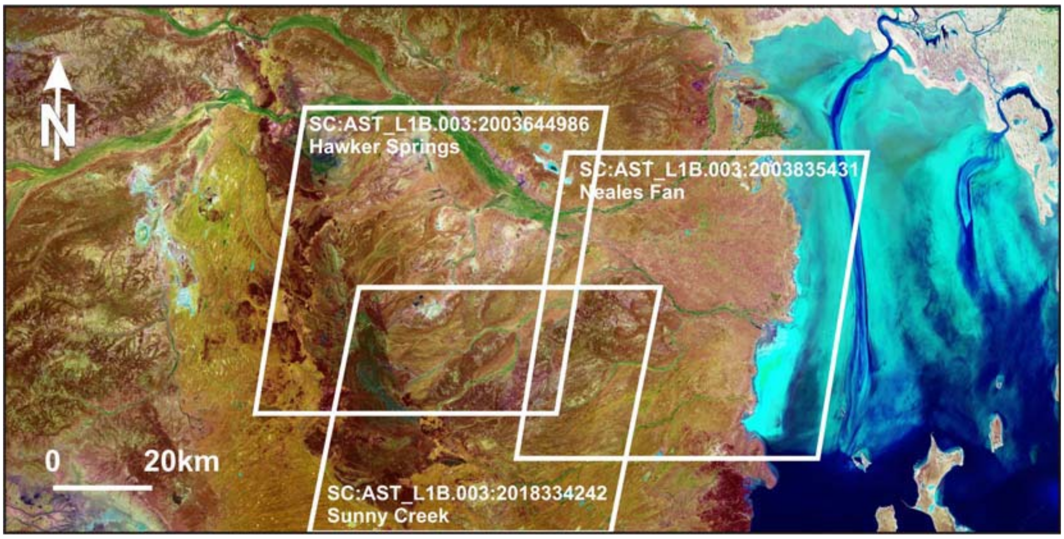

**Figure 4.15: Location diagram of ASTER data showing the position of the ASTER tiles used for analysis.**

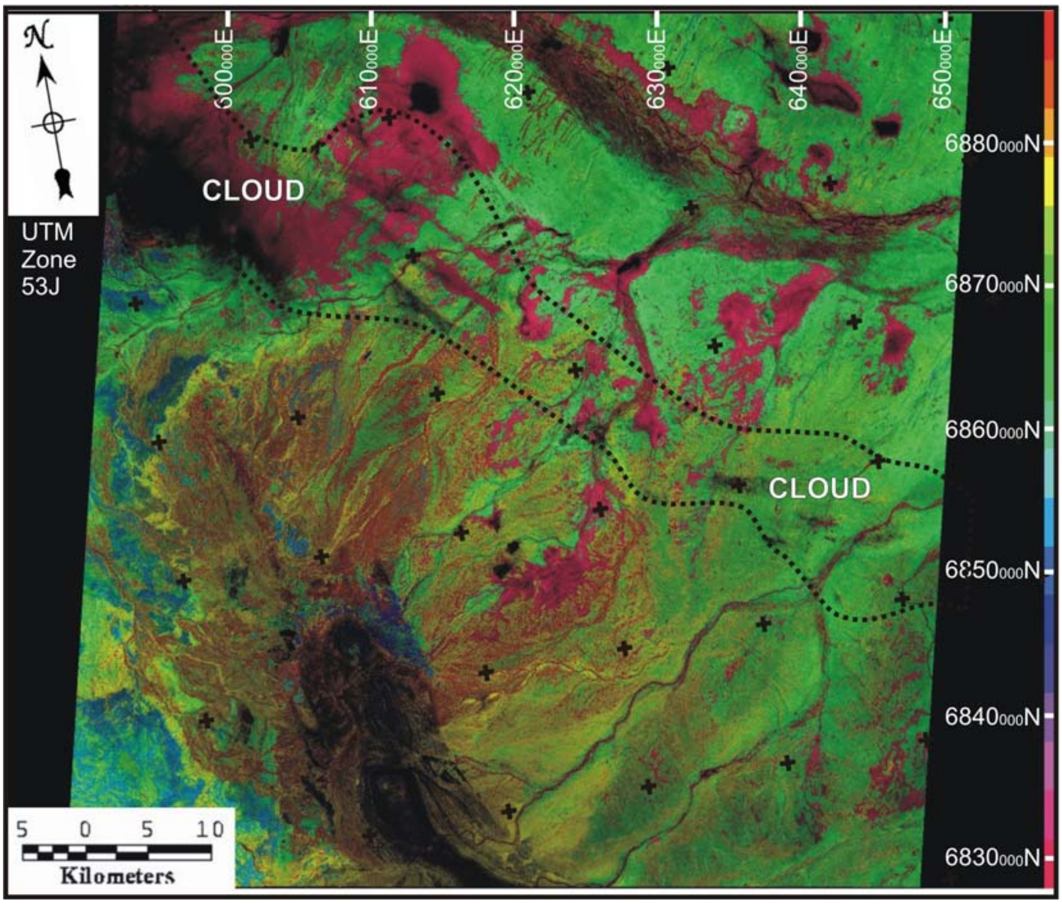

Figure 4.16: Non-Negative Principal Component Analysis (NNPCA) of Hawker Springs ASTER scene. The colour scale on the right-hand side represents 18 enforced endmembers. The magenta endmember highlights areas of fine-grained clays and evaporites typically associated with underlying Mesozoic sediments. The orange-yellow endmember highlights alluvial fans fringing the northern end of the Davenport Ranges. Sediment extending from the southern Davenport Ranges in a northeasterly direction is represented by the green-yellow endmember. The green endmember highlights erosional plains mantled with longitudinal dunes. A band of cloud is indicated by the dashed line.

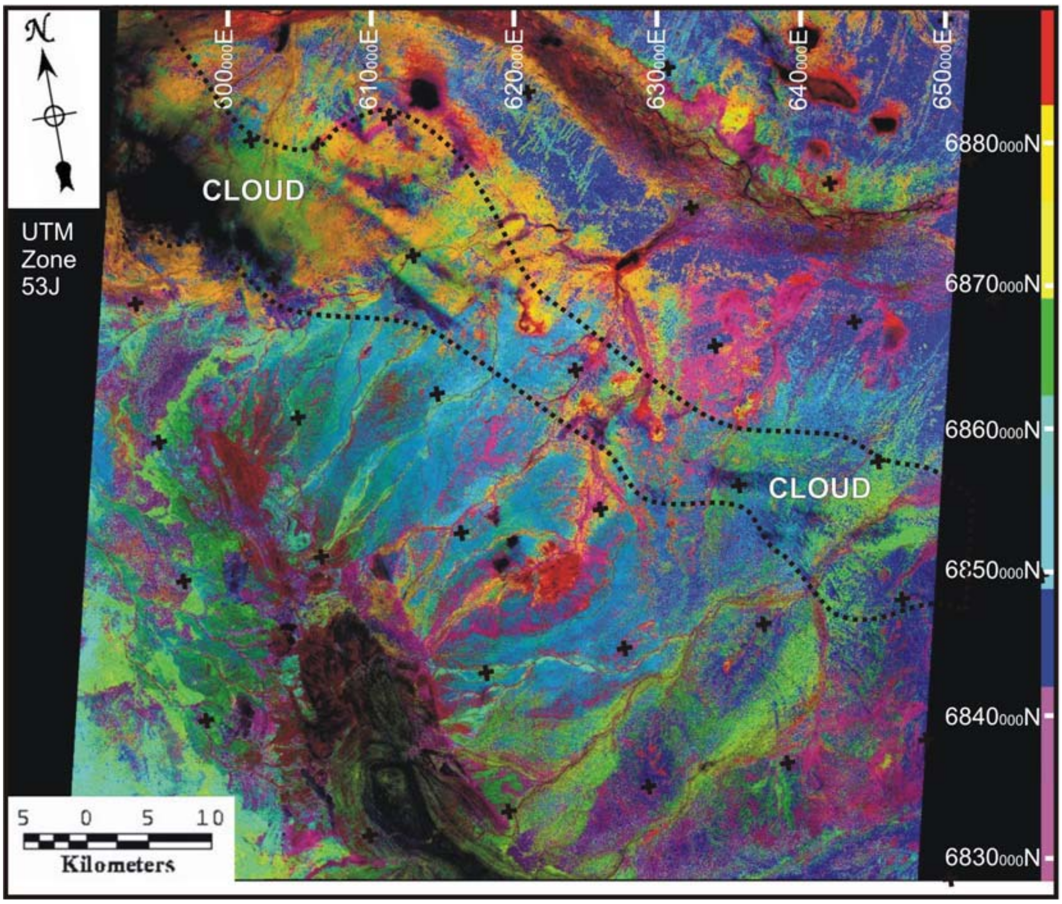

Figure 4.17: Independent Component Analysis (ICA) results for Hawker Springs showing Mesozoic sediments exposed by erosion in orange and magenta; fine-grained clays and evaporites associated with mound springs, floodouts and claypans in red; degraded alluvial fan sediments in pale blue; and relict colluvial plains in dark blue.

The similarity between surfaces on either side of the Neales River is apparent (Figure 4.17). These represent areas of gibber plain overprinted with longitudinal dunes. The Neales River has clearly carved its way through this plain creating an escarpment on its bank. The plain is composed of a gypcrete surface mantled with silcrete lag and fringed by a colluvial slope derived from the underlying Mesozoic units.

### Rowan's Ratios

Analysis of band depth ratio imagery, while it appears to state definitive occurrence of mineralisation, should be tempered with the knowledge that other types of minerals with similar relative band depths may be registering (Rowan & Mars, 2001). With this in mind observations from the three RGB colour composites demonstrate that areas of exposed lithic material possess the strongest response to this technique.

Figure 4.18 is a FCC displaying RGB muscovite/illite/smectite, clacite, alunite/pyrophillite for the Hawker Springs scene. Rowan's Ratios clearly highlight several features associated with Proterozoic sediments. Most evident are the metamorphic inliers of Spring Hill, the Skillogalee Dolomite, the Bungadilla Monzonite and the Unnamed Proterozoic units visible on the Warrina mapsheet (Rogers & Freeman, 1996). Landform features that are evident include alluvial channels, alluvial fans, mound springs and the floodplain flanking the Neales River (Figure 4.18).

The Skillogalee Dolomite appears to be dominated in fact by calcite with a smaller contribution from dolomite and alunite/pyrophillite (Figures 4.18, 4.19 & 4.20). Of significance is the manner in which these minerals are transported across the landscape. An examination of all three diagrams shows that the alluvial channels tend to carry calcite and alunite/pyrophillite material.

The Neales River passes through the Peake and Denison Ranges to the northwest. These ranges are composed of Proterozoic material. The Neales River valley floodplain appears to be covered by a layer of sediment composed of calcite and alunite/pyrophillite, evident as the pale blue areas in Figure 4.20. This floodplain is likely to be composed of reworked Proterozoic sediments sourced from the ranges.

The extent of alluvial fans is made evident by the location of muscovite/illite/smectite in the landscape. These fans abut the Davenport Ranges and are derived from the lithologies outcropping there, forming the large red-coloured fans in Figures 4.19 & 4.20.

Figures 4.19 and 4.20 also show that dolomite (in green) is commonly associated with areas dominated by gibber plain. This seems an unlikely result as these areas are mantled with a lag of desert varnish covered silcrete pebbles. This result is likely to be an artefact caused by a similar relative band ratio between the silcrete mantle and dolomite. A high degree of dolomite forming the desert varnish is not a probable cause of this phenomenon. (Figure 4.21)

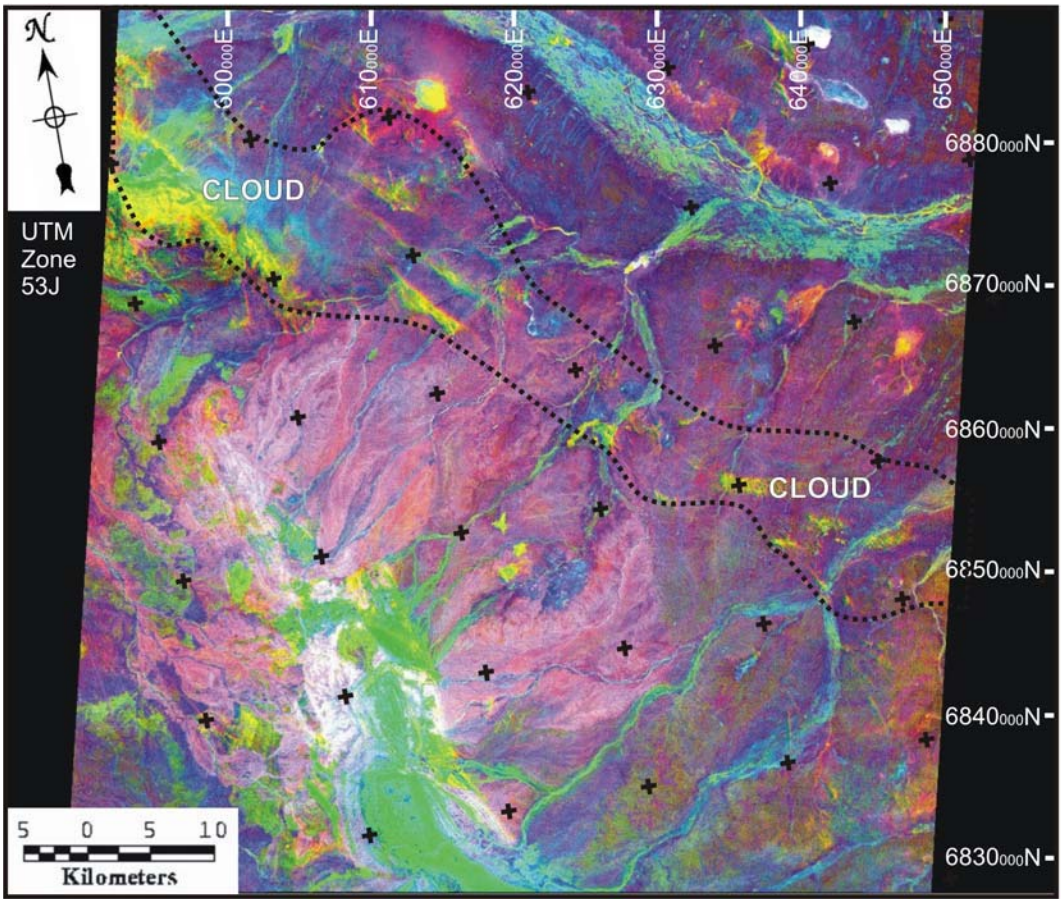

**Figure 4.18: Rowan's Ratios for RGB muscovite/illite/smectite, calcite, alunite/pyrophyllite for Hawker Springs ASTER scene, showing a strong response in the calcite ratio from dolomitic units in the Proterozoic sediments of the Davenport Ranges. Streams have a strong response in both the calcite ratio and alunite/pyrophyllite suggesting that stream sediments are derived from the Proterozoic sediments in the stream provenance rather than contribution from the surrounding landscape. Sand dunes display a strong alunite/pyrophyllite signal.**

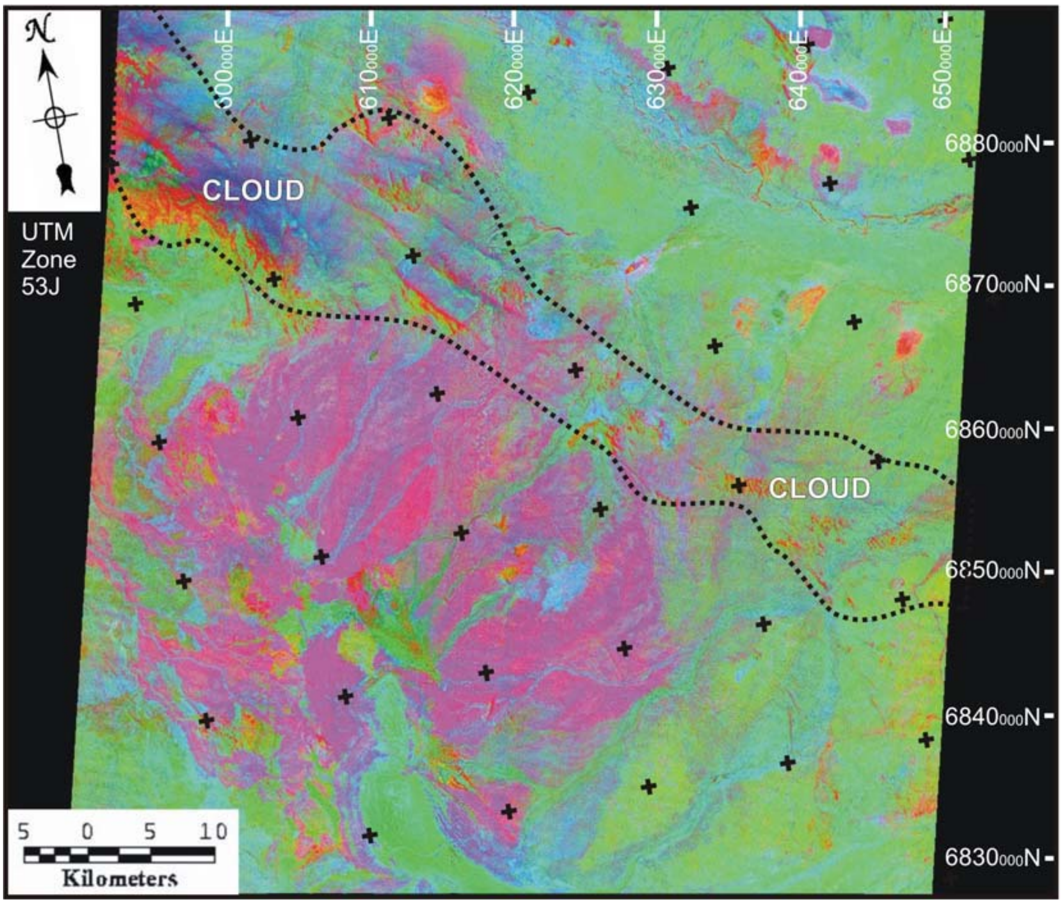

Figure 4.19: Rowan's Ratios for RGB muscovite/illite/smectite, dolomite, alunite/pyrophyllite for Hawker Springs ASTER scene, showing a strong response in the dolomite ratio from dolomitic units in the Proterozoic sediments of the Davenport Ranges. This response is further reflected in streams draining these bedrock units. Alluvial fans flanking the ranges possess a strong response in the muscovite/illite/smectite ratio with a similar response from source rocks in the Davenport Ranges. The southern sediments flanking the range and areas of gibber plain show a strong response in the dolomitic ratio. This is probably due to similar absorption features between desert varnish and dolomite spectra.

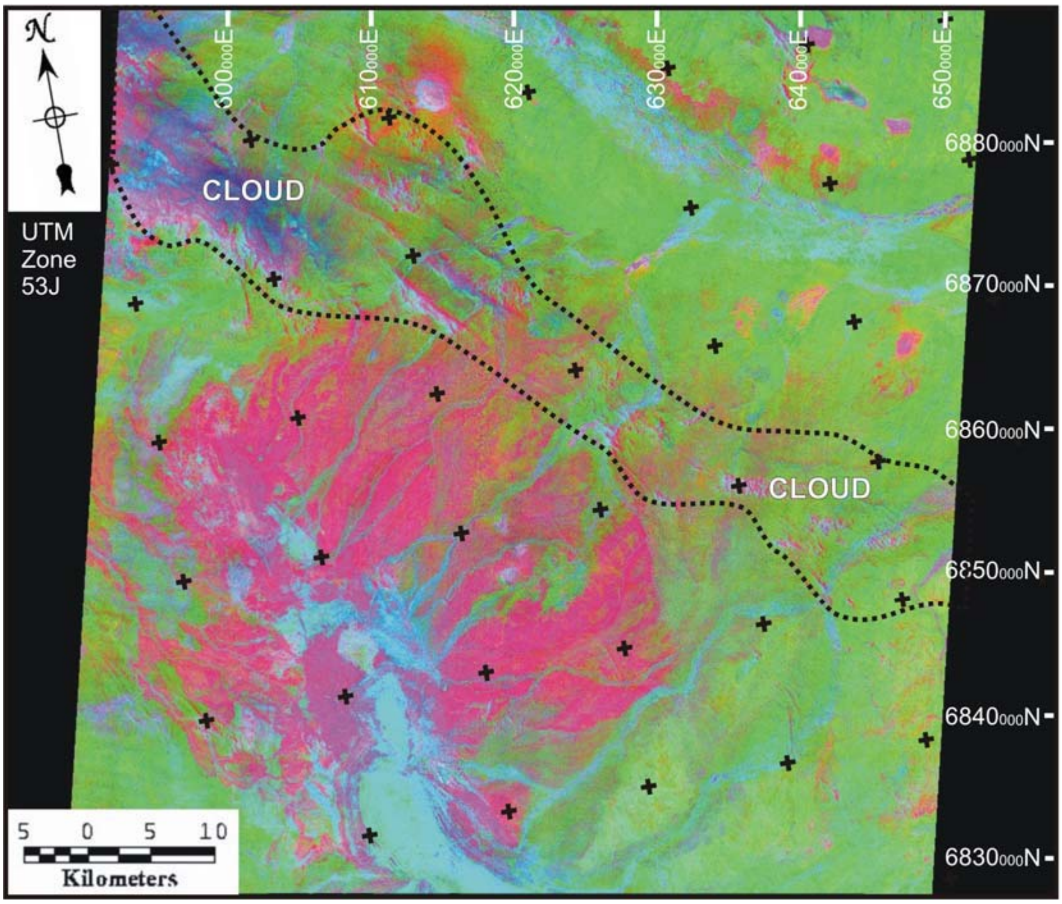

Figure 4.20: Rowan's Ratios for RGB muscovite/Illite/smectite, dolomite, calcite for Hawker Springs, showing a strong distinction between sources of sediment. Proterozoic sediments and alluvial fans have large amounts of muscovite-type minerals; the surrounding gibber plains appear to be dominated by a dolomite signal. This is probably due to similar absorption features between desert varnish and dolomite spectra. A unit in the Proterozoic sediments of the Davenport Ranges has a strong calcite signal. This is also evident along streams and indicates that this unit is the source for much of the stream sediment.

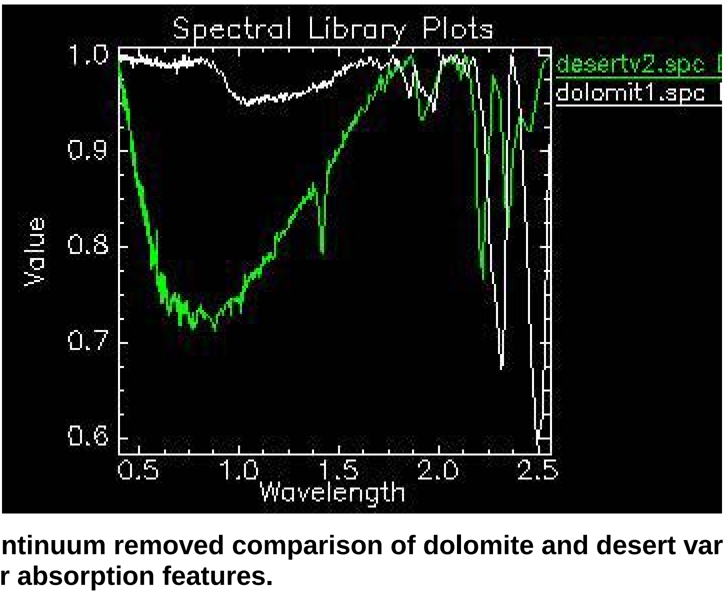

Figure 4.21: Continuum removed comparison of dolomite and desert varnish spectra showing similar absorption features.

The areas associated with mound springs are dominated by a response in the alunite/pyrophillite band ratio (Figure 4.18). Field observations at several of these sites reveal the presence of travertine deposits as precipitates from the mound springs. These may be causing a signal in the alunite/pyrophyllite band ratio but it is more likely that the response is due to evaporite deposits or vegetation associated with the water from the mound springs.

The distribution of the four band ratios throughout the landscape reveals that the lithic material exposed in the Davenport Ranges is the probable source of calcite that is moved down alluvial channels. Muscovite/illite/smectite is associated with alluvial fans and is probably formed due to the breakdown of clay-rich sediments in the Davenport Ranges. Alunite/pyrophillite is widely distributed throughout the landscape but is most strongly related to lithic source material, alluvial channels and longitudinal dunes. Dolomite is related to lithic source material within the Davenport Ranges.

### Supervised Classification

Supervised classification was conducted to distinguish between different landform features. Ignoring the errors introduced by the presence of cloud on the image, the Mahalanobis Distance Classification used training areas to demarcate between spectral features (Table 4.1). This was conducted at a Maximum Distance Error=100 and produced a classification map (Figure 4.22) that displays the relationships between landform features.

Several features are worthwhile noting. The green gypsum scarp unit highlights gypsum observed flanking Hawker Springs and the Davenport Ranges (Figure 4.22). It includes other areas of probable evaporite deposition surrounding mound springs and claypans. It also makes a spectral match with units of gypsite preserved on the Mount Margaret Surface of the Davenport Ranges (Wopfner, 1968). The yellow Neales River floodplain unit also obtains a match for large portions of the Davenport Ranges. This suggests a common provenance for much of the material transported down the Neales River as it passes through the Peake and Denison Ranges. The red alluvial fan training area clearly identifies related fan systems. The orange gibber plain training area identifies a fan-shaped feature representing a relict alluvial fan or surface distinct from the red alluvial fan surface identified above.

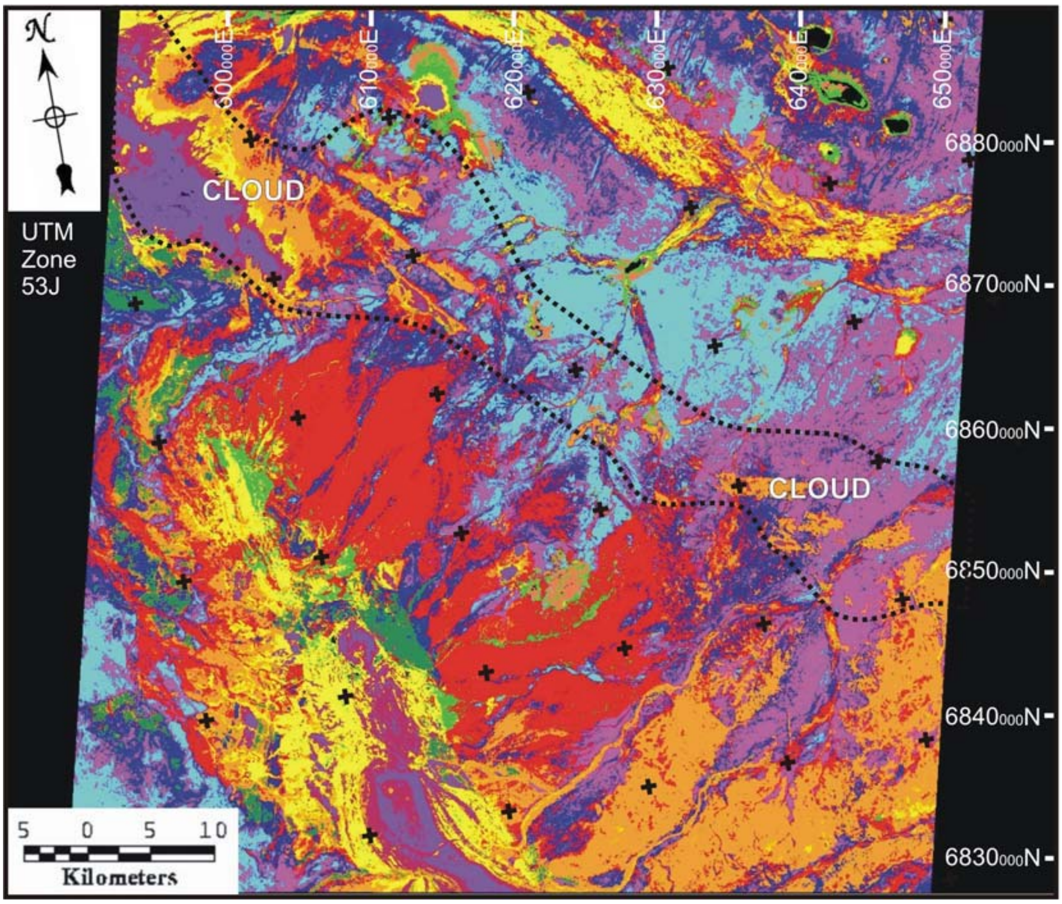

Figure 4.22: Mahalanobis Distance Classification image for ASTER Hawker Springs scene showing a strong correlation between spectral properties and landform type. There is a clear distinction between alluvial fans (in red) flanking the ranges and the sediment flanking the ranges in the southeast of the image (in orange). There is a strong similarity between sediment carried by the Neales River and sediment in the Davenport Ranges.

Table 4.1: Training Areas for Hawker Springs.

| UNIT COLOUR | DESCRIPTION |
|---|---|
| Red | Alluvial fans |
| Green | Gypsum scarp |
| Blue | Sand dunes |
| Yellow | Neales River alluvial plains |
| Cyan | Colluvial erosional plains |
| Magenta | Davenport Creek alluvial plain |
| Orange | Gibber plains |
| Sea Green | Lithic 1 |
| Maroon | Lithic 2 |
| Purple | Metamorphic inliers |
| Coral | Mound springs |

The magenta training area identified similar spectra on an alluvial plain along Davenport Creek (Figure 4.22). This demonstrates that there has been erosion in the headwaters and transport of the material downstream, forming a large flood deposit downstream of the junction with Umbum Creek. Colluvial erosional plains form a relict unit based on the cyan training area that is incised and covered by other units.

### 4.6.2 Neales Fan

#### Endmember Extraction

The NNPCA endmember extraction routine performed poorly in defining different landscape units on the Neales Fan ASTER scene (Figure 4.23). Three major units are evident apart from Lake Eyre. These are a yellow endmember associated with areas of erosion, a green endmember associated with areas of remnant landscape surfaces and a purple endmember associated with alluvial channels, possibly related to either water or vegetation.

The results from the ICA endmember extraction process provided finer discrimination (Figure 4.24). Colluvial erosional plains on the Neales Fan, in blue, are dissected by an endmember in orange and magenta that displays morphology consistent with a large distributary channel (Figure 4.24).

In the northwest and south, dune fields are clearly defined in pale green and the land surfaces beneath them can be distinguished: a blue endmember in the northwest and a red endmember in the south (Figure 4.24).

Alluvial channels are evident, and sediment flowing down Sunny Creek is different to the sediment in Umbum Creek and is probably a result of the different provenances of the two creeks (Figure 4.24).

#### Rowan’s Ratios

An examination of Figure 4.25 reveals that the scene is, overall, dominated by a response in the muscovite/illite/smectite ratio. This may be a result of the distribution of fine silts and clays through the landscape. To the north and south the alunite/pyrophillite signature becomes dominant and is associated with the longitudinal dune fields in these areas. Other features that can be readily distinguished are the major alluvial channels and the lake surface. Alluvial channels display a calcite response, except Sunny Creek, which displays a mild degree of alunite/pyrophillite.

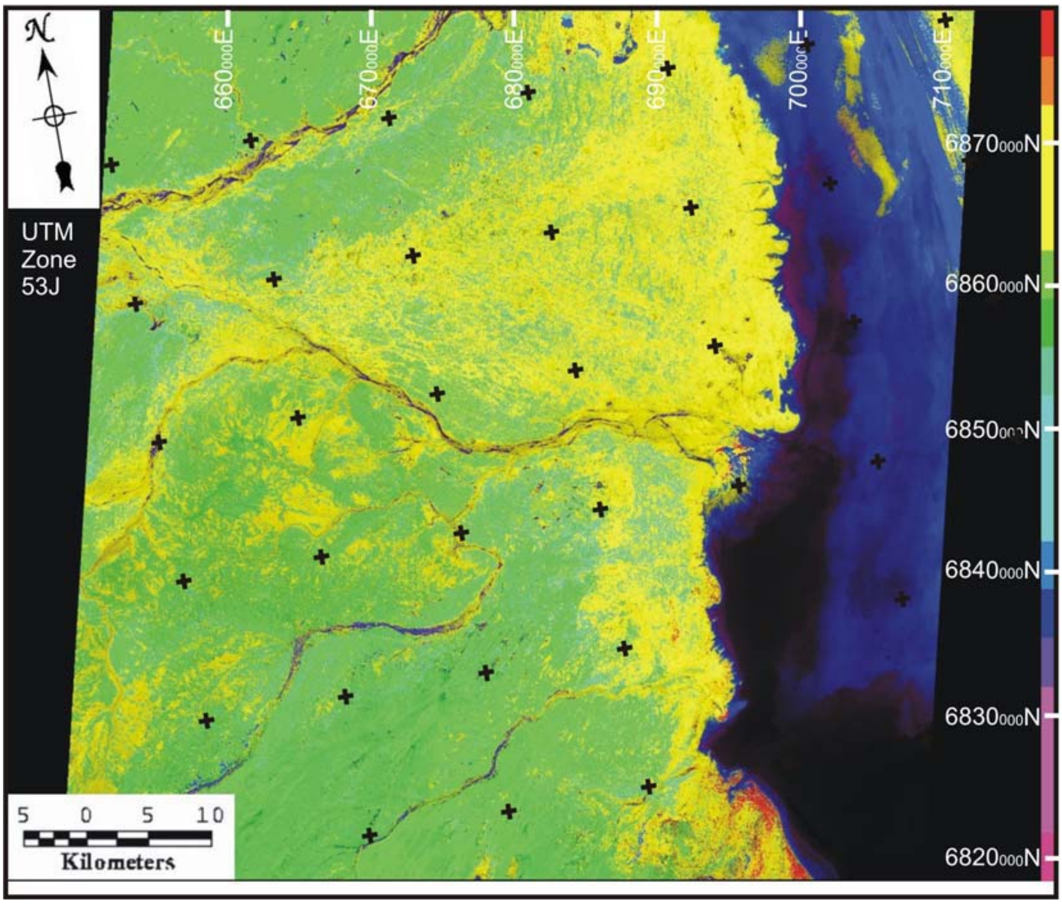

**Figure 4.23: Non-Negative Principal Components Analysis (NNPCA) results for ASTER Neales Fan image showing poor discrimination of surface features. It identifies areas of erosion in yellow; relict surfaces in green; and channels in purple.**

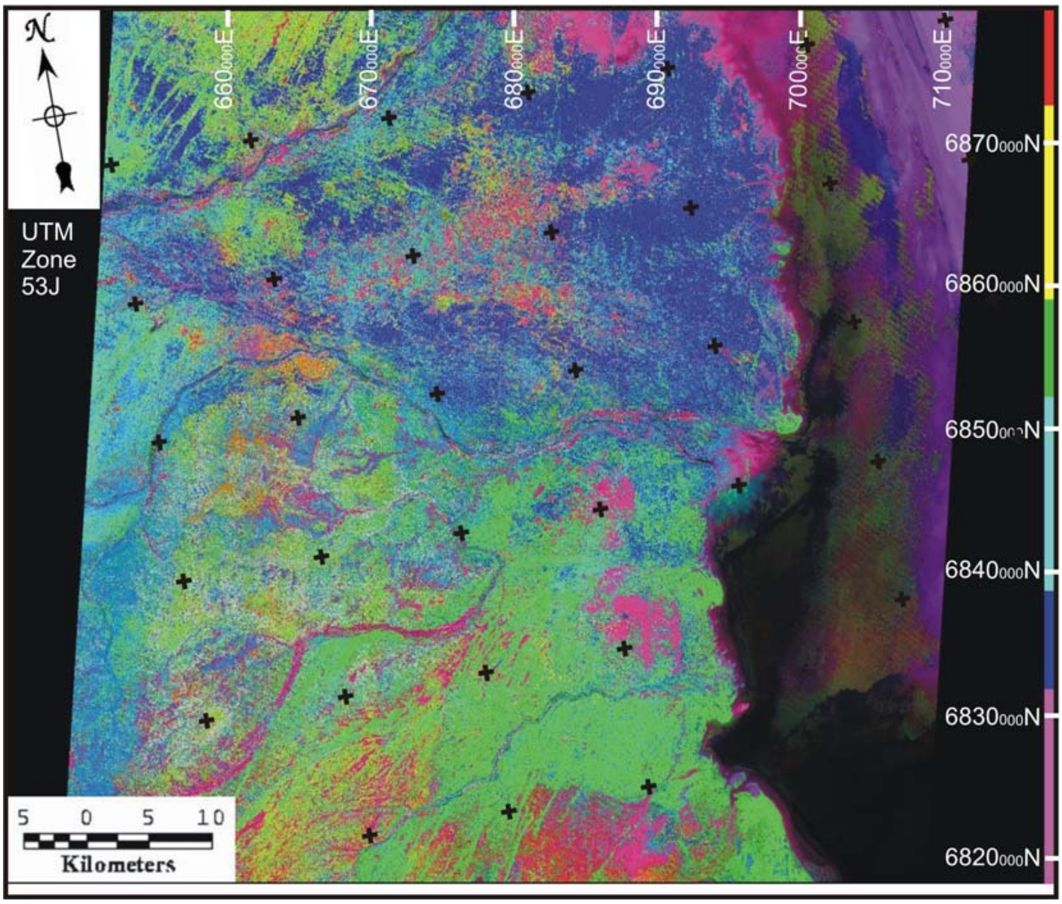

Figure 4.24: Independent Component Analysis (ICA) Neales Fan ASTER Image showing classification of the surface of the Neales Fan into several units. One of these appears to be a palaeochannel that bifurcates down the length of the fan (pink and pale blue). The yellow/green member is associated with a plateau on the northern side of the Neales River. Similar material is evident on the southern side.

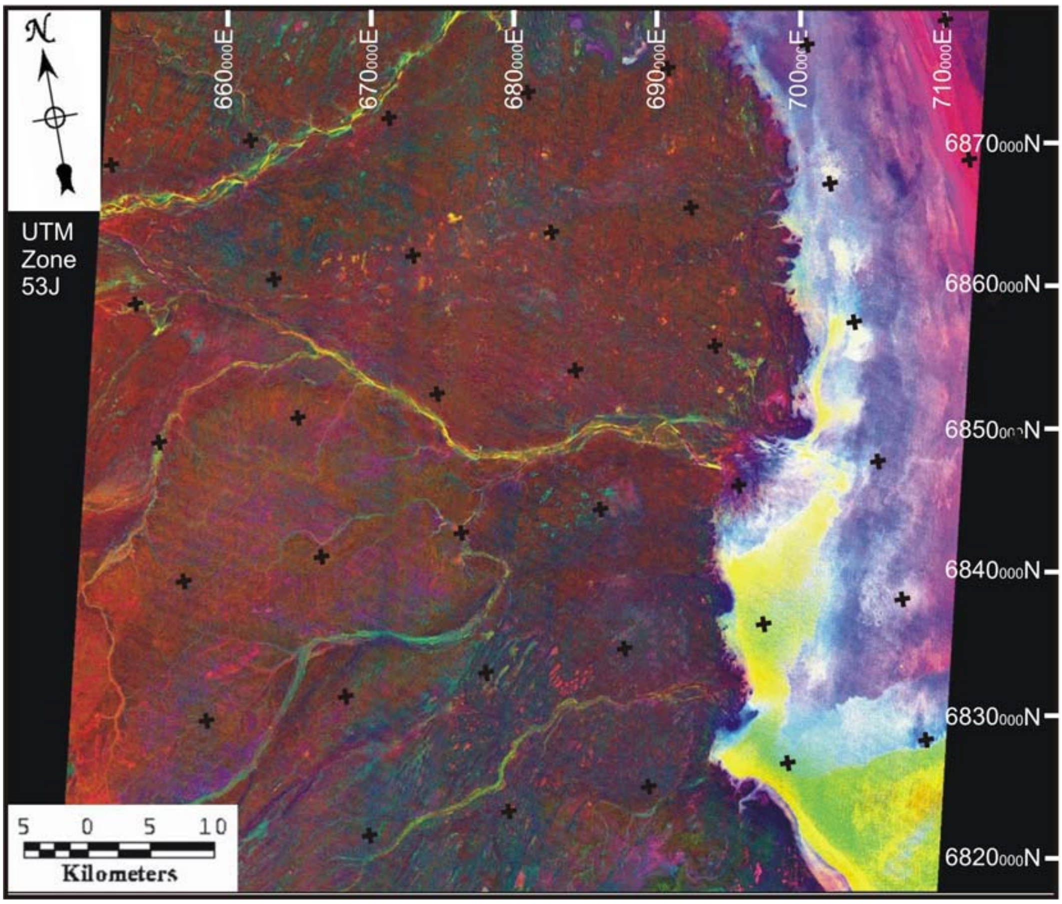

**Figure 4.25: Rowan's Ratios of RGB muscovite/illite/smectite, calcite, alunite/pyrophillite for the Neales Fan showing a strong signal response to muscovite minerals across the scene and an association with sand dunes and alunite/pyrophillite.**

### Spectral Indices

The information contained in the silica index image for this area reveals that large portions of the scene are covered with silica-dominated minerals (Figure 4.26). This is to be expected as the surface lags in the region are dominated by silcrete and quartz. Zones that posses a low silica index (SI) are therefore informative.

The most notable area with a low SI is the Lake Eyre surface. Again, this is to be expected, as the lake is an evaporative playa and often covered in a crust of halite. Where there is no crust the lake sediments are dominated by fine-grained sandy mud that would not have a high SI.

Alluvial channels and associated floodplains display low SIs. This is interpreted to be a function of the clay content. Several overflow, or chute channels, can be seen avulsing away from and rejoining both the Neales River and Umbum Creek. Similarly across the main Neales Fan is a broad area resembling a drainage pattern that displays a low SI.

Areas where alluvial channels cut down into the surrounding landscape and form erosional alluvial depressions have low SIs. This is due to the exposure of the underlying geology that consists primarily of Bulldog Shale and Oodnadatta Formation, which are dominantly mud and clay based units.

### Supervised Classification

The Mahalanobis supervised classification was also conducted for the Neales Fan ASTER scene. Apart from a little noise in the output this technique produced readily interpretable results (Figure 4.27 & Table 4.2).

Lake Eyre and the associated delta sediments are clearly visible in yellow in Figure 4.27.

The Neales Fan, classified with a training area from dunes located at the edge of the lake, is visible in red. It has a distinct boundary parallel to a lineament that crosses the Neales Fan in a north-south direction (Figure 4.27).

Alluvial channels and erosional depressions are classified in cyan and form a large region associated with a dissected gibber plain. This plain is evident as the zones of green amongst the cyan (Figure 4.27).

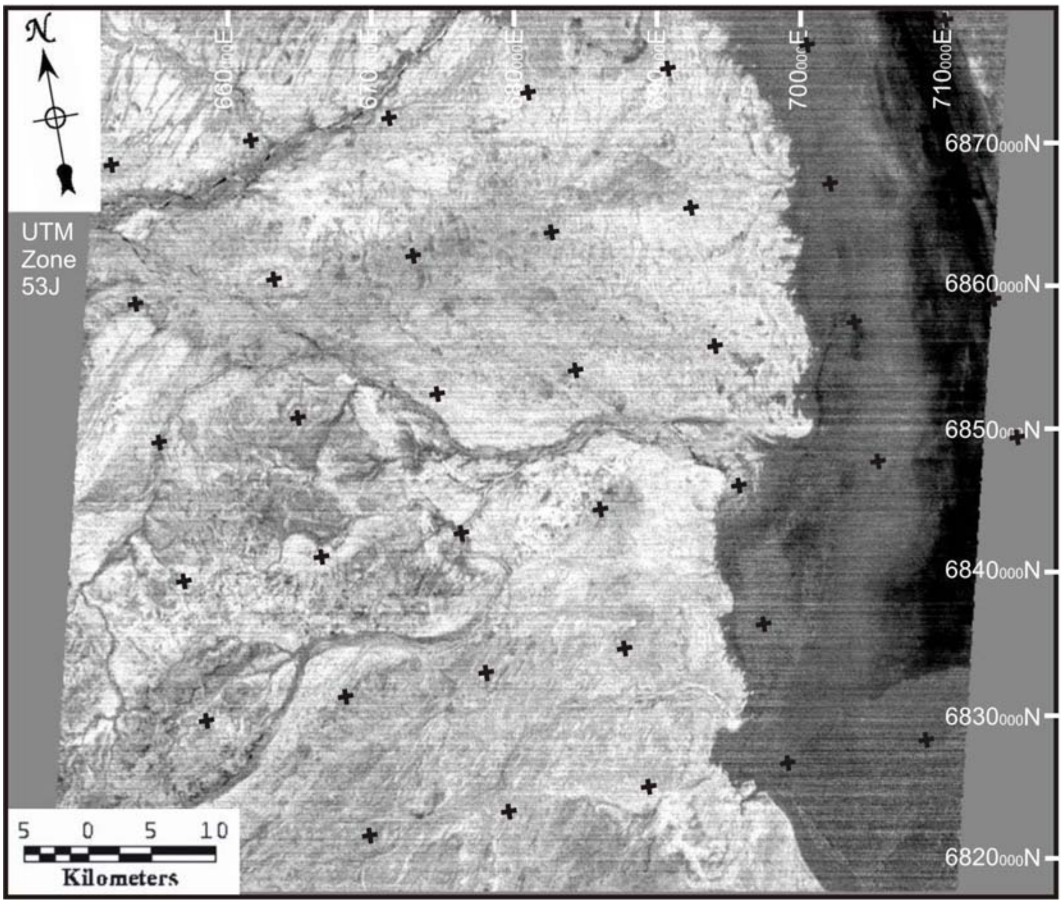

**Figure 4.26: TIR Silica Index for ASTER Neales Fan showing a strong signal response for areas covered in gibber plains.**

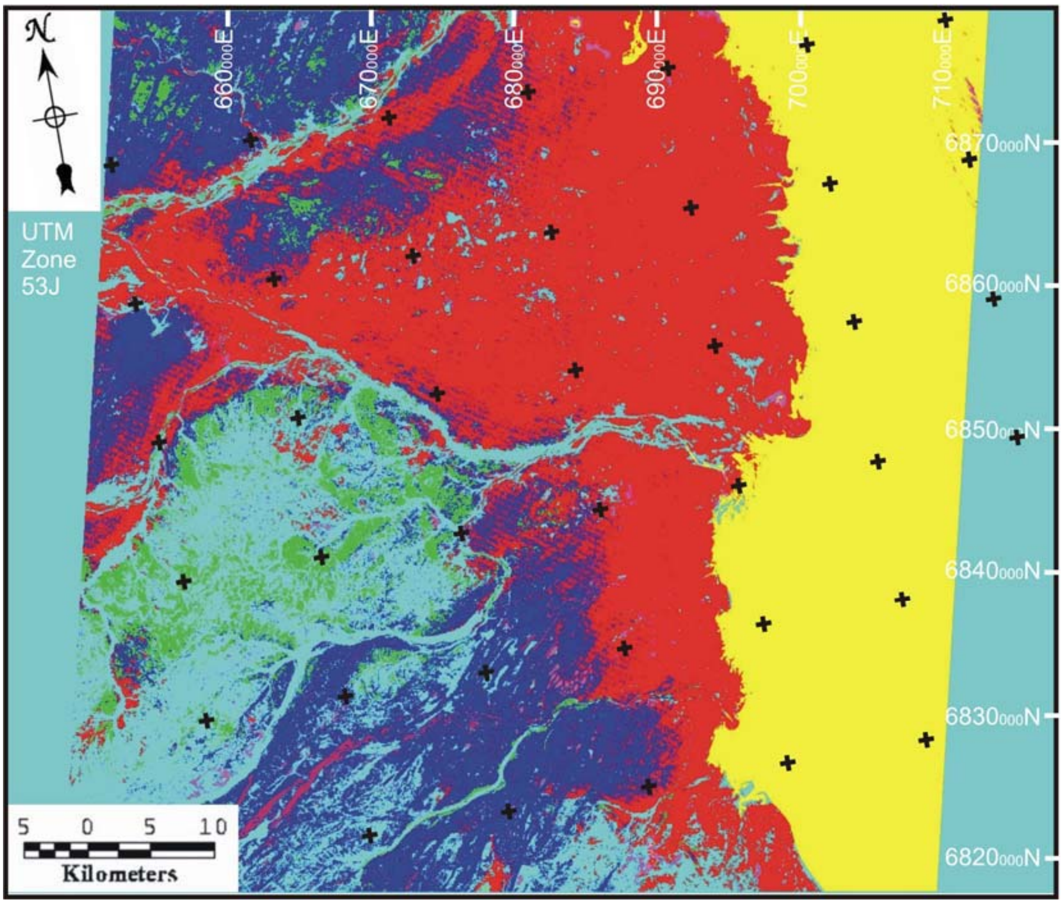

**Figure 4.27: Mahalanobis Distance Classification Image for Neales Fan ASTER scene, showing areas classified into three main units: areas of gibber plains (dark blue), areas undergoing active erosion (cyan) and areas that have been reworked by fluvial/shoreline processes (red).**

**Table 4.2: Training areas for Neales Fan**

| UNIT COLOUR | DESCRIPTION |
|---|---|
| Red | Clay dunes |
| Green | Gibber plain |
| Blue | Sand dunes |
| Yellow | Umbum Creek delta |
| Cyan | Alluvial erosional depression |
| Magenta | Clay pan |
| Maroon | Alluvial plain |

### 4.6.3 Sunny Creek

Endmember Extraction

The NNPCA results display a very blue image suggesting that there is a lot of spectral similarity across the scene (Figure 4.28). Non-blue areas consist of the exposed bedrocks of the Davenport Ranges, alluvial channels and interdunal playas. Areas in green represent either erosional depressions or alluvial plains (Figure 4.28).

Of the blue coloured endmembers, the darker colours correspond to gibber-covered surfaces or to Proterozoic sediment. The paler blues define the large longitudinal dunefield in the southern portion of the image (Figure 4.28).

The ICA endmember extraction provides further definition of units (Figure 4.29). The southern dunefield area is clearly divided into an eastern and western portion with the pink endmember dominating the east and the green endmember the west, reflecting the distinction observed in the radiometric data that shows potassium-rich dunes to the west of the Davenport Ranges and uranium-rich dunes to the east (Figure 4.29). The red endmember is associated with outcrops of highly ferrugenised sandstones and conglomerates of the Algebuckina Sandstone (Rogers & Freeman, 1996) (Figure 4.29). Orange defines erosional depressions and these can be seen to grade into pale green representing alluvial depositional plains (Figure 4.29). The bright blue in the northwest corner coincides with alluvial fans and the purple and blue region represents gibber plains (Figure 4.29).

Rowan’s Ratios

Figure 4.30 shows that the Davenport Ranges have a strong response in the calcite band ratio and that this sediment in the headwaters flows down the alluvial channels.

The blue band is occupied by the alunite/pyrophyllite ratio and this can be seen to have a strong response associated with the longitudinal dunefields.

These responses are evident again in Figure 4.31 with the dolomite in the green band displaying a milder expression. It also accentuates the alluvial fan sediments in the northwest corner of the scene that are more intensely orange than in Figure 4.30, suggesting a dilution by calcite. Similarly, the intensity of the alunite/pyrophyllite response in the southern dunefields has increased.

Figure 4.32 displays the region without the alunite/pyrophillite band, and its influence can be seen in the lower intensity colours of the remaining display bands inferring less concentrated mineralisation. The calcite and dolomite signals are evident throughout as the blue-green colour that dominates the scene. The alluvial fans in the northwest are displayed as purple, representing a mix of muscovite/illite/smectite and dolomite signals that is consistent with fans covered by clasts derived from the Proterozoic sediments of the Davenport Ranges and mixed with fine-grained silts and clays in the interstices. The muscovite/illite/smectite is also prominent along the alluvial channels and as interdunal playas (Figure 4.31).

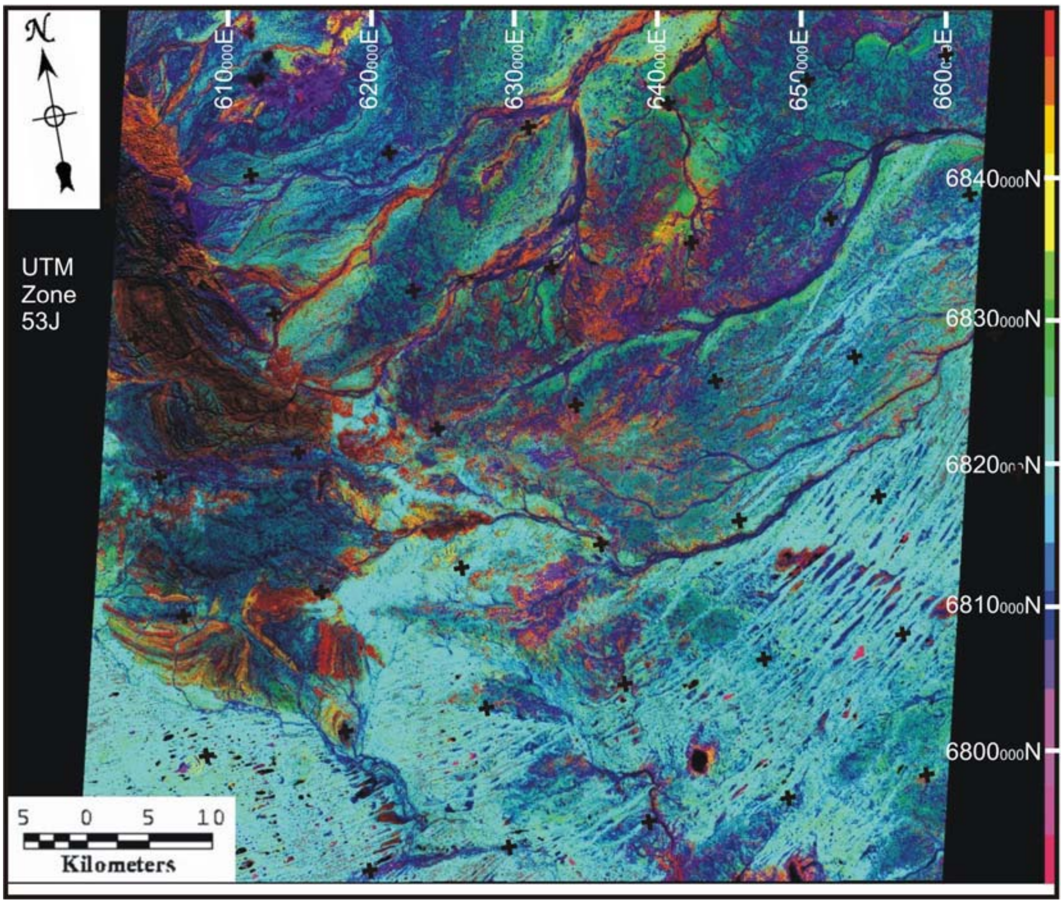

**Figure 4.28: Non-Negative Principal Component Analysis (NNPCA) of ASTER results for Sunny Creek showing dunefields to the south with significant inputs of sand from reworked Jurassic sediments.**

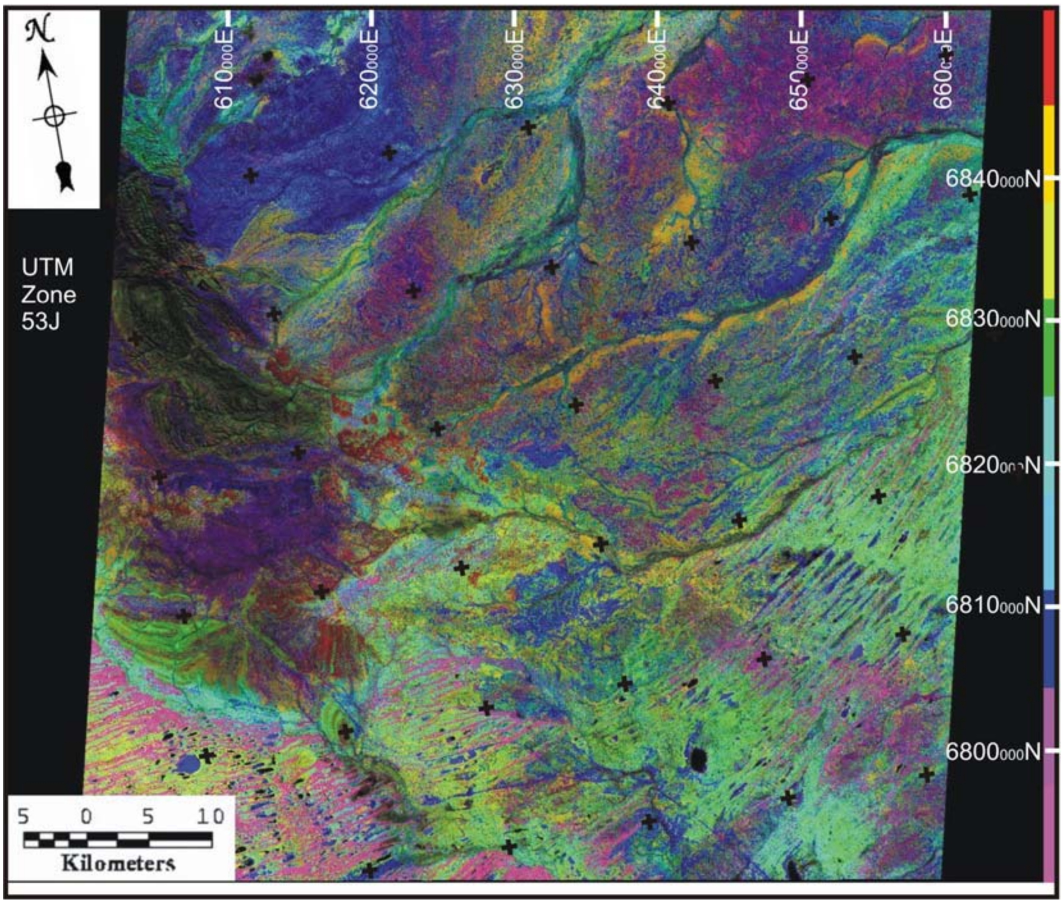

**Figure 4.29: Independent Component Analysis (ICA) ASTER Image for Sunny Creek scene showing a difference in dunefield composition between eastern dunes in green and western dunes in pink. Algebuckina Sandstone is displayed clearly in red. Orange defines erosional depressions that grade into alluvial depositional plains defined in pale green.**

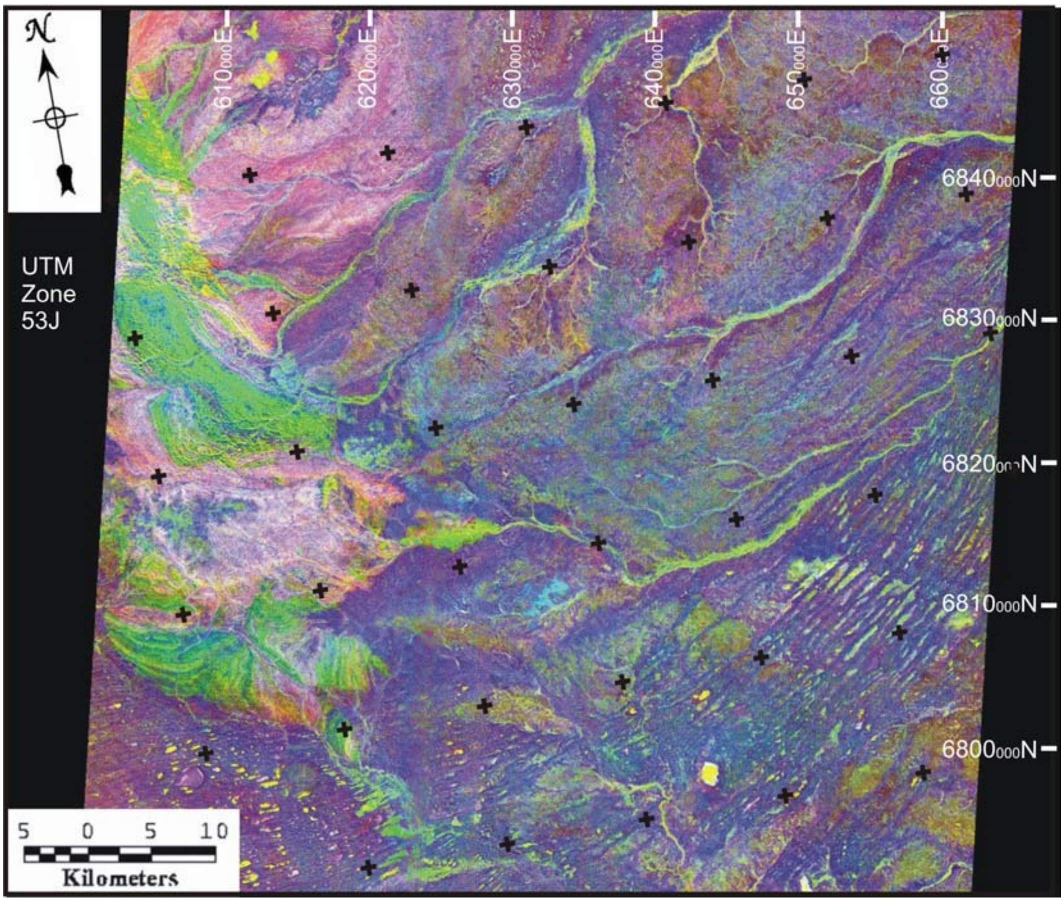

**Figure 4.30: Rowan's Ratios for RGB muscovite/illite/smectite, calcite, alunite/pyrophyllite for Sunny Creek ASTER scene, showing that the Davenport Ranges have a strong response in the calcite band ratio in green corresponding to the Skillogalee Dolomite Formation. This signal is also evident in the alluvial channels flowing from the ranges and is interpreted as the provenance for the sediment in these streams. Dunes in the east are dominated by alunite/pyrophillite signal in blue. Dunes in the west show a greater influence from muscovite/illite/smectite.**

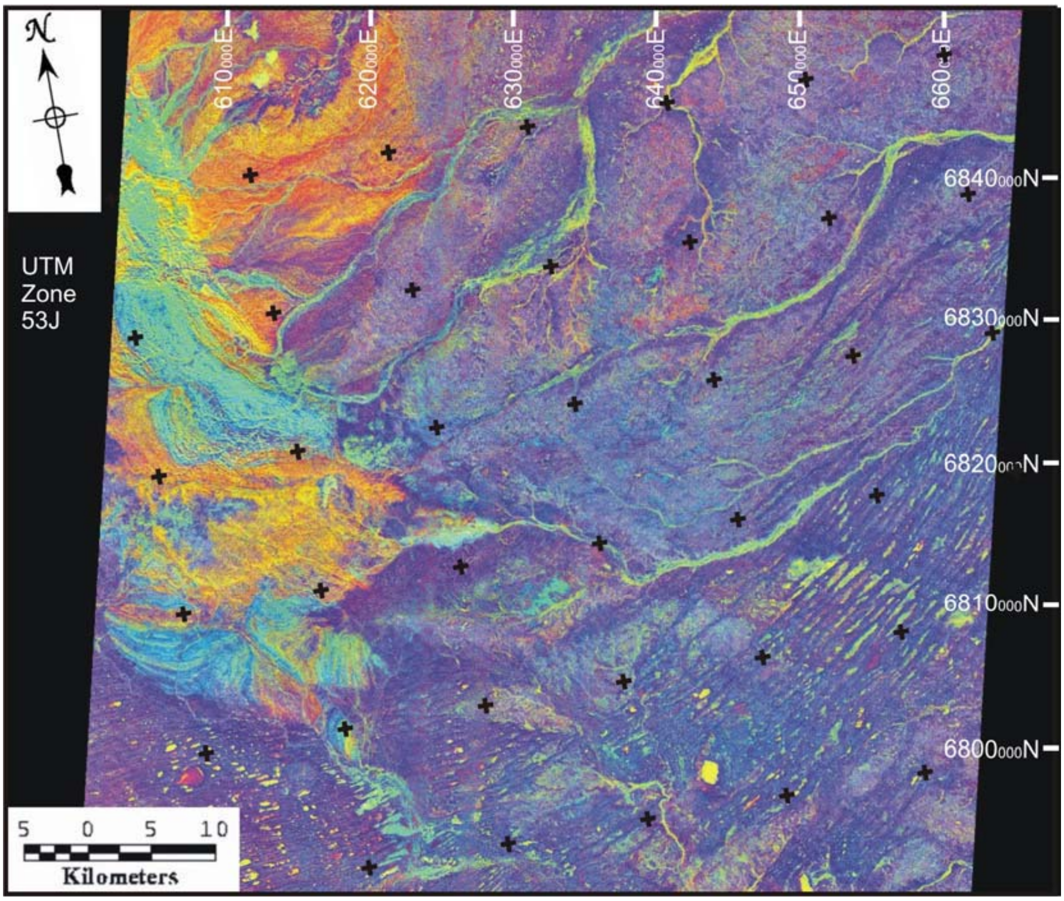

**Figure 4.31: Rowan's Ratios for RGB muscovite/illite/smectite, dolomite, alunite/pyrophyllite for Sunny Creek ASTER scene, showing a strong response from the alluvial fan sediments.**

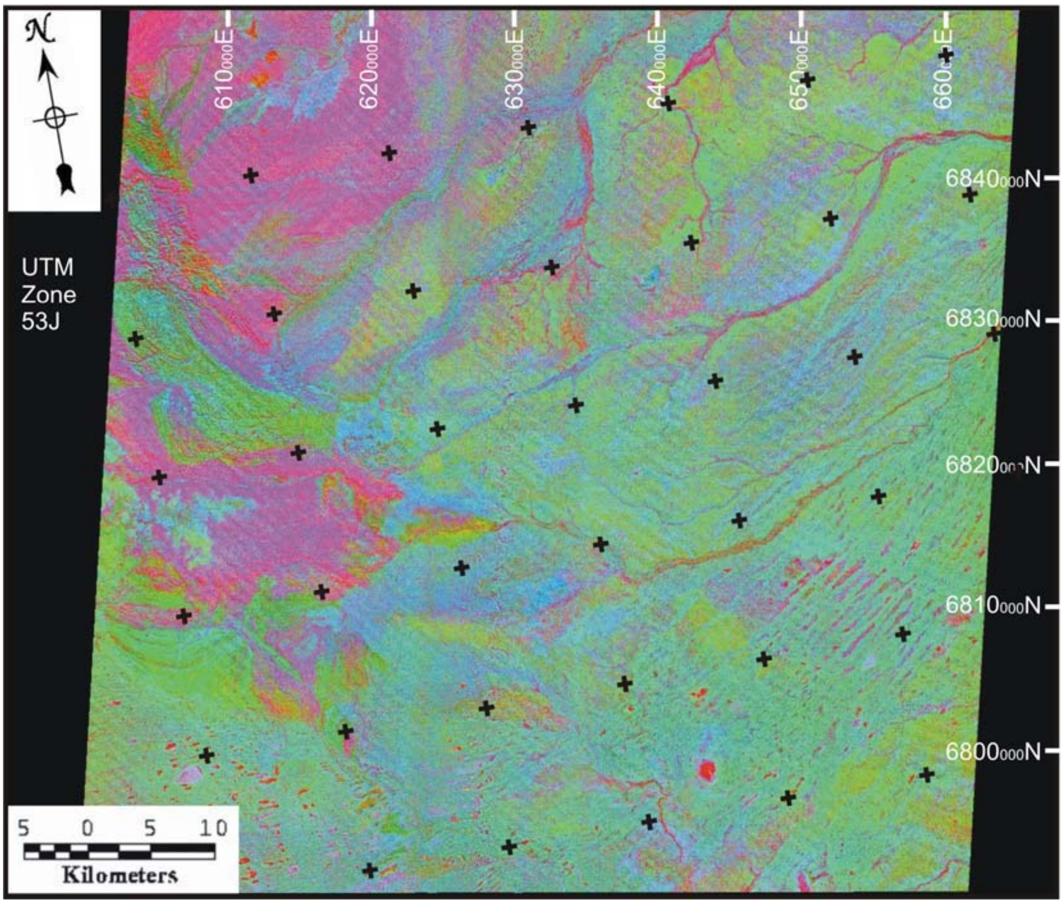

**Figure 4.32: Rowan’s Ratios for RGB muscovite/illite/smectite, dolomite, calcite for Sunny Creek ASTER scene, showing a mixed calcite and dolomite signal across the landscape. Alluvial fans have a strong muscovite mineral signature.**

### Supervised Classification

The Mahalanobis Distance Classification (Figure 4.33 & Table 4.3) for Sunny Creek displays many of the attributes seen previously.  The separation between the eastern and western dunefields is one example.

The red classification unit clearly is not restricted to identifying Algebuckina Sandstone alone and there are several outliers.  Many of these are associated with Proterozoic sediment and represent similar members in other units of the Adelaidean sequence.  Others are associated with zones of erosion (Figure 4.33).

The green alluvial fan endmember shows a similar response classifying other areas that are not the same landform.  Again, these include zones of Proterozoic sediment and erosion.

The interrelationship of the coral alluvial erosional depressions and chartreuse alluvial depositional plains endmembers is informative.  These two units are interspersed along alluvial valleys and reveal cycles of erosion and deposition occurring simultaneously in different locations, providing clear evidence of the heterogeneous nature of the erosional/depositional cycle in the modern landscape.  The erosional depressions are mainly formed over deposits of Bulldog Shale and similar Mesozoic sediments.

## 4.6.4 ASTER Summary

Analysis of three ASTER scenes has shown the relationship of landforms to each other and some of the chemical composition of the landforms.  Degraded alluvial fans flank the eastern edge of the Davenport Ranges.  These are dominated by muscovite/illite/smectite spectra, suggesting that they are composed predominantly of clays.  A distinct unit is associated with the fan-shaped colluvial erosional rises in the Four Hills region.  This area possesses a different spectral signal to alluvial fans formed to the north of this location.  Sand dunes are evident; overprinting erosional colluvial plains throughout the study area. They have a strong affinity for alunite/pyrophyllite.

The Neales River has incised through a relict surface and appears to contain sediment derived from a provenance similar to the outcropping rocks in the Davenport Ranges.  The Neales Fan has a palaeo-distributary network preserved across its surface.  The heterogeneity of the modern landscape is evident as alternating deposition and erosion along some streams.  Streams appear to transport calcite and alunite/pyrophillite.  Gibber plains are high in silica content.

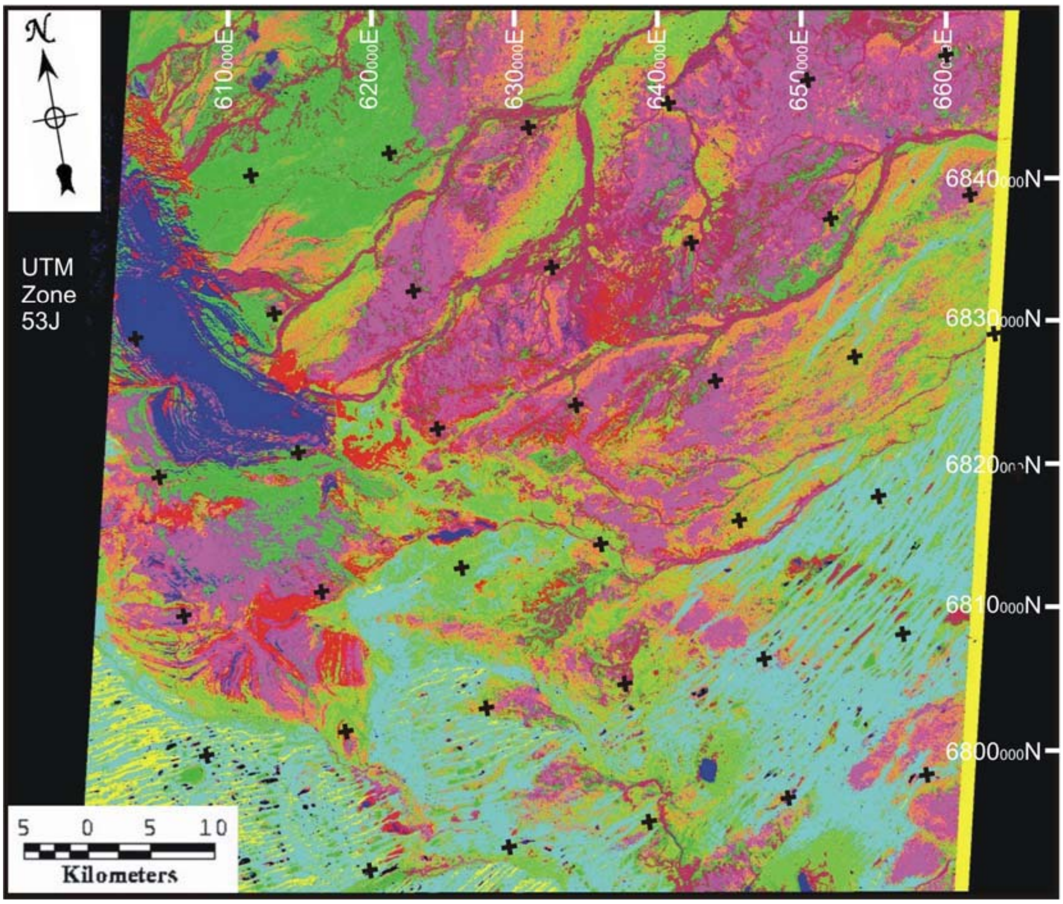

**Figure 4.33: Mahalanobis Distance Classification image for Sunny Creek ASTER scene, showing strong signal separation between defined units. Proterozoic sediments of the Davenport Ranges are well-defined in blue, as are Algebuckina Sandstone sediments in red. Green defines areas associated with erosion of Bulldog Shale, particularly in the Hawker Springs area. The eastern and western dunefields are clearly visible in yellow and cyan respectively. Alluvial channels are evident in maroon. These are flanked by alluvial erosional depressions in coral and alluvial depositional plains in chartreuse. These two features are interspersed downstream and demonstrate the heterogeneous nature of the erosion/deposition cycle in the region. Surficial lags composed of degraded fluvial sediment are evident in magenta. These mantle the area between Sunny and George Creeks and the area around Mount Anna where remnants of silcrete-cemented fluvial sediment are preserved and topographically inverted in the landscape.**

**Table 4.3: Training areas for Sunny Creek**

| UNIT COLOUR | DESCRIPTION |
|---|---|
| Red | Algebuckina Sandstone |
| Green | Alluvial Fans |
| Blue | Proterozoic sediment |
| Yellow | Eastern dunefield |
| Cyan | Western dunefield |
| Coral | Alluvial erosional depressions |
| Chartreuse | Alluvial depositional plains |
| Magenta | Gibber plains |
| Maroon | Alluvial channels |

## 4.7 JERS-1 SAR

Interpretation of radar images has different requirements to interpreting remote sensing imagery in the visible and infrared spectra. This is because the radar signal behaves differently, as it is an active system where the radar is beamed at the earth's surface and the signal return measured, rather than passive sensing of naturally occurring electro-magnetic radiation (e.g. Landsat TM). Several factors affect radar signal return.

Direct deflection of the radar signal from objects that are oriented at right angles to the incidence beam results in increased signal return and appear bright on the radar image (Babu Madhavan *et al.*, 1997). Similarly, surface roughness alters the signal, with rough areas returning more signal due to direct deflection, and texturally smooth areas, such as water bodies, reflecting the radar signal away from the sensor, thus appearing as dark areas on the radar image (Williams & Greeley, 2004). Additionally, it is the property of metal to conduct electromagnetic radiation and as such these appear as very bright features on radar images (Daniels *et al.*, 2003). Fences are a good example. These can usually be distinguished due to their obviously man-made linear nature. Methodology on the analysis of JERS1-SAR is presented in Chapter 2.2.3.

Two JERS-1 SAR scenes were chosen for the purpose of this study (Figure 4.34). Scene A (Figure 4.35) is located over the Davenport Ranges; it shows very little signal return across the alluvial fans flanking the ranges. These contrast with the area of higher signal return between George and Sunny Creeks. This area is characterised by surface colluvial deposits dominated by large sub-rounded cobbles of varying lithologies. Streams possess high signal return and clay pans are evident as dark areas. Lithic Proterozoic sediments are very evident as areas of strong signal response with faulted margins clearly displayed due to direct reflection of the radar signal. Similarly, metamorphic inliers and pods of topographically inverted silcrete also display strong signal response due, again, to direct reflection. Mound springs are areas that are highly vegetated in this arid environment and this vegetation causes strong signal response due to surface roughness (Figure 4.35).

NOTE: This figure is included on page 4-45 of the print copy of the thesis held in the University of Adelaide Library.

**Figure 4.34: Location diagram for JERS-1 SAR data showing the position of the JERS-1 SAR tiles used for analysis (Landsat 7 ETM mosaic courtesy of Exxon-Mobil).**

NOTE: This figure is included on page 4-46 of the print copy of the thesis held in the University of Adelaide Library.

**Figure 4.35: JERS-1 Synthetic Aperture Radar Scene A, showing strong reflections from two areas of bedrock and exposed faulted margins, moderate reflection from stream beds, sand dunes, mound springs, escarpments and areas with high surface roughness and poor reflection from clay. Original Data © NASDA, MITI (1995) distributed by ACRES.**

Scene B (Figure 4.36) is located over the Neales Fan; it shows very little signal return across the Neales Fan. Sand dunes can be distinguished on the surface and this appears to be due to direct reflection from the flanks of the dunes that are aligned approximately north-south, close to right angles with the satellite trajectory. Major streams are evident as features of high signal response and this is probably due to a combination of direct reflection from stream banks and surface roughness effects from vegetation and stream sediment. Little else distinguishes the surficial colluvial deposits that cover most of the surface of the Neales Fan. This may be due to signal attenuation of the colluvial lag absorbing the radar signal, resulting in poor signal response.

A secondary aim of the radar analysis was to attempt to map textural variation between colluvial and alluvial deposits and to detect previously unlocated silcrete outcrops via remote sensing. Many of these silcrete outcrops contain preserved features such as graded bedding and point-bar morphology that indicate a palaeochannel origin for the sands that were silicified. The locations of these features within the landscape are good indicators of the evolution of that landscape.

An examination of Scene A and Scene B shows that there is little to distinguish surface textural units. There is a region of high signal response along the north bank of Sunny Creek that suggests a texturally coarser unit. The highest signal response zones from this region coincide with known outcrops of silcrete. These are topographically inverted, standing high in the landscape and are surrounded by a very coarse colluvial apron of angular silcrete clasts. The silcrete is also evident in the ASTER datasets. A meld of ASTER (see Chapter 4.6) and JERS-1 datasets, combining the textural detection of radar with the chemical spectra detection of ASTER, should theoretically be capable of identifying zones of silcrete.

NOTE: This figure is included on page 4-48 of the print copy of the thesis held in the University of Adelaide Library.

**Figure 4.36: JERS-1 Synthetic Aperture Radar Scene B, showing high reflection from some areas of the Lake Eyre playa surface, streams, sand dunes, mound springs and topographically inverted silcrete (indicated by arrows); and poor reflection from claypans. Original Data © NASDA, MITI (1995) distributed by ACRES.**

## 4.8 JERS-1 SAR AND ASTER IMAGE MELDING

JERS-1 SAR and ASTER images have been melded to combine the textural detection of radar with the chemical spectral detection of ASTER to identify silcrete. Details on JERS-1 SAR and ASTER image melding are presented in Chapter 2.2.4. Figures 4.37 and 4.38 show the two sets of melded scenes. It is possible to distinguish differences between colluvial units based on texture and composition, as can be seen in Figure 4.37, where there is a clear difference between the alluvial fans that flank the Davenport Ranges and the sediment preserved on the interfluve between Sunny Creek and George Creek. Geologic units are visible within the Davenport Ranges with Skillogalee Dolomite, Bungadillina Monzonite, Algebuckina Sandstone and Cadna-Owie Formation readily distinguishable (Rogers & Freeman, 1996). Claypans and mound springs are very well defined in the meld image and appear as red and orange zones. Alluvial overbank plains flanking the Neales River are clearly marked.

Figure 4.38 shows compositional structure across the surface of the Neales Fan. Areas of gibber plain are displayed in green; yellow tends to highlight eroded alluvial channels and sand dunes. Alluvial sand plains are visible in orange and are associated with interdunal pans in blue. The relative distribution of these different units distinguishes several lineaments and structural trends. The sand plains and pans appear to be the remnants of a degraded palaeo-channel or palaeoflood deposits. A crevasse splay can be seen diverging from the sharp bend in Sunny Creek and a palaeochannel overflow leaving the Neales River near Brown Creek. Coastal dunes and palaeo-shorelines are readily distinguished inland of the modern shore of Lake Eyre. Topographically inverted silcretes are distinguished in purple and pink along the northern edge of Sunny Creek, however, these colours are not diagnostic.

### Summary

JERS-1 SAR image melding with ASTER data has revealed features in the landscape that were not identifiable from individual satellite datasets or other techniques (e.g. Band Ratios, Chapter 4.6). This technique identified a crevasse splay or palaeochannel feature leaving the sharp bend in Sunny Creek as well as probable palaeochannels formed along the continuation of Browns Creek. Other possible palaeochannels across the surface of the Neales Fan were highlighted. These features are interpreted to have been modified by aeolian processes forming broad sand sheets and sand dunes across the Neales Fan. Outcrops of silcrete were evident on the meld image; however, their characterisation was not diagnostic as other unrelated features possessed a similar response. Well-developed gibber plain surfaces are evident on the northern edge of the Neales Fan. These are interpeted as relict surfaces. Alluvial fans developed on the flanks of the Davenport Ranges are distinct from the surficial sediments on the interfluve between George Creek and Sunny Creek.

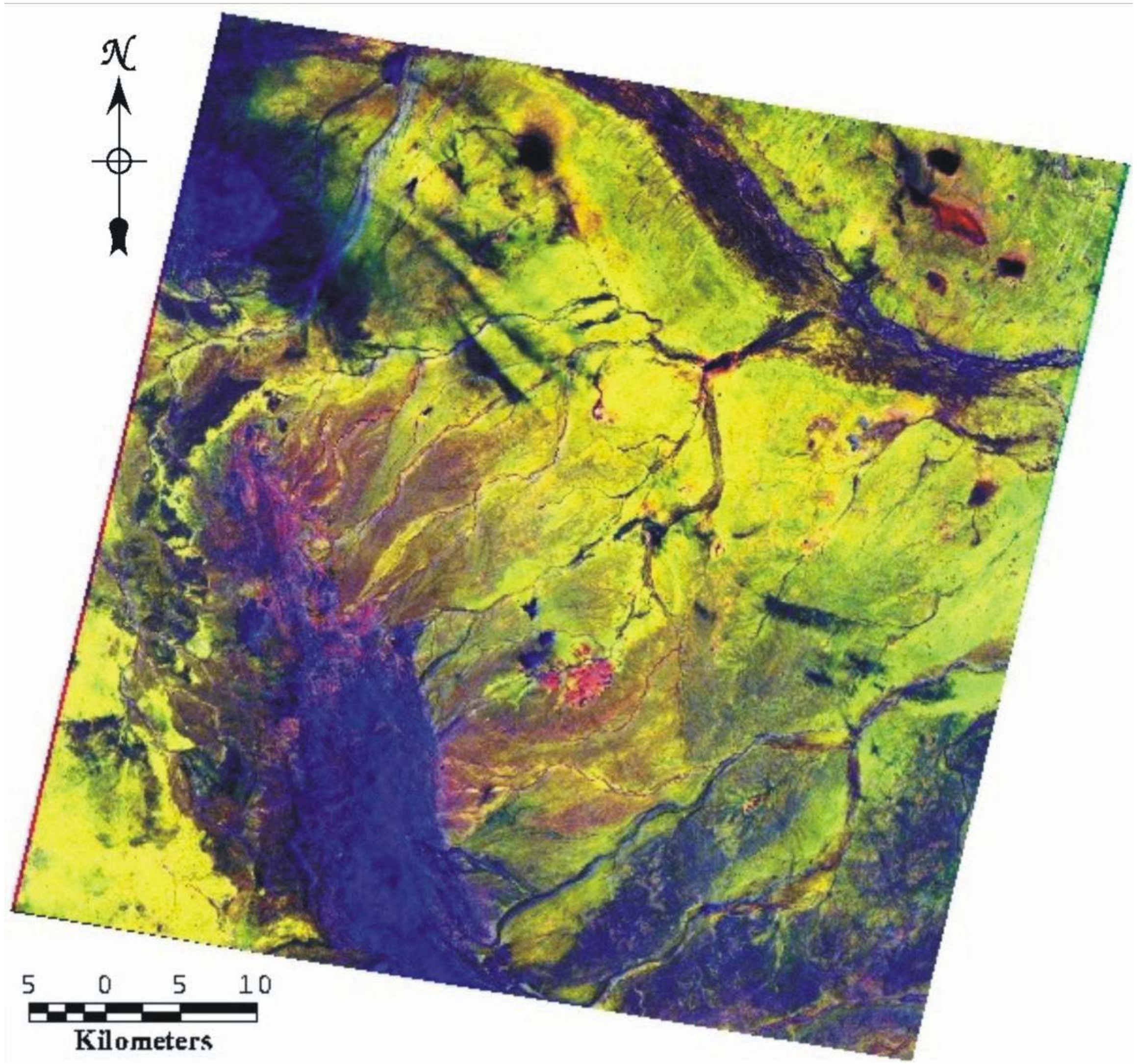

Figure 4.37: Scene A meld image JERS-1 SAR/ASTER showing distinction between geologic units within the Davenport Ranges. Claypans and springs are evident as red areas and floodplains flanking the Neales River are clearly defined in dark blue. The surficial lags between George and Sunny Creek in blue are distinct from the alluvial fans flanking the ranges in purple.

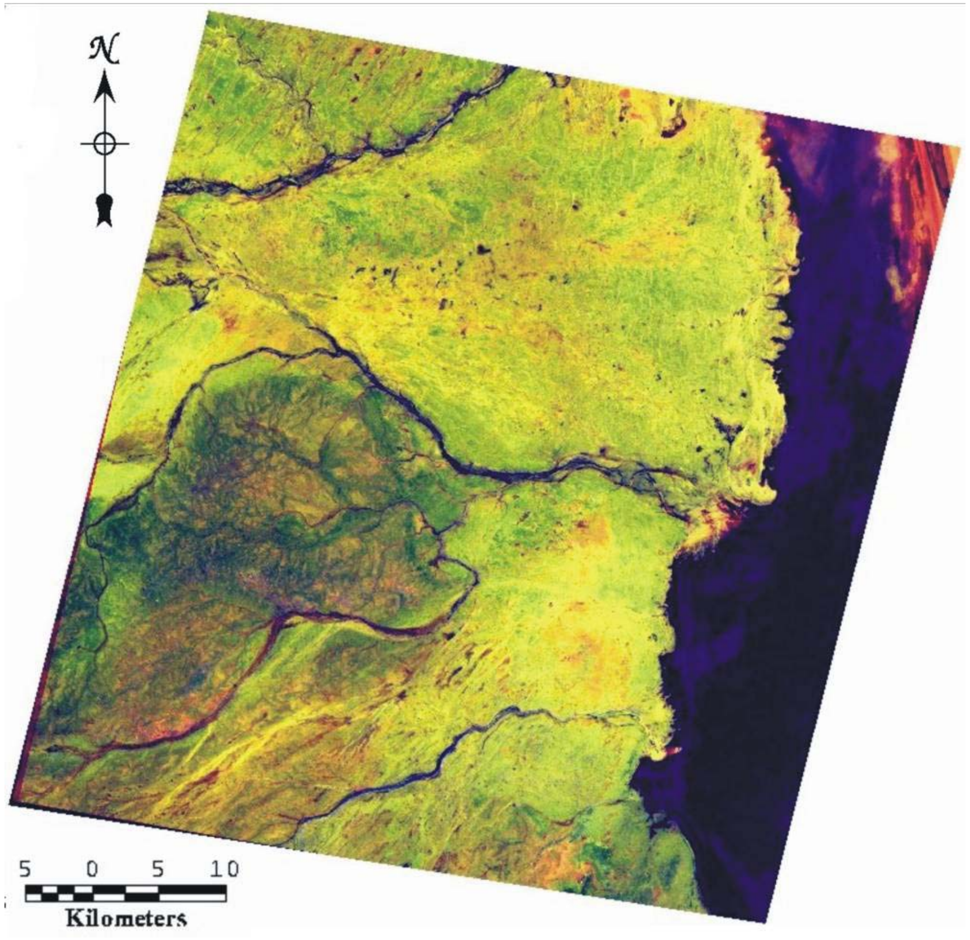

Figure 4.38: Scene B meld image JERS-1 SAR/ASTER showing the surface of the Neales Fan.  Areas of gibber plain are green; yellow tends to highlight eroded alluvial channels and sand dunes.  Alluvial sand plains are visible in orange and are associated with interdunal pans in blue.  A crevasse splay can be seen diverging from the sharp bend in Sunny Creek and an overflow leaving the Neales River where Brown Creek joins along a basement lineament.  Coastal dunes and palaeo-shorelines can be distinguished near the modern shore of Lake Eyre.  Topographically inverted silcretes are distinguished in purple and pink along the northern edge of Sunny Creek.

## 4.9 REMOTE SENSING SUMMARY

Remote sensing techniques have revealed an assortment of valuable information concerning the geology and geomorphology of the study area. In terms of landform identification, Landsat and ASTER data provide very strong capabilites. Similar arrangements of landforms are evident across several remote sensing platforms. In broad terms these are:

- Relict land surfaces overprinted by sand dunes north of the Neales River;
- Exposed Proterozoic sediments of the Davenport Ranges;
- Degraded alluvial fans flanking the northern Davenport Ranges;
- Alluvial fans that differ in composition to the northern fans and form the region surrounded by Davenport Creek, Umbum Creek and Sunny Creek;
- Lowland surfaces; and,
- A bifurcating, degraded palaeochannel across the Neales Fan.

Streams in this region tend to be controlled by underlying geological structure that also influences the arrangement of landform features. Stream diversions and landscape surfaces that suggest rearrangement by structural, possibly neotectonic, movement are evident.

The distribution of mineral composition and sediment type in the landscape can be determined. Gibber plains are often covered in a deep red desert varnish and this is reflected in the high level of iron detected for these units. Red longitudinal sand dunes respond in a similar manner. These two units are also high in silica; the gibber plain often formed by silcrete clasts.

Fine-grained sediments are associated with erosional depressions and areas of deposition such as claypans and floodouts.

The degraded alluvial fans possess a high degree of late weathering cycle smectitic clays as compared to sand dunes that have early cycle pyrophillitic clay content. This can be interpreted to indicate that the fans are significantly older than the dunes.

Chemical transport down streams is dominated by calcite. This may represent a chemical weathering feature, as a result of the composition of stream waters flowing from the Davenport Ranges. The geological composition of sediments in the Neales River can be strongly correlated with those present in the Davenport Ranges. Further north, the Neales River passes through a region of exposed Proterozoic bedrock and carries sediment from this region of similar composition to that seen in the ranges. The landscape as a whole is highly weathered and degraded.