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THE USE OF LANDSAT IMAGERY IN RELATION TO AIR SURVEY IMAGERY FOR TERRAIN ANALYSIS IN NORTHWEST QUEENSLAND, AUSTRALIA

ERTS FOLLOW-ON PROGRAMME STUDY Nº 2692B (29650)

FINAL REPORT

by

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1. INTRODUCTION

The investigations cover the Gregory River - Mount Isa - Cloncurry - Dobbyn area of northwest Queensland, Australia (Figures 1, 2 and 3). They were undertaken with a grant from the United Kingdom Department of Industry, under a contract with NASA and in collaboration with the Bureau of Mineral Resources and the CSIRO of Australia.

The main objective of the investigation was an evaluation of the imagery taken by the multi-spectral scanners on ERTS/LANDSAT I and 2 at different seasons of the year, namely March, July, September and December, for analyses of the features of the natural terrain with particular reference to geological mapping and mineral exploration. The imagery has been evaluated with reference to multi-spectral photography and thermal line scan imagery of selected areas flown in 1971 and 1975 (Figures 4, 5, 6, and 7) as part of a research project sponsored initially by the Ministry of Technology, subsequently Procurement Executive, Ministry of Defence. Interpretation has been verified by ground truth investigations.

2. TECHNIQUES

The multi-spectral imagery from the LANDSAT satellites and the multi-spectral and thermal imagery from aircraft have been interpreted both visually using additive viewers built at Bedford College and by semi-automated techniques using a Joyce Loebl 3CS microdensitometer and computer processing of the data.

Following initial studies of black and white prints of individual MSS bands of LANDSAT imagery at the 1:1 million scale, positive photographic plates were made of each MSS band from the NASA negatives. Using an additive viewer these bands were projected through appropriate filters, and studied both individually and in combination to produce colour composites on a screen at the 1:250,000 scale. Overlays of the spectral signatures displayed at this scale were prepared and the signatures were interpreted with reference to structural features, superficial and bedrock geology, vegetation, soils and other relevant ground truth information.

Following studies at the 1:250,000 scale grids were established over the LANDSAT frames and, from the NASA negatives of each MSS band, positive photographic plates were made for each grid section. These were displayed through appropriate filters, both individually and in combination to produce colour composites at scales of 1:50,000 or greater. Overlays of the spectral signatures have been prepared and interpreted with reference to the same environmental parameters as for the whole frame. Additionally, overlay maps showing (a) spectral tone and (b) spectral colour have been prepared using respectively systems of shading and symbols which permit production of black and white prints showing tone and colour individually and also in combination to portray spectral signatures. Separate maps showing vegetation, bedrock and superficial geology, faults and lineaments interpreted from the imagery have been prepared for selected areas.

Both for the whole LANDSAT frames and for individual grid sections of these, colour transparencies have been made of the individual MSS bands projected through appropriate filters and of the colour composites produced by combinations of them. These transparencies have been scanned and digitized with a Joyce Loebl 3CS microdensitometer and the data processed.

The data on the computer compatible tapes of LANDSAT imagery has been extracted using the programmes given in the Appendix and from the microfilm output positive photographic plates have been made and used to interpret the imagery in the same way as those produced from the negatives. Additionally, it has been possible to 'stretch' the information within given density ranges and thereby obtain superior colour composites and higher quality transparencies for subsequent scanning and data processing. The imagery from the CCT's has been displayed at scales of up to 1:10,000.

The interpretations of the LANDSAT imagery have been compared with those from multi-spectral photography at scales of 1:15,000 and 1:5,000. The aerial photography has been studied using conventional 9 x 9 inch black and white prints and a Hilger and Watts stereoscope, and it has also been studied using a system built at Bedford College which permits simultaneously the stereoscopic viewing of plates of the panchromatic film displayed at the same scale as the output from the microdensitometer and the display of the infra red colour or the true colour film on a projection screen.

3. ACCOMPLISHMENTS

The investigation covered by this report forms part of a long term research programme initiated in 1970, when, following promising results from studies of the early space photographs of central Africa and from experimental multi-spectral photography from a low flying aircraft over a sequence of Proterozoic sedimentary rocks in South West Africa and Botswana in which mineralized zones were distinguished by anomalous plant communities, northwest Queensland was chosen for evaluation studies of multi-spectral photography and thermal line scan imagery in the recognition of plant communities, physiographic and geological features assisting mineral exploration with the ultimate objectives of interpreting aircraft and satellite imagery using automated data handling techniques (Cole, Owen-Jones and Custance 1973).

Northwest Queensland was chosen for several reasons. The vegetation, soils, physiography/geomorphology and geology of the area was already documented on a regional scale and detailed information was available for small areas (Blake 1938; Twidale 1956 a and b; Whitehouse 1940; de Keyser 1958; and Denmead 1960; Carter Brooks and Walker 1961). The area is characterized by the juxtaposition of broad plains and dissected hilly terrain developed over Proterozoic and later geological formations which have a general north-south orientation and contain a variety of ore deposits, many of which could be sensed in a relatively small east-west flying block. Within the area the Dugald River Lode, northwest of Cloncurry, offered unique opportunities for sensing a large and little disturbed lead-zinc deposit outlined by an anomalous plant community (Nicholls, Provan, Cole and Tooms

1965) while the Lady Annie area, northwest of Mount Isa, where exploration was in progress offered a challenge to the use of remote sensing techniques in locating other, then unknown, deposits. Within this area the vegetation cover was known to reflect closely the nature of both the bedrock geology and the superficial cover (Nicholls, Provan, Cole and Tooms 1965) while the semi-arid climate promised clear atmospheric conditions for the acquisition of high quality aerial photography and LANDSAT imagery.

Under the initial research grant from the United Kingdom Ministry of Technology, multi-spectral and thermal imagery was acquired for the Mary Kathleen - Cloncurry and Dugald River areas (Figure 4). Similar imagery for the Lady Annie area (Figure 5) was flown for a mining company for whom the investigators undertook the interpretation on a consulting basis. The areas flown during the April-May period in 1971 when it was anticipated that, following the summer rains which promote active plant growth, the conditions would be most suitable for evaluating the relationships between spectral signatures, vegetation and geology. All areas were imaged at a scale of 1:15,000 while the Dugald River area was imaged at the 1:5,000 scale. The flying programme was undertaken in anticipation of receiving ERTS 1 imagery of the area. The latter however was not obtained until November 1972. In both 1971 and 1972 exceptional rains were received in western Queensland. The plant cover was in optimal condition during the air survey flying programme and in good condition during the first passes of ERTS I/LANDSAT I.

Field investigations were undertaken during and subsequent to the flying programme in 1971 and to the satellite passes in 1972.

Calibration marker boards were placed in position under each flight line for calibration of the multi-spectral photography. (Plate 1) Ground photography was undertaken to determine the contribution of plant cover, soils and bedrock to the spectral signatures. Temperature measurements were made over each type of surface (e.g. open water, moist soil, dry bedrock etc.) for calibration of the thermal imagery. The imagery was subsequently checked with reference to environmental components in the field, and soil and plant samples were collected across known mineralized zones and across spectral anomalies for geochemical and biogeochemical analyses. These investigations provided the background information for initial assessment of LANDSAT imagery.

Further investigations have been undertaken under grant from the United Kingdom Department of Industry and under contract with NASA for the evaluation of both archived and requested LANDSAT I and 2 imagery. The archived LANDSAT I imagery which has been received is given in Table 1 and the requested LANDSAT 2 imagery which has been received is given in Table 2. The latter was acquired in 1975 when again good rains fell in western Queensland. The areas covered by the imagery and studied in this report are shown in Figures 1 and 2. The availability of the requested imagery has permitted comparative studies of the information yielded by imagery at different seasons of the year. The results obtained from initial interpretations of colour composites generated from the negatives of the MSS bands were so encouraging as to warrant requests for the CCT's of the frames covering part of the study areas. The CCT's received are listed

Table 1 LANDSAT 1 imagery of northwest Queensland received from NASA

Name of Area	No of Frame NASA ID Ref.No.	Date of Imagery
Cloncurry-Dobbyn	1116-00073	16.11.1972
Cloncurry-Dobbyn	1152-00073	22.12.1972
Mount Isa-Urandangi	1027-00123	19.8.1972
Mount Isa area	1021-00121	19.8.1972
Mount Isa	1117-00132	17.11.1972
Mount Isa-Georgina River	1189-00133	28.1.1973
Cloncurry-Duchess	1206-00081	14.2.1973
Mount Isa-Gregory River	1207-00133	15.2.1973

Table 2. LANDSAT 2 imagery of northwest Queensland requested and received from NASA

Name of Area	No of Frame NASA 1D Ref. No	Date of Imagery	Date of Receipt of Imagery
Cloncurry - Dobbyn	2039 - 23555	2. 3.1975	18. 8. 1975
Cloncurry - Duchess	2039 - 23562	2. 3.1975	18. 8. 1975
Gregory River - Mount Isa	2041 - 00013	4. 3.1975	18. 8. 1975
Georgina River	2041 - 00020	4. 3.1975	18. 8. 1975
Julia Creek - McKinlay	2083 - 23503	1. 3.1975	18. 8. 1975
Lady Annie - Mammoth	2059 - 00012	22. 3.1975	3. 11. 1975
Georgina River	2059 - 00015	22. 3.1975	3. 11. 1975
Julia Creek - McKinlay	2128 - 23503	30. 5.1975	3. 11. 1975
Cloncurry - Williams River	2183 - 23552	24. 7.1975	11. 12. 1975
Julia Creek - McKinlay	2183 - 23554	24. 7.1975	11. 12. 1975
Mt Gordon - Lady Annie	2239-- 00001	18. 9.1975	2. 2. 1976
Georgina River	2239 - 00003	18. 9.1975	2. 2. 1976
Julia Creek - McKinlay	2236 - 23491	1. 9.1975	2. 2. 1976
Lady Annie - Mount Isa	2292 - 23594	10. 11.1975	13. 2. 1976
Cloncurry - Duchess	2291 - 23542	2. 11.1975	13. 2. 1976
Georgina River	2293 - 00000	11. 11.1975	13. 2. 1976

a

Table 3 LANDSAT 2 Computer Compatible Tapes of northwest Queensland received from NASA

Name of Area	No of Frame NASA ID Ref.No.	Date of Imagery	Date of Receipt of Imagery
Cloncurry-Dobbyn	2039-23555	2.3.1975	10.8.1976
Lady Annie-Mammoth	2059-00012	22.3.1975	16.12.1976
Cloncurry-Williams River	2183-23552	24.7.1975	16.12.1976
Mount Gordon-Lady Annie	2239-00001	18.9.1975	16.12.1976
Lady Annie-Mount Isa	2292-23594	10.11.1975	16.12.1976

in Table 3. Further field studies were made in 1974, 1975 and 1976 when rock samples were collected for measurements of thermal properties in connection with both the interpretation of the thermal imagery obtained in the 1971 aircraft flying programmes and for the forthcoming Heat Capacity Mapping Mission. On the basis of initial interpretation of LANDSAT I imagery, for selected areas additional airborne multi-spectral photography was acquired for narrow strips of country across areas of particular spectral interest in 1975. These areas are listed in Table 4 and two of them are outlined in Figures 6 and 7. The cost of this flying programme was met from the initial grant from the Ministry of Technology/Procurement Executive, Ministry of Defence.

In pursuit of the research programme's objective of interpreting satellite and aircraft imagery using automated data handling techniques the investigation covered by this report had five primary objectives or groups of objectives. The first was the identification and interpretation of the spectral signatures produced by a combination of plant cover, soils and bedrock outcrop; the interpretation included the identification of geological structures and lithological units, the recognition of faults and lineaments important for the loci of ore bodies and the identification of iron rich zones related to potentially mineralized horizons. It included the discrimination of plant communities indicative of particular bedrock units, and of differing types of superficial cover and their use in detecting the presence of near-surface bedrock. It involved the identification of areas of black soils plains and the recognition of drainage systems, changes of stream channel, subsurface drainage patterns and evidence of changes in the level of the water table. It also included an appreciation of changes of spectral signature due to differences in grazing activities, fire, roads and railways which are not related to physical characteristics of the terrain.

The second objective of the investigation was an assessment of the information contained in the LANDSAT imagery at different seasons of the year for the identification of the terrain features cited in the above paragraph. This involved the information contained in each of the MSS bands and in combinations of them, including particularly the colour composites generated by a combination of bands 4, 5 and 7 projected through appropriate filters.

The third objective involved a comparative assessment of the information obtainable from the negative and positive films of the LANDSAT MSS bands and that obtainable from the computer compatible tapes, when each MSS band is examined individually and in combination with others to produce colour composites.

The fourth objective was a comparative evaluation of the information obtainable from LANDSAT imagery and from air survey imagery for the recognition and interpretation of geological features of importance for the disposition of ore bodies. This objective included an assessment of the roles of both types of imagery in an integrated programme of geological reconnaissance and mineral exploration.

The final objective was a comparative assessment of visual interpretation and classification and of computer generated outputs from both LANDSAT imagery and air survey imagery. This involved appraisal of differing types of classification, enhancement and display relevant to the ultimate objectives of interpreting satellite and aircraft imagery using automated data handling techniques.

The accomplishments will be considered under the headings of the objectives outlined above. In order to assess them prior consideration of the outstanding features of the geology, relief and drainage, soils and vegetation which together make up the physical background of the area is necessary.

3.1 LANDSAT STUDIES OF NORTHWEST QUEENSLAND

THE PHYSICAL ENVIRONMENT

3.1.1 Geology

The greater part of the study area is underlain by rocks of the Precambrian shield. These are exposed in the belt of hilly country between Mount Isa and Cloncurry which extends northwestwards towards Lawn Hill and southwards towards Dajarra and Boulia. In the east Mesozoic and later sediments, mostly residuum and alluvium, cover level plains, drained by the Cloncurry river and its tributaries, which form part of the Great Artesian Basin. Beneath this however the Precambrian rocks of the Cloncurry area are believed to be continuous with those of the Georgetown area further east. The nature of the contact between the Precambrian shield of the Cloncurry area and the later rocks beneath the soil and alluvium of the Great Artesian Basin is not known.

3.1.1.1 Precambrian succession

The Cloncurry area is believed to have been the site of a narrow, mainly Lower Proterozoic, geosyncline lying between a hypothetical stable foreland (or high craton) now covered by the late Proterozoic and Cambrian sediments of the Camooweal and Urandangi area and a still more hypothetical submarine stable block (or low craton) to the east of longitude 141°E (Hill and Denmead 1960). Early in its history the geosyncline was divided into an eastern and western portion by a narrow meridional axial zone of uplift which today forms the welt in which the older rocks of the area, the Archaean Leichardt Metamorphics and the Kalkadoon Granites are exposed. This zone is believed to have shed sediments into the eastern and western geosynclinal areas which were subsequently folded and faulted by east-west compression during at least two major orogenic phases in the Lower Proterozoic. The sedimentation and the orogenic events differed in the western and the eastern geosynclinal belts so that today both the sequences of geological formations exposed at the surface and the geological structures are distinctive in each zone.

In the eastern geosynclinal belt a sequence of acid lavas, predominantly rhyolite, were poured out on the land surface east of the Leichardt Metamorphics to form the basal member of the Lower Proterozoic succession, known as the Argylla Formation. The basal lavas are interbedded with meta-sediments in the Duck Creek - Malbon and Limestone Creek areas southwest of Cloncurry while the upper parts of the succession comprise inter-bedded lavas and metasediments throughout the area of its occurrence. This sequence was followed by the deposition of quartz sandstone now altered to the Ballara Quartzite, the quartzite at the base of the Marraba Volcanics. This is restricted to a narrow belt northwest, west and southwest of Ballara. During the ensuing period of basic vulcanicity, associated with subsidence on either side of the welt of Leichardt Metamorphics, the Marraba Volcanics and the Soldiers Cap Formation which comprise basalts and metasediments were laid down. The Marraba Volcanics crop out in a regional anticlinal structure southwest of Cloncurry while the Soldiers Cap Formation forms the margin of the Precambrian with covered ground east and southeast of Cloncurry. This volcanic episode was followed by the deposition of arenaceous sediments which are now represented by the Mitakoodi Quartzite flanking the northern and eastern margins of the Marraba Volcanics.

As vulcanicity diminished vertical movements in the crust became more complex. This produced a variety of depositional conditions now reflected in the diversity of lithologies in the subsequent sedimentary formations within the Lower Proterozoic sequence. Thus, the Marimo Slate which comprises slate, quartzite, greywacke and calc silicate rocks was laid down to the south of Cloncurry.

In the southern part of the eastern depositional basin the Answer Slate, which is probably contemporaneous with the lower part of the Marimo Slate, was laid down unconformably over the Mitakoodi Quartzite and in turn was overlain by the Staveley Formation which consists of dolomites, calc silicates, quartzite, siltstone and shale and by the Kuridala Formation comprising black slates, quartzite and mica schist; the black slates at the base and the top of the Kuridala Formation contain important copper deposits.

The Corella Formation, which is the most widely distributed formation in the eastern geosynclinal area, was deposited more or less contemporaneously with the Marimo Slate, Stavely and Kuridala Formations. Today it consists mainly of calc silicates and a variety of other metamorphic and metasomatic rocks. In the Dugald River area carbonaceous slates in the sequence carry lead-zinc mineralization. In the west of the outcrop area the Corella Formation overlies the Argylla Formation, the Ballara Quartzite and the Leichardt Metamorphics. Further east it unconformably overlies the Soldiers Cap Formation.

Considerable thicknesses of sandstones, which now form the Roxmere and Knapdale Quartzites were laid down before orogenic movement with an east-west compression caused the folding and extensive shear faulting of all the strata in the eastern geosyncline. Following this the Deighton Quartzite was laid down in a narrow central zone in this eastern geosynclinal belt.

In the western geosyncline the Argylla Formation is absent and the Lower Proterozoic succession probably began with the deposition of sandstones now represented by the Leander Quartzite and the Mount Guide Quartzite which are probably contemporaneous with the Ballara Quartzite. These quartzites are characterized by meridional jointing producing patterns which facilitates their recognition on air photos. The deposition of the quartzites was followed by a major period of basic vulcanicity which produced the Eastern Creek Volcanics which are equivalent to the Marraba Volcanics and to the middle and upper part of the Soldiers Cap Formation in the eastern geosyncline. The Eastern Creek Volcanics consist mainly of basalts and inter-bedded metasediments which accumulated to depths exceeding 20,000 feet and spread over a wide area. Subsidence during their deposition was accompanied by tensional faulting. At the close of the major period of basic vulcanicity crustal movements caused local unconformity and the deposition of conglomerates along the western flank of the tectonic welt but further west sedimentation continued without interruption. During this period the Myally Beds and Judenan Beds were laid down contemporaneously in different areas. These consist predominantly of quartzitic sandstones with acid volcanics near the top of the succession.

The first Lower Proterozoic orogenic movements produced only minor effects in the western geosyncline, the most important being strong but local unconformities between the Myally Beds and the overlying Ploughed Mountain Beds, and again at the base of the Mount Isa Shale. West and southwest of Mount Isa the basement apparently did not yield and the sediments laid down were thicker than to the north whereas movement along a series of near meridional tension faults, caused subsidence in the most deeply subsiding part of the trough. Sedimentation became less rapid than previously and mainly dolomites, siltstones, shales and fine, grained sandstones were laid down. These form the Ploughed Mountain Beds, the Surprise Creek Beds, the Gunpowder Creek Formation and the Paradise Creek Formation with each of the first two being penecontemporaneous with the latter two. Algal colonies are a feature of the Ploughed Mountain Beds and of the Paradise Creek Formation within the study area near Lady Annie.

The Mount Isa Shale overlies both the Eastern Creek Volcanics and the Myally Beds and is in fault contact with the Judenan Beds. Although there is no break between the Myally Beds and the Mount Isa Shale a conglomerate marks the boundary in many places. It is believed that the Mount Isa Shale is contemporaneous with the Surprise Creek Beds and that it accumulated in a deeply sinking trough between the foreland on the west and the tectonic welt on the east.

Sedimentation ended with a renewal of orogenic movements which caused strong meridional folding in the eastern part of the western geosyncline and irregular open folding west of the Mount Gordon fault zone. Granite intrusion, which is expressed in the Wonga and Naraku granites, occurred during the orogenic deformations. These were followed by regional uplift and prolonged erosion.

3.1.1.2 Precambrian structure

The whole area has been folded and extensively faulted. The fold axes are near-meridional in the eastern geosyncline and in the eastern part of the western geosyncline. Further west irregular basin and dome structures predominate.

In the eastern geosyncline although overturned folds are common larger structures are relatively simple. The main anticlinoria and synclinoria developed during sedimentation. Folds generally strike north-south. Southwest of Cloncurry, however, a major northeast pitching anticlinorium - referred to later as the Mitakoodi anticlinorium - comprising the Bulonga and Duck Creek anticlines and the Wakeful syncline, and involving the Argylla Formation, the Marraba Volcanics and the Mitakoodi Quartzite, extends over a meridional distance of sixty miles. On the eastern limits of this fold the Mitakoodi Quartzite displays an intricate secondary fold pattern. It is believed that these folds were produced by shear folding parallel to the northeast striking component of the conjugate shear fold system produced by the compression, with the tuff; shale and limestone underlying and overlying the Mitakoodi Quartzite yielding readily to permit complex folding of the quartzite. Elsewhere folding of the more competent strata is generally simple but the Corella Formation displays a complexity of minor structures.

The rocks in the eastern geosyncline have been extensively faulted. Some of the faults are younger than Middle Cambrian and some may have been re-opened many times. Nearly all dip at high angles, generally more than 70°. Most of the faults belong to a conjugate system with northwest and northeast strikes, the latter particularly in the Mary Kathleen area where the Mount Remarkable, Wonga and Cameron faults may be cited. The faults are believed to have resulted from east-west compression. Many of the northeast striking faults are infilled with massive quartz veins. Some have a large horizontal displacement, that of the Mount Remarkable fault being about sixteen miles.

In the western geosyncline broad north-pitching meridional or near-meridional anticlines separated by narrow synclines characterize the area along and east of the Mount Gordon Fault zone. Here dips average 55° - 65° in the synclines and 40° - 50° over the intervening anticlines. Shales, siltstones, dolomites and sandstones are exposed in the synclines whereas sandstones and basalt form the anticlines. West of the Mount Gordon Fault zone the major folds are more open as in the vicinity of Lady Annie or form complex domes.

Most faults in the western geosyncline belong to the northwest, northeast conjugate system. Horizontal displacement is small but vertical movement in some faults is considerable. The complex Mount Gordon Fault strikes north-northeast at an angle to the conjugate shear system while the thrust movement of the complex Mount Isa fault, which is a high angle reverse fault with considerable lateral movement, is believed to be related to the shear fault system. The Leichardt fault which is parallel to and east of the Mount Isa fault is less complex but also has a longer displacement. Additional to these major faults there is a system of east-west faults which have played a major role in determining the distribution of the geological units in the western geosyncline.

3.1.1.3 Ores and Mineralization

Within the study area the rich Cloncurry - Mount Isa mineral province extends for some 200 miles from north of Mount Oxide to south of Mount Cobalt and for about 120 miles from west of Mount Isa to the Soldiers Cap area east of Cloncurry. The most important producing mines include the Mount Isa copper, silver-lead-zinc mine, now the largest single producing mine in the world, the Mammoth copper mine and the Mary Kathleen uranium mine. In the past Mount Oxide, Kuridala and Mount Elliott (Selwyn), and the Great Australia (Cloncurry) have been large producers of copper and Mount Cobalt of cobalt. There is a very large number of small copper mines and prospects throughout the area, while the Dugald River lead-zinc Lode north of Cloncurry, the Lady Loretta lead-zinc deposit near Lady Annie and the recently discovered lead-zinc belt extending from Squirrel Hills, south of Mount Cobalt through Marramunge to Fairmile west of McKinlay as well as newly discovered copper deposits near Mount Kelly south-east of Lady Annie, indicate the presence of a mineral potential as yet unworked or even unknown.

3.1.2 Relief and drainage

The area with outcropping and near surface Precambrian rocks comprises a highly dissected peneplain with fairly mature characteristics along many of the major rivers (Hill and Denmead 1960). It forms the divide between the drainage to the Gulf of

Carpentaria and that to the inland basin of Lake Eyre. Its elevation varies from 800 to 2000 feet above sea level. Flat topped ranges with accordant summit levels near Mount Isa and Cloncurry are testimony of the former extent of the Tertiary (Miocens) peneplain or pediplain while flat topped mesas capped by lateritized flat-lying Mesozoic rocks, north of Cloncurry, northwest of the Dugald River and northeast of Lady Annie indicate the former greater extent of Mesozoic rocks. (Plates 2 and 3) The present drainage patterns bear little relationship either to the dominant relief features or to the underlying geology. They appear to have been initiated on the mid-Tertiary peneplain or pediplain and to have become superimposed on the present surface. The acute features of the present relief and the extensive alluvial terraces along the major rivers are related to landscape dissection and drainage rejuvenation following warping and uplift in Tertiary and Recent times and to excessive erosion and mass movement of weathered material during and following heavy rains such as those which occurred in 1971, 1972 and 1975. In 1971 following exceptionally heavy rains the normally dry beds of the Leichardt, Dugald, Corella and Cloncurry rivers,for example, filled and overflowed; the last mentioned river rose more than eight feet above the causeway at the periphery of the town and all became raging torrents carrying large quantities of sediment as well as shrubs and trees which were eventually deposited as the waters sibsided. (Plate 4) This occurred immediately before the air survey was flown over the Mary Kathleen - Cloncurry, Dugald River and Lady Annie areas and before the acquisition of the first LANDSAT imagery.

The relief features of the area underlain by outcropping and near surface Precambrian rocks are closely related to the bedrock lithology and to geological structure. Rough bouldery terrain with prominent ridges characterizes the quartzites and acid volcanic rocks whereas open valleys of low relief occur over shales, siltstones, slates and schists. (Plate 5) Rugged terrain of subdued relief is characteristic of areas underlain by calc-silicate rocks and rough country with minor ridges and valleys is usual over dolomite and bedded limestones. Open sandy plains studded by tors or whaleback hills distinguish areas underlain by granite. (Plate 6) The most prominent relief features occur where steeply dipping interbedded hard and soft rocks outcrop to produce strike ridges and valleys and where, east of the Leichardt river, the major northeast trending quartz filled faults form prominent ridges, notably that with Mount Remarkable. (Plate 7)

Over the plains floored with Mesozoic and later deposits the relief is remarkably level, only isolated hills capped by laterite or outcrops of Proterozoic rocks breaking the surface. The most important variations of relief are associated with the major rivers which are characteristically braided. They change course during floods following heavy rains and this has left a legacy of islands,levees and abandoned channels encumbered with deposited sediments.

3.1.3 Vegetation

In response to the semi-arid climate and the skeletal nature of most of the soils,the typical vegetation comprises a low tree and shrub savanna characterized by small Eucalyptus trees, Acacia shrubs and the narrow leaved resinous Triodia pungens grass which forms widely spaced hummocks. (Plates 8 and 9) This covers the rugged hilly terrain where the Precambrian rocks outcrop or are relatively near surface. It gives way to a grassland dominated by Astrebla and Iseilemia species where dark brown loams and black cracking dry soils mantle the plains formed of Mesozoic and later rocks. (Plates 3 and 10) Where relict lateritic soils occur over flat topped residuals capped by Mesozoic rocks a woodland of Acacia cambagei and Triodia pungens predominates in the area east of Mount Isa but northwest of Mount Isa such areas carry a woodland of Acacia shirleyii with a sparse grass cover composed mainly of Enneapogon brachystachys. (Plate 11) Within the plains, stands of Acacia cambagei and A. shirleyii respectively, occupy areas with redistributed lateritic gravel. (Plate 12)

Within the low tree and shrub savannas of the hilly terrain different species of Eucalyptus occur over different types of bedrock, E. brevifolia being characteristic of siliceous rocks and E. argillacea being more common over calcareous rocks. The shrub layer is most strongly developed along the dissected margins of creeks where A. chisholmii is most common. The major cracks are followed by galleries of woodland composed mainly of E. camuldulensis, Tristania grandiflora and Melaleuca spp. (Plate 13) On the level interfluves with sandy soils derived from residuum a sparse cover of Enneapogon polyphyllus, Eriachne dominii and Sporobolus australasicus grasses occurs after rains. On the deeper more loamy soils formed from river levee material a close cover of Cenchrus pennisetiformis is usual.

Within the grasslands of the plains, lozenge shape patterns formed by concentric communities of different grass and herb species occurs where drainage is poor and water lies at or near surface for variable periods after rains. (Plates 14, 15 and 16) On better drained areas a variable cover of Eucalyptus pruinosa and Triodia pungens, or of Acacia cambagei and the broader leaved grasses occurs in response to differences in the nature of the soils which are associated with differing types of superficial deposits. (Plates 17 and 18)

3.2 REGIONAL STUDIES OF THE LANDSAT AND AIR SURVEY IMAGERY

3.2.1 THE CONTRIBUTION OF THE COMPONENTS OF THE PLANT COVER, SOILS, BEDROCK AND SUPERFICIAL GEOLOGY TO THE PRODUCTION OF DISTINCTIVE SPECTRAL SIGNATURES ON LANDSAT AND AIR SURVEY IMAGERY

In natural terrain the complex spectral signatures displayed on both LANDSAT and air survey imagery are made up of the spectral responses of the individual components of the vegetation, soils, relief and drainage, and superficial and bedrock geology. The relative contribution of each component depends on the nature and abundance of the plant cover, which influences the amount of bare soil, and on the nature and thickness of the superficial cover which influences the extent of bedrock outcrop. Additionally physiographic features and the moisture status of the soil produce variations in reflectances of the components.

The spectral signatures which may be recognised are characterized by the dominance of particular colour hues and density tones, and by particular textures and patterns; in natural terrain they frequently exhibit continuous variation in spatial extent. For visual interpretation of air survey imagery the spectral signatures have been coded by reference to the colour key of the Royal Horticultural Society (which is related to the Munsell system). On the LANDSAT imagery the variation in tonal density in the individual MSS bands is considerable while those in both tonal density and hue in the spectral signatures in the colour composites generated by combinations of individual MSS bands projected through appropriate filters is so great as to defy literary description. For the visual interpretation of this imagery the spectral signatures have been coded by a system of numbers for tonal density and of letters for colours. For the visual interpretation of the thermal imagery a simple range of emissivity levels has been used.

Comparative studies of LANDSAT imagery at different seasons of the year with multi-spectral air survey imagery and with ground truth information shows that the contribution of the plant cover to the spectral signatures varies with the season largely as a result of variations in the state of the grass and herb layer. These variations are particularly marked in plains areas characterized by savanna grassland with very few trees. Such is true north of Cloncurry, and southwest of Mount Isa. In these areas, red hues predominate on the colour composites of MSS bands 4, 5 and 7 of LANDSAT imagery, obtained after the summer rains when there is a good cover of broad leaved grasses, which reflect strongly in the near infra red part of the spectrum, whereas blue and green hues predominate in the dry season when the grasses have dried off and died down and the reflectivity from the soils and bedrock largely determine the spectral signature. In the hilly terrain characterized by scattered trees and widely spaced tussocks of narrow leaved Triodia spp of grass there is less seasonal difference in the contribution of the plant cover to the spectral signatures; at all seasons the reflectances from the vegetation are weak and the soils and bedrock make correspondingly greater contributions to the spectral signatures. Where the vegetation consists of closely spaced trees as for example where Acacia shirleyii stands cover lateritized residuals of Mesozoic rocks northwest of Mount Isa or where woodlands of Acacia cambagei or Eucalyptus pruinosa follow the tributaries of the Cloncurry and Williams rivers the vegetation is the major contributor to the spectral signatures which again show little seasonal variation, in this case because the trees retain their foliage throughout the year.

Within the areas of grasslands, woodlands and low tree and shrub savanna, differences of spectral signature are caused by differences in the species composition of the plant cover which in turn are related to differences of soil and bedrock. These differences have been examined with reference to the true colour and false colour air photos and to field investigations and the specific relationships have been established (Cole, Owen-Jones, Custance and Beaumont 1974).

The establishment of the relationships between the contributions of vegetation, soils and bedrock to the spectral signatures displayed by LANDSAT and air survey imagery at different seasons of the year provide the basis for the interpretation of the imagery for terrain analysis and particularly for geological mapping and the recognition of features relevant to the location of mineralization.

3.2.2 THE RECOGNITION OF LARGE SCALE GEOLOGICAL STRUCTURES ON THE LANDSAT IMAGERY

Initial studies of combinations of the individual MSS bands of the LANDSAT I imagery of the Mount Isa - Cloncurry - Dobbyn area for 22 December 1972 (ID 1152-00073) projected through appropriate filters to produce colour composites at a scale of 1:250,000 showed that these displayed some of the major structural features, distinguished between some of the contrasting lithological/ stratigraphical units within the major geological formations and discriminated iron rich zones which in some cases are associated with base metal deposits (Cole 1976).

On this imagery the contact between the Precambrian shield of northwest Queensland and the Great Sedimentary Basin which occupies the central part of the state is outlined. Within the Precambrian shield east of Mount Isa the welt comprising rocks of the

Kalkadoon - Leichardt basement is distinguished from the eastern and western sedimentary successions on either side, with the bounding faults, the Mount Remarkable fault particularly, being clearly displayed. Southeast of Mary Kathleen the anticlinorium which comprises the northeast plunging Duck Creek and Bulonga anticlines and the Wakeful syncline involving rocks of Proterozoic age is delineated. Within the Great Sedimentary Basin, complex patterns of spectral signatures suggest the presence of near surface bedrock in some areas and of variable superficial deposits in others. Throughout the area distinctive spectral signatures discriminate individual lithological units within the geological formations while discordant spectral patterns reveal lineaments, many of which were not known hitherto (Cole 1976).

The results of these initial studies were basically similar to those obtained by the Australian Bureau of Mineral Resources using imagery for the same area but in the form of black and white prints of individual MSS bands and colour composite prints of bands 4, 5 and 7 produced by NASA at the 1:1 million scale.

Using the additive viewing system initial studies of colour composites of individual grid sections of the LANDSAT imagery at the 1:50,000 scale showed that individual lithological/ stratigraphical units, lineaments and, in certain instances, ore horizons, which were not apparent at the smaller scale, could be identified. Subsequent studies of LANDSAT I and 2 imagery for the Gregory River - Lady Annie - Mount Gordon fault zone area and for the Mount Isa - Cloncurry - Dobbyn - Williams River area taken at different seasons of the year and examined at both the 1:250,000 scale and the 1:50,000 scale confirmed the identification of major structures recognised in the initial studies and revealed the presence of others, some of which were unknown hitherto.

Among the additional major structures distinguished in the later studies of the LANDSAT I and 2 imagery may be cited most of the major faults in the Mary Kathleen, Cloncurry and Dugald River areas, the major synclinal structures and major faults and regional lineaments in the Lady Annie - Mount Kelly - Mammoth - Mount Gordon fault zone and regional lineaments in the Dugald River and Squirrel Hills areas. Some of these will be considered in the detailed studies covering the recognition of structural features, lithological units and ore horizons on LANDSAT imagery taken at different seasons of the year over selected areas.

The most interesting and probably the most significant of the new structures disclosed by studies of the LANDSAT imagery at the 1:50,000 scale are a series of northeast-southwest trending lineaments which may be discerned in both the Lady Annie - Mammoth - Mount Kelly area and in the Dugald River - Naraku area where they are evident both in areas of outcropping or near-surface bedrock and in areas of covered ground. The known lead-zinc deposits of Lady Loretta and the Dugald River Lode and the known copper deposits at Mammoth, Lady Annie and Mount Kelly appear to be related to these lineaments which transgress both the outcrops of differing geological formations and the strike of individual formations.

3.2.3 THE RECOGNITION OF LITHOLOGICAL/STRATIGRAPHICAL UNITS, IRON RICH ZONES AND MINERALIZED HORIZONS FROM SATELLITE AND AIRCRAFT IMAGERY

Studies of the LANDSAT I and 2 imagery at the 1:50,000 scale have disclosed that distinctive spectral signatures are associated with particular lithological units and that the juxtaposition of contrasting signatures reveals sedimentary sequences and outlines structures. Thus on colour composites generated from the March 1975 imagery obtained after the summer rainy period over the Cloncurry - Dobbyn - Williams River area and the Lady Annie - Mount Kelly - Mammoth - Mount Gordon fault zone area, green/blue signatures of light tone characterize areas of outcropping quartzitic rocks which carry a sparse vegetation, dominated by small Eucalyptus brevifolia trees and narrow leaved Triodia pungens grass. Most areas of outcropping and near-surface dolomitic limestones and calc-silicate rocks which have a vegetation cover of broader leaved 'soft' grasses with scattered Eucalyptus argillacea and associated small trees, display a spectral signature of red and blue hue and medium tone whereas those of outcropping bedded limestones which carry a sparse cover of Triodia pungens grass with scattered Eucalyptus trees have dark blue spectral signatures. By contrast outcropping and near surface granite produces light toned signatures of yellow and red hue. Laterite and other iron rich rocks including gossans associated with mineralization have very dark blue to black signatures. Plains areas of dark brown loams and black cracking clay soils which have a sward of broad leaved perennial and annual grasses, including

Astrebla pectinata, Iseilima spp and Cenchrus spp dominantly have bright red spectral signatures but those with red sandy residuum and a sparse cover of Aristida contorta, Eriachne dominii and Sporobolus australasicus grasses which die off quickly after the rains, leaving most of the ground exposed, have light yellow spectral signatures.

Throughout the study areas on the imagery acquired during and after the summer rainy period, contrasting spectral signatures distinguish hilly terrain with outcropping and near surface bedrock from the plains areas with Mesozoic and later cover. Within each type of terrain differing spectral signatures and differing spectral patterns distinguish individual lithological/stratigraphical units, outline fold structures and disclose the presence of major faults and lineaments, iron rich zones and, in some cases, ore horizons.

During the dry winter period when the broad leaved grasses have died down or disappeared completely but Triodia pungens remains, the contrasts of spectral signature, as exhibited on colour composites of July, September and November imagery, are less marked. Nevertheless distinctive spectral signatures distinguish the individual lithological units and structural features are again clearly displayed.

3.3. DETAILED STUDIES OF LANDSAT IMAGERY OF SELECTED AREAS

THE RECOGNITION OF STRUCTURAL FEATURES, LITHOLOGICAL UNITS AND ORE HORIZONS ON LANDSAT IMAGERY FOR DIFFERENT SEASONS OF THE YEAR

3.3.1.1 THE MOUNT ISA - CLONCURRY - DOBBYN AREA

The most important mining area in northwest Queensland is that of Mount Isa which has the largest copper producing mine in the world and the new Hilton mine nearby. Studies of the LANDSAT I and LANDSAT 2 imagery of this area show that at the 1:50,000 scale the major geological structures and the individual lithological/stratigraphical units are readily recognised while the mine dumps and slimes dams as well as the residential areas of the town are discriminated. The two dams which supply Mount Isa with water, namely Lake Moondarra north of the town and Rifle Creek dam to the south are clearly outlined, and differences of areal extent and of water depth at different seasons may be measured. Studies of the colour composite of bands 4, 5 and 7 prepared from the CCT for 2 March 1975 (ID 2039-23555) and displayed at a scale of 1:10,000 reveal details of the deposition of sediment from streams entering the lake after rains.

Because the Mount Isa area is disturbed and contaminated by mining and smelting activities it was not included in the air survey programme. Instead the Mary Kathleen - Cloncurry and Dugald River areas were chosen for the acquisition of such imagery. The more detailed studies of the LANDSAT imagery have been undertaken for areas for which multi-spectral aerial photography is available.

3.3.1.2 THE MARY KATHLEEN AREA

On the colour composites of MSS bands 4, 5 and 7 of the LANDSAT I imagery covering the Mary Kathleen area obtained on 22 December 1972 (grid section 24 of frame ID 1152-00073) the Wonga, Cameron and Fountain Range faults are clearly distinguished by abrupt and discordant changes of spectral signature along their lengths. (Figures 8, 9, 10 and 11) Most of the other major faults may also be distinguished while major lineaments with which they appear to be associated may be recognised. One such lineament for example continues the trend of the Wonga fault in a south-westerly direction.

Some of the major geological formations within the Archaean and Lower Proterozoic sequences may be readily differentiated from one another by virtue of their distinctive and contrasting spectral signatures but in some areas complex patterns of spectral signatures occur within areas mapped as of one formation and in others the same or similar signatures straddle two or more formations. This is because the individual geological formations comprise varied lithological units which produce distinctive relief features and carry specific plant communities; and because similar lithological units occur within different geological formations, sometimes giving rise to comparable relief features with similar soils and vegetation in each case. Consequently whereas, for example, areas underlain by the Wonga granite have light yellow/red spectral signatures (2 cad, 3 cad) which contrast with the darker signatures of areas underlain by rocks of the Argylla and Corella formations, the quartzite units within both these formations usually produce green/blue signatures (5 dea) and the calc-silicate units generate green/red (5 dae) or blue/red (5 ead, 5 ea) components. Everywhere areas underlain by dolerite and amphibolite have dark green/blue signatures (5 pea, 6 epa) which contrast with those of the units they intrude.

The sharpest spectral boundaries occur between rocks of contrasting type and age. Southeast of Mount Devine the boundary between areas underlain respectively by the Leichardt metamorphics which give rise to relatively light spectral signatures of variable hue (3 dcae) and the Marimo Slate which has relatively dark green/blue signature (6 pea) is clearly defined; southwest of Mount Devine that between the Leichardt metamorphics much intruded by dolerite which produces darker signatures (6 epa) and the Kalkadoon granite which gives rise to lighter green/red signatures (4 dac) is less obvious. West of Lake Corella contrasts of tone and colour distinguish areas of Wonga granite (2 cad, 3 cad) from those of Argylla and Corella rocks (5 ead, 5 aed, 5 eda) and the latter in turn from those underlain by Ballara quartzite (4 ae, 2 acd). South of Lake Mary Kathleen similarly strong spectral contrasts delineate the Marimo Slate (6 eda) from the Leichardt Metamorphics (4 dae) and from the Argylla formation (4 dea, 5 dea). East and southeast of this lake the sharpness of the boundary between the Argylla formation and the Ballara quartzite is enhanced by changes in the directional orientation of the spectral signature which are related to differing lithologies and relief features between and within the two formations and to the occurrence of faulting in the Ballara quartzite and the overlying Corella formation.

The striking contrasts of spectral signature which outline the geological formations and the structural features in the area east and southeast of Lake Corella are considered in the section of the report covering the Mitakoodi fold feature.

Within the Mary Kathleen area the colour composite of bands 4, 5 and 7 of LANDSAT I imagery for 22 December 1972 thus displays the major structural features including faults and lineaments, differentiates the geological formations where the contrasts between them are characterized by marked changes of rock type and distinguishes lithological/stratigraphical horizons within these formations where individual bedrock units are associated with particular terrain features and plant communities. Overall the spectral signatures owe their characteristics to particular associations of vegetation, soil, relief and lithology and consequently it is contrasts in these which permit the recognition of structural features and delineation of geological boundaries.

Of particular interest is the fact that a spectral signature (6 ae) which is darker than those of terrain underlain by the Corella rocks (3 pcb, 5 dae) which are host to the Mary Kathleen uranium ore body,outlines the open-cut; over the tailings dam a light green/blue signature (3 de) contrasts with the light yellow/red signature (2 cad) produced by the surrounding terrain underlain by Wonga granite. Dark signatures (6 ea, 6 ead) occur over the area containing the Wee McGregor and nearby copper mines but distinctive signatures cannot be identified over any of the other small mines and prospects in the area.

Contrary to the widely anticipated view, based on the assumption that the geology is best displayed when the ground vegetation is minimal at the end of the dry season,on the colour composite of bands 4, 5 and 7 of the LANDSAT 2 imagery for 2 March 1975 (ID 2039-23555) covering the Mary Kathleen area,the major faults and lineaments and the boundaries between the geological formations are more clearly delineated than on the LANDSAT I imagery for 22 December 1972 (Plate 19 ; Figure 12). This underlines the importance of the contribution made to the spectral signatures by the vegetation which in fact reflects the bedrock geology.

In addition to the Wonga, Cameron and Fountain Range faults, among the major structural features which are more clearly distinguished on the March imagery may be cited the faults in the area south of Mount Devine, east and south of Lake Mary Kathleen and east and northeast of Mary Kathleen. Many of these were not apparent at all on the LANDSAT I December imagery. Their revelation on the LANDSAT 2 March imagery is due to both the sharp contrasts of spectral signature produced by the differing reflectances of different plant species at optimum growth after rains and to the discordant patterns of spectral signature on either side of them (Figure 12).

The geological formations, lithological/stratigraphical units and bedrock types and the boundaries between them cited in respect of the LANDSAT I imagery for December 1972 were as clearly or more clearly differentiated on the LANDSAT 2 imagery for March 1975. In most cases the spectral signatures differed although the relative contrasts of tone between the geological formations generally remained the same. Because the vegetation was reflecting more strongly in the infra red bands in March than in December, red and violet hues were present in some signatures but in many cases the dominant and/or subsidiary colours of the signatures of individual lithological units remained the same or were little changed. Thus southeast of Mount Devine the spectral signatures for March 1975 for the areas underlain by Leichardt Metamorphic rocks (3 dcae) and Marimo Slate (5 dea) were similar to those for December 1972 and the boundary was again clearly defined. Nearby the area underlain by the Marimo Slate was clearly distinguished from that of the Argylla formation which was characterized by a green/red spectral signature of medium tone (5 dae). The latter was not identified on the December 1972 imagery. Southwest of Mount Devine the spectral signatures of the Leichardt Metamorphics and associated dolerite intrusions (6 dea) and of the Kalkadoon granite (5 ade) showed minor changes of colour dominance. West of Lake Corella, in March 1975 red hues were more important in the spectral signatures of the areas underlain by the Wonga granite (3 ade, 4 dae) and by the Argylla and Corella rocks which again produce varied signatures (respectively 4 dae and 4 ad; and 3 acd and 4 agd); here the Ballara Quartzite was again differentiated by a reddish signature but by one of darker tone (5 agd) and with a violet component. Southeast of Lake Mary Kathleen the boundary between Marimo Slate and the Leichardt Metamorphics and Argylla formations was again sharp with each formation having similar spectral signatures in both December 1972 and March 1975. East of Mary Kathleen the area underlain by the Burstall Granite which was not clearly defined on the December 1972 imagery is delineated on that for March 1975. Farther east areas underlain by the Corella formation are outlined and within the formation a variety of spectral signatures reflecting differing lithological/ stratigraphical units of characteristic relief, soils and vegetation, are apparent.

Compared with the colour composites generated from the positive and negative films of bands 4, 5 and 7 of the LANDSAT I and 2 imagery, those produced from the same combinations of bands from the Computer Compatible tapes for 2 March 1975 provide clearer resolution, better definition of boundaries and more information regarding both structure and bedrock lithology/ stratigraphy of the area east and north of Mary Kathleen studied at scales of 1:30,000 and 1:28,000. (Figure 13) At these scales individual pixels could be discriminated.

On the CCT composite of the area east of Mary Kathleen interpreted at the 1:28,000 scale the Cameron fault and several other major faults may be clearly distinguished and the areas underlain by the different geological formations readily discriminated. (Figure 14) Due to the clearer resolution of the pixels and to the effects of level slicing on densities, colours and tones, the coding of some of the spectral signatures differs from that given for the composite generated from the LANDSAT negatives. Additionally a greater number of individual signatures has been distinguished within the areas underlain by the Burstall Granite and by the Corella rocks farther east. North of the Corella river the comparatively bright red signatures (6 a) which characterize a comparatively large area sharply delimited by a dark purplish red/green (8 gad) signature to the north and by light red/green (3 ade) yellow/red (2 cad) and yellow green (2 cd) on either side, evoke comment. Most probably it was produced by a good cover of strongly reflecting grasses which grew vigorously following rains after burning. Since the effects of burning which destroys the dead litter influences the vegetation and its reflectance and consequently the spectral signatures for several subsequent years (see pp90-92) the recognition of its occurrence is important in interpreting the relationships between spectral signatures and bedrock geology.

The colour composite generated from the computer compatible tapes was produced from density slices of MSS bands 4, 5 and 7. For each band the slicing was into twenty density groups using a 1 x 1 pixel discrimination. Studies of the outputs produced by density slicing the data on each of the four MSS bands reveal marked areal variations in density between the different bands and show clearly that each band provides different information on terrain features (Figures 15, 16, 17 and 18). Thus drainage lines are most clearly displayed on MSS bands 4 and 5 whereas only the courses of the main rivers are discernible on MSS band 7 and less clearly so on MSS band 6. This is because differences in moisture conditions and in surface texture are best discriminated on MSS bands 4 and 5, so that most creeks within the resolution limits of the imagery, can be identified. On MSS bands 7 and to a lesser extent on MSS band 6 differences in moisture conditions and surface texture are less readily distinguished but strongly reflecting vegetation is readily discriminated. Hence on these bands the strongly reflecting communities of trees following the main rivers permit the distinction of these drainage lines; the absence of such communities along the minor creeks precludes the discrimination of the latter. On MSS bands 4 and 5 differences between relatively high ground with outcropping bedrock and level plains covered by soil, residuum and transported cover is revealed by sharp changes of density. These are less obvious on MSS bands 6 and 7. The area north of the Corella river which, from studies of the colour composite, was believed to have experienced burning followed by strong regeneration of grasses following rains prior to the LANDSAT pass, is not distinguished on band 4 and is only weakly recognisable on MSS band 5. By contrast it is strongly discriminated on MSS bands 6 and 7 which reinforces the suggestion that its spectral signatures were the result of strong reflectances from vigorous grass growth following rains after burning.

The density slices of MSS bands 6 and 7 indicate that these MSS bands clearly reveal geological trends and discriminate changes of vegetation and of bedrock lithology. Thus the trends in the Corella sequence are clearly displayed and major faults are easily recognized. The Cameron Fault is delineated accurately while additional structural features which may be of considerable significance are indicated. These include a major north-northeast-south-southwest trending structure between the Cameron Fault and the Corella river which may represent a hitherto unmapped continuation of the Fountain Range Fault (Figure 19). Major northwest-southeast trending lineaments, one of which passes through the site of the Mary Kathleen Uranium ore body, may be recognized on MSS band 7 and less readily so on MSS band 6. By contrast a light density linear feature crossing the Corella river which is very clear on MSS bands 4 and 5 but less distinct on MSS bands 6 and 7 appears to represent a section of the Mount Isa - Cloncurry road.

Studies of the colour composites and of the individual MSS bands of the LANDSAT imagery for the area east of Mary Kathleen thus indicate that each output provides complementary information which should be integrated to provide a correct interpretation of the geology and of other relevant features of the terrain.

On the CCT colour composites of the area north and west of Mary Kathleen interpreted at the 1:30,000 scale, the major faults and the individual geological formations are clearly distinguished; (Plate 19; Figures 20, 21 and 22) additionally within the geological formations discrete spectral signatures reveal the presence of distinctive lithological units which are associated with particular relief features and vegetation associations while displacements of spectral signatures disclose the presence of lineaments in the earth's crust which in some cases are associated with faults and with ore deposits. Immediately north of Mary Kathleen spectral signatures of light tone and dominantly yellow and pink hue (2 ca) are produced over the level terrain covered by yellowish red soil and colluvium which supports a sparse cover of Chrysopogon fallax grass with scattered Eucalyptus brevifolia and E. terminalis trees and Acacia chisholmii shrubs. North of the Cameron river similar signatures characterize the area underlain by the Wonga granite where the vegetation, which is of similar composition, has not been burnt recently. South of the river, however, areas underlain by the same geological unit, which were swept by fire before the satellite pass, have dark green and red/purple signatures (6 de, 6 agd) produced by reflectances from extensive bare areas of dark yellowish brown soils and a sparse cover of Triodia pungens grass between scattered Acacia chisholmii shrubs and Eucalyptus brevifolia trees. North and east of Mary Kathleen light signatures of dominantly yellow and pink hue (1 cad, 2 acd) outlie sandy plains underlain by Argylla rocks whereas signatures of variable colour and tone occur over areas underlain by the Corella formation. Fairly light signatures are characteristic of level terrain which is veneered with sand and quartz rubble whereas darker ones are usual over dissected country; dark blue signatures dominate over calcareous bedrock, light green ones over quartzite and dark green ones over metabasalt; those over dolerite are of variable medium to dark tone and green and purple hue (5 dg, 5 de, 7 dae, 5 d, 6 d). The actual signatures depend on the vegetation, soils and degree of dissection of the terrain as well as on the bedrock lithology but overall contrasts between the spectral signatures effectively outline the geological units.

West of the Wonga fault the main structural features and the individual geological units are again clearly outlined on the colour composite generated from the computer compatible tapes and displayed and interpreted at the 1:30,000 scale. (Plate 20; Figures 23, 24 and 25) As well as the major regional northeast-southwest trending faults the smaller faults affecting the Ballara quartzite are particularly clearly displayed. A number of major lineaments may also be discerned. In some cases known faults occur along parts of these structures but additionally there is a series with a northwest to southeast orientation with which faulting is not associated. Some of the known mineral deposits occur along or near the intersections of faults and lineaments.

On this CCT colour composite faults and lineaments are particularly clearly displayed. They may be distinguished in five different ways. Firstly, they may be recognised by sharp changes of spectral signature on either side of the structural feature. This is particularly clearly seen along the Wonga fault. Secondly, they may be revealed by the displacement of spectral signatures along the structural feature, as is the case of the faults within the Ballara quartzite west of Mount Calcite. Thirdly they may be delineated by a series of different spectral signatures which terminate on either side of a structural feature at different locations along its length. The Mount Remarkable fault cited on p 16 is displayed in this way. Fourthly the presence of faults may be detected from a discordance in the trends of tones and hues within a mottled spectral signature such as is evident in the area underlain by Leichardt Metamorphic rocks. Lastly their presence may be disclosed by a narrow linear spectral signature of darker tone than the surrounding one.

In the area west of the Wonga fault the individual geological formations are again clearly distinguished by distinctive spectral signatures whose boundaries, in many cases, coincide with the geological boundaries of the 1:50,000 map produced by the Bureau of Mineral Resources (Figure 26). In the southern part of the CCT colour composite extensive areas underlain by the Leichardt metamorphic rocks exhibit distinctive pale pink spectral signatures (1 h, 1 he) which are lighter than those characteristic of areas underlain by this formation east of the Wonga fault. Ground truth information suggests that this may be due to the greater extent of quartz gravel and of reddish or yellowish brown soil cover and to the prominence of the tall feathery Chrysopogon fallax grass in the ground cover in the area west of the Wonga fault. Similar signatures also delineate the areas underlain by Leichardt metamorphic rocks in the northern part of the CCT colour composite and within the Marimo Slate belt.

Generally speaking the areas underlain by the Argylla formation to the west of the Wonga fault have medium to dark green spectral signatures (4 d, 5 dg, 5 dgb, 6 da) which are similar to those over the same formation east of the Wonga fault (4 dea, 5 dae, 5 ea, 5 eda). In both areas the range of lithologies, which includes volcanics, quartzites and schists, which, in turn, is associated with a variety of terrain features, accounts for the variety of spectral signatures characteristic of the formation. West of the Wonga fault the areas underlain by the Ballara Quartzite and by the Corella formation similarly display a variety of spectral signatures which in each case are comparable with those east of the fault. Light to medium tones of pink, violet, red or green characterize the Ballara Quartzite (2 hd, 4 age, 5 dac west of the fault, 2 acd, 4 ae, 5 agd east of the fault); these signatures being produced by the combination of reflectances from outcropping quartzite and the sparse vegetation of scattered Eucalyptus brevifolia trees and Triodia pungens grass. Within the Corella formation, the quartzites which have a similar vegetation are readily distinguished by their light spectral signatures (1 hc, 2 hc) whereas the calc-silicates, granofels and marls have medium to dark signatures of green, blue-violet or red hue (4 cdge, 5 dg, 5 dge, 5 eg, 5 dah west of the Wonga fault, 3 acd, 3 pcb, 4 cgd, 5 dae east of the fault).

As elsewhere the geological boundaries on the CCT colour composite of the area west of the Wonga fault are most clearly differentiated where there are sharp contrasts of spectral signature between the geological units. The large area of dolerite within which Mount Calcite is located is very clearly distinguished because its dark green spectral signatures contrast with the medium tone green/violet/blue ones of the Corella granofels, limestones and marls to the east and with the light yellow/pink signatures produced by the Corella quartzites to the west. Further west the latter are again clearly distinguished from the lower units of the formation which have dark green/blue signatures (6 de, 6 d). The boundaries between the Ballara Quartzite which has a light pink spectral signature and the Corella granofels, limestone and marls with dark green/blue signatures (6 ge, 7 ed) to the west and the Argylla formation with medium tone green/red signatures to the east (4 da, 5 dc) are also well defined. Everywhere the Marimo Slate, with its characteristically dark green spectral signatures frequently mottled with red or violet (6 d, 6 dc, 6 dg, 6 da, 6 dgc, 6 dge, 7 d, 7 da, 7 dag, 7 de etc) is sharply differentiated notably, where the unit is in contact with the Leichardt Metamorphics which have an exceptionally light signature (1 he).

Several spectral signatures evoke particular comment. In the south the characteristically light spectral signatures produced by areas underlain by the Deighton Quartzite give way to dark green ones (6d, 8 de, 7 d, 4 dh). The latter occur over an area, carrying a vegetation of Enneapogon polyphyllus grass with scattered Eucalyptus brevifolia and E. argillacea trees which was severely burnt in 1974 before the LANDSAT pass. The effects of the burn are responsible for the dark green signatures. Two areas along the Wonga fault are of particular interest. One to the west of the fault and south of the Cameron river has particularly dark spectral signatures (9 az, 8 abd). This area has an anomalous plant community of Polycarpaea glabra which is associated with iron rich gossan containing relatively large amounts of copper. The second, west of the Wonga fault and south of Breakfast Creek has a relatively dark red/violet spectral signature which contrasts sharply with those of adjacent areas but has not been checked in the field.

Differences in the composition of the ground vegetation and in the extent of bare soil and bedrock outcrop are important in the production of contrasting spectral signatures. Relief and the presence of iron rich bedrock or ferruginous cappings are also important. Generally speaking Triodia pungens grass which characterizes sandy soils and siliceous bedrock contribute blue hues to the spectral signatures whereas, in the March period, the soft grasses which reflect strongly after the summer rains, contribute red and pink hues. Since siliceous rocks and sandy soils tend to have a ground cover of Triodia pungens whereas argillaceous and calcareous rocks and more loamy soils tend to support the soft grasses, generally speaking green and blue spectral signatures characterize quartzites whereas pink and red ones are more common over slates and calc-silicate rocks. The amount of bedrock outcrop and of sandy soil cover respectively influence the extent of dark green or dark blue and of light yellow components to the signatures.

Overall the LANDSAT imagery displays the structure and grain of the country and outlines the major geological formations. The resolution is better on colour composites generated from the computer compatible tape than from negatives. More detailed information may be obtained from interpretation at the larger scales where the individual pixels are differentiated. Geobotanical anomalies may be recognised and Mary Kathleen uranium pit open cut and tailings dam identified.

3.3.1.3 THE MITAKOODI ANTICLINORIUM

Southeast of Mary Kathleen the Mitakoodi anticlinorium is clearly distinguished on the LANDSAT I and LANDSAT 2 imagery for 22 December 1972 (ID 1152-00073) and 2 March 1975 (ID 2039-23555) respectively. On the colour composite generated from MSS bands 4, 5 and 7 of the December imagery distinctive spectral signatures outline the geological units comprising the feature and the map showing these spectral signatures accords remarkably closely with the geological map of the area prepared from maps produced by the Australian Bureau of Mineral Resources (Figures 27, 28 and 29). On this dark spectral signatures of predominantly blue colour (7 epa, 6 eap etc.) outline the hills capped by Overhang jasperlite around the northern periphery of the anticlinorium (Plate 21). They contrast sharply with the lighter dominantly blue green spectral signatures (3 pa, 4 epa, 4 aed, 3 ade, 2 dac, 2 dea etc.) produced by the terrain underlain by the Mitakoodi quartzite (Plate 2). The contrast is particularly sharp along the north-south trending fault in the vicinity of longitude 140°20' in the north. The relatively light red and green spectral signatures (3 ade, 4 acd) produced by the hills of Mitakoodi quartzite in the centre of the Wakeful syncline (Plate 22) again contrast sharply with those produced by the surrounding level terrain developed over the Marraba Volcanics which are characteristically of blue green colour and medium tone (5 edc, 6 eda) (Plate 23). A great complexity of spectral signatures, mainly of medium tone and blue green colour occur over areas underlain by dolerite where they reflect the ramifications of the intrusions. In the south dominantly red spectral signatures (5 aed, 3 adce) delineate the broad plains along the Malbon river. In this area field investigations indicate that in December the sparse ground vegetation cover and skeletal soils over the hills results in reflectances from bedrock very largely determining the spectral signatures and thereby accounting for the sharp contrasts between areas underlain respectively by Overhang jasperlite and by Mitakoodi quartzite. Over the plains, however, reflectances from the grass cover are largely responsible for the spectral signatures. East of the Mitakoodi anticlinorium sharp contrasts of spectral signatures distinguish between the hills of the Marimo Slate formation and the intervening plains. Overall in this area the spectral signatures displayed on the colour composite correlate with the bedrock geology so closely as to suggest that they could be used for detailed mapping in the southern half of the frame where only the outline geology is known.

The colour composite generated from the LANDSAT 2 imagery obtained in March 1975 also clearly reflects the geology of the Mitakoodi anticlinorium while studies of the outputs obtained by density slicing each of the four MSS bands into twenty groups assists an understanding of the relationships between the spectral signatures displayed on the colour composite and the terrain features (Figures 29, 30, 31, 32 and 33). As in the Mary Kathleen area the drainage lines are most clearly displayed on MSS bands 4 and 5 whereas some of them are difficult to detect on MSS bands 6 and 7. The major structural features are apparent on all four bands but distinctions between the lithological units are most readily recognised on MSS bands 6 and 7. Overall, however, it is the colour composite generated from the MSS bands 4, 5 and 7 rather than the individual bands which displays the major features of geology of the area.

3.3.1.4 THE DUGALD RIVER - NARAKU AREA

The Physical Environment

The Dugald River - Naraku area is underlain by Lower Proterozoic rocks of the Knapdale quartzite and Corella formations which have been intruded by granites of probable Upper Proterozoic age. In the east these rocks are overlain by Mesozoic sediments and Cainozoic alluvium (Nicholls, Provan, Cole and Tooms 1964-65).

The Corella formation is composed dominantly of calc-silicate rocks including conglomerates, agglomerates and lenticular beds of shales, sandstones and dolomites. The Knapdale quartzite may represent a lithological unit within the Corella formation. The

Lower Proterozoic rocks have been folded along north northwest-south southeast axes. The structural interpretation is complicated by the occurrence of numerous faults but the Knapdale quartzite and the adjacent units of the Corella formation appear to be dipping very steeply westwards. West of the Cabbage Tree creek outliers of flat-lying red Mesozoic sandstones, conglomerates and shales rest unconformably on the Lower Proterozoic rocks.

Within the Corella formation a black graphitic and chloritic shale is host rock for the lead-zinc mineralization of the Dugald River Lode and associated West Lode. The mineralization consists predominantly of sphalerite, galena, pyrite and pyrrhotite. The lode is characterized by a well defined but discontinous gossan. The major topographic features are closely related to the geology. In the immediate vicinity of the Dugald River Lode the resistant Knapdale quartzites form a conspicuous ridge. (Plate 5) Other ridges within the general area are related to silicification along fracture zones, the most conspicuous being that of Mount Rosebee. The limestone-shale sequence enclosing the Dugald River Lode is somewhat silicified and forms a minor ridge parallel to that formed by the Knapdale quartzites. The graphitic host rock of the lead-zinc mineralization forms a topographic low within this ridge. (Plates 24 and 25) Occurrences of copper mineralization in the calc silicate rocks to the north, east and northeast of the Dugald River Lode are in relatively level terrain where, in some cases, they are associated with slight rises above the general surface.

The ground between the Knapdale quartzite range, the Dugald River Lode and Mount Rosebee is generally flat and featureless. West of the Cabbage Tree Creek outliers of very gently dipping Mesozoic rocks capped by laterite form plateau relics and isolated mesas. (Plate 3) Near Quamby and Naraku granite tors stud the otherwise level terrain. (Plate 6)

The major seasonal drainage is along rivers which are bordered by levees and often by more or less extensive series of alluvial terraces. Minor streams and tributaries appear to have been rejuvenated recently and are incised into coarse alluvium or, in some cases, residuum. This feature is particularly noticeable in the vale between the Knapdale quartzite and Dugald River Lode ridges; the streams draining this area flow in entrenched channels in their own alluvium and break through the Dugald River Lode in shallow gorges. Related to these features are those of the patterns of lozenge shape features, which are displayed on the air survey photography of the plains to the north and south of Little Eva mine. (pp 84-86 ; also Cole, Owen-Jones, Custance and Beaumont 1974). They are suggestive of drainage systems which have become subsurface following a lowering of the water table. (Plates 14 and 15)

Within the Dugald River area bedrock outcrops are rare and are mostly confined to ridges and scarp slopes where the residual or colluvial cover is only a few inches thick. In the low-lying ground between the ridges the depth of overburden above the less resistant rocks may exceed several feet. Great thicknesses of alluvial material occur near the foot of the higher topographical features, notably that of the Knapdale quartzite range. The levees flanking the major rivers often comprise more than twenty feet of alluvium.

Skeletal stony soils occur over the Knapdale quartzite range and over Mount Rosebee. Similar but somewhat finer textured reddish-brown soils occur over the siliceous shales of the ridge associated with the Dugald River Lode. Arid red earths of sandy to sandy clay loam texture are characteristic over both residual material and sheet wash deposits of the level terrain but give way to grey and brown soils of heavy texture on the plains bordering Cabbage Tree Creek to the north and south of Little Eva mine. Lateritic soils overlie the Mesozoic mesas west of Cabbage Treek Creek.

Within the low tree and savanna vegetation characteristic of the area an association dominated by Eucalyptus brevifolia and Triodia pungens is widely distributed over skeletal sandy soils derived from siliceous bedrock over the higher ground whereas one of E. argillacea and T. pungens covers the lower ground. E. dichromophloia occurs with E. brevifolia over part of the Knapdale quartzite range and E. papuana and E. terminalis may be associated with E. argillacea over the low ground. The last mentioned species favours iron rich soils and is conspicuous at the periphery of the Dugald River lead-zinc lode. It forms a larger tree with a heavier canopy than the other species of the area. The turpentine bush Acacia chisholmii forms a nearly continuous shrub layer with well developed foliage over the dissected terrain bear the stream courses. Well defined galleries of trees follow the major stream courses, with Tristania grandiflora and Eucalyptus camuldulensis characteristic of the stream bed and Bauhinia carronii, E. papuana, Terminalis aridicola and other species along the banks. (Plates 13 and 26)

These trees are larger and have heavier foliage than those over the rest of the area. The gidgea tree Acacia cambagei, with small trees and shrubs of Myoporum and Eremophila spp form a scrub woodland over the flat topped mesas capped by lateritized Mesozoic sandstone west and northwest of Cabbage Tree Creek and over lateritized shale west of the Knapdale quartzite range. Isolated stands of Acacia cambagei occupy patches of lateritic gravel along the banks of some streams emanating from the range.

The characteristic vegetation associations cut out over mineralized bedrock where they are replaced by treeless communities comprised of the small shrub Polycarpaea glabra the short grass Eriachne mucronata, the small sedges Bulbostylis barbata and Fimbristylis sp and the tall shrub Tephrosia sp nov. Over the Dugald River lead-zinc lode all these species are present : they constitute a geobotanical anomaly which is over one mile long and up to 300 feet wide. (Plates 24 and 25) A number of small geobotanical anomalies, most of which are comprised of Polycarpaea glabra and Eriachne mucronata, occur over copper bearing calc-silicate rocks. (Plate 27)

Concentric distributions of distinctive communities of grasses and herbs form lozenge shaped patterns on the plains with grey brown soils of heavy texture to the north and south of Little Eva mine. (Plates 3, 14 and 15)

Studies of the LANDSAT imagery

The LANDSAT I imagery for 22 December 1972 (ID 1152-00073) was used for initial comparative studies of the information available from satellite imagery of the Dugald River - Naraku area. (Cole, Owem-Jones, Custance and Beaumont 1974). Studies of the individual MSS bands indicated that band 4 most effectively discriminated the area of black soil plains northwest of Cabbage Tree Creek, that band 5 displayed the drainage features better than the other bands and that band 7 revealed most information on the geology of the area. Studies of different combinations of individual bands each projected through the appropriate filter, disclosed that most detailed information was accorded by the combination of bands 4, 5 and 7; this therefore was selected for subsequent work. Studies of the LANDSAT I imagery for 22 December 1972 disclosed a general accordance with the boundaries of the geological formations given on the published 1:253,440 geological map of the Cloncurry district prepared by the Bureau of Mineral Resources but additionally individual lithological units within the Corella formation could be discerned and in the vicinity of the Dugald River Lode their boundaries were similar to those given by the mapping of the Conzinc-Riotinto Company of Australia Limited. (Figures 34 and 35)

Since it was known from investigations undertaken in 1962 (Nicholls, Provan, Cole and Tooms 1964-65) that distinctive vegetation associations occur over individual lithological units LANDSAT 2 imagery for dates at the end of the summer rainy period and in the middle of the winter dry period was sought in order to compare spectral signatures at the times of greatest contrast in plant growth and hence of spectral reflectances. For the comparative studies of satellite imagery taken at different seasons over the Dugald River - Naraku area the LANDSAT 2 imagery for 2 March 1975 (ID 2039-23555) and the 24 July 1975 (ID 2183-23552) was used. Colour composites were generated from MSS bands 4, 5 and 7 and displayed at the 1:50,000 scale.

Initial comparison of these composites discloses the display at both seasons of the major structural features, of the individual geological formations and of the more important lithological/ stratigraphical units within them (Figures 36, 37, 38, 39 and 40). On both sets of imagery distinctive spectral signatures discriminate areas underlain by the Corella formation, by granite and by superficial deposits respectively. Lithological units and trends within the Corella formation may be delineated and extensions of these features may be discerned in areas of superficial cover. Faults and lineaments, only some of which have been mapped hitherto, may be detected. At both seasons the LANDSAT imagery provides more detailed information than is given on the existing 1:253,440 geological map covering the Cloncurry area and particularly in areas of superficial cover the March 1975 imagery obtained after the summer rains when there was a good ground vegetation cover provides more detail than either the July 1975 or the December 1972 imagery obtained respectively during and after the dry winter season when the ground cover was very sparse.

On the March imagery, dark blue and red purple spectral signatures (5 eda, 6 eda, 6 ae, 6 ade etc) distinguish areas underlain by the Corella formation; those of lighter tone outline the Naraku granite, (4 eda, 5 ed, 5 dea, 3 ac, 3 deac etc.) and yellow signatures delineate areas where residual soil covers bedrock (2 ca, 3 ca, 3 cae etc.) All these areas have a vegetation of scattered small Eucalyptus trees and a sparse ground cover of perennial Triodia pungens grass with variable amounts of the annual grasses Enneapogon polyphyllus, Aristida contorta and Sporobolus australasicus whose distributions are dependent largely on the depth and texture of the soil and on the type of bedrock. Because of the sparse vegetation,reflectances from soils and bedrock contribute to the spectral signatures. Bright red signatures (4 adce, 5 a, 5 ae, 5 ade etc.) characterize areas of black soils and of alluvium supporting closed grassland of Astrebla, Iseilima, Cenchrus and other strongly reflecting species. Here the reflectances from the vegetation dominates the spectral signatures on the March imagery. On the July imagery when the grass cover had dried off the contrasts of spectral signatures are less marked, the distinction between areas of outcropping and near surface bedrock and areas of covered ground is less obvious and that between individual geological units less clear.

The pattern of dark blue and red purple spectral signatures displayed by areas of Corella formation on both the March and July imagery suggests the presence of synclinal troughs, in places bounded by faults. These synclines are separated by narrow anticlines which in places have been intruded by the Naraku granite which is delineated by spectral signatures of lighter tone and more irregular texture and outline than those of the Corella rocks. The northeast-southwest trending lineaments, characteristic of the Corella rocks, are evident, however, in the spectral pattern of the areas of granite outcrop. They extend also across the soil and alluvium covered Cloncurry Plains, which are distinguished by dominantly red signatures in March and by dominantly yellow hues in July. Within these plains the occurrence of green and blue spectral signatures on the imagery for both seasons suggests the presence of near surface Corella or granite bedrock, with differences of spectral pattern and texture differentiating between them. (Figures 36, 39 and 40). Here the March imagery provides more information than that for July. The presence of these distinctive blue and green spectral signatures within this plains area suggests that it may be possible to delineate the geology of the Euroka ridge, the structural high which separates the structural depressions of the Carpentaria and Eromango basins in the sub-Cretaceous floor beneath the plains and possibly links the Precambrian highlands of the Mount Isa - Cloncurry area with those of the Einasleigh area. (Twidale 1966).

Within the Corella formation distinctive spectral signatures distinguish individual lithological units. This is most apparent in the area of the Dugald River lead zinc lode. Here on both the March and the July imagery the Knapdale Quartzite which forms a prominent ridge characterized by outcropping bedrock and by skeletal soils supporting a sparse cover of small poorly reflecting *Eucalyptus brevifolia* and *E.dichromophloia* trees and *Triodia pungens* grass, is outlined by a light green spectral signature (3d, 3 dae). By contrast the areas of calc-silicate rocks which form subdued rugged terrain supporting a mixed ground cover of Triodia pungens and of moderately strongly reflecting soft grasses, notably Enneapogon polyphyllus and Aristida contorta with scattered small E. argillacea trees have a darker signature of varying hue, dominantly green and blue in March (5 de, 5 dea etc.) and red and blue in July. Characteristically the well-bedded limestones which outcrop over an extensive area, west, southwest, and south of the Knapdale Quartzite range have dark blue/green spectral signatures in both March and July. (6 eda, 6 ead etc.) These areas have a sparse cover of the poorly reflecting Triodia pungens grass and scattered small E.brevifolia and E. argillacea trees and the amount of outcropping bedrock is largely responsible for the dark blue/green spectral signatures, which are characteristic also of the 1:15,000 infra red false colour air photography flown in April/May 1971. Similar signatures are produced again by well-bedded limestones which outcrop over a narrow belt immediately east of the Dugald River lead zinc lode. The graphitic shale host rock of the Dugald River lode has a medium tone red and green signature within which a darker signature, most evident on the March imagery, appears to indicate the position of the lead-zinc deposit. (7 ed) On the 1:15,000 infra red false colour air photos the Dugald River lode has a light blue/green spectral signature which contrasts with the dark blue/green one of the bedded limestones and with those of reddish hues over soil covered ground. The question arises as to whether the ore horizon produces a discernible spectral signature on the LANDSAT imagery which incorporates longer spectral bands i.e. bands farther into the infra red, than false colour aerial photography. The lode has a strike length of over 1.6 km (over 1 mile) and an average width of 8 metres (25 feet). It is delineated by an anomalous plant community dominated by Eriachne mucronata, a grass which from March to May may have a stronger reflectance than Triodia pungens, and by Polycarpaea glabra which is characterized by masses of white flowers and is most abundant later in the year. The lode is characterized by a prominent gossan. The evidence suggests that detection of the lode on the LANDSAT imagery is possible, since it has sufficient length for discrimination, its plant cover produces reflectances which contrast with those of the vegetation of adjacent areas at both seasons and its gossan could be expected to produce a dark spectral response. This is supported by the fact that similar signatures characterize the site of the Lady Clayre copper deposit which is located in bedded limestone host rock to the south of the Knapdale quartzite range and by the association of dark spectral signatures with iron rich rocks elsewhere in the Mount Isa - Cloncurry region.

Linears have been recognised where there is an offsetting or displacement of spectral signatures along a clearly defined line, where there are adjacent and parallel dark and light toned signatures transgressing other signatures and in some cases where there is an abrupt change of signature on either side of a clearly defined line. In the last mentioned case, care is needed to eliminate linear features caused by changes of spectral signature connected with fence lines, railways and roads on either side of which differing grazing practices cause differing spectral responses.

All the major faults shown on the published 1:253,440 geological map are clearly displayed on both the March and the July imagery (Figures 35, 41 and 42). Additionally the Mount Rosebee fault appears to extend further northwards through Kajabbi and further southwards through the old Moonlight and Native Companion mines. A series of linears with an east northeast-west southwest orientation is also apparent. Major sections of stream courses follow some of these while known areas of copper mineralization occur along two of them, namely the Lady Clayre and Volga deposits and that southwest of Mount Magnet. More linears are evident on the March than on the July imagery with those suggesting the presence of intersecting faults at the Dugald River lead zinc lode, the Little Eva copper mine and at Mount Rosebee near which there are several copper occurrences, being of particular interest. Closer examination of the linears particularly where the spectral signatures suggest the presence of near surface Corella rocks might well lead to the discovery of hitherto unknown base metal deposits. There is also a set of north northwest - south southeast trending linears which intersect the Mount Rosebee fault zone, are evident north of the Knapdale Quartzite range and again intersecting the Mount Quamby faults. These also may merit investigation.

The information yielded by the colour composites generated from films of the NASA imagery and displayed at the 1:50,000 scale encouraged the use of the computer compatible tapes for the generation of a colour composite of the Dugald River Lode area for display at the 1:10,000 scale. For this purpose MSS bands 4, 5 and 7 of the March 1975 imagery were used (Figure 43). At this

scale the individual picture units or pixels which give a ground resolution of 80 metres, are displayed. The areas of covered ground, which in March carry a sparse cover of strongly reflecting grasses are sharply distinguished from those of outcropping bedrock by red and orange spectral hues (5a, 6 a, 4 bh, 3 bh, 4 bhk etc.) (Figures 44 and 45). The steep western and eastern slopes of the Kanpdale quartzite range are delineated by dark green hues (5d, 6 d, 7 d) whereas the top of the range displays a range of light green colours (1 deh, 1 dec). Here the outcropping bedrock is mainly responsible for the spectral hues. The shale host rock of the Dugald River Lode is discriminated by a range of green, brown and grey hues of varying tone (6 dwkj, 5 dkw etc.) whereas the lode zone is shown by dark green/blue colours (6 d, 8 d, 6 de, 8 k) and the bedded limestone footwall rocks by very dark blue, grey to black and purple pixels (4 ek, 4 gew, 8 g, 8 k, 9 jk, 9 gjk, 6 awk etc.) The steep eastern slope of the minor ridge formed by the footwall rocks is partly responsible for the very dark hues. The discrimination of the drainage lines, notably Silvermine Creek, assists the location of the geological features.
While the colour composite at the 1:10,000 scale displays the individual pixels, and provides considerable detail, it has shortcomings; for to some extent the detail clouds the discrimination of the individual lithological units while at the same time not giving the resolution available in air photos at a comparable scale.

3.3.1.5 THE LADY ANNIE - MOUNT GORDON FAULT ZONE AREA

The Physical Environment

The Lady Annie - Mount Gordon fault zone area is underlain by Lower Proterozoic rocks of the Myally, Gunpowder Creek and Paradise Creek formations. These have been folded into a series of anticlines and synclines and have been highly faulted (Figure 46). East of the major fault to the east of the old Lady Annie copper mine, the Lower Proterozoic rocks are overlain unconformably by flat lying Middle Cambrian rocks and by Cainozoic soil and alluvium. Soil and alluvium also cover Lower Proterozoic and Middle Cambrian rocks along the valley of the West Thornton river. Tertiary laterite caps considerable areas to the northeast, south and southwest of Lady Annie while numerous small relicts of this material occur in the Lady Annie and Mount Kelly areas. Additionally ironstones some of which are gossanous occur in these areas.

Copper mineralization occurs at a number of localities. At the Mammoth mine there are four lenticular ore bodies which occur in sandstones with minor lenses of siltstone in the Myally Beds. At the old Lady Annie mine copper mineralization occurs in dolomitic shale of the Paradise Creek formation and is believed to be comparable in age with that in the carbonaceous shale at the old Mount Oxide workings. It occurs also in dolomitic shale at Mount Kelly. The Lady Loretta lead-zinc horizon occurs in a pyritic and carbonaceous shale in the Paradise Creek formation within the structure known as the Small Syncline. The Gunpowder Creek and Paradise Creek formations are considered to be time equivalents of the Mount Isa group which hosts the Mount Isa copper and silver-lead-zinc and the Hilton silver-lead-zinc ore bodies. In the Mount Isa group all the known economic mineralization occurs in the Urquhart Shale. The dolomitic and carbonaceous shales which host the known mineralization in the Lady Annie area may be of comparable age but no precise correlation between any units has been established. Within the Lady Annie area one objective of the remote sensing investigation was the recognition of spectral responses which might be identified with dolomitic and carbonaseous shales and with mineralization.

Within the study area the Cambrian Beetle Creek formation contains the important phosphate deposits at Lady Annie, east of Lady Loretta, and at Lady Jane.

The major topographic features are closely related to the geology and to the legacy of Tertiary plantation processes which produced peneplains which were subjected to deep weathering and lateritization. Regardless of the geology there is a general accordance of summit levels within the area but individual topographic features are related to resistance of lithological units to post-Tertiary erosion. The fault bounded blocks of Myally quartzite form upstanding flat topped plateaux. Rugged terrain characterizes the areas underlain by the Gunpowder Creek formation around the periphery of these plateaux (Plate 28) whereas subdued terrain occurs over the major syncline in which the Paradise Creek beds sub-outcrop south of Lady Annie copper mine (Plate 29). The pyritic and carbonaceous shale which hosts the Lady Loretta lead-zinc deposit forms a lateritized plateau some 60 metres above the surrounding plains. (Plate 28) The surface expression of the primary ore grade mineralization crops out within 10 metres of the plateau surface on the western limb of the Small Syncline while the pyrite-chert facies of the ore horizon on the eastern limb of both the Small and Big Synclines coincides with the plateau surface (Alcock and Lee 1974). The Middle Cambrian rocks containing the Lady Annie phosphate deposits also form a level plateau.

Within the low tree and shrub savanna characteristic of the Lady Annie area distinctive vegetation associations dominated by *Eucalyptus brevifolia* F. Muell and by different grass species distinguish the different lithological units (Plates 30, 31, 32 and 33). The plateaux underlain by Myally quartzites are readily distinguished by their sparse cover (Plate 29) which contrasts sharply with the scrub woodland dominated by *Acacia shirleyii* trees which characterize the iron rich horizons of the Gunpowder Creek and Paradise Creek formations and also laterite capped rocks. (Plate 11) Northeast and southwest of Lady Annie plant communities composed of a greater variety of species occupy the extensive Mesozoic lateritic plateaux.

Studies of the LANDSAT imagery

The LANDSAT 1 imagery for 15 February 1973 (ID 1207-00133) and the LANDSAT 2 imagery for 22 March 1975 (ID 2059-00012) 18 September 1975 (ID 2239-0001) and 10 November 1975 (ID 2292-23594) was used for comparative studies of the information available at different seasons of the year in the Lady Annie/ Lady Loretta and Mount Gordon fault zone area northwest of Mount Isa. Colour composites generated from the positive plates produced from negative films of MSS bands 4, 5 and 7 displayed at the 1:48,000 scale were used for the initial studies. This scale was chosen to accord with that of de Keyser's map of the Paradise Creek area (de Keyser 1968).

There are marked differences of tone and hue between the imagery from the two satellites and between the seasonal imagery from LANDSAT 2. (Figures 47 and 48) Distinctive spectral reflectances discriminate the geological formations and the individual lithological units within them at all seasons but the boundaries are most clearly displayed by the sharp contrasts of hue which characterize the March imagery and to a lesser extent that from November whereas they are delineated mainly by tonal contrasts in the red dominated imagery for September. (Figures 48, 49, 50 and 51) Lineaments believed to be related to faults and fractures in the Precambrian rocks even where overlain by Cambrian and later deposits are apparent at all seasons but are most clearly displayed on the March and November imagery whereas major and minor faults, including evidence for such features beneath cover of alluvium west of Lady Annie and east of the West Thornton river are most obvious on the September and November imagery. (Figures 50, 51 and 52).

The LANDSAT imagery confirms most of the major geological features of the Lady Annie - Mount Gordon fault zone area depicted on de Keyser's map, displaying some of them more accurately and in greater detail. On the broad scale sharp contrasts of tone, hue and textural pattern delineate the eastern complex highly faulted area of the Mount Gordon fault zone, which is underlain by rocks ranging in age from the Eastern Creek Volcanics to the Paradise Creek Formation, from the broad central area underlain for the most part by rocks of the Gunpowder Creek and Paradise Creek Formations disposed in a series of anticlinal and synclinal structures which, however, cannot be discerned on the imagery. In turn this area, covered in the west by Cambrian and later strata is clearly distinguished from the more closely folded and complexly faulted belt which characterizes the Lady Annie area. Here a major syncline is clearly outlined on the imagery and the fault which marks its eastern limit is revealed as a major structure extending northeastwards well beyond the limits of the area in which it has been mapped hitherto. Westwards of the Lady Annie fold belt the broad alluvium covered valley of the West Thornton river is outlined, but tonal and colour contrasts on the imagery, notably for September and November, suggest the presence of folded Proterozoic rocks beneath the alluvial cover in the east and distinctive spectral patterns and spectral signatures on the March and November imagery indicate the presence of sub-outcropping Cambrian rocks near the river in the West. Northeast and southwest of Lady Annie particularly dark signatures of irregular outline distinguish areas with lateritic cover. In the southwest sector of the frame, west of McLeod Hill, a sharply defined circular feature with a green spectral hue, which contrasts with the red hues of the surrounding area on the March imagery, coincides with the outline of Pilpah sandstone shown on the four miles to the inch geological map. (Figures 49, 50 and 51, Plate 34) The feature is equally strongly delineated on the LANDSAT 2 imagery for November and September 1975 and on the LANDSAT 1 imagery for February 1973, although in each case the tone and hue of the spectral reflectances produced by both the feature and the surrounding plains are different.

Within the areas outlined above the LANDSAT imagery delineates certain individual lithological units remarkably clearly. In the Mount Gordon fault zone area more lithological units are discriminated on the imagery than are indicated on de Keyser's map. The quartzites at the top of the Judenan formation are distinguished in March by their light green colours while the stratigraphically lower conglomerates, dolomites, argillaceous members and basal volcanics are revealed by a sequence of signatures which, according to the nature of the bedrock, are of light to medium tone and of dominantly green blue hue in March and of somewhat darker tone with a reddish orange component to the blue green hue in September. Where they outcrop within the fault zone the siltstone horizons of the Gunpowder Creek formation produce reflectances of medium tone and dominantly blue hue in March whereas to the west of the zone they are characterized by dominantly green ones : these spectral differences suggest that the rocks in the east are more calcareous and those in the west more siliceous. In both areas the dolomitic horizons within both the Gunpowder sequence and the overlying Paradise Creek formation are outlined by brownish red or blueish red colours in March. In September red hues dominate the spectral signatures of both the Gunpowder Creek and Paradise Creek formations but blue and green components respectively again discriminate between the calcareous and silicous siltstones of the former formation whereas reddish orange hues characterize the dolomitic horizons of both. The individual lithological units within the geological formations are clearly distinguishable also on the November imagery on which purple brown and grey hues predominate. The distinctive spectral signatures which discriminate the lithological units within the geological formations in the Mount Gordon fault zone at each season of the year result partly from the extent and reflectivity of the outcropping bedrock and partly from the nature of the vegetation cover, with the dominance of green spectral hues over the quartzite horizons being attributable to the poor reflectivity of the <u>Triodia pungens</u> grass cover and the persistence of red hues over the dolomites to the prevalence of soft grasses notably <u>Enneapogon polyphyllus</u>.

In the area between the Mount Gordon fault zone and the Lady Annie area distinctive spectral signatures distinguish between the Myally beds, the Gunpowder formation and the Paradise Creek formation on the LANDSAT 2 imagery for March, September and November (Figures 49, 50 and 51, Plate 11 and 33) with the most pronounced contrasts occurring on the March imagery. On this, as elsewhere, light green spectral hues (2 dc, 2 dae] characterize the Myally quartzites, whereas dominantly blue and red ones respectively characterize the siltstones of the Gunpowder formation (5 eap, 4 ead, etc.) and the dolomites of the Paradise Creek formation (4 adce, 3 ade, 3 aed etc.). In the west distinctive spectral signatures and spectral patterns differentiate the area underlain by Cambrian rocks, with red signatures characterizing the Thorntonian limestones and one of subtle purplish hue (4 gaed) outlining the Beetle Creek siltstones which in this area carry important phosphate deposits. This latter hue clearly differentiates the Beetle Creek formation from the overlying Inca siltstones. With a lighter tone it occurs again on the November imagery on which the older Cambrian horizons have yellowish signatures, while it is discernible on the November imagery. The phosphate deposits carry a clearly defined and anomalous plant community covering a large area and the very distinctive spectral signature over the Beetle Creek formation is in part due to the reflectance of this vegetation and in part due to the reflectance of the bedrock and soil cover. (Plates 35 and 36)

Sharp contrasts of spectral signatures on the LANDSAT imagery for March, September and November delineate the individual lithological units particularly clearly in the Lady Annie/Lady Loretta area, where studies of multi-spectral air photography and field checking of ground truth information has also been undertaken. (Figures 53, 54 and 55, Plates 37, 38, 39, 40, 41 and 42) Very light green signatures clearly outline the flat topped plateau blocks of Myally quartzites which carry a very open vegetation cover characterized by sparse Triodia pungens grass with scattered Eucalyptus trees both of which reflect poorly. The northern block is surrounded and the southern blocks are adjoined on one side by broken country with numerous mesas where the Gunpowder Creek formation has a laterite capping carrying a fairly dense growth of *Acacia shirleyii* woodland. (Plate 28) These rocks are clearly delineated by spectral signatures of exceptionally dark tone on the imagery for each season. The boundaries of both the Myally blocks and the Gunpowder formation are more clearly defined than on de Keyser's map and the sharp contrasts of spectral signature between the two and between the latter and adjacent outcropping Paradise Creek beds suggest a series of fault blocks not hitherto distinguished. In this area the clear delineation of the lithological units is due largely to the highly ferruginous nature of the Gunpowder rocks and to the heavy growth of *Acacia shirleyii*. On the northern side of the most easterly of the Myally blocks a very dark blue/red spectral signature occurs both over broken country where the basal unit of the Gunpowder Creek formation has a well developed laterite cap which in places displays gossanous features and extends northwards along the line of the major fault which separates the lower Proterozoic rocks from the overlying Cambrian rocks to the east. Here the possibilities of mineralization merit attention.

Structural features are also exceptionally well displayed on the LANDSAT imagery of the Lady Annie area. Here a major syncline involving rocks of the Paradise Creek formation is clearly delineated. (Figures 53 and 55) This is largely because highly ferruginous lateritic cappings producing very dark spectral signatures occur over the unit comprising algal cherts, chert breccias and dolomitic siltstones near the periphery of the structure. (Plates 42 and 43) At the eastern margin of the syncline sharp contrasts of spectral signature occur on either side of and serve to delineate the major fault along which the Cambrian rocks on the east abut against the Precambrian rocks on the west. Dark spectral signatures caused by iron rich rocks mark the line of this lineament which continued northeastwards beyond the area in which it has been mapped hitherto. The fault is clearly discernible through the area of laterite cover where striking differences of tone occur on either side of it on the imagery for each season.

Within the overall synclinal structure dark blue spectral signatures (7 ea) indicate the position of the pyritic and carbonaceous shale horizon which occurs within the Paradise Creek formation in the features known as the Big syncline and Small syncline east of Lady Annie (Cole 1977). In the latter structure it contains the Lady Loretta lead-zinc deposit which has a gossan at surface. The horizon shows most clearly in the LANDSAT I imagery for 2 March 1973 but is also distinguishable on the LANDSAT 2 imagery for March, September and November 1975. It produces narrow steep sided flat topped ridges with considerable laterite cappings. Open Triodia pungens grassland with scattered Eucalyptus brevifolia trees occur over the plateaux tops and dense Acacia shirleyii woodland occupies the steep slopes and the laterite caps. (Plates 39 and 40) The iron rich rocks, the dense Acacia shirleyii woodland and probably also the steep sided ridges contribute to the dark signatures. A strong lineament which appears to coincide with the position of the Carlton fault may be recognised in the area. It appears to extend east-northeastwards beneath the cover of Cambrian rocks and poses the likelihood of structures in the underlying Precambrian rocks with the possibility of concealed ore deposits.

Most of the major faults depicted on de Keyser's map are apparent on the LANDSAT imagery for March, September and November 1975. Some of these extend beyond the area in which they have been mapped hitherto. Other lineaments not previously known, may be recognised on the imagery (Figure 42). These include major structures respectively passing through the areas in which the Mammoth mine and the Mount Clark and Mount Kelly zones of copper mineralization are located. These have eastnortheast- west southwest and northnorthwest-south southeast orientations respectively. Additional lineaments with the same orientations, which are similar to those identified in the Dugald River area, may be detected particularly on the March and November imagery. Further major lineaments may also be recognised. Where very dark spectral signatures, suggesting iron rich rocks, occur along these as for example north of Lady Agnes mine, west and southwest of Lady Annie, northwest and southeast of Mount Kelly and within the Mount Gordon fault zone, exploration for base metals may be worthwhile.

The geological information yielded by the colour composite generated from the positive films of MSS bands 4, 5 and 7 of LANDSAT 2 imagery for 22 March 1975 (ID 2059-00012) merited studies of similar composites from the computer compatible tapes. For this purpose composites providing resolutions of individual pixels were generated for the Lady Annie - Lady Loretta and the Mount Kelly areas. (Figures 56, 57, 58, 59, 60, 61, 62, 63, 64, 65 and 66)

Studies of the Lady Annie - Lady Loretta composite at a scale of approximately 1:35,000 disclosed additional spectral signatures, discriminated greater lithological detail and, distinguished between different categories of laterite cover and of iron rich bedrock and revealed the presence of faults and lineaments not readily detected on the composites generated from the positive films.

As on the composites generated from the NASA films, the upstanding anticlinal blocks of Myally quartzites are distinguished by very light green and yellow spectral signatures (1 cdg, 1 cd, 1 xd). On the CCT composites more detail is available arising notably from differences of spectral signatures related to jointing and to bedding which suggest trends within the fold structures. The spectral signatures of the areas underlain by the younger Gunpowder Creek and Paradise Creek formations vary with lithology, with the presence of stromatolitic horizons and with the development of iron rich horizons. Again more detailed information is displayed, with the dark purple red (8 gad, 8 dga, 8 gd) signatures of the stromatolitic horizons providing useful markers. In striking contrast the siltstones and shales tend to have green spectral signatures and the dolomites to have deep pink or red ones. The individual lithological/stratigraphical units are particularly well displayed in the fold structures west of Lady Annie.

The details displayed within the Cambrian formation are of particular interest. The area of the Lady Annie phosphate deposits contained in the Beetle Creek siltstones is very clearly defined by a subtle light purple or mauve spectral signature. (5 ghe, 6 egh) To the south southeast this ends abruptly where red spectral signatures delineate Paradise Creek limestones and chert and vivid green ones (4 d) outline the area underlain by Gunpowder Creek siltstones. To the northwest bright magenta pink and yellow spectral signatures occur over the Inca siltstones with the light yellow signatures (5 hb, 3 hc) being associated particularly with spreads of red sand and quartz gravel. The airstrip made to sustain exploration activities in this area is delineated by a pale yellow signature. (c)

The unique spectral signature over the phosphate deposits is undoubtedly related to the distinctive vegetation which characterizes them in this area. This is composed of fairly closely spaced small _Atalaya hemiglauca_ trees with a ground layer dominated by _Chrysopogon fallax_ and _Enneapogon polyphyllus_ grasses. (Plates 35 and 36) Virtually no other trees or shrubs are present. The _Atalaya hemiglauca_ trees have canopies of narrow dark green drooping leaves whose reflectances in the infra red bands in March, like those of _Chrysopogon fallax_ and _Enneapogon polyphyllus_ which forms an incomplete ground cover over the dark brown soils, is weaker than that of the strongly reflecting perennial and annual grasses on areas of covered ground and limestone bedrock but is stronger than that of _Triodia pungens_ grass which is characteristic of siliceous soils and bedrock. The unique character of the spectral signatures over the phosphate bearing rocks is confirmed by the fact that it occurs over the Lady Jane phosphate area north of the Lady Agnes copper show in the northern part of the area covered by the LANDSAT composite.

The relationships between the spectral signatures and the vegetation cover is readily confirmed from field data obtained in the vicinity of the airstrip. Here the vegetation is composed of an admixture of Eucalyptus pruinosa and Atalaya hemiglauca trees with Chrysopogon fallax grass, which are largely responsbile for the pink and yellow spectral signatures (5 hb, 5 h, 3 hc). Further north this gives way to areas of Eucalyptus brevifolia and Triodia pungens which produces the green spectral signatures. (2 d) At the western end of the airstrip areas of red sandy soil contribute to the yellow signatures characteristic of that area.

Between the Lady Annie phosphate area and Paradise Creek dark red spectral signatures (6 ab, 9 a, 9 ab) distinguish the area underlain by dolomites of the Paradise Creek formation from that underlain by Cambrian limestones, which have a magenta pink spectral signature (5 hbc), to the west. The latter in turn is sharply distinguished from the area with green and yellow spectral signatures (1 cd) where Cambrian rubble veneers the surface, the change taking place along the line of a small creek. East of Paradise Creek and of its east bank tributary, a change to predominantly green spectral signatures (4 dg etc) marks the contact with the Gunpowder Creek siltstones. Within the bright red spectral signatures which characterize the dolomites of the Paradise Creek formation to the west of this tributary the pattern of the signatures of individual pixels reveals the bedding trends in the bedrock. North of Paradise Creek dark signatures disclose the presence of stromatolitic horizons which form marked relief features. Within this area the position of major faults is revealed by sharp changes of spectral signatures.

Within the area underlain by the Cambrian formation dark green spectral signatures (7 dg, 8 dg,z) outline areas capped by laterite which carry a woodland of Acacia shirleyii.

On the CCT colour composite distinctive spectral signatures discriminate between areas of laterite and of iron rich bedrock and between different categories of laterite. Thus in the northeastern part of composite predominantly dark green spectral signatures (7 dze, 7 dz, 93 d) outline the lateritic plateau which extends from the headwaters of Slatey Creek eastwards towards the Mount Oxide - Mammoth area beyond the margin of the frame. The exceptionally dark signatures at the periphery of this plateau are associated with outcropping laterite at the breakaway scarp feature which is characterized by stands of Acacia shirleyii trees. A sharp spectral boundary marks the northeastern extension of the major fault along the eastern boundary of the major Lady Annie synclinorium. To the west predominantly green signatures (7 dze, 7 z etc.) occur over red lateritic sandy soils which support mosaic distributions of savanna woodland associations. In places these are dominated by large Eucalyptus terminalis trees and Triodia pungens grass sometimes associated with small Petalostigma quadriloculare trees and Acacia spp shrubs. Elsewhere communities of low growing shrubs most commonly Acacia, Grevillea and Hakea spp associated with Triodia pungens grass occurs. The variations in the form and composition of these communities is responsible for the minor variations of spectral signature within the overall dark green one outlining the lateritic plateau. The very dark, almost black signatures are produced by dense stands of Acacia shirleyii. East of the fault green and red spectral signatures occur where broad leaved grasses accompany or alternate with Triodia pungens grass in the open savanna woodland of Eucalyptus brevifolia, E. pruinosa and other tree species.

In the central part of the composite dark purplish red and green spectral signatures (8 gad, 8 dga, 8 gd, 7 dge etc.) distinguish areas of ferruginous Gunpowder Creek siltstones and shale and Paradise Creek stromatolitic chert. The former are clearly delineated around the western and northern sides of the southern anticlinal blocks of Myally sandstone and around most of the northern block; in the latter area their south western boundary again suggests the block faulting cited on p.68. Further north individual laterite caps may be recognized. Within the dark spectral signatures produced over the Gunpowder Creek siltstones and shale unit at the northern end of the eastern Myally block there are two of exceptionally dark signatures. Both occur along a major southwest-northeast trending lineament, one of them where this intersects the major fault along which the lower Proterozoic rocks abut against Cambrian rocks to the east. This may be a favourable site for mineralization.

The stromatolitic cherts of the Paradise Creek formation are outlined by dark reddish purple spectral signatures in the southern part of the syncline lying between the northern Myally block and the lateritic plateau and again in the area to the west of the southwestern Myally block. In both these areas lateritic cappings contribute to the dark spectral signatures. In both the trends in the spectral signatures effectively disclose the fold structures.

Both limbs of the Small syncline and the eastern limb of the Big syncline in the Lady Loretta area are distinguished by very dark spectral signatures (z) which contrast with the vivid green spectral signatures (5 d) of those adjacent to the Lady Annie airstrip (delineated by its yellow signature) to the south. This information together with the presence of a lighter green signature (8 dz) in the centre of the Small syncline and of pixels of orange and yellow hue (5 b) on the plateau surfaces associated with the eastern limb of both synclines prompted study of this area at a scale of 1:10,000 (Figures 59, 60 and 61).

The colour composite of the Lady Loretta area generated from the computer compatible tapes at the 1:10,000 scale (Figure 59) was interpreted with reference to the geological map of Alcock and Lee published in 1974 (Figures 61 and 62). The Small syncline and the Big syncline may be distinguished. Within both features particularly dark spectral signatures (9 j, 9 k, 9 jk, 9 gz, 9 w, 10 w etc.) within the areas of generally reddish brown spectral reflectances which mark the pyritic and carbonaceous shale host rock of the lead-zinc mineralization, occur. In the Small syncline these appear to occur over the Ore Horizon. Similar reflectances, however, occur over stromatolitic horizons to the northwest of the synclines. East of Lady Loretta quite distinctive very dark green and grey spectral reflectances (7 d, 9 d, 9 w, 10 w, 7 dk) outline the areas of lateritic cover. The bright red (6 a) area within the Big syncline marks the line of a valley. North of Lady Loretta the southern sections of the two plateau blocks of Myally quartzite have light spectral reflectances as has also much of the area of covered ground to the southeast and southwest. While the resolution on the colour composite generated from the computer compatible tapes at the 1:10,000 scale is limited to that of the LANDSAT imagery i.e. 80 metres, nevertheless when the composite is compared with the detailed geological maps based on the work of Alcock and Lee (Figure 62) it is clear that it presents a remarkable amount of information. This suggests that LANDSAT imagery handled in this way has a considerable potential in mineral exploration. The information is most valuable when it can be compared with air survey photography at the same scale. Here a comparison of the colour composite of the most northerly of the Myally blocks, with the print lay-down of the air photos of the same area is useful. (Figures 63 and 64) Like the Lady Loretta area the colour composite of this Myally block was displayed at the 1:10,000 scale. The comparison with the print lay-down of the air photos indicates that the broken relief of the area underlain by the basal unit of the Gunpowder Creek formation plays some part in determining the very dark spectral reflectances which characterize the unit. At the same time the information yielded by the LANDSAT imagery suggests the need for some revision of the geological map of de Keyser, as modified by Alcock, Graylin, Dowling and Cox, including the recognition of additional faults. (Figure 55)

The colour composite generated from the computer compatible tapes for the Mount Kelly area southeast of Lady Annie was displayed at a scale of 1:44,000 for study with the geological map of de Keyser (de Keyser 1968). Interpretation of the spectral signatures disclosed relationships with terrain features which are broadly similar to those identified in the Lady Annie area. (Figures 65 and 66) Sharp contrasts of spectral signature distinguish areas of outcropping and near surface bedrock, which according to lithology display a range of tones and hues, from areas covered by alluvium and clothed with strongly reflecting grasses which have bright crimson pink or red ones. Light spectral signatures again delineate upstanding blocks of Myally quartzites with a sparse vegetation of _Eucalyptus brevifolia_ trees and _Triodia pungens_ grass but near Mount Kelly their hue is dominantly yellow (1 cd, 2 ch). Areas underlain by Paradise Creek dolomites have a reddish spectral signature (4 hg, 4 hd etc.) whereas those underlain by Gunpowder Creek siltstones have darker ones of purplish hue (6 g, 7 g). Within the areas underlain by these geological units however, there are considerable variations of spectral signature due to varied relief features, the presence of lateritic relicts and changes in the composition of the vegetation over relatively short distances. In the Mount Kelly area the most significant features disclosed by the satellite imagery are the faults and lineaments which in most cases are revealed by sharp discordances in the distributional patterns of spectral signatures. (Figures 66 and 67) In the vicinity of the old Mount Kelly mine (Plates 44 and 45) the two dominant sets of lineaments which respectively trend northwest-southeast and northeast-southwest, intersect and are cut by additional faults and lineaments which do not conform to these trends. Anomalous plant communities occur along some of these and in some cases are associated with copper mineralization. (Plates 46 and 47).

At the scales at which the satellite imagery of the Lady Annie - Mount Gordon fault zone was studied, both major structural features and distinctive lithologies within the major geological formations are very clearly displayed on the colour composites generated from the computer compatible tapes. In most cases the outputs confirm more precisely the information interpreted from the colour composites generated from the NASA films. In addition to the major faults and lineaments, including those along which the Lady Loretta lead-zinc deposit and the Mammoth, Lady Annie and Mount Kelly copper deposits are located, many smaller faults may be detected, some of them not mapped hitherto and possibly of considerable geological significance.

3.3.2 THE RECOGNITION OF THE NATURE AND DISTRIBUTION OF SUPERFICIAL DEPOSITS IN LANDSAT IMAGERY AT DIFFERENT SEASONS OF THE YEAR

Initial studies of the colour composites generated at the 1:50,000 scale from the MSS bands 4, 5 and 7 of the LANDSAT I and 2 imagery covering the extensive level plains north of Cloncurry, the smaller plains drained by Cabbage Tree creek northwest of the Dugald River Lode, and the extensive plains southwest of Mount Isa revealed unexpected complex patterns of spectral signatures which it was thought might be produced by the combined reflectance of plant communities and soils whose distributions were closely related to the nature of the superficial deposits and possibly to that of near surface bedrock geology. The most intricate patterns were displayed in the area between the Cloncurry and Williams rivers on the plains to the northeast of Cloncurry. This area therefore was chosen as one for detailed study and in 1975 multi-spectral aerial photography was flown over a strip of country which included each of the spectral signatures displayed on the LANDSAT imagery.

3.3.2.1 THE CLONCURRY PLAINS

The colour composites generated at the 1:50,000 scale from the negatives of the MSS bands 4, 5 and 7 of the LANDSAT imagery for 22 December 1972 (ID 1152-00073), the 2 March 1975 (ID 2039-23555) and the 24 July 1975 (ID 2183-23552) show large areas of relatively light toned signatures over the central part of the plains between the Cloncurry and Williams rivers, finger like areas of darker tone producing more complex patterns following the creeks tributary to the Williams river and a mosaic of smaller areas of variable tone and colour between the two. (Figures 68, 69, 70, 71, 72, 73 and 74) This pattern suggested possible contrasts between an open grassland over the central part of the plains, belts with tree growth along the creeks and grasslands with variable numbers of trees between the two. Much of the country is inaccessible but an examination of the true colour and false colour aerial photography over the strip of country flown in 1975 coupled with field investigations along carefully selected traverses undertaken in 1974, 1975 and 1976 have indicated that this interpretation is correct. (Plates 10, 12, 17, 18 and 48)

Comparison of the overlay of spectral signatures interpreted from the colour composite generated from LANDSAT 1 imagery for 22 December 1972 with a map showing the superficial deposits and bedrock geology prepared in 1970 by the Australian Bureau of Mineral Resources for the Cloncurry 1:250,000 sheet area and covering part of the plains west of the Williams river shows a remarkable coincidence of boundaries (Figures 68, 69, 70 and 75). This relationship is evident also from the LANDSAT 2 imagery for 24 July 1975. (Figures 73 and 74) There is less coincidence of boundaries between the spectral signatures recognised on the imagery for 2 March 1975 and the superficial deposits, doubtless because of the greater grass cover following rains at this period (Figures 71, 72 and 75). Certain boundaries however are common. A major spectral boundary running approximately north-south from Gipsy Plains to Mount Margaret is apparent on both the LANDSAT 1 December 1972 imagery and the LANDSAT 2 imagery for both March and July 1975. (Figures 70, 72 and 74) This coincides with the boundary separating areas underlain by grey clay and silt of the Older Alluvium to the west from that covered by colluvial sand and gravel with minor areas of Older Alluvium, and Allaru mudstone to the east. Field investigations carried out between June and September 1974 showed that the plant cover over the Older Alluvium on the western part of the plain comprised a savanna grassland composed mainly of perennial Astrebla and annual Iseilima species whereas that over the colluvial sand and gravel to the east comprised a sparse grass cover of annual grasses, mainly Aristida contorta and Sporobolus australasicus with some Triodia pungens, scattered Carissa lanceolata bushes and small Eucalyptus pruinosa trees. The soils were respectively yellowish brown (10 YR 5/4) clays drying to a grey colour at surface and reddish brown (5 YR 4/8) sandy clays. The well defined major spectral boundary at both seasons results from the contrasts of plant cover, which in turn are related to soils and superficial deposits. The differing spectral signatures at different seasons arise from differences in the state of the plant cover. At the end of the dry season in December the Astrebla and Iseilima spp grasses on the Older Alluvium were brown, very dry and reflecting weakly to give light green and yellow signatures (2 daec, 2 deca, etc.) on the imagery whereas the trees, shrubs and Triodia pungens grass over the colluvial sand and gravel were sufficiently green to give a light pink component to the spectral signature. (5 adeb, 4 aced, etc.) In March 1975 after the rains, however, the Astrebla and Iseilima spp grasses formed an almost complete green cover which was reflecting strongly to give crimson spectral signatures (6 a, 6 ag, 5 ae, 4 ae, etc.) By contrast the sparse cover of Triodia pungens, annual grasses, scattered shrubs and trees over the areas of colluvial sand and gravel was reflecting weakly so that blue and green hues dominated the spectral signatures (5 ead, 4 dea, 5 de, 3 dea etc). By July 1975, however, the Astrebla and Iseilima spp grasses were again relatively dry and reflecting more weakly to produce pink, green and yellow spectral signatures of light to medium tone (3 ade, 3 dea, 3 adc, 2 adc etc).

Within the area of Older Alluvium west of the line from Gipsy Plains to Mount Margaret the individual spectral signatures cover relatively large areas on both the LANDSAT 1 December 1972 and the LANDSAT 2 March and July 1975 imagery. East of this line, however, a mosaic of spectral signatures contrasting in both tone and hue is evident at all seasons. Here the distributional pattern of the signatures on the LANDSAT 1 imagery for December 1972 suggests a close relationship with both superficial deposits and bedrock geology, influenced in part by the nature of the soils and the composition of the vegetation. Dark violet and red spectral signatures (6 adec) occur over areas underlain by the Lower Cretaceous Allaru mudstone and adjacent areas of Modern Alluvium along the creeks. These areas are inaccessible but studies of the aircraft imagery indicate that they carry open woodland characterized by *Acacia cambagei* or by other *Acacia* and *Eucalyptus* species. On the March 1975 LANDSAT 2 imagery relatively dark spectral signatures of blue, green and violet or crimson hue (6 eda) occur over the same areas but extend also over adjacent areas of Older and Modern Alluvium, where new green grass growth may be contributing the crimson colour to the signature. At this season in this area the mosaic of spectral signatures bears little relationship to geology. Certain spectral boundaries coincide with fence lines on either side of which differing grazing practices have caused differences in the composition of the plant cover and hence in the spectral signatures. On the July 1975 imagery, the spectral signatures bear a closer relationship to the distribution of the superficial deposits but the differences in the composition of the plant cover on either side of fence lines is still apparent. Dark signatures of blue green and violet hue however again distinguish areas with stands of Acacia cambagei along the creek lines, particularly where the Allaru mudstone outcrops or suboutcrops.

Studies of the air survey imagery acquired in 1975, coupled with field investigations revealed the presence of areas with lozenge shaped features produced by concentric distributions of plant communities comparable with those found earlier on the 1971 air photo coverage of the Little Eva North Plains (Figures 80 and 81) (Cole, Owen-Jones, Custance and Beaumont 1974). This disclosure together with the evidence, cited above, of the close relationships between spectral signatures on the LANDSAT colour composites, vegetation, soils and superficial deposits prompted the generation of colour composites from the LANDSAT computer compatible tapes for 2 March 1975 for display at the same scale as the air survey photography ie 1:32,000. The objectives were twofold, firstly to investigate more closely the boundary zone between areas covered by Older Alluvium and Colluvium; and secondly to ascertain whether areas with lozenge shape features produce distinctive spectral signatures which can be identified on LANDSAT imagery.

The colour composite generated from the computer compatible tapes which covers the Gipsy Plains area (Figures 6 and 76) clearly differentiate between the areas covered by grassland dominated by strongly reflecting Astrebla pectinata and Iseilima macrathera and I. fragile species which produce bright crimson red spectral signatures (7 h, 7 ha, 6 had) and those characterized by open low tree savanna and by stands of Acacia cambagei trees which have dominantly green spectral signatures. The major boundary coincides with that between areas underlain by the Older Alluvium and those covered with colluvial sand and gravel; within the former green spectral signatures probably reveal a veneer of sand and gravel whereas within the latter bright red spectral signatures outline areas with alluvial cover characterized by vegetation patterns producing lozenge shape features. The boundaries between the individual types of superficial deposit appear to be more precisely delineated than on the published map (Figures 76, 77, 78 and 75). In the north the line of the fence running from Gipsy Plains homestead to the Gipsy Creek is clearly distinguished. On its northern side alternating stands of Acacia cambagei and Eucalyptus pruinosa trees associated with Acacia chisholmii shrubs and Triodia pungens grass occurring over colluvium give rise to the dark green spectral signatures (5 d, 6 d, and 7 d) whereas on its southern side Astrebla - Iseilima grassland with stands of Acacia cambagei produce a mosaic of predominantly red spectral signatures with a scatter of green ones.

Comparison of the spectral signatures recognised on the LANDSAT imagery with the interpretation of the air survey imagery reveals a remarkable degree of coincidence (Figures 78, 79, 80 and 81) The resolution of the LANDSAT imagery at this scale is good and the clear display of major fence lines northwest of Antion Downs permits easy correlation with the air survey imagery. The boundaries of the areas characterized by bright crimson red spectral signatures (6 hg, 6 hgb, 7 ha, 6 ha) accord very closely with those characterized by the lozenge shaped features outlined on the air photos, thereby indicating that such areas can be delineated from LANDSAT imagery acquired after rains when, as verified by field investigations, the plant cover is dominated by the strongly reflecting perennial grass *Astrebla pectinata* and the annual grasses *Iseilima macrathera* and *I. fragile*. Individual lozenge shaped features like those characteristic of the areas with bright crimson red spectral signatures (6 hg, 6 ha) north of Antion Downs (Figure 76) however, cannot be delineated on the LANDSAT imagery. Comparison of the air survey imagery and the colour composite covering the area between Antion Downs and Gipsy Plains shows that relatively light green, violet and red spectral signatures (4 dgh, 4 adg, 3 hdb) delineate open low tree savanna characterized by *Eucalyptus pruinosa* trees, *Acacia chisholmii* shrubs and *Triodia pungens* grass whereas dark green and violet spectral signatures (7 gda, 6 deg, 6 de, 7 gad) distinguish areas with dense stands of *Acacia cambagei* trees.

Examination of the individual outputs produced by density slicing the data in each of the four MSS bands into twenty groups, undertaken for the generation of the Gipsy Plains colour composite, reveals marked differences in the information between the four bands. Close study of these differences assists interpretation of the spectral signatures on the colour composite relative to ground truth information. Thus the output from MSS band 4 (Figure 82) shows sharp differences between areas of relatively light and relatively dark density ranges which respectively show a close relationship but not complete accordance with areas of contrasting red and green spectral hues, which in turn are related to areas of grassland over Older Alluvium and of open low tree savanna over Colluvium. Northwest of Gipsy Plains homestead relatively light density ranges occur ocer an area of low tree savanna characterized by Eucalyptus pruinosa trees which produce a green spectral signature (5 d) north of a clearly defined fence line. By contrast darker density ranges occur over adjacent areas of Acacia cambagei trees and producing a darker green spectral signature (6 d). Both these communities occur over Colluvium. South of Gipsy Plains homestead the boundary between areas of distinctive density range differs from that between areas with red and green spectral hues respectively in several places. Broadly speaking the boundary follows that between areas underlain by grey clay and silt of the Older Alluvium in the west and by reddish Colluvial sand, gravel and clay in the east. It departs from it where thin spreads of the latter material form an incomplete veneer over the former. Here light density ranges occur over areas with green blue spectral signatures produced by a cover of Triodia pungens, Sporobolus australasicus and Aristida contorta grasses and scattered Acacia chisholmii and Carissa lanceolata shrubs. The broad relationships between density range and the nature of the superficial deposits indicate that differences of colour, texture and especially of moisture content of the soil are discriminated by MSS band 4 whereas the discrepancies between density range and spectral hue suggest that differences in the plant cover are less readily distinguished.

On the output produced by slicing the data on MSS band 5 (Figure 83), with one or two exceptions, the relatively darker density ranges occur in the areas of red spectral signatures and the lighter ones in the areas with green and green blue spectral signatures, a distribution which contrasts with that in the other MSS bands. The boundaries between areas of contrasting density ranges do not generally accord with those between areas of red and green spectral signature. Northwest of Gipsy Plains homestead an area of light densities virtually coincides with a large outlying patch of Colluvium and straddles areas of red and green spectral signatures over grassland and low tree savanna. South of Gipsy Plains homestead the boundaries between areas of contrasting density ranges accord most nearly with those of contrasting spectral hue along the contact between the Older Alluvium and the Colluvium. In places along this contact, however, more diffuse differences of density range occur where thin spreads of colluvial sand partially cover the Older Alluvium, and cause minor changes in the vegetation which in turn produce variations of spectral hue,

The outputs produced by density slicing the data in MSS bands 6 and 7 contrast sharply with those of MSS bands 4 and 5. Here the densities are darker in the areas underlain by Colluvium and there are greater spatial variations and greater contrasts of density range over the whole area, notably in MSS band 7. This is due partly to contrast stretching in the slicing process. The darker densities generally coincide with the areas characterized by green and green blue spectral signatures on the colour composite whereas the lighter ones coincide with red spectral signatures. The density ranges in MSS bands 6 and 7 (Figures 84 and 85) are more closely related to the spectral signatures on the colour composite than is the case with MSS bands 4 and 5. This is because MSS bands 6 and 7 are reflecting variations in the plant communities which are of the greatest importance in the production of the spectral signatures. This is particularly apparent in the north of the frame where there are sharp changes of vegetation on the other side of the clearly defined fence line which cuts across the outlier of Colluvium delineated on MSS band 5. It is also apparent within the area of Astrebla - Iseilima grassland over the Older Alluvium in the west where changes of density and of spectral hue are caused by minor changes in the composition of the grassland.

Thus studies of the LANDSAT imagery acquired at different seasons of the year over the Cloncurry Plains and interpreted with reference to air survey imagery and field investigations have confirmed the presence of complex patterns of plant communties whose distributions are related to superficial and bedrock geology. They have demonstrated the value of LANDSAT imagery for mapping vegetation and geology in such areas and have indicated that the most effective discrimination of plant communities is obtained from MSS bands 6 and 7, that of superficial geology from band 5 and that of soils and soil moisture from band 4.

3.3.3 THE RECOGNITION OF SPECTRAL SIGNATURES REFLECTING CHANGES IN PLANT COMMUNITIES OCCASIONED BY OVERGRAZING AND BY FIRE

THE CLONCURRY AND URANDANGI PLAINS

Sharp changes of spectral signatures on either side of fences which were noted on the true colour and infra red colour photography of the Mary Kathleen - Cloncurry area suggested differences in the plant cover occasioned by differing grazing practices. Comparable differences were subsequently detected on the colour composite generated from MSS bands 4, 5 and 7 of enlarged grid sections of the LANDSAT imagery covering the Astrebla - Iseilima - Dichanthium grasslands which occupy the black soil plains in the Urandangi area which was imaged on 18 September 1975 (ID 2239-0003) Field investigations confirmed that, in each case the differences were due to differences in grazing intensities, with, in the Urandangi area, the frequency of Acacia georginae trees which occur sporadically through the grasslands playing some part. (Plates 49 and 50)

On the colour composite generated from MSS bands 4, 5 and 7 for the enlarged grid section of the LANDSAT 1 imagery covering the Cloncurry Plains imaged on 22 December 1972 two areas with sharply defined dark green spectral signatures (8 de, 8 dea, 7 dae) of irregular outline which transgressed all other spectral signatures were identified to the southeast of the Cloncurry river (Figures 68 and 86). Their nature and form suggested that they might indicate areas which had been burnt. Accordingly they were compared with those on the colour composites of the same areas generated from earlier and later LANDSAT passes.

Studies of the colour composite generated from an earlier LANDSAT 1 pass on 16 November 1972 (ID 1116-00073) showed that at that date the areas had dominantly red spectral signatures of medium tone (4 ade, 5 ade) which were characteristic of a much larger area covered by colluvium, sand and gravel southeast of Gipsy Creek (Figure 87). These spectral signatures indicated that the vegetation which comprised a sparse grass cover of Triodia pungens, Chrysopogon fallax and Aristida contorta with Eucalyptus pruinosa trees and Carissa lanceolata shrubs was sufficiently green to give relatively strong reflectances. This reinforced the suggestion that the dark green signatures within the region apparent on the December imagery were the result of fire between the two LANDSAT passes. Subsequent field investigations provided evidence of regeneration of tree, shrub and grass species after fire and studies of the colour composites generated from the LANDSAT 2 imagery for 2 March 1975 (ID 2039-23555) and 24 July 1975 (ID 2183-23552) permitted some assessment of the subsequent recovery of the vegetation. By March 1975 the outlines of the burnt areas were still discernible but the areas were now characterized by lighter green spectral signatures with red components (3 dae, 3 dea) indicative of reflectances from green vegetation; these signatures extended over a wider area. (Figure 88) By July 1975 the areas were characterized by darker dominantly red spectral signatures (4 ade) suggesting that their vegetation had almost recovered to its state in November 1972 before burning. (Figure 89)

c-2

Subsequently very dark green spectral signatures similar to those identified on the December 1972, LANDSAT 1 imagery covering the Cloncurry Plains were recognised in other areas, notably over the plains between Mount Isa and Urandangi where field investigations confirmed the identification and established the occurrence of fire.

Recognition of spectral responses which are attributable to the effects of fire and of grazing intensities on the vegetation rather than the influences of edaphic factors related to superficial and bedrock geology is important in the interpretation of the LANDSAT imagery for geological mapping and mineral exploration as well as for other purposes.

3.4 THE CLASSIFICATION OF LANDSAT AND AIR SURVEY IMAGERY OF NORTHWEST QUEENSLAND

Investigations of methods whereby the vast amount of information contained in LANDSAT and air survey imagery can be classified by semi-automated data handling techniques formed an important part of the remote sensing studies in northwest Queensland. For these investigations the LANDSAT imagery covering the Mary Kathleen area, the Cloncurry Plains, the Dugald River - Naraku area and the Lady Annie area and air survey imagery of the Dugald River area were used for comparative studies of the visual and semi-automated approaches to the recognition of spectral signatures and to their interpretation relative to environmental parameters. Both unsupervised and supervised approaches were used for the semi-automated classification of the spectral data. These were used first on the air survey imagery.

3.4.1 VISUAL AND SEMI AUTOMATED CLASSIFICATIONS OF THE AIR SURVEY IMAGERY OF THE DUGALD RIVER AREA

The air survey imagery of the Dugald River Lode area north of Cloncurry was chosen for comparison of the visual and semi-automated methods of classification because detailed ground truth information was available for the area which is characterized by a large well defined anomalous plant community related to a known lead-zinc deposit. The 1:15,000 infra red colour frame covering the central part of the lode was selected as the most suitable for subsequent comparison of colour composites generated from LANDSAT imagery.

For the visual interpretation of the imagery spectral signatures characterized by the dominance of particular colours and tones, by particular textures and patterns and by clearly defined boundaries were identified. (Cole, Owen-Jones et al 1975) These were coded by reference to the colour key of the Royal Horticultural Society (which is related to the Munsell system) and were mapped at the same scale on the microdensitometer output. The resultant map showed twenty one distinct spectral signatures and additionally a number of combined spectral signatures which could not be shown individually. (Figure 90)

For the semi-automated classification of the imagery the infra red colour frame was scanned three times by a microdensitometer incorporating successively red, green and blue primary filters and the data were outputted on paper tape. The area scanned in the frame was 50 mm square with a spot size of 0.5 mm square;

these figures corresponded to ground dimensions of 0.75Km square and 7.5m square respectively.

A simple form of preprocessing was applied to the data in that the red, green and blue intensities for each pixel were each divided by the sum of the three intensities, thereby normalizing the data. Any one of the three spectral channels then became a linear combination of the other two and consequently in the subsequent processing only the red and green channels were used. This proportioning of the data assisted in reducing the effect of undulations in the terrain whereby the intensity of the reflected radiation is subject to variations produced entirely by the geometry of the situation rather than by any change in the nature of the reflecting medium itself. For the same reason it also reduced the effect of variations in the intensity across the film produced by optical defects of the lens system.

The image was then classified using an unsupervised approach, in this case the polythetic divisive clustering algorithm POLYDIV developed by Lance (private communication 1972). For the infra red colour photography of the Dugald River Lode area this provided a satisfactory output. In this the degree of coincidence between the spectral signatures recognised by visual interpretation and those identified by the semi-automated approach depended on the degree of sophistication regarding the number of signatures recognised in each case. (Figures 90 to 97) Thus the crude distinction between areas characterized by the poorly reflecting spinifex grass <u>Triodia pungens</u> which produces a blue green signature (Signatures 8 to 19) and those covered by soft grasses of various species and varying density producing spectral signatures in the red purple range (Signatures 1 to 7, 20 and 21) was achieved by a two fold division of the POLYDIV classification which provided a remarkable degree of coincidence with the visual interpretation. (Figures 90 and 91) The anomalous plant community over the Dugald River Lode (Plate 24) was included in the POLYDIV category of soft grasses although it produced a pale blue green signature. A three fold classification by POLYDIV (Figure 92) distinguished areas characterized by the annual grass Eriachne dominii which produces a strong red purple (63 c) spectral signature (Signature 3) and by a combination of Enneapogon polyphyllus and Sporobolus australasicus with a greyed purple (186 d) signature (Signature 6) from those characterized by Enneapogon polyphyllus with a paler red purple (65 c) signature (Signature 5); these all occur over the red sandy clay loams derived from mixed colluvial and residual material on the level interfluves west of the Dugald River Lode where there is a remarkable degree of coincidence with the visual interpretation. East of the Lode, however, the coincidence was less good, the classification failing to distinguish the above name signatures from those produced by Sporobolus australasicus (Signature 2) and by a co-dominance of Triodia pungens and Enneapogon polyphyllus (Signature 11) which, with spectral signatures of violet (87 d) and blue green (123 c) occupy similar soils over similar terrain. At this level of classification, while there was some discrimination between the darker and lighter signatures it appeared that within the area covered by soft grasses the signature element produced by the soils was of greater significance than that produced by individual grass species.

The four fold classification (Figure 93) was notable for the discrimination introduced within areas characterized by a ground cover of Triodia pungens. In particular areas with scattered Eucalyptus trees (Signature 12) were distinguished from those which were virtually treeless (Signatures 8 to 10). In the southern part of the frame and in the area west of the main section of the lode the coincidence with the visual interpretation was very good but elsewhere there were discrepancies. Significantly at the four unit classification the areas where Triodia pungens occurred over bedded limestones east of the lode were distinguished from those areas where it occurred over residual and colluvial material masking calc-silicate rocks.

West of the lode the five fold classification (Figure 94) provided a more accurate delineation of areas characterized by the distinctive red purple (63 c) signature of Eriachne dominii (Signature 3) from those of areas covered by other soft grasses, but east of the lode some areas characterized by Enneapogon polyphyllus (Signature 5) were included. At the six group classification (Figure 95) for the first time the blue green (123 d, 123 c) spectral signatures of the anomalous plant community over the Dugald River Lode (Signature 1) was isolated from adjacent areas characterized by a cover of Enneapogon polyphyllus or Triodia pungens. The semi-automated output, however, did not coincide with the visual interpretation of this feature. Moreover, west of the lode, areas with much bare ground between a sparse cover of Enneapogon polyphyllus for which a red purple signature was recognised by visual interpretation, were classified with the lode by the semi-automated approach.

Classification by seven groups (Figure 96) did not provide closer coincidence with the visual interpretation than that with six groups but an eight fold grouping discriminated the creek lines from other areas with Triodia pungens (Figure 97).

Overall the semi-automated output using classification by POLYDIV provided a close relationship to the visual interpretation. In some areas coincidence was good, notably with the red purple spectral signatures produced by Eriachne dominii and the dark blue green one produced by Triodia pungens over bedded limestones. At the two fold classification the distinction between areas with a ground cover of Triodia pungens and those covered by soft grasses is also good. The comparison of the visual and semi-automated methods showed that the number of groupings should be chosen according to the amount and nature of the information required, with a six or eight fold grouping providing virtually as much information as the visual method.

Using the programme known as SOUP (Chandler 1977) the first attempts at a supervised classification of the information contained in the infra red colour photography of the Dugald River Lode area were less successful than those using the unsupervised approach. Recently however new training sets have been used and a greatly improved output showing nine groups has been achieved. (Figures 98 and 99) The output is similar to that obtained from the unsupervised approach but there is greater fragmentation of units over the soil covered terrain west of the lead-zinc lode, and the lode is less well defined.

The results obtained from the unsupervised and supervised approaches in the semi-automated classification of the air survey imagery of the Dugald River Lode area emphasize two outstanding problems in the classification of features of natural terrain. The first is the fact that within a given area of natural terrain the individual components of the vegetation, soils, relief, drainage and geology produce individual spectral responses exhibiting continuous variation in spatial extent. These components make up the spectral signatures which consequently are composite, complex and variable. Hence particularly on large scale air photos it is exceedingly difficult to define discrete training sets for supervised classification which are uniform over a sufficiently large area. These difficulties explain why the unsupervised classification using the polythetic divisive clustering algorithm POLYDIV which successively divides the data set in measurement space, according to certain decision making processes until the requisite number of subsets has been generated, appears to be more successful than the supervised approach using training sets.

The second problem relates to the dimensions of the Dugald River Lode, the feature whose identification by semi-automated methods of classification was particularly required. The feature is about 1.6 Kilometres long but is not more than 10 metres wide. which is too narrow for defining a satisfactory training set for a supervised classification. The feature is clearly delineated on the air survey photography. (Figure 100) It was identified but not uniquely discriminated by the unsupervised classification using the POLYDIV algorithm at the seven group level. It was less successfully identified by the supervised classification

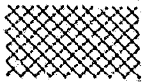
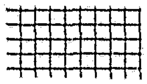
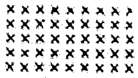
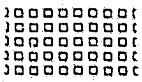
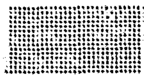
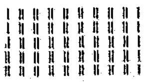
3.4.2 VISUAL AND SEMI-AUTOMATED CLASSIFICATIONS OF THE LANDSAT IMAGERY OF NORTHWEST QUEENSLAND

The scanning digitization and classification procedures used for the LANDSAT imagery were the same as those used for the air survey photography of the Dugald River Lode area. The image area scanned, however, was different, being some 18mm square with a pixel size of 0.2mm, the corresponding ground dimensions being 36 km and 400 metres. According to nature of the terrain unsupervised or supervised approaches were used for individual areas.

3.4.2.1 THE DUGALD RIVER - NARAKU AREA

The colour composites generated from LANDSAT imagery of the Dugald River - Naraku area, which encompasses the Dugald River Lode, taken on 2 March 1975 (ID 2039-23555) and 24 July 1975 (ID 2183-23552) were used for semi-automated classifications using the supervised approach. The imagery for March 1975 was analysed first. This contains a wide range of spectral classes which vary in both tone and hue (Figure 36). On the basis of visual assessment of the number of different classes present, seven classes were regarded as the optimum for classification purposes and training sets were chosen for use with the programme known as SOUP (Figure 101). These classes were selected on the basis of colour (tone and hue) only without references to ground truth data, and their essential details are given in Table 6.

Table 6 The essential details for the seven classes into which the Dugald River frame 30A (Figure 36) was classified.

Group		Colour	Shading	Ground Truth	Equivalence
1	BG	Blue green		quartzite	poor
2	P	Red/purple		soil and alluvium with soft grass cover	good
3	CR	Cream		Calc-silicate rocks masked by residuum	good
4	LR	Light Red		Soil and alluvium with soft grass cover	good
5	DR	Dark Red		Soil and alluvium with soft grass cover	good
6	BR	Brownish/purple		Soil and alluvium with soft grass cover	fair
7	DP	Blue Purple		Calc-silicate rocks	good

The resulting supervised classification map with the seven classes is given in Figure 102 with no threshold being employed.

Comparison of the supervised classification map with the colour composite and with the geological maps of the area (Figures 36, 35 and 38) shows that the groups 2, 4. 5 and 6 occur over areas mantled with soil and alluvium which after the considerable summer rains carried a grassland of strongly reflecting relatively broad bladed species. The state and nature of the vegetation were largely responsible for the strong red colour on the colour composite (Figure 36). Over the other parts of the image classified as 1, 3 and 7 bedrock is at or near to surface and the vegetation comprises a low tree and shrub savanna of scattered trees mainly Eucalyptus brevifolia and E. argillacea, and a sparse ground cover of Triodia pungens grass whose narrow rolled leaves have a weak infra red reflectance. Consequently soils,which are skeletal and bedrock make the major contribution to the spectral characteristics, that of vegetation being less important.

The recognition of four distinct classes within the area covered by soil and alluvium,for which ground truth information was not available at the time the classification was undertaken, indicates a requirement for a posterioi field investigations to establish the reasons for their apparent existance. The size of the area, the problems of access to many parts of it and the inevitability of seasonal changes in the vegetation which in a semi-arid climate are not necessarily repeated from one year to the next, makes the fulfilment of the requirement difficult if not impossible. Since, however, cultural effects in the vegetation are minimal, being those occasioned by low intensity cattle grazing and sporadic fire, it should be possible to establish the reasons for the classes displayed on the colour composite and distinguished by the semi-automated classification, by limited field investigations in critical key areas.

The range formed of Knapdale quartzite is revealed as a particularly prominent feature on the colour composite generated from the March 1975 LANDSAT imagery (Figure 36). The Dugald River lead-zinc lode occurs in shale host rock with a footwall of bedded limestone which are lower in the Proterozoic Corella sequence. They outcrop in low country to the east of the Knapdale quartzite range from which they are separated by a belt of dissected terrain over calc-silicate rocks. The quartzite range has been correctly classified on the semi-automated output but areas at least equal in total area to the outcrop of this quartzite have been incorrectly placed in the same category.

A strip to the west and a large area to the south and southeast of the quartzite range have been classified as 7. This agrees with the 1:253,440 geological map of the Bureau of Mineral Resources (Figure 35) which shows this portion of the image as underlain by undifferentiated calc-cilicate rocks. The classification does not differentiate the lithological/stratigraphical units or the structures indicated on the later interpretation of Cole (Cole et al 1976); (Figure 38). This is because it was not possible to define additional training sets representative of the well bedded argillaceous limestones within the Corella sequence.

It is evident from figure 102 that even with the relatively small number of seven classes the resulting classification map has an exceedingly complex pattern. Viewed in conjunction with the gradation of tones between classes in any natural vegetation distribution it is thus not feasible, given this complexity, to try and construct a classification accuracy table between the colour composite and the classified map (Figures 36 and 102).

The comments in the last column of table 6 consequently represent a visual assessment of the equivalence between each class in figure 102 and the areas in figure 36 considered to have the same colour as the appropriate training set. They are purely qualitative and, in themselves, highlight the problems of determining the classification accuracies of images of natural terrain. With an empirically calculated threshold for each class the accuracy could undoubtedly be increased with a considerable amount of computing but this procedure, in turn, raises the question of the amount of effort that should be devoted to this experiment and, of course, to its measurement.

The position of the Dugald River lead-zinc lode is indicated on figure 38. Its width of not more than 10 metres is less than the minimum theoretically detectable on LANDSAT imagery and although it is of sufficient length - 1.6 km - to be marginally detectable under conditions of high contrast from digital tape data, it is uncertain whether it can be uniquely discriminated on the colour composite. Recent colour composites generated directly from the computer compatible tapes where the 80 metre resolution can be maintained show distinctive spectal characteristics for the areas underlain by the shale host rock and by the bedded limestone footwall rocks of the lode and some evidence of very dark spectral signatures over the lode zone. The information, however, is too imprecise for there to be any possibility of extracting a training set for classification purposes.

The areas of Triodia pungens grassland covering the shale host rock and well bedded limestones within which the Dugald River lode is located are clearly displayed on the colour composite by their dark spectral signature (7 ed, Figure 37). The extraction of a training set for this class and the subsequent examination of the histograms with the present system would be just possible but extremely laborious. These limitations would not apply to those real time systems with visual display units in which a light pencil or analogue method can be used to delineate training areas of any shape and the histograms examined almost instantaneously, with a saving of many days' time.

The colour composite for July 1975 was generated from imagery acquired some five months later during the dry winter period. The softer broad bladed grasses had dried off and hence were contributing little radiation in the infra red band. As a result there are virtually no red spectral signatures on the colour composite which contains a restricted range of classes (Figure 103). After allowance is made for minor variations in the photographic processing there are still major differences in the imagery for July compared with that for March, due largely to the seasonal vegetation changes.

In terms of classifying the image the numerical data relating to the mean vectors and covariance matrices from the colour composite for March 1975 (Figure 36) could not be used for the July 1975 colour composite because there was no convenient way of cross-calibrating the scans for the two images. However it was possible to use the same geographical training areas for each class on both images and for the July image to calculate new values for the mean vectors and covariance matrices in the March image. The resulting classification map is shown in figure 104, with the same shading for corresponding classes as for figure 102 and again with no threshold.

There are certain similarities between the classification maps from the March and July imagery, notably for class 3 in the centre of the image, class 5 in the top right hand corner, class 6 across the top and class 7 in the bottom left hand corner.

Having regard to the quite different colours in the original images such a degree of correspondence is encouraging, since with seasonal changes in the vegetation and in soil moisture conditions complete agreement would not be expected. The classification map of the March 1975 colour composite shows considerable fragmentation into small units over the areas of soil and alluvial cover in the eastern half of the frame; that for the July colour composite shows larger classification units. These differences arose from wide variations in the moisture content of the soil over residuum and alluvium in March giving correspondingly wide variations in the composition and vigour and hence in the infra red reflectance of the grassland vegetation. By July much of the moisture would have disappeared and the sparser cover of dry grass would give a more uniform low infra-red reflectance over most of the area.

The Knapdale quartzite range has again been correctly classified but whereas on the colour composite for March it had a very distinctive bright blue/green appearance (Figure 36) on that for July it had a dull green appearance similar to much of the terrain in the lower central part of the image. A large part of this latter area has been placed in the same class although from ground truth information this is known to be incorrect.

In summary the classification of the July image using training areas determined, not by the classes in that image, but by those in the preceding March image, is reasonably successful in so far as the broad features of the terrain, including its geology, are concerned. This indicates that semi-automated classifications applied to successive LANDSAT images over a given area of terrain promise to display its outstanding features.

3.4.2.2 THE CLONCURRY PLAINS

The unsupervised approach only has been used to provide a semi-automated classification of the area of the Cloncurry Plains covered by the LANDSAT 1 imagery for 22 December 1972 (ID 1152-00073) This was because, from the results over the Dugald River Lode area, this technique appeared to be successful in areas of level terrain characterized by distinctive grass communities producing a range of spectral signatures.

As with the air survey photography of the Dugald River Lode area, the degree of coincidence between the spectral signatures recognised by visual interpretation of the colour composite of the LANDSAT 1 imagery of the Cloncurry Plains and those produced by the semi-automated approach depends on the number of groupings attempted in the latter. A seven fold division appears to provide the most satisfactory output, discriminating major units and avoiding excessive fragmentation. (Figures 68, 70, 75, 105 to 111) This division delineates the channels of the Williams and Cloncurry rivers (shading 1) which have medium tone dominantly red spectral signatures; it outlines the area with medium tone red blue or violet signatures which are produced by stands of Acacia cambagei trees with a sparse cover of Sporobolus australasicus grass over the level terrain characterized by yellowish brown (10YR 5/4) to brown or dark brown (10YR 4/3 dry, 10YR 4/4 wet) soils derived from alluvium along the creeks (shading 33) and separately distinguished those areas where the Acacia cambagei trees are associated with Eucalyptus pruinosa trees which have a lighter dominantly red spectral signature (shading 72). The semi-automated output clearly displays the area of medium tone pink or red and yellow spectral signatures produced by the grassland characterized by Aristida contorta and Sporobolus australasicus with some Triodia pungens and scattered Carissa lanceolata bushes and small Eucalyptus pruinosa trees occupying the red brown sandy clays developed over colluvial sand and gravel east of a line from Gipsy Plains to Mount Margaret (shading 128) and within it it differentiates areas with greater tree cover (shading 33) It clearly discriminates the western boundary of this area and outlines those areas to the west of it where in December the *Astrebla - Iseilima* and *Sporobolus australasicus* grasslands occupying the yellowish brown clays which dry to a grey colour at surface and are derived from the Older Alluvium, were producing light green spectral signatures (shading 72). It failed however to distinguish the areas with very dark green/blue spectral signatures due to burning southeast of the Cloncurry river.

For the Cloncurry Plains area where differences in the plant cover are largely responsible for differences of spectral signature on the colour composite generated from MSS bands, 4, 5 and 7 of LANDSAT the unsupervised approach using the POLYDIV algorithm gives a satisfactory classification of the spectral data. This technique appears suitable for this type of terrain but more recent work suggests that a better classification and output could be obtained by a supervised approach using carefully selected training sets.

3.4.2.3 THE MARY KATHLEEN AREA

Both the unsupervised and supervised approaches were used for classifications of the spectral data contained in the four MSS bands of the LANDSAT 2 imagery for 2 March 1975 (ID 2039-23555) covering the area northwest of Mary Kathleen. In each case units of 4 x 4 pixels were used. The outputs were compared with the visual interpretations of the colour composite generated from MSS bands 4, 5 and 7 displayed at the 1:30,000 scale and subsequently reduced to a scale compatible with that of the classified outputs. (Figures 23, 24, 25, 112, 113 and 114)

With the unsupervised approach using the POLYDIV classification (Cole et al 1975) a two fold division of data (Figure 112) gives a crude distinction between areas underlain by rocks belonging to the Leichardt Metamorphic and Argylla formations and by dolerite which respectively have spectral signatures of light tone and pink colour and of dark blue and green colour (Group 1) from those underlain by the Wonga granite and Corella formations which have spectral signatures of dark tone and purple and red colours (Group 2). The position of the Wonga fault is evident. The grouping of both light and dark tone signatures in one category and in particular the failure to discriminate the light tone spectral signatures of the area underlain by Leichardt Metamorphic rocks is puzzling. The threefold division (Figure 113) also fails to identify this unit. The fourfold division (Figure 114) distinguishes the areas of Leichardt Metamorphic rocks (Group 4) but overall this and further divisions produce extremely fragmented classifications which are of value only in discriminating areas of dolerite bedrock. The unsupervised approach using the POLYDIV classification appears unsatisfactory for the area northwest of Mary Kathleen. The reasons for this are not clear but appear to be related to changes of spectral signature over relatively short distances occasioned by variations in vegetation and relief.

For the supervised approach ten training sets each representative of a characteristic spectral signature within the major geological formations were selected. (Figure 115) The classified output (Figure 116) shows a remarkably close correlation with the geological units. The area underlain by the Leichardt Metamorphic rocks which have dominantly light pink spectral signatures (1 he, 2 hg) were very clearly discriminated (group 4) and the dolerite dykes which intrude them are distinguished as a consequence of their darker spectral signatures (3 heg, 4 ehg, 4 dac, etc.). The extensive areas of outcropping and sub-outcropping dolerite northwest of the Wonga fault (group 3) are well defined doubtless because their dark green spectral signatures (6 d, 6 da, 5 d etc) contrast sharply with the much lighter signatures of the adjacent areas underlain by Corella rocks. Southeast of the Wonga fault those areas of Wonga granite whose dark green/blue/purple spectral signatures (6 dge, 6 de, 6 gd, etc.) suggest that they have been burnt are clearly displayed on the supervised classification (group 1) but the unburnt areas which are characterized by lighter spectral signatures are less readily distinguished from adjacent areas underlain by rocks of the Argylla formation (group 2). The Ballara quartzite (group 5) is clearly outlined around the eastern side of the main dolerite mass and the Corella units (groups 7 and 8) are satisfactorily displayed near the areas used for the training sets at the northern end of this dolerite outcrop. On the western side of the dolerite, however, the Corella units are not clearly differentiated by the automated output, probably because variations of reflief and lithology give rise to varied spectral signatures in this area. They are clearly displayed again however, near the training set in the northwest corner of the frame (group 9). Areas underlain by Marimo slate (group 10) which have dark green/purple spectral signatures are quite well displayed on the automated output.

The major faults, notably, the Wonga fault may be distinguished but not the smaller ones.

Overall the automated output obtained by the supervised approach displays most of the major geological units in the area northwest of Mary Kathleen quite well. The degree of success in discriminating these units is related to the strength of their spectral signature and to the size and homogeneity of the training set. Very dark and very light spectral signatures are the most clearly distinguished and large uniform training sets assist precise classification. The relatively large extent of the areas underlain by the Leichardt Metamorphic rocks and by dolerite west and northwest of the Wonga fault and by the Wonga granite to the southeast together with the strength and homogeneity of the spectral signatures produced by the combination of reflectances from uniform low tree and shrub savanna, residual soils, subdued relief and unobtrusive outcrop, are largely responsible for the clear display of these units on the automated output. On the other hand similarity of spectral signatures associated with the similarity of vegetation, relief and lithology is responsible for the failure to discriminate between the Corella and Ballara quartzites and the Argylla formation in some areas. In others the small training sets occasioned by the narrowness of the zones underlain by some units of the Corella formation together with variations of vegetation and relief which cause heterogeneous spectral signatures have resulted in further failures. Overall it is apparent that the supervised approach leads to a successful classification of the major geological units in the Mary Kathleen area where the unit characterizes a large area with distinctive vegetation, soils and relief producing a homogeneous spectral signature and permitting the delineation of a relatively large training set for the classification process.

3.4.2.4 THE LADY ANNIE - MOUNT GORDON FAULT ZONE AREA

The availability of LANDSAT imagery of the Lady Annie - Mount Gordon fault zone area for dates in three seasons, namely 22 March 1975 (ID 2039-00012) 18 September 1975 (ID 2239-0001) and 10 November 1975 (ID 2292-23594) from LANDSAT 2 provided opportunities for comparing the outputs from semi-automated classifications on a temporal basis. Since the area contains the Lady Loretta lead zinc deposit the problems involved in identifying a mineralized horizon using semi-automated techniques may be compared with those in the Dugald River area. As the geology and terrain features of the area differ in several important respects from those in the Mary Kathleen - Cloncurry and Dugald River areas the effectiveness of the semi-automated classifications can be assessed further.

After allowances for minor variations in the photographic processing the colour composites generated from the LANDSAT 1 and 2 imagery acquired at different seasons of the year exhibit remarkable variations in tone and hue. Notwithstanding the semi-arid nature of the terrain these changes are due primarily to seasonal changes in the vegetation, notably differences in the state of the grass layer occasioned by the incidence of rainfall. Changes in the soil moisture conditions and the effects of increasing dust in the atmosphere as the dry season progresses contribute to the changes. The objectives of the attempts at semi-automated classifications of the spectral data on the colour composites were twofold.

The first objective was to achieve a satisfactory classification of the spectral data on the colour composite for 22 March 1975 which exhibited the greatest contrasts in tone and hue and which as indicated on pp 63 to 79 provided remarkably detailed information on the terrain features. The second objective was to ascertain whether the classification of successive LANDSAT images using the same training areas would yield similar information on terrain features. To achieve these objectives both the unsupervised and the supervised approaches were used and in the case of the latter the number of training areas was varied in attempts to achieve the most satisfactory output.

The attempts to classify the spectral data on the colour composite generated from MSS bands 4, 5 and 7 for 22 March 1975 (ID 2059-00012) (Figure 48) using the unsupervised approach with the POLYDIV algorithm proved relatively unsuccessful. With three groupings the areas covered respectively by soil and alluvium and by laterite were distinguished from areas of outcropping and sub-outcropping bedrock largely because their spectral signatures of medium tone and dominantly red hue associated with a continuous grass cover contrasted with the dominantly lighter tones and green, blue and purple hues of the areas of surface and near surface bedrock where woodland characterized by scattered trees and a sparser grass cover prevails. Greater division of the data caused fragmentation without providing better discrimination of the spectral signatures or of the geology.

A supervised approach using six training sets selected by the tone and colour of spectral signatures recognised visually on the colour composite generated from the MSS bands 4, 5 and 7, however, produced an output in which the major geological units were clearly distinguished. (Figures 48, 117 and 118) On this the areas of Proterozoic Myally quartzite which have a pale green blue signature on the colour composite of the LANDSAT imagery are clearly delineated north of the Lady Annie mine and in the areas to the west of the Mount Gordon fault zone. (Group 5, Table 7). In the last mentioned zone, however, and again south of the Lady Annie mine the areas underlain by the lower Judenan beds, which have a darker blue signature on the colour composite of the LANDSAT imagery, are placed in the same class as the Myally quartzite on the automated output. Those areas underlain by the dolomites of the Paradise Creek formation are distinguished on the automated output which discriminates between those horizons producing respectively red/purple and brownish/purple spectral signatures (Groups 2 and 4 respectively, Table 7) on the colour composites of the LANDSAT imagery. East of the Lady Annie fold zone the areas of Cambrian limestones which on the LANDSAT imagery have similar red/purple signatures are placed in the same class as the Paradise Creek dolomites on the automated output. The area of the Beetle Creek phosphatic siltstones which has a brownish purple signature on the LANDSAT imagery is not distinguished on this automated output. Within both the Paradise Creek formation of the Lower Proterozoic and the Cambrian the automated output discriminated between the predominantly dolomitic and predominantly siltstone horizons which respectively have distinctive signatures on the LANDSAT imagery.

Those areas of the Gunpowder Creek formation which have a very dark, almost black spectral signature on the colour composite of the LANDSAT imagery are clearly distinguished on the automated output (Group 6, Table 7) but those with a blue signature have been placed in the same class as the Myally quartzite. Areas covered by laterite have been placed in the same class, (Group 6, Table 7) as the areas underlain by the Gunpowder Creek formation. Areas covered by alluvium which have bright red spectral signatures on the colour composite of the LANDSAT imagery are clearly delineated. (Group 1, Table 7)

Table 7 The essential details for the six class into which the Lady Annie frame 11A (Figure 118) was classified.

Group	Colour	Shading	Ground-truth	Equivalence
1	Red		Soils and alluvium	good
2	Red purple		Paradise Creek formation dolomites, siltstones etc.	good but many small scattered areas
3	Blue/Green		Eastern Creek Volcanics - basalts	good
4	Brownish purple		Paradise Creek formation dolomites, siltstones etc.	good but many scattered areas
5	Light blue		Myally quartzite	good
6	Dark green/ black		Gunpowder Creek siltstones, and shale	good

Overall the automated output based on six groupings of spectral signatures recognised visually on the colour composite of the LANDSAT imagery succeeded in discriminating the major geological units. Like the colour composite it provides a basis for an initial interpretation of the imagery for subsequent field investigations. The complexity of the colour composite and of the classification map, however, prevented any quantitative classification accuracy being quoted.

The six classes and the same training sets were used for classifications of the LANDSAT 2 imagery for 18 September 1975 and 10 November 1975.

The colour composite for November 1975 (Figure 47) acquired towards the end of the dry season when most of the grasses had dried off is remarkable for the pale colour of the spectral signatures over most of the area. Red spectral signatures are absent from the image. Two of the training set areas,namely those over the light blue and blue green spectral signatures over the Myally quartzite and Eastern Creek Volcanic rocks on the colour composite for 22 March 1975,were outside the area of colour composite for 10 November 1975 which was scanned to generate the classified map shown in figure 119. The classes for which training sets were established on this colour composite and on that for 18 September 1975 are shown in Table 8.

Table 8 Classes for which training sets were generated in the Lady Annie frames 7A and 29A

Group	Colour	7A	29A
1	Red	X	X
2	Red/Purple	X	X
3	Blue/Green	-	-
4	Brownish Purple	X	X
5	Pale blue	-	-
6	Dark green/Black	X	X

The classified map of the colour composite for 10 November 1975 displays the same areas in group 6 as was the case for the classified map of the 22 March 1975 colour composite but additionally includes other areas in the same group. (Figure 119) The areas which are correctly classified on both maps are those capped by laterite which produces very dark spectral signatures at all seasons of the year. They include small elongated areas located around the margins of the flat topped plateaux of Myally quartzite north of Lady Annie and larger areas north of Mount Kelly. These areas are underlain by Gunpowder Creek siltstones which in places are lateritized and they carry <u>Acacia shirleyii</u> woodland. They are clearly displayed on the colour composite for 10 November 1975. On the classified map of this colour composite more areas are classed in group 1 than might have been anticipated. Whereas in March the training areas of this group had red spectral signatures produced by strongly reflecting grasses, by November they had pale grey pink spectral signatures produced by reflectances from both the dry grasses and the intervening bare soils. Those areas on the November colour composite which had this spectral signature and were classified in group 1 included some which on the March colour composite had brownish purple spectral signatures and were placed in group 4. Relative to both vegetation and geology the classification for November was less good than for March. Given the extremely dark and very light spectral signatures of groups 6 and 1 it is not surprising that much of the colour composite for 10 November 1975 has been classified in the two remaining groups which on 22 March 1975 had brownish purple and red purple reflectances. If this colour composite were classified independently of other images at least one additional class would be introduced and a better classification achieved.

The colour composite for 18 September is dominated by brownish red, blue purple and deep purple hues; these colours being related to the weaker reflectances from the vegetation and to the greater contributions of soil and bedrock to the spectral signatures than was the case in March. On the classified map the lateritic areas and the areas underlain by the Gunpowder Creek siltstones which have dark spectral signatures have again been correctly placed in group 6. (Figure 120) The areas which in March had purplish red and brownish red spectral signatures have been reasonably successfully discriminated but larger areas have been classed in each group. In the western part of the frame large areas have been placed in group 1 which in March had red spectral signatures. This is because, on the colour composite for 18 September 1975 the spectral signatures over much of this area were closer to the red than to the purplish red and brownish red hues of groups 2 and 4 and were classified accordingly. This indicates that for this colour composite the use of training areas based on another image carries a requirement for an additional class if a satisfactory classified map is to be achieved. Furthermore this additional class is a different one from that required for a satisfactory classification of the 10 November 1975 image.

The principal conclusion arising from this study of three images of the same area taken at different times is that, starting with an image which contained the greatest-range of classes; and therefore advantageous to the study, it would have been necessary in each of the two other images to introduce at least one new class in order to obtain a satisfactory classification. The new classes would be different for each image. Using the same training areas for each image there is, nevertheless, some common content between the four maps, particularly with the very dark spectral signatures of group 6. For precise measurement of change it would be necessary to have fiducial marks on the images and possibly scale transformations in order that a computer comparison can be made. This procedure also implies that all the classes which may be encountered in any of the images being compared have training-set data available. This is a difficulty in itself since it means that an accurate comparison could only be made after all the imagery has been examined.

Furthermore, as will be apparent from the preceding sections, it is not sufficient merely to classify the whole of the image with a predetermined number of classes and no other constraints, since no consideration has been given to the use of a threshold. Clearly a threshold would be used as a matter of principle in order that pixels should not be allocated to a class on the basis of having the highest relative probability of belonging to that class, but according to some absolute level of probability. This leads now to the consideration in appendix 1 of having a separate threshold. To these questions there is no simple answer and they most certainly merit detailed study in any future investigation.

In an attempt to refine the output and to discriminate a larger number of geological units a supervised approach using training sets for nine spectral signatures recognised visually on the colour composites of the LANDSAT imagery for 22 March 1975 was also used. This succeeded in differentiating the Beetle Creek formation which contains the important Lady Annie phosphate deposits and in identifying areas near the west Thornton Creek west of Lady Annie where Cambrian rocks underlie variable thicknesses of alluvium. It did not succeed in separating the area underlain by the Myally and Judenan formations, however, and it produced such a fragmented pattern of individual symbols as to make the recognition of major geological units or indeed other environmental units virtually impossible.

A further attempt using ten different training sets, however provided a more satisfactory and less fragmented classification. (Figures 121 and 122) In this the relationship between the units displayed on the semi-automated output and the spectral signatures produced by the combination of vegetation, soils and geology on the colour composite is remarkably good except in the Mount Gordon fault zone in the east. Here, over relatively short distances, frequent changes in the spectral signatures associated with the narrow outcrops of the individual geological units and with sharp differences of relief, make the selection of training areas extremely difficult. The same ten training sets, used for the colour composite of the 22 March 1975 imagery are now being used to classify the spectral signatures on the colour composites for 18 September and 10 November 1975.

The choice of symbol and the method of displaying each class influences the success of the automated output for visual interpretation. The most successful outputs are those in which the density of the symbols is related to the tone of the spectral signatures and where contrasting symbols are used for adjacent classes. Over a large area with a complex pattern of spectral signatures the latter may not be possible over the whole frame. The outputs using the supervised approach and six, nine and ten groupings respectively for classifying the 22 March 1975 colour composite of the Lady Annie area show that six groupings with the symbols used in figure 118 produces the most satisfactory result. At nine groupings only the iron rich areas with dark spectral signatures are easily recognised. Elsewhere fragmentation and lack of contrast between the symbols for adjacent areas renders interpretation difficult. With ten groupings improved selection of training sets and a better choice of symbols the output provides relatively easy discrimination between classes (Figure 122). Where the pattern of classes is complex it may be desirable to display each one individually as in figures 123 to 132 when the success or failure of the classification relative to the spectral signatures recognised visually on the colour composite becomes apparent and may suggest the need for changes in the selection of training areas.

Appendix 1

The Requirements for a Threshold in Classification Procedures.

Before discussing the results some comments should be made on the purpose of a threshold. The absence of a threshold means that every pixel, however unlike the training set for each designated class, is nevertheless allocated to that class for which it has the highest probability, although that probability may still be low. This may well lead to a meaningless classification since it is inevitable that as one moves some distance away from the reference frame a new terrain type will appear. Little purpose will be served by allocating it to one of the original groups when it is in fact quite separate and unrelated vegetatively or geologically to any of these original classes.

It is thus desirable to have a threshold probability such that, if the probability of the pixel belonging to any of the prescribed classes is less than a particular value, the pixel will be unallocated and placed in an unclassified category. There is no objective value for a threshold and it can only be stated in terms of the probability of belonging to a particular class.

In the three-dimensional measurement space dealt with here the elements of the covariance matrix for a given training set are different and hence surfaces of equal probability are ellipsoidal. For another training set the axes of the ellipsoid with the same surface probability will be different. In theory, therefore, if the probability of an unidentified pixel belonging to any designated class is set at a fixed value, then the threshold for each class will be different. Classification of an image with a constant probability threshold thus requires the determination of a threshold distance for each class. In practical problems in remote sensing there is no precise way of calculating this distance and values can only be obtained by exceedingly tedious trial-

-and-error methods involving many practical assumptions.

In practice, since SOUP effectively calculates the distance of a pixel from a training set it is very much easier to adopt a fixed threshold distance and assume it to be valid for all classes. Since the covariance matrix elements for the training sets in any one image are fairly similar, such an assumption is not likely to lead to a major error in the classification, particularly when the random variations which occur in nature are considered.

The empirical way in which an appropriate threshold distance for each class may be determined and the relatively minor effect upon the answer may well explain why, in the open literature, there is only one reference to classification maps with a threshold related to the calculation of different threshold distances (LARS,1968).

If too low a threshold is used pixels will be wrongly allocated while, with too high a threshold, pixels which should have been placed in a particular class will be placed in the unclassified category. The actual value for the threshold distance in a specific image is thus dependent upon subjective considerations and the nature of the area which has been imaged, whether it be agricultural, afforested or natural terrain, etc., when particular factors will be relevant.

Appendix 2

A Priori Class Probability

Having examined the results of classifying a number of different images, according to a decision rule which allocates each pixel to that class to which it has the greatest probability of belonging, it is appropriate at this stage to consider an aspect which has not so far been discussed. This concerns the basis of the decision process represented by the equation.

$$C_i + \log|Q_i| + (x-\mu_i)^t \; Q_i^{-1}(x-\mu_i) < C_j + \log|Q_j| + (x-\mu_j)^t Q_t^{-1}(x-\mu_j) \qquad 1.$$

in which C_i and C_j are constants related to the priori probabilities of classes C_i and C_j. It is computationally convenient to make all these a priori probabilities equal and this is usually done either explicitly, e.g. Henze and DeZur (1975) or, more frequently, implicitly, with no specific reference being made to this simplification.

With agricultural crop-type classification it is usually possible, if required, to estimate these probabilities reasonably accurately from the ground truth data. With natural terrain this information is difficult if not impossible to obtain from the ground truth data and the probabilities are made equal on the basis of expediency alone.

In the present project the probability is not calculated directly but is simplified by calculating the function

$$\log|Q_i| + (x-\mu_i)^t \; Q_i^{-} \; (x-\mu_i) \qquad 2.$$

and then determining for which class this function has a minimum value.

If the a priori probability of $P(C_i)$ is now included then equation 2 becomes

$$\log|Q_i| + (x-\mu_i)^t \; Q_i^{-1}(x-\mu_i) - 2\log p(C_i) \qquad 3.$$

The question now arises as to what extent the inclusion of the appropriate values for log $P(C_i)$ would have had on the final classification. Table 9 shows an example of the function given by equation 2 in the column headed "distance" for a number of pixels with a four category classification, i.e. four distances. Each pixel is allocated to the class for which the distance is a minimum and the right-hand column gives this class (FITS). It will be noticed that the distances for any one pixel vary widely and that the minimum distance is usually much less than the next smallest distance. In general, it was found that the greater the number of classes the closer do the two smallest distances become.

Suppose now that a map with two classes only (C_i, C_j) was being generated and that the a priori probabilitities are $P(C_i) = 0.1$ and $P(C_j) = 0.9$. Then the additional term in equation 3, $- 2 \log P(C_i)$ is, with these two classes

for $P(C_i) = 0.1$, $-2 \log P(C_i) = + 2.00$

for $P(C_j) \doteq 0.9$, $-2 \log P(C_j) = + 0.09$.

These values of 0.1 and 2 represent approximately the extreme values for $P(C_i)$ and indicate the magnitude of the term which would have to be added to the appropriate column in table A. It is evident that, for the above range of values of $P(C_i)$, it is highly improbable that adding terms of between 0.1 and 2 will alter the column in which the minimum distance occurs.

Thus, from a purely empirical standpoint, the incorporation of the a priori probabilities is unlikely to have any significant effect on the resultant classification.

Finally, in classifying natural terrain there does not appear to be any really feasible way of assessing these a priori probabilities. For these reasons this factor was not incorporated in the distance calculations and all such probabilities were assumed to be equal.

Table 9. An example of the function 5.2

DISTANCES				FITS
1898.2814	464.6379	276.2858	233.3484	4
1373.9155	468.3938	3678.4728	394.1232	4
1698.8023	453.8495	4442.1456	626.2319	2
1243.1947	552.4873	1883.4261	51.2337	4
1351.7884	443.4629	4193.9496	491.8420	2
821.2816	385.8027	4484.6147	595.7370	2
863.4936	378.9224	3874.9694	435.8687	2
978.6976	459.6834	697.2563	78.4401	4
722.5652	188.6234	1955.1421	163.2796	4
1239.9609	281.3118	2264.3129	97.3814	4
1312.7408	358.5139	2894.3851	162.6567	4
1291.2319	363.7282	1821.6368	72.8631	4
499.8735	143.1292	455.1425	898.7724	2
1119.1441	251.4659	549.1361	488.2567	2
1318.2619	321.9287	2460.4989	99.6979	4
1287.9317	339.5824	3718.8322	863.9196	4
1489.9528	563.4916	4768.9890	858.4674	2
792.6516	443.8852	223.6797	248.2137	3
1231.6419	378.5864	1868.5484	76.8242	4
1133.4134	265.8766	2318.1846	95.5999	4
938.4934	234.8471	2254.3579	94.8683	4
1885.7576	439.2386	1116.4118	52.2812	4
433.1114	259.4967	461.3898	378.4477	2
675.9734	186.8679	595.1942	442.3723	2
591.1184	22.15619	351.9966	559.4261	2
786.4683	398.5674	284.3193	247.6862	4
514.8517	529.5556	312.4743	164.6778	4
611.2794	543.5240	236.8719	164.2711	4
638.4261	536.4877	278.3778	122.8936	4
720.1046	829.4657	576.1233	37.5178	4
801.7655	767.8399	378.2975	29.6575	4
822.6463	862.3119	264.4578	38.5661	4
486.2689	574.2298	155.4113	177.8516	3
359.1896	624.3388	148.8378	154.2676	3
598.9388	918.5142	374.4363	28.5678	4
962.6385	988.5658	549.6714	55.5329	4

3.4.3 FEATURE EXTRACTION USING DIGITAL IMAGE PROCESSING TECHNIQUES

The LANDSAT 2 imagery of the Lady Annie - Mount Gordon fault zone area for 22 March 1975 (ID 2039-00012) was used to explore the potential of information extraction using the density slicing, colour rotation and contrast stretching facilities available on the Plessey Radar Digital Image Processor.

As a preliminary step the MSS band 7 was sliced to give seven density levels to each of which a discrete colour was assigned. This produced a display in which two types of terrain and/or bedrock geology were clearly discriminated. These were the alluvial plains covered with strongly reflecting grasses along the Thorntonia river and on Koolamarra property and the areas with ferruginous bedrock, notably Gunpowder Creek siltstones, and with laterite cover. Some areas of limestone bedrock could be distinguished but generally speaking the density slice failed to discriminate lithology or geological unit or to distinguish structural features. It classified the information in the one band and enhanced the types of terrain cited.

In attempts to discriminate between different lithologies and to distinguish individual geological units MSS bands 4, 5 and 7 were used together and subjected to colour rotation and contrast stretching. Three displays produced by differing combinations of colour and degrees of contrast stretching were generated. On the first the areas underlain by Cambrian limestones and siltstones were clearly displayed . Both areas covered by laterite and those underlain by ferruginous Gunpowder Creek siltstones were discriminated as were areas of non-ferruginous Gunpowder Creek beds and also some areas underlain by Paradise Creek beds. The dolomitic horizons of the latter formation, were differentiated with those to the west of the Gunpowder and Paradise Creeks being distinguished from those northeast of Mount Kelly. Elsewhere discrimination of lithology and geological unit was poor. Alluvial plains with a strongly reflecting grass cover were distinguished from those with thin superficial cover and sparser vegetation. The structural features which are clearly displayed on the unaltered colour composite of MSS bands 4, 5 and 7 were lost on this colour rotated and contrast stretched display.

The second display showed some discrimination within the areas covered by alluvium particularly along the Thorntonia river. Here areas where Cambrian rocks are relatively near to surface beneath thin cover of soil and alluvium were clearly delineated. Distinctive colours distinguished the dolomites of the Paradise Creek formation west of the confluence of the Paradise and Gunpowder Creeks from those in other areas. Apart from extracting the above features the display failed to discriminate between areas of differing bedrock lithologies or different geological units. It did however, provide some indication of fold structures in the area west of Lady Annie.

The third display extracted different but rather more information than the other two. The areas underlain by Cambrian rocks were again clearly distinguished as were areas covered by laterite or characterized by ferruginous bedrock. The Paradise Creek dolomites west of the confluence of the Paradise and Gunpowder

Creeks were again discriminated. The fact that this discrimination occurred on all three displays suggests that the Paradise Creek rocks in this area differ in important respects from those in other areas. Areas underlain by the quartzite of the Myally beds which are so clearly discriminated on the original colour composite of MSS bands 4, 5 and 7 were not distinguished on any of the displays generated by colour rotation and contrast stretching. On this third display structural features had again been lost. The results of the preliminary investigations using the Plessey Digital Image Processor indicated that additional specific information could be extracted by colour rotation and contrast stretching of individual MSS bands but that this information was complementary to that available in the original colour composite generated from the bands whose interpretation should precede the use of enhancement procedures.

3.5 CONCLUSIONS

3.5.1 LANDSAT INFORMATION ON TERRAIN FEATURES IN A SEMI-ARID ENVIRONMENT

The studies undertaken in northwest Queensland have shown that in such a semi-arid environment LANDSAT imagery yields a wealth of information on vegetation, on soils and drainage conditions and on geological structures and lithologies. Different information is contained in each of the four MSS bands with band 4 yielding valuable information on moisture conditions, band 5 on drainage and bands 6 and 7 on vegetation and geology.

Most information is obtainable from colour composites generated from MSS bands 4, 5 and 7 and more can be extracted from displays at scales of 1:10,000 to 1:50,000 than is possible from those at smaller scales. Contrary to general belief imagery obtained after the rainy period yields more information on geological structures and lithologies than that obtained during the dry season. This is because differences of vegetation, which reflects most strongly on the infra red after rains, reveals the geological features better than the soils and the weathered bedrock itself. For correct interpretation of the imagery, knowledge of the vegetation is essential. With such knowledge the influence of seasonal changes in the plant cover on the spectral signatures on the imagery can be understood and the latter can be interpreted from successive LANDSAT passes at different seasons of the year to provide complementary information on the geology and other terrain features. In this way, as the investigations have shown, major faults and lineaments can be discerned; in areas of near surface bedrock fold structures can be outlined, especially where marker beds, such as the stromatolitic horizons in the Paradise Creek formation near Lady Annie, are present; distinctive lithologies can be discriminated; mineral deposits such as the Lady Annie phosphate deposits can be delineated and orebodies such as the Dugald River and Lady Loretta lead-zinc deposits can be detected. In areas of superficial cover, such as the Cloncurry Plains, the distribution of the different types and ages of alluvium and colluvium can be ascertained; here also the presence and nature of near surface bedrock beneath the superficial cover can be detected and the existence of faults and lineaments discerned.

In areas of outcropping and suboutcropping bedrock and in those with superficial cover distinctive spectral signatures on the imagery reveal the effects of burning and of grazing activities, cognisance of which is essential for correct interpretation of terrain features. In all areas the roles of LANDSAT and air survey imagery, of colour composites generated from NASA films or from computer compatible tapes, and of visual and semi-automated classifications and interpretation requires assessment.

3.5.2 COMPARATIVE EVALUATION OF THE INFORMATION AVAILABLE FROM LANDSAT AND AIR SURVEY IMAGERY FOR THE RECOGNITION OF PLANT COMMUNITIES TERRAIN FEATURES AND GEOLOGICAL STRUCTURES AND LITHOLOGIES ASSISTING MINERAL EXPLORATION

Studies of the multi-spectral air survey imagery concentrated on establishing the precise relationships between discrete spectral signatures and the environmental components contributing to them, in order to recognise and map plant communities (which may reflect superficial and bedrock geology), soil types (which may reflect either the nature and depth of over-burden or the bedrock type), relief and drainage features (which may provide guides to bedrock geology and to subsurface water) and bedrock geology. Initially the true colour, infra red colour and black and white panchromatic imagery were studied individually and in combination using enhancement techniques but subsequently attention concentrated on the infra red false colour imagery which was found to yield the most information and which is also most nearly comparable with the colour composites of MSS bands 4, 5 and 7 of the LANDSAT imagery.

Air survey imagery has the advantages over LANDSAT imagery of larger scale, greater resolution and stereoscopic viewing. Its particular attributes depend on the scale and resolution and the most suitable level for these may vary for particular geological features and for particular types of terrain. Both the 1:15,000 and 1:5,000 scales used in the research programme in Australia provides such detailed information that individual trees can be recognised, the minutae of relief and drainage ascertained, the bedding and jointing of bedrock discerned. The large scale and wealth of detail detract from an overview of major structures. Depending on the scale and the nature of the terrain, lithological/stratigraphical units, dykes and sills can be discriminated, the precise position of faults determined, the dip and strike of outcropping bedrock ascertained stereoscopically, geobotanical anomalies associated with ore deposits identified and mine workings located. Here a summary of only a few features will be made.

Between Mary Kathleen and Cloncurry several large dolerite dykes which do not give rise to marked changes of relief or vegetation and which are not readily apparent on the ground are clearly delineated on the infra red false colour photography at the 1:15,000 scale. These features are apparent but cannot be accurately located on LANDSAT imagery.

Within the Mitakoodi anticlinorium the structural features and lithological boundaries are more difficult to appreciate on the aerial photography than on the LANDSAT imagery but with stereoscopic viewing and field checking their precise positions can be accurately determined.

In the Dugald River area the recognition of lithological/ stratigraphic units on the air photos depends partly on the thickness of residual and transported cover. Characteristic spectral tones, hues and textural patterns delineate outcropping Knapdale quartzite and bedded limestones within the Corella succession while vegetational banding within these units reveals trends, lineations and bedding patterns. The other lithological/ stratigraphical units within the Corella formation are less readily identified, but quartz reefs may be recognised and the Dugald River lead-zinc lode is clearly distinguished largely because of the anomalous treeless plant community which outlines it (Plates 24 and 25, Figures 36, 39, 43 and 100). The lode zone has a very distinctive spectral signature on both the false colour infra red and the true colour imagery while it is clearly distinguished by its uniform light tone on the panchromatic photography. Similar signatures of much smaller size have been identified in a number of other localities where similar plant communities have been found to be associated with high levels of copper and/or cobalt in soils emanating from mineralized bedrock. Features of this size and nature cannot be detected on LANDSAT imagery.

North of the Dugald River lode remarkable lozenge-shaped features occur on the air photos: they are caused by zonal patterns of plant communities whose distribution reflects the subsurface drainage systems and indicates that a lowering of the water table may have occurred since the drainage was initiated in Tertiary times. These features occur over black soil plains where bedrock is concealed beneath deep cover. They cannot be detected on LANDSAT imagery, on which, however, distinctive spectral signatures characterize the areas in which they occur, thereby permitting the mapping of black soils plains. (Figures 71, 76 78, 79, 80 and 81).

On the air photos of the Lady Annie area the blocks of outcropping Myally quartzite are clearly distinguished from adjacent areas underlain by the Gunpowder Creek Formation by virtue of the spectral contrasts between the flat topped plateaux of the former geological unit and the dissected terrain of the latter. In the area south of Lady Agnes mine the lines of the major block faults disclosed by the LANDSAT imagery are apparent and are followed by drainage lines across the Myally block (Figures 63 and 64). In the Lady Loretta area the air photos display very clearly the sharp relief features which outline the position of the Small syncline and the Big syncline. Here distinctive spectral signatures of very light tone occur over the anomalous treeless plant communities which characterizes the narrow flat topped plateau above the Lady Loretta lead-zinc ore body whereas very dark signatures occur where dense stands of <u>Acacia shirleyii</u> cover the steep slopes below, which are strewn with lateritic and gossanous gravel, and likewise the areas where laterite caps the bedrock. The dark signatures may be equated with the dark signatures on the LANDSAT imagery. They contrast sharply with signatures of medium tone produced by the infra red false colour imagery where <u>Eucalyptus brevifolia</u> trees stud a grassland of either <u>Triodia pungens</u> or the soft grasses mainly <u>Enneapogon polyphyllus</u> of the plains.

In summary investigations in both the Dugald River area and the Lady Annie area have shown that the LANDSAT imagery provides remarkable details of the geology on a regional basis and by the revelation of lineaments and iron-rich horizons can be used to target areas of possible ore deposits but that multi-spectral and thermal air survey imagery is required for detailed geological information of small areas and for the precise location of ore deposits. The LANDSAT and air survey imagery are essentially complementary.

3.5.3. ASSESSMENT OF THE VEGETATIONAL AND GEOLOGICAL INFORMATION AVAILABLE IN COLOUR COMPOSITES GENERATED RESPECTIVELY FROM LANDSAT FILM AND LANDSAT COMPUTER COMPATIBLE TAPES

Studies of the information available from colour composites generated from the LANDSAT computer compatible tapes have been confined to selected areas within the Cloncurry- Dobbyn and Lady Annie - Mount Gordon fault zone frames imaged respectively on 2 March 1975 (ID 2039-23555) and 22 March 1975 (ID 2059-00012). The selected areas were the Dugald River Lode area, the Lady Annie - Lady Loretta area and the Cloncurry Plains. For these the colour composites were displayed at scales of up to 1:10,000. Individual pixels were discriminated.

Comparative studies showed that it is possible to obtain more information from the computer compatible tapes. This arises from the possibilities for stretching the density scales on individual MSS bands until a suitably balanced colour composite is produced and from the detail discernible at the 1 x 1 pixel display. In the Lady Annie- Lady Loretta area for example the clear discrimination of the air strip within the Lady Annie phosphate area facilitates location of the vegetation associations, revealed by distinctive spectral signatures, which outline the Beetle Creek phosphatic siltstones. This is not possible on the colour composite generated from the NASA films. In the Lady Loretta area the structural features of the Big Syncline and of the Small Syncline with which the Lady Loretta lead-zinc deposit is associated are revealed on the colour composite generated from the computer compatible tapes and displayed at the 1:10,000 scale. It has not been possible to achieve a display of adequate resolution for this area from the NASA films. This is true also of the Dugald River Lode area where the distinctive spectral signatures on the colour composite generated from the NASA computer compatible tapes, outline each geological unit, including that of the lead-zinc lode. On the colour composites of the Cloncurry Plains generated from the computer compatible tapes it has been possible to differentiate areas characterized by lozenge shape features produced by the concentric distributions of plant communities reflecting specific drainage features from neighbouring areas characterized by different plant communities over more freely drained ground. This is not possible on those generated from the film.

It may be anticipated that studies of vegetational changes such as those following burning may be monitored relatively easily from comparison of colour composites generated from the magnetic tapes whereas it would be more difficult to do so for those generated from films.

The facilities for stretching the individual MSS bands and the possibilities for discriminating relatively small areas of distinctive vegetation together with the better resolution permit the more precise location of structural features and a more accurate differentiation of lithological units on colour composites generated from the computer compatible tapes than is possible on those generated from the NASA films.

The studies carried out in northwest Queensland show that the colour composites generated from the NASA films of LANDSAT imagery provide a wealth of information on vegetation associations, drainage conditions, geological structures and lithologies provided that suitable scales are employed for the displays, but that those produced from the computer compatible tapes, due to better resolution and to the opportunities for stretching individual MSS bands, give additional information and finer details at larger scales. Whereas a display scale of 1:50,000 appears to the the effective limit for colour composites generated from the films, one of up to 1:10,000 is possible from the computer compatible tapes.

3.5.4 VISUAL AND SEMI-AUTOMATED CLASSIFICATIONS OF IMAGERY

The investigations in northwest Queensland have shown that both LANDSAT and air survey imagery can be satisfactorily classified by visual techniques but that because of the complex patterns of spectral signatures this is a slow process. Hence automated methods are essential if the enormous amount of LANDSAT imagery is to be fully utilized for terrain analysis and evaluation.

For obvious economic reasons most computer classification work has been directed towards agricultural crop-type and relatively little attention has been given to the classification of natural terrain. Most attempts to classify bedrock type have been based on conventional photo-geological interpretation while classificatory work on natural vegetation has concentrated on heavily vegetated areas such as the Florida Everglades National Park where, using a 12-channel scanner, dependable spectral signatures could be obtained for each vegetation class without contaminating contributions from soil or bedrock. (Kolipinski et al 1969).

The classification of natural terrain is intrinsically more difficult than that of agricultural areas because the individual components of vegetation, soils, relief, drainage and bedrock exhibit continuous spatial variation. It is particularly difficult in highly dissected areas,not because the analytical or statistical aspects are insufficiently developed but because it is exceedingly difficult to define representative training areas.

There is very little literature on the classification of natural terrain and those authors who have attempted the exercise have commented on the difficulties. For example Blodget et al (1975) considered that multi-spectral classification techniques were severly limited in the digital mapping of lithologies in Saudi Arabia using LANDSAT imagery. Those authors could not recognise any colour anomalies associated with mineralized areas. In using SKYLAB imagery of the semi-arid areas of central Colorado in the U.S.A. Sawatsky et al (1975) found that vegetation distributions were influenced by moisture conditions, slope aspect and altitude rather than by bedrock geology. A vegetation anomaly in California which was detected by Bechtold et al (1975) using SKYLAB and LANDSAT imagery was also considered to be influenced by moisture conditions rather than mineralization. In western Pakistan, however, Schmidt et al (1975) have detected colour anomalies associated with mineralization. Using LANDSAT 1 imagery they established a training set over a known sulphide copper deposit and produced a computer generated classification map obtained by a five cycle adaptive learning method. This map indicated twenty three spectrally similar areas of which five were found to contain some pyrite. These five were in areas considered by geologists to be unfavourable for mineralization.

Attempts to classify air survey multi-spectral imagery of natural terrain in Georgia (Weber et al 1972) and in Colorada (Driscoll and Spencer 1972) have produced results regarded as acceptable by the investigators. In each case a 12 channel scanner was used, the selection of training areas was relatively easy and only the data from the four best channels was used. The results achieved by Smedes et al (1971) who applied a cluster analysis to a simple false colour image and generated a classified map displaying nine classes with a mean accuracy of 85%, are of closer relevance to the present study.

There is virtually no literature on the machine detection of temporal changes in natural terrain. This absence is almost certainly related to the difficulty of classifying a simple LANDSAT image, let alone a temporal sequence from successive LANDSAT passes over a given area.

In the above context the attempts to classify both the air survey imagery and the LANDSAT imagery of northwest Queensland using both unsupervised and supervised approaches achieved a large measure of success.

For selected areas in the Mount Isa - Cloncurry region covered by LANDSAT imagery and by multi-spectral photography, the semi-automated outputs produced by the unsupervised approach using the POLYDIV algorithm and by the supervised approach using training sets based on the spectral signatures recognised visually on the colour composites indicate that successful classification depends on the range, strength and homogeneity of the spectral signatures. These in turn are dependent on the nature of the terrain, on the choice of a suitable number of data groupings, on the selection of suitable training areas and on the choice and method of display of each class for the output.

Whereas the unsupervised approach using the POLYDIV classification provided satisfactory outputs for the infra red air survey photography of the Dugald River Lode area and for the colour composite of the LANDSAT imagery of the Cloncurry Plains, it proved unsuccessful for classifying the spectral data contained in colour composites of the LANDSAT imagery for the Lady Annie and Mary Kathleen areas. The success in the first two areas is believed to be due to the distinct and homogeneous spectral signatures produced by discrete plant communities over level terrain whereas the failure in the latter two areas is thought to be due to the heterogeneous spectral signatures associated with plant communities of varying composition over rugged terrain. The supervised approach however, using carefully selected training sets proved successful in these areas and is considered to be superior for all areas.

The most suitable number of groupings varies from one area to another, being dependent on the number of distinctive spectral signatures on the imagery. For this reason for any one area the number may vary from one season to another, but appears to be between six and ten, above which the output is too fragmented. The most promising results for geological interpretation may be expected from imagery taken when conditions favour contrasting spectral signatures which in the Mount Isa - Cloncurry area appears to be the summer months when the vegetation is in a state of optimum growth and maximim reflectance. Beginning with the classification of imagery acquired during this season and using carefully selected training areas it is believed that successful classification for subsequent seasons can be achieved.

It may be concluded that considerable success has been achieved in the machine classification of a single colour air photo frame and of a single LANDSAT colour composite. Some success has been obtained in classifying successive LANDSAT images of a given area based on training sets defined for the first image. The machine detection of temporal changes in natural terrain, however, is a difficult task. It presents many problems and will require much development work of a practical nature, (the theory being already in existence) before acceptable successful results can be obtained.

3.5.5 CONCLUSIONS

The investigations carried out in northwest Queensland have demonstrated the value of LANDSAT imagery for the identification of features of the natural terrain with particular reference to geological mapping and mineral exploration in a semi-arid environment. They have revealed contrasts in the type of information available respectively in rugged country and over level plains. In the former the differences of spectral signatures are determined more by bedrock lithology and relief than by vegetation whereas in areas of level terrain veneered by alluvial and colluvial deposits the differences of spectral signature are due mainly to variations in the composition of the vegetation which in turn reflects differences in the nature of the superficial material and in the drainage conditions. Recognition of these important differences is important for geological mapping, notably for the recognition of structural features and the detection of near surface bedrock. Here the identification of burnt areas, which is possible on the colour composites, is also important.

The investigations indicate that the satellite imagery is particularly valuable in discriminating major structures, differentiating stratigraphical units of contrasting lithology and revealing zones of iron rich rocks which may be associated with base metal mineralization. When examined at the 1:50,000 scale lineaments which are not evident on air photos may be discovered, including those present in Precambrian rocks beneath cover of younger materials. In the Dugald River and Lady Annie areas lineaments which appear to be associated with known base metal deposits may be recognised.

The three great advantages of the LANDSAT imagery are firstly the overview of large areas with minimum distortion; secondly the availability of information in different spectral bands with the attendant opportunities for display of these bands, individually and in combination to produce colour composites; and thirdly the availability of repetitive cover so that imagery at different seasons, when different information may be yielded, can be studied.

For the precise location of lithological/stratigraphical boundaries, of dykes and sills, of faults and shears, for the stereoscopic measurement of dip and strike in bedrock and the interpretation of folded and faulted structures, for the identification of geobotanical anomalies associated with ore deposits and for the locating of present and former mine workings large scale air survey photography is needed. The multi-spectral air photography and especially the infra red false colour photography facilitates a more accurate mapping of lithological units and of folds and faults than is possible with conventional black and white photography while anomalous plant communities which delineate ore deposits can be more readily identified.

The studies in northwest Queensland have demonstrated the contribution which LANDSAT imagery and multi-spectral photography from aircraft makes to the understanding of the geology and the detection of ore deposits in semi-arid terrain. In conclusion it should be emphasized that satellite and aircraft imagery is complementary and that both should be used on an interactive basis for geological mapping and mineral exploration. Finally, automated methods of display and data handling offer opportunities for more rapid and more accurate interpretation of imagery than is possible by visual methods and increasingly should aid investigation in inaccessible terrain.

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3.7 REFERENCES

Alcock, P.J. and Lee, M.F. 1974 'Aspects of the geology and exploration of the Lady Annie-Lady Loretta lead-zinc-silver deposit, northwest Queensland'. In Recent technical and scientific advances in the north Australian minerals undustry: papers presented at the regional meeting, Ausust 1974 (Mount Isa: Australian I.M.M. Queensland Branch 1974) 207-315 (Symposium series no 6)

Beaumont, T.E. 1977 'The use of multispectral photography in studies of the relationships between the distribution of vegetation units and environmental parameters in northwestern Queensland, Australia. Thesis submitted for Ph.D degree. University of London.

Bechtold, I.C., Reynolds J.F. and Wagner, C.G. 1975 'Applications of Skylab imagery to resource exploration in the Death Valley Region'. NASA Earth Resources Survey Symposium 1-B Houston, Texas, pp 665-672

Blake, S.T. 1938 'The plant communities of western Queensland and their relationships, with special reference to the grazing industry, Proc.Roy.Soc.Qld. XL1X No 16; Univ.Qld. Dept. Biology papers 1 No 8

Blodget, H.W., Brown and Moik J.G. 1975 'Geological mapping in northwestern Saudi Arabia using LANDSAT multispectral techniques'. NASA Earth Resources Survey Symposium 1-B Houston, Texas pp 971-989

Carnegie, D.M. and Degloria S.D. 1972 'The usefulness of ERTS 1 and supporting aircraft data for monitoring plant development in range land environments' Proc 8th Int Symposium on Remote Sensing, Ann Arbor, Michigan pp 1471-1490

Chandler, B.J. 1977 Some basic programs for imagery processing

Cole, M.M. 1977 'LANDSAT and airborne multispectral and thermal imagery used for geological mapping and identification of ore horizons in Lady Annie-Lady Loretta and Dugald River areas, Queensland, Australia'. Trans Instn Min Metall. Lond. Vol 86

Cole, M.M. and Owen-Jones E.S. 1975 'Applications of remote sensing to terrain mapping'. Central Office of Information. London

Cole, M.M., Owen-Jones, E.S., Beaumont T.E. and Custance, N.D.E., 1974, 'Recognition and interpretation of spectral signatures of vegetation from aircraft and satellite imagery in western Queensland, Suastrali'. In European Earth Resources Satellite experiments: proceedings of a Symposium, Frascati Italy, 1974 (Neuilly, France : European Space Research Organization, 1974) 243-87, (ESRO SP 100)

Cole , M.M., Owen-Jones E.S., Catt P.C., Cousans, C.M. and Chandler, B.J. 1975 'An evaluation of visual and semi-automated approaches to the recognition of spectral signatures in air survey and satellite imagery of mineralized natural terrain'. Convegno Internazionale Sullo Spazio, Roma 1975, 363-73

Cole, M.M., Owen-Jones E.S., Catt P.C. and El Lahan, N. 1976 'The use of multi-spectral and thermal imagery taken at different seasons from aircraft and satellite platforms in the recognition of superficial and bedrock geology, structural features and ore horizons in western Queensland, Australia'. Paper presented to 25th International Geological Congress, Sydney 1976. In press.

Cole, M.M., Owen-Jones E.S., and Custance N.D.E. 1974 'Remote sensing in mineral exploration'. In Environmental remote sensing - applications and achievements : Bristol symposium 1972 (London: Edward Arnold, 1974) 51-66

Custance, N.D.E. 1974 'The application of terrain classification techniques to visible, near infrared and thermal infrared'. Ph.D. thesis, University of London.

de Keyser F. 1958 'Geology and mineral deposits in Paradise Creek area northwestern Queensland'. Rec.Bur.Miner.Resourc. Aust. 1958/100 (Unpublished).

Driscoll, R.S. and Spencer M.M., 1972 'Multispectral scanner imagery for plant anomaly recognition'. Proc 8th Int. Symposium on Remote Sensing, Ann Arbor Michigan, pp. 1259-1278.

Henze, J. and DeZur, R. 1975 'Interactive digital image manipulation system (IDIMS). NASA Earth Resources Survey Symposium 1-B, Houston, Texas. pp 1415-1435

Hill, D. and Denmead, A.K. eds. 1960. 'The Geology of Queensland'. J.Geol.Soc.Aust. 7, 474 p.

Hoffer, R.M. and Goodrick, F.U. 1971 'Variables in automatic classification over extended remote sensing test sites' Proc. 7th Int. Symposium on Remote Sensing, Ann Arbor, Michigan. pp. 1967-1981

Kolipinski, M.C., Higer, A.L., Thomson, N.S. and Thomson, F.J. 1969 'Inventory of hydrobiological features using automatically processed multispectral data'. Proc.6th Int. Symposium on Remote Sensing, Ann Arbor, Michigan, pp 79-95.

Kriegler, F.J. 1971 'Implicit determination of multispectral scanner variation over extended areas'. Proc. 7th Int.Symposium on Remote Sensing of Environment Univ. Michigan p. 759

Kristof, S.J. and Zacharm A.L., 1971 'Mapping soil types from multi-spectral scanner data'. Proc.9th Int. Symposium on Remote Sensing, Ann Arbor Michigan pp 2095-2108

Marshall, R.E., Thomson, N., Thomson, F. and Kriegler, F.J. 1969 'Use of multispectral recognition techniques for conducting rapid wide area wheat surveys'. Proc. 6th Int. Symposium on Remote Sensing, Ann Arbor, Michigan pp 3-20.

Maizels, Dr J.K. 1977 'Digital Processing of LANDSAT imagery'. A User's Guide to the Bedford College Image Processing Program Library.

Merembeck, B.F. et al, 1974 'Transferance of ERTS 1 Spectral Signatures in time and space'. Proc. 9th Int. Symposium on Remote Sensing of Environment, Ann Arbor, Michigan pp 152-162.

Nalepka, R.F. and Morgenstern, J.P. 1972, 'Signature extension techniques applied to multispectral scanner data'. Proc. 8th Int. Symposium on Remote Sensing, Ann Arbor, Michigan pp. 881-893.

Nicholls, O.W., Provan, D.M.J., Cole, M.M. and Tooms, J.S. 1964-65. 'Geobotany and geochemistry in mineral exploration in the Dugald River area, Cloncurry District, Australia'. Trans.Instn. MIn. Metall, Lond. 74, 695-799.

Owen-Jones, E.S. 1974, 'Pattern Classification of Agricultural and Non-Agricultural Areas', Second Technical Session of the Remote Sensing Society, Sheffield, 1974.

Owen-Jones, E.S. 1974, 'Densitometric Methods with Special Reference to Crop-types and Terrain Studies', Proceedings of Second Bristol Symposium on Remote Sensing.

Owen-Jones, E.S., Chandler, B.J. 1975, 'The Application of Photographic Technique to Earth Resources Surveys', Journ.Brit.Int.Soc. 28

Sawatsky, D.L. Prost, G., Lee, K. and Knopper, D.H. 1975, 'Geologic significance of features observed in Colorado from orbital altitudes', NASA Earth Resources Survey Symposium, 1-B, Houston, Texas, pp 713-760.

Schmidt ,R.G., Clark, B.B. and Bernstein, R. et al 1975 'A search for sulfide bearing areas using Landsat 1 data and digital image processing techniques'. NASA Earth Resources Survey Symposium 1-B, Houston, Texas pp. 1013-1027.

Short, N.M. and Marrs, R.W. 1975 'The anatomy of an anomaly' <u>NASA Earth Resources Survey Symposium</u>, 1-B Houston,Texas pp 641-663.

Smedes, H.W., Spencer, M.M. and Thomson, F.J. 1971 'Preprocessing of multispectral data and simulation of ERTS data channels to make computer terrain maps of a Yellowstone National Park Test Site. <u>Proc. 7th Int. Symposium on Remote Sensing</u>, Ann Arbor, Michigan, pp. 2073-2094.

Twidale, C.R. 1956 (a) 'Pediments at Naraku, northwest Queensland'. Aust.Geog. 6 (6) 40-42

(b) Cronology of denudation in northwest Queensland, <u>Geol.Soc.Am</u>. 67(7) 867-881.

Twidale, C.R. 1966 'Geomorphology of the Leichardt-Gilbert area, northwest Queensland'. <u>CSIRO Land Research Series</u> No. 16

Vincent, R.K., 1973 'Ratio maps of iron ore deposits, Atlantic City District, Wyoming'. <u>NASA Symposium on significant results obtained from Earth Resources Technology Satellite - 1</u>, 1-A, Houston, Texas pp. 379-386.

Weber, F.P., Aldrich, R.C., Sadowski, F.G. and Thomson, F. J. et al 1972 'Land use classification on a southeastern forest region by multispectral scanning and computerized mapping. <u>Proc. 8th Int. Symposium on Remote Sensing</u>, Ann Arbor, Michigan pp. 351-373.

Whitehouse, F.W. 1940 'Studies in the late geological history of Queensland'. <u>Papers Univ.Qld.Dept.Geol</u>. 2 (1)

4 SIGNIFICANT RESULTS

The following significant results have been obtained:-

1. On the colour composites generated from LANDSAT 1 and LANDSAT 2 imagery displayed at scales of up to 1:10,000

   1. Distinctive spectral signatures discriminate areas underlain by distinctive lithological/stratigraphical units where bedrock either outcrops or is relatively near to surface in the Lady Annie-Mount Gordon Fault Zone area, the Mary Kathleen and the Dugald River-Naraku areas within the Mount Isa-Cloncurry region of northwest Queensland, Australia.

   2. Distinctive spectral signatures associated with discrete plant communities distinguish different types of Superficial Deposits over the Cloncurry Plains.

   3. Distinctive spectral signatures reveal the presence and nature of concealed bedrock beneath cover of residuum and Superficial Deposits where this is relatively thin over the Cloncurry Plains.

   4. Major faults are clearly displayed in areas of outcropping and near surface bedrock: in some cases their continuations are indicated in areas of covered ground where they have not been mapped hitherto.

   5. Sets of lineaments with preferred orientations have been identified in the Lady Annie and Dugald River areas. Known base metal deposits, notably those at Mammoth Mine, Lady Loretta, Mount Kelly and the Dugald River occur along these features.

   6. Ironstones and ferruginous outcrops are readily identified

at all seasons of the year. These include gossans associated with mineralization and laterite.

7. Certain types of mineral deposits which are characterized by well-defined geobotanical anomalies may be identified at scales of 1:30,000 o 1:10,000. These include the Lady Annie phosphate deposits. The presence of base metal deposits such as the Dugald River and Lady Loretta lead-zinc deposits may be detected if they are of sufficient size and if they are distinguished bv well-defined geobotanical anomalies producing distinctive spectral signatures.

8. Areas of black soil plains characterized by vegetation communities whose distributions outline lozenge shaped features whose pattern of distribution appears to disclose subsurface drainage conditions, may be identified by unique spectral signatures on imagery acquired after the rainy season when the grassland vegetation is reflecting strongly in the infra red.

2. More information regarding vegetation and geology may be obtained from colour composites of LANDSAT imagery displayed at scales of 1:50,000 and greater than at smaller scales.

3. More detailed information on vegetation and geology may be obtained from colour composites generated from the computer compatible tapes than is possible from those generated from the NASA films.

4. Colour composites generated from LANDSAT imagery acquired in March after the rainy period provide more information on vegetation and geology than those generated from imagery acquired at other seasons of the year. However, imagery acquired at different seasons provides complementary information and assists geological mapping and interpretation of terrain features.

5. Areas which have been burnt may be identified and the subsequent regeneration of the vegetation may be monitored from successive

6. For geological mapping and mineral exploration LANDSAT and air survey imagery are complementary. Whereas LANDSAT imagery provides remarkable details of the geology on a regional basis and by the revelation of lineaments and iron rich outcrops can be used to target areas of possible mineralization, multispectral and thermal air survey imagery is required for detailed geological mapping and for the precise location of ore deposits.

7. Successful semi-automated classifications of both LANDSAT and air survey imagery have been achieved notwithstanding the difficulties involved in classifying features of the natural terrain whose components of vegetation, soils, relief and geology exhibit continuous variation in spatial extent. The success achieved is promising for the handling of large quantities of LANDSAT and air survey imagery of remote areas.

5. PUBLICATIONS

1. Beaumont T.E. 1977, ' The use of multispectral photography in studies of the relationships between the distribution of vegetation units and environmental parameters in northwestern Queensland, Australia.
   Thesis submitted fro the Ph.D. degree, University of London.
2. Chandler B.J. 1977, 'Some basic programs for imagery processing
3. Cole M.M. 1977, ' LANDSAT and airborne multispectral and thermal imagery used for geological mapping and identification of ore horizons in the Lady Annie-Lady Loretta and Dugald River areas, Queensland, Australia.'
   Trans Instn Min Metall. Lond. Vol. 86

4. Cole M.M. 1977, 'Geobotanical expression of ore bodies' Third meeting of Geological Societies of British Isles, Swansea.

5. Cole M.M. and Brown R.C. ' The vegetation of the Ghanzi area of western Botswana.' J. of Biogeography, Vol.3. pp 169-196.

6. Cole M.M. and Owen-JOnes E.S. 1975, ' Applications of remote sensing to terrain mapping.' Central Office of Information, London.

7. Cole M.M., Owen-JOnes E.S., Beaumont T.E., and Custance N.D.E 1974, ' Recognition and interpretation of spectral signatures of vegetation from aircraft and satellite imagery in western Queensland, Australia.' European Earth Resources Satellite Experiments: Proceedings of a Symposium, Frascati, Italy, 1974. ESRO SP 100, pp 243-87.

8. Cole M.M., Owen-JOnes E.S., Catt P.C., Cousans C.M., and Chandler B.J., 1975, 'An evaluation of visual and semi-automated approaches to the recognition of spectral signatures in air survey and satellite imagery of mineralized natural terrain.' Convegno Internazionale Sullo Spazio, Roma, 1975, pp 363-73.

9. Cole M.M., Owen-JOnes E.S., Catt P.C., and El Lahan N. 1976, 'The use of multispectral and thermal imagery taken at different seasons from aircraft and satellite platforms in the recognition of superficial and bedrock geology, structural features and ore hroizons in western Queensland, Australia. Paper presented to 25th International Geological Congress Sydney, 1976. In the press.

10. Cole M.M., Owen-Jones E.S., and Custance N.D.E., 1974, ' Remote sensing in mineral exploration.' in Environmental Remote Sensing --applications and achievements: Bristol Symposium 1972. Ed.Barrett E.C. and Curtis L., London, Edward Arnold. pp 51-66.

11. Custance N.D.E., 1974, ' The application of terrain classification techniques to visible, near infrared and thermal infrared. Ph.D. thesis, University of LOndon.

12. Owen-Jones E.S., 1974, 'Pattern classification of agricultural and non-agricultural areas.' Second Technical Session of the Remote Sensing Society, Sheffield, 1974.

13. Owen-Jones E.S., 1974, Densitometric methods with special reference to crop types and terrain studies.' Proceedings of Second Bristol Symposium on Remote Sensing.

14. Owen-Jones E.S. et al. 1974, ' The interpretation and use of infrared and true colour photography of part of Argentina obtained by Skylark Earth Resources Rockets.' Ninth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, pp 1475-96.

15. Owen-Jones E.S., and Chandler B.J., 1975, 'The application of photographic techniques to earth resources surveys.' J. Brit. Int. Soc, Vol. 28

16. Owen-Jones E.S., Galloway I, and Chandler B.J., 1974, 'The application of pattern classification techniques to Skylark Earth Resources Rocket Imagery.' I.E.R.E. Conference Proceddings No 29, pp 81-9.

6. PROBLEMS

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7. DATA QUALITY AND ACQUISITION

Most of the LANDSAT imagery for northwest Queensland has been of very high quality.

8. RECOMMENDATIONS

The results achieved under the project indicate that imagery from a thermal channel and imagery of higher resolution such as that planned from LANDSAT C would provide valuable additional information on the type of semi-arid terrain characteristic of northwest Queensland. Both LANDSAT and air survey imagery displayed at appropriate scales and suitable enhanced should be used as complementary sources for the mapping and interpretation of terrain features, including vegetation and geology.

9. CONCLUSIONS

The high quality LANDSAT imagery available for northwest Queensland provides valuable information on the terrain features, particularly on vegetation, geology and drainage. It has revealed plant community distributions, indicated subsurface drainage features and disclosed geological structures hitherto unknown. The studies undertaken have demonstrated that for geological mapping and mineral exploration LANDSAT and air survey imagery are complementary. The LANDSAT imagery effectively displays the regional geology and reveals lineaments which may be important for mineralization. It assists the selection of target areas for which multispectral and thermal air survey imagery are required for detailed geological mapping and for the precise location of ore deposits. The successful attempts at the semi-automated classification of both LANDSAT and air survey imagery are promising for the handling of large quantities of imagry of remote areas of natural terrain.

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