

AN EVALUATION OF LANDSAT MSS DATA FOR  
ECOLOGICAL LAND CLASSIFICATION AND  
MAPPING IN THE NORTHERN CAPE

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VOLUME 1

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## EXECUTIVE SUMMARY

### PAPER 1

#### A VISUAL INTERPRETATIVE INVESTIGATION TO DETERMINE THE VEGETATION MAPPING CAPABILITIES OF MULTISPECTRAL DATA IN THE SEMI-ARID REGIONS OF SOUTH AFRICA

This paper examines the issues that arise in the use of visual interpretation of Landsat data during the analysis, classification and mapping of the natural vegetation of the semi-arid Northern Cape.

Initial research involved the classifying and mapping of the vegetation using conventional methods. A vegetation map, accompanying legend and descriptive key were produced. The problems encountered during this process, and the constraints of manpower, time and funds, stimulated the investigation of Landsat imagery as a means of improving the speed and accuracy of vegetation classification and mapping.

A study area comprising one Landsat scene and which met certain requirements was selected:

- a) The area had already been surveyed and mapped at a scale of 1:250 000.
- b) As many vegetation units as possible were included.
- c) There was maximum diversity, complexity and variability in terms of soil, geology and terrain morphology.

Initially a suitable mapping scale was selected, viz. 1:250 000, as it met the requirements of nature conservation authorities and agricultural planners. The scales of survey and remote sensing were based on this. The basic unit of survey was the 1:50 000 topographical map and satellite imagery at a scale of 1:250 000 was found to meet the requirements of reconnaissance level mapping.

The usefulness of Landsat imagery was markedly affected by the quality of image production and enhancement. Optimum image production was vitally important and to this end, interaction between the user and the operations engineer at the Satellite Applications Centre, Hartebeeshoek was essential.

All images used, were edge-enhanced and systematically corrected. While these procedures were costly, they proved to be fundamental to the success of the investigation. Precision geometric correction was not required for reconnaissance level investigation. The manual superimposition of the UTM grid, using ground control points from 1:250 000 topographical maps, proved to be accurate and convenient.

Pattern recognition on single-band, panchromatic imagery was difficult. The scene lacked crispness and contrast, and it was evident that black and white imagery did not satisfy the objectives of the study. Three-band false colour composite imagery was superior to single-band imagery in terms of clarity and number of cover classes. The addition of colour undoubtedly facilitated visual interpretation.

False colour composite imagery was investigated further to establish which year, season and possibly time of season would best suit the objectives of the investigation. It was found that the environmental parameters affecting reflectance are relatively stable over time and it was not necessary to acquire imagery of the same year as field surveys. However, the year of imagery should be chosen so that similar climatic conditions prevail. While, in certain instances, imagery captured during winter had advantages in separating complex mosaics, summer imagery was superior in most respects. Furthermore, given "normal" climatic conditions, the ideal period during which there was maximum contrast between and within ground classes, and thus spectral classes, was narrowed to mid-January to mid-April.

Units which were acceptably heterogeneous (relatively homogeneous) in terms of reflectance levels were delineated manually on the image. This delineation was done at three levels of complexity and the units were compared with the vegetation map. A series of field trips aided the interpretation of the images, especially where discrepancies occurred between the map and the image.

In general, there was a close degree of correspondence between the prepared vegetation map and the delineated image. Field investigation revealed the image units to be more accurate than those on the vegetation map, and the image served to highlight the inadequacies inherent in classifying and mapping vegetation of extensive areas with limited resources. Certain patterns,

hues and textures on the image could be related to specific vegetation formations despite the fact that natural vegetation generally accounted for a small percentage of the spectral reflectance owing to the low projected canopy cover. Natural vegetation is extremely sensitive in its response to changes in abiotic factors, and thus a close correspondence between the image and the vegetation could be inferred.

Since the projected canopy cover of the vegetation in semi-arid regions is generally low, it was imperative that the relationships between abiotic parameters and the delineated image classes be examined. Broad subdivisions on the image most often had a high degree of unity in terms of pattern, hue and texture, and were found to have a high degree of unity in terms of soil, geology and frequently, terrain morphology. Spectral units correlated directly and strongly with soil and geological type and there was a good correspondence between spectral and topographical/terrain morphological classes. Coarse texture on the image related primarily to elevated terrain. Drainage basins had a distinct character and pattern, and water bodies were easily discernible. Excessively moist soils with low vegetal cover had the same hue as water bodies.

In terms of vegetation structure, physiognomy and floristics, soil/geological types correlated well with major plant structural types, while moisture levels and topography affected the lower scale, plant floristic types, some of which were below the effective resolution of Landsat imagery. In many instances the successional stages of the vegetation could be ascertained from the image, and the interrelationships between vegetation types and between plant communities were often portrayed. However, clarity or distinctiveness of pattern, hue and texture on the image did not necessarily relate to the same degree of distinctiveness in the environment.

The interpretation phase of the study served to highlight the importance of obtaining good ground reference data. In the semi-arid to arid regions, with low vegetal cover, contrasts portrayed on the image are not due to vegetation alone. The spectral classes were multiple parameter classes and adequate interpretation of these classes implied collecting field data on all the parameters which affected reflectance levels. Furthermore, the spectral classes delineated on the image could not be arranged in an orderly and meaningful manner directly. Once these classes had been shown to portray

specific ground cover classes, the basis for a classificatory system was available. To this end, suitable and adequate ground reference data was essential.

In many cases discrepancies between supportive information maps (topography, soil, geology and land type) were the result of inaccuracies in the maps rather than the image. Outstanding ground features such as farm homesteads with calcrete surrounds, could be pin-pointed exactly on the image. The synoptic view of the landscape afforded by the Landsat image proved to be most advantageous and the fact that both the remote sensing product and the supportive information maps were of the same scale facilitated orientation in the field and correlation of unit boundaries.

It was shown that:

- a) The boundaries delineated on the Landsat image were real in terms of soil types, geological types, vegetation, and frequently, terrain morphological type as well.
- b) The delineated units had unique combinations of these parameters.
- c) The units were minimally heterogeneous throughout the range of variation of these parameters.

The vegetation map was altered and improved subsequent to the investigation using Landsat imagery. Boundaries between units could be placed far more accurately and the omission of several units was rectified. The multispectral image contains surrogate data of parameters used in the classification of the landscape, i.e. vegetation, soils, geology, topography and climate (moisture and temperature). Thus vegetation maps produced using satellite imagery as a central resource contain vegetation-landscape units. The landscape is an integrated system; when one environmental variable changes, so do others, and the natural vegetation is the most sensitive indicator of these changes.

It was concluded that the close agreement between the image spectral classes and the spatial distribution of vegetation units, albeit mainly structural and physiognomic, makes Landsat imagery a valuable tool in the production of accurate reconnaissance scale vegetation maps of the semi-arid regions of South Africa.

PAPER 2A COMPUTER PROCESSED INVESTIGATION TO DETERMINE THE VEGETATION MAPPING CAPABILITIES OF MULTISPECTRAL DATA IN THE SEMI-ARID REGIONS OF SOUTH AFRICA

A major vegetation survey of the Northern Cape necessitated the production of 1:250 000 scale maps of the study areas. Paper 1 of this report discussed the visual interpretation possibilities of Landsat imagery. Criticisms may be levelled at this procedure because of its subjectivity and because it disregards the numerical characteristic of Landsat MSS data. Computer classification of the data is concerned with the actual measurements in conjunction with probabilistic or simple numerical algorithms. It was decided to evaluate the usefulness of such methods in aiding vegetation map production in the semi-arid regions of South Africa. In this paper, the methods and results of computer techniques, applied to the same set of data as was used for visual interpretation, are described. The basic aim of this study was to find out if such analysis techniques would lead to more accurate, less time-consuming and less costly vegetation maps. Furthermore, it was hoped that the method would lead to better extrapolation and interpolation capabilities.

Computer classification of Landsat MSS data requires that the computer recognise classes of information within the data set. Each pixel is assigned to a specific class by matching the spectral signature with the range of signatures determined for the class. Thus pixels with similar spectral signatures are grouped together. In the final interpretation, there is correlation of the data classes with ground cover classes. The range of signatures for a specific spectral class is obtained from a training class. The training class is a small set of data within a selected training area used to "train" a classification algorithm. Three different training class selection techniques were employed in this study, viz. supervised, unsupervised and hybrid.

Two training areas were chosen for the development of training classes and the selection of training sites as not all cover types could be adequately represented by one training area. The northern training area is referred to

as the Kalahari Thornveld Training Area and the southern one as the Ghaap Plateau Training area.

Both training areas were classified using the supervised method initially and the classifications were assessed for accuracy of classification, good separation of spectral classes, misclassifications and non-classifications. Similar classes were combined and further training classes were included to improve the classification. Owing to the problems encountered in the supervised classification, the unsupervised and hybrid methods were used on the Ghaap Plateau Training Area only. Once again, the accuracy of the classifications was assessed at each stage, and improvements made.

The supervised classification of the Kalahari Thornveld Training area resulted in the selection of 21 discrete training classes. The computer-generated classification was compared with the vegetation map and was assessed for accuracy. No single vegetation-landscape unit was uniquely classified and the computer classification lacked cohesion. Many of the colour-codes representative of specific vegetation-landscape units were present in varying amounts in other units throughout the classification. There was thus considerable confusion of units. It was concluded that this confusion was to some degree the result of the intrinsic heterogeneity of the landscape.

As a result of experience gained in the classification of the Kalahri Thornveld Training Area, the classification of the Ghaap Plateau Training Area was restricted as far as possible to a single ecological region - the Ghaap Plateau. This was achieved by means of placing a positive spatial mask over that portion of the training area which would be used in the classification. A total number of 28 spectral classes were generated during the classification.

The classification of the Ghaap Plateau Training Area was more successful than that of the Kalahari Thornveld Training Area. This improvement was attributed to the fact that the classification had been restricted to a single ecological region, as well as the fact that three classification techniques had been employed. Several vegetation-landscape units were classified clearly and accurately, but the computer classification still lacked cohesion. There was confusion between some vegetation-landscape units and once again this was attributed to the heterogeneity of the natural landscape.

The classification results of both training areas were not considered sufficiently successful to justify classification of the entire scene by means of signature extension.

Bispectral plots were used to assess and improve the separability of the training classes of each training area during the classification process. Bispectral plots were used again in conjunction with ground cover interpretation, and subsequent to the final computer-generated classifications, to aid in the assessment of the confusion between vegetation-landscape units. In many instances, especially in the Kalahari Thornveld Training Area, it was difficult to ascribe the clustering of spectral classes to a common environmental resource class, though on occasions this could be done. However, when a common resource class could be found to explain a spectral cluster, it was not based on any vegetal characteristics. The practice of pooling or deleting spectral classes which displayed a lack of spectral separability was viewed with caution as it was felt that classes should be combined only if the ground cover types that they represented were sufficiently similar to justify such a move.

In certain instances no plausible explanation could be given for the incorrect classification of pixels and it was concluded that the misclassification could be due to a Landsat system error. This was termed the "mixed pixel" problem and refers to the assignment of pixels to several cluster centres. The problem of mixed pixels is dependent on the resolution of Landsat and the type of cover class. If the intrinsic environmental pattern distribution is larger than the pixel size and pixels fall wholly within and straddle one or another ground feature, resulting reflectance values vary from one pixel, or group of pixels, to another over the geographical distribution of the cover class type. This was referred to as the "between mixed pixel" problem. The distinction of ground cover classes is scale dependent, where what might be classed as a single cover type at a scale of 1:250 000, may well be split into several cover classes at a larger scale of investigation. A lower resolution could possibly help to solve this problem.

If the intrinsic pattern of the cover class is smaller than the pixel size, the "within mixed problem" could occur and serious classification inaccuracies may result. Two individual pixels representing different ground cover classes could have the same resultant mean reflectance and so be grouped

together. No amount of classification on a pixel-by-pixel analysis would separate the two. Increased satellite resolution would possibly resolve this problem.

Both types of "mixed pixel" problems served as a reminder of the complexity of the natural terrain surface. The detail shown in any map is scale-dependent. The computer classification portrayed the natural complexity of the landscape in the patchiness and mixing of colour-codes. It was felt that the pixel-by-pixel analysis of the computer classification forced a scale of research to larger than the initial reconnaissance scale, in that the classification of small groups of pixels had to be interpreted and explained. The spatial organization of the data was lost in this pixel-by-pixel classification.

No statistical assessment of the accuracy of the computer classification of the training areas was made. Accuracy was assessed both qualitatively and semi-quantitatively by means of 1:1 overlays of the vegetation maps and the computer-generated classifications. The accuracy of the classification was assessed at three levels:

- a) overall pattern accuracy (the correspondence of area, including the position of the boundary)
- b) details shown within the overall pattern (mosaicism)
- c) the uniqueness or discreteness of each separate cover type.

While the classification of the Ghaap Plateau Training Area was considered more accurate than that of the Kalahari Thornveld Training Area, it must be borne in mind that the two training areas represent different ecological regions. The Ghaap Plateau Training Area was more diverse in terms of combinations of environmental parameters; the greatest disadvantages of the Kalahari Thornveld Training Area were the uniformity of vegetation, the widespread presence of Kalahari sands and the general narrow-range, high reflectance levels of the training area. The supervised, unsupervised and hybrid classifications were executed on the Ghaap Plateau Training Area data and many more training classes were signaturized to account for spectral variability. Overall classification percentages were judged to be low, but an "overall" assessment hides the fact that classification accuracy was variable. More homogeneous cover types were more accurately classified than the more heterogeneous cover types.

The results of the computer classification were neither straightforward nor predictable. The broad, overall pattern of vegetation-landscape units was present, in that two units, separated by some space, were identified, but they may have been classified as similar or different. Interpretation of minor pixel class assignments forced the level of investigation to a scale larger than the mapping objective of the study, viz. 1:250 000. It was felt that the computer classification led more spontaneously to map products at scales between 1:10 000 to 1:50 000.

It was apparent that inadequate signaturization of classes resulted in some classification confusion, but forcing a "tidy" classification by an iterative procedure of retraining the classifier was rejected as contrary to the objectives on the study. In many instances no meaningful resource class could be found to explain spectral groupings and thus improving spectral homogeneity by retraining the classifier does not result in improved classification accuracy even though the classification may appear more cohesive.

Throughout the study the importance of good ground reference data was evident. The quality of ground reference data is fundamental to the accuracy of the classification and to the interpretation thereof. The basic aim of the study was to assess whether computer classification of Landsat MSS data would lead to an improvement over visual techniques in terms of the production of more accurate, less time-consuming and less costly vegetation maps. The approach was essentially a *priori* and at times, subjective and qualitative. It was concluded that, in the light of the aims of this particular study, the visual interpretation of Landsat imagery was more successful and that significant effort would be required to obtain discrete computer classifications of heterogeneous environments.

PAPER 3VEGETATION LAND CLASSIFICATION BY PRINCIPAL COMPONENTS ANALYSIS OF  
MULTITEMPORAL LANDSAT DATA

During the period 1983 to 1986 visual interpretation of Landsat imagery was successfully used in the classification and mapping of the vegetation of the Northern Cape. In 1984 supervised, unsupervised and hybrids methods of classification were used to classify two subscenes of the single date Landsat MSS data used in the initial visual interpretation. The classification objectives of the study were not met during the computer classification which resulted in confusion between physiognomically and structurally dissimilar field units. This paper discusses the use of multitemporal overlays of Landsat MSS data in an attempt to improve the computer classification of the Kalahari Thornveld Training Area used in the single date investigation. The objective of the multitemporal investigation was to improve the meaningful separability of spectral classes.

The overlay procedure involved the precise superimposition of two MSS data sets of the same area but of different dates. It was hoped that the extra information content in the form of the data from the second image as well as the differences between the two images, would improve classification accuracy. It was thus desirable to superimpose two contrasting sets of data and to this end, data sets captures during winter and summer were selected. Only two subscenes of the Kalahari Thornveld Training Area were classified, viz. the North-West (NW) Quadrat (Kalahari Thornveld) and the South-East (SE) Quadrat (Ghaap Plateau).

In order to superimpose the two sets of data accurately, the winter data set was precision geometric corrected by means of ground control points visible on both the 1:50 000 topographical map and the satellite image. The summer image was then registered to the winter image using the same ground control points. A ground accuracy of 100 m between the two images was considered acceptable. Adequate registration of the two images can make a fundamental difference to the success of the classification.

The superimposition of two four-bands sets of data results in an eight-dimensional data set. The dimensionality of the data was reduced by means of

a principal components transformation, the Karhunen-Loeve transformation. In both data sets approximately 90% of the variance was accounted for by the first two principal components. For both quadrats, the first and second principal components of the winter and summer data were combined and an unsupervised computer classification was performed on the resulting four-dimensional data sets.

In the NW Quadrat, eight areas were positively masked for the unsupervised classification. Sixteen classes were generated from this procedure and two classes were combined, resulting a in total a fifteen spectral classes. The entire quadrat was then classified. The procedure followed in the SE Quadrat was similar, except that six areas were positively masked and nine classes were finally generated.

It was extremely difficult to assign any meaningful description the the spectral classes generated during unsupervised classification, and none of the classes could be given meaning in terms of a vegetal resource class. The separability of the spectral classes was assessed by means of a divergence matrix and bispectral plots of component one against component two for both seasons. In both quadrats, a number of adjacent classes were found to have low divergence measures and some class overlap (within one standard deviation) occurred between adjacent and some non-adjacent classes. The spectral separability of the classes was reasonably good, and more so in the SE Quadrat.

The computer-generated classification was compared with the prepared vegetation map and assessed for correctness and accuracy of classification. The classification showed better overall cohesion than the single date classification, and if vegetation-landscape units were viewed as distinct combinations of colour-codes rather than individual colour-codes, a clearer pattern of classification emerged. Classification of the entire training area by means of signature extension was not considered worthwhile.

A single false colour composite image was produced from the data set used in the classification. This resulted in an enhanced image which contained more information than a single date image from either season. Colour contrast and range of brightness were good, and topographical features were enhanced.

The multitemporal overlay led to a sophistication and detail beyond the simple addition of two single date data sets.

The superimposition of two four-dimensional data sets gives rise to many different possibilities of data combinations and analyses, only one of which was examined here. Possibly a different data combination and/or a different method of analysis would have yielded better results. It was concluded that the computer classification of the multitemporal overlay yielded better results than that of a single date MSS data set. The level of detail resulting from the classification was far beyond that required for reconnaissance level mapping, and the importance of good ground reference data in the interpretation of the classification was evident. It is doubtful whether the improvement in the classification in terms of the objectives of the study justified the costs involved.

#### PAPER 4

#### COMPUTER CLASSIFICATION OR VISUAL INTERPRETATION, MULTITEMPORAL OF SINGLE DATE DATA SET? - A DISCUSSION

The objective outlined in the preceding papers was to test the usefulness of Landsat imagery in the classification and mapping of the vegetation of semi-arid areas. To this end a number of Landsat products as well as techniques of analysis were investigated. This paper examines the strengths and weaknesses of the products and techniques in so far as was not done in preceding papers. Several issues concerning the future use of Landsat imagery are discussed.

The computer classification of single date and multitemporal data sets for the north-west and south-east quadrats of the Kalahari Thornveld Training Area were compared. The classification of the south-east quadrat was more successful in both instances and this was ascribed to the less frequent occurrence of transitional zones between vegetation-landscape units and a higher degree of contrast between any one vegetation-landscape unit and the others. Both classifications portrayed the hierarchical interrelationships, the mosaicism within vegetation-landscape units and the east-west gradient across the south-east quadrat.

Computer classifications cannot generalize about the heterogeneity of natural landscapes in the same way that the human eye can, and thus both classifications lack cohesion though the multitemporal classification to a lesser extent. In the interpretation of the computer classifications, patterns emerged in terms of specific combinations of colour-codes rather than in terms of cohesive patches of single colour-codes.

In both instances there were accuracy problems associated with the classification of transitional zones. The transitional zones were either classified with one of the units to which they were transitional or with some distant, unrelated unit (in the case of single date only). The multitemporal classification was superior in this regard.

Upon analysis of the classification accuracy of the vegetation-landscape units contained in the quadrats, it was evident that the multitemporal classification was more accurate in most cases. The superimposition of two sets of data resulted in improved distinction between grassy shrublands (or woodlands) and shrubby (or woody) grasslands. There were a few instances where the added information content appeared to have affected the classification adversely. This was ascribed either to imperfect registration of images or the fact that the changes between the two seasons were subtractive rather than additive. Despite the improved classification obtained in the multitemporal overlay of two data sets, neither classification was regarded as successful in terms of the objectives of the study.

During the course of the multitemporal investigation an FCC image of the Kalahari Thornveld Training Area was photographically produced from the first and second principal components of winter and summer. The quality of this image was impressive and though no formal visual interpretation investigation was executed, this photographic FCC image was compared with the single date image of the Kalahari Thornveld Training Area, also photographically produced.

Fine detail was clearly noticeable on the multitemporal image. In most instances these details could be seen on the single date image, but only on

closer inspection. In rare cases there was no apparent improvement in the multitemporal image, but on the whole this image was superior.

The production of multitemporal imagery is costly and the precise superimposition of the two images is fundamental to the success of the project. In view of these constraints, and the highly satisfactory results obtained with the visual interpretation of single date imagery, it was concluded that the use of multitemporal imagery in the case of general vegetation mapping, could not be justified.

In the final assessment, a comparison of the results obtained using visual interpretation of false colour composite imagery as opposed to those using automatic machine processing techniques was undertaken. The results of this study indicated that visual interpretation techniques produce more reliable end products than do digital analyses techniques.

Visual methods of analysis tend to be qualitative, descriptive and subjective, while computer-assisted methods are quantitative and objective. Ultimately the units produced in a computer classification must be interpreted, identified and described from field observations, and this step always includes a level of subjectivity. Subjectivity *per se* was not necessarily regarded as a weakness of the system as it gives the end product meaning.

The use of FCC images in the field enables the investigator to observe the environmental parameters which may be responsible for the spectral information. This identification aspect is not possible when computer techniques are used alone, yet the influence of vegetation is often regarded as a continuous, unique variable present in every spectral cover class. The identification of the environmental basis for spectral differences facilitates extrapolation over large areas.

When working at the reconnaissance level, it is often easier and safer to generalize on the FCC image than on the computer-generated classification "map". By its very nature this "map" focuses attention on small groups of classified pixels whose contrasting colour-codes portray differences which are in fact not as large as they seem to be. The interpretation of these pixel groups requires detailed ground reference data. By way of contrast, the

human brain is capable of generalizing spectral classes through rapid interpretation of pattern, hue and texture.

There is an urgent need for reconnaissance level recording of vegetation throughout South Africa. Information acquired by conventional means at present is not timely, consistent, accurate or economical and remote sensing programmes such as Landsat can improve this situation. Satellite remote sensing products are ideally suited to an operational scale of 1:250 000.

Simple techniques of analysis will probably be used for some time to come owing to the restrictions involving advanced techniques. Computer analysis will at some time in the future hold its rightful place in the study of ecological processes in the semi-arid regions, especially in the field of environmental monitoring. To date, few computer-assisted methods have become operational despite the fact that such methods theoretically make better use of the data.

These studies have repeatedly shown that the use of Landsat imagery in no way replaces the need for adequate ground reference data, regardless of the analysis techniques employed. Satellite imagery will, however, replace the conventional use of aerial photography to a large extent.

In most instances, vegetation ecologists using Landsat imagery are not aware of the full potential of the data and do not have an intimate understanding of the techniques of analysis and evaluation. The remote sensing analysts, who possess these skills, most often lack the environmental knowledge and thus the data is not put to optimum use. There is a need for an integrated educational programme which is freely available to all potential users of satellite data. Education in both the visual and numerical techniques of analysis is an economically wise investment.

There is no doubt that Landsat data has already broadened the horizon of plant ecology in this country. In time this will no doubt result in the elimination of the current emphasis on extreme, local, idealistic and individualistic studies and give proper emphasis to the ecosystem approach. It must be concluded that the production of reconnaissance scale vegetation maps from the visual interpretation of Landsat FCC imagery at a relatively low cost is a reality in any part of South Africa.

PAPER 5A NEW METHOD OF VEGETATION ANALYSIS AND MAPPING USING LANDSAT FALSE COLOUR COMPOSITE IMAGERY

Quick and reliable methods of obtaining spatial information on vegetation are required for planning purposes. At present there seems to be a lack of urgency in this regard and it has become necessary for vegetation data to be collected on an *ad hoc* basis. A vegetation map provides a valuable basis for any environmental management programme. Vegetation delineation on the basis of hue, texture and pattern of Landsat imagery has been shown to be a cost-effective technique for obtaining mappable units. This paper discusses a method of vegetation classification and mapping based on the landscape concept and using the visual interpretation of Landsat false colour composite imagery. Vegetation description on its own, however, is inadequate when using Landsat imagery as a mapping tool. The collection of ground reference data should be in accordance with the environmental attributes responsible for the spectral classes depicted on the image.

The landscape approach considers each parcel of land to be unique and classifies each on the basis of a complex of attributes that are applicable to the purpose of the map. The attributes generally used are land form, soil and vegetation. While the method proposed in this paper is orientated towards the collection of vegetal data, the concept is based on similar criteria. There is a good comparison between broad ecological classifications and landscape maps. The advantage of classification and mapping based on ecological regionalization is the close linkage of the units with their respective biotypes.

The study described in Paper 1 showed that these landscape units are real. Furthermore, it was shown that soils, geology, terrain morphology and climate, besides vegetation physiognomy, were responsible for the spectral cover classes. The approach to classification and mapping of the vegetation units resulted in an integrated survey of all these attributes at each sample site. Subsequent to the study described in Paper 1, two other areas (Prieska-Postmasburg and Vanwyksvlei-Copperton) were mapped at the

reconnaissance level of vegetation mapping. The method used is outlined here briefly.

In both cases summer imagery was chosen from dates approximately three to four weeks after good general rains had fallen. The images were delineated manually into spectral cover classes. This procedure was executed on the image itself. The Landsat image was then prepared for field investigation by the accurate positioning of the latitude and longitude grid on the image. This procedure did not result in a precise, geometrically corrected image, but rather constituted the accurate superimposition of the co-ordinate system on the systematically corrected, edge-enhanced image.

Using the Landsat image and 1:250 000 topographical maps, a field route was plotted in advance. To a large extent this route was dictated by the spatial patterns of the image. Previous studies had shown that it was not necessary to criss-cross a spectral cover class thoroughly and the route was planned so as to cut into the spectral cover class and pass as near the centre as possible.

Field trips, which took place during mid- to late summer, were undertaken. Field work and satellite image interpretation took place simultaneously. The basis of the scale of survey was the 1:50 000 topographical map. The scale of mapping dictated the size of vegetation pattern recognized and the image had already been delineated tentatively at this scale. Initially the spectral class boundary was checked to ensure that a change in landscape attributes occurred at that position. A sample site near the centre of the cover class was chosen for detailed investigation. All sample sites were required to portray the potential of the vegetation. Site records included soils type, geological type, terrain morphology and vegetation structure and floristics.

On completion of the central sample, the field route continued towards the opposite boundary of the same cover class. Notes were made on pertinent environmental information. Finer delineations of the image were done in the field. After the area had been thoroughly surveyed in this manner, and the image delineated, data synthesis took place in the laboratory. The classification stage consisted of two pseudo Braun-Blanquet tables, viz. floristic composition and structural and abiotic attributes. This resulted

in an hierarchical classification scheme in which the ground cover classes were grouped at three levels, viz. ecological regions; ecological regions divided into vegetation types and vegetation types divided into major plant communities. Ground cover classes represented this latter level and occasionally unique plant communities. These were indicated on the image as delineated spectral cover classes. The basic units of the vegetation map were thus identified. The resultant vegetation map was an integrated landscape map with an emphasis on vegetation. A legend and descriptive key accompanied the map.

The Landsat-based maps are true vegetation maps, but with supplementary ecological information on attributes which have given rise to the vegetation units and their distribution. Vegetation units are a function of the integrated environmental attributes of the landscape unit. The method outlined in this paper has validity for the identification of nature conservation priority areas, as well as the demarcation of acceptable heterogeneous farming units. Broad ecological processes may also be identified.

Disadvantages of this method are the subjectivity of analysis and the fact that prior ecological knowledge of the region is required. Despite this, it is felt that the method will allow for the mapping of large areas of South Africa within a few years, the lack of manpower notwithstanding. The time and effort saved in field work offset the initial cost of acquiring imagery. The Landsat image replaces the need for aerial photographs. There is no doubt that Landsat imagery offers an excellent method for generating sound, simplified and inexpensive 1: 250 000 vegetation-landscape classification maps of the extensive semi-arid regions of South Africa.

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## PAPER 1

# A VISUAL INTERPRETATIVE INVESTIGATION OF LANDSAT IMAGERY TO DETERMINE THE VEGETATION MAPPING CAPABILITIES OF MULTISPECTRAL DATA IN THE SEMI-ARID REGIONS OF SOUTH AFRICA

### 1. INTRODUCTION

It is the purpose of this paper to examine the issues that arise in the visual interpretation of Landsat data for the analysis of natural vegetation on a regional basis.

The techniques employed and discussed are described as an aid to other researchers who are involved in similar regional or subregional vegetation studies with limited time, manpower and funds.

The McGregor Museum (Kimberley) is responsible for a wide field of research in the Northern Cape: a vast, underpopulated, semi-arid region of approximately 170 000 km<sup>2</sup> (15,45% of the surface area of South Africa) (Fig. 1). Central to the wise use of natural resources of this region is the identification of the geographic areas which support different vegetation types. In the research into the structural and floristic classification of the vegetation, great difficulty is being experienced in mapping the distribution of the numerous vegetation units accurately. Aerial photographs, used in several large test areas, have been found to be too detailed and confusing, numerous and costly, as well as outdated, to be contemplated for total coverage of such a large study area. Boyle et al. (1988) mentioned the costs involved: the basic cost of satellite imagery is 200 times less than black and white aerial photography at a scale of 1:24 000 and 50 times less than colour infra-red photography at a scale of 1:20 000. The Northern Cape and Great Karoo are vast areas and involve approximately 24 vegetation maps at a scale of 1:250 000. The success of the system in one map could result in its use for the remaining 23 maps, with considerable savings in manpower, cost and time - not to mention the increased accuracy of the mapped vegetation units.

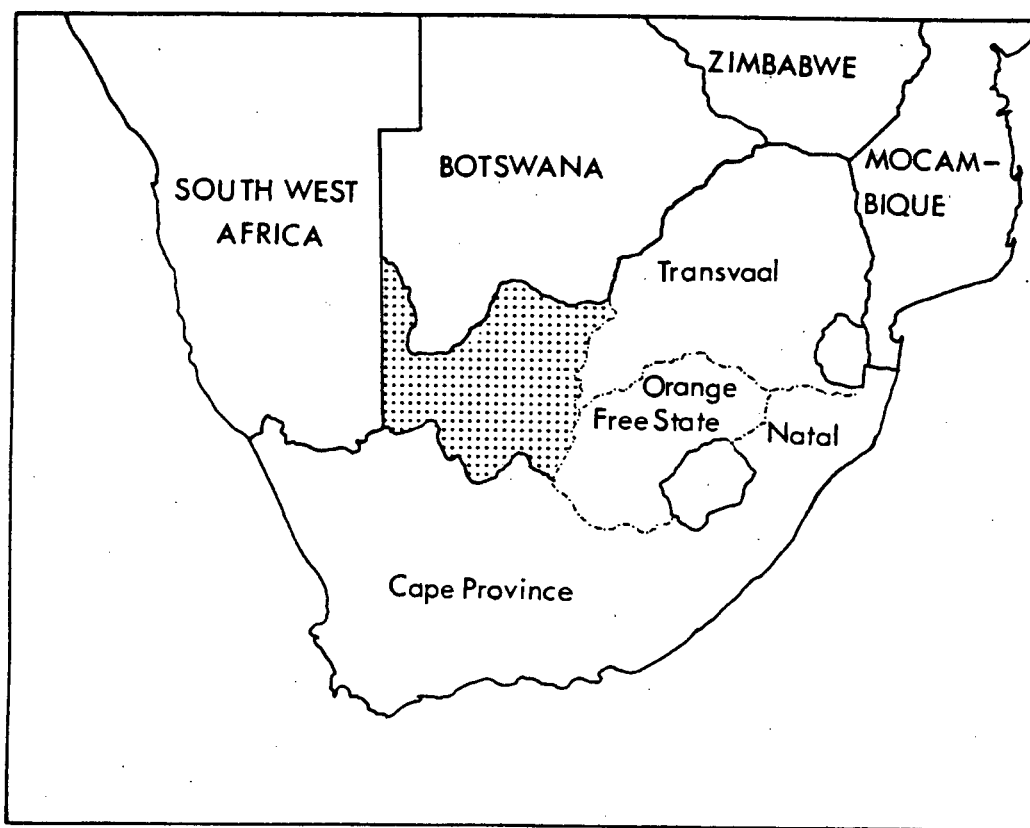


Figure 1 The Northern Cape, a vast, sparsely populated, semi-arid region of approximately 170 000 km<sup>2</sup> (15,45 % of the surface area of South Africa).

The approach in this study has been to seek a basic understanding of the relationships between the reflectance characteristics of the Landsat data representing these semi-arid landscapes and the vegetation of these landscapes. If relationships do exist, use of Landsat data by application of "translation" methods may lead to increased classification and mapping accuracy and a simultaneous increase in the rate of production of information. Information can be derived from data only to the extent that the data are accurate, timely, unexpected and relevant to the subject under consideration (Cooper 1986). These characteristics of data, and especially that of relevance, are tested here.

## 2. VEGETATION MAPPING AND CLASSIFICATION USING CONVENTIONAL METHODS

### 2.1 FIELD SURVEYS

After a survey of relevant literature, the first step was the consideration of the biotic and abiotic environmental parameters to be selected for measurement in the field. Selection was based on the findings of a pilot study (Crowe et al. 1981) from which an eclectic field data sheet was derived (Appendix 1). These environmental parameters were viewed as essential to an ecologically relevant investigation of the structural and floristic attributes of the semi-arid, Northern Cape vegetation.

Aerial photographic investigation followed the development of the field data sheet. In general, panchromatic aerial photographs for the Northern Cape are outdated. Early aerial photographs cover all seasons of the year, making comparisons difficult, and the quality is most variable. The study area was subdivided according to patterns evident on 1:30 000 black and white (B/W) aerial photographs. Patterns on the aerial photographs were transferred to 1:50 000 topographical maps for ease of correlation with field patterns. Transference made use of a variograph, which either magnifies or reduces the scale of aerial photographs.

All field surveys were undertaken during the summer, rainy seasons of 1979/80 to 1982/83 in vegetation of reasonably good condition. In order to facilitate species recognition or herbarium identification, and for the recording of potential vegetation of a given vegetation unit, all vegetation overutilized by domestic stock or game, or disturbed in any other way (fire, lack of adequate rainfall, etc.), was purposefully not surveyed. Selection

of area for investigation was not systematic (grid reference) but rain-dependent, i.e. 2 to 3 weeks after at least 15 to 25 mm of rain had fallen. This allowed for full expression of structural and floristic potential of vegetation - an important factor in terms of correct identification of plant material to species level and for the standardization of the state and composition of the vegetation. Unfortunately, this sampling method led to a patchy distribution of surveyed areas although with time (some years) unsampled areas would eventually be surveyed. (The area investigated using Landsat imagery had been relatively well sampled by the author: a reason for its selection.)

The patterns transferred from the aerial photographs were compared with the vegetation patterns observed in the field. These aerial photograph patterns were used purely as a guide in the demarcation of vegetation units for mapping purposes, and did not take precedence over what was found in the field. If patterns correlated with minimally heterogeneous (relatively homogeneous) field units, sample sites were subjectively selected and positioned, and the vegetation floristically (using the Braun-Blanquet method) and structurally sampled. Samples were thus stratified (each 1:50 000 topographical map was investigated), centralized and non-random (sample plots were subjectively positioned as close as possible to the centre of the vegetation unit in vegetation of a moderate to high successional stage of development). Major vegetation units were recognized purely on physiognomic merits, minor vegetation units on physiognomic- and dominant floristic merits and major plant communities mainly on floristic merits. Sample plots were quadratic and varied in area according to the structure and species composition of the vegetation. The distribution of the field layer species (average totals range between 60 and 100 species for a given vegetation unit) is frequently dependent on the structural (vertical and horizontal) pattern of the height-dominant species, especially in open shrubland and woodland formations. Voucher specimens are housed in the McGregor Museum KMG Herbarium. B/W photographic prints and colour transparencies of each plot were taken. Soil and geology samples were collected and identified.

## 2.2 LABORATORY INVESTIGATION

In the initial phytosociological investigation sample sites were transferred to 1:250 000 topographical maps. Soil and geology samples were identified

and classified. The vegetation (floristics) and other environmental parameters were shuffled manually to obtain the identification and distribution of ground-based vegetation units. With reference to the aerial photograph-derived vegetation patterns, as well as other supportive information, such as Land Type/soil, geology and terrain morphology maps, transparent overlays at a scale of 1:250 000 were prepared using 1:250 000 topographical maps as base maps. The final product was a vegetation map depicting the distribution and relationships of the major and minor vegetation units in the study area.

### 2.3 INITIAL OBJECTIVES AND SOME PROBLEMS ENCOUNTERED

Two of the main objectives of the phytosociological survey of the Northern Cape were:

- a) the production of a vegetation map which could be used by agricultural planners and nature conservation authorities, among others
- b) the provision of a framework within which other biological surveys could be carried out at the same or larger scales.

The severe drought of the 1980's and consequent reduction of funds called an untimely halt to the detailed phytosociological studies. Since sufficient knowledge and experience of environmental parameters had been gained and a preliminary analysis of the data testified to the presence of at least 21 ecological regions, a tentative vegetation map was produced. In terms of the objectives stated above, these ecological regions were subdivided into vegetation units and major plant communities. The accuracy of these unit boundaries was unsatisfactory.

While more than 500 completed sample sites could be placed with confidence into major plant communities, difficulty was experienced with collating the unit boundaries which had been drawn on aerial photographs and topographical maps. The paucity of sample sites in certain areas required extrapolation in order to delineate boundaries, and the problem encountered now was how to devise a method of extrapolation given the constraints of funding, manpower and time. A synoptic view of larger areas was required. In this regard small scale colour aerial photographs would have been suitable but these were not available. Landsat imagery was the most promising possibility to investigate. Wessels & van Vuuren (1986) reported that terrain features not

easily noticeable on large scale aerial photographs are clearly visible in the synoptic view offered by Landsat imagery.

### 3. LANDSAT IMAGERY AS A POSSIBLE TOOL IN VEGETATION MAPPING

Remote sensing is concerned with the acquisition of information about a portion of the earth's surface by using sensing devices operated from a remote location (Hoffer 1971; Johannsen & Barney 1981). The Landsat series of satellites evolved in concept from the photographic observations of earlier Mercury and Gemini orbital flights (Anon.[a] 1986). These flights indicated the potential success of recording the earth's resources from space. The use of Landsat imagery as an alternative form of remote sensing was investigated. The Landsat MSS (Multispectral Scanner) system was designed primarily for the study of surface vegetation and geology (Shannon & Anderson 1982). Field surveys have shown a positive correlation between vegetation units and the soil/geology complex in the semi-arid regions of South Africa. An additional positive characteristic of Landsat imagery as an alternative form of a remote sensing medium is the synoptic view and the relatively large surface area covered by a single image (185 km x 185 km). The excellent quality of Landsat imagery stimulated further investigation.

#### 3.1 REMOTE SENSING OBJECTIVES

Not many South African researchers have considered the potential role of satellite remote sensing in their work. As Johannsen & Barney (1981) stated, a possible reason is that, in earlier years, people were led to believe that satellite capabilities were beyond what they transpired to be. On occasions, satellite products were used because they were flashy, multi-coloured classification maps. Today, sensible use focuses on the use of remote sensing products in conjunction with conventional sources such as ground reference data, aerial photographs and supportive information maps. Use of satellite imagery in this country has been initiated mainly during the last 5 to 10 years. Further growth can be expected with emphasis, in the near future, on the monitoring of changes in surface cover. The potential use of the NOAA satellites, with a resolution of 1 km<sup>2</sup> and 4 km<sup>2</sup> and fly-overs twice a day, seems to have been overlooked with regard to monitoring the landscape.

The major objective in the use of remote sensing techniques was the facilitation of the meaningful recognition of broad patterns of vegetation units already structurally and floristically identified and researched in the field. The speed and accuracy of the final mapping phase had to be increased, especially the delineation of vegetation unit boundaries. It must be made clear that Landsat imagery was not used as a replacement for the gathering of floristic and structural data. This study was initiated not to test various methods of mapping nor primarily to discover which vegetation units are present, but to test Landsat imagery as a tool for the accurate positioning of vegetation boundaries in the semi-arid regions of South Africa.

### 3.2 REMOTE SENSING ASPECTS TO BE INVESTIGATED

As the title of this paper indicates, it concerns the "visual", "eyeballing", "image orientated" or "manual" approach to the analysis and interpretation of satellite "photographs"/images. Curran (1983) pointed out that the term "photograph" refers to those pictures taken with a camera, while "image" is preferred here, as it refers to those pictures produced by electro-optical or radar sensors. An investigation concerning the "digital", "computerized" or "numerically orientated" approach is discussed in Paper 2. It was felt that to commence the pilot study with visual interpretation techniques and then move on to computer classification would be sensible in terms of experience, cost and manpower requirements.

The Landsat visual interpretation pilot study investigated the following:

1. The delineation of the geographical distribution and extent of major vegetation types.

This involves pattern recognition (i.e. correlation of Landsat surrogate information with field identified and classified vegetation units) in two ways:

- a) field identification prior to visual interpretation
- b) field identification and visual interpretation simultaneously

2. Imagery selection.

This involves three aspects:

- a) comparison of black and white single band with false colour 3-band imagery
- b) selection of imagery with respect to season and time of season
- c) scale of imagery

### 3.3 LANDSAT TECHNICAL DETAILS

#### 3.3.1 THE LANDSAT SERIES OF SATELLITES

The Landsat series of satellites was designed specifically for the monitoring and management of the earth's renewable and non-renewable resources (Botha 1982). The first satellite was launched as early as 1972 and was known as ERTS-1 (Earth Resources Technology Satellite) (Mercanti 1973). Since an appropriate name-change in 1975, this satellite has been known as Landsat 1. Landsat 2 was launched in 1975 (Sabins 1978, Anon 1982) but was suspended in 1982 (SENSOR 1982), at which stage the SAC (Satellite Applications Centre) was unable to produce imagery from Landsat 3. Landsat 3 was launched in 1978. Landsat 4 (also referred to as Landsat D prior to launch-date) was launched in 1982 (Anon.[b] 1986). Landsat 5 was launched in March 1984 (Anon.[b] 1986). Landsat 4 and 5 are the bridge between the old and the new satellite systems (Anon.[a] 1986). Landsat 1 retired in January 1978, Landsat 2 in July 1983 and Landsat 3 in September 1983 (although imagery from these satellites can still be obtained from SAC archives). Landsat 4 and 5 continue to provide consistent MSS data to receiving stations. Landsat 1, 2 and 3 all had identical orbital parameters, making direct comparisons between these satellite products of different dates possible. The same applies to Landsat 4 and 5. The SAC commenced receiving MSS data direct from the Landsat satellites on an operational basis in December, 1980 (Botha 1982). The SAC (Satellite Applications Centre) was formerly known as the SRSC (Satellite Remote Sensing Centre) and is part of the Division of Microelectronics and Communications Technology (DMCT) of the National Institute of Telecommunications. Landsat is now the property of EOSAT. The price of products is expected to rise with a market economy in operation. NASA has relinquished control.

#### 3.3.2 MAJOR COMPONENTS OF LANDSAT

Fig. 2 gives a general idea of the structure of the Landsat series of satellites. Of major importance for this report is the multispectral scanner system (MSS) on the satellite.

##### MULTISPECTRAL SCANNER SYSTEM

The sensor on Landsat which is responsible for the collection of digital data used in the production of imagery is the multispectral scanner (MSS). The multispectral scanner system, with its high quality data, has proved to be the key to the success of Landsat. The Landsat MSS records in four spectral bands of reflected sunlight (Fig. 3): band 4 (0,5  $\mu\text{m}$  to 0,6  $\mu\text{m}$ ), band 5

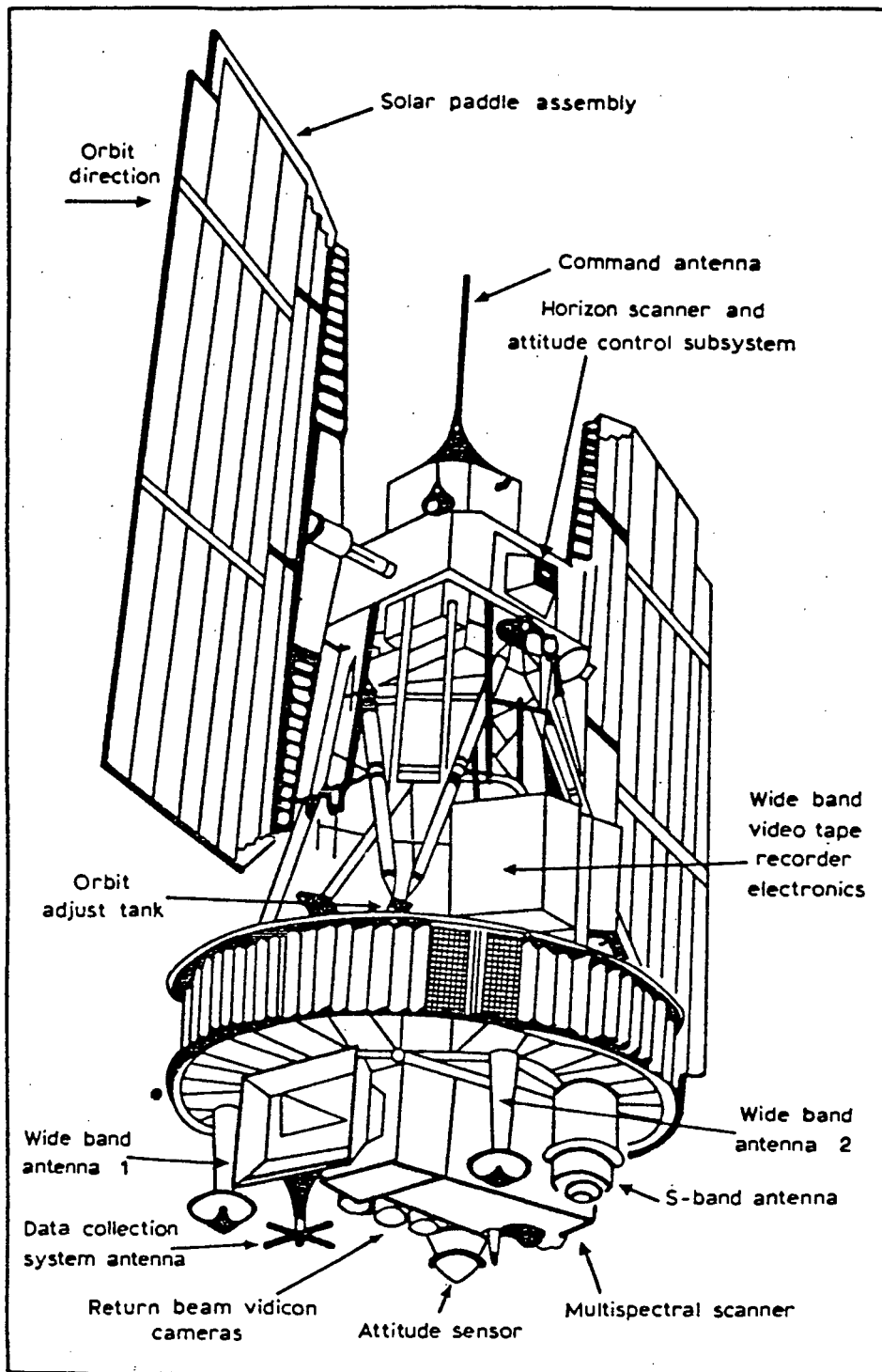
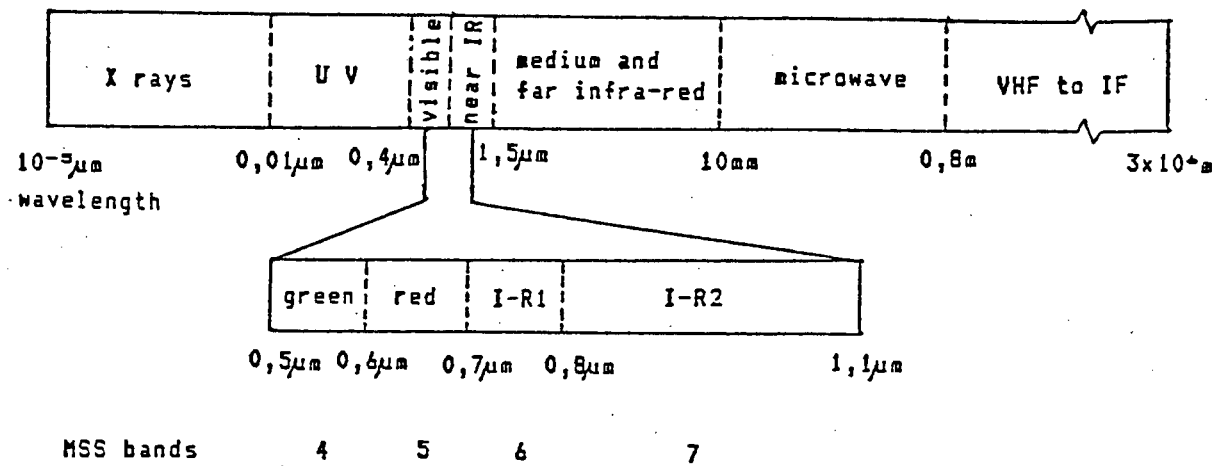


Figure 2 Diagram of Landsat 1 and 2 showing major components. Of importance to this study is the multispectral scanner. (From NASA 1976 in Sabins 1978).



**Figure 3** Portion of the electromagnetic spectrum showing the region of reflected solar energy recorded by the Landsat sensors. (From Jarman 1981).

(0,6  $\mu\text{m}$  to 0,7  $\mu\text{m}$ ), band 6 (0,7  $\mu\text{m}$  to 0,8  $\mu\text{m}$ ) and band 7 (0,8  $\mu\text{m}$  to 1,1  $\mu\text{m}$ ), corresponding to visible green, visible red and two invisible infra-red channels (Anon.[a] 1986). Landsat 3 also recorded in a fifth band, the thermal infra-red region of the electromagnetic spectrum (10,4  $\mu\text{m}$  to 12,6  $\mu\text{m}$ ) (Turner 1987). Landsat 4 and 5 have the above four bands as well as the thematic mapper (TM) which has a further 7 bands, three of which are in the spectral range of the MSS. The TM is a more advanced scanner, having more spectral, radiometric and geometric sensitivity (Anon.[a] 1986). The new spectral coverage regions are the blue (0,45  $\mu\text{m}$  to 0,52  $\mu\text{m}$ ), the higher reflective infra-red (1,55  $\mu\text{m}$  to 1,75  $\mu\text{m}$  and 2,08  $\mu\text{m}$  to 2,35  $\mu\text{m}$ ) and the thermal infra-red (10,40  $\mu\text{m}$  to 12,50  $\mu\text{m}$ ) (Anon.[a] 1986). The new blue band has been included primarily for the measurement of stress in agricultural crops. Black and white imagery consists of any one of the 4 MSS bands, while false colour composite imagery normally consists of a combination of bands 4, 5 and 7 (Newton 1984). Multiband MSS imagery is usually displayed by deleting band 6 and displaying band 4 along the blue axis, band 5 as green and band 7 as red along the orthogonal set of co-ordinates. This gives rise to the familiar "false colour" presentation (Lasserre et al. 1983; Taylor 1974).

The MSS scans with an oscillating mirror. Each band has six individual sensors, thus giving a total of 24 detectors for the 4 bands. The MSS scans in a direction perpendicular to the satellite's forward track, i.e. west to east. Image data are recorded only during the east-bound mirror sweep (Turner 1987). Data are recorded continuously along the orbit path at a rate of six lines simultaneously in each of the four spectral bands for each mirror sweep. These data are transmitted to the Satellite Applications Centre (SAC) ground-receiving station at Hartebeeshoek for recording as digital numbers on magnetic tape (Fig. 4). The tapes are processed to produce images (Landsat scenes) such as those used in this study, or in computer compatible tape format. With an array of detectors, the multiband sensor registers the intensity of energy (electromagnetic radiation) reflected or radiated by features and objects on the earth's surface. This reflected energy is passed into a data stream, is recorded and stored in digital format and subsequently transmitted to earth.

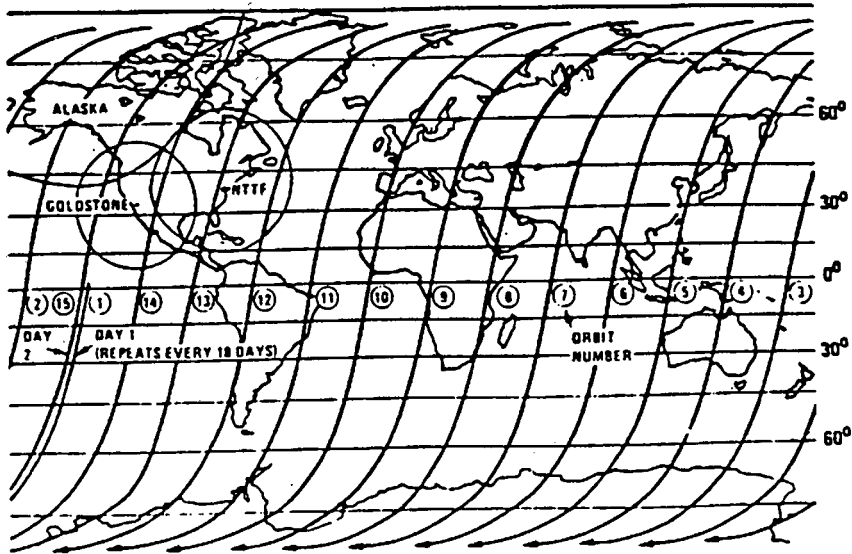
### 3.3.3 LANDSAT ORBITAL PARAMETERS

Positioned at a nominal altitude of 918km (Landsat 1 to 3) or 705 km (Landsat 4 and 5), Landsat has a near circular, near polar, sun-synchronous orbit (Gonzales & Sos 1974; Mercanti 1973; Sabins 1978; Botha 1982). Being sun-synchronous, South Africa's ground surface is scanned at approximately 09h45 in the same north-south direction and at the same place with each passover. Unfortunately, Landsat 4 and 5 have different orbital parameters, thus imagery is not directly comparable with that of Landsat 1, 2 and 3 (SENSOR 1983). The new orbital parameters were dictated primarily by the desire to achieve compatibility with the NASA space shuttle for retrieval purposes (Anon.[a] 1986)

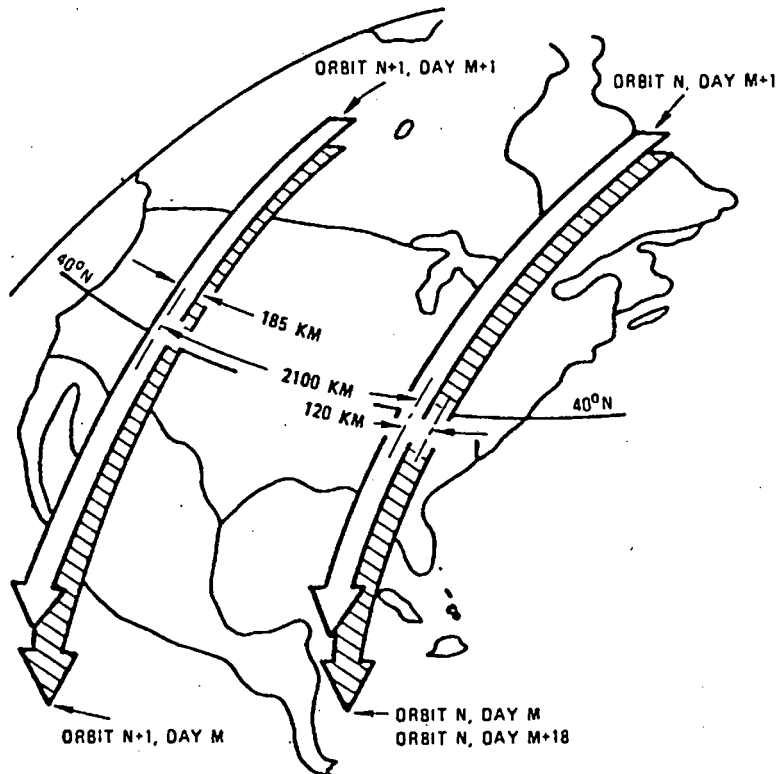
The satellite (Landsat 1, 2 and 3) crosses a given latitude at the same sun-time (Graetz et al. 1980). The satellite orbits the earth approximately 14 times per day (every 103 minutes) with approximately 2800 km between orbits at the equator and takes 18 days (251 revolutions) to return and repeat-scan the same path as day one (Fig. 4) (Mercanti 1973; Sabins 1978; Botha 1982). Any given locality is potentially "photographed" 20 times a year. The daily coverage swath, the distance between adjacent ground tracks, is shifted approximately 160 km westwards each day. The coverage pattern provides 15% to 30% crosstrack overlap (Fig. 5). The satellite travels and records north to south (the northbound orbits cover the dark side of the earth) with a perfect north-south, along-track match of the continuous strip-scans of individual same-date images, though processing allows approximately 10% overlap between north-south frames.

### 3.3.4 LANDSAT IMAGERY

Each revolution of the satellite produces a continuous strip of information 185 km wide. The satellite's forward motion provides a continuous sequence. This strip is processed into portions representing a ground size of 185 km x 185 km (Sabins 1978) and each is referred to as a Landsat image, or more correctly, a Landsat scene representing a broad regional coverage of 34 000 km<sup>2</sup> with uniform scale and minimal distortion (Mercanti 1973; Sabins 1978; Graetz et al. 1980) (Fig. 6). The images or scenes ("image" refers more to what it consists of or how it is produced, and scene refers more to the dimensions) are shaped like parallelograms rather than rectangles, owing to the offset of the scan lines approximately 13 km to the west to compensate for the earth's west to east rotation during the 28 seconds



**Figure 4** Typical daytime Landsat orbital paths for a single day. The satellite orbits the Earth 14 times per day, shifting westwards by 160 km each day so that every 18 days the ground trace is repeated. (From NASA 1976 in Sabins 1978).



**Figure 5** Landsat orbits on successive days. Note the ground coverage pattern sidetrack overlap. (From Sabins 1978).

required to scan the 185 km x 185 km area of the earth's surface (Sabins 1978). There is thus a tilt of the image with respect to the north-south line (Graetz et al. 1980).

### 3.3.5 LANDSAT IMAGE STRUCTURE

The image is divided into many tiny equal areas, called pixels or picture elements, arranged in regular lines and columns (Sabins 1978) (Fig. 7) and representing individual spectral measurements proportional to the intensity of the reflected energy received by the satellite's sensor (Fig. 8). Calibration of the MSS enables voltage measurements to be converted into milliwatts per square centimetre per steradian which are then converted to values in digital counts (Robinove 1981). The brightness of each pixel has a numerical potential ranging from 0 to 255 which could be represented as a range of tones (black and white, single-band imagery) or colours (false colour composite imagery). A Landsat scene is comprised of approximately 3240 pixels per line and 2286 lines in one spectral band, giving approximately 7,5 million pixels per band (Hancock & Fish 1984). This results in approximately 30,5 million reflectivity values for all bands (Fig. 7). The Landsat resolution is dictated by the size of the pixel or ground resolution cell, which is the basic unit of the image. A ground resolution cell covers an area of 79 m x 79 m, but due to a cross-track overlap of pixels the effective size of the pixel is 56 m (east-west) x 79 m (north-south) (Hancock & Fish 1984; Jarman 1981). The Landsat 4 and 5 thematic mappers have a resolution or instantaneous field of vision - IFOV - of 30 m, a linear geometric resolution of about 2,6 times that of the MSS. Therefore the IFDV of the TM is a 30 m x 30 m pixel as compared with the 79 m x 79 m pixel of the Landsat 1 to 3 MSS and the 82 m x 82 m pixel of the Landsat 4 and 5 MSS.

A further satellite, not belonging to the Landsat series, but nevertheless worthy of mention, is the French Space Agency's (CNES) SPOT 1. SPOT 1 was launched in February 1986. Imagery is available from the SAC but was not considered in this study owing to the small scene size (60 km x 60 km) and the high resolution (great detail) of 10 m in panchromatic mode and 20 m in multispectral mode. A brief review of example documentation and imagery suggests that the scale (1:25 000 to 1:100 000) and resolution of SPOT 1 will be ideal for detailed to semi-detailed vegetation/landscape investigations of localized areas of interest (Anon.[d] 1986; Botha 1987;

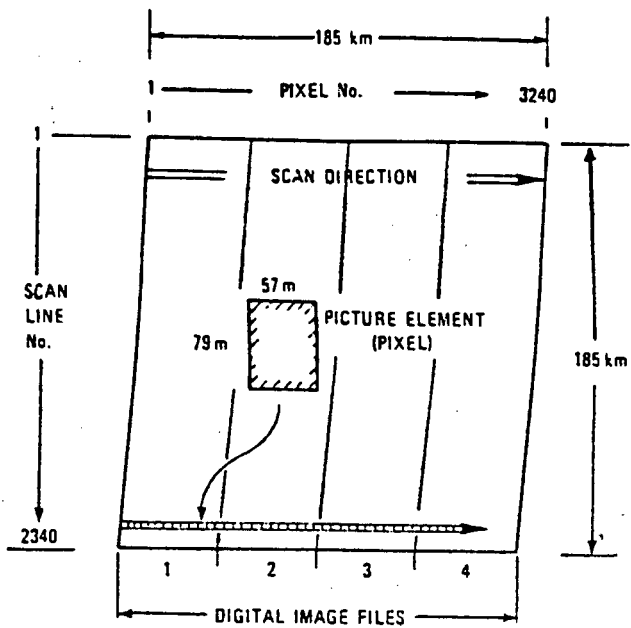


Figure 7 The Landsat MSS image picture elements (pixels) are arranged into a reference system of scan lines and columns. (From Sabins 1978).

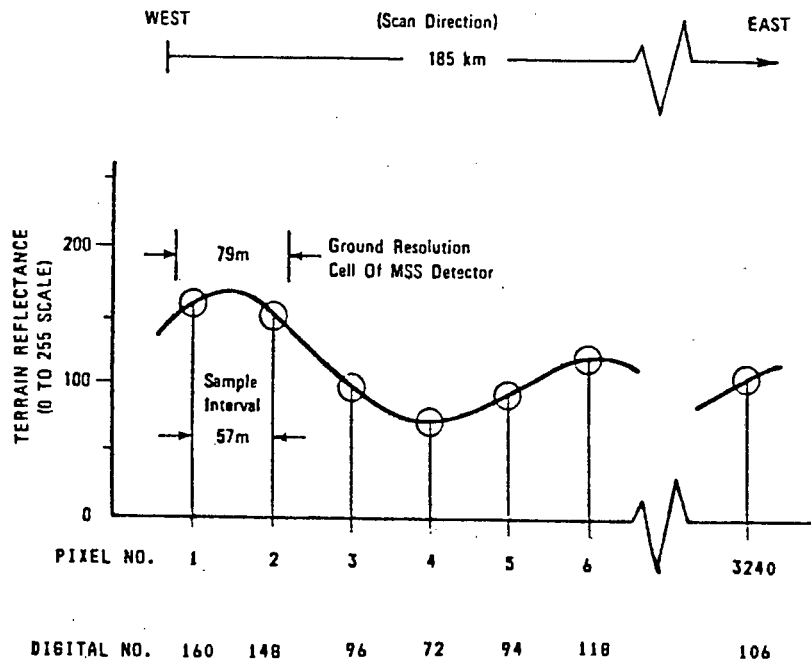


Figure 8 Plot of terrain reflectance along a Landsat scan line. The reflectance curve is sampled to generate the digital number for each pixel. (From Sabins 1978).

Bullard 1983). Although SPOT 1 imagery at a scale of 1:200 000 and 1:400 000 is available, the small scale format greatly reduces the potential of the data in visual interpretation.

The reasons for the initial interest and subsequent investigation of Landsat hardcopy imagery for the mapping of natural vegetation units in the semi-arid regions of South Africa have been introduced. Basic Landsat technical details have been given so that the reader has a minimum of basic information on the functioning of the system. This has been necessary mainly owing to the important fact that Landsat imagery, unlike aerial photography, portrays surrogate reflectance information on the terrain cover of the earth's surface and not real world objects. Patterns are purely reflectance patterns and are not necessarily depictions of vegetation pattern. The success or failure of the use of Landsat imagery as a tool in the classification and mapping of natural vegetation units rests solely on the favourable correlation of Landsat surrogate units with the field vegetation units. Accordingly the practical and not theoretical applications are discussed in this paper.

#### 4. THE TEST AREA

Although approximately 55% of the Northern Cape has been sample-surveyed using the Braun-Blanquet (Mueller-Dombois & Ellenberg 1974) phytosociological method (floristics) and an eclectic method (structure) for vegetation classification and mapping purposes, a smaller test area was required to test the usefulness of Landsat imagery as a tool in ecological regionalization studies. It was decided that a single Landsat scene would form the basic dimensions of the test area.

With regard to the location of the test area, or more accurately the choice of Landsat scene, certain criteria had to be met. The most important of these was the inclusion of as many of the ecological regions/major vegetation units as possible, as well as maximum diversity, complexity and variability in soil forms, geological formations and terrain morphology. For interpretation purposes, ground reference data for the test area had to be excellent. The Landsat scene, ID: 2250-07345 WRS: 185-79 (World Reference System), 15 January 1982, was chosen for detailed investigation (Fig. 9, Plate 1). This area (34 000 km<sup>2</sup>) is the meeting point of several extensive and less extensive ecological regions and contains a variety of soil-

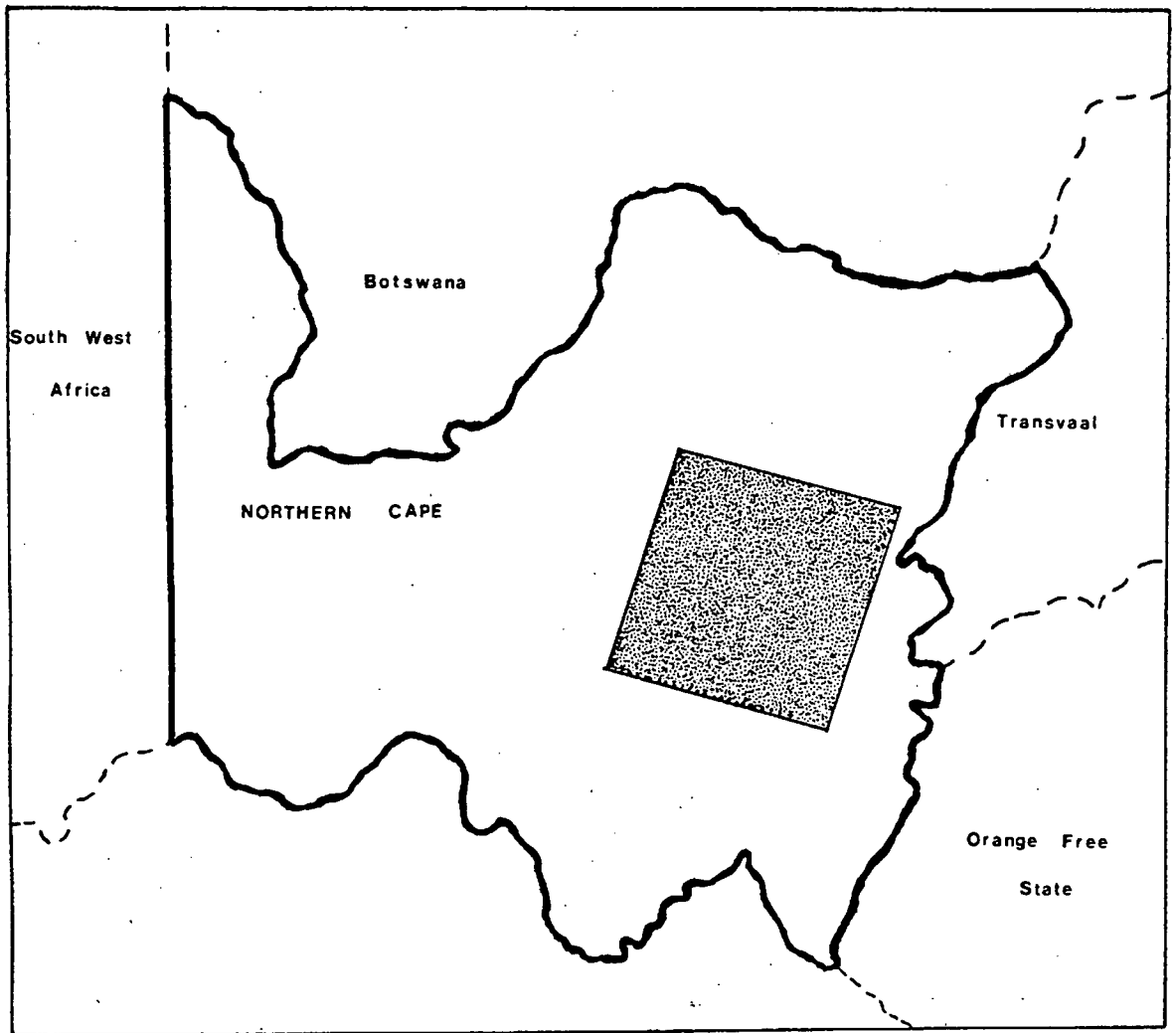


Figure 9 Map of the Northern Cape showing the position of the study area, Landsat scene WRS 185-79.

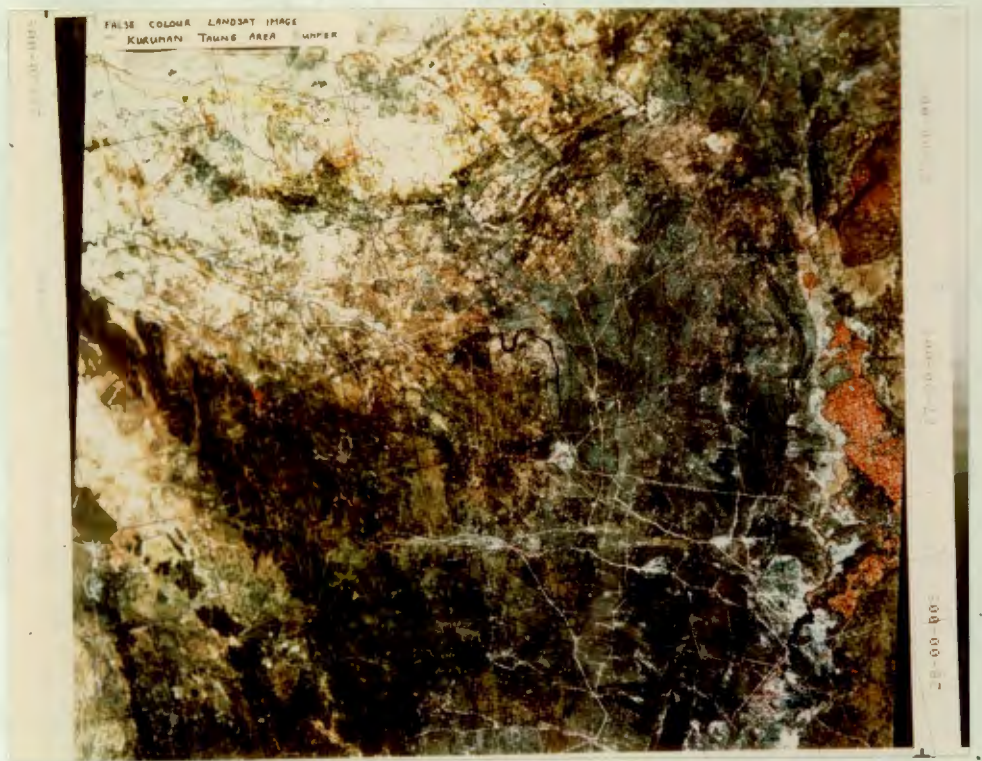


Plate 1 False colour composite of Landsat image WRS 185-79, ID: 22550-07345, 15 January 1982 (summer).

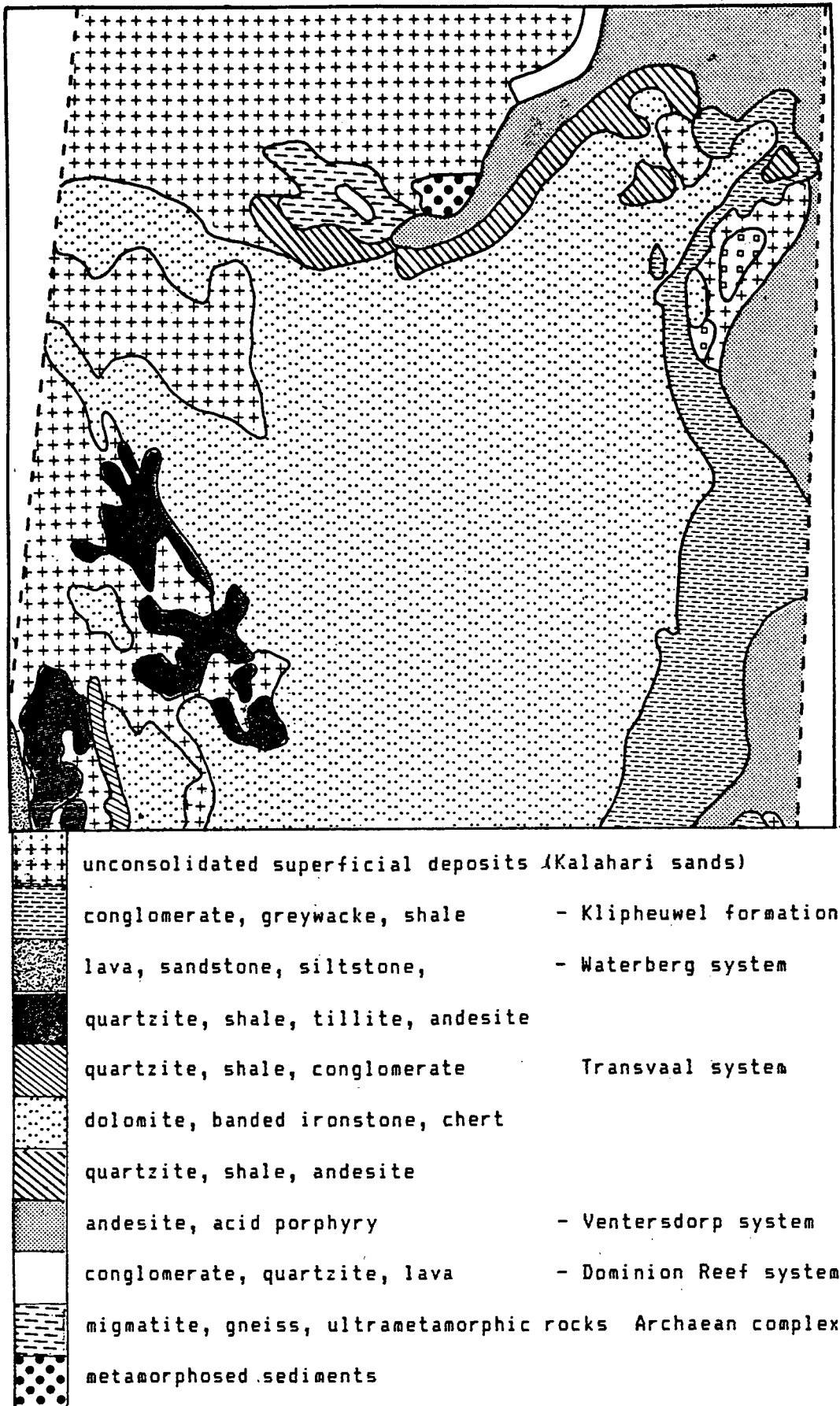
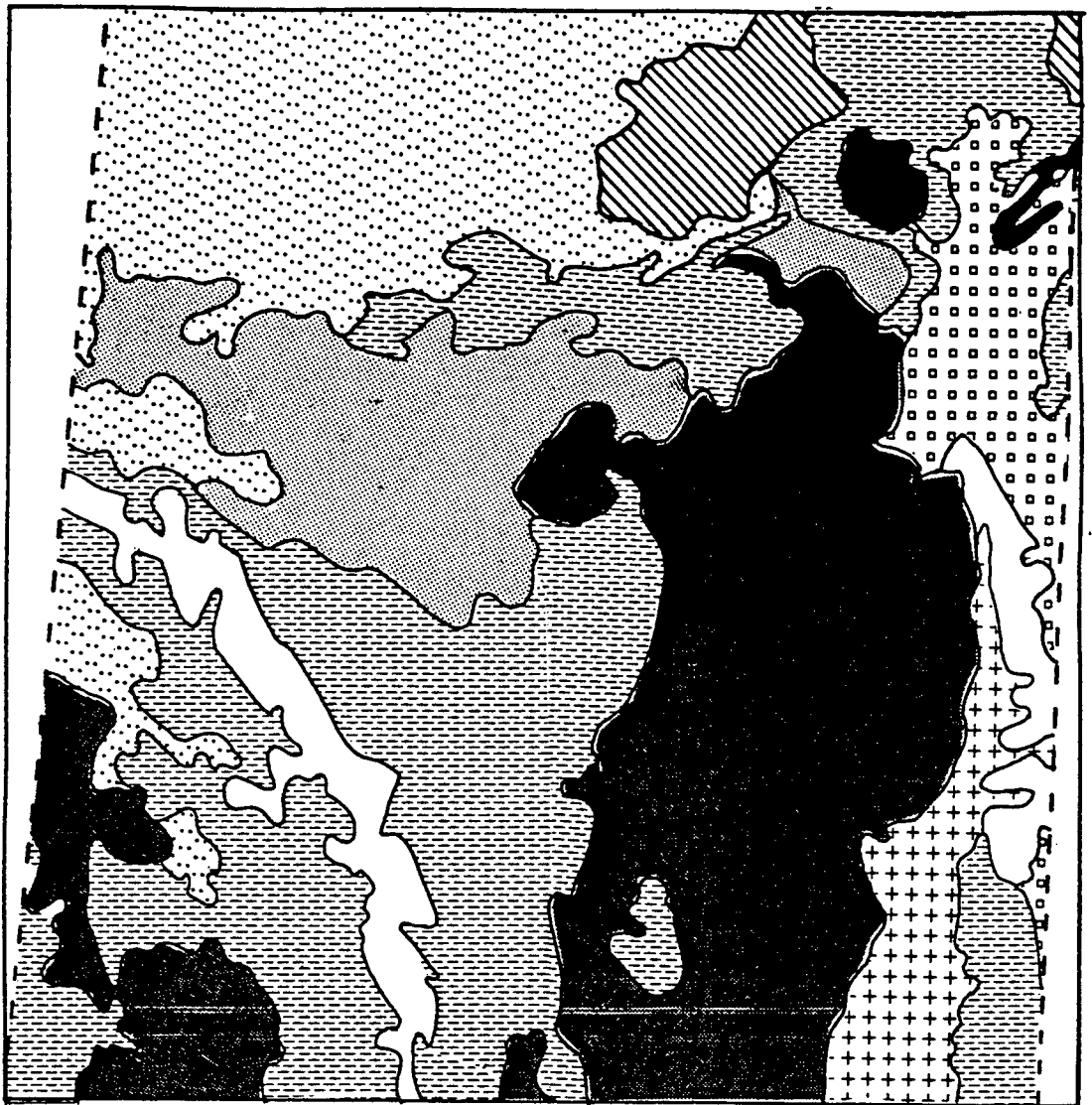









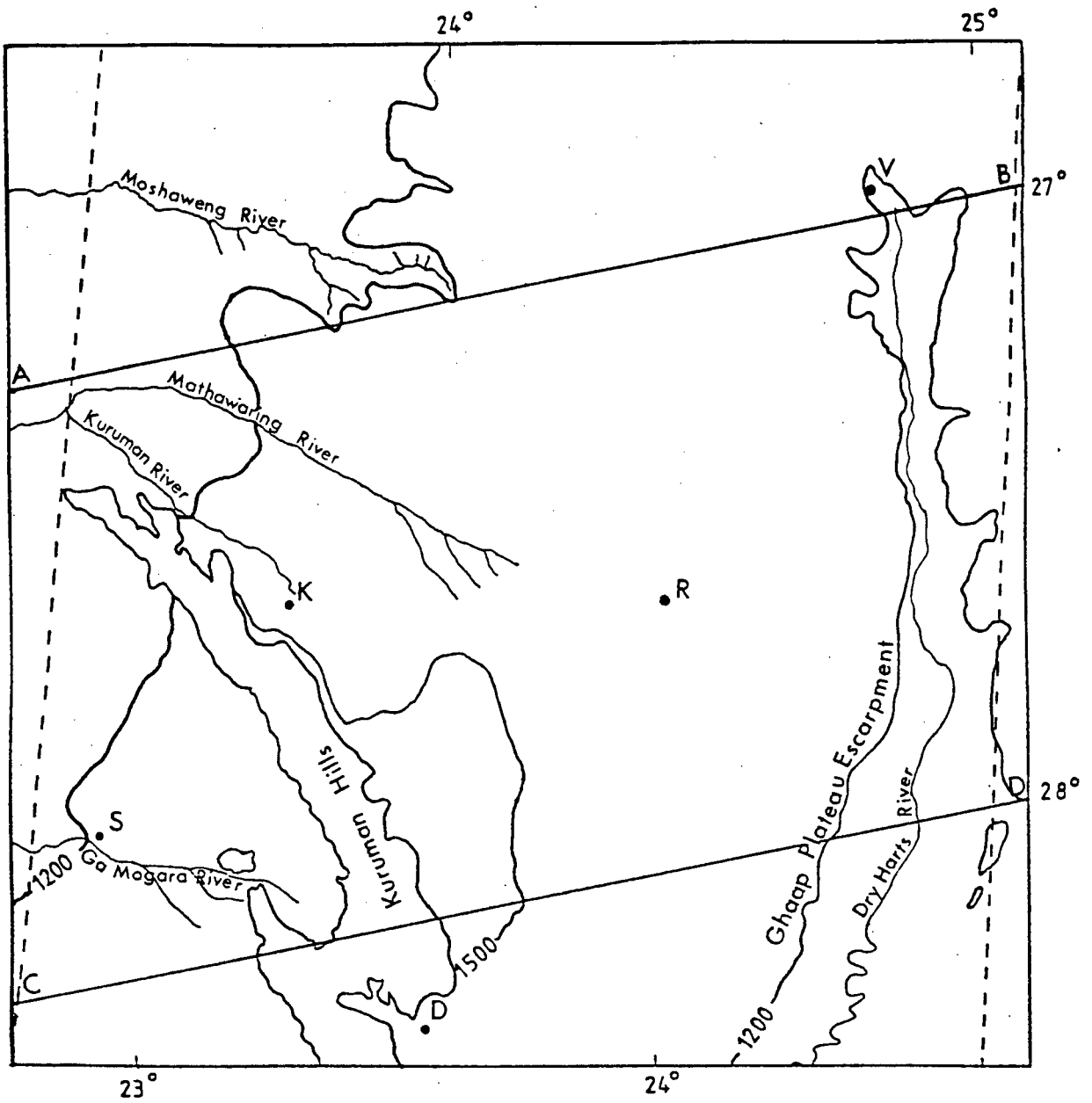


Figure 10 Map showing the simplified geological formations in the study area, Landsat scene WRS 185-79.



-  red and yellow, high base status, usually 15% clay
-  red, high base status, 300mm deep (no dunes)
-  red, high status, 300mm deep
-  rock areas with miscellaneous soils
-  yellow, high status, usually 15% clay
-  eutrophic: red soils widespread
-  undifferentiated
-  lime generally present in entire landscape
-  one or more of: vertic, melanic, red, structured diagnostic horizons

**Figure 11** Map showing the simplified land types (based primarily on broad soil patterns) in the study area, Landsat scene WRS 185-79.



**Figure 12** Map showing the simplified terrain morphology of the study area, Landsat scene WRS 185-79. (K = Kuruman, V = Vryburg, S = Sishen, R = Reivilo, D = Danielskuil)

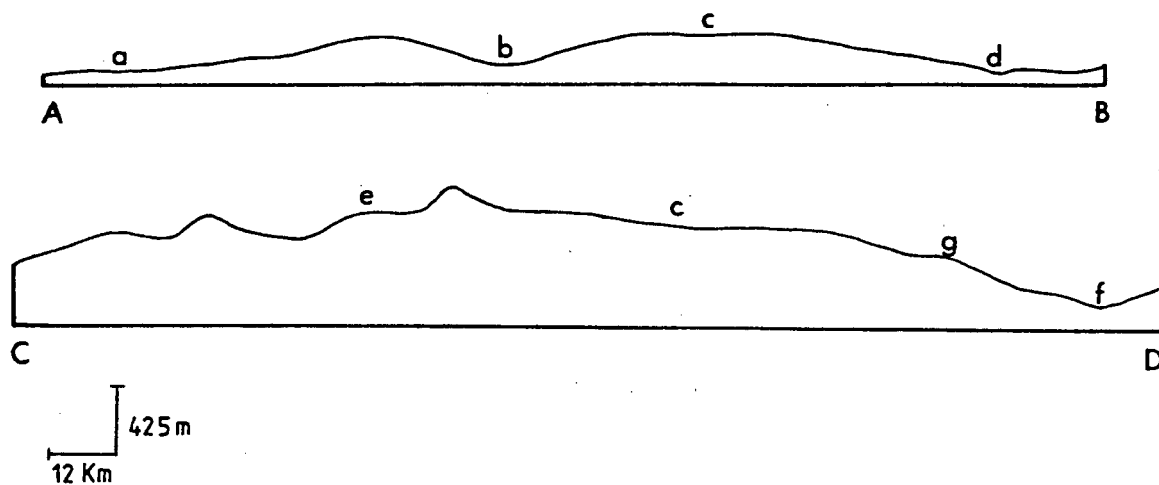


Figure 13 East-West traversing profile sections A-B and C-D (see Figure 12) depicting major terrain morphological units in Landsat scene WRS 185-79. (a = Matlhawaring River, b = Moshaweng River, c = Ghaap Plateau, d = dry Hartz River, e = Kuruman Hills complex, f = Hartz River, g = Ghaap Plateau escarpment)

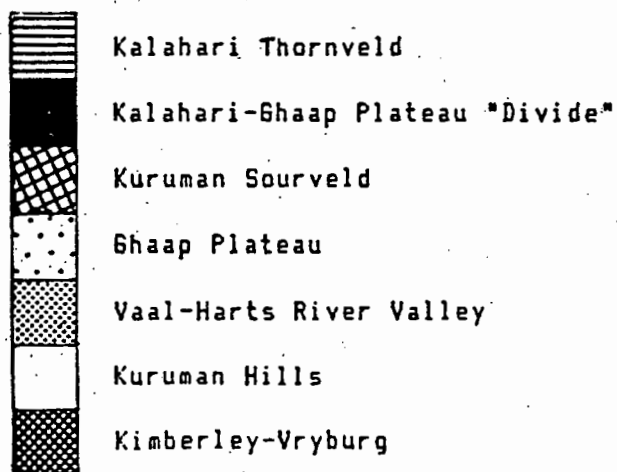
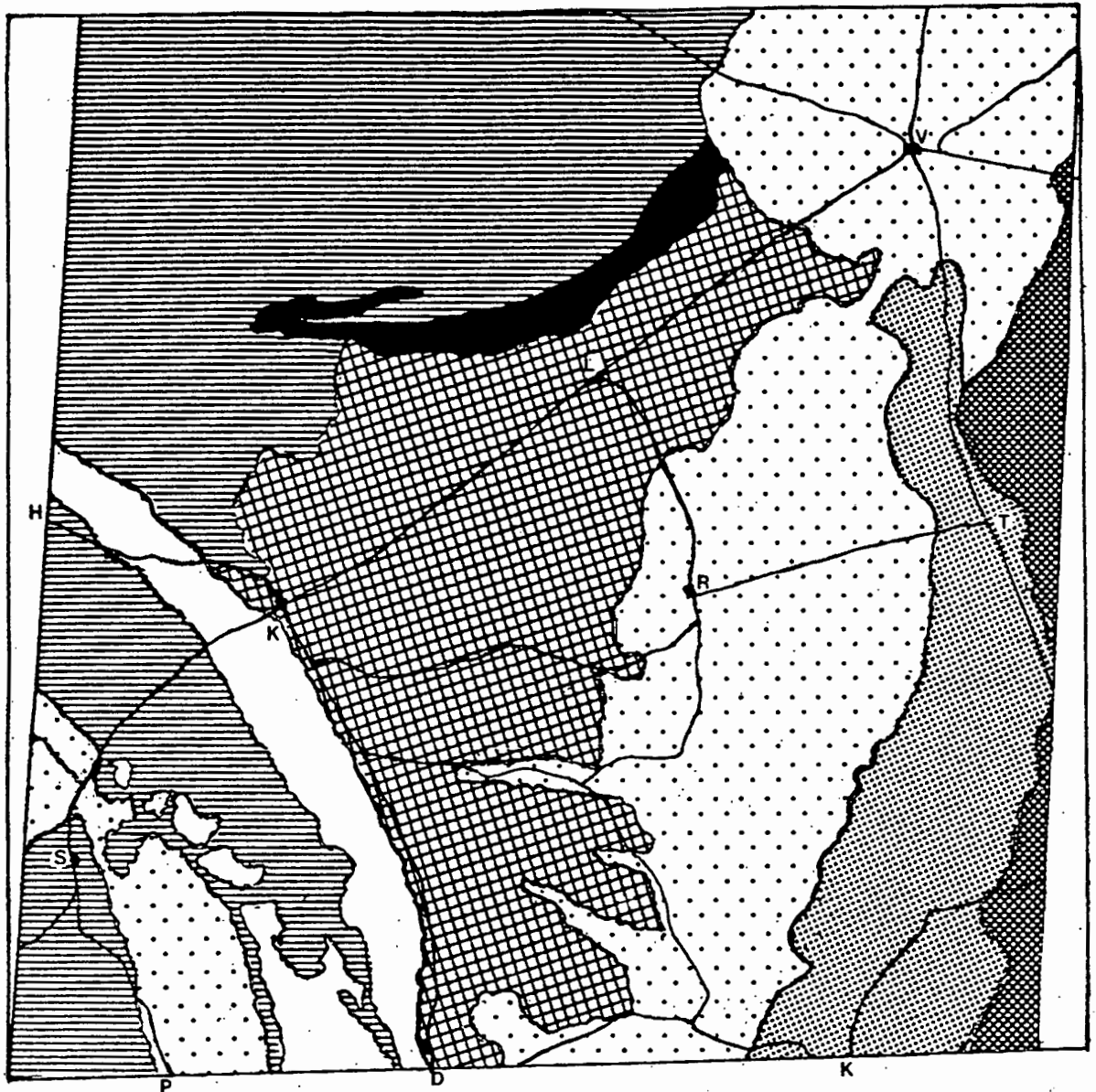


Figure 14 Constituent ecological regions of Landsat scene WRS 185-79.

geological types and topographical features (Figs. 10 to 13). The major ecological regions are shown in Fig. 14. An ecological region is defined as a landscape unit with a distinct combination and recurring pattern of topography, soil, geology and vegetation, and is relatively uniform throughout.

#### 4.1 THE KALAHARI THORNVELD ECOLOGICAL REGION

This region (Plate 2) consists of gently undulating, aeolian, red to yellow, high base status Kalahari sands of presumed Pleistocene age. These unconsolidated, superficial deposits, often reaching great depths, frequently overlie calcrete bedrock. Altitude is approximately 1100 m to 1200 m above sea-level. The area is traversed by several east-west draining, dry riverbeds. The vegetation is mainly sparse to open, low to short *Acacia* woodland. Other structural groups and formation classes cover a small area. Towards the north-east the vegetation becomes a more closed, short, mixed shrubby woodland (*Acacia erioloba* and *Tarchonanthus camphoratus*). Occasional stretches of closed, short *Terminalia* woodland occur on yellow, leached, dystrophic sands, especially on high-lying areas. The grassy, dry riverbeds are covered by closed, low to short grasslands and the sandy floodplains by very sparse to open, dwarf to low, grassy woodlands (*Acacia haematoxylon*).

#### 4.2 THE KURUMAN HILLS ECOLOGICAL REGION

Most of the rolling to rugged terrain of the Kuruman Hills and outliers is surrounded by loose, deep aeolian Kalahari sands. This ecological region (Plate 3) ranges in height from 1300 m to 1800 m (lower slopes to higher peaks). Deep kloofs and broken, twisting drainage lines run outwards to the east and west of the hills. The soils are highly litholitic and often lack depth. Geologically, the region consists mainly of banded ironstone and chert, with occasional, rugged, quartzitic outliers to the west. The vegetation consists of several structural types belonging to two formation classes:

- a) the slopes, kloofs and broken peaks are covered by intermediate to closed, tall to high, mixed, woody shrublands and thickets (*Euclea* spp., *Rhus* spp., *Maytenus* spp. and *Tarchonanthus minor* among others)
- b) the gently-rounded to plateau-like, high-lying areas are covered by short, closed, sourish grasslands with emergent, tall woody shrubs.



Plate 2 Typical vegetation of a major plant community of the Kalahari Thornveld Ecological Region. Low, open to intermediate, mixed *Acacia* woodland on red Kalahari sands. Height 3 - 6 m. Common species: *Acacia erioloba*, *Tarchonanthus camphoratus*, *Grewia flava*, *Boscia albitrunca*, *Schmidtia pappophoroides*, *Eragrostis* spp., *Aristida* spp., *Stipagrostis uniplumis*.

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Plate 3 Typical vegetation of a major plant community of the Kuruman Hills Ecological Region. Short, closed grasslands on shallow, rocky soils and scattered woody shrubs on rocky outcrops. Height 300-450 mm (grasses) and 1 - 2 m (woody shrubs). Common species: *Themeda triandra*, *Rhynchelytrum* spp., *Elionurus argenteus*, *Eragrostis* spp., *Cymbopogon* spp., with emergent shrubs: *Tarchonanthus camphoratus*, *Rhus* spp., *Euclea* spp. and *Boscia albitrunca*.

#### 4.3 THE KURUMAN SOURVELD ECOLOGICAL REGION

This vast region, triangular in shape, has its widest front in the north, stretching from 30 km west of Vryburg approximately 125 km. This ecological region narrows in the south, but always borders on the eastern edge of the Kuruman Hills. The terrain is similar to the Ghaap Plateau Ecological Region, but more undulating. The shallow, brown, base soils are frequently mixed with chert and banded ironstone pebbles and chips, and overlie dolomite bedrock. The widespread absence of calcrete, so common in the adjacent Ghaap Plateau, is of importance.

In general, the physiognomically open vegetation consists of sour grasslands to open shrublands. Towards the west near the Kuruman Hills and in the north central regions the vegetation consists of an extensive mosaic of short, closed grasslands (with emergent short, woody shrubs, especially *Diospyros austro-africana*, and emergent high, woody shrubs and short trees such as *Diospyros lycioides*, *Protasparagus laricinus* and *Acacia karroo*) and very sparse to open, short to tall, grassy shrublands (mainly the low, rounded hillocks and superficial outcrops of chert and jaspellite pebbles and stones, where the shrubs are *Tarchonanthus camphoratus* and *Lebeckia macrantha*).

The extensive "impure" sourish grasslands are a surprising sight in the normal woodland and shrubland formation classes of the Northern Cape. Near the Kuruman Hills, the vegetation is more dense (Plate 4), consisting of intermediate to closed shrublands with typical species: *Tarchonanthus camphoratus*, *Rhus ciliata*, *R. tridactyla* and some of the woody species of the Ghaap Plateau Ecological Region. In the vicinity of Kuruman (to the north and south), the vegetation is not as pure because some Kalahari sands have been blown in from the north and have been arrested by the Kuruman Hills. Some woody species are found here and *Acacia mellifera* has obtained a foothold.

#### 4.4 THE GHAAP PLATEAU ECOLOGICAL REGION

As the name implies, this region (Plate 5) is generally flat with occasional low, undulating areas in the west to where this ecological region abutts the Kuruman Sourveld. Occasional outliers stretch as far west as the Kuruman Hills. Over its length and breadth, altitude varies minimally (1350 m to 1400 m north-south and 1300 m to 1500 m east-west). Soils vary from red to



Plate 4 Typical vegetation of a major plant community of the Kuruman Sourveld Ecological Region. Tall, open shrublands on brown soils shallowly overlying dolomite. Height 2 - 3 m. Common species: *Tarchonanthus camphoratus*, *Rhus ciliata*, *R. tridactyla*; grasses: *Themeda triandra*, *Cymbopogon plurinodis*, *Elionurus argenteus*, *Heteropogon contortus*, *Setaria* spp.



Plate 5 Typical Vegetation of a major plant community of the Ghaap Plateau Ecological Region. Medium-high, intermediate to closed shrublands on red-brown loamy soils overlying calcrete and occasional dolomite. Height 1,5 - 2,5 m. Dominant species is *Tarchonanthus camphoratus* with *Rhus ciliata*, *Grewia flava*, *Maytenus heterophylla* and occasional *Acacia karroo*, *Rhus lancea*, *Olea europaea* ssp. *africana*. Common grasses are *Themeda triandra*, *Cymbopogon plurinodis*, *Eragrostis* spp.

reddish brown, depending on the proximity of the Kalahari region and on the type of parent rock. They are loamy, of high base status and very shallow (100 mm to 300 mm). The entire landscape is covered with calcrete which is exposed throughout the eastern areas. Transecting the Ghaap Plateau are linear "faults", consisting of pure, soft, crumbly calcrete - 1 m to 5 m in height, 10 m to 100 m in width and 2 km to 15 km in length. These "faults" are remarkably straight and often cut across each other. The western areas contain occasional low, rounded hillocks of chert and jaspellite pebbles which belong to the Kuruman Sourveld. Shallow, pan-like, grassy "depressions" are dotted throughout the Ghaap Plateau. These contain dolomite bedrock superficially covered with a thin layer of calcrete, but are often exposed. Infrequent linear vlei/marsh communities are ecologically important. During a good summer rainfall season, water drains from these and off the eastern edge, over the Ghaap Plateau Escarpment (Plate 6). The drop in altitude towards the eastern edge frequently begins as a series of exposed dolomite "steps", often many kilometres apart but becoming closer as they near the escarpment. The escarpment drops from 1300 m to 1100 m and slopes are gradual to very steep. In places abrupt to precipitous edges drop 50 m or more over a horizontal distance of several metres. The soils are chocolate brown, very shallow, with dolomite slabs and rugged breaks commonly exposed. This region is, for the most part, inaccessible to vehicles. This natural boundary between ecological regions is infrequently cut by deep, often mesic, kloofs. Pure calcrete or breccia tufas "flow" over the escarpment, forming sheer cliffs. Many small fountains bubble out at the base of the escarpment, and in years of excessive rainfall, there are many small seasonal waterfalls.

The major portion of the Ghaap Plateau, for the south central to the north north-east of the test area, consists of an extensive, uniformly structured, intermediate to closed, high shrubland (*Tarchonanthus camphoratus* - *Rhus ciliata* community with emergent *Acacia karroo* (in the north); *Rhus pyroides*, *R. ciliata* and *Olea europaea* ssp. *africana* (in the south) - high, woody shrub and short tree species). The south central portion also contains extensive mosaic patches of sparse to open, low to short, park-like, grassy woodlands (*Olea europaea* ssp. *africana* and/or *Rhus pyroides*, *R. tridactyla*). Shallow, pan-like, grassy "depressions" consist of short, closed grasslands, fringed with short, open to intermediate woodlands (*Rhus lancea* and *Olea europaea* ssp. *africana*). The linear vlei/marsh mesic



Plate 6 Typical vegetation of the Ghaap Plateau escarpment near Taung. Flowing streams are an uncommon sight. Tall, closed, mixed, shrubby woodland to thicket formation classes. Height 4 - 8 m. Common species (from base to upper edge): *Rhus lancea*, *Celtis africana*, *Rhus pyroides*, *R. undulata*, *Nuxia gracilis*, *Ziziphus mucronata*, *Acacia karroo*, *Ficus cordata*, *Rhigozum obovatum*, *Acacia tortilis*, *A. mellifera*, *Euclea undulata*, *Tarchonanthus* spp. and many more.



Plate 7 Typical vegetation of a major plant community of the Kalahari-Ghaap Plateau "Divide" Ecological Region. High, open to intermediate, mixed woody shrubland on shallow, rocky soils and sands. Height 2 - 4 m. Common species: *Acacia robusta*, *A. erioloba*, *A. tortilis*, *A. mellifera*, *Euclea undulata*, *Grewia retinervis* and *Rhus tenuinervis*. Occasional sandy pockets contain *Terminalia sericea*. Grasses typical of Kalahari.

drainage lines consist of short to tall, closed, reedy grasslands (Cyperaceae, *Typha capensis*) fringed with tall, mixed, woody shrublands or thickets (*Tarchonanthus camphoratus*, *T. minor*, *Euclea* spp., *Rhus* spp., *Maytenus heterophylla*, *Olea europaea* ssp. *africana* and many others - a species-rich community). Raised, linear, calcrete "faults", with a high water table, support a species-rich, high, closed, mixed, woody shrubland, occasionally reaching thicket proportions (*Acacia karroo*, *Rhus lancea*, *Diospyros lycioides* and many of the species mentioned above). The escarpment, as well as the area covered by the step-like rise to the true plateau, supports a structurally and floristically varied and species-rich vegetation. Generally, the vegetation can be described as a tall to high, intermediate to closed, mixed, woody shrubland (*Olea europaea* ssp. *africana*, *Acacia tortilis*, *Euclea undulata*, *E. crispa* ssp. *ovata*, *Rhus lancea*, *R. tridactyla*, *R. undulata*, *Maytenus heterophylla*, *M. undata* (steep kloofs), *Tarchonanthus camphoratus*, *T. minor*, *Ficus cordata* (escarpment and steep kloofs), *Rhigozum obovatum*, *Ehretia rigida* and many more). Short to tall thickets form around fountains and where kloofs and drainage lines open at the base of the escarpment. An outlier of the escarpment-type vegetation (without the kloofs, drainage lines and steep slopes) lies in the south-west corner of the test area.

#### 4.5 THE KALAHARI-GHAAP PLATEAU "DIVIDE" ECOLOGICAL REGION

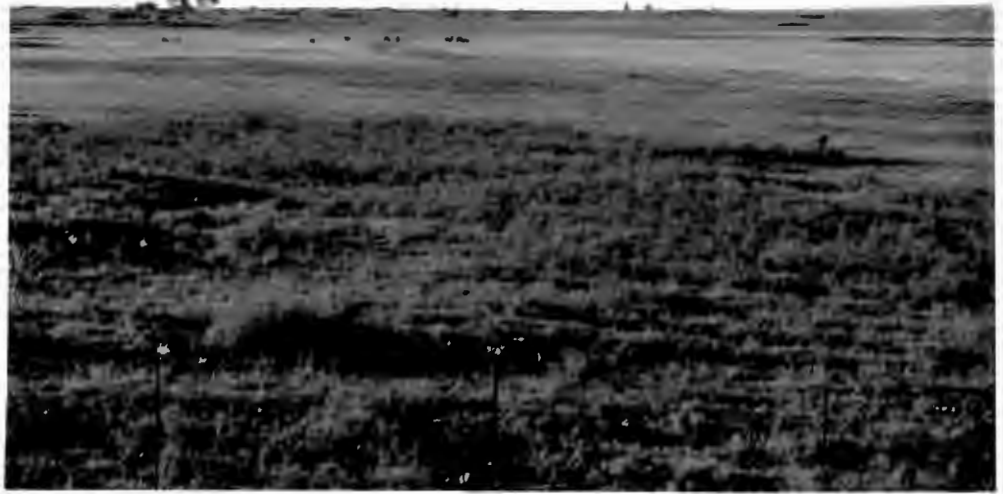
North of the Ghaap Plateau, and running from east to west, is an ecological region which is largely transitional between the Kalahari and the Ghaap Plateau (Plate 7). Topographically the region consists of an east-west ridge (1200 m to 1350 m). There are several geological formations which have been largely overburdened with aeolian Kalahari sands (the lower and middle slopes). In places these sands have encroached into the north central areas where they shallowly overlies calcrete bedrock and result in the grass layer belonging to the Kalahari Thornveld Ecological Region, while the large shrub and tree species typically belong to the Ghaap Plateau Ecological Region. This shows that the Kalahari Thornveld is still naturally and of geological time scale proportions, shifting in a south south-east direction. The ridge, complex in terms of vegetation (structure and floristics), soil, geology and terrain morphology, could rightly be separated into a number of small ecological regions, but for the purposes of this paper, have been combined into a single region. Soils are yellow, of high status and usually have 15% clay content. Geological types (often interbedded) consist of

parallel ridges of quartzite, andesitic lava, migmatite, gneiss and ultrametamorphic rocks with metamorphosed sediments. Lower and middle slopes to the south of the ridge are calcrete-covered, with some aeolian Kalahari sands. The north-facing slopes of this ridge are gradual to steep while the south-facing slopes are gentle and much more extensive.

The view from the ridge, facing northwards, is of a drop to the Acacia Kalahari Thornveld stretching deep into Botswana. The boundary to the north is abrupt. The ridge along the east-west length is structurally and floristically very varied and ranges from short, closed grasslands on quartzite ridges (with emergent *Vangueria infausta*, *Acacia robusta*, *Boscia albitrunca* and *Terminalea sericea* on rocky outcrops), to short, sparse to open, mixed, grassy woodlands on sand-filled, metamorphosed ridges (*Acacia robusta*, *Terminalea sericea*, *Acacia erioloba*, *Rhus undulata*), to intermediate to closed, tall to high, mixed, woody shrublands on rocky, andesitic ridges (*Euclea undulata*, *Acacia tortilis*, *Tarchonanthus camphoratus*, *Acacia mellifera* and many more). The south-facing, gentle and extensive slopes support several structural types of which the two dominant forms are low, intermediate woodlands (*Acacia mellifera*-dominant), and tall, intermediate to closed shrublands (*Tarchonanthus camphoratus* with emergent *Acacia karroo* and *A. mellifera*). There are occasional patches of Kalahari Thornveld on deep, red aeolian Kalahari sands which have been blown over the ridge and have settled in pocket depressions and valleys over time.

#### 4.6 THE VAAL-HARTS RIVER VALLEY ECOLOGICAL REGION

To the east of the Ghaap Plateau the terrain drops from the escarpment (1300 m) to the floor of the north-south orientated Vaal-Harts River Valley (1025 m), which is approximately 10 km (north) to 40 km (south) wide and 110 km long. Only the northern section, i.e. the Harts Valley, falls within the test area (Plate B). This perennial river has its chief catchment to the east of the Northern Cape, but receives some water from the overflow off the Ghaap Plateau escarpment, especially during excessively wet seasons. Much of the soil in the vicinity of the river is alluvial, while outer slopes consist of red, vertic and melanic, structured, high status, shallow soils, especially in the west. To the south, most of these slopes contain calcareous soils, shallowly overlying calcrete bedrock. Also present are conglomerate, greywacke and shale. Within this ecological region (central and south) several steep-sided, dolerite ridges and koppies



**Plate 8** Typical vegetation of a major plant community of the Vaal-Harts River Valley Ecological Region. Short, closed grasslands to sparse, low to medium-high woodlands on alluvial soils and gravels (wide floodplains and lower slopes). Height 200 - 600 mm. Typical alluvial, mesic grasses (*Cynodon* spp., *Chloris virgata*, *Panicum* spp., *Eragrostis* spp.) with emergent *Acacia karroo*, *Ziziphus mucronata*, *Diospyros lycioides*. Outer slopes support medium-tall, shrubby *Acacia* woodlands.



**Plate 9** Typical vegetation of the outer, east-facing slopes of the Vaal-Harts River Valley Ecological Region (below the Ghaap Plateau escarpment). Low, closed woodlands - thickets on calcretes (soils reddish brown but frequently exposed) and conglomerate (red, loamy soils). Some bush encroachment. Height 2,5 - 4,5 m. Common species: *Acacia mellifera*, *A. tortilis*, *Rhus undulata*, *R. tridactyla*, *Boscia albitrunca*, *Cadaba aphylla*. Common grasses: *Eragrostis lehmanniana*, *E. superba*, *E. pseudo-obtusa*, *Enneapogon* spp., *Cenchrus ciliaris*, *Aristida* spp., *Heteropogon contortus*, *Stipagrostis obtusa*, *Sporobolus fimbriatus*.

occur with shale and red, loamy lithosols on the lower, gentle slopes and in the surroundings. In the north, on the outer west-facing slopes, is an area of deep, eutrophic Kalahari sand which is an outlier of the Kalahari Thornveld Ecological Region. This area is intensively cultivated (Vaal-Harts irrigation scheme).

The vegetation, as expected, consists of narrow, longitudinal bands parallel to the Harts River. The riverine and associated vegetation is not well developed and consists of low to short, closed, seasonally mesic grasslands on the alluvium, with emergent short *Acacia karroo* trees and various short to tall shrubs. The river is fringed with a short, mixed woody thicket (*Acacia karroo*, *Diospyros lycioides*, *Protasparagus* spp., *Lycium hirsutum*, *Acacia erioloba* and *Ziziphus mucronata*). The dolerite koppies and ridges support a slope- and aspect-dictated, intermediate, tall to high, mixed woody shrubland (*Tarchonanthus camphoratus*, *Acacia mellifera* and *A. tortilis*). The outer east-facing slopes (Plate 9) consist of intermediate to closed, low to short, mixed *Acacia* woodland (*A. mellifera*, *A. tortilis*, *Rhus undulata*, *Boscia albitrunca*, *Cadaba aphylla*), interspersed with patches of intermediate to closed, tall shrublands (*Tarchonanthus camphoratus*) on exposed conglomerate. The outer west-facing slopes consist of deeper, red, eutrophic soils and support a short, intermediate to closed, mixed shrubby *Acacia* woodland (*A. erioloba*, *A. karroo*, *A. tortilis* and *Tarchonanthus camphoratus*).

#### 4.7 THE KIMBERLEY-VRYBURG ECOLOGICAL REGION

Only the western edge of this ecological region (Plate 10), the Kimberley-Vryburg ridge, is in the test area. This region runs the full eastern length of the test area. This is a low-lying, flat-topped, rocky ridge, dissected by valleys and dry drainage lines. The ridge consists of shallow, red, high base soils and frequently exposed andesitic lava rocks and boulders. Occasional quartzitic ridges also occur. The vegetation consists of an open to intermediate, short to tall, mixed, woody shrubland (*Tarchonanthus camphoratus*, *Rhus ciliata*, *R. leptodictya*, *Acacia robusta*, *A. mellifera*, *A. tortilis*, *Ehretia rigida* and *Boscia albitrunca*), interspersed with sparse to open grassy woodlands (*Acacia tortilis* and *A. robusta*) on higher, plateau-like areas.



Plate 10 Typical vegetation of a major plant community of the Kimberley-Vryburg Ecological Region. Tall, open to intermediate, mixed, shrubby woodlands on red soils overlying andesite lava and dolerite rocks. Height 2 - 5 m. Common species: *Acacia tortilis*, *A. robusta*, *A. mellifera*, *Tarchonanthus camphoratus*, *Boscia albitrunca*, *Grewia flava*, *Aloe* spp. and many of the Ghaap Plateau grass species. Hills and ridges.

The following points are of note:

- a) The descriptions outlined above and the ecological regions depicted in Figure 14 are simplified. All these ecological regions extend beyond the area covered by the image.
- b) More extensive ecological regions lying chiefly outside the area covered by the image have not been included in the descriptions or in Figure 14.
- c) Only major vegetation units within each ecological region have been discussed.
- d) Full details may be found on the 1:250 000 vegetation map (Gubb 1984, unpublished).
- e) The "species" *Tarchonanthus minor*, though not recognized by the National Herbarium, Pretoria, has been recorded as separate from *T. camphoratus*. The author in concurrence with Acocks (pers. comm. 1978; herbarium specimens) has retained this distinction because of marked differences in palatability, habitat, habit, leaf and floral morphology, colour and phenology.

## 5. LANDSAT IMAGERY FOR VISUAL INTERPRETATION

### 5.1 SCALE OF VEGETATION MAPPING, SURVEYING AND REMOTE SENSING

As stated by Küchler (1967) and Edwards (1972), it is essential to understand the relationships and differences between the terms "scale of survey", "scale of remote sensing" and "scale of mapping". The Northern Cape has been poorly classified and mapped (Acocks, pers. comm. 1978) at a scale of 1:1 500 000 (Acocks 1953). A vegetation mapping scale of 1:250 000 was selected as it was considered to be a natural step in mapping detail and it met the requirements of nature conservation authorities and agricultural planners. In a structural and floristic vegetation analysis of 170 000 km<sup>2</sup>, a relatively small scale of study is required. This scale of final map product dictated the scale of surveying (the basic unit in the field survey has been the 1:50 000 topographical map) and the scale of remote sensing (as far as possible). Panchromatic aerial photographs at scales of 1:20 000 to 1:30 000 and Landsat imagery at a scale of 1:250 000 were used. Since the Northern Cape is a semi-arid environment, and the major vegetation units are extensive, a mapping scale of 1:250 000 was found to be practical.

Jarman's (1981) approach was to decide initially on the scale of survey, which dictated the scale of mapping, scale of remote sensing and the

appropriate field sampling procedure. The approach here has been to decide initially on the mapping scale (dictated by the mapping scale of the previous study plus that which is required by end users) and this then dictates the scale of surveying, remote sensing and finally the appropriate field sampling procedure.

#### 5.1.1 SCALE OF SURVEYING

With the mapping at a scale of 1:250 000, a class of vegetation pattern present in the field for surveying must be identified visually. This visual identification is done in the field and with the help of aerial photographs. A reasonable knowledge of the study area and its ecology is important, removing problems such as over- or under-sampling. With experience, the correct scale of pattern recognition becomes relatively easy. The investigator almost subconsciously subdivides and lumps vegetation units at the required scale during field investigation. The extensiveness of units is identified with the aid of aerial photographs and verified in the field at the time of sampling. With semi-detailed to reconnaissance level vegetation mapping of extensive areas, major units are physiognomic units with the same dominant species throughout. Minor units are floristic units (i.e. floristic variation is larger than the physiognomic variation). While in the field, important and/or minor, unmappable, often repetitive units are sampled for classification and descriptive purposes. At a mapping scale of 1:250 000, in an area with rather extensive, repetitive vegetation units, the basic unit on which to record the survey is the 1:50 000 topographic map. Vegetation boundaries are transferred onto the topographic map for field verification and adjustment (derived from the patterns recognized on the aerial photographs). Most often, the aerial photographs (visually interpreted prior to, during and after field surveys) contain more information than will eventually be used for mapping purposes, and relationships between aerial photograph units are difficult to identify prior to field surveys without a good working knowledge of the study area. With the advent of the field surveys, these units are invariably lumped in a meaningful way.

Jarman & Edwards (1972) stated that samples should be non-regular, of low density, recording structural types and dominant floristics, with the aim of the study being the determination of main plant communities/ ecological relations within regions or sub-regions. The scale of surveying should

vary according to the complexity of the vegetation of the area, i.e. the units are more complex and of larger scale in the east of South Africa. There is no disagreement with the aim or the scale of survey suggested by Edwards & Jarman (1972), but in this study total floristics instead of dominant floristics were recorded, owing to the requirements of the end-users. In addition, Acocks (1953 and 1976) recorded total floristics for his 1:1 500 000 scale mapping and vegetation types classification investigation of the veld types of South Africa. There seemed no point in collecting less floristic data than that which is already available for the area even though the area was not investigated extensively in much detail and several ecological regions were not sampled at all. Acocks (1953) did not classify the floristic communities structurally, giving only a brief physiognomic description at best.

#### 5.1.2 SCALE OF REMOTE SENSING AND MAPPING

Jarman (1981) stated that the scale of remote sensing is larger than the mapping scale. The scale difference makes vegetation boundaries very accurate on the final vegetation map. This was done, though for no reason other than that the only aerial photographs available were at a scale of 1:20 000 to 1:30 000. This scale was found to be too large and detailed for reconnaissance level investigation and resulted in too much information which had to be lumped, firstly for field surveys and then again for mapping purposes. While panchromatic aerial photographs, at a scale of 1:30 000, have good resolution, too much detail can prove to be as problematical as too little. Aerial photographs at this scale make interpretation a slow process at the reconnaissance level. Jarman (ibid.) stated that at the reconnaissance level of survey the appropriate aerial photograph scale is 1:40 000 to 1:500 000 (final mapping scale being 1:50 000 to 1:1 000 000). It is now possible (January 1987) to obtain high altitude space shuttle aerial photographs (Anon. 1987). These are available in print, slide and transparency form. Resolution ranges from 40m to 80m (range equivalent to SPOT 1 - Landsat MSS).

In terms of laid-down relationships between scale of surveying, mapping and remote sensing products, the Landsat imagery used to produce a map at a scale of 1:250 000 should be at a larger scale, i.e. 1:50 000 (Edwards & Jarman 1972; Jarman 1981, see Appendix 2). Landsat imagery at this scale is not ideal as the resolution is too crude. Deutsch (1987), using a TM

image at a scale of 1:50 000, successfully investigated geology and ground water in Kenya. (TM has a resolution of 30 m and seven bands of spectral data.) Unfortunately, TM was not available at the time of this study. Zietsman (1982) used a 1:100 000 scale false colour composite for analysis of regional land-use patterns. Schreier et al. (1982) reported that scales larger than 1:100 000 result in highly variable planimetric accuracies. It was found that Landsat imagery at the same scale as the final map product (1:250 000) was quite acceptable owing to the vast amount of information on the imagery. (According to Jarman et al. (1981), at this scale of remote sensing the final map product should be in the region of 1:1 000 000.)

The vegetation map at a scale of 1:250 000 is necessarily a thematic map where the individual units are much broader than the cover classes detailed on the Landsat image. The vegetation map and Landsat imagery, both at a scale of 1:250 000, are not identical in detail as the image contains much more information, similar to that required for vegetation mapping at a scale of 1:50 000. Consequently 1:250 000 imagery is ideal for mapping vegetation thematically at any scale ranging from 1:50 000 to 1:250 000, though 1:250 000 would seem to be optimum. Incorporating imagery at a scale of 1:250 000, others have used smaller mapping scales, e.g. 1:1 000 000 (Moll & Bossi 1984) and 1:500 000 (Timberlake 1980; Bossi 1984). Furthermore, the primary aim of the imagery investigation was to delineate the boundaries of classified vegetation units more accurately; 1:250 000 imagery had the added advantage of allowing transparency overlay comparisons between the vegetation map, the imagery and supportive information maps. Deutsch (1987) used 1:50 000 Landsat TM imagery enlargements for direct comparison with geological maps of equivalent scale. Geological and soil maps at this scale are unavailable for the Northern Cape.

The synoptic view of a large area which Landsat imagery affords, has positive implications for reconnaissance surveys. Jarman (1981) found that the reconnaissance scale of mapping best uses the satellite digital data. The classification information accompanying a vegetation map should be at the level of detail appearing on the map, while more information about the vegetation should appear in a separate, accompanying text. Further Landsat imagery investigations for reconnaissance mapping in the Prieska-Postmasburg area of the Northern Cape and the Vanwyksvlei-Brandvlei area of Bushmanland, using the general relationships between

scale of study and scale of mapping laid down by Edwards & Jarman (1972) showed, with slight modification, the success of their relationships, but Landsat imagery was used instead of aerial photographs. Details of the method used are given in Paper 5.

Landsat false colour composite transparencies at a scale of 1:1 000 000 were also used in the investigation. The detail in terms of number of cover classes and sharpness of boundaries is ideal for thematic mapping at a scale of 1:250 000 where only ecological regions are depicted. (The detail in a 1:1 000 000 transparency is comparable to the detail in a 1:250 000 support information map.) However, problems were encountered when working from 1:50 000 and 1:250 000 support information maps to the transparency. A further problem was encountered in the field, where differences in scale did not allow for direct overlaying. In order to be most effective the transparency requires the use of a light table and the use of the Landsat image in the field at the time of investigation was considered to be of prime importance.

Landsat 2 and 3 MSS resolution is approximately 79 m. The resolution is fundamental to the scale of the final map product. Literature research shows that many authors find this resolution level too coarse, while others find it too fine. Frequently, inadequate results obtained in Landsat imagery-based investigations are blamed on this limitation. Sometimes, especially in the 1970's, the objectives were somewhat unrealistic. The scale of final map product is dependent on the aims of the investigation. It was found that the effective resolution was not fixed at the given size but varied according to the degree of contrast of various environmental features in the ecological region under investigation.

## 5.2 IMAGE PRODUCTION AND ENHANCEMENT

### 5.2.1 LANDSAT PRODUCTS

The SAC, Hartebeeshoek, of the National Institute of Telecommunications Research is the southern African supplier of Landsat products. From this institute, the potential Landsat user may obtain details of standard and non-standard products available, price lists, catalogues (relevant details of imagery spatially and temporally acquired over southern Africa, its quality and cloud cover, etc.) and index maps (showing orbital paths of the various Landsat series of satellites and a convenient identification system

for the ordering of any image scene). Examples, with explanations, are given in Appendix 3. These details and many more have been published by Botha (1982) and Van der Westhuizen (1985).

In this report, only Landsat products used in the visual interpretation investigation are discussed. In the selection of suitable imagery further consideration must be given to aspects such as scale of study and Landsat imagery, resolution, season and time of season, final form of product, etc.

### 5.2.2 THE IMPORTANCE OF IMAGE QUALITY

The production of the image data into the "photographic-like" hardcopy print is often viewed as the work of the SAC personnel - the user's involvement beginning only on receipt of the image. The error of this assumption cannot be over-stressed. Differences in contrast which may and do occur during processing are as significant as any inter- or intra-seasonal differences (see 5.5 below). The user input in this processing step is welcomed by the operations engineer, as he is well aware of its importance in producing an image of good quality and tailor-made to meet the requirements of the user. In the majority of cases the operations engineer receives the order for the imagery by post or telephonically. Often the user is not intimately familiar with the study area - the operations engineer will certainly not be.

Below is a description of the procedure used in the production of Landsat colour prints (Marais, pers. comm. 1985). Either there is or is not interaction between the operations engineer and the user. If there is not and the operations engineer has no information concerning the area and use of the image, the following procedure is used to produce the prints:

- a) The full Landsat scene is displayed on an image display device, at a reduced resolution.
- b) Histograms of this data are displayed. (A histogram shows how many relative pixels at certain intensity values (0 to 255) are present in the image).
- c) From the histograms, a linear contrast stretch curve is produced for each of the spectral bands. Usually bands 4, 5 and 7 are used for false colour prints.
- d) Each band is then individually contrast-stretched to give the best possible contrast/intensity.

- e) The scene is displayed in colour, and "fine-tuned" by contrast stretching each band again to give the best possible colour combination/saturation.
- f) The next step is the production of a colour positive transparency utilizing the contrast stretch curves.
- g) After the transparency has been developed, it is visually checked for correct contrast and density, as well as for any deficiencies and problems.
- h) If the transparency is acceptable to the operations engineer, the print is then produced. With the use of negative processing in the near future (Boyle 1985), the print paper will stay flatter, a worthwhile improvement, as the image print tends to curl.
- i) To optimize the print, the average density of the transparency is determined. This is used to find the correct exposure time and development variations. The exposure time and development variations are also of importance, as less or more exposure and developing not only affects the overall balance of the print but can affect the contrast between cover units. The photographic processing, which affects the colour balance, may enhance the image (Dean & Spencer 1982).

The operations engineer's ability to judge whether points (d) and (e) were carried out satisfactorily, depends to a large extent on experience, but even so, will vary from person to person. It is here that detailed user information is imperative, as the user may be interested in only a single part of the scene and/or wish certain features to be displayed prominently. Accepting for the moment that intensity values over the whole scene are reasonably uniform, this procedure will result in a fairly good mean value final product. Unfortunately not many scenes are relatively uniform throughout, and if the user is interested in small details (e.g. a geologist) then the image will not be ideal, as a mean value is selected at each step. If, however, there are large areas of very low intensity (e.g. rugged, elevated terrain with dark rock frequently exposed) occurring with large areas of very high intensity (e.g. floodplains or extensive areas covered by aeolian Kalahari sands), it becomes virtually impossible to produce a contrast-stretch curve that will give good definition in both these areas. It is in such a case (occurring more often than not) that the operations engineer requires more information from the user, who should have

some knowledge of the area or should know what he wants from the image. Contrasting for maximum information for the rugged, geologically dominant terrain will result in absolutely no detail in the high intensity areas. Contrasting for maximum information in the areas of high intensity will bring out many more cover classes (whites, yellows, oranges and browns), but will result in the low contrast areas appearing as a series of browns, greys and black. This is what happened in several of the scenes investigated, especially in Bushmanland. The option chosen was maximum information in the high intensity areas.

Without the information available to the operations engineer, the best possible compromise is made which results in the user not obtaining full use of the image, especially if his prime area of interest is predominantly either in the light or the dark areas. Again the user must decide on acceptability or supply the operations engineer with enough information so that a calculated product can be produced by him. If large areas of high intensity are present on the transparency and they are of importance to the user, these areas are masked during the printing process to give them less exposure, and the dark areas, if present, more exposure. This procedure is not practical in situations where there is a complex mosaic of high and low intensity areas. An alternative which was employed in this study, with excellent results, is the production of two images of the same scene and date, one contrast-stretched for the high intensity areas and the other for the low intensity areas. This would be appropriate when the user is interested in the entire scene.

The SAC is soon to change to negative processing of colour film and prints (Boyle 1985). The negative processing results in better colour separation and saturation with greater detail in the dark and light areas and more information content though less contrast.

Initially, a personal visit is advisable as this leads to a more detailed understanding of the user's discipline and the procedure in operation at the SAC. During such a visit the user can be interactively involved in the production of the contrast-stretched curves. The procedure used is basically

the same as that described above but during some of the steps there is user involvement:

- a) The full Landsat scene is displayed on the image display device, at a reduced resolution.
- b) The user identifies the area(s) of interest.
- c) The area is then displayed at full resolution.
- d) Histograms are calculated.
- e) Contrast-stretch curves are produced.
- f) Each spectral band is contrast stretched by the user, until the maximum amount of information is discernable. At this stage the user is already visually interpreting the image, looking for recognisable patterns. Histograms are altered to enhance meaningful patterns, etc. This is the user's chance to have the final product produced the way he wants it. Furthermore the process is statistically calculated, so in the production of mosaics, images of the same orbit can be identically colour-balanced.
- g) The scene is displayed in colour and "fine-tuned".

During the whole procedure, the SAC staff member operates the equipment and guides the user in how much contrast and/or density variation can be tolerated before the final product becomes unusable. The knowledge that the user has of the area he is looking at, and what he expects to see in the image, is of prime importance during the contrast-stretch phase of the procedure. Any changes made are immediately visible and the end results will be tailored to his needs, with the maximum amount of data in his specific area of interest being present. Once the user has obtained this firsthand experience, it is not necessary to visit the SAC each time false colour composite imagery is requested; the relevant information can be conveyed to the operations engineer.

Thus, the more interaction there is between the user and the SAC, the better the final print will be. In South Africa, many a user has condemned the use of Landsat imagery as a tool in the research process because of the initial use of a product not suited to his purposes. Howman & Kempster (1983) stated, "It is through the medium of a visual display that the full impact of what satellite imagery can achieve, is best shown." Lasserre et al. (1983) concluded that the presentation of the mass of MSS data is best

achieved in visual form. Clearly, optimum production of this "visual display" is vitally important.

### 5.2.3 SYSTEMATIC AND PRECISION GEOMETRIC CORRECTIONS (IMAGE-ENHANCEMENT)

During the original image restoration process the data is corrected for errors, noise and geometric distortion introduced in the scanning and transmission processes (Jarman 1981). Furthermore, the image may also be enhanced and improved by manipulation of the original data, i.e. the image is made more visually comprehensive (Piper 1981) (as discussed in 5.2.2 above). In all Landsat standard products, automatic correction for systematic errors, such as the earth's rotation, earth curvature, panoramic distortion, non-linear scanning mirror velocity, line length variation and aspect ratios are applied to both B/W and false colour composite imagery (Botha 1982). Imagery produced with the above corrections is called bulk processed imagery (BPS). At this stage no enhancement processes have been applied to the digital data. BPS imagery has been found to be undesirable for visual interpretation purposes as much of the information content of the data is unavailable to the user; the image lacks contrast and appears to be "washed out". Newton (1984) referred to the inferiority of BPS imagery for visual interpretation.

The following step in image processing is image-enhancement, which includes haze-removal, de-stripping, edge-enhancement and correction of systematic errors. After this process the image is referred to as a systematically corrected image (SCR). The information content and contrast of the image are now greatly improved. The edge enhancement alone seems to contribute greatly to the remarkable difference between BPS and SCR images. Image enhancement renders the image easy to assimilate visually. The enhancement process, though costly, is absolutely essential for vegetation mapping applications, especially where accurate boundaries are to be identified and positioned, either on the image or on supportive information maps or both. In this regard, images used by the author have never been found to be inaccurate by more than 2 km at the edges, i.e. over a distance of 185 km. The inaccuracy is mainly due to slight distortion and is therefore not of equal magnitude throughout the image. Furthermore, this inaccuracy is not constant, for the centre of the image may be almost "spot-on" while the edges (often the eastern and western edges more than the northern and southern) may vary in inaccuracy. For reconnaissance-type vegetation mapping this degree of inaccuracy (2 km to 5 km) is not of note, especially

as boundary positioning of ecological regions is often of the same order, or larger. According to SAC information, geographical inaccuracies may be up to 15 km (Botha 1982). In this study, inaccuracies were found to be of a far smaller magnitude. UTM (Universal Transverse Mercator Grid), a latitude and longitude grid, can also be overlaid on the SCR imagery during production but this was found to be of little value as grids were often displaced by 5 km to 15 km or even more, a fact seldom realized initially by investigators.

Another optional step in processing accurate images is precision geometric correction (PGC). This procedure places pixels in their precise geographical position and an accuracy of one pixel (80 m x 80 m) can be and often is obtained. Precise geometric correction of Landsat imagery is costly since it involves a process of applying accurate ground control points (taken from 1:50 000 topographical maps) to the image. Since the vegetation mapping was at a reconnaissance level and SCR images were found to be reasonably accurate, the considerable additional cost involved in obtaining PGC imagery could not be justified.

Precision geometric correction is necessary for very precise work, e.g. crop identification studies, where the boundaries of agricultural fields have to be positioned.

### 5.3 VISUAL INTERPRETATION TECHNIQUES

#### 5.3.1 PATTERN RECOGNITION

It was immediately apparent that Landsat imagery patterns (hue and texture) were numerous and highly complex. Field detail had been simplified into manageable units - the same had to be done with the detail depicted on the imagery. Comparisons between the vegetation map and imagery showed good correlation. In addition, many topographical features, soil and geological types and anthropogenic influences were easily recognizable. Based on these findings, it was decided to investigate satellite imagery capabilities further.

#### 5.3.2 SUPPORTIVE INFORMATION

In the interpretation of Landsat imagery, ancillary data such as data derived from field investigations, aerial photographs and soil, geology and

topography maps, are referred to as supportive information. Supportive information used for initial laboratory investigations of the various cover classes depicted on the Landsat imagery was in the form of the Land Type (primarily soil types, but also incorporating climatic and terrain morphology data), geology and terrain morphology and topographical maps, all at a scale of 1:250 000. The identification and accuracy of the cover classes were tested against this supportive information. In addition, supportive information was helpful in the interpretation process. If successful, then future investigations would utilize Landsat imagery as supportive information in vegetation classification and mapping exercises. Thus, in this study, one potential support information base was being tested by a series of standard support information resources. This aspect of the study revealed some interesting and surprising results in terms of accuracy of support information.

### 5.3.3 METHODS OF VISUAL INTERPRETATION

Supportive information maps are essential for good visual interpretation of Landsat imagery portraying natural landscapes. Experience with visual interpretation of aerial photographs is obviously helpful as Landsat imagery may be interpreted in much the same manner. In the interpretation of Landsat imagery, three aspects of the data must be considered, viz. brightness and contrast, resolution and sharpness and visual texture (repetition of visual pattern across an image) (Pendock & De Gasparis 1985). In imagery, some experience and a degree of "feel" for the medium is required. In South Africa, no formal course exists for the visual interpretation of surrogate Landsat cover classes. Generally, visual interpretation of surrogate Landsat imagery information, using standard photo-interpretation techniques, involves pattern recognition, i.e. "How well does the surrogate data represent the real information?" It must be remembered that imagery is not akin to aerial photographs. The synoptic view of 34 000 km<sup>2</sup> (one Landsat scene) requires acclimatization, not only in terms of scale but also in the considerable amount of spatial information presented. Furthermore, the majority of vegetation ecologists in South Africa have not dealt with colour photography. When dealing with false colour Landsat imagery, the interpreter is faced with colour pattern recognition and false colour at that. (Actively growing vegetation, with higher than 50% PCC (projected canopy cover), appears red on the imagery.)

In the visual interpretation of Landsat imagery, a form of self-training occurs at the time of investigation. Little or no stereoscopic viewing is possible due to the lack of radial displacement in the north-south orbital direction. This can be viewed as a major shortcoming of Landsat imagery (Story et al. 1976). Imagery available from the SPOT 1 satellite allows reasonably good stereoscopic viewing. One has to be reminded that the patterns, hues/tones and textures are due to numerical reflectance values of the information classes on the earth's surface and may have no direct bearing on what is seen in the field, especially in terms of colour. The digital information of the image represents reflectance values of the land cover. An aerial photograph may show a dolerite ridge clearly in terms of topography, geological structures, soil pockets and the vegetation covering it. In the Landsat imagery, the reflectance values of each pixel representing the position of the dolerite ridge, are surrogates for the description and attributes of the feature itself. Units are spectral and not landscape units, and the principal source of information is the spectral, spatial and temporal (where applicable) variations of the electromagnetic energy evidenced by the scene (Swain 1983). Visual interpretation takes into account the data's spectral, spatial and temporal characteristics. The patterns, hues and textures portrayed are much larger than the resolution of the sensor and thus more information is available to the interpreter. The longer an image is scrutinized, the greater the detail observed. It should be viewed from a distance to obtain the best results in the initial (primary) subdivision of major patterns, hues/tones and textures. Unlike aerial photographs, Landsat imagery has negligible geometrical distortion due to the narrow scan angle (11.56 degrees) (Sabins 1978). This allows for direct comparison of Landsat imagery and supportive information maps of the same scale.

A method was devised to cater for the slight inaccuracies occurring as a result of using SCR images. The latitude and longitude grid references were placed on the image by selecting acceptable ground control points (GCP's) on 1:250 000 topographical maps that were clearly visible on the image. (The accurate placement of latitude and longitude is essential for comparisons with support information maps). In most cases, there was a difference of a few millimetres between the GCP's and this difference had to be averaged in order to draw any particular line of latitude or longitude. Once the degree and half degree lines had been positioned, the squares were subdivided to form the quarter degree grid squares (equivalent to the area covered by a

1:50 000 topographical map). In order to transfer data from support information maps onto the image or vice versa a transparent plastic quarter degree grid square subdivided into 10 x 10 smaller squares was used. This method proved to be accurate and convenient as there was no need to produce large overlays of 1:250 000 maps which are cumbersome to handle. It is preferable to work with a single quarter degree grid square at a time since the overall distortion makes the positioning of large overlays difficult. It must be pointed out that often sections of the Landsat image are so geographically accurate that no correction is necessary.

#### 5.4 COMPARISON OF BLACK AND WHITE AND COLOUR IMAGERY

The major portion of the comparison was between single band B/W and 3-band false colour composite prints at a scale of 1:250 000, though B/W positives and negatives, and false colour transparencies, at a scale of 1:1 000 000, were also investigated.

The first image acquired was a single band (band 4), B/W image at a scale of 1:250 000 (Plate 11). This was visually interpreted using normal aerial photograph techniques. The Landsat image was pattern-demarcated visually. This involved the consideration of spatial pattern, tones and textures, of which the latter was found to be of the least importance. Pattern recognition was found to be poor. Demarcated patterns were difficult to circumscribe completely owing to many tonal gradients occurring between classes. Boundary demarcation, one of the important aspects of the exercise, became inconsistent and inaccurate. Generally, the scene lacked crispness and good contrast. In terms of spatial distribution and numbers of units, there was poor comparison between the vegetation map and the black and white imagery. It was evident that B/W Landsat imagery did not satisfy the objectives of the study.

It was decided to investigate colour Landsat imagery. No colour aerial photography was available, though Jeter (1975) and Stephens (1976), among others, found colour aerial photographs highly successful with increased mapping quality and efficiency. It was hoped that colour imagery would meet with the same degree of success.

A 3-band (bands 4, 5 and 7) false colour composite, at a scale of 1:250 000 was acquired (Plate 12). It was immediately evident that the colour was a

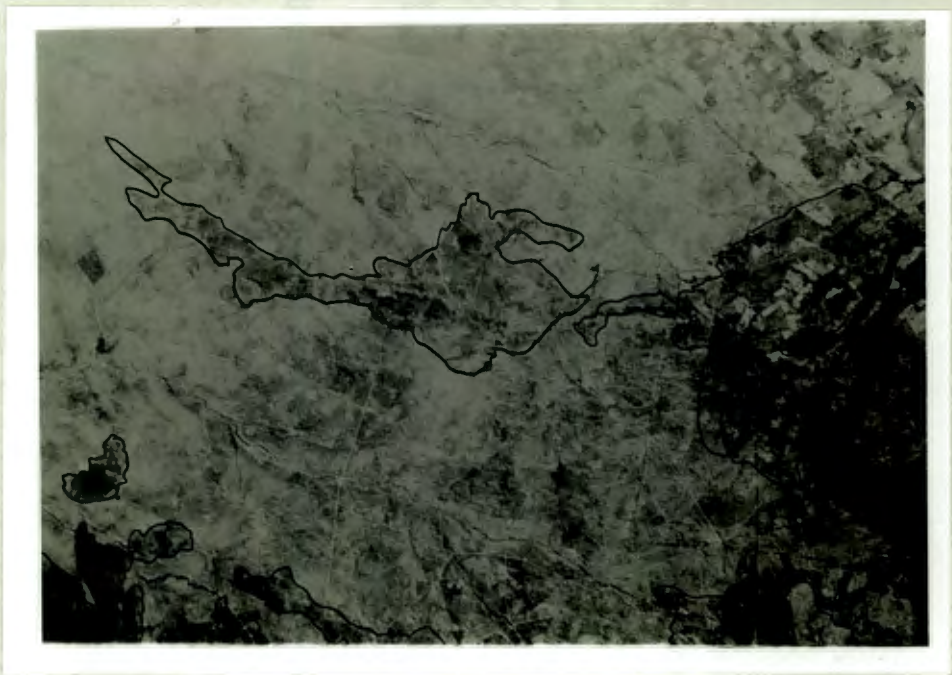


Plate 11 Portion of black and white Landsat image (band 4), originally at a scale of 1: 250 000.

worthy addition. Similar data acquisition existed for both the B/W and colour imagery, making direct comparison possible. The colour image was superior in terms of number of cover classes and clarity (crispness). Also evident was the sharpness of boundaries, owing to the colour contrasts between cover classes. The false colour often emphasized the differences between unrelated adjacent cover classes. It was obvious that the addition of colour enhanced visual interpretation. Spatial patterns in colour are both pleasing to the eye and instantaneously obvious. It has been stated that the human eye is able to recognize many more hues than tones (20 000 and 200 respectively) (Jarman 1981) and is very sensitive to green (luminance) and blue (contrast) (Piper 1981). In terms of information content, the false colour composites combine the reflective variations from three MSS bands and B/W imagery from a single band only. This is why a number of "invisible" cover classes became "visible" - the detectability of cover classes was enhanced.

It is both interesting and surprising to note that Story *et al.* (1976) gained no aggregate advantage from the use of false colour over B/W imagery. The majority of the authors agree with the findings given here. Nelson & Hoffer (1979) found that colour imagery gave the analyst a better feeling of the area in which he was working, and simplified the broad stratification of a scene into smaller areas of interest. In their study of flood boundaries, Philipson & Hafker (1981) found colour and B/W equally accurate. Sabins (1978) concludes that colour composite Landsat images are superior to the black and white individual bands for most applications.

In this study not all individual bands were investigated at a scale of 1:250 000 and one band may well have contained more information than another. All individual bands were investigated at a scale of 1:1 000 000, both as positive prints and negative transparencies, and certainly no individual band was found to contain more information or contrast than the 1:1 000 000 colour transparency. Colour transparencies were investigated at SRSC, Hartebeeshoek. With these, boundaries, contrast and crispness were found to be superior but owing to the differences in scale between these and the prepared vegetation maps as well as certain practical problems discussed previously in 5.1, no further investigations were undertaken.

### 5.5 COMPARISON OF SEASON AND TIME OF IMAGERY

With Landsat imagery, images of different seasons and dates are readily available (see section 3.2, Landsat technical details). Imagery from winter and summer months, of different dates and years was investigated. Maximum imagery information means maximum contrast between cover classes. The reflectance of various ground cover classes varies with season, time of season and from year to year. Assuming that there is a direct correlation between imagery cover classes and ground cover classes, then at the time of minimum contrast between ground cover classes, there is less information present in the Landsat imagery. For the image to be a worthwhile tool in the mapping procedure, maximum information is desirable. One cannot conjure up detail where it does not exist, while too much detail can either be ignored or simplified into intra-associated manageable units.

The Northern Cape communities seldom have vegetation covering more than 50% of the ground surface. In terms of reflectance sensed by the scanners on the satellite, environmental parameters such as soil type, exposed geological type and terrain morphology must account for a substantial amount of reflectance information and must be taken into account, not only in interpretation methods but also in striving for maximum contrast of imagery. In regions where the PCC of the vegetation is less than 50%, it does not necessarily follow that the time of the imagery chosen is that time when there is maximum vegetal contrast, as this may coincide with the time when the remaining terrain parameters are less contrasting. While one aims at maximum vegetal contrast in vegetation investigations, a slight compromise in timing may be necessary. In potential reflectance values, geological types and terrain morphology would not vary as much as soil type and vegetation. Soil reflectance varies with moisture content. Sun altitude and azimuth affect the angle of reflectance from objects on the earth's surface and the size of shadows in areas of high terrain (Piper 1981). The clarity of the atmosphere also affects the image as incoming and outgoing radiation is absorbed and reflected by particles in the atmosphere.

Vegetation units are temporally and spatially affected by climatic conditions (mainly rainfall and temperature) and by anthropogenic disturbances, which control the state and development (floristics, structure and functional dynamics) of plant communities. The primary interest was the potential of the imagery for mapping vegetation in a semi-arid area, where the vegetation

accounts for less than 50% of the ground cover. The date of imagery should relate not only to the time of maximum information content (contrast), but also to the time when the vegetation affects the reflectance levels most.

It is apparent that many parameters must be considered in the selection of season and time of imagery. Of importance is how single parameters or complex combinations thereof affect the spectral response of the imagery (Hoffer 1971). Jarman et al. (1983) gave broad suggestions, but it has been found that best overall contrast varies from region to region, e.g. Karoo, Northern Cape and Orange Free State, with differing vegetation, soil formations, climate and topography have differing optimal season and time of imagery selection.

#### 5.5.1 YEAR OF IMAGERY

All initial selections, other than the first two black and white and false colour composite images, were made using the 1:1 000 000 transparencies (and a light table) at the SRSC, Hartebeeshoek. The western, semi-arid areas of South Africa experienced a severe drought from 1983 to early 1988. (The effects of the drought on species composition will be felt for a few years to come.) The drought had an obvious effect on the vegetation; many summer "rainy" seasons led to a response little better than the state and development of the vegetation during the senescent, frosted stage of the winter season. All vegetation surveys took place prior to the onset of the drought, and, because contrast during the years of the drought was not optimum, only transparencies and prints from 1978 to 1982 were considered.

Owing to the superiority of colour over B/W, only colour imagery was compared with regard to year and season. It soon became evident that there was little overall synoptic difference in spatial patterns, hues and textures of imagery between years of acquisition. These findings were directly related to the scale of operation; mapping at a scale of 1:250 000 requires that units (cover classes) approximately 15 mm x 15 mm on the image (ground area of 14 km<sup>2</sup>) are generally ignored and most changes between the years were connected with areas of similar size (i.e. typical farm camp). These findings were important as it was no longer considered imperative that orbital date of image be as close to date of field survey as possible. Hoffer (1971) is in agreement with this statement. Furthermore, the results could be related to the stability of the vegetation over long periods

of time. Given the "normal" dynamic changes of the environment in western South Africa, these are not rapidly changing regions.

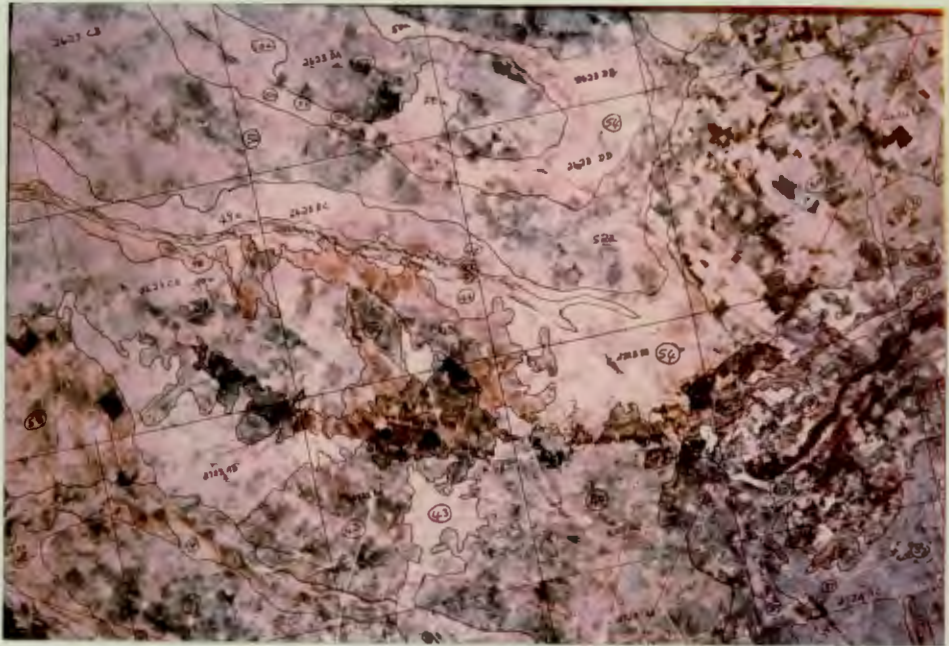
### 5.5.2 SEASON OF IMAGERY

The seasons investigated were autumn-winter and spring-summer. Again 1:1 000 000 false colour composite transparencies were used, as well as two 1:250 000 false colour composite prints (Plates 12 and 13). It was evident that very significant differences occur. The most obvious difference was that the reflectance values were higher in the summer image. Dos Santos et al. (1980) and Warren & Hutchinson (1983) concurred on this point. In general, summer imagery was superior in contrast, clarity and number of patterns, hues and textures (Plate 10). (It is interesting to note that both Viljoen et al. (1975) and Warner (1985) reported that winter images contain minimal geological information. As will be seen later, the findings of this study do not fully support their comments.)

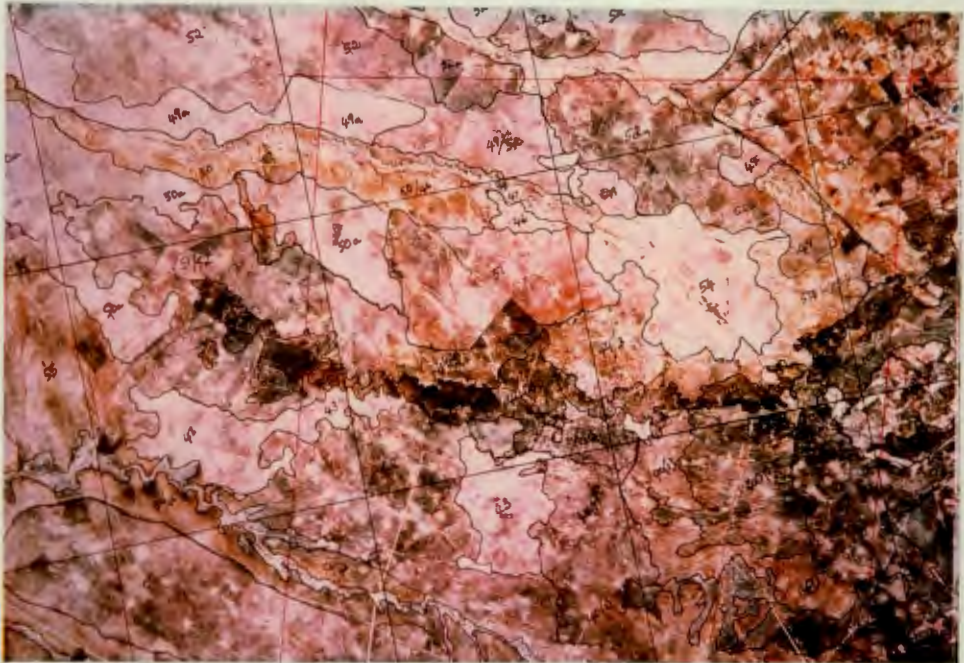
### AUTUMN-WINTER IMAGERY

Factors in favour of winter imagery were:

- a) High probability of cloud-free images during this period. This was not of ultimate importance as there is always a high probability of obtaining summer season imagery associated with cloud-free conditions. Banking of cumulus clouds usually begins around 12h00 to 14h00 and the skies are covered until early evening. The Landsat imagery over the Northern Cape is, however, recorded at approximately 09h25 when the skies are usually free of cloud.
- b) Ease of distinction between units (cover classes) corresponding with deciduous- or evergreen-dominated growth forms. An example in the Kalahari Thornveld is the mosaic of sparse to open, short *Acacia* woodland and intermediate to closed, short *Terminalia* woodland, on deep aeolian sands. The *Terminalia* woodland is early deciduous (June), and the *Acacia* woodland is very late deciduous (late August to mid-September; effectively evergreen).
- c) The unravelling of complex ground cover classes. In the western areas of the Ghaap Plateau, a mosaic of short, closed grasslands (on dark soils overlying dolomite bedrock) and very sparse to open, short to tall, grassy shrublands (on low, rounded chert and jaspellite hillocks covered by reddish soils) occurs. In winter the grasslands are bleached a pale straw colour and the grassy shrublands have a good



**Plate 12** Portion of false colour composite Landsat image (bands 4, 5 and 7; winter), originally at a scale of 1: 250 000.



**Plate 13** Portion of false colour composite Landsat image (bands 4, 5 and 7; summer) originally at a scale of 1: 250 000.

contrast between the grass layer and the evergreen shrubs. Furthermore, stronger reflectance from the two soil/geological types during winter also occurs, which helps with the separation of the two structural types.

The above points notwithstanding, winter imagery is generally unfavourable. There is a lack of contrast and thus a loss in potential maximum information. This lack of contrast is due mainly to two factors:

- a) During winter, the field stratum (an important layer in the Northern Cape vegetation units) is a blend of creams, yellows and light browns, as a result of the senescence and dormancy of perennials and mortality of annuals (ephemerals) caused by low temperatures and frequent frosting from early May to early September. Frosting has a uniform effect on the field layer throughout the Northern Cape. Curran (1981) also referred to the problem of senescent vegetation.
- b) Owing to the strong winds and lack of rain (late July to early September), there is a general atmospheric haze. Wind-blown dust particles cause a scattering effect on incoming and outgoing radiation. Grootenboer (1973) commented on this. Also, much of the foliage is dust-coated during this period, which further reduces contrast.

Since the PCC of the vegetation is low, soil type, geological type and terrain morphological classes play a large role in reflectance from the ground surface, if not a dominant one. Spectral response is contaminated by the reflected radiation from the abiotic background (Hielkema 1979). During winter, these on their own do not lead to much contrast as the range of reflectance is from light brown to black. In addition, the dark colours of the woody vegetation have similar reflectance levels. An image which is not conducive to optimum pattern recognition results. Although the winter imagery is still usable it is inferior. In practical terms, the imagery is dominated by many areas with high reflectance (grass and light coloured soils), interspersed with many areas with low reflectance (topography, geology and woody vegetation). The Kalahari Thornveld vegetation types are dominated by "white" winter grasses and pale pink to red sands, resulting in a lack of detail on the imagery. Vegetation types of the Kuruman Hills and dolomitic regions are dominated by dark green, physiologically inactive leaves of the large woody shrubs (*Euclea* spp., *Rhus* spp. and others), dark

banded ironstone and exposed dolomite bedrock. (This has implications for the production of good quality imagery, see section 5.2).

A further disadvantage of winter imagery is the low plant phytomass available for reflectance, owing to grazing of the vegetation by high numbers of domestic stock and game species, with no replacement by new growth. This biological removal of plant tissue enhances that portion of the radiation reflectance range emanating from the abiotic component. Also, lack of rainfall further reduces contrast between soils with good and poor water holding capacity. The vegetation is also low in water content and there is a subsequent loss of tissue turgidity, a point discussed in agriculture-orientated satellite investigation. Presumably this reduces the reflectance from natural vegetation to the same extent as that from agricultural crops. In the rugged, topographically prominent terrain of the Kuruman Hills, it was found that texture played an important role in the winter imagery and had to be utilized frequently in boundary identification between the intermediate to closed, high, mixed, shrubby woodlands and high-altitude, sour, closed, short to dwarf grasslands.

In summary, winter imagery is generally inferior in terms of maximum contrast and clarity. This results in minimum information content for pattern recognition. It has its uses in separating complex mosaics where soil/geological types must be largely relied upon and in its superiority of texture-related cover classes, where in winter, longer shadows are cast at various angles in rugged, topographically-prominent and elevated terrain. While it is not advised that winter imagery be acquired as the primary imagery source, it should be considered as an addition, if funds permit.

#### SPRING-SUMMER IMAGERY

The superiority of summer season imagery in contrast and clarity is the result of a number of obvious factors. The Northern Cape receives an average of 85% of its total annual rainfall during the spring-summer seasons. Given adequate moisture levels, the high temperatures are conducive to high rates of phytomass production. Good vegetative ground cover results, i.e. deciduous species produce new foliage. This combined with the complex of darker soils (mostly damp to moist), geological types and topographical classes results in good hue contrast. A contrast between vegetation growth- and life-forms (structural groups) is desirable, but most of the contrast

arises from complex reflectance interactions between the vegetation and the abiotic components. Furthermore, as the use of the imagery is for vegetation mapping purposes, the time of maximum vegetation cover is advisable. A good example of this biotic/abiotic-emphasized contrast is found in the Kalahari Thornveld vegetation types. In the summer imagery, spatial patterns are clearly discernable, but not in the winter imagery when the high albedo of Kalahari sands saturates the Landsat response and severely reduces the quality of the imagery. The reverse is true of geology-dominated, elevated terrain cover classes.

Summer rains remove dust particles from the atmosphere and wash the foliage of evergreen vegetation. The environment is generally dominated by fresh colours. As mentioned earlier, the summer imagery is remarkably detailed and many more cover classes are discernable than is practical to map at a scale of 1:250 000. However, this detail is useful in terms of orientation and understanding of the interrelationships between ground cover classes. This is important for an understanding of why season of imagery should be correlated with season of field investigation.

It is interesting to note that Newton's (1984) results showed that the most important factor in the differences between seasonal imagery is not changes in vegetation, but changes in sun elevation. It must be borne in mind that Newton was investigating Landsat imagery for relevance in geological interpretation and, secondly, imagery depicting areas supporting more arid, karroid types, mainly to the south of the Northern Cape, with much less projected canopy cover. It is understandable that in this area a very high percentage of the sensor response is due to the soil/geology complex, both during winter and summer seasons. Personal experience with imagery over a large part of this karroid region has shown that good rains result in quite large changes and improvements in pattern, hue and texture, and even enhance soil and geological investigations. In geological investigations both Viljoen *et al.* (1975) and Warner (1985) found that summer imagery provides for more effective discrimination. PCC increases rapidly to approximately 35% to 40% in most communities. The soil and geological types are well correlated with vegetation units and vegetation presence *per se* is not of ultimate importance but maximum information to the user is. Grootenboer (1973) stated that marked seasonal differences occur on imagery depicting intermediate climatic zones in South Africa.

It has been concluded from three mapping studies using Landsat images representing semi-arid regions of South Africa that, in selecting imagery for visual interpretation, season of rainfall and season of maximum leaf production (which is directly related to season of rainfall) are of primary importance. Jarman (1981) stated that the time of maximum contrast varies with climate and vegetation structure. In selecting season of imagery, the purpose of the study is of importance. In regions with vegetation cover of 30% to 50% PCC, a wider range of hue contrasts is evident in summer, rainy season imagery, while in regions with a PCC of 5% to 30%, colour contrasts do not change much between winter and summer imagery. The range may not be so wide, but season of rain enhances patterns (mainly soil and geology) and results in enhanced crispness and clarity of image.

### 5.5.3 TIME OF SEASON OF IMAGERY

As has been debated in the previous section, summer season imagery is superior on the whole. In addition, there are certain times during the summer season when it would be easy, or easier, to separate specific cover classes from one another. It is at this stage that the finer details in the imagery are scrutinized. Hoffer (1971), referring to agricultural crops, stated that finer cover classes are spectrally similar at certain times and completely different at others.

Jarman (1981) found that in grassland formations (mainly in the central regions of South Africa) during the autumn period (April to May) grass colours give maximum contrast. Jarman further stated that in open woodlands and shrublands (good grass cover, interspersed with trees or large shrubs) imagery should be acquired when contrast between trees or large shrubs and grass is maximal, such as just prior to the trees losing their leaves when the grass is dying back, or after the first flush of spring when the tree leaves are green, but the grass is still a winter, yellow colour. This has been found not to be the case with the mixed semi-arid tree and large shrub woodlands in the Northern Cape.

For the investigation on time of summer season with maximum contrast, false colour composites only were investigated and were subdivided into three groups: period 1 - Mid-September to late November; period 2 - December to Mid-February; period 3 - Mid-February to late April. The rationale behind

this strategy was based on the rainfall regime, and its effect on the structural and functional dynamics of the vegetation. Under "normal" climatic conditions in the Northern Cape, rainfall is dispersed between the three periods as follows: 16% falls during October/November and is locally referred to as "grass rains"; 15% in December to mid-February and approximately 69% from mid-February to mid-April and is locally referred to as "tree and shrub rains". The reason for these local descriptions is that all the early rains (October/November) are utilized by the grass layer before the moisture leaches to depths below the grass root layer (a fact which has a profound effect on bush encroachment in overgrazed areas). The late summer rains (February to April), in the absence of high temperatures and cloud cover, leach to considerable depths. This may not result in shoot and leaf growth in the trees and large shrubs so late in the season, but the moisture is available for spring growth the following season. During December and January, exceptionally high temperatures are experienced which reduce and retard plant growth and often result in the temporary dying back of many of the forbs and grasses.

In terms of the summer rainfall season, the above three periods or divisions are physiological ones with regard to the structural and functional dynamics of the vegetation.

PERIOD 1 - Mid-September to late November: This period sees great changes in the vegetation. As soon as temperatures begin to rise in September, the trees and large shrubs begin to produce new shoots and leaves. In most species, flower production follows rapidly. The grass layer and many of the forb species remain dormant and senescent until the first "good" rains arrive, which, on average, is not until mid to late October. Rains of at least 15mm to 20mm must fall before any reasonable grass growth takes place, and then it must be followed by at least the same amount again within a two to three week period. Contrast in the vegetation cover is relatively good during this period. Until late November, the cover (PCC) is still relatively low to moderate while the field layer continues to grow and replace that which has been grazed during the winter months. Considerable seedling production and growth takes place. Although the field layer (yellow with some green growth protruding) contrasts well with the fresh green of the large shrub and tree species, PCC is still relatively low and much of the image spectral response is dominated by the soil/geological complex.

PERIOD 2 - December to mid-February: This is an exceptionally hot period of the year with temperatures commonly soaring to 38°C. The growth of many species is physiologically retarded. The imagery, especially until late January, lacks crispness and clarity, probably due to the high temperatures, the wilting of many plant species, atmospheric heat haze and general, rapid loss in soil moisture. Though rain may be received, it is generally ineffective owing to high evaporation rates. Skies are most often clear throughout December and January. From late January to mid-February, the situation begins to improve somewhat. During this period many of the grass species produce culms and inflorescences and cover is relatively good; contrast begins to improve.

PERIOD 3 - Mid-February to mid-April (or until the first frosts in mid-April and rarely early May): Most important for this period is the almost daily build-up of cumulus cloud, especially in the afternoons, which gives considerable relief from the heat. With good rains falling during this period, phytomass production is rapid and substantial. From mid-February to mid-March the grass layer matures. Many contrasting colours are present, e.g. the colour variations between the mature grass inflorescences with good seed production (whites, yellows, browns, greens, reds and purples), and the mature, dark-green to blue-grey colours of the large shrubs and trees. PCC is at its greatest, so there is also maximum information from maximum contrast. The atmosphere is clear and the remaining non-vegetated ground cover allows for good contrast between the vegetation and soil/geology complex. Rains have fallen, the foliage has been washed, plant tissue is turgid, soil moisture content is high, temperatures are effectively lower and sun angle and altitude are reasonable. The only disadvantage is the greater possibility of cloud cover affecting the imagery. Nevertheless, one still should have a time-span of two months (as mid-January to mid-February is also acceptable) over a period of years, from which to select the imagery. The imagery for mid-March until the first frosts, lacks the same contrast owing to the maturity of the vegetation (mainly deep green to brown).

It has been concluded that, given "normal" climatic conditions, time of the summer season is important, and that mid-January to mid-March is the best period in which to select false colour composite imagery. As a decision was made not to use post 1982 imagery, few images were available and cloud-cover

was a real problem. (The SRSC commenced direct receiving of MSS data in December 1980.) This forced imagery for practical use to be selected from late January to mid-February. It has been noted, though, that good results were obtained.

A point which may be a disadvantage in the use of late summer imagery is the lack of some contrast in a number of communities with relatively high PCC (50% to 75%), since with the denser vegetation cover typical of mesic communities the greens of the grass layer (5% to 10% of the PCC) are too similar to the greens of the tree and shrub layer and there is practically no response from the soil/geology complex. This situation was not tested. What is also clear from the study is that the smaller the study area, e.g. nature reserves, and/or the more complex the plant communities, the more difficult the choice of time of season, i.e. the more specific or aware one has to be in terms of maximum contrast between individual plant communities in association with each other. It is unfortunate that the vegetation mappers in South Africa (the few that have used Landsat imagery) have not given much time to this important aspect, especially in the original investigation of ERTS 1 imagery.

#### 6. CORRELATION OF GROUND REFERENCE DATA WITH LANDSAT IMAGERY SURROGATE INFORMATION

As stated in section 1, the primary objective of the study was to define relationships between field-measured properties (information classes) and satellite-measured responses. Imagery from the Landsat series of satellites only was used and by far the greater portion of the study utilized good quality summer imagery. In considering the practical use and applicability of the imagery as a mapping tool, at least some level of correlation between the spectral and the field units must exist. This qualitative determination of the relationship between the Landsat data and the attributes of the land surface has been termed "translation" (Graetz et al. 1980). The correlation may be direct, i.e. ground subject under investigation, or indirect, i.e. the ground subject under investigation can be correlated with a high degree of confidence with a particular environmental parameter (vegetation with geological or soil type) which is in turn directly correlated with the

imagery patterns, hues/tones or textures. Meaning must be given to the patterns, hues/tones and textures resulting from the digital data.

The correlation part of the study involved working from the known, the ground cover classes, to the unknown, the spectral cover classes of the image. As stated by Erasmus (1983) the major task is determining relationships between the reflectance information supplied by the Landsat images and the particular area of study. Since the spectral cover classes contain information from the complex landscape surface, the major environmental parameters - vegetation, soil, geology, climate and terrain morphology - had to be considered in the correlation phase.

It must be made clear that no ground or field surveys (collection of ground reference data) were specifically undertaken for this Landsat imagery investigation. The floristic and structural vegetation map was produced prior to the Landsat imagery investigation, using standard procedures. Ground surveys falling within the test area were extracted from data collected. In testing the suitability of Landsat imagery for the accurate derivation of boundaries on vegetation maps, it is imperative that the Landsat image be compared to a vegetation map already compiled using conventional procedures. This minimizes investigator-derived bias. A similar procedure was followed by Jarman (1981).

Prior to the transparency-overlay comparisons between the imagery and the prepared vegetation map, the imagery units were delineated at three levels of complexity, where ink lines were drawn around areas/units which were acceptably heterogeneous (relatively homogeneous) in reflectance levels. In this way a composite, integrated map product was generated where units might correspond to vegetation, soil and geological formations, climate and terrain morphology in varying combinations and degrees. These units were then directly compared to the vegetation map. A series of field trips served to help with the interpretation of the image, especially where discrepancies between the vegetation map and the image occurred.

The Landsat image-associated fieldwork was purely supportive of already compiled data, i.e. double-checking of discrepancies found between the two products and a more detailed classification of the abiotic components of the vegetation units already classified. The 1:250 000 black and white single

and 3-band false colour composites were taken into the field. The location, size and "homogeneity" of the imagery cover classes were checked by means of "minimum content ground referencing", i.e. vehicle tracks through an image unit, appearing on the 1:250 000 topographical map, were located in the field and checked at the boundary between imagery cover classes for a change in biotic and/or abiotic parameters. Likewise, the approximate centre of the unit was checked, as well as the exit area. Using this method, at least three checks (often many more, though some cover classes had to be investigated on foot) were made of each unit and changes in spectral reflectance levels were compared with changes in vegetation physiognomy/structure and floristics, and abiotic parameters, from one cover class to the next. By being subjective, the minimum amount of surface area per unit was sampled, but in such a way that maximum opportunity for correlation between the terrain feature and image unit and interpolation between the sample points resulted.

Much of this section of the paper surrounds the investigation of what the Landsat image patterns, hues/tones and textures actually portray in terms of land cover, more specifically which portion of the imagery information is due to vegetation reflectance values (physiognomy, floristics and functional dynamics) and which portion is due to the abiotic component. It will be shown that the importance of Landsat imagery lies not in the mapping of vegetation units directly, but in the mapping of reflectance classes which can be associated with the distribution of types of vegetation.

#### 6.1 COMPARISONS BETWEEN SPECTRAL CLASSES AND ABIOTIC DATA

The first step in the exercise was the preparation of detailed, supportive information map transparent overlays of soil types, geological types and terrain morphological types. This type of abiotic data had been collected during the field sampling stage so cross-checking was possible. It is interesting to note that occasionally the abiotic field data did not agree with the abiotic supportive information maps, at least in terms of surface-subsurface strata, e.g. soil and geological types. The Land Type maps (primarily soils) at a scale of 1:250 000 were found to be the most inaccurate and geological maps, at the same scale, the most detailed and accurate, but unfortunately few of these maps of the Northern Cape have been completed and published.

### 6.1.1 SOIL, GEOLOGY AND LAND TYPE

Spectral units correlated directly and strongly with soil and geological type (colour) and some strongly with topography and moisture levels. Ellis et al. (1983) reported on detailed soil classifications using Landsat imagery in the Great Karoo and Bushmanland regions. They experienced some difficulty with soils covered by desert pavement. The satellite's sensors record soil colour, which in turn is related to soil properties. In terms of vegetation structure (and physiognomy) and floristics, soil/geology types correlated well with major plant structural types while moisture levels and topography affect the lower scale plant floristic types, some of which are below the effective resolution of Landsat imagery. Although there were some discrepancies between abiotic units and mapped vegetation units, especially in the regions of the boundaries, these were not checked in the field at this stage, but only after the abiotic and spectral cover units had been correlated.

The worst correlation occurred between Land Type cover classes and spectral cover classes. This is because Kalahari sands often encroach and overlie bedrock for some distance in the transitional zone, often not portrayed on the Land Type map. The best fit occurred with the geological cover classes, though these were often shown to be more extensive on the geology map. There were discrepancies between supportive information maps and the Landsat image in terms of roads and other features. Many of these features were new additions to the terrain, not described on the outdated supportive information maps; some were simply inaccuracies inherent in the supportive information maps. This showed that precision geometrically corrected Landsat images could quite easily be used to update and improve the accuracy of supportive information maps and in this context, the Land Type maps were the worst and the geology maps the best.

It soon became obvious that the patterns (units) depicted on the thematic geology and soil maps correlated most accurately with the spectral cover class patterns and spatial boundaries of the imagery. Vinogradov (1977) found congruency of geobotanical boundaries with boundaries of the space images. Discrepancies with the soil type units were frequently due to inaccuracies rather than large changes in soil types. It must be added that soils (especially aeolian sands and alluvium) have the highest range of reflectance on the image (as Graetz et al. (1980) found in Australia). The

Land Type maps, owing to their agricultural orientation, were also based on climatic and terrain morphological changes (slope, aspect). It is possible that these, probably uncorrelated, combinations caused many of the inaccuracies apparent from initial field surveys and later supported by the Landsat imagery. Certainly, one of the most important aspects of the environment and one which reflects the environmental variables the best, viz. the natural vegetation, is the one aspect of the environment which has not been taken into account in the classification procedure used to obtain the Land Type units.

### 6.1.2 TOPOGRAPHY

Spectral cover classes were compared with topographical/terrain morphological classes. The fit was generally good and here, for the first time, it was noted that coarse texture on the image related primarily to elevated terrain - the areas which one could classify as topographically rugged, e.g. Kuruman Hills. These hills are clearly identifiable on the image as a darker (black with a coarse texture) area bordered on the east by the Ghaap Plateau (dark blue, with a finer texture) and on the west by Kalahari sands (yellow to light brown, with a smooth texture). Despite the dark hue, textural differences within the Kuruman Hills cover class were evident especially when viewing the image on a light table. Other Landsat scenes have been investigated which do not contain elevated areas but are rugged in terms of broken terrain. It was found that texture was not as clearly depicted, e.g. Ghaap Plateau broken dolomitic plains and the step-like ridges on the edge of the Ghaap Plateau Escarpment where the hue dominates the textural potential. The Orange River Broken Veld (Veld Type 32, Acocks 1976) between Douglas and Prieska is dissected and contains geological contrasts. It has excellent texture and hue.

It was concluded that topographical change, which was not rugged and did not have good contrast, generally showed up as hue difference or some textural difference masked by dark hues due to the geological similarity. Topographical changes between extensive areas of similar topography showed as patterns of different hues. Slight changes in topography were often more evident on winter imagery than on summer imagery. These were identified as changes in pattern and subtle hue variations. In some cases this could be explained in terms of phenology and seasonality of the vegetation (deciduous woodlands). In other instances, little or no phenological or seasonal

change occurs and the variation in pattern and hue must be attributed largely to changes in sun altitude and azimuth, which emphasize slight altitudinal variation.

In the Kalahari dunefields, tall parallel dunes (15 m to 30 m), with wide dune valleys ("strate"), showed up clearly on the image as dark yellow to brown streaks on a yellow background. Soil and vegetation differences help to emphasize these topographical features. Often changes in slope and aspect were not discernible on the Landsat imagery, especially where these changes covered a small area, e.g. a koppie (1 km X 1 km) appears as a certain hue throughout, regardless of aspect or slope in the middle to upper regions. However, hydrological features such as a maze of drainage lines and dry water courses show clearly as spatial patterning in all seasons but mainly during winter. Drainage basins have a distinct character and pattern, and have high reflectance (Story et al. 1976).

### 6.1.3 MOISTURE AND TEMPERATURE

The following step involved correlation of climatic data with image spectral cover classes. In terms of rainfall/moisture, water bodies are obvious on the image, the hue depicting the depth and clarity and possibly velocity of the water. Deep irrigation dams were always dark, while shallow rivers and dams showed as blue-black. Most interesting was the spectral reflectance of loamy-shale soils around the base of ridges and koppies. They always appeared pale blue just like shallow seasonal pans. On inspection it was found that no standing water occurred though the soil was exceptionally water-logged. Thus Landsat imagery does depict excessively moist soils when vegetation cover is very low (10% to 15%). Alluvium, though associated with perennial rivers, is generally low in moisture content and is not this pale blue colour - neither are the banks of rivers. This soil is well covered by riverine thickets or gallery forests. Soils which have a high moisture content are probably much cooler. High and low atmospheric and ground temperatures may affect the Landsat image and the general feeling was that they do, though no quantitative data was collected in this regard.

### 6.2 COMPARISON BETWEEN SPECTRAL CLASSES AND THE VEGETATION MAP

Comparisons of the prepared vegetation map and the imagery showed a satisfactory fit, though the boundaries in most cases did not coincide exactly. It was evident that certain patterns, hues and textures were

indicative of, or related to, specific vegetation formations (albeit inferred). Smooth-textured, yellow-cream cover classes were always grasslands to sparse woodlands. Pale cream cover classes were vegetation units on alluvium. Dark cover classes were most often closed woodlands or closed shrublands. (Note that the reverse inference cannot always be made, e.g. not all grasslands are yellow-cream.) The image contained many more cover classes than were mapped initially. Some were rather extensive. Most were on a much smaller scale and often depicted classified and described vegetation units designedly not mapped at the reconnaissance scale. These did not raise concern but the extensive, unidentified units and general lack of close fit of boundaries did.

All unmapped, extensive units on the image were in remote areas with no or few access roads and were thus not adequately sampled. Constraints imposed by the nature of work in the field must be understood. In many cases vegetation boundaries were difficult to establish - often the only aid being some elevated vantage point such as a windmill, vehicle roof, tall tree and on rare occasions, hilltops. Often "dead", intervening ground (not visible) was taken to be covered by a certain vegetation type if both the point of survey and the horizon were covered in this vegetation. The Landsat image showed that this was often not the case. A subsequent effort was made to reach these areas. All were found to be real vegetation units and were subsequently incorporated in the classification scheme.

All boundary discrepancies between the Landsat imagery and the vegetation map were checked. It was found that the Landsat image was correct in every detail. Vegetation boundaries were exactly where the Landsat image portrayed them and by means of topographic overlays, boundaries were repeatedly located 50 m to 200 m from where they were portrayed on the systematically corrected image. Sharp field boundaries could be pin-pointed exactly.

Inaccuracies of vegetation boundaries occurred in all ecological regions. The omission of vegetation units was most prevalent in the Kalahari Thornveld Ecological Region (extensive; lacking in access roads and elevated sites) and the Ghaap Plateau Ecological Region (very broken, rugged terrain; access in the vicinity of the escarpment on foot only). The imagery has thus shown the importance of obtaining good ground reference data before a vegetation map and

classification is attempted, let alone before Landsat imagery can be interpreted! Lastly, one must not underestimate the powers of inference. Once a unit has been identified using ground reference data combined with pattern, hue and texture on the image (geographical dimension), then associated or related areas for which data exists, can be similarly classified.

As a result of the comparison undertaken between the conventionally prepared vegetation map and the false colour composite Landsat image, a new map was compiled (Appendix 4). Several aspects of the map are worthy of mention.

The spectral units are most closely related to landscape units because the satellite sensors record the total environment. The map legend reflects this, although major emphasis is given to description of vegetation. The colours on the map depict the broadest grouping: units on unconsolidated Kalahari sands (red), Kalahari ecotones (orange), units on elevated sites (brown), grasslands (yellow), shrublands (blue) and riverine plains (green). These are based primarily on topography.

The broadest vegetation-landscape units are the ecological regions. There are twelve of these in the area covered by the Landsat image. Of aerial importance are: Kalahari Thornveld, Kuruman Hills, Ventersdorp Lava Hills (Kimberley-Vryburg Woodlands), Harts River Valley, Kuruman Sourveld, Ghaap Plateau and Vryburg Shrublands. The ecological regions are based on vegetation, soil/geology and topography. An ecological region contains one to several vegetation types which in turn may contain one to several major plant communities (indicated by an alpha-numeric code in the legend). Any given ecological region potentially contains several structural groups and formation classes, e.g. low, closed grasslands, tall, open shrublands and short, sparse woodlands.

### 6.3 DISCUSSION OF SOME NOTEWORTHY POINTS WHICH EMERGED DURING THE COMPARISON PHASE OF THE STUDY

1. Vegetation patterns fitted the spectral cover classes portrayed on the imagery exactly. It was noted that the imagery often portrayed the interrelationships between vegetation types and between plant communities. Various ecological regions were easily discernible from each other in terms of broad spatial patterns, hues and, in some cases, texture. It should

also be mentioned that, on several occasions, floristically similar vegetation units were portrayed as having little interrelationship with regard to spatial pattern and texture, and especially hue. This was disappointing and the importance of having good ground reference data was emphasized once again.

2. It was quite clear that successional stages of the vegetation, caused by various farming management systems, affected the spectral cover classes of the Landsat image. Often specific farm boundaries were depicted on the image, and in a number of cases, farm camps. This related to the grazing systems, regimes or strategies employed by the various farmers. Often the same vegetation units spanned several farms but the grazing strategies appeared as various intensities of reflectance, divided from each other by straight lines corresponding with fences. Rotational systems showed several adjacent, subtle changes in spectral reflectance intensities. In some areas, over-utilization was readily evident. Generally, the most over-utilized areas had a high spectral reflectance resulting from the increased soil exposure. Synoptic evidence of the fact that degradation of the vegetal cover and subsequent erosion leads to high reflectance was shown clearly by Clarke (1986) and Van Wyk (1986). Frank (1984) investigated whether the effects of changes in vegetation cover and subsequent erosion could be isolated and recorded by Landsat sensors. He concluded that albedo emerged as the single most important indicator of change in vegetal cover. A few areas with dark soils and lighter vegetation were portrayed as low spectral reflectance cover classes (dark hues) when the vegetation was over-grazed.

In elevated terrain, e.g. the Kuruman Hills, with strong texture on the image, successional aspects of the vegetation were always difficult to ascertain; probably because of the strong texture and the heavy, dark-coloured cover classes associated with these spectral reflectance units. (Elevated terrain generally has a high percentage of surface geology and shadow, and, because of the slopes, emits a low level of direct radiation into the atmosphere.)

The Kalahari Thornveld showed the successional aspects most clearly because of a strong field layer consisting mainly of grass species, i.e. sparse to open, short *Acacia* woodlands. The grass stratum was responsible for approximately 75% to 95% of the spectral reflectance due to vegetal cover. Domestic stock

and most game species are grazers. High stock or game numbers result in heavy use of the grass layer which has a marked effect on the spectral reflectance. Often crude stages of succession such as pioneer, sub-climax and climax could be extrapolated over large sections of the image once the reflectance resulting from each stage had been identified in the field for a given ecological region and had been correlated with a hue or hue-range on the image.

Successional stages in some of the ecological regions were not easy to discern on the image. In general these, unlike the elevated terrain example, were intermediate to closed, tall to high woody shrublands with dark green canopy foliage, (e.g. the eastern areas of the Ghaap Plateau Ecological Region). The grass layer is well hidden by the woody shrubs. The majority of browsers utilize the lower half of the shrubs. This results in a well-grazed grass layer not readily detectable from above. Besides the extensive removal of the grass layer, the only other notable change in the vegetation, which could affect the spectral reflectance, is due to the phenological and seasonal differences in deciduous-dominated communities (*Acacia mellifera* and *A. karroo* dominated communities).

As a generalization, high albedo is usually associated with degraded landscapes in Landsat imagery (decreased vegetation cover, increased soil cover and possibly erosion). Knowledge of the type of vegetation and soil cover is necessary for a given vegetation-landscape unit before changes in albedo can be related to successional stages in the vegetation (cover, quality, etc.). The relationship is not always as simple as reflectance tending to decrease with an increase in vegetation cover (Frank 1984). Albedo is also affected by soil moisture, and strip rains in the Northern Cape also affect reflectance levels, as do topography background changes in soil colour and slope angle and aspect. The effects of phenological changes on albedo are discussed below. There is thus a danger of falsely attributing changes in albedo to successional changes in vegetation ranging from reduced cover to dense bush encroachment. Furthermore, the direction of change cannot be concluded from changes in albedo within a terrain unit, i.e. vegetation condition cannot be assessed. Warren & Hutchinson's (1983) study on indicators of rangeland change and their potential for remote sensing showed this fact clearly. The study revealed that an increase in albedo due to destruction of the grass layer is followed by a decrease in albedo as shrub

and bush encroachment commence. Therefore, misleading conclusions could be drawn if albedo is related to environmental degradation without taking into account the type of vegetation cover. A wide range of albedos could result when reflectance from vegetation in varying successional stages is combined with reflectance from the abiotic parameters. Similar reflectances may be observed from units or subunits in very different stages of succession. Comment on the degree of disturbance in a unit and its effect on reflectance can be made on comparison of current condition, and potential condition and potential reflectance level.

3. An interesting phenological aspect of annual loss and production of new foliage in the large shrubs and trees of the Northern Cape is that the majority of species are, what the author has termed "11,5 month evergreen", where leaf-fall occurs with the high winds at the end of winter or the onset of spring. At the same time or closely thereafter, new foliage is produced. Exceptions are species such as *Diospyros lycioides*, *Ziziphus mucronata*, *Acacia mellifera* and *Terminalia sericea* which are early- to mid-winter deciduous. It is in these communities that seasonality and phenological changes are discernible on the imagery. (Warren & Hutchinson (1983) recorded reflectance level differences relating to leaf growth phenology). This is especially true of the *Acacia mellifera*- and *Terminalia sericea*-dominated vegetation units. These communities are commonly extensive, especially in the Kalahari Thornveld Ecological Region. The time of leaf-fall is related to the susceptibility of these species to winter frosts. In years of below average rainfall the majority of large shrubs and trees have early-winter leaf-fall. Some years experience outbreaks of phytophagous caterpillars which strip the foliage from as much as 50% of the population and 90% of the leaves of several *Acacia* spp. The obvious effect of this leaf-loss is higher soil-surface reflectance. The sudden flush of new growth shows as a faint red tinge to the cover class, more obvious in the Kalahari Thornveld *Terminalia sericea* woodland owing to the contrast of the new leaves with the high-reflectance background of the pale, leached Kalahari sands. McDaniel & Haas (1982) showed quantitatively that Landsat MSS data are sensitive to seasonal change in vegetation growth within a relatively uniform vegetation/soil system. (This would support the method of stratifying relatively uniform vegetation-landscape units on Landsat imagery.)

The effect of other new-growth vegetation in communities along river banks and drainage lines, dominated by *Acacia karroo* and *Prosopis* spp., was evident. When using satellite imagery it is important to be knowledgeable about seasonal changes and the spectral response associated with such changes (Hoffer 1971). The only primary hue that could be ascribed, with absolute certainty, to plant material, is the magenta-red of actively growing mesic vegetation and natural vegetation along water courses. In one of the images the distribution and potential spread of *Prosopis* spp. could be noted. (*Prosopis* spp. are aggressive exotics, spreading rapidly throughout the semi-arid regions of South Africa, having their nuclei in dry finger-like drainage lines which cover vast areas of the Northern Cape and Karoo.) Capehart et al. (1977) experienced great difficulty in isolating the spread of the exotic *Melaleuca quinquenervia* in southern Florida, even using sophisticated, computer-based techniques.

4. In the Kuruman Hills, with the same geological formation throughout, the mosaic of complex kloof thickets interspersed with woody shrublands on slopes and grassland on crests and plateaus, was obvious on the image. Were the changes in reflectance due to changes in vegetation or topography or both? Certainly shadows caused by the terrain morphology as well as the vegetation are appreciable. From these investigations and many similar correlations, it must be concluded that spectral reflectance directly due to the vegetation is low (except in a few plant communities), but that part which is responsible is reflected as faint, often different, hues superimposed, so to speak, on the dominating hue of the soil/geology complex. In some cases, this faint hue is totally masked by the background hue. Contrast between the (mainly) soil/geology background and the foreground vegetation is important for quantitative measurements. In many differential environmental studies, reflectance from various environmental parameters, both biotic and abiotic, is viewed as disadvantageous. In this investigation it proved most helpful, giving much-needed contrast.

However, lack of contrast in winter imagery solved a number of problems. Encroachment of *Acacia mellifera* ssp. *detinens* due to overgrazing appeared as slightly darker areas on summer imagery. Winter imagery reflected the true nature of these areas, i.e. that they should belong to the surrounding vegetation type. This was due to the winter deciduousness of *A. mellifera*, allowing the underlying environmental parameters to dominate the reflectance

signal. A more faded, uniform spectral class resulted for the entire region. This example related to the Ghaap Plateau Ecological Region and had important implications for the mapping procedure, despite the fact that summer imagery was used.

A. *mellifera* bush encroachment is even more extensive in the Kalahari Thornveld Ecological Region, but the winter imagery was of no help in this case. Unlike the Ghaap Plateau Ecological Region, winter deciduous tree species dominate in the Kalahari Thornveld Ecological Region. Reflectance levels are dominated by white grasses and red sands. The winter imagery of this region consists of pale cream, yellow and fawn hues, and even if the imagery is enhanced for maximum contrast, many major plant communities are still not discernible. It is clear that imagery suited to one region may not be suited to another.

#### 6.4 DISCUSSION

Initially, it would seem that, in a vegetation classification study, there would be little point in extrapolation from the known vegetation to the unknown spectral cover classes. The aim of the study, however, was to test applicability of Landsat imagery as a tool in the accurate positioning of vegetation boundaries for mapping purposes, i.e. the relationship, if any, between the satellite's reflectance data and the ground reference data. The physical basis for spectral differences must eventually be identified, otherwise the reason for this spectral class will not become apparent (Salmon-Drexler 1977). Without the identification of the character(s) most responsible for the spectral class's uniqueness, no extrapolation is possible.

It is evident that there is reasonable to excellent correlation between the patterns of the prepared vegetation map units and the spectral cover classes, though Little & Scotney (1973), in their initial evaluation of ERTS 1 imagery, found a general lack of correlation with previously defined ecological units. The quality of current imagery, however, is far superior to that of ERTS 1. In addition, there is the possibility of less success in the high PCC areas of the eastern regions. Similar results were found by MacVicar (1973), with respect to soil types in increased rainfall areas. What is clear from this study is that where several dense, dissimilar, adjacent vegetation units occur, they are difficult to separate visually on

the image. The degree of contrast does not correspond with the environmental differences. Perhaps the lack of exposed terrain features (hidden by the dense canopy and thus unavailable to the satellite's sensors) has led to this unfortunate inseparability.

In the semi-arid to arid western regions of South Africa, one knows from the outset that the differing spectral classes may not be (and often, are definitely not) due to contrast in the vegetation alone. Nevertheless, in the search for the ideal image to use for mapping, one still looks at contrasts in the vegetation when choosing times of imagery to be sampled. There must be a starting point in the investigation - geologists choose geology, soil scientists soils and vegetation ecologists vegetation. The investigator must be aware of the part other surface features may play in the total spectral response of a specific cover class, whether on the ground or on the image. After all, the ground cover and the image are constantly being interrelated. Spectral cover classes on imagery of the western regions are almost always "multiple parameter" cover classes in that they represent the aggregate of the reflectance from several different environmental parameters. Maximum contrast within the vegetation layer, combined with contrasts due to remaining environmental parameters, results in maximum overall contrast.

Where spectral and vegetal boundaries are similar, patterns, hues and textures within the spectral boundary are due to the reflectance from the vegetation or some other variable with similar distribution. This must be known before alterations can be made. What exactly are the sensors on the satellite measuring? To make any sound judgement, detailed, relevant ground reference data must be available. The sensor must be sensitive to the data before one may look at the possibility of the data having a secondary correlation with the vegetation. Many authors have tried using Landsat MSS data (especially computer processing and recognition schemes) to classify parameters impossible for the satellite to sense. In these cases results may be highly circumstantial (Salmon-Drexler 1977). McDaniel & Haas (1972) reported that much of the reflectance from plants originates from the leaves. This resulted from the characteristics of the leaf structure, maturation, quantity, relative ground covered by and the density of the leaves. At best, separation of vegetation types is dependent on vegetation cover and not species. Only a few environmental features are sensed. If there is good

correlation between vegetation types and these physical features, then these features may be used indirectly, via the image, for classification and mapping purposes.

To pinpoint the data accounting for the spectral cover class on the image, ideally one needs to refer to more than one image, and imagery preferably from different seasons. In this part of the study, only winter and summer false colour composites were used (although some information was also obtained from earlier black and white imagery, band 4, acquired for the initial comparison of information). Unfortunately no "time of season" differences in winter imagery were used.

It is at this stage that refinement in visual interpretation techniques is at its height, i.e. in vegetation types with moderate levels of PCC, the interplay between vegetation structure, functional dynamics and floristics, moisture, temperature, soil and geology types and terrain morphology is at its most critical. It is also at this stage that the value of detailed ground reference data is at its most appreciable. Every change in spatial pattern, hue and tone, as well as textural class, must be interpreted, otherwise the worth of the image cannot be truly evaluated, i.e. one cannot aim for greatest complexity or detail on the image without knowing that the complexity is meaningful. It was found that every image cover class, 4 km<sup>2</sup> to 6 km<sup>2</sup>, could be traced in the field. In fact, outstanding ground units such as small calcrete pans and farm homesteads, 50 m x 50 m to 100 m x 100 m, are frequently traceable on the Landsat image, as long as they contrast well with the surrounding units. To know which parameter is responsible for the different spectral response may prove more difficult. In using Landsat imagery for vegetation purposes, in the field one looks at changes in the vegetation over the summer season and then compares the times of changes with imagery of similar times. This is relatively straightforward in regions with high PCC of the vegetation where one is guaranteed of a good percentage of the spectral response being associated with the vegetation. These regions usually receive in excess of 450 mm rainfall per annum. Problems in contrast may arise where over 80% of the PCC of the vegetation is due to large shrubs and trees, as not much contrast in this vegetation may occur during the summer months and one may have to rely on autumn months or even change to winter season imagery.

#### 6.4.1 SOIL/GEOLOGY COMPLEX

Soil/geology complex, topography, climate and vegetation were involved in the final total spectral reflectance of an image cover class. No single abiotic component is wholly responsible for the spectral reflectance classes depicted on the image. In some units one variable was more dominant; in other units, another was. It is often difficult to know just which variable is spectrally dominant. The general impression was that the soil/geology complex played a greater role than did climate, topography and vegetation. This was inferred mainly from the much better fit of the spectral reflectance units and the soil/geology units (based on field data and support maps). Timberlake (1980) came to the same conclusions.

In many cases it is obvious that bare soil cover accounts for most of the reflectance value. As was found by Graetz et al. (1980), bare soil, in contrast to all the other combined attributes, is the key component to Landsat applications in arid and semi-arid regions. In the mapping of natural vegetation using satellite imagery, discrimination of the vegetation from the soil background is not of primary importance. Where this does play an important role is in the analysis of agricultural crop production. In their comprehensive study of the effect of soil background on vegetation discrimination using Landsat data, Ezra et al. (1984) showed that vegetation greenness (phytomass) is not influenced by soil background, while changes in background soil do influence vegetation greenness. Moist soil adds to the contrast of the spectral unit portrayed. Obviously, there is in most cases other than alluvium and areas where soil has been carried by water or born by wind and deposited far away from site of origin, a direct relationship between soil type and parent rock. From field surveys and aerial photographs, it can be seen that the soil type has a much higher percentage cover than geological type. Based on this fact, it may be concluded that in terms of abiotic units, generally soil type accounts for most spectral reflectance, followed by geology, then topography and lastly climate. Kalahari sands, being the most extensive and the least variable, result in large areas of the image having high reflectance and lacking good contrast though several very different (physiognomy, structure, floristics) vegetation units occur. It may be concluded that bare Kalahari sands account for as much as 80% of the spectral reflectance from these information classes. Similarly, the Kuruman Hills with an increased percentage of exposed, "hard" geology have low reflectance, although some of the plant communities support vegetation which

should result in high reflectance (plateau grasslands). The impression was also gained that, where geology is close to the surface, though not necessarily visible, it possibly accounted for some of the reflectance.

#### 6.4.2 VEGETATION

The most variable environmental parameter affecting the reflectance from the landscape is the living vegetation, especially in phenological and seasonality changes between winter and summer, yet investigations show that probably the least percentage of the total spectral reflectance in a given cover class on the image is due to the vegetation. Comparisons of winter and summer imagery show that, for the most part, the patterns, hues and textures are very similar in the two images. In the images investigated, generally the highest PCC's occur in the north of the Northern Cape and the lowest in Bushmanland. Vegetation PCC ranges from approximately 50% to 10% respectively though obviously the full range occurs on the northern image while one would be hard-pressed to find 50% PCC in Bushmanland. Undoubtedly, the generally low PCC plays an important role in the spectral reflectance directly due to the vegetation (or lack thereof). The only areas where the reflectance from the vegetation dominates the total recorded, are cultivated pastures and irrigated croplands adjacent to the large perennial rivers, viz. Orange, Vaal and Harts rivers.

Which characteristic is responsible for the reflectance from vegetation - physiognomy, structure or floristics? If the spectral cover classes represent integrated landscape units, then the answer to why two cover classes appear different can always be validated in the field as long as one or more of the variables is different in the two landscape units under investigation. When investigating the characteristic of the vegetation which accounts for the spectral reflectance due to vegetation, one needs two landscape units which have all variables, except vegetation, being equal. This situation is extremely difficult to find in the field. The vegetation is the most sensitive variable to any change in the environment. In practice, vegetation change was always accompanied by a change in soil/geology (resulting in large changes in structure and floristics), and/or topography (resulting in moderate changes in structure and floristics), and/or rainfall (vegetation changes occurring on a subregional scale). One situation where all abiotic variables were within acceptable limits of uniformity, but where the vegetation was different, was the transitional

zone between the Kalahari Thornveld in the north and the adjacent Ghaap Plateau in the south. In this area, the calcretes, typical of the Ghaap Plateau, are shallowly covered with red, aeolian Kalahari sands. The grass layer is thus a mixture of Kalahari and Ghaap Plateau types, while the trees and large shrubs are typical of the Ghaap Plateau. The important point is that the Landsat sensors are able to measure surface reflectance only. The calcretes, while affecting the vegetation, are hidden by the Kalahari sands. The vegetation, compared with that of the Kalahari Thornveld to the north, is floristically quite different but structurally and physiognomically quite similar. Spectrally, the two vegetation units are sufficiently similar to be grouped as the same cover class at first level subdivision of the image. It would thus seem that structure/physiognomy accounts for more of the spectral reflectance than the actual species involved, though dominant species can be obtained from the ground reference data. Jarman (1981) reported a strong link between vegetation height and spectral map class. By way of contrast, in this study, it was found that usually the same spectral signature was obtained for the same vegetation units of differing heights. In the Kalahari Thornveld, extensive physiognomic vegetation units show reduction in height of the dominant tree and large shrub species towards their extremities. On the image, these units are similar throughout.

The broadest level of classification is what has been, for the purpose of this study, termed "ecological region". These are also the most extensive areas on the image, which readily group together in terms of general pattern, texture and hue. Ecological regions have the same soil formation, parent rock, general terrain morphology, general vegetation structure, physiognomy and floristics. The resolution of satellite images, unlike that of aerial photographs, does not allow any identification at the species level. However, using surrogate data, species may be identified if they are a) densely packed and b) cover an area of at least a few hundred pixels, and then c) only if the canopy foliage is very different in colour to the other species in the vegetation unit. The species must be spectrally distinguishable from differences within the vegetation cover (Salmon-Drexler 1977). The canopy uniqueness must relate to a specific species or group of species (Morain 1974). Only canopy-dominant species, with spectral detectability have potential. Changes in image pattern, hue and texture within a given vegetation unit must be shown to be a function of changes in the species PCC in a highly homogeneous plant community, without any

noticeable (reflectance sensitive) change in the other attributes of the community. This is practically impossible in medium to small scale studies. Grassland areas which are interspersed with thicket patches (sour grassland east of the Kuruman Hills, with patches of *Acacia karroo* - *Diospyros lycioides* thickets) are an example, but the cover within the thickets must be approximately 75%. It was noticed that soil/geology of the thicket patches was very different and one must be sure that this is not responsible for the spectral differences. It is extremely difficult to produce floristic maps from Landsat imagery; most floristic units are derived through inference.

Structural as well as floristic vegetation units can be identified on the image, though, in the semi-arid regions, their identification is most often ancillary, using surrogate soil/geological or topographical units. The use of surrogate information notwithstanding, structural and floristic vegetation units may be identified. However, this does imply that the parameters responsible for the cover classes must be adequately recorded during field investigation. A broader, landscape-orientated method of data assimilation and analysis is required. This results in the classification and mapping of natural ecological regions.

It must be noted that clarity or distinctiveness of pattern, hue and texture on the image does not necessarily relate to the same degree of distinctiveness or lack thereof in the environment, e.g. subdivisions of the Ghaap Plateau Ecological Region lack clarity on the image, while those of the Kalahari Thornveld do not, yet in fact the subdivisions of the two regions may be regarded as hierarchically equivalent. Sweet et al. (1980) reported similar findings where some related but reasonably distinct communities are not differentiated on the Landsat image. The situation was not a common occurrence in this study, where scale of investigation was relatively extensive. Several investigators reported an inability to distinguish between grasslands and sparse to open woodlands (Jarman & Edwards 1972). However, these authors worked with inferior products. Little & Scotney (1973) reported an inability to distinguish Moll's (1965) *Aristida junciformis* and *Themeda - Trachypogon* grassland types with ERTS-1 imagery. In the Northern Cape, the distinction between grassland types often required sensitive interpretation, except between Kalahari types and all others, where good results were obtained. Grasslands are physiognomically similar and thus abiotic factors play an important role in their separation on the

image. In terms of hue, grasslands are generally lighter (higher reflectance) - yellows, creams and whites. In terms of texture, grasslands are smooth, while sparse to open woodlands are finely grained. In this region, grasslands constitute a smaller area; thus a corresponding result is obtained in terms of image pattern. Using similar techniques, distinctions can be made between other formation classes such as shrublands and woodlands.

#### 6.4.3 THE IMPORTANCE OF GOOD GROUND REFERENCE DATA

Ground reference data include all field-measured variables, plus data from aerial photographs and supportive information maps. Wessels & van Vuuren (1986) clearly showed the importance of extensive ground reference data in arid region investigations. In this study of Landsat imagery and vegetation mapping, the identification, delineation and mapping of vegetation types - floristic and physiognomic - are of importance. Without ground reference data, the imagery is practically useless. In fact, owing to the great amount of detail on the image, the more detailed the ground reference data, the more valuable the image becomes. Worcester & Dalstead (1980) drew a similar conclusion in this regard in their soils classification investigation. The spectral variations in the imagery relate to features on the earth's surface. In areas such as the underpopulated and extensively farmed, arid to semi-arid regions of western South Africa, these variations are an indication of the number and size of cover types which are of interest to the reconnaissance scale vegetation mapper. The vegetation ecologist must become knowledgeable about causes of spectral variability so that the Landsat data can be interpreted more accurately (Hoffer 1971).

Several investigators refer to aerial photographs and supportive information maps as adequate ground reference data or "ground truth" (an unacceptable term) (Curran 1981). This is a rather dangerous practice, as many supportive maps are less accurate than the Landsat image being tested. Aerial photographs are more accurate but do not supply the same synoptic view. Aerial photographs and satellite imagery should not be compared on a competitive basis as was done by Quirk & Scarpace (1982), especially when scales differ so markedly. Furthermore, thematic maps frequently display only one type of theme, e.g. soil, geology, floral regions, whereas the Landsat image depicts features responsible for spectral cover classes, which are usually composites of several themes. These cover classes may not even delineate the feature which is of interest to the investigator. As stressed

before, the landscape is an integrated system; when one environmental variable changes, so do others. It becomes difficult to know whether one is mapping the soil/geology complex, topography, vegetation or any other environmental variable, as these variables are so interrelated (Armstrong 1975). Without personal knowledge and good ground reference data, supportive maps could be (and often are) misleading in pattern recognition and feature extraction investigations. It is of interest to note that the field ecologist/range manager relies heavily on field reference data for visual interpretation of Landsat imagery, using other landscape orientated maps as true supportive information; the laboratory ecologist/computer orientated researcher relies heavily on supportive maps, aerial photographs and resource managers as sources of "field reference data". In the western half of South Africa, the problem with the latter approach is that aerial photographs and supportive maps are often outdated, lack detail and are too inaccurate for use as a basis in highly quantitative, objective investigations.

Often the accuracy of remote sensing maps is judged by "ground truth" maps (Smedes 1975). Smedes agreed that the implied assumption that the "ground truth" map more closely approaches the "truth" is not valid for maps of the terrain surface, except possibly geological maps which show surface-subsurface bedrock. Ironically, maps produced of the terrain surface from Landsat imagery are often more accurate than the current ground control reference maps. Smedes (1975) stated that the reasons for the difficulty in making an accurate "ground truth" map of the surface terrain include spatial complexity, mixed terrain classes and the problem of boundaries. The lack of complete homogeneity of natural cover classes results in mappers using the "best fit" when depicting the spatial distribution of cover classes. For this reason, the term "minimally heterogeneous" rather than "relatively homogeneous" has been used in this paper. The Landsat image is generally more accurate because it is a pictorial display of the complex variations of cover classes. The accuracy of boundaries is a function of the contrast between the Landsat image spectral cover classes. In initial comparisons between generalized supportive maps and Landsat imagery derived maps, one is inclined to believe that the latter are erroneous.

Transitional zones and ecotones between two or more vegetation units result in investigators differing markedly in the positioning of boundary lines. At a scale of 1:250 000, the difference may be as much as several kilometres.

Of course, this is also a problem of scale. Small scale maps often ignore broad ecotones; on large scale maps, the ecotone may be raised to the level of a separate unit altogether. It is interesting to note that it was found that the boundary lines could be positioned more accurately after consulting the image. Beyond this level, the production of super accurate maps is a waste of time, money and effort, and is not justified in terms of the scale of survey, classification and mapping under discussion.

As has been shown, "ground truth" maps were found to be less accurate than the Landsat imagery being tested. Furthermore, there were disturbing variations between maps in aspects where they should have been identical, e.g. towns, rivers, roads. This created additional problems with transparency overlays. The intention was to overlay transparencies on the image to check surface features, but often the image had to be used as a source of accurate information. The image also contained recent changes in man-made surface features. With good ground reference data and a good "on the ground knowledge" false data could be corrected.

In the 1970's, the term "ground truth" became unpopular. Errors in data collection have caused ground truth to be false data (Hoffer 1971). With regard to those authors who have used or are using aerial photographs and supportive information maps as "ground truth" data, this phrase is misleading. Terms such as "ground reference data/ observations", "surface reference data/observations" are preferred. In the literature, a clear distinction should be made between data collected in the field and that obtained from aerial photographs and/or supportive information maps. In the identification of conifer species groupings using Landsat digital data, Mayer & Fox (1981) referred to aerial photographs in the accuracy evaluation. This photo-interpretation serves as ground reference data and the assumption is made that it provides the true vegetal cover. Ground or surface reference data must include terrain sampling data. After analysis of the data extrapolations and interpolations may be made using aerial photographs and/or satellite digital data.

What type of ground reference data should be collected? Generally, the ground reference data required must be closely related to the objectives of the research and the problems involved (Hoffer 1971). In phytosociological investigations, the majority of the data relate to the classificatory aspect

of the vegetation. This, in itself, may be viewed as the end-product. In many studies, the production of a vegetation map is not considered. Data collected in community classification is, with further manipulation, readily usable in the production of vegetation maps. Many vegetation ecologists shy away from the final mapping stage - often the most important stage for the end user. In a study such as this, where one is required to establish the correct type of ground reference data with which to test the applicability of Landsat imagery in the production of a vegetation map, complete and detailed environmental records over areas remotely sensed, are imperative. Accordingly, an area which had been surveyed in detail was chosen. An example of the field data sheet appears in Appendix 1.

The Landsat image was interpreted using this field data and those parameters which related to the spectral reflectance cover classes were identified. Obviously the final assessment rested on the degree of correspondence between the spectral cover classes and the vegetation cover classes. It was at once evident that adequate ground reference data played a key role in the success of the investigation. The amount of detailed data required for image interpretation is not as great as that required for the Braun-Blanquet phytosociological method of vegetation community analysis and classification. Floristic data, however, is required for the key to units depicted on the map (subdivisions of larger physiognomic units). Other data required in the interpretation of plant communities but not for image interpretation, are subsurface data such as underground bedrock, subsurface rock size, shape and percentage by volume, depth of soil, soil pH, moisture content and depth of water table. It is obvious that, in this case, relevant ground reference data did not have to be obtained at the time of the overflight of the satellite.

In brief, the type of data collected in the field must be related primarily to the objectives of the research. If Landsat imagery is to be used in the production of a vegetation map, then the data collected must also take into account what the spectral cover classes represent in the field. The three primary types of measurements obtained from the image must be considered (Hoffer 1971):

- a) Spectral - variation in reflectance (hue and texture)
- b) Spatial - geographical distribution (patterns of hue and texture)
- c) Temporal - year, season and time of season.

Temporal aspects are most often overlooked. In the semi-arid regions, natural perturbations occur frequently, often with marked changes in the natural vegetation. Phytosociological studies represent the vegetation at one point in time. Hopefully the time of study represents the "normal" situation (unless the study is investigating a specific condition). What is "normal" in these areas? The vegetation is adapted to natural utilization and climatic perturbations (often cyclical, with a duration of at least a decade) and responds with parallel changes in species composition, abundance and distribution. It becomes important to know about these changes and collect pertinent ground reference data to interpret the spectral response associated with such changes.

## 7. CONCLUSION

This paper has examined the issues that arise in the visual interpretation of Landsat data for the analysis and mapping of natural vegetation on a regional basis. Initially a suitable mapping scale was selected and the scales of survey and remote sensing were based on this. For practical reasons, a mapping scale of 1:250 000 was chosen, and thus the scale of survey was 1:50 000. Satellite imagery at a scale of 1:250 000 was found to meet the requirements of reconnaissance level mapping adequately. Timberlake (1980) used imagery at a scale of 1:500 000 with some success in his reconnaissance mapping of south-east Botswana. He concluded that while this scale served mapping purposes adequately, imagery at a scale of 1:250 000 would have been more suitable.

It was found that the usefulness of the Landsat imagery was markedly affected by the quality of the image production and enhancement. Systematic correction and edge-enhancement of the image are essential. Precision geometric correction is not required for reconnaissance level investigations. Interaction between the user and the operations engineer during the process of image production results in an image which is tailor-made to suit the needs of the user.

Three-band false colour composites are superior to single band, panchromatic images when using manual interpretation. Since the environmental parameters

affecting the reflectance data are relatively to very stable over time, it is not necessary to acquire imagery of the same year as field surveys. The year of imagery, however, should be chosen so that similar conditions prevail. Summer imagery is, in most respects, superior to that captured during winter. The latter may be of use in certain instances such as the unravelling of complex mosaics which contain deciduous vegetation. Furthermore, the ideal period during which there was maximum contrast between and within ground classes, and thus spectral classes, was narrowed to the latter third of summer.

The effects on the spectral classes of abiotic factors (soil, geology, topography and climate) were investigated. Broad subdivisions on the image most often had a high degree of unity in terms of pattern, hue and texture and in the field were found to have a high degree of unity in terms of soil, geology and frequently, terrain morphology. In many cases, discrepancies between spectral classes and supportive information maps were due to inaccuracies in the latter. In this regard, the Land Type maps were the worst and geology maps the best.

There was generally a close degree of correspondence between the prepared vegetation map and the delineated image. On further field investigation, it was found that the image units were more accurate than the vegetation map units, and the image served to highlight inadequacies inherent in classifying and mapping the vegetation of extensive areas with limited resources. In addition, it was found that certain patterns, hues and textures on the image could be related to specific vegetation formations, but that the vegetation, per se, did not necessarily account for a large percentage of the spectral reflectance of the unit. Most often the natural vegetation was found to account for a small percentage of the spectral reflectance due to the low PCC. Natural vegetation, nevertheless, is extremely sensitive to changes in the abiotic components, and thus a close correspondence between the image and the vegetation could be inferred. Vegetation maps produced using satellite imagery as a central resource contain vegetation-landscape units. The multispectral image contains surrogate data of parameters used in the classification of the landscape, i.e. vegetation, soils, geology, topography and climate (moisture and temperature).

It was shown that:

- a) The boundaries delineated on the Landsat image were real in terms of soil types, geological types, vegetation, and frequently, terrain morphological type as well.
- b) These delineated units had unique combinations of the above parameters.
- c) The units were minimally heterogeneous throughout the range of variation of the above parameters.

The spectral classes delineated on the image cannot be arranged in an orderly and meaningful manner directly. Once the spectral cover classes have been shown to portray specific ground cover classes, the basis for a classificatory system is available. To this end, suitable and adequate ground reference data is essential.

In conclusion, the close agreement between the image spectral reflectance cover classes and the spatial distribution of vegetation units, albeit mainly structural and physiognomic, makes Landsat imagery a valuable tool in the production of accurate vegetation maps (1:250 000) of the semi-arid regions of South Africa. It must always be remembered that soil/geology plays a dominant role in the formation of image cover classes, but that there is also a high correlation between soil/geology and vegetation. Jarman (1981), Nelson & Hoffer (1979), Craighead (1986) and the author have found that Landsat remote sensing techniques can alleviate logistical problems by reducing the amount of fieldwork required: thus timely information can be provided to planners (Anon.[c] 1986). Satellite imagery is an additional aid to mapping vegetation-landscape units at the reconnaissance scale, but it is imperative that ground reference data be available for the recognition process.

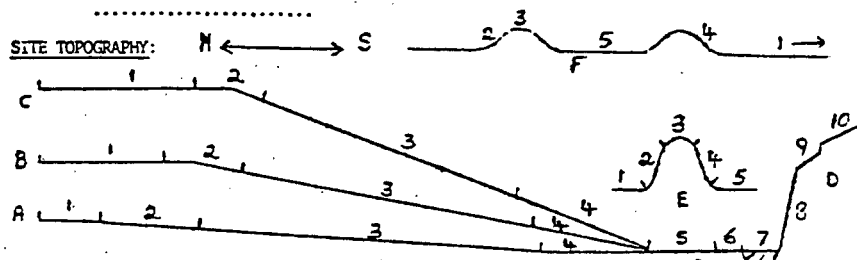
Appendix 1 An example of a field data sheet used in the investigation, analysis and classification of the vegetation of the Northern Cape. Major emphasis is on the recording of floristics and structure.

FIELD DATA SHEET

STRUCTURAL-VEGETATION ANALYSIS

MMK/12/EC3

NAME: ..... DATE: ..... SAMPLE NO: ..... AREA: .....  
LOCALITY: ..... GRID REF: ..... ALTITUDE: .....  
GEOLOGY: ..... ASPECT: N NE E SE S SW W NW N



- |                   |   |       |                       |       |
|-------------------|---|-------|-----------------------|-------|
| TALLS, TERMITARIA | A | ..... | LEVEL (0 - 3°)        | ..... |
| DUNES, KLOOF      | B | ..... | GENTLE (4 - 8°)       | ..... |
| PAN, VLEI         | C | ..... | MODERATE (9 - 16°)    | ..... |
| KOPPIE, VALLEY    | D | ..... | STEEP (17 - 26°)      | ..... |
| PLAIN, CLIFF      | E | ..... | VERY STEEP (27 - 45°) | ..... |
| SLOPE, HILL       | F | ..... | PRECIPITOUS (>45°)    | ..... |

OTHER/EXPLANATION: .....

BIOITIC INFLUENCES: GRAZED BROWSED ERODED BURNT PATHS ALIEN VEG.

OVERGRAZED TRAMPLING DUNGHEAPS DUSTEATHS

OTHER/EXPLANATION: .....

PARTICLE SIZE: DUST SAND PEBBLES ROCKS BOULDERS BR PROFILE:

ROCK COVER : o r + 1 2a 2b 3 4 5

BARE SOIL COVER o r + 1 2a 2b 3 4 5

SOIL COLOUR : BLACK GREY WHITE YELLOW PINK RED BROWN

- SITE DRAINAGE:
- 1) IMPEDED - SEASONALLY WET
  - 2) SLOW - SEASONALLY MOIST
  - 3) MODERATE - TEMPORARILY
  - 4) WELL-DRAINED - DRY

AVERAGE HEIGHT VEGETATION STRATA

HERB LAYER	-	.....	cm	BUSH LAYER (1)	-	.....	M
GRASS LAYER (SHORT)	-	.....	cm	BUSH LAYER (2)	-	.....	M
GRASS LAYER (MEDIUM)	-	.....	cm	TREE LAYER (1)	-	.....	M
SHRUB LAYER ('KAROO')	-	.....	cm	TREE LAYER (2)	-	.....	M
GRASS LAYER (TALL)	-	.....	cm				

STRATUM	COVER						STRATUM TOTAL COVER	DECID ER/CR	SPINE	SUCCU	OTHER	NO
	HERB	SHRUB	GRASS	MS BUSH	TREE							
1	0-20											14
2	20-50											15
3	50-120											16
4	1, 2-2											17
5	2-3											18
6	3-5											19
7	> 5											20
CATEGORY TOTAL												21
DOM SPECIES												22
1												23
2												24
3												25
4												26
5												27
6												28
7												29
8												30
9												31
10												32
11												33
12												34
13												35
DOM SPECIES												36
STRATUM												37
COV/ABUND.												38

Appendix 2 General relationship between scale of study, scale of mapping and scale of remote sensing product using visual interpretation techniques. (From Edwards & Jarman 1972.)

Scale of Survey	Aim	Final Map Product Scale	Appropriate Air Photo Product Scale	Appropriate field sampling procedures
General and General Reconnaissance	Ascertain major classes of vegetation at regional and sub-regional landscape levels	1 : 1 000 000 or smaller	1 : 500 000 - 1 : 1 000 000	Descriptive, non-defined non-regular samples usually recording physiognomic types
Reconnaissance	Determine the main plant communities/ecological relations within regions or sub-regions	1 : 50 000 - 1 : 1 000 000	1 : 40 000 - 1 : 500 000	Non-regular samples, low density of plot samples recording structural types & dominant floristics
Semi-detailed	Investigation of physiognomic/structural and floristic structure of communities and habitat relations	1 : 10 000 - 1 : 50 000	1 : 5 000 - 1 : 20 000	Defined samples, moderately high density, recording structural types and total floristics
Detailed	Study of structure and function of community or part of community	1 : 500 - 1 : 10 000	1 : 5 000 or larger	Intensive quantitative sampling on defined plots
Ultra-detailed	Study within community species/species group/habitat relations	1 : 500 or larger	1 : 500 or larger	Intensive quantitative sampling on defined plots/species

**Appendix 3** Information brochures from Satellite Applications Centre, National Institute of Telecommunications Research, the southern African supplier of Landsat, SPOT and NOAA products.

```

SSSS AAAA TTTT EEEE L L IIII TTTT EEEE M M OOOO TTTT EEEE
S A A A T E L L I I T T E E M M O O T T E E
SSSS AAAA T EEE L L L I I T T EEE M M M O O T T EEE
S A A A T EEE L L L L I I T T EEE M M O O T T EEE
SSSS A A T EEEE LLLL LLLL IIII T EEEE M M OOOO T EEEE

SSSS EEEE N N SSSS IIII N N GGGG CCCC EEEE N N TTTT RRRR EEEE
S E E E NN N S I NN N G C E NN N T R R R E
SSSS EEE N N SSSS I NN N G GG C EEE N N N T RRRR EEE
S E N NN S I N NN G G C E N NN T R R E
SSSS EEEE N N SSSS IIII N N GGGG CCCC EEEE N N T R R EEEE

```

C/O NATIONAL INSTITUTE FOR TELECOMMUNICATIONS RESEARCH  
P.O. BOX 3718  
JOHANNESBURG 2000  
REPUBLIC OF SOUTH AFRICA

TEL. NR (012) 265271

TELEX. NR 3-2105 S.A.

\*\*\*\*\* THIS CATALOGUE CONTAINS LANDSAT-4 DATA ACQUIRED BY DIRECT RECEPTION AND ARCHIVED ON HDDT AT SRSC UP TO 31ST DECEMBER 1982. \*\*\*\*\*

Future catalogues of all data acquired during a calendar year will be available on request. Scenes can be ordered from SRSC on CSIR Format CCT or as standard or IAS processed photographic products.

\*\*\*\*\*  
\*WRS TRK-FRM: \*Worldwide Reference System Track and Frame. Track and frame designations key the location of each Landsat image to the worldwide reference system. Track and frame cannot be used for ordering, since at one WRS location many dozens of Landsat images may have been acquired. However, they can be used to identify areas for geographic inquiries.  
\*SCENE-ID: A ten digit number which uniquely identifies a particular Landsat MSS or RBV scene. The form of the ID is SDDDD-HHMMMS, where S = Spacecraft No.; DDUD = Days since launch for that spacecraft; and HHMMMS = Greenwich Mean Time (GMT) of scene centre in hours, minutes and tens of seconds. All Landsat products being ordered should refer to a Scene ID.  
\*HDDT NO: Serial number of bulk data High Density Digital Tape on which scene is archived.  
\*HAND QUAL: For Landsat imagery, each band is rated individually in sequence (i.e. bands 4,5,6,7,8). An asterisk (\*) indicates no data. NOTE: Quality rating is subjective and based on many characteristics of the imagery and therefore does not directly indicate image useability for any given purpose.  
\*SOURCE TYPE: Type and format of master copy of digital data. HDDT = bulk data available at SRSC on high density digital tape.  
\*CLOUD COVER: Cloud cover over each of the four quadrants of the image is given in increments of 1%. The order of the four quadrants is: North West, North East, South West, South East.  
NOTE: Classification of percent of cloud cover is subjective and is relative to the types and amount of clouds present.  
\*DATE: Date that image was acquired (year, month, day).  
\*SCENE CENTRE: LAT: Latitude in degrees and minutes (DD-MM) or degrees and decimals of a degree (DD.DD). LONG: Longitude in degrees and minutes (DD-MM) or degrees and decimals of a degree (DD.DD).  
\*\*\*\*\*

INDEX OF ALL LANDSAT-4 SCENES AVAILABLE ON HDDT, LISTED IN WRS AND DATE ORDER.

WRS TRK-PRM	SCENE ID	HDDT No.	BAND QUAL. 45678	SOURCE TYPE	CLOUD COVER	DATE	SCENE LAT	SCENE LONG	REMARKS
*	173-073	40111-07462	8888*	HDDT	6211	821105	S18.81	E25.66	ZIMBABWE BOTSWANA
*	173-073	40127-07471	8888*	HDDT	8889	821121	S18.81	E25.52	ZIMBABWE BOTSWANA
*	173-073	40143-07472	8888*	HDDT	9989	821207	S18.81	E25.52	ZIMBABWE BOTSWANA
*	173-073	40159-07470	8888*	HDDT	4441	821223	S18.81	E25.66	ZIMBABWE BOTSWANA
*	173-074	40095-07470	8888*	HDDT	5889	821020	S20.26	E25.21	BOTSWANA
*	173-074	40111-07464	8888*	HDDT	4377	821105	S20.26	E25.33	BOTSWANA
*	173-074	40127-07473	8888*	HDDT	9989	821121	S20.26	E25.18	BOTSWANA
*	173-074	40143-07474	8888*	HDDT	8888	821207	S20.25	E25.18	BOTSWANA
*	173-074	40159-07472	8888*	HDDT	5287	821223	S20.26	E25.32	BOTSWANA
*	173-075	40095-07472	8888*	HDDT	9999	821020	S21.70	E24.88	BOTSWANA
*	173-075	40111-07471	8888*	HDDT	7699	821105	S21.70	E24.99	BOTSWANA
*	173-075	40127-07480	8888*	HDDT	8899	821121	S21.70	E24.84	BOTSWANA
*	173-075	40143-07481	8888*	HDDT	9999	821207	S21.70	E24.85	BOTSWANA
*	173-075	40159-07475	8888*	HDDT	5713	821223	S21.70	E24.99	BOTSWANA
*	173-076	40095-07474	8888*	HDDT	1126	821020	S23.14	E24.53	BOTSWANA
*	173-076	40111-07473	8888*	HDDT	9967	821105	S23.14	E24.65	BOTSWANA
*	173-076	40127-07482	8888*	HDDT	7833	821121	S23.14	E24.50	BOTSWANA
*	173-076	40143-07483	8888*	HDDT	9898	821207	S23.14	E24.50	BOTSWANA
*	173-076	40159-07481	8888*	HDDT	0000	821223	S23.14	E24.64	BOTSWANA
*	173-077	40095-07481	8888*	HDDT	4837	821020	S24.59	E24.18	BOTSWANA
*	173-077	40111-07480	8888*	HDDT	8587	821105	S24.59	E24.30	BOTSWANA
*	173-077	40127-07484	8888*	HDDT	0100	821121	S24.58	E24.15	BOTSWANA
*	173-077	40143-07490	8888*	HDDT	9998	821207	S24.58	E24.16	BOTSWANA
*	173-077	40159-07483	8888*	HDDT	0000	821223	S24.58	E24.30	BOTSWANA
*	173-078	40095-07483	8888*	HDDT	7486	821020	S26.03	E23.83	R.S.A. BOTSWANA
*	173-078	40111-07482	8888*	HDDT	5825	821105	S26.03	E23.94	R.S.A. BOTSWANA
*	173-078	40127-07491	8888*	HDDT	0000	821121	S26.02	E23.80	R.S.A. BOTSWANA
*	173-078	40143-07492	8888*	HDDT	9998	821207	S26.02	E23.80	R.S.A. BOTSWANA
*	173-078	40159-07490	8888*	HDDT	0000	821223	S26.02	E23.94	R.S.A. BOTSWANA
*	173-079	40095-07490	8888*	HDDT	8847	821020	S27.47	E23.47	R.S.A.
*	173-079	40111-07484	8888*	HDDT	1111	821105	S27.47	E23.58	R.S.A.
*	173-079	40127-07493	8888*	HDDT	0000	821121	S27.46	E23.44	R.S.A.
*	173-079	40143-07494	8888*	HDDT	8764	821207	S27.46	E23.44	R.S.A.
*	173-079	40159-07492	8888*	HDDT	0000	821223	S27.46	E23.58	R.S.A.
*	173-080	40095-07492	8888*	HDDT	2627	821020	S28.90	E23.10	R.S.A.
*	173-080	40111-07491	8888*	HDDT	3232	821105	S28.90	E23.22	R.S.A.
*	173-080	40127-07500	8888*	HDDT	0000	821121	S28.90	E23.07	R.S.A.

LANDSAT 1, 2 EN 3 INDEKSKAARTE VIR SUIDELIKE AFRIKA



**LANDSAT 1, 2 EN 3**

Stekke die benoemde posities aan van beeld-  
 dekking deur Landsat 1, 2 en 3. Die  
 swart reëls dui die dekking van die  
 satelliet aan. Die wit reëls dui die  
 dekking van die satelliet aan.  
 As voorbeeld word die benoemde dekking van 'n  
 MSS-beeld by posisie 183-80 (Bosmanfontein)  
 getoon.  
 As groep van die satelliet in wêreldkaart & name  
 in die indekskaart vir Landsat 1, 2 en 3.  
 R. S. A. 1:250 000 dekking

**S.W.A. 1:250 000 Dekking**  
 Die reël van die S.W.A. 1:250 000 kaart  
 VIR KLEINER SKALE INDEKSKAARTE VIR SUIDELIKE AFRIKA

**LANDSAT 1, 2 AND 3**

Check the approximate position of  
 satellite coverage indicated by  
 the numbers in the first and  
 second the row.  
 As an example the approximate coverage of a  
 MSS image at position 183-80 (Bosmanfontein)  
 is shown.  
 The index map does not apply to Landsat 4,  
 due to differences in orbit.

R. S. A. 1:250 000 Coverage  
 S.W.A. 1:250 000 Coverage  
 The rule of the S.W.A. 1:250 000 map  
 FOR SMALLER SCALE INDEX MAP OF S.AFRICA

**REPRODUCTION OF THE INDEX MAP**  
 REPRODUCED TO 1:500 000 SCALE

1. The index map is a reproduction of the original map.  
 2. The index map is a reproduction of the original map.  
 3. The index map is a reproduction of the original map.  
 4. The index map is a reproduction of the original map.  
 5. The index map is a reproduction of the original map.  
 6. The index map is a reproduction of the original map.  
 7. The index map is a reproduction of the original map.  
 8. The index map is a reproduction of the original map.  
 9. The index map is a reproduction of the original map.  
 10. The index map is a reproduction of the original map.

**REPRODUCTION OF THE INDEX MAP**  
 REPRODUCED TO 1:500 000 SCALE

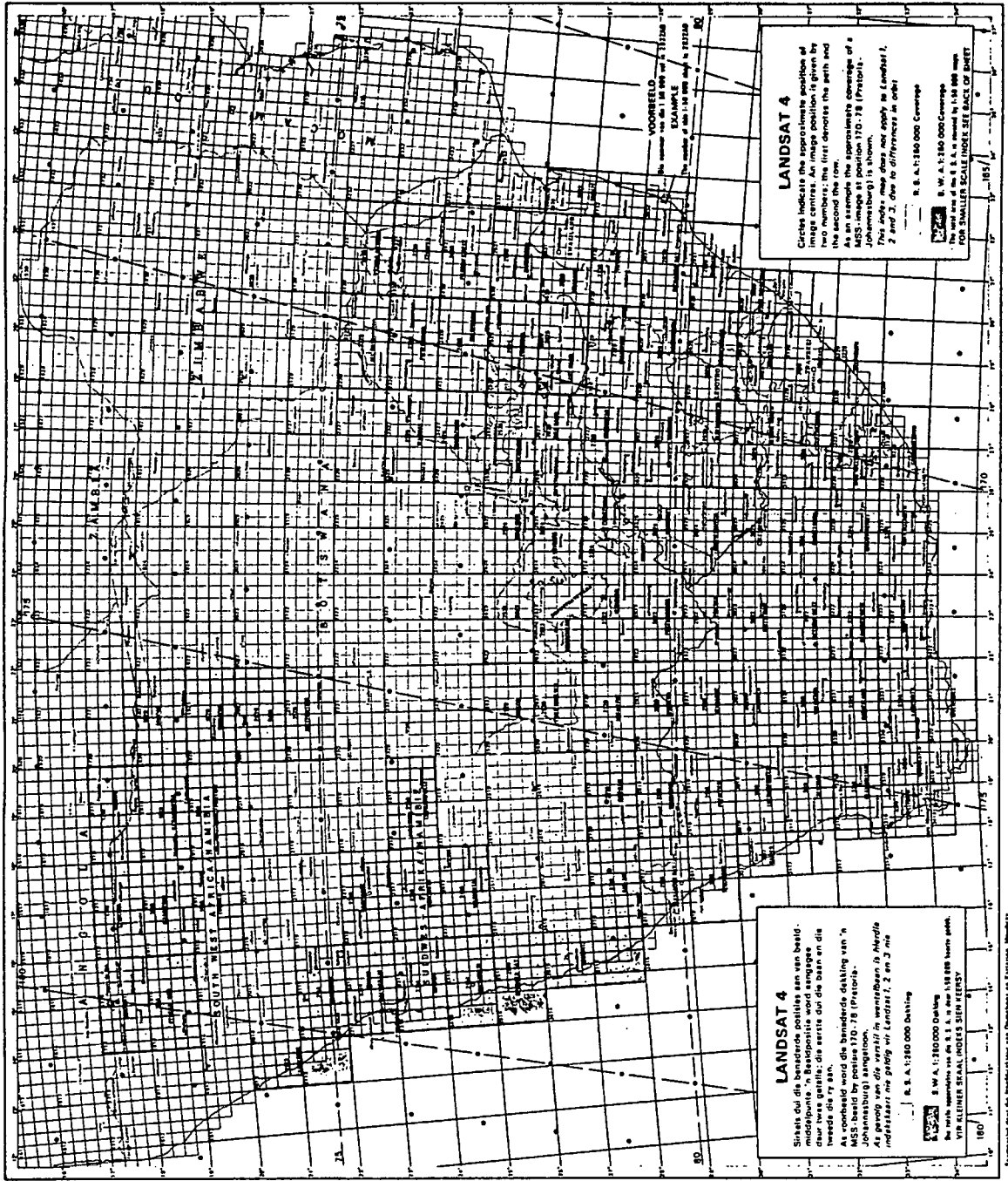
1. The index map is a reproduction of the original map.  
 2. The index map is a reproduction of the original map.  
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 4. The index map is a reproduction of the original map.  
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**REPRODUCTION OF THE INDEX MAP**  
 REPRODUCED TO 1:500 000 SCALE

1. The index map is a reproduction of the original map.  
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 10. The index map is a reproduction of the original map.

Approved for the Department of Defense, as required, by the Chief Director of Services and Supplies, Pretoria.

LANDSAT 4 INDEKSKAARTE VIR SUIDELIKE AFRIKA



VERHOUDINGSKOPPEL 1:50 000 000 VELLE  
 REFERENSIE 701 50 000 000

A B C D

1. Die posisie van die kaart is deur die  
 2. Die posisie van die kaart is deur die  
 3. Die posisie van die kaart is deur die  
 4. Die posisie van die kaart is deur die  
 5. Die posisie van die kaart is deur die  
 6. Die posisie van die kaart is deur die  
 7. Die posisie van die kaart is deur die  
 8. Die posisie van die kaart is deur die  
 9. Die posisie van die kaart is deur die  
 10. Die posisie van die kaart is deur die

VERHOUDINGSKOPPEL 1:50 000 000 VELLE  
 REFERENSIE 701 50 000 000

1. Die posisie van die kaart is deur die  
 2. Die posisie van die kaart is deur die  
 3. Die posisie van die kaart is deur die  
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 6. Die posisie van die kaart is deur die  
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 8. Die posisie van die kaart is deur die  
 9. Die posisie van die kaart is deur die  
 10. Die posisie van die kaart is deur die

VERHOUDINGSKOPPEL 1:50 000 000 VELLE  
 REFERENSIE 701 50 000 000

1. Die posisie van die kaart is deur die  
 2. Die posisie van die kaart is deur die  
 3. Die posisie van die kaart is deur die  
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 8. Die posisie van die kaart is deur die  
 9. Die posisie van die kaart is deur die  
 10. Die posisie van die kaart is deur die

**LANDSAT 4**

Circles indicate the approximate position of  
 image centres. The first circle is given by  
 the first two digits of the grid reference  
 (the second the easting).  
 As an example the approximate coverage of a  
 MSS image at position 70-78 (Pretoria-  
 Johannesburg) is shown.  
 The other circles in Landsat 1,  
 2 and 3, give no differences in orbit.

S. W. A. 1:50 000 000 Coverage  
 FOR SMALLER SCALE INDEXES SEE PAGE 100

**LANDSAT 4**

Sirkels dui die benaderde posisies aan van beeld-  
 middelpunte. Die eerste sirkel word aangedui  
 deur twee getalle; die eerste dui die baan en die  
 tweede die ry aan.  
 As voorbeeld word die benaderde dekking van 'n  
 MSS beeld by posisie 70-78 (Pretoria-  
 Johannesburg) aangedui.  
 Die ander sirkels in Landsat 1, 2 en 3  
 indikasie van verskille in baan.

S. W. A. 1:50 000 000 Dekking  
 VIR KLEINER SKAAL INDEKS SIE PAG 100

Gebruik van die Kaart deur die Direkteur van Opleiding en Opleiding, Kaart- en  
 Opleiding deur die Direkteur van Opleiding en Opleiding, Kaart- en

SATELLITE APPLICATIONS CENTRE

OF THE

DIVISION OF MICROELECTRONICS AND COMMUNICATIONS TECHNOLOGY

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 Telex : 3-21005 SRSC SA

PRICE LIST FOR STANDARD LANDSAT MULTISPECTRAL SCANNER PRODUCTS

The following price list is effective from 01 April 1989.

1. Standard Black and White Products

<u>Nominal Image Size</u>	<u>Material</u>	<u>Price</u>	
18,5cm	Film Negative	R 40	(Note 1)
18,5cm	Film Positive	R 40	(Note 1)
18,5cm	Paper	R 50	
37,0cm	Paper	R100	
74,0cm	Paper	R200	
74,0cm	Film Positive or Negative Transparency	R300	(Note 2)

**Note 1** A surcharge of R50 per spectral band will be made to produce registered negatives (or positives) of the same scene, i.e. for negatives of two spectral bands registered with each other, the surcharge will be R100, and for four spectral bands R200 etc.

**Note 2** Transparent material used for this product is Kodak Kodagraph.

2. Standard Colour Products

<u>Nominal Image Size</u>	<u>Material</u>	<u>Price</u>
18,5cm	Film Positive	R300
18,5cm	Paper	R 75
37,0cm	Paper	R150
74,0cm	Paper	R300
* Printing master transparency generation		R300

\* This cost must be added to cost of colour products made from the printing master transparency (retained by SAC). If a printing master exists, no charge will be made.

3. Computer Compatible Tape (CCT)

9 Track, 6250 BPI or  
9 Track, 1600 BPI CCT's ..... R 750  
BIL LGSOWG or  
BIL JSC/CCRS format

Note: Contact SAC for details of formats.

4. Standard Enhanced Imagery

\* Processed high quality LANDSAT black and white or colour composite imagery can be provided in limited quantities. Enhancement includes haze removal, de-stripping, edge enhancement and correction of systematic errors, all following standard procedures. UTM or longitude and latitude grids can also be provided. The absolute geographical accuracy of grids depends on how well the satellite orbital parameters are known, but it is generally better than  $\pm 15$  kilometers. It should be noted that no ground control points are used ... R 300

\* Precision geometric correction using ground control points can also be performed on LANDSAT imagery where 1:50 000 survey maps are available. Under favourable conditions, geographic accuracies of better than one 80 metre by 80 metre picture element can be obtained. .... R1 000

5. LANDSAT Products from non-standard World Reference Series (WRS) Scenes

Surcharge to produce any non-standard WRS LANDSAT product. R 200

6. Data of Floppy Discs

Subscenes of 512 pixels by 512 lines of any spectral band of any standard LANDSAT scene can be provided.

The image data is written to a 360KB, 5¼" floppy as a MS-DOS file. The size of the file is 262 144 bytes, where each byte represents the intensity of a pixel, in the range 0-255.

Cost of each floppy is ..... R 60

7. 35mm Colour Slides

- |     |                                                                                                           |               |
|-----|-----------------------------------------------------------------------------------------------------------|---------------|
| 7.1 | Slides taken from Comtal high resolution screen while customers are using SAC Image Analysis System ..... | R 3 per slide |
| 7.2 | Slides taken from Comtal high resolution screen for all cases other than 7.1 above .....                  | R25 per slide |
| 7.3 | Slides taken from SAC master colour transparencies .....                                                  | R25 per slide |
- Prices include processing and mounting.

8. Catalogues

LANDSAT 2 and 3

Catalogue listing all LANDSAT 2 and 3 MSS data acquired directly from the satellites by the SAC.....

R 60

LANDSAT 4 and 5

Catalogue listing all LANDSAT 4 and 5 MSS data acquired directly from the satellite by the SAC per calendar year.....

R 60

Note:

- \* Catalogues for an uncompleted calendar year are available at R5,00 per completed month. i.e. A catalogue containing all MSS data from January to the end of July would cost R35,00 etc.
- \* Enquiries regarding the availability of LANDSAT data at a specific geographic location can be made by letter, telex, telefax, or telephone and will be answered free of charge.

9. Emergency Orders

Emergency orders for a single LANDSAT image or CCT will be accepted and dispatched within two working days. Surcharge for emergency orders will be 100 %.

If delivery time is not met, surcharge will not be levied.

10. Payment

- \* For orders originating outside the Republic of South Africa and Namibia:

Payment by Bank draft in South African currency in favour of "CSIR".

- \* For orders originating inside the Republic of South Africa and Namibia:

Payment with order is required. Order documents from approved customers are acceptable. Such customers will be invoiced on completion of the order. General Sales Tax must be added to all local orders.

### 11. Delivery

The SAC attempts to deliver products within 10 to 20 working days after receipt of order, depending on workload at the time. Longer delays are sometimes experienced, especially with colour prints. CCT's are usually delivered within 5 working days.

### 12. Packing, Postage and Airfreight

Destinations within South Africa and Namibia:

* 18,5cms Images (Max 10)	.....	R 5,00
* 37cms Images (Max 5)	.....	R10,00
* 74cms Images (Max 5)	.....	R20,00
* CCT's (Per CCT)	.....	R10,00

Destinations outside the borders of South Africa and Namibia:

* 18,5cms Images (Max 10)	.....	R50,00
* 37cms Images (Packaging only)	.....	R10,00
* 74cms Images (Packaging only)	.....	R10,00
* CCT's (per CCT) (Packaging only)	.....	R 5,00

**Note :**

18,5cm Images will be sent by airmail.

All 37cm, 74cm images and CCT's will be sent by airfreight, freight forward. i.e. Airfreight will have to be paid at destination by customer.

### 13. Discount

Discount will apply if the number of products bought exceeds five, whether ordered together, or over a period of one calender month.

Any mix of products will be taken into account to calculate the percentage discount applicable.

From 5 - 10 products	.....	5%
From 11 - 20 products	.....	10%
From 21 - 30 products	.....	15%
Above 30 products	.....	20%

14. General Notes

- \* All prices exclude general sales tax (GST).
  - \* GST is not applicable to orders outside South Africa and Namibia.
  - \* Postage/Packaging charges must be added to price of products.
  - \* All prices are subject to change without prior notice.
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SPOT DATA AVAILABLE FROM THE SATELLITE APPLICATIONS CENTRE

GRS	DATE	SPECTRAL MODE	SOURCE
094-368	870615	PANCHROMATIC	CCT, B/W NEGATIVE
103-396	860729	MULTISPECTRAL	CCT
106-379	860628	MULTISPECTRAL	CCT, COLOUR NEGATIVE
107-379	860623	MULTISPECTRAL	CCT, COLOUR NEGATIVE
107-380	860623	MULTISPECTRAL	CCT, COLOUR NEGATIVE
108-379	860623	MULTISPECTRAL	CCT, COLOUR NEGATIVE
108-380	860623	MULTISPECTRAL	CCT, COLOUR NEGATIVE
109-380	860618	MULTISPECTRAL	CCT, COLOUR NEGATIVE
111-407	871126	MULTISPECTRAL	CCT
111-407	871126	MULTISPECTRAL	CCT, COLOUR NEGATIVE
111-407	880221	MULTISPECTRAL	CCT, COLOUR NEGATIVE
111-407	880221	MULTISPECTRAL	CCT
111-408	870327	MULTISPECTRAL	COLOUR TRANSPARENCY Q1 + 4
112-407	870618	PANCHROMATIC	CCT ) STEREO
112-407	870622	PANCHROMATIC	CCT ) PAIR
112-407	870628	MULTISPECTRAL	CCT
117-418	871212	MULTISPECTRAL	CCT, COLOUR NEGATIVE
117-418	880128	PANCHROMATIC	CCT ) STEREO
117-418	880201	PANCHROMATIC	CCT ) PAIR
118-418	861101	MULTISPECTRAL	CCT
124-405	860731	MULTISPECTRAL	CCT
127-399	880325	MULTISPECTRAL	CCT, COLOUR NEGATIVE
128-407	860408	MULTISPECTRAL	CCT
129-403	861103	MULTISPECTRAL	CCT
130-401	860525	MULTISPECTRAL	CCT, COLOUR NEGATIVE

SPOT-IMAGE SPOT/DATA  
(available) 1

**SPOT DATA AVAILABLE FROM THE SATELLITE APPLICATIONS CENTRE**

GRS	DATE	SPECTRAL MODE	SOURCE
131-398	860529	MULTISPECTRAL	CCT
131-399	860329	MULTISPECTRAL	CCT
131-408	880316	MULTISPECTRAL	CCT, COLOUR NEGATIVE
131-409	880316	MULTISPECTRAL	CCT, COLOUR NEGATIVE
132-398	860329	MULTISPECTRAL	CCT
132-399	860329	MULTISPECTRAL	CCT
132-403	880808	MULTISPECTRAL	COLOUR POSITIVE
132-404	860329	MULTISPECTRAL	CCT, COLOUR NEGATIVE
133-399	860515	MULTISPECTRAL	CCT
133-402	860403	PANCHROMATIC	CCT, B/W NEGATIVE
133-402	860403	MULTISPECTRAL	CCT, COLOUR NEGATIVE, B/W B1,2,3
133-402	870821	PANCHROMATIC	CCT
133-402	870821	MULTISPECTRAL	CCT
135-417	880203	MULTISPECTRAL	COLOUR POSITIVE
136-399	880427	PANCHROMATIC	B/W NEGATIVE
136-400	880427	PANCHROMATIC	B/W NEGATIVE
137-408	860531	MULTISPECTRAL	CCT, COLOUR NEGATIVE
137-409	860531	MULTISPECTRAL	CCT, COLOUR NEGATIVE
138-400	860531	MULTISPECTRAL	CCT
138-402	860531	MULTISPECTRAL	CCT
138-402	880603	PANCHROMATIC	CCT ) STEREO
138-402	880607	PANCHROMATIC	CCT ) PAIR
138-409	860531	MULTISPECTRAL	COLOUR POSITIVE
139-402	880603	PANCHROMATIC	CCT ) STEREO
139-402	880607	PANCHROMATIC	CCT ) PAIR

SPOT-IMAGE SPOT/DATA  
(available) 2



SATELLITE APPLICATIONS CENTRE

OF THE

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PRICE LIST FOR STANDARD METEOSAT PRODUCTS

The following price list is effective from 01 April 1989.

1. Standard Black and White Products

<u>Nominal Size</u>	<u>Material</u>	<u>Price</u>	
25,0cm	Film Negative	R 25	
25,0cm	Film Positive	R 25	
25,0cm	Paper	R 40	
50,0cm	Paper	R 80	
100,0cm	Paper	R150	
100,0cm	Film Positive or Negative		
	Transparency	R250	(Note)

Note Transparent material used for this product is Kodak Kodagraph.

METEOSAT image subscenes, at reduced or full resolution, are available. Any region of the METEOSAT image can be specified, and visible, infrared or water vapour imagery can be used.

Multiple scene images can contain up to 9 or 42 sub-scenes.

Cost : Basic charge for photographic plate ..... R 25

**plus**

Each raw unprocessed image subscene ..... R 5

**or**

Each registered, enhanced or processed image subscene ..... R 20

Example

A 25cm x 25cm plate with 42 raw or unprocessed image subscene would cost R30 + (42 x R5) ..... R240

A 25cm x 25cm plate with 42, registered, enhanced or processed image subscenes would cost R30 + (42 x R20) ..... R 870

2. Standard Colour Products

<u>Nominal Size</u>	<u>Material</u>	<u>Price</u>
25,0cm	Film Positive	R300
25,0cm	Paper	R 50
50,0cm	Paper	R100
100,0cm	Paper	R200
* Printing master transparency generation		R300

\* This cost must be added to cost of colour products made from the printing master transparency (retained by SAC). If a printing master exists, no charge will be made.

3. METEOSAT Computer Compatible Tapes (CCT's)  
(2 400 foot, 9 track, 1600 BPI or 6 250 BPI)

CCT containing complete METEOSAT frame (all bands) ..... R 200

CCT containing series of METEOSAT image subscenes of a selected band or bands:

Basic charge for CCT..... R 50

**plus**

Each raw or unprocessed image subscene ..... R 5

**or**

Each registered, enhanced or processed image subscene ..... R 20

Example

Cost of METEOSAT CCT with a hundred 512 x 512 raw, unprocessed image subscenes would cost R50 + (100 x R5) ..... R 550

Cost of METEOSAT CCT with a hundred 512 x 512 registered, enhanced or processed image subscenes would cost R50 + (100 x R5) ..... R2050

3/...

**Notes:**

1. A maximum of a hundred image subscenes of 512 lines by 512 picture elements can be stored on one 2 400 foot, 9 track, 1 600 bpi magnetic tape.
2. Image subscenes are limited to a maximum size of 750 lines by 750 picture elements. For larger subscenes, a customer has to purchase a complete METEOSAT scene.
3. Tape format specifications are available from the Satellite Applications Centre (SAC) free of charge, upon request.

**4. Data on Floppy Discs**

Subscenes of 512 pixels by 512 lines of any spectral band of any standard METEOSAT scene can be provided.

The image data is written to a 360KB, 5¼" floppy as a MS-DOS file. The size of the file is 262 144 bytes, where each byte represents the intensity of a pixel, in the range 0-255.

Cost of each floppy is ..... R 50

**5. 35mm Colour Slides**

Slides taken from Comtal high resolution screen ..... R2 per slide

**6. Packing, Postage and Airfreight**

Destinations within South Africa and Namibia:

* 25cms Images (Max 10) .....	R 5,00
* 50cms Images (Max 5) .....	R10,00
* 100cms Images (Max 5) .....	R20,00
* CCT's (Per CCT) .....	R10,00

Destinations outside the borders of South Africa and Namibia:

* 25cms Images (Max 10) .....	R50,00
* 50cms Images (Packaging only) .....	R10,00
* 100cms Images (Packaging only) .....	R10,00
* CCT's (per CCT) (Packaging only) .....	R 5,00

**Note:**

25cms Images will be sent by airmail.

All 50cm, 100cm images and CCT's will be sent by airfreight, freight forward. i.e. Airfreight will have to be paid at destination by the customer.

7. Discount

Discount will apply if the number of products bought exceeds five, whether ordered together, or over a period of one calendar month.

Any mix of products will be taken into account to calculate the percentage discount applicable.

From 5 - 10 products .....	5%
From 11 - 20 products .....	10%
From 21 - 30 products .....	15%
Above 30 products .....	20%

8. General Notes

- \* All prices exclude General Sales Tax (GST).
  - \* GST is not applicable to orders outside South Africa and Namibia.
  - \* Postage/Packaging charges must be added to price of products.
  - \* All prices are subject to change without prior notice.
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PRICE LIST FOR STANDARD NOAA/AVHRR PRODUCTS

The following price list is effective from 01 April 1989.

NOAA products can be produced from:

- Raw data
- Data geometrically corrected to Level 1
- Data geometrically corrected to Level 2
- Temperature calibrated data

All photographic products are corrected to Level 1, unless otherwise requested.

See section 4 for details on the various corrections.

1. Standard Black and White Products

<u>Nominal Size</u>	<u>Material</u>	<u>Price</u>
25,0cm	Film Negative	R 25
25,0cm	Film Positive	R 25
25,0cm	Paper	R 40
50,0cm	Paper	R 80
100,0cm	Paper	R150
100,0cm	Film Positive or Negative Transparency	R250

(Note 1)

Note 1 Transparent material used for this product is Kodak Kodagraph.

2. Standard Colour Products

Nominal Size	Material	Price
25,0cm	Film Positive	R 300
25,0cm	Paper	R 50
50,0cm	Paper	R 100
100,0cm	Paper	R 200
* Printing master transparency generation		R 300

\* This cost must be added to cost of colour products made from the printing master transparency (retained by SAC). If a printing master exists, no charge will be made.

3. Computer Compatible Tapes (CCT's)

3.1 Customer can specify the following:

- 8 or 10 bit data;
- Tape density of 1600 or 6250 BPI;
- Number of lines;
- Number of channels;
- Correction levels:
  - Raw Data
  - Level 1
  - Level 2
  - Temperature calibrated data.

3.2 Cost of Data per Spectral Band

8 or 10 bit data up to 2 700 lines .....	R40
8 or 10 bit data up to 5 400 lines .....	R80
Basic charge for CCT .....	R50

3.3 Examples of Cost for Raw or Level 1 Data

- 3.3.1 8 or 10 bit data;  
 Number of lines up to 2 700;  
 Tape Density 1600 BPI.

Number of Spectral Bands	Cost
1	R 90
2	R 130
3	R 170
4	R 260
5	R 300

For more than 3 bands, a set of two CCT's are required.

- 3.3.2 8 or 10 bit data;  
Number of lines up to 2 700;  
Tape density 6 250 BPI.

Number of Spectral Bands	Cost
1	R 90
2	R 130
3	R 170
4	R 210
5	R 250

One CCT for any number of bands is required.

- 3.3.3 8 or 10 bit data;  
Number of lines up to 5 400;  
Tape Density 1600 BPI.

Number of Spectral Bands	Cost
1	R 130
2	R 260
3	R 390
4	R 520
5	R 650

One CCT per spectral band is required.

- 3.3.4 8 or 10 bit data;  
Number of lines up to 5 400;  
Tape density 6 250 BPI.

Number of Spectral Bands	Cost
1	R 130
2	R 210
3	R 290
4	R 370
5	R 450

One CCT for any number of bands is required.

### 3.4 Data corrected to Level 2

Only 2 048 lines of 8 bit data can be supplied.

Continental outlines and latitude/longitude grids can be embedded in the data, or supplied as a separate file on the CCT.

#### 3.4.1 Example of cost

Number of Spectral Bands	Cost
1	R 240
2	R 280
3	R 320
4	R 360
5	R 400

### 4. Data on Floppy Discs

Subscenes of 512 pixels by 512 lines of any spectral band of any standard NOAA scene can be provided.

The image data is written to a 360KB, 5¼ floppy as a MS-DOS file. The size of the file is 262 144 bytes, where each byte represents the intensity of a pixel, in the range 0-255.

Cost of each floppy is ..... R 50

### 5. Geometrically corrected NOAA data

Two levels of geometric corrections are available.

#### 5.1 Level 1:

Earth rotation and earth curvature corrections are carried out using orbital elements as well as an antenna position during the overflight.

#### 5.2 Level 2:

In addition to the Level 1 corrections, a precision correction is carried out by registering the scene to a map overlay, using ground control points. The data can be corrected to either a Mercator or Sterographic projection, and continental outlines as well a latitude/longitude grids are available ...

R 150

### 6. Temperature calibrated NOAA data

The auxiliary data received from the spacecraft, as well as

6. Temperature calibrated NOAA data

The auxiliary data received from the spacecraft, as well as a set of normalized response curves are used to temperature calibrate the reflectance values in bands 4 and 5, resulting in data which is optimized for sea surface temperatures.

Cost for doing temperature calibrations ..... R 50

The cost for geometric corrections (Level 2) and temperature calibrations must be added to the cost of the required product(s).

7. 35mm Slides

B/W slides taken from Comtal high resolution screen ..... R 2 per slide  
Uncorrected or Level 1 only

To cover the entire SAC reception area, two slides per overflight per spectral band are required.

8. Packing, Postage and Airfreight

Destinations within South Africa and Namibia:

* 25cms Images (Max 10)	.....	R 5,00
* 50cms Images (Max 5)	.....	R 10,00
* 100cms Images (Max 5)	.....	R 20,00
* CCT's (Per CCT)	.....	R 10,00

Destinations outside the borders of South Africa and Namibia:

* 25cms Images (Max 10)	.....	R 50,00
* 50cms Images (Packaging only)	.....	R 10,00
* 100cms Images (Packaging only)	.....	R 10,00
* CCT's (per CCT) (Packaging only)	.....	R 5,00

Note:

25cm Images will be sent by airmail.

All 50cm, 100cm images and CCT's will be sent by airfreight, freight forward. i.e. Airfreight will have to be paid at destination by customer.

9. Discount

Discount will apply if the number of products bought exceeds five, whether ordered together, or over a period of one calendar month.

Any mix of products will be taken into account to calculate the percentage discount applicable.

From 5 - 10 products .....	5%
From 11 - 20 products .....	10%
From 21 - 30 products .....	15%
Above 30 products .....	20%

10. General Notes

- \* All prices exclude general sales tax (GST).
- \* GST is not applicable to orders outside South Africa and Namibia.
- \* Postage/Packaging charges must be added to price of products.
- \* All prices are subject to change without prior notice.

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