A methodology for producing small scale rural land use maps in semi-arid developing countries using orbital imagery

Final report to NASA under investigation SR 9686
September 1976

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Dr JL van Genderen
Mr BF Lock
Geography Department
University of Sheffield

London
Department of Industry
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Final Contractor's Report
Original contains colour imagery and fold-out maps.
Original photography may be purchased from the EROS Data Center, 10th and Dakota Ave., Sioux Falls, South Dakota, 57198, U.S.A.
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II. PRINCIPAL INVESTIGATOR:
Dr. J.L. van Genderen

III. AUTHORS OF REPORT:
Genderen, J.L. van and Lock, B.F.

IV. ADDRESS OF ORGANIZATION:
Fairey Surveys Limited
Reform Road
Maidenhead
Berkshire SL6 8BU
United Kingdom
(Formerly:
Department of Geography
University of Sheffield
Sheffield S10 2TN
United Kingdom)

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Mr. Martin L. Miller
Code TF6
NASA, Johnson Space Center
Houston
Texas 77058
U.S.A.

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BACKGROUND TO FINAL CONTRACTOR'S REPORT

In January 1972, Dr. J.L. van Genderen submitted a "Proposal for Participation in Space Flight Investigations Using Data from the Earth Resources Experiment Package (SKYLAB-EREP)" to NASA for consideration. On April 11th, 1973, a letter was received from Charles W. Mathews, Associate Administrator for Applications at NASA, that Dr. van Genderen had been selected as a Principal Investigator to analyse data returned from the SKYLAB Earth Resources Experiment Package (EREP). This letter stated that the above mentioned "Proposal" (NASA Control Nos. INT-UK-08 and SR 9686) had been accepted.

On 17th May 1973, a copy of the "Provisions for Participation in the NASA Skylab Earth Resources Experiment Program" was signed by the Department of Industry (as sponsoring institution) and by Dr. van Genderen and returned to NASA.

Several delays were experienced in receiving the first sets of data from the SKYLAB sensors. In the meantime excellent LANDSAT I data was being examined in order to gain further experience of orbital imagery.

The first data from SKYLAB arrived in May, 1974. In total, only the following data was received of the test area in South-East Spain: contact positive and negative transparencies from the S190A Data Acquisition Camera and 2x and 4x enlargments of these. No S190B imagery was provided of the test area. Alternative cover of Arizona and the Spanish/French border zone was provided, but proved of limited value in assessing its value due to lack of ground data. No S192 MSS data was provided of the study area as requested in the EREP Investigation Requirements Document. Again, alternative cover was received but of little value. No colour composites of the 13 MSS Channels were provided, although ten different combinations were promised. Although the official reason for not providing any data except some S190A photographs of the study area was that the weather was predicted to be marginal, each of the S190A frames had less than 5% cloud cover.

In the light of this lack of suitable data being provided by NASA, many of the objectives outlined in the "Proposal" could not be met. However, of the thirty publidations listed in the Cumulated Bibliographic Listing, 21 relate specifically to SKYLAB. These are indicated by an asterisk (*). Meanwhile, in the absence of suitable SKYLAB imagery, work was progressing on LANDSAT image interpretation.

During 1975, arrangements were made for Mr. B.F. Lock, Senior Lecturer at the Salisbury College of Advanced Education in Adelaide, South Australia, to come to the Geography Department, University of Sheffield, to study LANDSAT data for rural land use surveys under the direction and supervision of Dr. van Genderen. This resulted in one year's full time research being spent on the project. The following report, commencing on page 1 gives the results of the research programme. It is preceded by a complete cumulated bibliographic listing of all published articles, progress reports and conference papers related to the EREP Contract, in which all the other results obtained during the investigation have been reported. These are not repeated in this final report, and the reader is referred to the original articles for details of earlier findings.

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SUMMARY OF SIGNIFICANT RESULTS

(1) The results of this study have shown that it is feasible to design a methodology that can provide suitable guidelines for the operational production of small scale rural land use maps of semi-arid developing regions from LANDSAT MSS imagery using inexpensive and unsophisticated visual techniques.

(2) The suggested methodology should provide immediate practical benefits to map makers attempting to produce land use maps in countries with limited budgets and equipment.

(3) The methodology presented here should considerably reduce the time spent by researchers in trying to locate and assess the different techniques involved in the various stages of map production that have been reported in numerous, but often obscure articles during the last few years. This has been achieved by presenting and evaluating the most appropriate pre-processing, interpretation, classification and ground truth procedures in a simplified and systematic manner.

(4) Initially, many pre-processing and interpretation techniques were considered, but rejected on the grounds that they were inappropriate, mainly due to the high cost of the imagery and/or equipment, or due to their inadequacy for use in operational projects in the developing countries. This review highlighted the need for a low-cost, low-level technology, visual approach which would be fully operational rather than experimental, and the results of which could be

statistically assessed.

(5) The suggested imagery and interpretation techniques, consisting of colour composites and monocular magnification proved to be the simplest, fastest and most versatile method.

(6) In order to maintain a standardised classification of land use, the criteria and hierarchical structure presented in the U.S.G.S. Circular 671 were found to be acceptable as a general basis for researchers and organisations wishing to develop systems for their own regions. However, it should be stressed that these recommendations should only be used as guidelines for the development of an adequate system for a particular region.

(7) As no satisfactory method could be located which provided directions for systematically analysing the results of the interpretation, a new scheme was devised and tested. This proved to be successful, in the operational sense, during the production of the land use map of the Murcia Province.

(8) Although the statistical sampling system was based on the commonly-used stratified random strategy, one important aspect that was developed in this study was the method of determining the most appropriate sample size.

(9) The statistical concept developed and presented in the report incorporates the probability of making incorrect interpretations at particular prescribed accuracy levels, e.g. 85%, 90% or 95% for a certain number of errors, e.g. 0, 1, 2, 3 etc. for a particular sample size. This contrasts

with the usual practice of expressing the interpretation errors as a percentage of a subjectively derived number of sample sites. Consequently, it is felt that the approach adopted in this report offers a more meaningful explanation of the interpretation accuracy level of the whole operation, and within each category of land use.

(10) The statistical sampling and testing procedure developed for use with orbital imagery in this investigation, should also prove to be very useful in most other types of operational remote sensing projects where stringent contract specifications need to be met but, prior to this study, it was not possible to check the accuracy of the work in any reliable, statistical manner. Hence it is recommended for use by such controlling agencies as U.N.D.P., F.A.O. etc. as well as to the Remote Sensing Survey Companies and to the clients who can now incorporate safeguards into their requirements, to ensure these are being met.

(11) In their applications, the suggested methodology and resultant land use map should be used in the context in which they were designed.

(12) In conclusion, it has been demonstrated that the proposed methodology can play an important role in providing a suitable link between the acquisition of the LANDSAT MSS data and its operational application in land use mapping in developing countries using inexpensive techniques.

J.L. van Genderen
B.F. Lock
September 1976

CUMULATED BIBLIOGRAPHIC LISTING OF ALL PUBLISHED ARTICLES, PROGRESS REPORTS AND CONFERENCE PAPERS RELATED TO THE EREP CONTRACT

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24.	Department of Rural Land Use Surveys I.T.C. P.O. Box 6 Enschede, The Netherlands	Two
25.	Dr. R.L. Wright Director, UNESCO-Sheffield International Postgraduate Course in Natural Resources Research Department of Geography University of Sheffield Sheffield S10 2TN, United Kingdom	One
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33.	Mr. E.K. Leggett Division of Plant Industry Department of Agriculture State Office Block Phillip Street Sydney, N.S.W. 2000 Australia	One
34.	The Chief of Division Division of Land Resources Management C.S.I.R.O. Riverina Laboratory Private Bag, P.O. Deniliquin, N.S.W. 2710 Australia	One
35.	Mr. N.M. Dawson Supervising Development Planning Officer Division of Land Utilization Department of Primary Industry Queensland State Government Brisbane, Queensland Australia	One

1. INTRODUCTION

1.1. PURPOSE OF STUDY

The major aim of this research is to develop a viable methodology for producing small scale rural land use maps in semi-arid developing countries using imagery obtained from orbital multi-spectral scanners. At present no such methodology is available and it is felt that there is an urgent need for a detailed description of all the stages involved in the production of small scale land use maps using MSS data similar to the methodologies that have been developed for use with conventional aerial photography.

1.2. THE NEED FOR SMALL SCALE RURAL LAND USE MAPS

Nunnally (1974) and other researchers (Howard,1974; Estes et al., 1974) have asserted that remote sensing technology can make one of its biggest and most significant contributions in the area of land use data collection. This has been due to a variety of reasons, including the development of many different types of sensors, data storage devices and recording platforms.

Until the 1960's, detailed rural land use surveys have been mainly carried out in developed countries and land use maps have been produced for a range of purposes with a wide variety of scales and classifications. The primary purpose of these surveys has been to determine the spatial distribution of land use at a particular time. The resultant land use maps have provided planners with useful analytical tools for general or reconnaissance evaluations as well as establishing a permanent data base as part of a continual monitoring system of the landscape. These surveys have been carried out using time-consuming and often expensive methods involving the collection of information from various statistical agencies, field reports and vertical black and white panchromatic aerial photography (Kriesman, 1969).

With the emergence of many new independent nations since World War II, the planning of their economic development policies has often necessitated the use of medium-small scale land use maps which have permitted broad overviews of regions and have provided the bases for more detailed and diverse investigations at larger scales. Also, with the ensuing changes in agricultural products and land management procedures, they have provided a system for establishing permanent and systematic records of landscape changes.

However, there have been problems in the production of these medium-small scale land use maps in both developing and developed countries mainly associated with the collection of base data (Thaman, 1974). The introduction of panchromatic vertical aerial photography allowed a comparatively rapid method of recording the land use characteristics of the landscape but certain problems became obvious with this type of data collection technique. Essentially, the problems have been concerned with time and cost factors. In order to produce medium-small land use maps the task of handling and interpreting large numbers of photographs became a major barrier to the rapid production of the completed map. Also, the costs involved in providing adequate, consistent and repetitive coverage over large areas by conventional vertical aerial photographic surveys in a wide range of weather conditions have added to the production problems (King and Blair Rains, 1974).

When the Earth Resources Technology Satellite (ERTS 1 now named LANDSAT 1) was launched in July, 1972 a new system of rapid data collection became available which permitted consistent coverage of the earth's surface through a variety of sensors. For the first time, regular synoptic overviews could be used in plotting man's utilization of the earth's surface. This was particularly encouraging for the developing countries where the costs and other problems associated with the collection of agricultural data on a repetitive basis by conventional methods have often been the major deterrents against the production of land use maps. Also, in some countries it was the first time that complete aerial coverage had been available (Rijnberg and van den Broek, 1975).

Since 1972 there has been a virtual explosion in the amount of research carried out on data obtained from LANDSAT 1, LANDSAT 2 and Skylab. But, according to Nunnally (1974) there has been no attempt by anyone to evaluate in a systematic manner the relative effectiveness of all of the different sensors capable of recording land use data. Many investigators have considered the comparatively conventional photographic processes including black and white panchromatic and infra-red, colour and colour infra-red photography in land use studies (Colwell, 1970; Vink et al., 1965). More recently, other researchers have investigated the use of multispectral scanners, radar and thermal infra-red with varying degrees of success (Easams, 1972; Nunnally, 1974; Allen, 1975; Smith, 1975; Henderson, 1975).

Although the development of techniques for collecting remotely sensed data has progressed very rapidly, many problems still persist in the utilisation of the information. They include the correct selection and calibration of sensors for specific purposes as well as an understanding of their design capabilities and functions. Also, the identification of image characteristics and the lack of clarity caused by the quality and resolution factors of the remotely sensed data have presented difficulties in the interpretation of land use at medium to small scales (Landgrebe, 1972). Seasonality or the time of imagery acquisition is another important factor that can affect the nature of the data collected (Owen-Jones,1975).

Other problems include the lack of appropriate techniques for establishing ground truth using satisfactory sampling techniques (Kelly, 1970; Zonneveld, 1974; Allan, 1975), the lack of a proven and versatile land use classification scheme suitable for use with small scale imagery(Anderson, 1971; Anderson et al., 1972; Dodt and van der Zee, 1974) and the lack of adequate training for persons involved in interpreting this imagery (Nunnally, 1974). Also, the high costs incurred in using many of the computer based interpretation systems that have been evolving during the last two or three years will probably preclude their future use in many countries (Sweet et al., 1974; Lietzke & Stevenson, 1974).

1.3. THE NEED FOR A METHODOLOGY FOR PRODUCING SMALL SCALE LAND USE MAPS USING ORBITAL IMAGERY

It has, therefore, become apparent that a detailed outline of a methodology for producing small scale rural land use maps from data obtained by remote sensing techniques could have immediate practical applications. The methodology would be particularly beneficial if the suggested techniques could be applied using relatively accessible equipment and materials as many developing countries lack suitably qualified staff, technology and equipment. In addition, it appears that adequately tested automatic systems for interpreting land use patterns from orbital imagery will not be functional in the foreseeable future (Hempenius, 1975; Savigear, 1975). These systems need to incorporate spatial, spectral and temporal factors in order to interpret land use under a wide range of conditions and, although much research has been carried out, no completely successful system has been developed.

It is envisaged that the methodology will include an outline of relevant remote sensing techniques including their scope and limitations, guidance on pre-processing procedures, selection of correct data bases, discussion of map scale selection, interpretation procedures, the development of suitable land use classification schemes, clarification of ground truth procedures, especially sampling methods and the production of the final land use map. This methodology should present a basis from which medium-small scale rural land use maps could be produced without resorting to exhaustive background research and training or the use of expensive equipment and technologies.

1.4. OBJECTIVE

The development of a methodology for producing small scale rural land use maps in semi-arid developing countries using remote sensing techniques, especially orbital multispectral scanners.

The areas that will receive particular attention are:-

a) a critical evaluation of the uses and limitations of remote sensing devices that can be utilised in carrying out land use surveys;

b) a resume of relevant pre-processing techniques;

c) a description of various interpretation procedures that may be used;

d) the development of a suitable rural land-use classification system for use with small scale orbital imagery;

e) clarification and assessment of ground truth procedures.

2. CAPABILITIES OF REMOTE SENSING TECHNIQUES FOR LAND USE SURVEYS USING ORBITAL IMAGERY

2.1. INTRODUCTION

As different features of the landscape exhibit different spectral responses, it is very important that sensing devices employed in land use surveys should be correctly selected and utilised. At the present level of technological development, sensors which record data in the ultra- violet, visible, near visible infra-red, thermal infra-red and microwave portions of the electromagnetic spectrum have the greatest potential (see Figures2.1 and2.2). The most satisfactory sensors developed that have direct applications in orbital land use surveys include photographic sensors, multispectral scanners and side-looking radar. The following discussion will consider the nature and limitations of these sensors, especially their suitability for inclusion in orbital earth resources imaging systems. Return beam vidicon systems and independent thermal infra-red systems have not been discussed in detail because interpretation techniques have not reached a satisfactory level that would allow them to be considered as operational bases for orbital land use surveys in the foreseeable future. This is mainly due to the lack of sufficient data from these sensors and research workers have been unable to evaluate their spectral responses and their usefulness for rural land use surveys.

2.2. PHOTOGRAPHIC SENSORS

2.2.1. General

Until recently photographic techniques have been by far

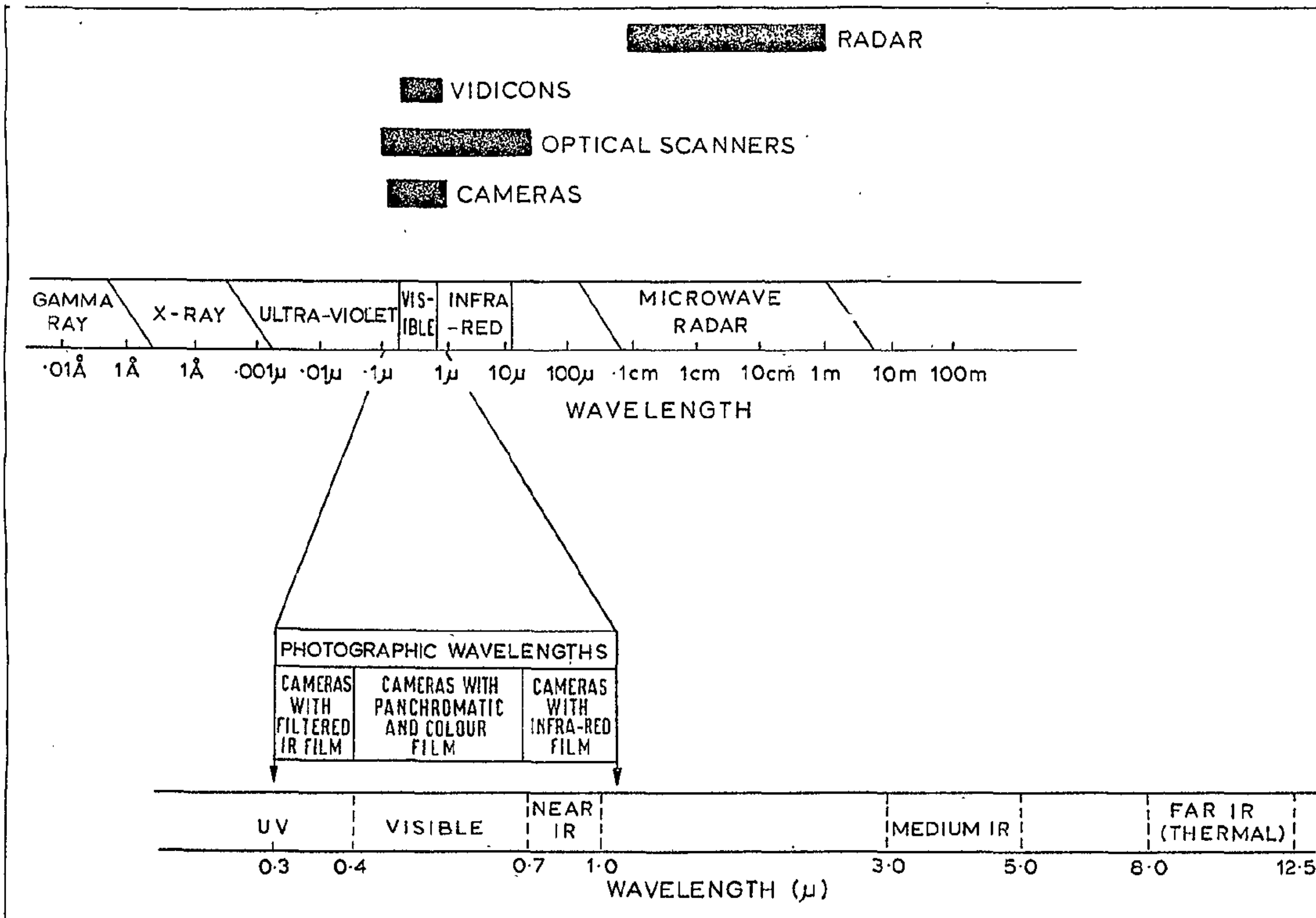

Figure 2.1 Spectral relationships of various remote sensors used in land use surveys

the best methods for recording the spatial, spectral and temporal characteristics of land use patterns. According to Thaman (1974) almost all of the operational surveys that have been carried out throughout the world have utilised photographic sensing systems. There is no doubt that they will continue to play a very important role in medium-large scale land use surveys and, due to their excellent spatial resolution and established interpretation methodologies, they will serve also as valuable aids in small scale land use surveys based on orbital imagery.

Photographic sensors are passive and direct in the sense that they incorporate various combinations of cameras, filters and films that are capable of recording the reflected radiation in the visible and near visible portion of the electromagnetic spectrum from approximately 0.3 to 1.1. micrometres (see Figures 2.1 and 2.2). These sensors do not produce or transmit any energy in order to "illuminate" the earth's surface (c.f. radar) and the varying amounts of reflected radiation are usually presented as positive prints or transparencies (Cooke and Harris, 1970).

There are many factors that still make photographic sensors the most viable method for operational land use surveys at medium-large scales. These include the wide range of film, filter and lens combinations that may be utilised to investigate selected portions of the visible and near infra-red portions of the electromagnetic spectrum. Also, this type of imagery has the advantage that it can be viewed stereoscopically which allows the interpreter to consider the relationship between slope and land use either qualitatively or quantitatively. In addition, as it usually reflects closely the actual on-the-ground situation, photographic interpretation is a comparatively straightforward process (Heller, 1970) which can be aided by established methodologies that have been developed over many years (A.S.P.,1960, Vink et al., 1965; Olson, 1973). Interpretation is also assisted by the high spatial resolution of the photography and the relative ease in which the photography may be rectified to give the correct geometric portrayal of the earth's surface. The latter characteristic makes photography an ideal medium for mapping the spatial distribution of land use. Overall, vertical aerial photography and the subsequent film processing and interpretation are operations which do not depend on expensive platforms or sophisticated electronic equipment for image generation and analysis.

However, there are a number of disadvantages associated with conventional photographic sensing. Probably the most important is that it is not an all-weather, day or night system due to the fact it utilises the reflected radiation of the visible and near visible infra-red portion of the electromagnetic spectrum. Therefore, the operational costs in normal airborne photographic surveys are indirectly increased by high aircraft stand-by costs whilst waiting for suitable weather conditions. In satellite photography large areas may be covered by one frame compared with the large number required to cover the same area by conventional aerial photography but much of the photograph may be rendered virtually useless for land use surveys due to excessive cloud cover. Other problems associated with orbital photography involve

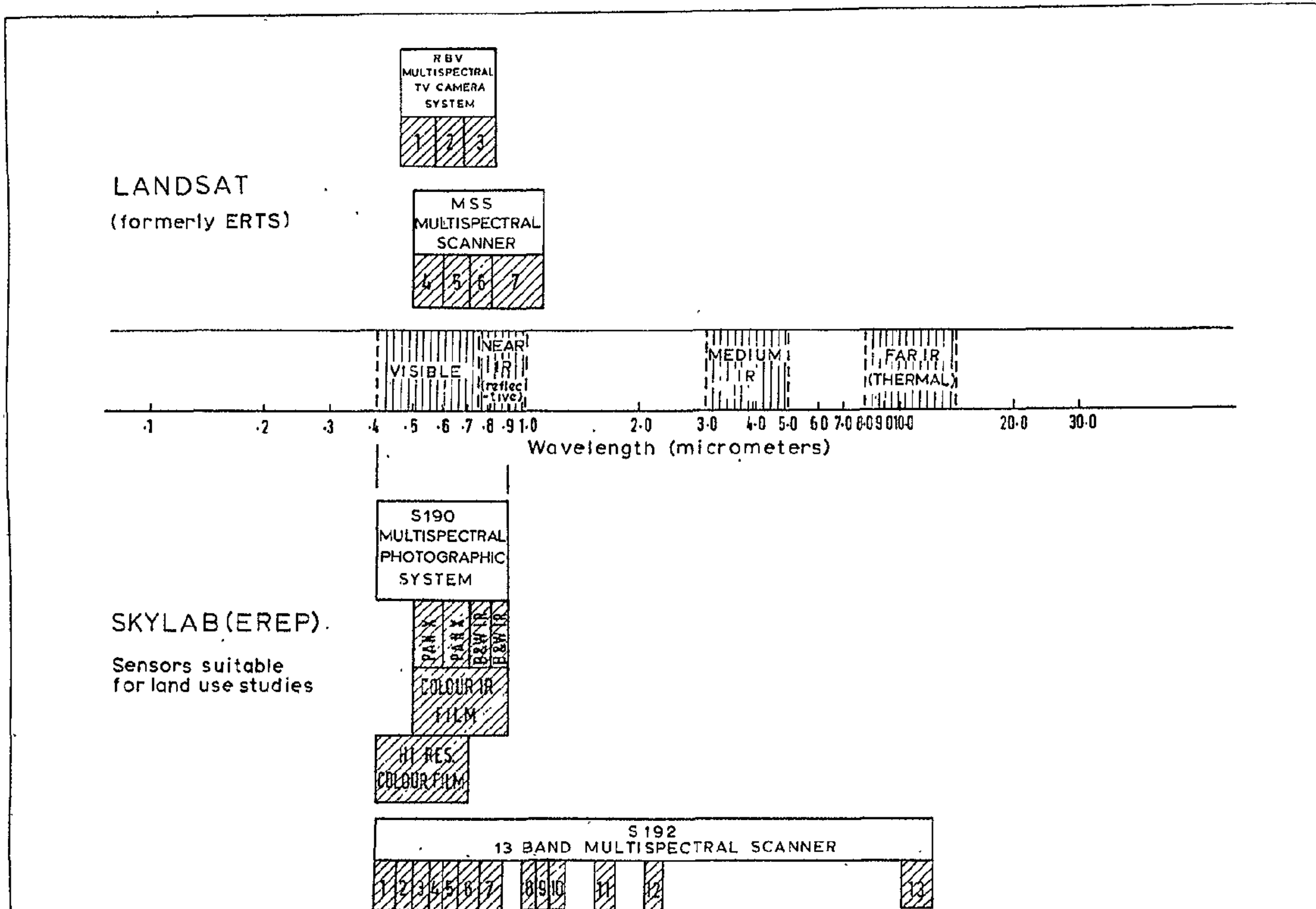

Figure 2.2 Simplified diagram showing spectral bands of Landsat and Skylab (EREP) Sensors

the return of film from unmanned satellites.Although, it is technically possible to retrieve films from unmanned satellites (Clayton, 1974), it is operationally difficult and expensive (Entres,1974). Also, due to the nature of photographic sensors, adequate protection must be provided to prevent extraneous radiation affecting the film during all stages of the operation.

Consequently, the use of photographic sensors for repetitive, global or regional land use surveys in unmanned long-term satellite operations will be very limited but they will continue to be the major operational technique for obtaining airborne imagery for many years. The latter role will provide important background material required for interpreting orbital imagery obtained by other satellite sensors, especially multi-spectral scanners, even though the photography may be out-of-date and may only partially cover the survey area at a relatively large area,ie. they may provide a type of "ground truth" for orbital data in a similar way that field work provides ground truth for conventional aerial photographic surveys.

2.2.2. Photographic Sensing Systems

It is beyond the scope of this dissertation to provide detailed explanations of the methods used in obtaining photographic images. However, a brief summary of the major components of photographic sensing systems, viz. cameras, films and filters will be presented together with references to relevant articles which contain detailed technical explanations.

There are several types of aerial cameras that have been designed for various purposes. They include the conventional vertical framing camera (see Figure 2.3), trimetrogon, panoramic, continuous strip, divergent forward oblique and forward oblique cameras. Detailed descriptions of each type can be found in Navair,(1967); Strandberg,(1967); Jensen, (1969); Am.Soc. Photogrammetry, (1968, 1975); Spurr, (1973); Estes,(1974).The most common system used in land use surveys has been the vertical framing camera but, in recent years the multi-band (or multilens) adaptation has been investigated as a possible method for obtaining additional photographic information for use in land use surveying (Lauer,1971; Yost and Wenderoth, 1971; Lins and Milazzo, 1972; Potter et. al., 1974). The multi-band vertical framing cameras, with their various combinations of lenses, films and filters, have permitted much more detailed investigations of the reflected radiation from features of the landscape within the visible and near-visible infra-red portion of the electro-magnetic spectrum. Some attempts have been made to record the reflected radiation from the ultra-violet region with limited success (Estes, 1974).

Black and white panchromatic aerial photography has been the major operational system used in land use surveys for many years and the comparatively recent introduction of colour photography, both conventional and colour infra-red, has increased the potential information content of photographs. However, the marked increase in costs associated with the production of colour photographs have tended to limit their use, especially in developing countries. Also, in order

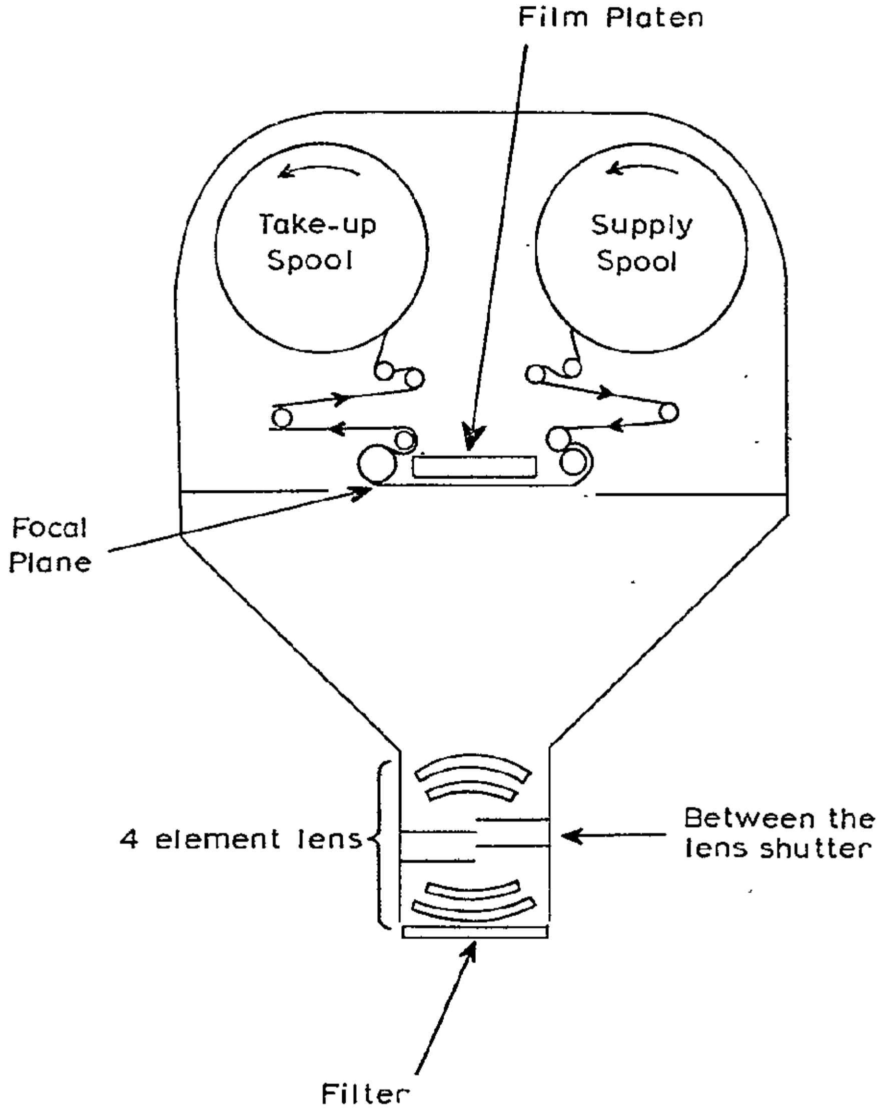

Figure 2.3 Vertical Framing Camera

to interpret and evaluate the imagery produced by these recent air-borne, photographic techniques, a basic understanding of the range and limitations of the overall photographic systems, especially film emulsions, is required. This is particularly necessary in the utilisation of colour infra-red photography where the normal colours of objects are replaced by "false" colours. Furthermore, careful selection of film filter-lens combination is required to provide imagery that maximises the landscape characteristics being investigated and to avoid selecting combinations that produce similar imagery. Detailed explanations of the technical aspects of films and filters may be found in Navair(1967), Jensen (1968), A.S.P. (1960,1968,1975), Meyer and Maklin (1969), Levine(1969), Heller (1970), Colwell et al.,(1970), Thomson (1973a, 1973b, 1975).

2.3. MULTISPECTRAL SCANNERS

Multispectral scanning systems provide a basis for data acquisition that permits the simultaneous measurement and recording of reflected and/or emitted radiation from various portions of the electro-magnetic spectrum by non-photographic methods (see Figure 2.4). This type of system can provide information that may be used to supplement imagery obtained by using photographic sensors as well as recording data outside the spectral range of photographic emulsions. The operational scope of the scanners ranges from the near ultra violet to the thermal infra red ie. from approx. 0.3 μ to 14 μ.

Some of the most sophisticated scanning instruments can divide the relevant portion of the electro-magnetic spectrum

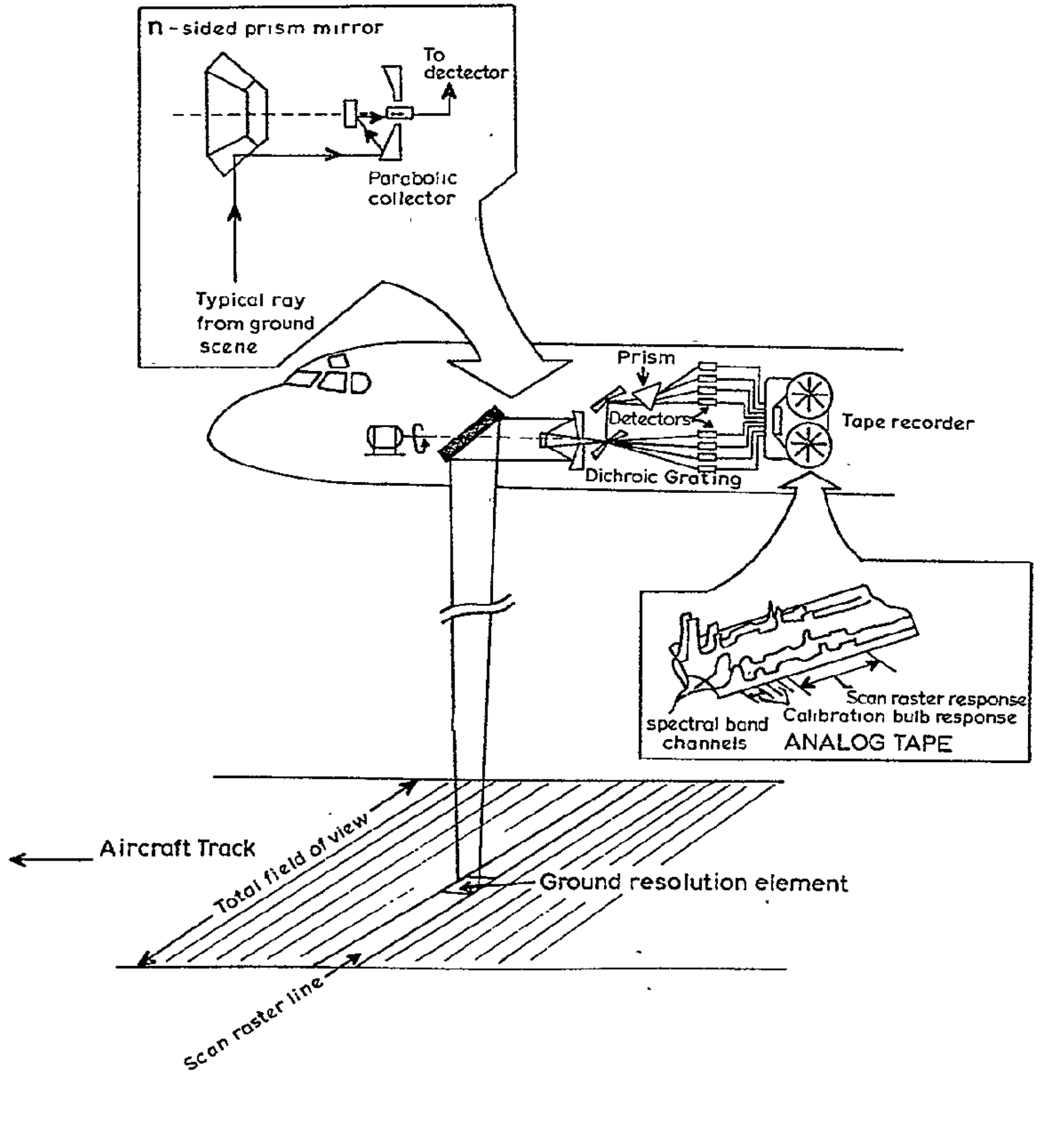

Figure 2.4 Simplified diagram of an airborne multispectral scanning system (adapted from Estes, 1974 and Langrebe, 1971)

into 24 channels and the respective reflectance or emittance levels can be recorded on magnetic tape. Operationally,only 4 bands have been implemented in LANDSAT 1 and 2 scanning systems and 13 bands were used in Skylab (see Figure 2.2 and Tables 2.1.and 2.2).Roberts (1975) states that "it does not automatically follow that an increase in accuracy is obtained by increasing the number of channels." He refers to research that has demonstrated that only a relatively small increase in accuracy of classification is obtained when using 12 bands as compared with 4 or 5 bands. He also points out that it has not been possible to make any general rules with regard to the number and spectral range of bands that should be used.

There is no doubt that multi-spectral scanners will play a major role in future small scale land use mapping based on orbital imagery and that it will be the dominant system employed in this type of survey for the next decade (Clayton, 1974; Savigear, 1975; Hempenius, 1975). The primary advantage of multispectral scanners over other remote sensing systems is that recorded information can easily be relayed to earth receiving stations from the unmanned satellites. Also, this system can acquire data about portions of the electromagnetic spectrum that are not easily obtained by other sensors. The data collected are suitable for digital conversion and can be made readily available in computer compatible form for automatic processing in a wide range of investigations.

Overall, multi-spectral scanners provide data acquisition systems that embrace a comparatively broad spectral range and, when combined with satellites, they have the capabilities to permit almost continuous monitoring of the earth's surface.

TABLE 2.1

TYPES OF SENSORS CARRIED ON LANDSAT SATELLITE

(formerly ERTS - Earth Resources Technology Satellite)

SENSOR: RBV - multi-spectral camera system

Spectral bands:	0.475 - 0.575 μ
	0.580 - 0.680 μ
	0.690 - 0.830 μ

SENSOR: MSS - multi-spectral scanner system

Spectral bands;	0.5 - 0.6 μ
	0.6 - 0.7 μ
	0.7 - 0.8 μ
	0.8 - 1.1 μ

TABLE 2.2

TYPES OF EREP (Earth Resources Experiment Package)
SENSORS CARRIED ON SKYLAB SATELLITE

SENSOR: S190 - Multi-spectral Photographic Facility

Spectral bands:	0.5 - 0.6 μ (Pan X)
	0.6 - 0.7 μ (Pan X)
	0.7 - 0.8 μ (B&W I.R.)
	0.8 - 0.9 μ (B&W I.R.)
	0.5 - 0.88 μ (Colour I.R.)
	0.4 - 0.7 μ (HiRes Colour)

SENSOR: S191 - Infra-red Spectrometer

Spectral bands:	o.4 - 2.4 μ
	6.2 -15.5 μ

SENSOR: S192 - 13 Band Multi-spectral Scanner

Spectral bands:	0.41- 0.46 μ
	0.44- 0.51 μ
	0.52- 0.56 μ
	0.56- 0.61 μ
	0.62- 0.67 μ
	0.68- 0.76 μ
	0.78- 0.88 μ
	0.98- 1.08 μ
	1.09- 1.19 μ
	1.20- 1.30 μ
	1.55- 1.75 μ
	2.10- 2.35 μ
	10.2 -12. 5 μ

SENSOR: S193 - Microwave System

Spectral band : 13. 9 GHz

The synoptic overview and the limited amount of geometric distortion give the orbital multi-spectral scanning systems the most potential for small scale land use mapping in the foreseeable future.

Unfortunately, certain limitations still exist with orbital multi-spectral scanning systems.The most important include the relatively poor spatial resolution, i.e.approximately 79 metres on LANDSAT 1 and 2 imagery and 50 metres on Skylab imagery and, in many investigations, expensive equipment and trained operators have been required to analyse and interpret the data. In addition, as multi-spectral scanners record reflected and emitted radiation, they do not have the all- weather, day or night flexibility of radar. Consequently, in any particular orbit, large areas of the earth's surface may be rendered unsuitable for the acquisition of data due to cloud cover. However, the relatively rapid orbiting of the earth often allows sufficient coverage of the earth to be obtained and, with the recent launching of LANDSAT 2 and the future launching of LANDSAT 3, the temporal resolution will be improved considerably providing the sensors continue to function. Another disadvantage is that stereoscopic viewing is not normally possible by using forward overlap within a strip. Until recently it could only be obtained through side overlap (Poulton, 1973; van Genderen, 1974a)but, an innovation by the U.S. Geological Survey Astrogeology Division has been introduced whereby the digitised 1:250,000 topographic map data covering a scene is merged with the LANDSAT image data and the appropriate displacement is computed to produce any desired parallax (Beaumont, 1975).

Unfortunately, this technique will not be feasible in many developed and developing countries due to the lack of adequate, quantitative topographic map information.

Although the spectral characteristics of many land use features can be measured and recorded on magnetic tape and later reconstituted into visual imagery by many different techniques, the problem of data interpretation has lagged far behind the capabilities of multi-spectral data collection.

As different materials possess different reflectance, absorption and emission properties, much research has been instigated in order to determine the specific spectral signatures of the various features of the landscape, eg. vegetation, rocks, minerals, water, soils. The identification of unique spectral signatures would enable the data obtained from remote sensors to be automatically classified. But, according to Savigear (1975), most of the research has been carried out under strictly controlled laboratory conditions and the signatures determined in this manner can only provide a guide for the selection of spectral bands that should be used in operational surveys. With regard to the search for unique spectral signatures in crop surveys and the idea that a library of "crop signatures" could be produced, Roberts (1975), reported that this approach has been abandoned by most researchers. He stated that it was apparent that "at the present stage of development, spectral data can only be interpreted meaningfully when it is compared with ground truth or training sites which are close in space and time to the survey area".

Factors that have affected the amount of recorded radiation, or emitted energy from a particular crop include

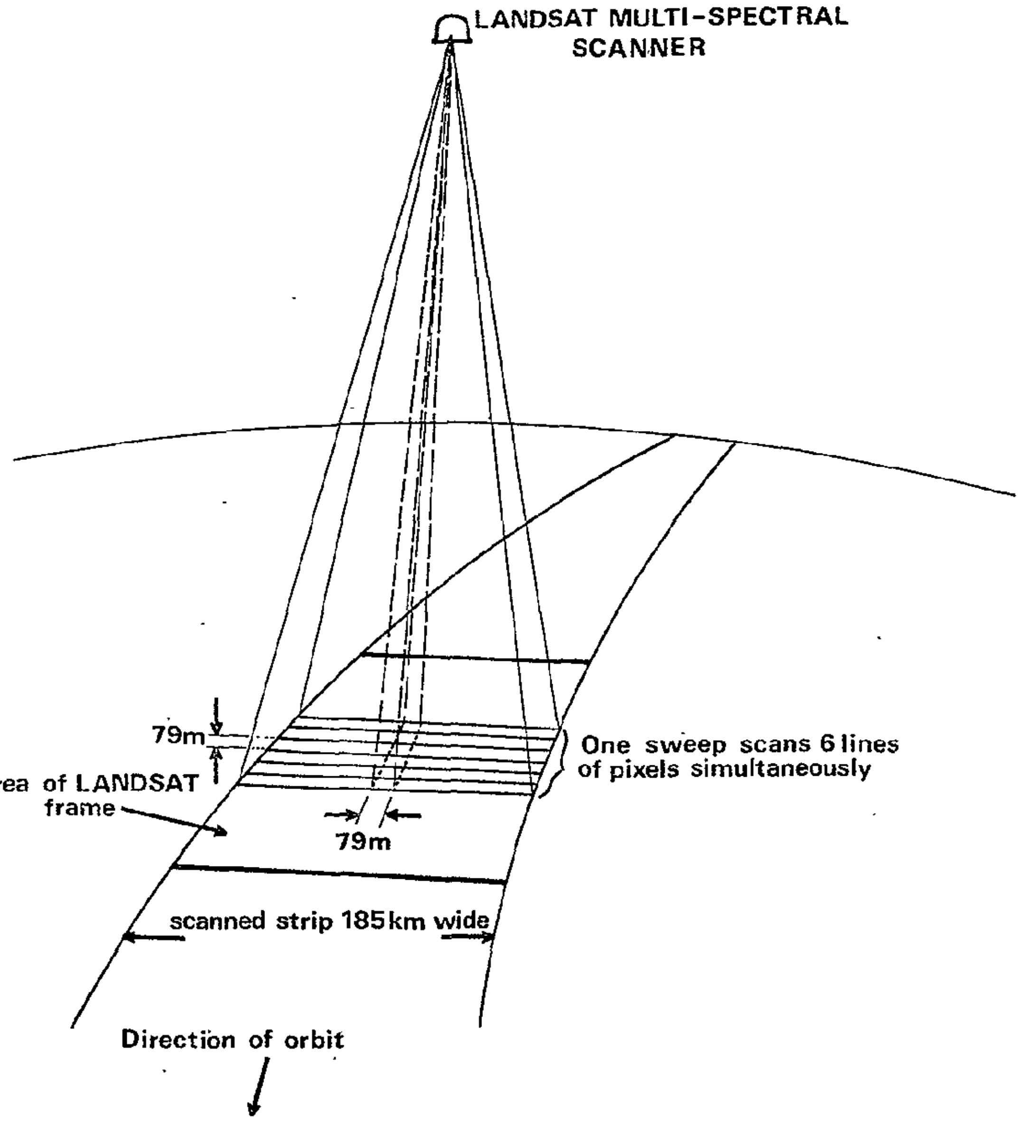

Figure 2.5 DIAGRAMMATIC REPRESENTATION OF THE RECORDING OF LANDSAT MSS DATA

the time of day as well as the time of the year in which the measurements were made. These temporal aspects affect the level of solar illumination and the stage of crop growth and have presented major problems for researchers attempting to develop automatic crop classifying procedures. The major developments have occurred in parts of the United States where large scale monoculture is practiced but LACIE (Large Area Crop Inventory Experiment) appears to be the only technique that has reached an operational level (Allen,1975). Therefore, despite earlier over-exaggerated claims, it appears that the use of the data obtained from orbital multi-spectral scanners for the automatic production of detailed land use maps will not eventuate in the near future especially in developing countries. This will be particularly relevant in areas where the landscape is subjected to a wide range of crops and where the field sizes are small and fragmented. The probable trend during the foreseeable future will involve the utilization of certain computer based techniques to assist in visual interpretation.

More specific explanations and a wider range of references dealing with the various aspects of the utilization of MSS data in land use surveys are provided in the general review in Chapter 3.

2.4. RADAR

Radar is the only viable remote sensing system, other than photographic sensors and multi-spectral scanners, that appears to have any real potential for obtaining land use data from orbiting platforms in the foreseeable future. (Hempenius,1975). As an active remote sensing system, radar provides its own source of illumination in the microwave portion of the electromagnetic spectrum. The nature of this illumination can be controlled to a high degree but, because it is usually based on a single frequency between 0.8 cm. and 1 metre rather than a spectral band used by passive sensors, the use of radar in vegetation and land use studies is limited unless both like and cross-polarised imagery are taken simultaneously (van Genderen,1975).

Due to its active nature and the utilisation of longer wave lengths, radar has all-weather, day and night capabilities which produces a distinct advantage over photographic sensors and multi-spectral scanners. Long term flight planning can be carried out and aircraft standby costs markedly reduced. Also, it enables monitoring of agricultural crops at critical phases, even if adverse weather conditions exist at the time. Additionally, it can provide the basis for an accurate system for the recognition of land surface features (Entres, 1974).

With regard to the future use of orbital radar, Hempenius (1975) listed many advantages of Synthetic Aperture Orbiting Radar (SAOR). For example, it is expected that the spatial resolution of Seasat SAOR (to be launched in 1978) will be 30 metres which will be at least as good as present operational airborne radar and the broad swath width will provide a good synoptic view (see Figure 2.6). The almost constant look angle may allow the automatic processing of textural information to be carried out and the relative steepness of the look angle will considerably increase the range of applications by permitting detailed investigations of hilly terrains. However, Hempenius believes that the major land

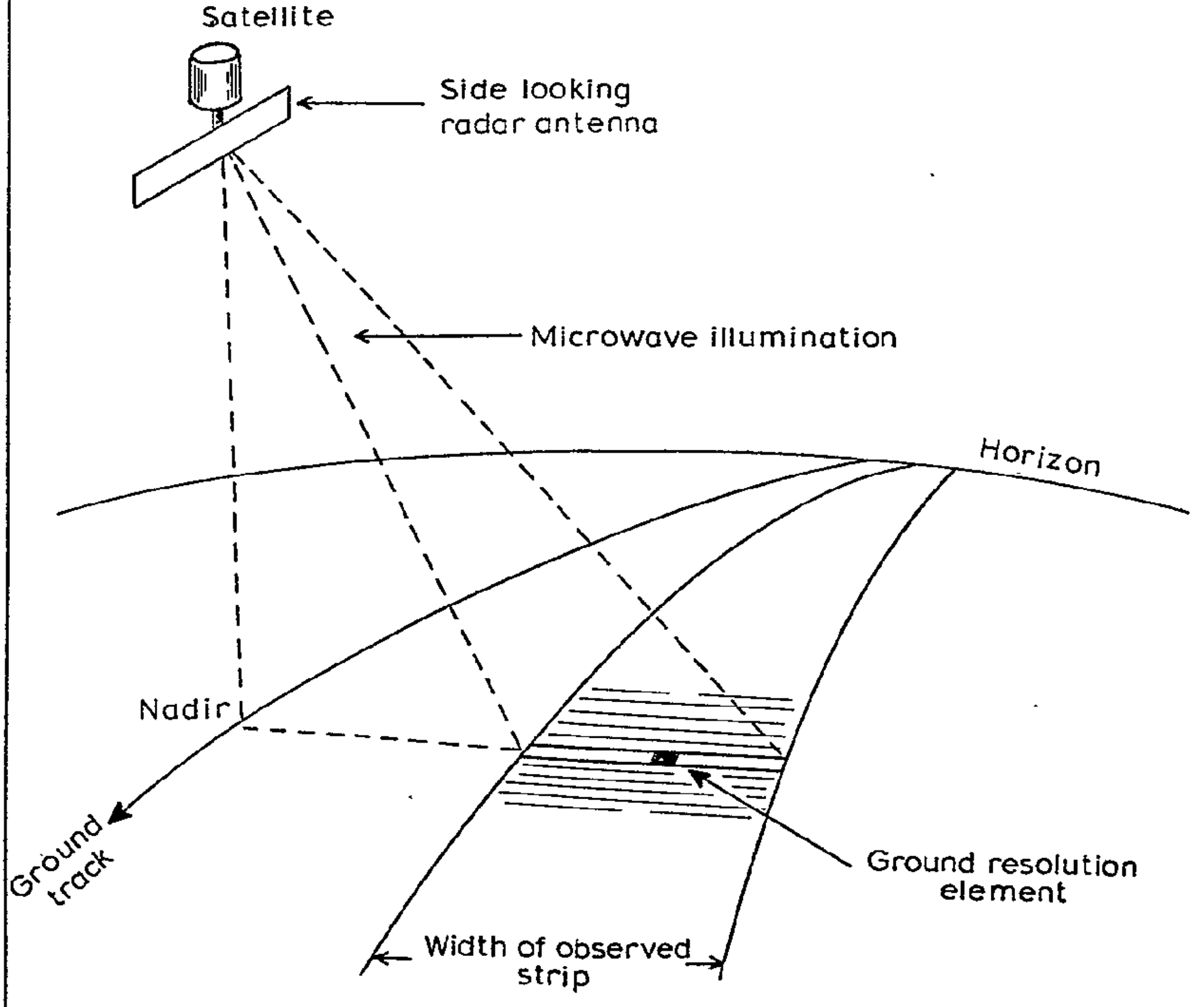

Figure 2.6 Diagrammatic representation of orbiting side looking radar (adapted from Entres, 1974)

use application of SAOR when it becomes operational in the mid-1980's will be to monitor vegetation in areas which are subjected to occasional or seasonal heavy cloud cover as well as investigating sparse vegetation patterns in semi-arid zones. But these tasks will be supplementary to the major role of SAOR in monitoring sea and ice characteristics.

As with other remote sensing systems the characteristics of the recorded imagery are caused by the interaction of the properties of the sensor system and surface phenomena and serious misinterpretations could occur if the interpreter does not understand the basic principles underlying the image formation. This problem is particularly evident with radar. Domville (1974) has stressed that, if the full operational potential of radar imagery is to be realised, it will be necessary to embark on a considerable research programme devoted primarily to the recording, processing and interpretation of the data obtained. Additional support for the need for more research into the interpretation of radar imagery comes from Morain (1974) who has investigated the use of radar in vegetation mapping. He believes that researchers have only just begun to explore the content of radar imagery and the best ways to interpret it, especially with regard to the meaning of tone and texture. Furthermore, he suggests that it would be highly desirable to develop a true multi-spectral capability for use in vegetation science.

The problems associated with interpreting radar imagery are greater than with photographic images although many similar factors including the image characteristics of tone, texture, size, shape and stereoscopy can be utilised.

This is due to the fact that the radar system provides its own source of illumination and the nature of the reflectance of this energy by the target makes the accurate identification of ground features more difficult. The amount of energy returned to the radar sensor is dependent upon the properties of the transmitted electromagnetic energy and the properties of the surface features. The factors affecting the nature of the transmitted electromagnetic energy and, subsequently, the imagery itself include the operational wave-length, polarization, look direction, flying height, size and type of antenna. The properties of the surface phenomena which can affect the imagery include the dielectric and conducting properties, the surface roughness and shape, surface slopes, vegetation cover and the nature of the subsurface materials. Detailed discussions on these aspects may be found in deLoor, (1969); Holter, (1970); EASAMS, Vols. 1-6, (1972); Domville, (1974); Nunnally, (1974) and reports on applications of radar in vegetation and land use surveys can be seen in Morain and Simonett, (1966,1967); Simonett, (1968,1970); Viksne et al, (1969); Morain, (1974).

2.5. RETURN BEAM VIDICON

The television camera usually favoured for orbital remote sensing is based on the return beam vidicon (Entres, 1974) which contains a photo-sensitive surface on which an image is exposed initially and an internal scanning device converts the picture of relative radiation intensities to an analogue signal. This signal can be telemetered directly back to an earth recording station or tape recorded and sent back later (Landgrebe, 1972) in a similar manner to the method used with multi-spectral scanners.

Vidicons are restricted to approximately the same spectral range as photographic sensors and, due to the relative ease of data retrieval they could prove to be a viable alternative to photography in unmanned satellites as well as supplementing the data collected by multi-spectral scanners.

The return beam vidicon used on LANDSAT 1 recorded imagery in 3 bands viz. 0.475-0.575µ (green) 0.58-0.68µ(red) and 0.83µ (near IR) (Stone, 1974). Unfortunately, the system malfunctioned and had to be shut down a month after launching and insufficient data were obtained to allow a realistic appraisal of the imagery and its potential for providing information for small-scale land use surveys.

2.6. SUMMARY

Nunnally (1974) has reported that although a series of independent studies have been carried out by researchers interested in specific remote sensing systems there has been no attempt to evaluate in a systematic manner "the relative effectiveness of all the different sensors capable of recording land use data". Even though this statement is quite correct, it tends to be more relevant to air-borne rather than orbital techniques because only one remote sensing system is operational for obtaining orbital land use data.

As mentioned in the earlier discussions about various remote sensing systems that have potential applications in orbiting satellites, the only viable technique that will permit the rapid and regular collection of data for small land use surveys during the next decade will be multi-spectral scanning systems. Even though photographic sensors can offer much better spatial resolution and relative ease of interpretation, the problem of retrieval of exposed film severely restricts their ability to provide continuous monitoring facilities. In addition, multi-spectral scanners can provide data in a form that is more suitable for digital conversion and automatic processing. Radar has not yet reached a satisfactory level of development to be considered as an alternative orbital remote sensing system and according to Hempenius, (1975) Synthetic Aperture Orbital Radar (SAOR) will not provide adequate imagery for land use monitoring for a decade. But its all weather, day or night capabilities would make radar a very important addition to the multi-spectral scanner if problems of interpretation, rectification and data storage can be overcome. Thermal infra-red line scanners appear to have limitations and cannot be considered as important alternative land use data collection techniques and will only be able to provide supplementary information. Return beam vidicons have distinct advantages but have provided insufficient data to allow satisfactory assessment of their potential in providing satellite imagery for small scale land use surveys.

However, multi-spectral scanners will not provide a panacea for small scale land use surveys, but at the present stage of technological development, they offer the major advantage that information gathered by this method can be readily retrieved and stored in computer compatible form. Also, the data have the capacity to be reconstituted into a series of images singly or in varying combinations of spectral lands at scales normally up to 1:250,000 or larger allowing regular synoptic overviews of the earth's surface. But unfortunately, the collection of data by orbital multi-spectral scanners has outstripped the development of interpretation techniques. Many researchers have investigated a wide range of automatic and semi-automatic techniques using authentic and simulated LANDSAT and Skylab data. However, there are very few organisations in the world that are capable of utilizing the information that is being obtained from the current operational satellites. Furthermore, no proven techniques have been developed that will allow automatic identification of features of the earth's surface without associated ground sampling. Owen-Jones, (1975), believes that it will be highly improbable that completely automatic interpretation will be achieved. Human decisions and assistance will be required but the level and nature of the human assistance varies amongst researchers and much work is still being carried out in many different disciplines.

Savigear (1975) suggests that the research involving the evaluation of the use of multi-spectral scanning data should be considered in two separate but related programmes. Firstly, the research involving the identification of unique spectral signatures should be an important long term situation. Secondly, in the short term, the uses of multi-spectral data in different types of environments in regions of limited area should be identified and assessed. Also, the research programmes should be oriented towards the requirements of the region rather that the world scene. Eventually the identification of the different spectral, spatial and temporal properties of different parts of a region may lead to the development of a satisfactory semi-automatic system for regional analysis using multi-spectral data. However, this would involve more refinements of current interpretation techniques and ground truth procedures as well as the establishment of detailed and tested methodologies for carrying out particular investigations. In the case of small scale land use surveys, particular attention would be required in the formation of a suitable land use classification scheme and the effects of seasonality on image identification. Generally, the short term approach would be particularly helpful for many countries which could benefit from the relatively inexpensive and readily accessible multi-spectral scanning data if a satisfactory methodology for conducting small scale land use surveys, primarily based on orbital MSS data, could be established.

Hence, this section has shown that most of the machine assisted methods used in the developed countries are experimental rather than operational and that there is a lack of detailed methodologies suitable for use in developing countries. Consequently, there is an immediate need for a simple approach in order to maximise the usefulness of readily available LANDSAT MSS data for workers in developing countries to obtain relevant and reliable land use information.

3. REVIEW OF LAND USE SURVEYS USING ORBITAL IMAGERY

3.1. INTRODUCTION

As far as can be ascertained, no comprehensive review of current research dealing with land use surveys involving orbital remote sensing techniques has been published since Nunnally (1974) considered investigations up to and including 1972. His article included details of research that only involved preliminary assessment of LANDSAT data. Therefore, it is apparent that this type of review is presently necessary in order to bring together the main "threads" of world-wide research. But it is beyond the scope of this present study to detail all of the wide-ranging applications that have emerged during the last four years. The major consideration will involve the utilisation of imagery obtained from orbital multispectral scanners in small scale rural land use surveys in developing countries. However, in order to avoid the confusion that often occurs in current terminology it is necessary to indicate the precise meaning of land use surveys in the context of this research.

3.1.1. SMALL SCALE RURAL LANDUSE SURVEYS

The term "small scale rural land use survey" refers to the grouping of the spatial distribution of land use into distinct categories at a particular time. Due to the small scale (i.e. 1:200,000 or smaller), urban areas may be distinguished but are usually not examined in depth. The major emphasis is placed on the uses to which man assigns various parts of the rural areas. The overall aim is not to produce a detailed description of all the items that give a certain region its particular character or try to offer a detailed explanation of the factors affecting the spatial distribution of land use both within and between different parts of the region. Generalised land use categories are determined rather than a complete enumeration which normally involves the detailed collection and description of land-use characteristics in terms of type and a real extent. Thus, the final small scale rural land use map is a generalised cartographic representation of the ways in which man has utilised the surface of the earth at a particular time and these uses have been influenced by the interaction of environmental, technological, economic, social and political factors but no attempt is made to explain the extent of this interaction.

The level of accuracy of interpretation of land use from orbital imagery is a function of the type and quality of imagery, scale, spatial resolution, time of acquisition and the interpreter's knowledge of the area. These, in turn, affect the complexity of the land use classification system that can be used and, in fact, affect the whole nature and approach of the survey. The dominant purpose behind the production of small scale rural land use maps is to produce rapid cartographic descriptions of large parts of the Earth's surface. These maps may be used for a variety of purposes such as the initial reconnaissance of an area that has been poorly mapped or, in other areas, as a record of the land use characteristics of the region at a particular time. Consequently, there is a marked difference between the small scale land use surveying techniques used in this study and those used in other types of land use surveys e.g. land use inventories, integrated land systems surveys and landscape studies.

3.1.2. RURAL LAND USE INVENTORIES

The major aim of rural land use inventories is to carry out a complete enumeration of all the land within a particular region. They provide detailed information about the type, acreage and distribution of land use that is essential for efficient regional planning and management but they are time-consuming and expensive to produce. Originally, data were collected by census interviews or field mapping as well as information obtained from various statistical agencies, mail questionnaires, and specific sample surveys. Later, vertical aerial photographs were added to the data sources and permitted the rapid location and quantification of certain land use characteristics (Coppock, 1963; Luney and Dill, 1970). Unfortunately, the current level of automatic interpretation and the relatively poor spatial resolution and subsequent small-scale mapping limitations of orbital multi-spectral scanning imagery cannot provide the detailed information required for land use inventory surveys. This is particularly obvious with LANDSAT 1 and 2 data where spatial resolution is approximately 80 metres and the identification and classification of rural land use can only be established under relatively broad categories with large fields and not individual small fields or small holdings. However, orbital imagery can provide valuable assistance in the form of rapid synoptic coverage of large regions which cannot be achieved by conventional vertical aerial photography. Many attempts have been made to develop computer assisted automatic land inventory systems using orbital imagery with varying levels of success. Roberts (1975) reports that considerable improvement in both data acquisition and processing will be necessary before orbital MSS data can be used operationally. The following references provide a general cross-section of the nature of this type of investigation :-

Allen, (1975); Bankston, (1973); Carlson et al., (1974); Draeger and Benson, (1972); Hall et al., (1974); Haralick and Shanmugam, (1974); Horton and Heilman, (1973); Johnson and Coleman, (1973); Jones, (1974); Kriegler et al., (1972); Lundelius et al., (1973); Mooneyhan, (1973); Mower, (1972); Owen-Jones, (1975); Ratti and Capozza, (1974); Richardson et al., (1974); Roberts, (1975); Savigear et al., (1975); Shelton and Hardy (1974); Simonett, (1974); Sweet and Pincura, (1974); Thomson, (1973); Turinetti and Mintzer, (1974).

3.1.3. INTEGRATED LAND SYSTEMS SURVEYS

An integrated land systems method was developed by the Australian C.S.I.R.O. Division of Land Research in order to carry out preliminary surveys of land resources in the Northern Territory, N.W. Queensland, the northern part of Western Australia and Papua (Young, 1973). Details about the concepts of these surveys have been well-documented by Christian and Stewart (1968). According to Blake and Paijmans (1973), a "land system" was initially defined as an area or group of areas throughout which there was a recurring pattern of topography, soils and vegetation.

As vertical aerial photographs became readily available they became the major information source for the recognition and delineation of the land systems because "the recurrence of a number of (land) units within a land system in a regular pattern gives rise to a distinctive pattern on the aerial photograph" (Christian and Stewart, 1968).

The surveys have been accomplished by a team usually consisting of a geomorphologist, plant ecologist and pedologist who delineated preliminary land systems on the basis of air photo interpretation which was followed by field checking. After the field check, the data from the team members were integrated and descriptions of the systems and their sub-systems (or land units) together with an assessment of their capabilities and resources were published.

The C.S.I.R.O. integrated land systems approach, due to its rapidity and comparatively low cost, has been adopted and used in a number of countries and the British Directorate of Overseas Surveys Land Resources Divisions use essentially the same method for planning agricultural development in extensive, unsurveyed regions (Mitchell,1973). Similar methods of landscape evaluation have been developed in U.S.S.R and Canada since World War II but use different terminology.

A later adaptation of the C.S.I.R.O. method has been the landform type method used in East Papua which places more emphasis on landforms and rock types which are mapped by the geomorphologist mostly independently from the plant ecologist. The same survey team structure is maintained as well as the basic techniques using aerial photography and field data (Blake and Paijmans, 1973). Wright (1972a) also maintains that geomorphology can provide the necessary classificatory framework which will permit the team specialists to co-ordinate and extrapolate their finding and he has presented a detailed account outlining the principles and problems involved in devising the framework.

Criticisms of the land systems approach have included the comments that the technique of mapping patterns from aerial photographs is too subjective as it mainly depends on the available field data and the bias of the individual members of the survey team. Also the systems and sub-systems defined by the survey team are not classifications in the strict sense and do not rely on prescribed objective procedures for the grouping of categories. This aspect, the critics claim, affects the reliability of comparing land systems in one area with those in another area if they have been determined by different survey teams. Another criticism of this approach has been levelled at the concentration on the description of the physical environment compared to the brief evaluation sections which contain no economic analysis. Furthermore, Young (1973) reports that the technique has been condemned by Davidson (1965), also on economic grounds, because he believed that the teams were collecting information which was useless as an investment guide and, therefore, a waste of government money. Young also discusses an argument that ecology should replace geomorphology as the basis for resource assessment so that the effects of development on the ecosystem could be predicted. But he agrees that, although there is merit in this approach, the development of a versatile survey procedure based on an ecological method has not yet eventuated. Similarly, Rogers (1972) stressed the need for an ecological approach to resource surveys but did not offer any advice on how it could be implemented.

At the present time, it appears that orbital imagery has not been used to any extent in integrated land system or landform type surveys. Howard (1974) has stated that "the potential contribution of satellite imagery to integrated surveys in developing countries is only beginning to be appreciated". He claims that the major problem has been due largely to the resolution and small scale of the orbital imagery and the difficulty of identification and he has proposed a list of hierarchical land-units that could be incorporated in integrated surveys using orbital imagery.

The problem of identifying land units has been considered by van Genderen(1972a,1973b) who suggested that meaningful boundary delimitations can be made on orbital imagery using various image enhancement techniques. These have been incorporated into an experimental procedure involving the analysis of imagery using conventional visual photo-interpretation methods and tested in the Murcia region of S.E. Spain.

3.1.4. SUMMARY

Overall, the integrated land systems surveys have played an important role in rapidly providing descriptions of underdeveloped regions. But, the criticisms about which discipline should be emphasised e.g. geomorphology, ecology, economic and the subjective nature of the description of land systems do not directly affect the nature of the delineation of boundaries in small scale rural land use surveys being considered in this investigation. The major concern is to identify and classify the various ways in which the surface of the land is being utilised at a particular time rather than produce a complete enumeration or description of the region. However, it is interesting to note that Alexander (1973 a)has reported that the CARETS (Central Atlantic Regional Ecological Test Site) investigators of the Geographic Applications Program, U.S. Geological Survey have set up a basic hypothesis of interdisciplinary regional analysis in which "land use at least in a highly developed region, is an indicator or resultant surface expression of several interacting environmental processes." Also they claim that of all the environmental and socio-economic processes which contribute to the surface patterns, land use is the one with data sets most accessible to LANDSAT sensors. On this basis, the CARETS investigators believe that remote sensor derived data sets and land use should become the "basic data entry into a regional information system to serve regional planners and land managers". They also believe that the dividing of LANDSAT data into sub-sets or photomorphic regions may provide a very economical sampling strategy for selecting sites for more detailed measurements if many other environmental variables prove to be correlated with the similarity of patterns on LANDSAT imagery.

The over-riding problem in small scale land use surveys based on orbital imagery appears to be the lack of a detailed methodology which outlines the most satisfactory techniques that could be used in pre-processing, interpretation, classification and the establishment of ground truth and would be appropriate for use by countries which do not possess sophisticated equipment. Consequently, it seems that the most logical approach in reviewing the existing "state of the art" would be to consider, in a general sense, a cross section of investigations and applications that have been used in various studies around the world.

3.2. REVIEW OF RELEVANT UNITED STATES RESEARCH

3.2.1. INTRODUCTION

Small scale land use surveys utilising LANDSAT MSS imagery have been undertaken in many parts of the world using a wide variety of techniques. The majority of these surveys have been carried out in the United States or by United States organisations on behalf of foreign government or organisations. However, the situation in the United States is not typical of the rest of the world, excluding North Western Europe. Most countries have not had the advantages of extensive and up-to-date background information in the form of topographic maps, agricultural statistics services, existing land use maps and readily accessible aerial photography. Also, there has been very active concern in the United States, during the last decade or so, with the wide-ranging effects of population pressure on the environment, including the encroachment of urban expansion on rural areas, the intrusion of recreation pursuits on relatively untouched regions as well as the many forms of environmental pollution. (Anderson & Place (1972), Bale and Bowden (1973), Place (1974).

This concern over the future of the environment has led to the introduction of legislation at State and local government levels which has either directly or indirectly, instigated a series of land use surveys, (Brown et al., 1973; Nunnally, 1974; Carlson et al., 1974). Furthermore, since 1970, a number of legislative proposals at Federal government level have been introduced including "The Land Use Policy and Planning Assistance Act of 1973" which aimed to develop and implement a natural land use policy, in association with State and local bodies, which would incorporate environmental, aesthetic, economic, social and other factors. The Act was not passed in the House of Representatives but it acted as a catalyst which activated a host of investigations throughout the country by Federal, State and local government organisations as well as many tertiary institutions (Lindgren and Simpson, 1973; Shelton and Hardy, 1974).

Some of the main problems foreseen in the implementation of the new Federal Act were the recording of the land use characteristics so that future planning could operate from a suitable base and the development of a method which could rapidly monitor land use changes. With the launching of ERTS 1 (LANDSAT 1) in July, 1972 a vast amount of environmental information became available every 18 days and this led to a wide variety of interpretation, classification and map-making investigations. Many of these were essentially computer-based inventory techniques which have been discussed briefly in Section 3.1.2 where a broad range of articles on descriptions and criticisms have been listed. However, most of these investigations have not reached the operational stage.

3.2.2. GENERAL REVIEW

A number of studies have investigated the extent to which conventional image interpretation and computer-based analysis techniques could be applied to LANDSAT data in order to detect, classify and measure the extent of land use over large areas (Dornbach and McKain, 1974; Brown et al.,1973, Wilms, 1973). But, as mentioned previously, one of the aims of this research is to consider uncomplicated and inexpensive techniques that may be incorporated into a methodology that could be used in countries which lack sophisticated equipment and highly trained staff. Therefore, the following discussion will concentrate on presenting a general outline of a number of relevant United States research projects which have utilised LANDSAT data to produce small scale rural land use maps. However, as stated earlier, many of the procedures adopted in most of these studies cannot be applied in other countries because the U.S. researchers have had the advantage of extensive background material and, in some cases, special high and/or low altitude sub-orbital photography was flown to coincide with the acquisition of the orbital imagery. An attempt will be made to outline the level and direction of the pre-processing, interpretation, classification and ground truth procedures adopted.

One series of investigations in the Central Coastal Region of California by Estes, Thaman and Senger, Geography Remote Sensing Unit, University of California, Santa Barbara before and after LANDSAT imagery became available has shown how small scale orbital and aircraft imagery could be used to investigate and monitor regional land use changes. (Estes and Senger, 1972). In later studies, the major emphasis was placed on the establishment of a detailed data base of the region and a classification system was devised for the preparation of land use maps using high altitude colour photography and selective ground reconnaissance (Estes, 1973). This background material was then used to evaluate the information content of LANDSAT imagery with regard to land use mapping and it was found that the classification system required modification. In addition, they found that the spatial resolution of the imagery placed limitations on the amount of detail that they could identify. The smallest area classified was 2.641 sq. km. which represented approximately 0.026 sq. cm. on the image at a scale of 1:1,000,000. But they claimed that the resolution restrictions could be off-set to a large extent by the synoptic overview provided by each LANDSAT frame.

In a recent report, Estes, Thaman and Senger (1974) outlined the procedure that they adopted in their analysis of LANDSAT data and provided some guidelines that could be incorporated in the development of a detailed methodology for the production of small scale land use maps employing unsophisticated techniques. These suggestions were derived after investigations were carried out using NASA 9½" x 9½" (1:1,000,000) black and white transparencies of at least two spectral bands (usually 5 and 7) and 10X enlargements of selected portions of the LANDSAT images which were optically enhanced by magnifiers and stereoscopes. They believe that, after the preparation of a suitable classification scheme and the establishment of an adequate data base, the following stages should be followed:-

" (i) an initial phase during which the image interpreters familiarise themselves with the unique scales, resolution, contrast and tonal and textural characteristics of LANDSAT imagery

(ii) preliminary interpretation of the imagery for representative test sites to determine the interpretability and classification-related information content of the LANDSAT imagery

(iii) evaluation and modification of classification schemes based on the preliminary studies

(iv) completion of data base maps for the entire California test site

(v) the application of LANDSAT data to ancillary problems with particular focus on interfacing with and trying to encourage resource management agencies and other user groups to attempt to utilise LANDSAT type data on an operational basis."

They concluded that LANDSAT data could be a valuable source of environmental resource information but the comparatively poor spatial resolution creates problems when a wide range of environmental phenomena are located in small areas. But, as they emphasised in previous reports, the synoptic overview and the relative ease of repetitive monitoring and up-dating offer compensating advantages.

The Geographic Applications Program of the U.S. Geological Survey (GEO GAP) has initiated a series of investigations involving LANDSAT imagery. One study has considered the Phoenix quadrangle, Arizona and, initially, the project was designed "to make effective use of past experience in making land use maps and collecting land use information" and to investigate ways in which small scale orbital and aircraft imagery could be utilized (Anderson and Place,1972). The first specific objective was to make a small scale land use map (1:250,000) using Apollo 9 and aircraft imagery using at least eight major categories and several sub-categories which could be identified and mapped. The second major objective was to develop a " geographically oriented data bank of land use information" that could eventually be digitised and the computer would "print out on all land use maps, land use information in tabular form and to make several different kinds of analyses of land use".

The Phoenix quadrangle was chosen for a number of reasons including the fact that considerable recent analytic research had been carried out by the U.S. Geological Survey and a large amount of current imagery was available. Also, the clear skies and low latitude ensured that additional imagery from future manned and un-manned satellites should be available.

During the initial investigations, imagery was mainly obtained using conventional aerial cameras with a variety of film-filter combinations but considerable emphasis was placed on colour infra-red photography. In order to verify the interpretations of the aerial photography, ground information was collected by field teams. Occasionally low-flying aircraft were fitted with "metric cameras with long focal lengths" to collect photographic samples of ground conditions which could serve as checks in the interpretation of the "lower resolution satellite-type photographs".

Probably the greatest interest created by the initial Phoenix quadrangle study has been its association with attempts to construct a versatile classification scheme that could be used in preparing small scale land use maps from orbital imagery. The researchers agreed that, although it was very unlikely that one ideal classification of land use would ever be developed or accepted, there was a definite need for a standardised approach. So, prior to the final construction of their classification they listed certain criteria that should be attained, viz.

"1. A minimum level of accuracy of about 85% to 90% or better should be approached in the interpretaion of the imagery being used.

2. A well-balanced reliability of interpretation for the several categories included in the classification scheme should be attained.

3. Repeatable or repetitive results should be obtainable from one interpreter to another and from one time of sensing to another.

4. The classification scheme should be useable or adaptable for use over an extensive area.

5. The categorisation used in the classification scheme should permit vegetative and other cover types to be related to activity-oriented categories whenever possible.

6. The classification scheme should be suitable for use with imagery taken at different times during the year.

7. The classification scheme should permit effective use of sub-categories that can be obtained from ground surveys or from the use of imagery available at a larger scale or with the use of colour photography.

8. A need to collapse the categories of the classification scheme into a smaller number of categories must be recognised.

9. Comparison with land use information compiled at earlier points in time and with data that will be collected in the future should definitely be possible.

10. The classification scheme should recognize the multiple-use aspects of land use whenever possible".

Detailed explanations of these criteria have been reported in a separate article(Anderson, 1971).

A land use classification scheme for the Phoenix area was then established and it was evaluated against the suggested criteria and, although some criteria could not be satisfied immediately, the overall scheme worked satisfactorily. The researchers concluded that land use maps "of reasonable accuracy and quality" could be compiled at a scale of 1:250,000 from orbital imagery and that "agreement on a framework or scheme of land use classification for use with orbital imagery will be necessary for effective use of land use data". This desire for a satisfactory scheme was virtually fulfilled when a Land Use Classification System for use with Remote-Sensor Data was presented in U.S. Geological Survey Circular 671 (Anderson, Hardy and Roach, 1972). The system was designed so that it could be used with remote sensing imagery with minimal reliance on supplementary information at two generalised levels of categorisation (ie. Level 1 and Level 2) (see Tables 3.1. and 3.2). Also, a modified list of criteria which the system should meet was included in the Circular. They were based on the list that was previously proposed by Anderson and Place (1972). A more detailed discussion of this classification system is presented in the next part of this investigation (see Chapter 4).

Later investigations in the Phoenix quadrangle were primarily designed to test and verify the validity of the land use classification system proposed in U.S.G.S. Circular 671 as well as analysing the applicability of LANDSAT imagery for detecting land use changes and up-dating maps (Place, 1974). LANDSAT 1 9"x 9" 1:1,000,000 transparencies were interpreted using a range of techniques including the use of colour composites and an I^2S colour additive viewer to create a number of specific colour composites using selected spectral bands at different time periods. After testing many techniques the researchers claimed that the best method of distinguishing land use change was by making seasonal comparisons of LANDSAT colour composites using bands 4, 5 and 7.

Another study initiated by the Geographic Application Program of the U.S.Geological Survey has been reported by Alexander (1973a) who described the use of LANDSAT colour composite images in a preliminary study of land use classification and land use change in the Central Atlantic Regional Ecological Test Site (CARETS). Significant land use changes were identified using conventional visual interpretation techniques and enlargements of the colour composites in association with 1:100,000 maps produced from 1970 high altitude photography. These results were achieved after the interpreter familiarised himself with the principal visual signatures of the various land use types as they appeared on the enlarged LANDSAT imagery. Land use classification was based on the U.S. Geological Survey Land Use Classification System (U.S.G.S. Circular 671) and the interpreter attempted to classify the existing land use to second order of accuracy, ie. Level 2. Attempts were then made "to verify whether changes had actually occurred and whether the correct interpretations of that change had been made" by utilising the

1972 LANDSAT underflight (U-2) photography of the area. The researchers considered that the results of the land use change analysis was highly promising even without employing more sophisticated spectral signature techniques that werepossible with the LANDSAT multi-spectral data. They also claimed that a high proportion of Level 1 and 2 land use was detected and identified correctly.

In another associated investigation LANDSAT imagery of the CARETS region was examined at a variety of scales ranging from contact prints of 70mm film chips supplied by N.A.S.A. at a scale of 1:3,369,000 to enlargements up to 1:100,000 (Anderson, 1973b). One procedure that was found to be useful for a regional overview was the production of an uncontrolled mosaic from enlarged prints of band 5 imagery at 1:1,000,000. A zonal map based on visible tones and textures on the mosaic was constructed and the patterns were compared with existing small scale maps of the region representing relief, land surface forms, geology, soils, vegetation, forest types and land use. As mentioned previously, it was found that the zones located on the LANDSAT mosaic most closely resembled the patterns on the existing small scale land use map. This discovery supported the hypothesis of the CARETS investigators that remote sensor derived data sets on land use and land use change should become the basis for a regional information system which could serve the needs of regional planners and land managers.

Many other studies have been independently initiated throughout the United States and land use maps with various scales and/or classification systems have eventuated. In Nebraska, a 7 colour 1:1,000,000 scale,Level 1 general land

TABLE 3.1 A LAND USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA (U.S. Geological Survey Circular 671; U.S. Department of the Interior, 1972)

Prepared by: J.R. Anderson, E.E. Hardy, J.T. Roach

Level 1	Level 2
1. Urban and Built-up Land	1. Residential 2. Commercial Services 3. Industrial 4. Extractive 5. Transportation, Communications, and Utilities 6. Institutional 7. Strip and Clustered Settlement 8. Mixed 9. Open and Other
2. Agricultural Land	1. Cropland and Pasture 2. Orchards, Groves, Bush Fruits, Vineyards, and Horticultural Areas 3. Feeding Operations 4. Other
3. Rangeland	1. Grass 2. Savannas (Palmetto Priaries) 3. Chaparral 4. Desert Shrub
4. Forest Land	1. Deciduous 2. Evergreen (Coniferous and Other) 3. Mixed
5. Water	1. Streams and Waterways 2. Lakes 3. Reservoirs 4. Bays and Estuaries 5. Other
6. Unforested Wetland	1. Vegetated 2. Bare
7. Barren Land	1. Salt Flats 2. Beaches 3. Sand other than Beaches 4. Bare Exposed Rock 5. Other
8. Tundra	
9. Permanent Snow and Ice Fields	

TABLE 3.2 TENTATIVELY PROPOSED REVISIONS FOR A LAND USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA (U.S.G.S. Circular 671)

Prepared by: James R. Anderson, Chief Geographer, U.S. Geological Survey; October, 1973

Level 1	Level 2
1. Urban and Built-up Land	1. Residential 2. Commercial and Services (including institutional) 3. Industrial 4. Extractive (excluding strip mining, quarries, and gravel pits, etc.) 5. Transportation, Communications, and Utilities 6. Mixed (including strip and clustered settlement) 7. Open and Other
2. Agricultural Land	1. Cropland and Pasture 2. Orchards, Groves, Vineyards and Ornamental Horticultural Areas 3. Confined Feeding Operations 4. Other
3. Forestland	1. Deciduous 2. Evergreen (coniferous and others) 3. Mixed
4. Wetland	1. Forested 2. Non-forested
5. Rangeland	1. Herbaceous Range 2. Shrub-Brushland Range 3. Mixed
6. Water	1. Streams 2. Lakes 3. Reservoirs 4. Bays and Estuaries 5. Other
7. Tundra	(Proposed level-2 categories are currently under study in Alaska and will be reported separately)
8. Permanent Snow, Icefield, and Glaciers	(Proposed level-2 categories are currently under study in Alaska and will be reported separately)
9. Barren Land	1. Salt Flats 2. Beaches (including mudflats) 3. Sandy Areas other than Beaches 4. Bare Exposed Rock 5. Strip mines, quarries, and gravel pits 6. Transitional Areas 7. Other

(from Third ERTS Symposium, N.A.S.A., 1974, pp. 31-32) use map was produced during the summer of 1973 for the State Office of Planning to assist in the preparation of recommendations for land use planning regulations (Carlson et al, 1974). Alarger scale 1:62,500 Level 2 supplementary land use map was also produced in a pilot study using aerial photographs.It is interesting to note that no reported attempt was made to utilise LANDSAT imagery at Level 2 classification. The major purpose of the small scale map was "to be a tool for orientation and for visual impact of both the land use data and remote sensing applications". This was achieved by considering LANDSAT imagery at 1:250,000 scale and then reducing it to 1:1,000,000. The major interpretation technique involved the use of colour additive viewer with various filter and spectral band combinations in order to enhance certain categories. No details of ground truth procedure used in the production of the small scale map were provided but the authors stated that after field checking the map was found to be 90% accurate.

Brown et al, (1973) University of Minnesota, in co-operation with regional, State and Federal agencies associated with land management responsibilities, examined LANDSAT 1 imagery to determine its suitability for satisfying some of the land use data needs in their state. They developed land use class definitions that could be operationally employed within the overall framework of the existing Minnesota Land Management System. They distinguished four broad areas of land use in their test site and did not consider the guidelines provided by U.S.G.S. Circular No 671. However, before they made their final detailed classification they consulted local and State land and resource management authorities regarding their information needs. Overall, they found that the potential of the LANDSAT imagery as a basis for mapping land use information was beyond their expectations and that, by using high quality imagery at appropriate seasons of the year, their unsophisticated techniques yielded much more detailed land use detail than existed at that time. This, they claimed, was achieved in their state which was already regarded as a leader in the field of land management. The main interpretation procedures involved the use of 70mm positive transparencies which were projected individually or combined in a Mini-Addcol viewer. The colour combined schemes were photographed and projected for interpretation at scales ranging from 1:250,000 to 1:30,000. Later experimental analyses included an image analyser which provided density slices from 1:1,000,000 positive and negative transparencies. The authors stated that ground truth procedures were carried out to support their investigations and that they were based on field investigations and a variety of aerial photographs but did not elaborate any further.

Sweet et al., (1974) have used LANDSAT 1 and Skylab imagery in association with conventional and multi-spectral underflight photography and radio-metric ground observations in experimental studies using a variety of interpretation techniques. A wide range of interpretation equipment was available including a multi-spectral viewer and density slicing colour viewer with built-in electronic planimeter. Also, LANDSAT 1 MSS data was received periodically in 70 mm, 24 cm x 24 cm imagery and digitised tape formats. After this investigation, they concluded that N.A.S.A. satellites could provide the data necessary for comprehensive and routine inventorying and mapping of Ohio's natural and cultural features at scales of 1:24,000 and smaller at less cost and with better accuracy than with previous techniques. They used the U.S. Geological Survey Circular No 671 Land Use Classification as the basis for their land use surveys.

Researchers at the University of California, Riverside also found that LANDSAT 1 imagery has great potential for monitoring land use change as well as a data source for future regional planning in the Northern Coachella Valley, California (Bale and Bowden, 1973). Their research was activated by the concern of Federal and State agencies who wanted to monitor the effects of the recreational pursuits of people from the heavily populated coastal plain on the sensitive arid environment. LANDSAT 1 imagery was used as the primary data source and high altitude photography was obtained from U-2 and RB-57 flights to assist in interpretation and field work. Land use classification was based on previous conventional surveys. Most of the mapping was accomplished using enlarged positives or projected slides taken from images previously projected onto the screen of an additive viewer using bands 4,5 and 7. Two different formats of LANDSAT 1 imagery were used in the viewer to produce false colour images. Selected portions of 24 x 24 cm 1:1,000,000 positive transparencies and complete 70 mm 1:3,360,000 positive transparencies were used with various filters. The use of the enlarged selected portions of the larger scale transparencies allowed viewing on the view plate at approximately 1:150,000 but provided less resolution than the 70 mm transparencies. Further enlargements up to 1:62,500 for the actual mapping processes was achieved by producing positive enlargements or by projecting slides of portions of the reconstructed image on the colour viewer view plate. The researchers claim that "resolution usually extended to 80 acre $^{1}/_{8}$ sections" (approx. 33 hectares) but was better where intense spectral signatures were associated with specific uses. Ground truth procedures were carried out to verify the type and amount of land use change and it was found that there were only two cases where the land use had been mis-interpreted but overall the location of boundaries could not be determined accurately. Several factors that influenced the quality and resolution of land use information obtained during the investigation were listed, viz. the scale of the final map, the availability of secondary data sources, the expertise of the interpreter and his detailed knowledge of the area.

In addition to the general trend of complimentary remarks about the ability of LANDSAT imagery to provide valuable data for the preparation of satisfactory base maps for regional planning, groups of researchers have emphasised how the imagery can permit the rapid production of small scale land use maps. For example, Lindgren and Simpson (1973) produced an 11- category map of Rhode Island in 8 man-days but they did not discuss the operational procedures. However, they claim that the maps displayed considerable accuracy when compared with maps compiled from high altitude aircraft imagery. Also, in the previously mentioned investigation by Estes, Thaman and Senger (1974) they reported that they produced an 8 category land use map of the Central Coastal Region of California in 7 man-days (an area of 52,213 sq. km).

3.2.3. LOW COST AND UNSOPHISTICATED TECHNIQUES

It is apparent that few research projects have been undertaken in the United States specifically to investigate unsophisticated and inexpensive land use mapping techniques. One interesting investigation by Hardy, Skaley and Phillips (1974) of Cornell University was carried out to develop low cost, manual techniques that could be used to enhance LANDSAT 1 imagery and to prepare it "in suitable format for use by users with wide and varied interests related to land use and natural resources information". They asserted that "experience has shown that the more sophisticated the method of processing resource information, the smaller is the number of potential users of that information". They believe that this situation is mainly due to the fact that most local officials associated with resource management decisions "do not feel at ease with, or trust, information prepared in a manner they themselves cannot accomplish or duplicate". Therefore, they have directed their investigations towards low cost, manual interpretation techniques incorporating photographic processes. During the inital stages the researchers experimented with films and filters to provide a more balanced density range of the 70 mm LANDSAT film chips. This permitted the imagery to be enlarged to scales of 1:150,000 or larger with better spatial resolution. Positive transparencies carefully prepared from the negatives were then run through the diazo process and any of the spectral bands could be produced in cyan, magenta or yellow. When band 4 (yellow), band 5 (magenta) and band 7 (cyan) were printed and superimposed they produced high quality false colour images.

Enlargement of the false colour images to scales as large as 1:66,000 were made and the researchers claim that information for land use classification could still be interpreted.

Other experiments have been carried out by Hardy, Skaley and Phillips and they assert that "although work needs to be continued on the development of a prediction model of the possible combinations of colour and what they relate to, we have been able to identify any land use information by isolating it in a colour of unique contrast with its surrounding areas". Furthermore, they claim that the prepared imagery has high resolution capabilities and boundaries between contrasting colours and hues are sharp. They also maintain that imagery can be used for the direct transfer of data at scales of 1:250,000 (with map units of approx. 25 hectares) to 1:150,000 or larger and with projection techniques and inexpensive equipment it can provide excellent results at 1:24,000 or larger. Also, they have suggested a simple procedure for data extraction, viz.

"1. Prepare a base map at the desired scale with a few geographic references such as lakes and streams.
2. Trace regions of like hue identified as homogenous spectral category onto the overlay.
3. Construct a spectral map from different composites to fill in the desired information for the mapped area.
4. Relate areas to Universal Transverse Mercator coordinates and record on appropriate forms for computer storage and retrieval."

The accuracy of this procedure was verified by comparison with low altitude photographs, existing land use surveys and field checking and results have shown "a high degree of correlation, usually close to or over 90%. The researchers have found this technique very useful for up-dating previous inventories, analysis of seasonal change, compilation of new maps e.g. forestry and agriculture, the isolation of one specific land type or land use and that it has been used by planning agencies and a number of state agencies. The claimed advantages of the system are its low cost, high accuracy levels wide selection of operational scales, the material is readily understood and that it does not require expensive and sophisticated equipment. They maintain that "the whole process can be carried out anywhere in the world with equipment costs of $ 10,000 or less". Unfortunately, the last assertion tends to contradict one aspect of the objective of this study, viz. a low cost system because the researchers' perception of low cost may not necessarily match the views of researchers in other countries.

It appears that no recent comprehensive review of U.S. investigations that have used unsophisticated techniques to produce small scale rural land use maps has been published. However, Joyce (1974) has presented a concise summary of some interpretation and classification techniques using mainly U.S. examples. He states that conventional visual interpretation of MSS imagery using cues of tone, texture and pattern to define land use has been the most common method used and all Level 1 and many Level 2 categories were identified at acceptable levels. Black and white imagery of individual bands and colour composites constructed mainly from bands 4, 5 and 7 have been the primary data bases and the most satisfactory results have been achieved by interpreting colour composites at scales ranging from 1:1,000,000 to 1:100,000 with 1:250,000 being the most common.He also asserts that suitable results have been obtained using simple techniques involving optical magnifying instruments and standard 1:1,000,000 colour composites or by direct visual interpretation of the enlarged colour composite. The most common smallest unit area that has been consistently identified and measured has been 40 acres (160,000 m^2) whilst some researchers have claimed to have achieved 10 acres (40,000 m^2). A higher degree of classification has been obtained using additive viewers and other more refined enhancement techniques but Joyce points out that they are time-consuming and require special equipment and skilled operators. In addition, he maintains that the increase in the number of Level 1 categories that can be identified and the improvement in the level of accuracy does not warrant the marked increase in cost and time. He also uses this argument for most Level 2 categories but he does concede that the colour enhancement techniques can be very beneficial in extracting specialised information not generally required at Level 2. He believes that there are advantages and disadvantages associated with both the visual interpretation and computer based classification systems and that some balanced combination of the two will need to be produced in order to extract the maximum amount of information from the LANDSAT data.

Peterson (1975) has produced a short article designed to assist geographers interested in land use mapping and has suggested certain techniques that could be helpful. He does not suggest any special pre-processing of the data other than the techniques used to produce the normal "off-the-shelf" material available from EROS Data Centre. He also suggests that the U.S. Geological Survey Circular No. 671 Land Use Classification System could be used in association with a colour coding system proposed by Paludan (1973) at a scale of 1:1,000,000. Essentially, the interpretation procedures are unsophisticated and designed for the delineation of categories at the same scale. The author stresses that the use of imagery from different seasons is important for accurate interpretation. No ground truth techniques were presented.

3.2.4. SUMMARY

Overall, the United States researchers have considered a very wide range of techniques in the pre-processing, interpretation, classification and ground truth stages. However, most reports of their studies have only placed emphasis on a few of these aspects. For example, some present detailed accounts of their investigations into pre-processing techniques (Hardy, 1973; Hardy et al., 1974; Dragg, 1974) or their attempts to classify land use (Nunnally and Witmer, 1968; Anderson and Place, 1972; Anderson, 1971; Anderson et al., 1972). Very few researchers have attempted to give extensive descriptions of ground truth and interpretation procedures although accuracy levels have often been stated. This may have been due to the fact that the very good supply of secondary information in the form of existing detailed land use, and topographic maps as well as low and high altitude photography could have provided much assistance. Or, it may have been felt that these techniques have been adequately reported in other investigations. Therefore, it appears that no published report of any United States investigation can be used to provide adequate guidelines for the production of small scale rural land use maps from LANDSAT imagery using inexpensive techniques.

Probably the major direct contribution of the United States studies has been the development of the land use classification scheme for use with remote sensor data by the U.S. Geological Survey (Anderson, 1971; Anderson and Place, 1972); Anderson et al., 1972, Anderson, 1974) which attempted to standardise land use mapping throughout the U.S. It seems that this aim has been achieved to a large extent as many of the recent reports have tended to adopt it. However, this may have been due to expendiency on the part of the researchers and they may have merely adopted it for convenience and speed. Also, it may have been caused by the fact that the researchers worked for, or may have been sponsored by, an organisation that had accepted the scheme. Some researchers, however, have been restricted by an existing scheme that had been established before the U.S.Geological Survey classification was introduced.

In general, U.S. researchers have emphasised that the synoptic coverage and the rapidity of data collection have given LANDSAT MSS imagery distinct advantages in small scale land use studies by providing generalised land use information as well as assisting in the monitoring of land use changes. But the reasons for the level of accuracy in the final maps have often been attributed to different factors by different researchers. Some of the factors that have been emphasised include the final (or completed) scale of the map (Hardy et al., 1974; Nunnally, 1974), the time of acquisition of the imagery (Place, 1974; Carlson et al., 1974; Peterson, 1975), the interpreter's knowledge of the area (Bale and Bowden, 1973; Estes et al., 1974; Nunnally, 1974), the spatial resolution of the imagery (Lins and Milazzo,1972; Hardy et al., 1974; Thaman, 1974), the nature of the classification system (Nunnally and Witmer, 1968; Anderson, 1971) and the type of pre-processing system available (Joyce, 1974a;Estes, 1974).

3.3. REVIEW OF RELEVANT RESEARCH IN OTHER COUNTRIES

3.3.1. INTRODUCTION

Outside of the United States various attempts have been made to investigate the feasibility of utilizing LANDSAT MSS imagery in the production of small scale land use maps. Overall, they have not been as elaborate or extensive in their scope and have generally employed un-sophisticated and less expensive techniques. As far as can be determined no comprehensive reports of non- United States research have been published. However, this review is not intended to provide an exhaustive cover of investigations. Instead, a representative range of studies will be presented in an attempt to demonstrate the approaches and trends that have been considered dealing mainly with pre-processing, interpretation, classification, sampling and ground truth procedures. Only those workers involved with visual techniques are discussed.

3.3.2. THE NETHERLANDS

Several studies utilizing LANDSAT imagery in developing countries have been carried out by members of I.T.C. Enschede, Holland. Among them, Rijnberg and van der Broek (1975) have made use of LANDSAT data in a preliminary soil survey and land suitability classification of a portion of S.W.Sudan to determine areas suitable for mechanised rain-fed farming. The imagery was used for basic data collection in this remote area where no aerial photographs or reliable maps exist and has also provided a basis for future planning. Preliminary investigations were also undertaken in a range of associated studies including mapping existing land use. Imagery consisted of black and white prints of each spectral band at 1:1,000,000 scale, 70 mm dia-positives of the same bands and dates as well as an ozalith print at 1:250,000 of band 7 for one date and a colour composite of the same date and scale. Four undefined "landscapes" were determined but identification was mainly based on geomorphological features and vegetation patterns. The authors maintain that the use of imagery obtained at different times of the year should be considered especially with regard to the use of colour composites as they believe that "the fine differences in colour express fine differences in ecosystems". They consider that "these spectral properties show to full advantage when soil moisture differences become critical, at some point in the early stage of the dry season". Another aspect that the investigators considered was the possibility of extrapolating "the value of a particular colour at a specific position, to the same colour somewhere else". They claim, in a subjective manner, that this was apparently possible to a large extent and that this technique assisted in the rapid preparation of the interpretation map. Also, comparison with some recently acquired aerial photographs indicated that the interpretation of the imagery had been comparatively successful.

3.3.3. SOUTH AFRICA

The Department of Planning, Pretoria has assessed the value of LANDSAT imagery in urban and regional land use mapping and inventorization for planning purposes using unsophisticated techniques (la Grange et al., 1973). Clearest images were obtained using a stereoscope with 6X magnification on black and white positive prints (1:1,000,000) of bands 5 and 7 with band 6 as a "good control". Band 4 was difficult to interpret. The type and intensity of agriculture was clearly distinguished and irrigated as well as intensive and extensive dry land cultivations were identified. The investigators concluded that the LANDSAT imagery could make a significant contribution to regional land use mapping. No indication of any attempt to verify the interpretations by field checking was made.

Other researchers (Malan et al., 1974) have experimented with the production of inexpensive 1:500,000 false colour photolithographic prints of LANDSAT imagery which have been used to a limited extent in agricultural land use planning studies. According to the researchers, the quality of the products have been consistently good and easy to interpret with limited training.

A later and very pertinent investigation by Little and Scotney (1974), Department of Agriculture, Natal Provincial Administration has also considered the utility of LANDSAT imagery for producing land use maps using un-sophisticated techniques. The research was designed to develop and test methods that could be used to record and monitor land use change and provide a basis for future land management programmes. The authors assert that due to the high cost and the time required using conventional methods and materials previous land use surveys in Natal had been unco-ordinated and 'patchy' and that there was a distinct need for a standardised land classification scheme. Their arguments followed closely those that were proferred by Anderson and Place (1971) but they did not establish a basic set of criteria that the system should meet. Their classification system contained three levels, viz.

Level 1 - to serve broad regional requirements

Level 2 - to contain information needed for sub-regional needs

Level 3 - to key-in with the current town planning classification in Natal which records detailed building and land use.

These categories were designated by an alphabetic and colour coding system. Overall, the classification places more emphasis on urban and built-up land than the U.S.G.S. Circular 671 classification (Anderson et al., 1974) (see Table 3.2) and includes Transport, Recreation, Industry, Commerce and Extractive Industries at Level 1 (see Table 3.3).

The major interpretation technique considered was the use of various combinations of colour transparencies made by the diazo process. The resolution of the transparencies were examined at various scales from 1:1,000,000 to 1:100,000 and the researchers decided that the most suitable scale for land use detection was 1:250,000 which permitted the identification of all Level 1 categories and some Level 2. The interpreters had little experience with LANDSAT imagery but they had first hand knowledge of the area and claim that they had little difficulty adjusting to the new format. Additional detailed information from previous land use surveys carried out in 1954 and 1972 was available and used as the major method for establishing ground truth. A limited amount of field inspection was undertaken.

The investigators concluded that the date of acquisition of the imagery played an important part in the interpretation procedure and they stated that more detail could be extracted

TABLE 3.3 LAND USE CLASSIFICATION (Little and Scotney, 1974)

LEVEL 1 (Regional)		LEVEL 2 (Sub-Regional)		
LAND USE	CODE	LAND USE	CODE	COLOUR
Agriculture	A	Dryland arable and grassland Sugar cane Irrigated arable land Pineapples High intensity crops (veg.) Inactive agriculture Fibre crops (sisal, phorium)	Ac As Aw Aa At Ai Af	738
		Orchards Vineyards	Ao Av	737
		Veld (grassland) Veld (karoo bush) Veld (bush thicket)	Ap Ap Ap	51 57 740
		Bantu farming	Ab	As above
Forestry	F	Pine plantation Wattle plantation Gum plantation Poplar plantation Jungle	Fp Fw Fg Fm Fj	41
Water Resources	W	Natural ponds, lakes, pans Artificially impounded water Streams and rivers Marine waters	Wn Wc Ws Wm	740
		Wooded wetlands (swamps) Vlei	Ww Wb	735 / 740
Commerce	C	Central business district Shopping centres Strip development (commercial) Tourist resorts Hotels and motels	Cu Cc Cs Cr Ch	746

TABLE 3.3 (continued) LAND USE CLASSIFICATION

LEVEL 1 (Regional)		LEVEL 2 (Sub-Regional)		
LAND USE	CODE	LAND USE	CODE	COLOUR
Residential Use	R	High density housing Medium density housing Low density housing Strip development (Housing) Ribbon development (housing) Rural hamlet Agricultural plots and holdings Bantu housing (townships) Bantu housing (kraals) Bantu Housing (compounds)	Rh Rm Rl Rs Rd Rr Rp Rb Rk Rc	745
Industry	I	Heavy industry Light industry	Ih If	752
Recreation	O	Outdoor recreation Game reserve National park	Or Og On	739
Extractive Industry	E	Underground mining Stone quarry Sand and gravel pits Opencast mining	Eu Eq Es Em	746 / 752
Public Areas	P	Public and semi-public areas	P	744
Transport	T	Roads and major interchanges Railway facilities Airports Harbours Communications and utilities9	Th Tr Ta Ts Tt	 734 1740 / 747 1740 / 747 744
Natural Rock and Sand	N	Exposed rock (sparse veg.)	Nt	735 / 746
		Dune sand (nil vegetation) Erosion	Ns X	735

if the imagery could be obtained during different seasons. They stress that, in order to produce accurate land use maps, the interpreter should have detailed knowledge of the area and should have sufficient base maps and aerial photographs to accurately locate data. Furthermore, they believe that the diazo transparencies extend the range of interpretation and have great potential. However, this view is not shared by Viljoen and Viljoen (1975) who assert that, although in theory diazo colour composites should be as good as photographic composites, in practice their image definition is poorer.

3.3.4. SPAIN

An attempt has been made by Spanish researchers to utilize LANDSAT data in identifying large areas of citrus groves and rice groves in the Valencia region of Eastern Spain (de Sagredo and Salinas, 1973). The basic methodology involved the delimitation of all the citrus trees and rice fields in the test sites on National Topographic Maps at a scale of 1:50,000 using ground truth information obtained from aerial photographs and a recent Citrus Trees Census. These plots were then reduced to various scales ranging from 1:100,000 to 1:400,000 and then compared with enlargements of imagery from each spectral band of the LANDSAT imagery. Preliminary results indicated that, once their simple techniques became operational, the imagery could be used in the production of a small scale land use map to supersede the existing one that was published in 1958.

3.3.5. SWEDEN

Researchers in Sweden have examined the possible uses of LANDSAT 1 data for environmental studies especially water quality studies and land use mapping (Hellden and Olsson, 1976). In previous research, they established pre-processing and interpretation methods involving traditional visual techniques and "an objective evaluation of the grey tones" which have allowed them to differentiate up to 18 different land use categories. Their latest investigation has involved the production of a 12 category land use map of the County of Kronoberg, Southern Sweden involving 27 map sheets at a scale 1:50,000 based on black and white diapositives of the four spectral bands of LANDSAT imagery at a scale of 1:1,000,000. Pre-processing included partial enlargements by means of an Additive Colour Viewer to produce false colour composite pictures of bands 4 (green), band 5 (blue) and band 7 (red). Detailed interpretation using a Stereoautograph B8S permitted further enlargement up to 6 times with the aid of a connected pantograph. Additional enlargement of selected areas (up to 15 times) was carried out with an Interpretoscope. One of the major controls on the level on interpretation was the spatial resolution of the recorded LANDSAT imagery and that certain objects could dominate the recorded spectral response and lead to misinterpretation.

The 12 land use categories included gravel pits, fields, pastures, spruce forest, pine forest, deciduous forest, mixed forest, meadow land, lakes, bogs, marshes and built-up areas but it has not been stated whether the classification was developed specifically for this area or whether it was adapted from existing systems or whether any attempt had been made to standardise the classification system. Ground truth was carried out but few details of the method adopted have been presented. The authors claim that preliminary results indicate that the accuracy of the majority of land use categories exceeds 85%. Also a partial check has been made possible by comparing the final map with a beech forest inventory carried out in 1967-68 and results of a preliminary check have been described as satisfactory.

3.3.6. UNITED KINGDOM

The probability of using orbital imagery for land use mapping in the United Kingdom has attracted a certain amount of attention and investigations have ranged from the applica tion of fully computerised techniques which have plotted corrected MSS data directly onto film (Smith, 1975) to less sophisticated techniques. However, most of the research has concentrated on other countries. This may have been due to a variety of factors including the availability of research funds and the fact that the United Kingdom is not particularly suitable for the use of MSS data due to the frequent cloud cover, complex land use patterns and small field sizes. Also, several large scale national land use surveys have been carried out in the past (Coleman, 1961) and, at present, a national land use survey of the developed areas of England and Wales is being undertaken using vertical aerial photography (van Genderen and Smith, 1975). Furthermore, the United Kingdom has an extensive coverage of large scale topographic maps, thematic maps, vertical aerial photographs and statistical services.

However, Brereton and White,(1975) have considered the use of LANDSAT 1 imagery in land use mapping in hydrological studies as the nature of the land use can have considerable effect on many hydrological parameters, eg. evaporation, soil moisture content, run-off, etc. Therefore, the provision of up-to-date information on the amount and type of land use changes could be very beneficial in their studies. Unfortunately, they have found that although LANDSAT imagery offered synoptic overviews and repetitive cover, one major drawback for United Kingdom studies has been the strong likelihood of cloud cover that either totally obscured areas or created haze problems. On the frames that they selected,certain land use categories were easily detected, eg. urban areas, water bodies, and woodland but areas with detailed land use and vegetation patterns caused problems in interpretation. Rural land use was classified into four broad types, viz. intensive arable areas, extensive pastures and common land, mixed farming areas and woodlands. No deliberate attempt was made to incorporate or employ any existing land use classification system and the establishment of ground truth information was not discussed. Most of the interpretation was undertaken using black and white photographic prints and colour composites at scales of 1:1,000,000 and 1:500,000 as well as a multi-spectral viewer. They conclude that LANDSAT imagery is only useful for detecting the broader features of geology, water movement and land use, especially if imagery from different seasons is available and that this type of imagery would have more value in arid countries where the collection of the imagery is not affected so much by atmospheric conditions.

A group of researchers at the University of Bristol in association with the Ministry of Agriculture have carried out a series of investigations to establish ground truth procedures

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for sensor testing and/or calibration and for estimating the accuracy of remote-sensing analysis (Curtis and Hooper, 1974). From their studies, they have demonstrated that the notion of a ground truth site varies according to the user's objective and the size of the study area. They have suggested that the allocation of sample plots can be made "statistically more efficient if the area can be stratified into relatively homogeneous areas (e.g. grassland)" and the number of sample plots can then be estimated by "the method of proportional allocation". The size of the sample plot should be determined by "the study objectives, statistical considerations, scale of phenomena and time factors" as well as the total area covered by each frame. Another important aspect of their studies involved a consideration of the type of data that can be collected in land classification and agricultural land-use studies. The main factors investigated were the time of observation, crop height, crop colour, perspective, soil exposure, agricultural treatments but the researchers pointed out that the range of ground data that should be collected depends on the nature of the region and its soil, relief and climatic characteristics. In general, they believe that four types of data are required if multi- purpose investigations are to be performed, viz. site morphology, crop/vegetation cover characteristics, cultivation/husbandry features and soil surface conditions.

A later study (Williams and Curtis, 1975) has extended the field studies to include seasonal and diurnal variations of many of the previously mentioned factors using a mobile ground multi-spectral data collection system and automatic recording systems that can be left running for several weeks at a time. Also, the conventional quadratting procedures used in the previous study to measure percentage crop cover was found to be too slow and new photographic quadratting techniques are being developed. However, no details of this new sampling procedure have been presented.

One of the most interesting and detailed U.K. studies has been presented by a group of researchers at the University of Reading who have attempted to evaluate LANDSAT 1 MSS imagery for erosion studies, land use analysis and woodland detection within Basilicata Province, Southern Italy (Justice, Williams, Townshend and Savigear, 1976). With regard to land use, their provisional results indicate that the identification of woodland can be carried out successfully in upland areas but other types of land use especially in lowland areas are more difficult to detect. The researchers suggest that the use of texture as well as tone can provide useful results. Initial pre-processing included the preparation of enlarged prints of selected areas from each channel of the original imagery from LANDSAT 1 at scales of 1:500,000, 1:250,000 and 1:90,000 and colour composites were produced using the Diazo process and a Fairey Additive Viewer. Also, uncontrolled airphoto mosaics were compiled at 1:90,000 and 1:60,000. The data were then studied using a wide variety of interpretation techniques ranging from stereoscopes and an Interpretoscope to the use of a Fairey Additive Viewer and a Video Processing Unit. Ground truth information was collected on reconnaissance traverses in the form of general landform descriptions, vegetation and land use and ground-level photographic records. The researchers attempted "to collect information which was relatively time-independent" as the MSS data was recorded in August and November, 1972 and the field work was carried out in March-April, 1975. No detailed description of the actual sampling procedures that were adopted has been presented but "sample areas were chosen according to preliminary pre-field tone-textural division of the LANDSAT imagery and from revisions made during the initial reconnaissance". However, the authors stated that the land use within the selected sample areas was mapped at 1:25,000 onto a topographic base and at 1:32,000 onto air-photo bases. In addition, detailed records of environmental parameters were made at "chosen sample sites within the sample areas using a site sampling card system".

The effects of scale and seasonality on the imagery were initially considered at a scale of 1:500,000 and different amounts and types of environmental information were obtained. The researchers believe that the small scale MSS imagery can be valuable as a coordinating agent for information from many different sources and provide a data source when aerial photography is unavailable as well as permitting "extrapolation from one area to another to be made with more confidence". However, they claim that these factors have limited use in regional planning and that information at much larger scales is required. Therefore, their investigations have been directed towards the interpretation of imagery at larger scales by first looking at the delineation of woodland from other land use and secondly by attempting to distinguish different types of land use in more complex landscapes. They found that the delineation of woodland in upland areas depended on the time of the year when the imagery was recorded. On the lower areas of the test site difficulties arose when trying to distinguish between areas of evergreen pines, shrubs, olives and oranges on band 5 imagery but maquis could be distinguished from orchards and pines using a colour composite (bands 4,5 and 7).

In the study of the more complex land use areas a six category land use classification system was based on information derived from field data and aerial photographs. It appears that no attempt was made to adapt the land use categories to an existing scheme. The classification appears to have been developed to accommodate the land use existing within the particular area and the map "served as the ground data with which to assess the LANDSAT imagery". The researchers found that "from a subjective visual analysis of the November LANDSAT imagery, the degree of tonal contrast and variation and thereby presumably the ease of analysis declined in the order 5,6,7 and 4 and channel 5 was, therefore, used subsequently in the analysis". More detailed objective testing of the tonal characteristics of the imagery for each land use category was carried out using a Video Processing Unit in five selected test areas. The individual categories could not be classified satisfactorily but four groups of land use could be determined using tonal slices, viz. bare clay lands, gully scrubland, wheat fields and rough grazing, olive groves and evergreen woodlands. Further discrimination in the latter class could be obtained by using a colour composite. Analysis of the August imagery was not as successful and band

5 was again found to be the most useful but the ease of analysis declined differently to the November imagery, viz. bands 4,6 and 7. The researchers believe that the interpretation of the land use patterns recorded on the imagery has been influenced by the effect of slope on land use, the time of the year when the imagery was recorded and the spatial resolution of the imagery. They claim that it is doubtful whether LANDSAT imagery can be used to produce comprehensive land use maps for the whole region mainly due to the conflict between the coarse spatial resolution of the imagery and the fine texture of the land use patterns in certain parts of the test site. However, this statement is difficult to criticise objectively as the authors do not directly state the actual scale of the proposed comprehensive maps.

An earlier study at the Department of Geography, University of Reading (Townshend, et al., 1974) compared the capabilities of LANDSAT 1 and SKYLARK Earth-Resources rocket for resource surveying in Central Argentine. Crop surveying was the only land use aspect considered in the investigation and a direct comparison between the imagery obtained from the two platforms could not be carried out due to the different dates of data acquisition and the lack of suitable ground truth information. The authors point out that SKYLARK has several distinct advantages, viz. greater control over the time of imagery acquisition, better spatial resolution and comparatively low cost but the advantages of repetitive monitoring and data storage facilities offered by the LANDSAT multi-spectral scanner make it more amenable for use in crop surveys.

Other groups of U.K. researchers have been active in investigating the extent to which LANDSAT imagery can be utilized in land resource surveys in developing countries by employing low cost techniques. King and Blair Rains (1974) have compared LANDSAT 1 imagery with pan-chromatic aerial photography for use in land resource surveys and considered the Rift Valley Lakes Basin, Ethiopia as a test site. They believe that the LANDSAT imagery is a "significant aid to map production in areas where the present map coverage is poor, but its scale is too small for detailed analysis". However, the latter criticism may have been caused by the researchers as they restricted themselves to a narrow selection of MSS imagery. They stated that "apart from some enlargements to 1:500,000 and 1:250,000, most of the analysis was undertaken using black and white paper prints at 1:1,000,000 " and separate bands were compared using a mirror stereoscope. No mention of optical enlargement was made. In addition, they considered a colour composite of one frame and "coloured translumencies" of each band of another frame but they did not state the scales. They conclude, from their observations, that because of its synoptic overview, repetitive cover and especially its low cost, LANDSAT imagery can be useful in land resource surveys "but only as an additional tool to the available aerial photography".

Hunting Surveys and Professor Shackleton, University of Leeds have examined the potential of LANDSAT imagery for mapping a variety of natural resources including soils and land forms, vegetation and land use in addition to their primary task of using the imagery to revise the geological map of Ethiopia(White, 1974). The investigators assert that "single channel black and white imagery is not satisfactory for mapping vegetation and land use in Ethiopia". They believe that spectral colour comparison is essential and they used false colour prints and a multi-spectral viewer in their studies. Although the investigation with respect to land use was only exploratory, the researchers believe that "it appears to be perfectly feasible to map out the major vegetation formation and land usage." No attempt was made to develop an overall land use classification scheme or to describe ground truth procedures but some field checking of initial interpretations was carried by making "a few traverses by Land Rover". The researchers made a generalized conclusion by stating that "different subjects, however, require different levels of supporting ground information and also different formats of imagery " but they did not offer any detailed advice. However, they did stress that they agreed with other investigators thatLANDSAT imagery, due to its synoptic coverage can be an "excellent first-stage approach to the surveys necessary for development and management" as well as the monitoring of dynamic situations.

3.3.7. U.N. FOOD AND AGRICULTURE ORGANISATION

Howard (1974) has presented a general report on the F.A.O.'s investigations in applying LANDSAT imagery in a range of projects in developing countries including Morocco, Ethiopia and Sudan. He states that initially the imagery was used to provide synoptic views as an aid to regional surveys but this interest has extended to the use of re-constituted false colour imagery and computer-generated false colour mosaics and large scale maps. Furthermore, he claims that the LANDSAT imagery can be used to provide a very wide range of valuable data including thematic maps at a scale of 1:250,000 which provide background information for areas that have previously been unmapped and could also assist in monitoring landscape changes. In particular, he has been enthusiastic about the role of orbital imagery in integrated surveys of land use and natural resources and stresses that "the potential contribution of satellite imagery to integrated surveys in developing countries is only beginning to be appreciated". Overall, the article pursues the concept that geomorphology should be the central component in integrated surveys and, consequently, it does not offer any concrete guidance for the production of small-scale land use maps, per se, other than some indirect comments on pre-processing and interpretation.

3.3.8. VENEZUELA

Conventional photo-interpretation techniques have been applied to LANDSAT imagery in a study of the Valencia Lake Basin region, Venezuela (Salas et al., 1974). Common instruments, viz, a magnifying glass and microfilm reader were used to identify tonal contrasts on colour composites and bands 5 and 7 (presumably black and white paper prints) at scales ranging from 1:1,000,000 to 1:100,000. Basically, the project was designed to assess the use of aerial photographic interpretation techniques to determine the amount of human intervention on the natural landscape. A two level vegetation/land use classification system was developed with the first level being determined by classifying "tonal groups by aggregating tonal similarities to micro-relief units and sociological aspects of vegetation". At the second level, the tonal characteristics derived at the first level were sub-divided into more detailed vegetation and land use sub-classification. Ground truth procedure involved the use of panchromatic photographs at scales of 1:50,000 and 1:25,000 and field checking. The authors used a sampling technique to determine and map the degree of human intervention and to define more precisely the vegetation borders and agricultural types.

3.3.9. SUMMARY

In a similar manner to the investigations in the United States, researchers in other parts of the world have tended to concentrate on only a few of the stages involved in producing small scale rural land use maps from LANDSAT imagery. Some have presented interesting statements on various preprocessing techniques (Little and Scotney, 1974; King and Blair Rains, 1974; Justice et al., 1976; Rijnberg and van der Broek, 1975). Other aspects, including factors that have influenced the interpretation of the MSS imagery and the gathering of satisfactory ground truth information, have also been considered (Curtis and Hooper, 1974; Williams and Curtis, 1975; Justice et al., 1976). Apparently the problem of standardisation of land use classification schemes has not concerned most of the investigators who appear to have adapted existing local schemes or they have devised their own scheme to fit their research objectives. However, Little and Scotney (1974) have proposed a classification scheme in an attempt to standardise land use mapping in Natal, South Africa (see Table 3.3). It is probably the most interesting classification that has been developed outside of the United States. Unfortunately, it does not have the general flexibility offered by U.S.G.S. Circular 671 (Anderson, 1974) (see Tables 3.1 and 3.2.).

Most of the investigators have praised the synoptic coverage, the monitoring capabilities and the rapid collection of data offered by the LANDSAT multi-spectral scanning system. Also, they have considered many of the factors that caused concern with the U.S. researchers including the selection of a satisfactory final map scale (Howard, 1974; Little and Scotney, 1974; King and Blair Rains, 1974) and the correct selection of spectral bands (Justice et al., 1976; la Grange et al., 1973; de Sagredo and Salas, 1973; Salas et al., 1974). The problems caused by the time of acquisition of the imagery also concerned some researchers (Brereton and White, 1975; Justice et al., 1976; Rijnberg and van der Broek, 1975) and Little and Scotney (1974) emphasised that the interpreter should have a good knowledge of the region being studied.

3.4. GENERAL SUMMARY

This chapter has shown that, although there has been many detailed studies in various aspects of small scale land use surveys, there has been no satisfactory overall attempt, either in the United States or elsewhere, to bring together all the findings of the researchers. It is evident, therefore, that the formulation of a methodology detailing all the stages of the preparation of the maps which would establish the general framework for the rapid and inexpensive production of this type of map could provide extremely valuable assistance to individuals or organisations wishing to produce small scale land use maps from LANDSAT imagery. If presented satisfactorily, the methodology should avert the necessity for detailed research and testing of the many different aspects involved in the production. However, before the methodology can be formulated a more detailed appraisal of specific points emphasised by previously mentioned researchers will be considered in the next chapter under the categories of pre-processing, interpretation, classification systems and ground truth. In addition, a range of relevant comments presented by workers in other areas of research will be investigated and then, in the following chapter, a number of techniques will be evaluated before the detailed methodology is presented.

4. TECHNIQUES APPLICABLE TO RURAL LAND USE MAPPING USING LANDSAT MSS IMAGERY

4.1. INTRODUCTION

As mentioned in the previous chapter, a detailed appraisal of the main stages of the production of small scale rural land use maps from LANDSAT MSS imagery is required before an adequate methodology can be devised. This is necessary as very few attempts have been made to bring together details of all the relevant stages needed in the overall production using inexpensive and unsophisticated techniques. The general aim of this section is to provide a review of techniques that have been used in relevant studies in order to select a range of appropriate techniques that can be evaluated in the field before formulating an overall methodology. The division into pre-processing, interpretation, classification and ground truth have not been intended to be arbitrary as certain topics are common to several of them, e.g. scale and resolution. But it is thought that the divisions provide the most satisfactory format which permits an adequate consideration of all aspects of this type of mapping. The problem of overlapping topics has been alleviated by cross-referencing.

4.2. PRE-PROCESSING

4.2.1. GENERAL

One of the first problems confronting an investigator involved in small scale land use mapping from orbital imagery is the selection of the most appropriate visual output of the digital data that has been obtained from the LANDSAT multi-spectral scanner. This means that he should be aware of the range of standard pre-processed products which are available to him as well as the pre-processing techniques which he might be able to utilise in order to provide the best materials for the application of visual interpretation techniques.

Pre-processing has been defined by Hempenius (1975) as "the processing or data handling with the purpose of re-arranging, compressing, simplifying, enhancing, etc. the data prior to interpretation" and the broad scope of this definition has been accepted for the purpose of this research. But, as one of the main aims of this research is to consider relatively inexpensive and unsophisticated pre-processing and interpretation techniques, computer-based pre-processing techniques utilising LANDSAT MSS digital data will not be assessed. Detailed summaries of these may be found in articles by Simonett (1974) and Steiner and Salerno (1975). Further specific examples of computer based pre-processing techniques may be obtained from Anuta and McDonald, (1971); Landgrebe, (1972); McDonald, Bauer, Allen, (1973); Weber et al.,(1973); Bressanin et al., (1973); Hall, Bauer and Malila, (1974); Haralick and Shanmugan, (1974); Ratti and Capozza, (1974); Allan, (1975); Leamer, Weber and Wiegand, (1975).

Pre-processed LANDSAT MSS data can be purchased from EROS Data Center in a number of different formats (see Table 4.1) which may be interpreted in standard form or may be used as the basis for further pre-processing by researchers. The scope of pre-processing techniques that have been employed by investigators is quite wide and ranges from simple photographic enlargements to more sophisticated image enhancement processes. However, the extent to which these techniques can be utilised in operational land use mapping depends upon the objectives of the survey, the finance and time available as well as the resolution and scale limits imposed by the nature of the investigation.

Most of the techniques that have been used in this type of research may be considered under the term"image enhancement" as most of the other aspects stated in Hempenius' definition, viz.re-arrangment, compression, and simplification are normally carried out by applying computer based techniques to the MSS digital data. Image enhancement has been defined in a variety of ways but for this research it can be considered as "the various processes and techniques designed to render optical densities on the imagery more susceptible to interpretation" (Estes and Senger, 1974). Essentially, the image enhancement techniques that can be used to produce hard copies from LANDSAT MSS imagery may be classified into two broad groups, viz. photographic and electronic. Relevant visual optical enhancement methods (c.f. photographic enhancement techniques) will be discussed in the section dealing with interpretation techniques (see Section 4.3) as they are generally used by researchers to enlarge or combine imagery visually rather than to produce hard copies. Detailed discussions of image enhancement procedures may be found in Simonett (1974), van Genderen (1975) and Steiner and Salerno (1975).

4.2.2. PHOTOGRAPHIC ENHANCEMENT

4.2.2.1. ENLARGEMENT

The most commonly used image enhancement technique involves the photographic enlargement of one or more of the

TABLE 4.1

LANDSAT MSS PRODUCTS AVAILABLE FROM EROS DATA CENTRE

Aug. 1, 1975

Image Size	Scale	Format
2.2 inch	1:3,369,000	Film Positive for each spectral band
2.2 inch	1:3,369,000	Film Negative for each spectral band
7.3 inch	1:1,000,000	Film Positive for each spectral band*
7.3 inch	1:1,000,000	Film Negative for each spectral band
7.3 inch	1:1,000,000	Paper Print for each spectral band*
14.6 inch	1: 500,000	Paper Print for each spectral band*
29.2 inch	1: 250,000	Paper Print for each spectral band*

* indicates that colour composites may be available in that format

Computer Compatible Tapes (CCTs) are also available for purchase

(also see Appendices I and II).

four spectral bands of the basic imagery acquired from EROS Data Center (see Table 4.1). These enlargements may be produced in the form of positive or negative, black and white or colour, film or paper prints at various scales and they have been used in a variety of ways to assist in land use interpretation e.g. mosaics and overlays. Also, there has been an increasing tendency to use transparencies in interpretation due to the lower level of graininess which permits greater magnification than would be possible with paper prints (Estes and Simonett, 1975 ; van Genderen, 1975).

The selection of the most appropriate scale that should be used when interpreting LANDSAT MSS imagery has caused a great deal of concern and various viewpoints have been discussed in a separate section (see Section 4.2.4.).

4.2.2.2. COLOUR

The production of colour composites in hard copy for specific purposes is relatively expensive and investigators have tended to accept the EROS Data Center false colour composites derived from bands 4, 5 and 7 and presented in film positive or paper print form (Joyce, 1974a) (see Section 4.3. for more details). However, one viable and economic alternative has been the use of the Diazo process which, although not a photographic process in the strict sense, has the capability of producing single colour film transparencies from black and white positive images of selected spectral bands. The base is an optically clear, thin polyester material with high stability which is sensitised with a diazo coating. Development is achieved by passing the film through a dyeline machine. Details of the exposure procedure, etc. are described by Keates (1973). Diazo films are available commercially in a range of colours, eg. red, magenta, yellow, orange, green, violet, blue, cyan, brown. Once the colour transparencies are developed they can be super-imposed in any desired combinations to form a variety of false colour composites. Various researchers have acclaimed this technique. Hardy, Skaley and Phillips (1974) maintain that they have applied it successfully to produce high false colour images at scales up to 1:150,000 from LANDSAT imagery after balancing the density of the imagery through a step enlargement procedure from the initial 1:3,369,000 chip. Other aspects of their research has been considered in detail in Section 3.2.3. Little and Scotney (1974) also believe that the Diazo process has great potential but Viljoen and Viljoen (1975) assert that the image definition is poorer than photographic composites (see Section 3.3.3.). After experimenting with the process, the author agrees with the general conclusions of Hardy et al., and Little and Scotney. The main attraction of the Diazo process is that it is inexpensive and that both the materials and the equipment are commonly used in drawing offices throughout the world.

The use of colour additive viewers has been considered under optical enhancement techniques (see Section 4.3.4.2.).

4.2.2.3. DENSITY SLICING

In this process special developing techniques are used to extract and reproduce single grey levels (or slices) which can be used for further investigation of the spectral responses from various types of land use, but the procedure is time-consuming and difficult (Simonett, 1974). However, special density slicing film has been made available by several commercial firms and various researchers have investigated its potential.Ranz and Schneider (1971) have considered Agfa-contour film with normal photographs and have experimented with it in association with Diazo film colour composites of the different density slices. Dragg(1974) claims that LANDSAT MSS imagery "because of the uniformity of the data and small look-angle lends itself to this relatively simple technique particularly in level areas" but did not elaborate on its application.

4.2.2.4. CONTRAST PRINTING

This is a commonly used pre-processing technique that may be used to make slight grey scale differences more detectable in visual interpretation and has been applied to LANDSAT MSS imagery (Simonett, 1974). Hardy, Skaley and Phillips (1974) have used this technique in their attempts to develop a low cost manual method of enhancing LANDSAT MSS imagery that could be used in land use mapping.

4.2.2.5. EDGE ENHANCEMENT

In this procedure a positive and negative are superimposed, slightly displaced and re-photographed. Edges at right angles to the direction of displacement will appear as white lines on the forward edge and black lines on the trailing edge but other edges will not be enhanced. Simonett (1974) discusses methods of overcoming the problem of directional enhancement by placing the positive and negative on a rotating disc with an exposure light mounted off-axis above the disc. This technique has been used in attempts to detect boundary changes in land use on aerial photographs but no articles can be located which discuss its use with LANDSAT MSS imagery.

4.2.2.6. IMAGE ADDITION

One advantage of this technique is it's ability to assist interpreters in detecting landscape changes. This can be achieved photographically by combining a positive transparency of a photograph taken at a particular time with a negative of a photograph of the same scene taken at another time and printing a new photograph through both. Areas of change are indicated by light or dark tones whereas areas of no change will be medium grey.

4.2.3. ELECTRONIC IMAGE ENHANCEMENT TECHNIQUES

These techniques which include micro-densitometry, iso-densitometry, electronic dodging and image quantizing will not be considered as the cost of equipment prohibits their use in this type of investigation. Detailed discussions of the techniques may be found in articles by Simonett (1974), van Genderen (1973,1975), Steiner and Salerno (1975).

4.2.4. IMAGE SCALE

The problem of selecting the optimum image scale is an important aspect in the overall mapping procedure as it interacts with the resolution of the sensing system and, consequently, affects the level of interpretation. Therefore, a compromise must usually be reached between the image resolution, the operational mapping scale and the objectives of the study. However, most investigators using conventional visual techniques have tended to utilize the standard pre-processed LANDSAT MSS imagery which has a maximum scale of 1:250,000 available only as opaque prints but the image resolution is markedly inferior to the prints and transparencies available at 1:1,000,000. Further photographic enlargement leads to poorer image resolution although various researchers have claimed to have successfully used enlargements at much larger scales (Hardy et al., (1974); Justice et al., (1976).

Very little guidance about the most appropriate scales that should be considered with the various types of LANDSAT MSS imagery formats which can be used in land use mapping. Nunnally (1974) commented that "few studies have been undertaken which have attempted to evaluate the effects of scale and resolution on an interpreter's ability to identify different types of land use". He also claims that the results of those studies that have been attempted have been inconclusive. Joyce (1974b) noted that, although the scale of enlargement of LANDSAT MSS imagery can usually be determined by the scale of available maps, it is also dependent upon the quality of the particular imagery that has been selected and the nature of the enhancement equipment available to the investigator. Howard (1974) claimed that there was increasing evidence to show that with adequate ground checking a range of discipline oriented thematic maps could be prepared at 1:250,000. Most subsequent reports have been in the form of general statements rather than critical appraisals and little concrete assistance can be obtained from them. In this investigation the main image scales will be controlled by the available standard formats of the LANDSAT MSS imagery, i.e. 1:3,369,000; 1:1,000,000; 1:500,000 and 1:250,000 although some evaluation at slightly larger scales will be attempted mainly by visual optical enlargement processes (c.f. photographic enlargement).

4.2.5. RESOLUTION

In the interpretation of all remote sensor imagery the resolution of the imaging system puts practical constraints on the accuracy levels that may be obtained. Unfortunately, the term "resolution" has been given a wide variety of connotations by different researchers in a number of different contexts (see Table 4.2). Some writers have clearly defined their use of the term whereas others have either not stated the intended meaning or have adopted very loose definitions which occasionally mislead the reader. Olson, (1973, article written in 1969) has stated that "unfortunately resolution is one of the most misunderstood and misused qualities of the photographic system; at least by photographic interpreters". The situation has become even more uncertain since the advent of other more sophisticated remote sensing systems including multi-spectral scanners and radar. It has caused Estes and Simonett (1975) to comment that "resolution is a complex subject and the various methods used to measure resolution may not always properly characterise the information content of the image".

There are a number of different types of resolution that should be considered when using and describing the capabilities of orbital MSS imagery. Their relative importance depends on the scale of the imagery and the nature of the survey in which the imagery is employed. The dominant aim of each type of resolution, however, is to maximise the contrast between objects and their background. If very little contrast exists then the objects become difficult to identify. The following types of resolution have the most effect on the contrast levels of LANDSAT MSS imagery. Their definitions have been adapted from those provided in Table 4.2.

1) Spectral resolution - the number and width of spectral bands within which data is collected. Hence, the spectral resolution of LANDSAT MSS data is four broad bands. These band widths and their relative position along the electromagnetic spectrum are shown in Figure 2.2, Table 2.1.

2) Spatial resolution (or ground resolution)- the smallest area on the ground, i.e. pixel from which the multi-spectral scanner can measure radiant energy. The spatial resolution of LANDSAT MSS is 79 m. by 79 m.

3) Image resolution - the ability of the entire MSS system to render a sharply defined image. This means the ability to record visually each pixel on the recording base. However, if photographic copying or enlargement occurs, then photographic image resolution should also be considered and this is usually expressed in terms of lines per mm. for a given photographic emulsion under given conditions. The combined effect is shown in Table 4.3.

4) Temporal resolution - the time period (usually expressed in days) between successive orbits over the same area, i.e. the time period between each successive data acquisition of the same area. Temporal resolution is mainly affected by cloud cover and the operating schedule of the recording stations.

TABLE 4.2

SOME DEFINITIONS OF TYPES OF RESOLUTION USED IN REMOTE SENSING

Hempenius (1975) p.8 (confining his definitions to multi-spectral remote sensing)	Spectral resolution - the number of bands. In addition one should know the exact location of the various bands and their width Intensity resolution - the number of levels in which the radiant energy is sampled Spatial resolution - the area on the ground, i.e. pixel, from which the radiant energy is integrally measured during the very short time that the instantaneous field of view is directed to that area Temporal resolution - the number of days between successive flights over the same area, if carried out continuously
Manual of Remote Sensing Glossary (1975), A.S.P. p.2102	The ability of an entire remote sensor system, including lens, antennae, display, exposure, processing and other factors, to render a sharply defined image. It may be expressed as "line pairs per millimetre" or metres, or in many other manners. In radar, resolution usually applies to the effective "beam width" and "range" measurement width, often defined as the half-power points. For infra-red line scanners the resolution may be expressed as the "instantaneous field of view". Resolution also may be expressed in terms of "temperature" or other physical property being measured
Estes and Senger (1974) Glossary	The ability of a remote sensing system to distinguish signals that are close to each other spatially, temporally, or spectrally Ground resolution - the minimum distance between two or more adjacent features or the minimum size of a feature which can be detected; usually measured in conventional distance units, e.g. feet or inches Image resolution - resolution expressed in terms of lines per millimetre for a given photographic emulsion under given situations Thermal resolution - image resolution expressed as a function of the minimum temperature difference between two objects or phenomena
Thaman (1974) p.197	The smallest ground resolvable distance (G.R.D.); that is, the size, length or area of the smallest object discernable on an image, taking into account the difference in contrast ratio across an image
Olson (1973) p.102	The ability of a photographic system (including lens, filter, emulsion, exposure and processing, as well as other factors) to record fine detail in a distinguishable manner
Estes and Simonett (1975) p.977	The ability of a human observer to detect a changing pattern consisting of parallel bars of alternating radiance (see Table 4.3)

Other types of resolution, e.g. thermal resolution and intensity resolution, although relevant in other studies have relatively little importance in this type of investigation and, therefore, have not been included in the list of definitions.

The wider range of spectral resolution available with LANDSAT MSS imagery has certain advantages and disadvantages when compared with conventional black and white and colour aerial photographs and these aspects are discussed in Section 4.3.3. Besides the problems of image and spatial resolution involved in the visual interpretation of the LANDSAT MSS imagery (see Section 4.3.) they also affect the selection of the most appropriate size of the sampling "point" in field surveys when trying to establish the accuracy level of interpretation. This problem is considered in Section 4.5.2.4. The high frequency temporal resolution of the LANDSAT system provides a major advantage in studies involving vegetation cover and further details of its use in this investigation are provided in Section 4.3.6.

4.2.6. SUMMARY

The main problem associated with pre-processing involves the correct selection of enhancement techniques and the most convenient scale and resolution for the interpretation procedure that is considered to be the most appropriate for the task in hand. This is particularly important when using LANDSAT MSS imagery because the spectral responses displayed on the black and white and colour transparencies and opaque prints are relatively unfamiliar to interpreters and a great deal of uncertainty still exists over which combination of scale

TABLE 4.3

LANDSAT MSS SYSTEM RESOLUTION

(in metres/bar for Band 4)

Based on standard U.S. Air Force tri-bar resolution target

(from Estes and Simonett, 1975)

	High Contrast Scene	Low Contrast Scene
MSS Output	44	97
Input to NASA Data Processing Facility	44	97
Bulk		
70 mm archival film	54	126
70 mm positive (3rd generation)	53	118
9.5 inch positive (3rd generation)	57	136
CCT	44	97
Precision		
9.5 inch positive (5th generation)	79	184
CCT	80	193

and spectral bands give optimum visual interpretation conditions. Therefore, until more conclusive evaluations and descriptions of techniques have been published, the use of more refined pre-processing techniques may tend to cause more problems with interpretation instead of aiding the identification of objects. Arnold (1974) has been particularly critical of the way in which image enhancement procedures have been used and he has stated that "it does appear that these techniques have been employed on occasions in cases where they can offer little advantage and have apparently only been used because they are currently fashionable. This is, of course, a criticism of the experimenters and not the technology". Consequently, the scope of the pre-processing techniques used in this investigation will be restricted to standard pre-processed material from EROS Data Center accompanied by some enlarging procedures as well as some investigatory uses of the Diazo process. There is no doubt that more experimental work needs to be carried out to develop a methodology on the role and usefulness of image enhancement techniques in rural land use surveys.

4.3. INTERPRETATION

4.3.1. INTRODUCTION

Visual image interpretation has been defined as the act of examining photographs and/or images for the purpose of identifying objects and phenomena and judging their significance (Estes and Simonett, 1975; Am. Soc. of Photogrammetry, 1960). However, the level of interpretation of most remote sensor imagery, including LANDSAT MSS imagery, depends on the quality and nature of the imagery itself, the type of interpretation techniques utilised, the enhancement facilities available, the interpreter's specific and local knowledge and his access to other relevant information, e.g. aerial photographs, publications, statistical data, etc. In addition, the purpose of the investigation places constraints on the extent and nature of the interpretation procedure.

Conventional photographic interpretation techniques have been used successfully with black and white LANDSAT MSS imagery of individual spectral bands and with colour composites produced from combinations of various spectral bands. Thus, the identification of objects from LANDSAT MSS imagery has involved the use of one or more of the elements of image interpretation, viz. shape, size, tone and colour, texture, pattern, shadow, site, association and resolution. These aspects have been well-documented in articles on the interpretation of black and white and colour aerial photography, e.g. Olson, (1973) ; Strandberg, (1967); Allum, (1966); Avery, (1968); A.S.P., (1960, 1968). Probably the most relevant and recent article dealing with interpretation techniques and their application to a wide range of remote sensor imagery has been presented by Estes and Senger (1975).

In land use studies involving LANDSAT MSS imagery there has been a wide divergence of ideas about which combination of imagery, scale, enhancement techniques and other factors would be best to adopt as the basis for satisfactory visual interpretation. As a wide variety of approaches have been used it is important that many of the ideas and opinions should be brought together in order to establish a satisfactory base from which a framework can be formulated as part of the development of an overall methodology. The aspects will be considered under the following topics; the visual interpretation process, visual interpretation aids, selection of spectral bands, seasonality or the use of multi-date imagery and the interpreter's knowledge of the region being considered as well as his expertise in particular disciplines and his understanding of the relevant remote sensing system. Although they are not necessarily independent, the separation into various topics should permit a wider view of the problems associated with the establishment of a satisfactory interpretation system which could be adopted for use in land use mapping with LANDSAT MSS imagery.

4.3.2. THE VISUAL INTERPRETATION PROCESS

The process of visual image interpretation is a complex operation which various researchers have attempted to explain by means of a series of stages or phases. Most of the explanations have originated from the study of the interpretation of black and white aerial photographs but the overall approaches have application in the visual interpretation of other types of remote sensing imagery.

One commonly accepted explanation offers scope for incorporating into the description a methodology for producing small scale land use maps from LANDSAT MSS imagery. The initial stage of this approach has been described by various terms including the "observational" stage (Spurr,1973; originally written 1957) and the "photo-reading" stage (Vink, 1964; Strandberg, 1967; Benneman and Gelens, 1969). It involves the detection or discovery of an object on the imagery from its background. This is very closely associated with the recognition phase in which the object's shape, size and other properties permit it to be recognised, "discovered" or "measured" in the physical or psychological sense. As mentioned previously, detailed discussions of these interpretation properties (or elements) may be found in most textbooks on photo-interpretation. The most comprehensive, recent statement appears in A.S.P. "Manual of Remote Sensing" (1975). Then, according to the explanation, the object is identified by its common name or scientific terminology. But, the level of detection, recognition and identification depends on many factors including the physical characteristics of the object itself, the resolution of the imagery (see Section 4.2.5.), the scale of imagery (see Section 4.2.4.) and the background knowledge of the interpreter (sometimes called the "reference level"). Various aids, including image interpretation keys have been developed to assist the interpreter during this stage (see Section 4.3.4.3.).But,with the interpretation of LANDSAT MSS imagery and the imagery produced by other comparatively recent remote sensing techniques a much more detailed knowledge of the capabilities and limitations of the various environmental and sensor parameters which affect the imagery is required by the interpreter than is required with conventional aerial photographs. Otherwise, it may lead to the interpretation of certain spectral bands which may produce different results when compared with the interpretation of other bands.

The next stage involves the systematic delineation or division of the identified objects into logical patterns or units on the imagery. The important aspect of this stage is to establish the reliability or accuracy of the boundaries.

This may then be followed by a classification stage in which the patterns or units may be described and arranged into various types of classification systems with their individual methods of categorisation and codification, The problems associated with the establishment of a satisfactory rural land use classification scheme for use with LANDSAT MSS imagery are discussed in Section 4.4.

The process of visual interpretation is basically a deductive process in which the interpreter progresses through the above stages by consciously or unconsciously using various combinations of the elements of image interpretation. The ability to incorporate these elements depends to a large extent on the specific and regional knowledge of the interpreter (see Section 4.3.5.) which may be supplemented by various types of collateral material (see Section 4.3.4). However, with LANDSAT MSS imagery some of the elements decline in importance due to resolution and scale factors and colour or tone becomes the most dominant (see Section 4.2.5.). Also, the task of integrating the information from the four spectral bands is extremely difficult by visual means (van Genderen, 1975). Colour composites produced from three of the four spectral bands tend to alleviate the problem but further interpretation problems are introduced by the false colour nature of the imagery (see Section 4.2.2.2.).

Although the various stages of conventional photographic interpretation may be followed in the interpretation of LANDSAT MSS imagery, the nature of the physical and psychological processes will differ. Consequently, care should be exercised at each stage in order to determine whether accurate interpretation is, in fact, being carried out.

4.3.3. SELECTION OF SPECTRAL BANDS

Unlike conventional black and white aerial photography, the problem of selecting the appropriate data base from a range of spectral bands of pre-processed LANDSAT MSS imagery poses difficulties. The major task is to choose the best spectral band or combination of bands for a particular task as certain bands are more appropriate for interpreting features than others and this has led to a certain amount of disagreement amongst investigators.

The official EROS Data Center brochure lists some details about the main uses of each spectral band:-

Band 4 The green band 0.5 to 0.6 micrometres, emphasises movement of sediment laden water and delineates areas of shallow water, such as shoals, reefs, etc.

Band 5 The red band 0.6 to 0.7 micrometres, emphasises cultural features. This band gives the best general purpose view of the earth's surface.

Band 6 The near infrared band 0.7 to 0.8 micrometres, emphasises vegetation, the boundary between land and water and land forms.

Band 7 The second near infrared band 0.8 to 1.1 micrometres provides the best penetration of atmospheric haze and also emphasises vegetation, the boundary between land and water, and landforms.

Howard (1974) has diagrammatically described the spectral reflectance curves of several natural surfaces associated with land use studies (see Figure 4.1.). On the black and white imagery the surfaces with high spectral reflectance, e.g. healthy vegetation in band 7 would be nearly white whereas the spectral reflectance from water surfaces in band 7 would be shown as black. The problems associated with

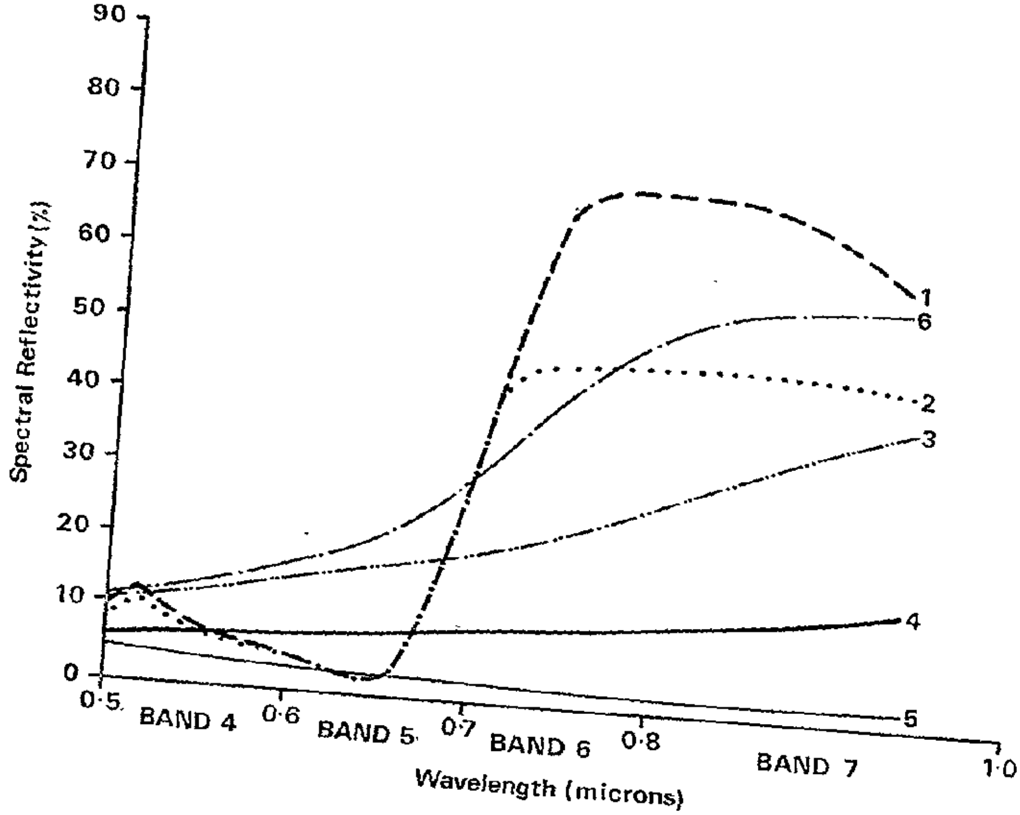

Fig 4.1 Characteristic spectral reflectivity curves of several natural surfaces:-

1 Healthy green vegetation (leaf area index: 4)
2 " " " (leaf area index: 1)
3 Dry loam
4 Wet loam
5 Water surfaces
6 Dry grasses

SOURCE: Howard, 1974

interpretation based on tonal responses on the imagery become evident when it is seen that different surfaces give similar spectral reflectances within a band. For example, in band 5 healthy green vegetation and water surfaces have similar reflectance values. This problem is also obvious in band 4 where healthy green vegetation, dry loam and dry grasses have similar reflectances in the shorter wave length region but then diverge in the longer wave length portion of the band. Band 7, on the other hand, shows that the six surfaces indicated in the diagram have wider separation in reflectance and, therefore, should show greater grey-scale variation on the black and white imagery. A recent, detailed discussion of the reflectance characteristics of crops and soils has been presented by Myers et al., (1975)..

Many investigators associated with land use studies believe that bands 5 and 7 are the most useful bands (de Sagredo and Salinas, 1973 ; la Grange, 1973; Salas et al., 1974; King and Blair Rains, 1974).Justice et al., (1976) considered that the most useful band for erosion and land use studies was band 5 followed by 6,7 and 4. However, Peterson, (1975) stated that band 6 was recommended to him by a representative of EROS Data Center as the best for land use mapping and, after investigation, he agreed with that assessment.

An increasing number of investigators maintain that colour composites offer greater scope for interpretation than the black and white imagery. The colour composites are normally produced by exposing three of the four black and white bands (usually 4,5 and 7) of the same area through different filters onto colour film, However, due to the false colour nature of the process, colours of objects appear different and this poses specific interpretation problems and investigators are required to adjust to viewing objects in completely new colours than they would encounter in normal colour viewing. For example, healthy green vegetation appears as bright red; clear water appears as black and sediment laden water appears as a light blue colour.

Despite the limitations imposed by the false colour nature of the colour composites, many investigators have found them easier to use than black and white LANDSAT MSS imagery in land use studies. (Salas et al., 1974; White, 1974; Rijnberg and van den Broek, 1975 ; Parry, 1974). Also, Joyce, (1974b)in his summary of interpretation techniques adopted in land use mapping with LANDSAT imagery stated that the most satisfactory results have been obtained by interpreting the colour composites. Howard, (1974) asserted that "there was no doubt that the MSS colour imagery at a scale of 1:1,000,000 was quicker and less tedious than black and white imagery at the same scale" and he also believed that more data could be obtained from colour composites. His subjective statement has been partly substantiated by tests carried out on the relative interpretability of SKYLAB Earth Resources Experimental Package photographic imagery and LANDSAT MSS imagery which indicate that, although EREP 190-A colour infra-red photographic imagery ranked highest in overall interpretability, LANDSAT colour composite imagery ranked second ahead of EREP S 190 B colour, S 190 A black and white infra-red and LANDSAT band 7 imagery (Estes and Simonett, 1975).

The projection of three black and white bands through three different filters onto colour film to form a colour composite produces a much broader range of visual stimuli in the form of colour differences. This permits a more detailed analysis than allowed by the 15 steps of the grey scale on each of the standard black and white images of each spectral band. Various researchers have used an intermediate stage between the use of black and white images and colour composites by considering two bands using an additive colour viewer or magnifying stereoscopes with varying results (Bale and Bowden, 1973; Carlson, 1974; van Genderen, 1974 a) Further combinations have been achieved in additive colour viewers by increasing the number of bands and the colours of the filters (other details of this process are provided in Section 4.3.4.2.). Another type of colour composite has been produced using the Diazo process with black and white MSS imagery. This technique has been in more detail in Section 4.2.2.2. but further enhancement can be obtained by using equi-density film (Nielson,1974).

Colour is a property of an area and it is this characteristic in association with the areal recording nature of the multi-spectral scanner which gives the LANDSAT MSS colour composites certain advantages in the identification of land use patterns (Hempenius, 1975). As the scale of the imagery decreases, the relative importance of the normal range of interpretation elements changes and colour becomes more important. Thaman (1974) states that "as resolution becomes progressively poorer, the information content of an image decreases. As resolution decreases, size, shape and pattern, shadow and texture decrease in importance as interpretative tools until a point is reached where resolution (spatial) is so poor that only tone and hue can be used as interpretative tools". Therefore, changes in colour between areas due to different levels of spectral reflectance tend to provide the main element for identifying land use types on LANDSAT MSS imagery. But, if the colour difference between two different categories is only slight, the interpretation becomes more difficult. Consequently, the interpreter may seek alternative combinations of enhancement by using a colour additive viewer or other techniques (see Section 4.3.4.2.) but more complexities may be introduced by extending the level of abstraction involved in the interpreting of the false colour process and other enhanced imagery. Very careful interpretation of the unnatural colours created by the enhancement techniques is required and this difficulty can be partly overcome if the interpreter has a high reference level with regard to the vegetation and agricultural practices of the region as well as an understanding of the enhancement techniques (see Section 4.3.5.). Finally, if the differences in colour between the land use categories cannot be identified satisfactorily then the classification system must be modified.

4.3.4. VISUAL INTERPRETATION AIDS

4.3.4.1. INTRODUCTION

Besides the various photographic and electronic pre-processing techniques that were discussed in Section 4.1. certain other methods can be used to assist in the interpretation of the imagery and these can be considered under the collective term "visual interpretation aids". They include optical enhancement techniques, image interpretation keys and collateral information.

4.3.4.2. VISUAL OPTICAL ENHANCEMENT TECHNIQUES

These techniques include the use of monocular magnifiers (Salas, 1974; Joyce, 1974b, Hilwig et al., 1974), light tables, binocular viewing of the combined image of two spectral bands using a stereoscope to produce an image mixing effect (van Genderen, 1974a; Hilwig et al., 1974), steroscopes utilising the limited scope for stereoscopy between frames (van Genderen, 1974b, Hempenius, 1974). Other investigators have used overhead projectors, rear-view projectors (Sweet et al., 1974), micro-film readers (Salas, et al., 1974), micro-fiche readers (Hardy and Hunt, 1975), 35mm slide projectors (Howard, 1974) but problems of distortion when projected onto screens have led to limitations in their applications.

A more sophisticated approach involves the use of optical additive colour viewers in which the black and white imagery is used in various combinations with filters to produce false colour images (Howard, 1974; Bale and Bowden, 1974; Carlson et al., 1974; Hilwig et al., 1974; Justice et al., 1976.). Like the electronic additive colour viewers, this system is more time-consuming and expensive than conventional techniques and, according to Joyce (1974), their use has been limited to those investigators with the special skills and equipment needed for the enhancement techniques. The main advantages of optical additive colour viewers over electronic viewers are that they have higher resolution capabilities, uniform brightness and easy interpreter interaction but a computer interface is difficult to achieve if further interpretative techniques are required (Estes and Simonett, 1975). As the relatively high cost, special interpretation skills and the time-consuming aspect of optical additive viewers contravene the basic aim of this investigation, i.e. to consider inexpensive and unsophisticated techniques for producing small scale rural land use maps from LANDSAT MSS imagery, they will not be examined in depth. Further details of optical and electronic additive colour viewers can be obtained from Estes and Simonett, (1975).

4.3.4.3. IMAGE INTERPRETATION KEYS

Interpretation keys have been used with a wide range of remote sensor imagery. Their basic aim is to assist interpreters in the correct identification of objects and many different types with varying levels of complexity have been devised. The design of the keys generally depends on the experience of the interpreter, the type of imagery, the interpreter's reference level (see Section 4.3.5.), the scale and resolution of the imagery and the purpose of the investigation.

Image interpretation keys can be grouped into two categories, viz. "selective" and "elimination" and each category offers certain interpretation advantages. Selective keys have been designed so that the interpreter can select from a wide variety of examples, the type which most clearly resembles the object that he wishes to identify. Details provided with the selected key can provide the interpreter with information that aids his final interpretation. Elimination keys have been designed so that the interpreter can follow a sequence of steps and, by means of a process of elimination which removes incorrect choices, the key normally guides the interpreter to the correct identification of the objects.

A recent summary of the various types of keys that have been developed for use with remote sensor imagery, especially aerial photography has been presented by Estes and Simonett, (1975). More details of their use in photographic interpretation can be found in A.S.P. 1960; 1968; Bigelow, 1963, Colwell,1970.

Nunnally (1974) has been concerned with the problem of training interpreters to use LANDSAT MSS imagery in land use studies and he has suggested that "one way of minimising the effect of experience is to establish interpretation keys". But, as far as can be ascertained no keys have been developed to assist the visual interpretation of LANDSAT imagery. Probably the most common technique that has been adopted has been the process of making the interpreter familiar with the various visual signatures on the imagery by comparing them by means of transparent overlays. (Alexander,1973b).

4.3.4.4. COLLATERAL INFORMATION

Collateral information is generally accepted as that data or material which provides supplementary details about the region being investigated that can assist in the accurate identification of objects or phenomena on the imagery. It is available in many forms including topographic maps, various types of thematic maps, e.g. soils, vegetation, land use, geology, etc., statistical reports, publications and aerial photographs. Detailed examination of this type of material can provide valuable background knowledge which in turn aids the interpretation and the formulation of an adequate classification system. Some investigators, e.g. Estes et al., (1974) prefer to include data collected in the field as collateral but for the purpose of this investigation field data has been considered under the general term of "ground truth" (see Section 4.5.).

4.3.5. INTERPRETER'S REFERENCE LEVEL

In many articles dealing with photographic interpretation, the authors have emphasised the importance of the background knowledge or reference level of the interpreter (Vink, 1964; Bennema and Gelens, 1969; Nunnally, 1974). They have generally referred to the specific skills and expertise that the interpreter has acquired within specialised disciplines, e.g. soil science, vegetation science, geomorphology and their knowledge of the region being investigated. Without this knowledge, the scope for recognition, identification and classification of various objects on the imagery is limited.

The level of interpretation of LANDSAT MSS data also depends on the reference level of the interpreter and various investigators have discussed the relative importance of knowledge in specialised disciplines (Thaman, 1974; van Genderen, 1975) as well as general regional knowledge (Estes et al., 1974; Little and Scotney, 1974). With the interpretation of land use from small scale LANDSAT MSS imagery the major concern involves the identification of the spectral and spatial relationships exhibited by the vegetation. Consequently, a broad knowledge of the agricultural practices and the vegetation of the region should be required for optimum data extraction (Bale and Bowden, 1973; Lee et al., 1975).

This broad reference level should be supplemented by relevant collateral material (see Section 4.3.4.4.). However, Nunnally (1974) has expressed concern about the problem encountered by interpreters, having been trained to interpret land use in one region, who are then required to investigate different regions with unfamiliar land uses. He claims that the effects of cultural background or "environmental modulation transfer function (Schwarz et al., 1969)" have been frequently encountered but not adequately assessed.

In addition to the background knowledge mentioned previously, the interpreter should have a detailed knowledge and understanding of the image acquisition facility of the remote sensor technique. This is particularly important with the interpretation of MSS imagery due to the wide range of combinations of spectral bands that are available to the interpreter (see Section 4.3.3.). His main task is to obtain the best possible imagery at the most appropriate scale so that optimum information extraction is achieved. However, unless he understands the nature of the various spectral responses exhibited by landscape features and their representation at various scales on the imagery, his interpretation skills will be limited even though his specific and regional knowledge may be high. Consequently, an interpreter using LANDSAT MSS imagery to map land use should ideally possess a reference level which emphasises regional vegetation and agricultural practices as well as a detailed knowledge of the various environmental and pre-processing parameters that affect the formation of the imagery.

4.3.6. MULTI-DATE IMAGERY (OR SEASONALITY EFFECT)

Another important technique that aids the interpretation of LANDSAT MSS imagery involves the utilisation of the relatively high temporal resolution of the system (see Section 4.2.5.). Theoretically, it is possible with LANDSAT 1 and 2 to produce imagery of the same part of the earth's surface every 9 days but, in practice, the weather conditions and operating procedures can extend this quite considerably. However, if imagery can be acquired so that the major seasonal effects of the vegetation are recorded, the task of interpreting rural land use can be simplified. Ideally, the imagery acquisition should be "coupled" with the growing cycles of the vegetation in the area being studied (Estes and Simonett, 1975) but this is very difficult to achieve in practice. Most researchers claim that colour MSS imagery from at least two seasons permit maximum potential for identification (Estes et al., 1974; Place, 1974; Peterson, 1975; Justice et al., 1976). Also, the dynamic nature of the vegetation permits scope for other types of photographic enhancement techniques, e.g. edge enhancement to detect boundary changes and density analyses to detect changes in crop patterns (see Section 4.2.2.).

4.4. LAND USE CLASSIFICATION SYSTEMS

As discussed previously (see Section 3.2.2.) the problem of developing a satisfactory land use classification scheme has caused considerable concern to some investigators using imagery obtained from orbital sensors (Anderson, 1971; Nunnally, 1974; NASA, 1974) whereas others have been content to develop ad hoc systems for particular areas being investigated

(Rudd, 1971; Parry, 1974). Most researchers agree that no single classification system can be devised that would be suitable as a basis for all types of land use mapping. This is mainly due to a combination of factors including the purpose of the map, the final mapping scale, the resolution and quality of the imagery, regional characteristics, adequate descriptions of categories and the major land use types that should be included.

The need for a broad framework in order to bring some form of standardisation between the mapping programmes by different organisations has been recognised in the United States and various attempts have been made to produce systems suitable for use with orbital imagery. Anderson (1971) outlined his ideas by proposing two systems for consideration by interested organisations. However, his approach, based on fixed classifications has not been accepted by all researchers as a satisfactory solution. For example, Nunnally (1974) and Mower (1972) prefer the inductive approach to land use classification recommended by Clawson and Stewart (1965) and Nunnally and Witmer (1970) in which the interpreter should interpret land use in as much detail as possible within the limitations imposed by the scale and resolution of the imagery and then group the uses into categories most appropriate to his own investigation. Nunnally believed that "if basic classes were properly defined and adequately described, the original data could then be used effectively by others since all detail would then have been preserved". Anderson (1971) agreed with the criticism, which was also presented by Nunnally and Witmer (1970), that it was quite probable that gaps would not be properly filled by using a pre-conceived classification. But, he asserted that an hierachical arrangement appropriate to a particular need for a land classification system seemed to be necessary in order to guide the interpretation of remote sensor imagery. He used the argument that the inductive approach could lead to a misdirected and possibly expensive effort which may not be needed for a particular purpose. Consequently, in his initial attempts to produce satisfactory guidelines for the preparation of land use maps from orbital imagery at scales ranging from 1:250,000 to 1:2,500,000, he outlined two schemes for consideration (see Tables 4.4 and 4.5.). The first scheme was an attempt to devise a more activity oriented or functional categorization which would be compatible with some of the classification systems that were in widespread use. This scheme was intended for use with orbital imagery in conjunction with information obtained from other sources. The other scheme was Anderson's idea for a classification system that could be used over the whole of the United States. It was designed so that little or no supplementary information from other sources was necessary but it assumed that vegetal cover surrogates could be effectively used to identify activity-oriented uses. Both schemes were designed to meet the requirements of a set of criteria which Anderson developed in order to gain a better understanding of current problems related to producing effective classification schemes for use with remote sensor imagery at scales ranging from 1:250,000 to 1:1,000,000. (see Section 3.2.2.)

The background research by Anderson provided part of the frame-work from which the Inter-Agency Steering Committee on Land Use Information and Classification attempted to develop ." a national classification system that would be receptive to inputs of data from both conventional sources and remote sensors on high-altitude aircraft and satellite platforms, and that would at the same time form the framework into which the categories of more detailed land-use studies by regional, state, and local agencies could be fitted and aggregated upward for more generalized smaller-scale use at the national level" (Anderson et al., 1972). The committee was composed of representatives from the Geological Survey of the United States Department of Interior, the National Aeronautics and Space Administration, the Soil Conservation Service of the United States Department of Agriculture,the Association of American Geographers, and the International Geographical Union. Its work was supported by N.A.S.A. and the Department of Interior and was co-ordinated by the U.S. Geological Survey. The Steering Committee accepted the basic premise that a flexible land use classification scheme was highly desirable in the United States where for many years data had been collected independently and with little coordination by many organisations at various governmental levels. This situation had often led to duplication of effort and, at certain times, it had been found that "data collected for a specific purpose were of little or no value for a similar purpose only a short time later" (Anderson et al., 1972). Hence, the committee felt that the development and acceptance of a land use classification system for use with remote sensor imagery which was compatible with existing systems was urgently needed.

An important policy forming conference on Land Use Information and Classification was held in Washington during

TABLE 4.4.

SCHEME I of Land Use Classification System Proposed by

J.R. Anderson, Photogrammetric Engineering, 37,

4, 379-387, (1971)

A Tentatative Classification Scheme for Use with Orbital Imagery and with Some Supplementary Information for Making Land Use Maps for the United States Ranging in Scale from 1:250,000 to 1:2,500,000

(This scheme assumes availability of some supplementary information from other sources. Vegetal cover terminology in parenthesis where applicable.)

- I Resource Production and Extraction
  - A. Agricultural
    - (1) Crop Production (Cropland)
      (Cropland-harvested except for orchards, groves, and vineyards; cropland used only for pasture; and cropland not harvested and not pastured)
      - (a) Irrigated Crop Production
      - (b) Non-Irrigated Crop Production
    - (2) Fruit and Nut Culture (orchards, groves, vineyards)
      - (a) Irrigated Fruit and Nut Culture
      - (b) Non-Irrigated Fruit and Nut Culture
  - B. Grazing (Grassland and Shrubland)
    - (1) Rangeland Grazing (Rangeland)
      (Native grasses, shrubs and brushland including sage brush, scattered mesquite and some other shrub types in the West)
    - (2) Livestock Pasturing (Pastures)
      (Tame grasses and legumes and scattered brushland in the East)
  - C. Forestry
    - (1) Non-Commercial Tree Raising (Arid Woodland)
      (Generally of little commercial value for timber or wood products but may be of value for watershed protection, grazing, wildlife habitat and recreation)
    - (2) Lumbering and Pulping (Forest Land)
  - D. Mining and Quarrying
- II Transportation, Communication and Utilities
  - A. Motoring (Highways)
  - B. Railroading (Railroads)
  - C. Flying (Airports)
  - D. Communication and Utility Activity (Communication and Utilities)
- III Urban Activities
  - A. Urbanized Livelihood Areas (Urbanized Land) (1970 definition yet determined by the Bureau of the Census)
    - (1) Industrial (Industrial Land)
    - (2) Commercial (Commercial Land)
    - (3) Residential (Residential Land)
    - (4) Other Livelihood (Other Land).
  - B. Other Urban Livelihood (other Urban Land). (Populated places of more than 2,500 but not including urbanized areas)

Table 4.4 (cont.)

IV Towns and Other Built-Up Livelihood Areas (Town and Built-Up Land). (With a lower areal limit which is identifiable through interpretation.)

V Recreational Activities
- A. Mountain Oriented (Mountains)
- B. Water Oriented (Water Bodies)
- C. Desert Oriented (Desert)

VI Low-Activity Areas (Other Land). (Excluding land of these types on which land using activities are found.)
- A. Low-Activity Marshland Oriented (Marshland)
- B. Low-Activity Tundra Oriented (Tundra)
- C. Low-Activity Barren Land Oriented (Barren Land) including lava flows and mountain peaks above timber line

VII Water Using Activities (Water Bodies)

June 28-30, 1971 and was attended by morethan 150 representatives of Federal agencies, state and local government, universities, institutions and private concerns. Ensuing discussions led the Steering Committee to propose that it would develop and test a land use classification system that could be used with remote sensor imagery with "minimal reliance on supplemental information at the more generalized first and second levels of categorization" and which would recognize the need for compatibility with other more generalized levels of land use categorization in classification systems that were currently in use in the United States (Anderson et al., 1972).

As well as utilizing the previously-mentioned contributions by Anderson, the Steering Committee considered other relevant investigations, including research carried out by Hardy et al., (1971) and Pettinger,(1971). Finally, the recommended system was submitted for review and testing by interested organisations and individuals as U.S. Geological Survey Circular 671 entitled "A Land-Use Classification System for Use with Remote Sensor Data". Several interesting features have been adopted in this system. Firstly, it is land cover oriented at the two most generalised levels, i.e. the levels most concerned with small scale imagery and detailed descriptions of each category have been provided in the circular. The activity aspect of land use is utilised in the third and fourth levels of categorization but they have not been described in detail because they were beyond the scope of the investigation. Secondly, four classification levels were developed on the assumption that different sensors could provide information for different levels of classification (see Table 4.6).

TABLE 4.5.

SCHEME II of Land Use Classification System proposed by
J.R. Anderson, Photogrammetric Engineering, 37,
4, 379-387, (1971)

A Tentative Classification Scheme for Use with Orbital Imagery but with Little or No Supplementary Information for Making Land Use Maps Ranging in Scale from 1:250,000 to 1:2,500,000

(This scheme assumes little or no supplementary information from other sources but the assumption is made that vegetal cover surrogates can be effectively used to identify these activity-oriented uses)

I Agricultural (with no distinction attempted between cropland and orchards, groves, and vineyards and between irrigated and non-irrigated

II Grazing

III Forestry

IV Mining and Quarrying

V Transportation, Communications, and Utilities (first order only)

VI Urban Activities

VII Recreational (only if mountains, water bodies, desert, etc., are used as surrogates and only if inference by knowledgeable persons is employed

VIII Low Activity Areas (Other Land) (marshland, tundra and barren land excluding those classified by use of surrogates and inference as recreational)

IX Water Using Activities (Water Bodies)

The committee proposed that, due to the relatively small scale of the imagery, Level 1 could only provide a general classification based on major differences in land cover, whereas Level 11, based on larger scale imagery and supplementary information, permitted the complexity of the system to be increased (see Table 4.6.). In addition, the committee accepted the criteria suggested by Anderson (1971) (see Section 3.2.2) and the system was designed to meet these requirements.

The definitions for each of the categories in Level 1 and 11 were subjected to testing and evaluation by the U.S. Geological Survey in three regional projects, viz, the Central Atlantic Regional Ecological Site (CARETS) the Phoenix Pilot Project, and Land Use Mapping for the Ozarks Regional Commission. Initial tests mainly involved imagery obtained from high altitude flights but the system was later found to work satisfactorily when used with satellite imagery. Other organisations have used the system (Carlson et al., 1974; Dornbach and McKain, 1974; Hardy et al., 1975) and, according to Lietzke and Stevenson (1974), investigators have found that all Level I and II categories with the exception of Level II Institutional could be delineated. They also stated that investigators have differed in the number of categories that they have been able to detect ranging from 6 Level I categories to 34 categories including 7 Level I, 16 Level II and 11 Level III. They also listed a number of land use categories which have been detected on LANDSAT imagery which were not included in U.S. Geological Survey Circular 671 (see Table 4.7.). Some of these categories have been included in the amended version of the classification (Anderson, 1974) (see Table 3.2.) but, as stated in the

TABLE 4.6.

LAND USE CLASSIFICATION LEVELS

(from Anderson et al, (1971), U.S. Geological Survey Circular 671)

Classification Level	Source of Information
I	Satellite imagery, with very little supplemental information. Concerned with imagery obtained at scales of 1:250,000 or smaller
II	High altitude and satellite imagery combined with topographic maps. Concerned with imagery obtained at scales of 1:100,000 or smaller
III	Medium altitude remote sensing combined with detailed topographic maps and substantial amounts of supplemental information. Concerned with imagery obtained at scales at 1:40,000 to 1:15,000
IV	Low altitude imagery with most of the information derived from supplemental sources. Concerned with large scale imagery

circular, the system was designed to be flexible within certain limits and, therefore, a particular organisation could modify it providing the recommended criteria were met.

After careful examination of its development and structure and on the basis that it is the only nationally accepted land use classification system for use with remote sensor imagery as well as the fact that it has been successfully tested, evaluated and implemented by many U.S. organisations, the system has been accepted as the general frame-work for land use classification in this investigation. Additionally, the system outlined in the U.S.Geological Circular 671 would probably be more acceptable to overseas organisations in an overall methodology for the production of land use maps rather than the inclusion of a completely new and virtually untried system. The U.S. system is quite flexible and should meet the needs of most countries in providing a general working framework from which a standardised land use classification system could be developed for a particular situation.

4.5. GROUND TRUTH PROCEDURES

4.5.1. INTRODUCTION

The use of the term "ground truth" in remote sensing has caused a certain amount of controversy. Some investigators including Estes (1974), Savigear et al., (1975) have stated or inferred that it is quite adequate and they have not been concerned with interpretations of its literal meaning. On the other hand, other investigators, e.g. Lee et al., (1975) have emphatically rejected the term in favour of "ground investigation" or "ground data". They believe that "ground truth" is jargonistic and that it is a vague and misleading term

TABLE 4.7

LAND USE CATEGORIES DETECTED ON LANDSAT-1 IMAGERY
WHICH ARE NOT IN LEVELS I AND II OF CLASSIFICATIONS
IN THE U.S. GEOLOGICAL SURVEY CIRCULAR 671

(from Lietzke, K.R. and Stevenson, P.A. (1974))

Mobile Homes	Agricultural (plowed)
Parking Lots	Agricultural (non-plowed)
Unimproved Open Space (bare)	Extractive (mines)
Improved Open Space (irrigated)	Extractive (tailing pipes)
Unimproved Open Space (with trees)	Extractive (basins)
Low Density Residential	Extractive (gravel pits)
High Density Residential	Sanitary Land Fill
Developer Open Space (urban)	Water (natural basin)
Rural Open Land	Water (excavated basin)
Right-of-Ways in Forest	Wetlands (Northern Bogs)
Rural Settlements	Wetlands (Southern Perennial)
Wooded Rangeland	Wetlands (Southern Seasonal)
Soy beans	Low Income Residential
Corn	Coastal Strand
Exposed soil	Coastal Salt Marsh
Winter Ryegrass	Coastal Sage
Stubble	Woodland Savannah
High Density Single Family	Riparian Vegetation
Low Density Single Family	
Mixed Multiple and Single Family	

which suggests that "the truth may be found on the ground". For the purpose of this investigation ground truth has been accepted as a commonly adopted and generally understood term which has been used to describe the fieldwork associated with the establishment of a detailed record of the "on-the-ground" situation in order to validate the interpretation of remote sensor imagery. This aspect has often been criticised by researchers as the most neglected aspect of remote sensing investigations (Benson et al., 1971; Nunnally, 1974).

The amount and type of ground truth data acquired usually depends upon the nature of the project being undertaken, the quality, scale and resolution of the imagery, the range of interpretation techniques, the availability of supplementary information including topographic maps, reports and statistical data. Therefore, careful selection of the variables that should be investigated and the extent of their measurement and/or description should be a major consideration in any mapping programme based on remote sensor imagery. In this investigation the emphasis is placed on the collection of data in the operational sense. This is in contrast to the more strictly controlled basic research approach in which very detailed measurements of surface and sub/surface variables may be taken at various stages before, during and after the acquisition of the imagery in order to establish environmental parameters which significantly affect the image characteristics, e.g. Curtis et al., 1974; McDonald et al., 1973.

The data will be used initially to ascertain whether the preliminary interpretation was correct (i.e. whether the required accuracy levels are attained). Also, additional information collected at the sample sites will be used to determine reasons for possible mis-interpretations and whether the classification system is satisfactory. Accordingly, the interpretation of image patterns covering comparatively large land surface areas on small scale imagery is the dominant problem rather than the establishment of possible causal relationships between the various image responses and environmental factors as attempted in the more intensive ground truth studies.

As the major aim of this research is to present a methodology for the rapid production of small scale land use maps using unsophisticated techniques, the nature of the variables to be observed and the development of an overall sampling procedure that would permit quick collection and evaluation of data therefore forms an important stage in the investigation. But, in addition, the extent of the ground truth data collection is closely tied to the structure of the classification system which, if correctly established, has certain controlling requirements or criteria that tend to regulate the scope of the inquiry (see Section 3.2.2.). These criteria usually determine the accuracy levels to which imagery should be interpreted, the minimum size of areal units and other aspects which can affect the nature of the overall ground truth procedure. Also, the majority of ground truth information in this type of investigation will normally be collected after the LANDSAT MSS data has been recorded at the ground receiving station. This situation is due to a combination of factors including the operating schedule of the receiving station, the data processing time, evaluation of the imagery for cloud cover and spectral qualities, and delivery time. Consequently, the dynamic nature of the landscape, especially vegetation patterns must be taken into consideration when collecting ground truth data in this kind of study. Most investigators recommend that imagery from different seasons should be used if possible so that a reasonable representation of the spectral responses can be observed (see Section 4.3.6.). This means that, as well as the careful selection of variables and the most appropriate sampling procedure, the most suitable time(or times)for field checking should be selected in order to avoid expensive and time-consuming field surveys. A more detailed discussion of seasonality and its effects on interpretation is presented in the section dealing with Interpretation Techniques (see Section 4.3.).

4.5.2. SAMPLING PROCEDURES

4.5.2.1. GENERAL

Due to time and cost constraints it would be virtually impossible, in the practical sense, to check completely each land use parcel throughout any region. Therefore, a valid sampling procedure is required. Unfortunately, different viewpoints and a certain amount of uncertainty exists about which approach is most appropriate and various researchers have attempted to provide satisfactory compromises between theoretical and practical demands. Sampling techniques in land use surveys have ranged from simple North-South and East-West traverses and the identification of doubtful points (Kriesman, 1969) to multi-stage strategies (Aldrich, 1971; Rehder, 1973).

During recent years financial and temporal limitations, combined with the problem of adequately representing important minor classifications in the areal sample, have tended to focus the attention of reseachers involved in land use surveys towards some form of stratified sampling technique rather than a strictly random sample. The major difference between the two approaches is that with stratified random sampling the areal sample space is divided into strata and each stratum is treated as a separate sub-universe in which simple random sampling is employed (Kelly,1970). However, no complete description of appropriate stratified random sampling procedures applicable to this investigation can be located. Most researchers have stated that they have adopted a particular strategy without fully describing the methods they used for selecting samplesizes,the location and areas of sample sites and the criteria adopted for accepting or rejecting the sites.

Zonneveld (1972b)has strongly emphasised that random sampling in land evaluation surveys tends to give too much prominence to the larger areas to the detriment of smaller areas which may be equally as important as the larger areas. He believes that the selection of points within a fully homogeneous area as indicated by interpreted patterns on the imagery should be random rather than using an overall random sample. In a later article he states that "pure random sampling is only appropriate in pure scientific surveys of small areas, where nobody is waiting for the results, except the scientist, who is amusing himself and can afford to spend much time". (Zonneveld, 1974). However, he does not present an in-depth account of his technique and he does not give any indication of the number of sample points required with each category other than "the total number of samples to be taken is then divided between these preliminary communities."

In an attempt to evaluate land classification procedures using simulated space photographs, Rudd (1971) considered that stratified random sampling was the most appropriate. After interpretation, the area of each category was measured and the smallest category (in area) was allocated five samples points and the other categories were allotted sample points in proportion to their respective areas. No reason was given for adopting five sample points for the smallest area.

Dodt and van der Zee(1974) have discussed the importance of ground checks in the identification of rural land use by photo-interpretation in order to verify all non-identifiable and ambiguous objects as well as sampling each category to check the accuracy of interpretation. No indication of sampling method or suggestions about the appropriate number of sampling sites was given but they did include some criteria for establishing interpretation accuracy including the 85- 95% limits suggested by Anderson (1971).

Stobbs (1968) has described how he used a random sampling technique to measure land use in Malawi. In effect, it is a stratified random sampling method because he actually stratified his region by using prescribed areas on individual aerial photographs and calculated the number of points to be sampled on each photograph by using a pre-determined formula (see Table 4.8). Although it is one of the few published reports where the mathematical basis for determining the number of sampling points is adequately detailed, the design parameters do not permit it to be used in this investigation. A similar sampling approach utilising the same formula has

TABLE 4.8

DETERMINATION OF THE TOTAL NUMBER OF POINTS REQUIRED TO SAMPLE THE COMPLETE PHOTO COVER OF AN ECOLOGICAL, OR ADMINISTRATIVE, UNIT IN ORDER TO PROVIDE AREA ESTIMATES OF VARIOUS LAND USE CATEGORIES, WITHIN SELECTED ERROR LIMITS

from Stobbs, A.R., 1968
The Cartographic Journal, 5, 2, 107-110

$$N = (100-P) \cdot \frac{38,400}{P \times E^2}$$

N = the total number of sampling points

P = the percentage of the total area of the ecological or administrative unit occupied by the most critical land use category (in the first instance, P is usually an estimate) made on the safe side

38,400 = a constant based on Student's "t", taken at the 95 per cent level of probability

E = the percentage error within which results can be expected to fall in 95 per cent cases

Thus, if the most critical land use category covers some 5 per cent of the total area of the unit, and the sampling error is to be no greater than 5 per cent then substituting in the above formula, we get

$$N = (100-5) \times \frac{38,400}{5 \times (5)^2}$$

$$= 29,184$$

Thus, in this example, if 1000 photos are involved the central portion of each photograph should be sampled by a template having 29 randomly distributed points been carried out in Nigeria by Alford et al., (1974).

Multi-stage sampling procedures have been used in studies associated with the production of land use maps from LANDSAT imagery. Usually, the interpretation of the land use patterns on the orbital imagery becomes the first stratification in the multi-stage design. This is then accompanied by several stages of sub-sampling using low and/or high altitude photography and/or ground data acquisition to quickly and efficiently check land use interpretations. Unfortunately, the problem of insufficient published details about this type of sampling design applied to visual interpretation techniques still exists. Poulton et al., (1975) in a review of synoptic resource inventories claimed that "methods and sampling theories developed primarily in forestry (Langley,1969) are beginning to be applied successfully to various rangeland problems (Driscoll and Francis, 1970; Johnson, 1973; Langley, 1974) ". No further details were provided and, unfortunately, two of the last three references quoted by Poulton were personal communications and the other could not be located. Therefore, specific details of their approaches could not be investigated. However, Aldrich (1971) has utilised Langley's extension of the theory of probability sampling to develop multi-stage sampling designs for timber mortality surveys and National Forest Management Plan inventories in attempts to determine gross volumes of timber from small scale imagery. But, the procedure is not directly applicable in this investigation as it involves larger scale imagery and was primarily designed to estimate timber volumes.

In summary, stratified random techniques have been readily accepted as the most appropriate method of sampling in land use studies using remote sensor imagery so that smaller areas can be satisfactorily represented. But the problem remains about how to select the best sample size for each category. Several alternative methods have been used, e.g.

(1) stratify the region geometrically and then randomly select points within each square or rectangle (Berry and Baker, 1968). The number of points may be determined by utilising formulae (e.g. Stobbs, 1968; Alford et al., 1974);

(2) stratify the region by interpreted land use categories and then estimate the total number of sample points that could be visited due to the constraints imposed by time and money and then distribute them proportionally by area (e.g. Zonneveld, 1974);

(3) stratify the region by interpreted land use and then allocate a certain number of sample points to the category with the smallest area and then distribute sample points to the other categories in proportion to their areas (e.g. Rudd, 1971).

It is considered that the above methods do not provide sufficient statistical justification for the allocation of sample points in each category of rural land use utilising LANDSAT MSS imagery. Consequently, a more detailed and more reliable method for determining the most appropriate (i.e. minimum) sample size should be ascertained.

The method proposed by the author is explained and justified in the section on Sample Size (i.e. Section 4.5.2.2.).

It is this method which was adopted for use in the ground truth phase of the project as described in Chapter 5.*

4.5.2.2. SAMPLE SIZE

As one of the basic objectives of the present study is to devise a classification of rural land use on the basis of LANDSAT MSS imagery, the function of the ground truth survey in such an operational system is to utilize a sound statistical sampling design which will test the correctness of the attribution by interpretation of specific sites to classes in the classification. That is, for any sample point, it should be shown whether the remote sensing attribution to a class within the classification is correct or in error.

Some of the main aspects that need to be considered in such a remote sensing sampling design are :-

(i) the frequency that any one land use type (on the ground) is erroneously attributed to another class by the interpreter. For example, in Table 4.9 $^{3}/_{15}$ of A is erroneously attributed to the other classes;

(ii) the frequency that the wrong land use (as observed on the ground) is erroneously included in any one class by the remote sensing interpreter. For example, in Table 4.9 $^{5}/_{17}$ of A attributions are erroneously interpreted;

(iii) the proportion of all land (as determined in the field) that is mistakenly attributed by the interpreter. For example, in Table 4.9. $^{8}/_{51}$ of all attributions are

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* The writer gratefully acknowledges the assistance and guidance of Dr. A. Hay, Senior Lecturer in the Department of Geography, University of Sheffield, in the formulation of the statistical sampling methodology which the author has adopted for use in remote sensing studies.

TABLE 4.9

MATRIX SHOWING HYPOTHETICAL NUMBERS OF SITES IN ACTUAL AND INTERPRETED LAND USE CATEGORIES

LAND USE (on the ground)

LAND USE (interpreted from imagery)

	A	B	C	Sum
A	12	1	4	17
B	2	19	0	21
C	1	0	12	13
Sum	15	20	16	51

incorrect; and

(iv) the determination of whether the mistakes are random (so that overall proportions are approximately correct), or subject to a persistent bias. For example, in Table 4.9. is there a significant tendency to mis-attribute land use C (on the ground) to category A, i.e. $^{4}/16$?

Thus, one of the objectives is to design a sampling and statistical testing procedure which will allow an approximate answer to each of these aspects.

In order to determine the optimum sample size* for a stratified random sample of a region which has been mapped by remote sensing techniques, it is necessary to consider first of all, one land use type or category (stratum) which has been identified from the LANDSAT MSS imagery. A sample of x points in that land use type can then be selected, and the number of errors (f) checked in the field.

If such a procedure adopts a very small sample (e.g. x = 10), the number of errors would normally also be small (e.g. f = 0,1,2,3, ...).However, the achievement of perfect results (i.e. f = 0) in such a small sample does not imply that the method is error free, as such a result may occur by chance in a situation where a substantial proportion of the land use classification was in fact, erroneous. This point has seldom been appreciated by many image interpreters when checking the accuracy of their remote sensing land use survey. The proportion of the interpretation which is in error

* "optimum" sample size is defined as the minimum number of points that need to be checked in the field in order to meet a specification requirement of q accuracy. Especially for low cost, operational surveys, it is critical that a method of sampling is used which is both reliable and fast (i.e. the method should enable the operational mapping organisation to meet the accuracy levels required in the shortest possible time).

TABLE 4.10

PROBABILITY OF SCORING NO ERRORS IN SAMPLES OF VARYING SIZES FROM A POPULATION WITH A RANGE OF REAL ERROR PROPORTIONS q

SAMPLE SIZE

specified interpretation accuracy q \ x	5	10	15	20	25	30	35	40	45	50	60
.99											0.5472
.95						0.2146	0.1661	0.1285	0.0994	0.0769	0.0461
.90			0.2059	0.1216	0.0718	0.0424	0.0250	0.0148	0.0087	0.0052	
.85			0.0874	0.0388	0.0172						
.80		0.1074	0.0352								
.70	0.1681	0.0282									
.60	0.0778										
.50	0.0313										

——— stepped line indicates approximate .05 level of probability would, however, be identified in a very long run study, and is normally called p% (or p as a decimal fraction). The probability of making no interpretation errors when taking a sample of x from a remote sensing based classification, with real errors having a probability p, is given by the binomial expansion $(p+q)^x$ in which $q = 1 - p$. In the case of no errors in the interpretation, the last term of the expansion is the only one of interest (i.e. q^x).

Table 4.10 shows the probability of scoring no interpretation errors in samples of varying sizes taken from a population with a range of real error proportions q. Examination of this table shows that no error sample results can quite easily arise in small samples even when the true error rate is high. Taking the conventional probability level of ·95/·05 (i.e. 95%/5%), it is clear that the table can be divided into two parts by a 'stepped' line. Above and to the left of the line, the probabilities of obtaining error free sample results are low, even when true errors may be present in appreciable numbers. On the other hand, below and to the right of the line, it is possible to identify the high probability that these error free results could have been obtained except from a method which was not truly error free. This shows that, if the permissible error rate in image interpretation is predetermined, for example, 85-90%, as suggested by the U.S. Geological Survey Circular 671 (Anderson et al., 1972) or as required in an operational job specification, the sample size for each land use category (stratum) necessary for 85% interpretation accuracy should be at least 20, and for a 90% accuracy, it should be at least 30. Thus, by using this table,

TABLE 4.11

PROBABILITY OF SCORING ERRORS IN SAMPLES OF VARYING SIZES FROM
A POPULATION WITH REAL ERROR PROPORTION OF 85%
i.e. THE SPECIFIED INTERPRETATION ACCURACY LEVEL IS 85%

sample size \ number of errors (f)	0	1	2	3	4	5
15	.0874					
20	.0388	.1368				
25	.0172	.0759	.1607			
30	.0076	.0404	.1034			
35	.0034	.0209	.0627	.1218		
40			.0365	.0816		
45			.0206	.0520	.0963	
50				.0319	.0661	.1072
55				.0189	.0434	.0781
60					.0275	.0544
65						.0365

——— stepped line indicates approximate
.05 level of probability

the minimum sample size required for checking any interpretation accuracy level can be determined. It is a minimum because for any smaller sample size even a "perfect" (i.e. error free ground check) result signifies very little. Tables 4.11 and 4.12 provide more detailed calculations of the probabilities of scoring errors in samples of varying sizes with specified interpretation levels of 85% and 90% respectively.

Although strictly speaking a sample of the calculated size should be selected for each land use classification category (or stratum), it is recognized that some land use categories will occupy such a small proportion of the total area (e.g. reservoirs, salt lakes, small forests), that such a sample size would be difficult to obtain. In such cases it is normally feasible to visit each of these sites during the field check in order to verify the accuracy of interpretation.

4.5.2.3. SAMPLING STRATEGY

It has been demonstrated above that a minimum sample size of at least 30 is necessary for each land use type in order to meet the U.S. Geological Survey Circular 671 criterion of 90% interpretation accuracy in land use surveys using remote sensor imagery. To locate these 30 points, random point sampling within a land use category (or stratum) can then be performed by sampling using random spatial coordinates. By this method, each random point is attributed to the interpreted land use type in which it falls until a sufficient number of points (e.g. 30) has been achieved in all categories. Once one land use type has been sufficiently sampled, further points that fall in that type may be ignored, whilst the random sampling continues until all types have 30 points

TABLE 4.12

PROBABILITY OF SCORING ERRORS IN SAMPLES OF VARYING SIZES FROM A POPULATION WITH REAL ERROR PROPORTION OF 90%, i.e. THE SPECIFIED INTERPRETATION ACCURACY LEVEL IS 90%

sample size \ number of errors (f)	0	1	2	3
15	.2059			
20	.1216			
25	.0718	.1994		
30	.0424	.1413		
35	.0250	.0973		
40		.0657		
45		.0436	.1067	
50		.0286	.0779	
55			.0558	.1095
60			.0393	.0844
65				.0636
70				.0470

——— stepped line indicates approximate .05 level of probability within them. Normally, however, the land use categories in which such discounted random points have fallen should be noted together with their location, in order to provide a larger sample size for each land use type. This allows sufficient reserve points to be collected in order to ensure adequate coverage caused by the inability to reach a particular site due to unforeseen circumstances.

This type of remote sensing sampling strategy has the advantage that it could be easily adapted for use with most forms of remote sensing imagery including orbital data. Thus, the proposed sampling strategy developed above and tested in the field (as described in Chapter 5) provides a reliable framework for testing the accuracy of any remote sensing image interpretation-based land use classification using the minimum number of points; thereby saving time and money especially if it is employed in operational surveys where high accuracy levels have to be guaranteed.

4.5.2.4. <u>SIZE OF SAMPLE POINT</u>

Obviously, the term sample "point" in this type of study is a misnomer because, even though the theoretical location of the sample site may be determined by the grid intersection, the practicalities of field work make it virtually impossible to locate and classify. Therefore, a selected area around the point must be considered and its actual size will depend on the scale and resolution of the imagery, the map scale and the purpose of study. Again, there appears to be little guidance in the published literature but it is generally accepted that the quadrat should not be smaller than the ground resolution of the system used. Consequently, in the case of LANDSAT

MSS imagery the size of the "points" in land use surveys should be greater than pixel size, i.e. greater than 79m. by 79m.

Lietzke and Stevenson (1974) have reported that the "threshold of resolution is 10 acres (4.05 hectares) for comprehensive land use mapping and 2 to 5 acres (0.8 to 2.03 hectares) for some specific categories". No mention of mapping or imagery scale was given but, on the basis of this information, the minimum resolution, i.e. the smallest identifiable land use pattern would be an area equivalent to 200 m. by 200 m, or approximately 6 times the area of a pixel.

Joyce (1974a) states that "the minimum-sized unit area delineation of 40 acres (16 hectares) or larger is most common" and refers to research by Alexander (1973a) Sizer, and Brown, (1973); and Hardy, Skaley and Phillips, (1974). Consequently, it appears that the size of the sample "point" should fall between the resolution threshold (200 m. by 200 m.) and the minimum size area that can be delineated, i.e. 400 m. by 400 m. (16 hectares). Joyce did not state the scale of the maps he was discussing but Hardy et al., mentioned that "direct transfer may be made at ratios of 1:250,000 and 1:150,000 with map units of about 25 hectares (500 m. by 500 m.) and 10 hectares (316 m. by 316 m.) respectively". For the purpose of this investigation a square of 250 m. by 250 m. has been adopted as the size of the sample point. More details on scale and resolution have been presented in Sections 4.2.4. and 4.2.5. respectively.

4.5.3. GROUND DATA ACQUISITION

As mentioned previously the correct selection of the variables which should be investigated in the field forms an important part of the overall ground truth procedure. The variables should represent the dominant factors that have affected the spectral nature of the image and the extent to which they should be recorded in the field is mainly a function of the scale and resolution of the imagery, the classification system and the purpose of the study.

The main variables that have been considered in small scale land use surveys have included soil,bedrock,vegetation, surface morphology, urban centres, water surfaces, slope and aspect. But, the appropriate level of measurement and/or description has not been adequately described and most guidance can be obtained by examining the data acquisition sheets devised for land use mapping from aerial photographs, e.g. Benson et al., 1971, terrain analysis studies, e.g. Mitchell, 1973, other closely related studies, e.g. Henderson's (1975) investigation of the role of radar in land use mapping or the more basic research oriented studies investigating LANDSAT MSS imagery (e.g. Curtis and Hooper, 1974). These different approaches,at least,give some idea of the level of description at the particular scale that the researchers have decided to investigate.

Small scale land use surveys have had the constraints of the classification system super-imposed over the data collection techniques and this has controlled the extent to which data has been collected. Therefore, if the broad outlines provided by the U.S. Geological Survey Circular 671 are adopted then the land use variables should be measured or described in a hierachical manner to coincide with the various levels of the classification scheme, i.e. Levels 1 to 4.

This means that a satisfactory ground data sheet should be designed so that the information can be collected at different levels of sophistication but with an operational rather than a research bias. The extent and type of data collection in the field are largely influenced by time and cost factors and rigidly controlled observations which aid the very detailed analyses of spectral responses are not required.

The major factors to consider at Levels 1 and 2 are those which lead to the spectral responses on the imagery associated with broad categories of vegetation. These mainly include the distribution patterns of the vegetation and the colour of vegetation and soil associated with those patterns. Data may also be collected which coincides with the U.S. Geological Survey Circular 671, Levels 3 and 4. This permits the more specific identification of vegetation types at the sample point and their use may not be obvious during field work but the data may be helpful when trying to isolate reasons for mis-interpretation. For example, the seasonal variation in some types of vegetation may vitally affect the response recorded on the imagery.

Other factors which affect the spectral responses should be recorded, e.g. slope, vegetation spacing and height, colour of surface. Provision should be made for recording possible seasonal changes in vegetation characteristics at different levels as well as possible new development projects in the region which could cause discrepancies between the imagery and the data collection. Ground level photographs of the sites have been found useful in assessing mis-interpretations. In addition, vertical aerial photographs have been used by various researchers as an alternative method of establishing the accuracy of their interpretation of orbital imagery (van Genderen, 1973b; Sweet et al., 1974).

The stages in the preparation for data collection and the associated field procedure will be described in detail in the next Chapter.

4.5.4. SUMMARY

The collection of information about selected variables at an appropriate level requires the development of an appropriate sampling design and ground data collection procedure which will enable the rapid collection of data to check the accuracy of interpretation and to help isolate possible reasons for mis-interpretation. Basically, this necessitates the selection of an adequate sampling strategy, optimum sample size, area of sample "points" and the development of an adequate ground data collection form and traversing procedure.

Investigation has shown that the most appropriate sampling strategy for this study is the stratified random technique. However, no established method for determining the ideal number of sample points could be discovered and a special method has been developed to overcome this problem (see Section 4.5.2.2.). The size of the sample "point" was established after considering the minimum mapping unit and image resolution (see Section 4.5.2.4.). Detailed explanations of the application of these aspects in the operational sense and the development and use of a ground data acquisition sheet and field traversing routine are presented in Chapter 5.

4.6. GENERAL SUMMARY

The overall aim of this chapter has been to consider the main factors that affect the level of accuracy of the production of small scale land use maps from LANDSAT MSS data in order to assess the relevant approaches that have been utilised within a broad range of remote sensing techniques. In addition, it has brought together the results of many research projects which have focussed on specific problems that are applicable in the production of small scale land use maps. Consequently, the summary of techniques has permitted the evaluation and elimination of some methods and it has also allowed some procedures to be adapted and new ones to be developed so that the basis for a feasible methodology can be established.

It appears that the major problems to be investigated revolve around the selection of the most appropriate imagery format and scale, visual interpretation procedures, the development of a satisfactory classification scheme and the establishment of a viable sampling procedure for testing the results of the interpretation as well as locating possible reasons for mis-interpretation. The next logical step, therefore, is to test the most relevant techniques involved in each stage in the operational sense and Murcia Province, South East Spain was chosen as the most suitable location. The results of these investigations are described in the next chapter.

5. PRODUCTION OF MURCIA PROVINCE (1:250,000) RURAL LAND USE MAP

5.1. INTRODUCTION

The general aim of this chapter involves the evaluation and selection of the most appropriate techniques that may be utilised in the production of a small scale rural land use map of Murcia Province, South East Spain. The findings will then be used as the basis for the formulation of a detailed methodology that may be applied in the production of similar maps in other regions, in particular, semi-arid developing regions. Most of the methods that were reviewed in Chapter 4 will be tested and several new methods will be proposed. But, before any mapping programme can commence, the objective behind the production of the final map and its specifications, especially the final mapping scale, should be clearly defined as they place constraints on all aspects of the map production.

In this study, the main objective was the rapid production of a small scale map from LANDSAT MSS imagery showing the broad distribution of rural land use patterns in the Murcia Province which could serve as a basis for monitoring land use changes, e.g. the growth of the irrigated areas and possible changes in forest boundaries. No land use map of the Province has been published and only a few large scale land use maps covering comparatively small portions of the Province have been produced. The use of conventional aerial photography techniques would have been too time-consuming and expensive, and the LANDSAT MSS imagery offered the only viable method.

The selection of the final mapping scale required careful deliberation as it tended to control many of the practical aspects involved in the subsequent mapping procedure. However, before it could be finalised, the availability and resolution of imagery in appropriate formats and scales as well as possible investigation techniques were investigated. In addition, available reference material including relevant maps, reports, aerial photography and the main objective needed to be included in the assessment and a compromise reached over which scale would suit the limits imposed by each factor. Also, a limited amount of guidance was provided by other investigators involved in producing land use maps from LANDSAT MSS imagery. (see Section 4.2.4.)

The final mapping scale of 1:250,000 was selected for use in this study after careful consideration of the purpose of the completed map, the available imagery and the current topographic and thematic maps of the region. Although the most relevant Spanish topographic maps have been produced at a scale of 1:200,000; thematic soils, geology and vegetation maps of the Province have been published at 1:250,000. The existence of these thematic maps at 1:250,000, plus the fact that the colour composites from the EROS Data Center are also at 1:250,000 helped to resolve the problem of the scale of the resultant land use map. Furthermore, additional enlargement would lead to poorer resolution and possibly a lower level of interpretation accuracy. Also, as the main user of the map is to be the Spanish Ministry of Agriculture through its Instituto de Orientacion y Asistencia Tecnica del Sureste based in Murcia, who produced the 1:250,000 soils, vegetation and geology maps referred to above, the rural land use map produced in this study will supplement this series as well as serving as a base in their overall planning of agricultural development of the Province.

In order to establish a satisfactory background that will permit a better understanding of the relationships between the different spectral responses on the imagery and the land use patterns, an initial general description of the vegetation and agricultural practices will be presented. This will be accompanied by details of relevant collateral material. Then, detailed descriptions of the various stages of the map production will be presented.

5.2. STUDY AREA : MURCIA PROVINCE

Murcia Province was selected as the study area for a variety of reasons, viz:

(1) it is a semi- arid region readily accessible from the United Kingdom (see Figure 5.1.).

(2) it is an official N.A.S.A. and E.S.A. (formerly E.S.R.O.) ground truth site for testing remote-sensing techniques (see Figure 5.2.).

(3) large irrigation schemes are being developed in the region and they will change the farming practices over large areas (Lopez-Bermudez, 1975) (see Figure 5.3.).

(4) the Province contains many detailed agricultural patterns with associated land management problems.

(5) no land use map of the whole Province exists.

(6) the Department of Geography, University of Sheffield possesses a wide range of imagery including orbital and conventional aerial photographs covering the test site (see Figures 5.4.5.5.). Also collateral material including Ph.D., M.Sc. theses, unpublished

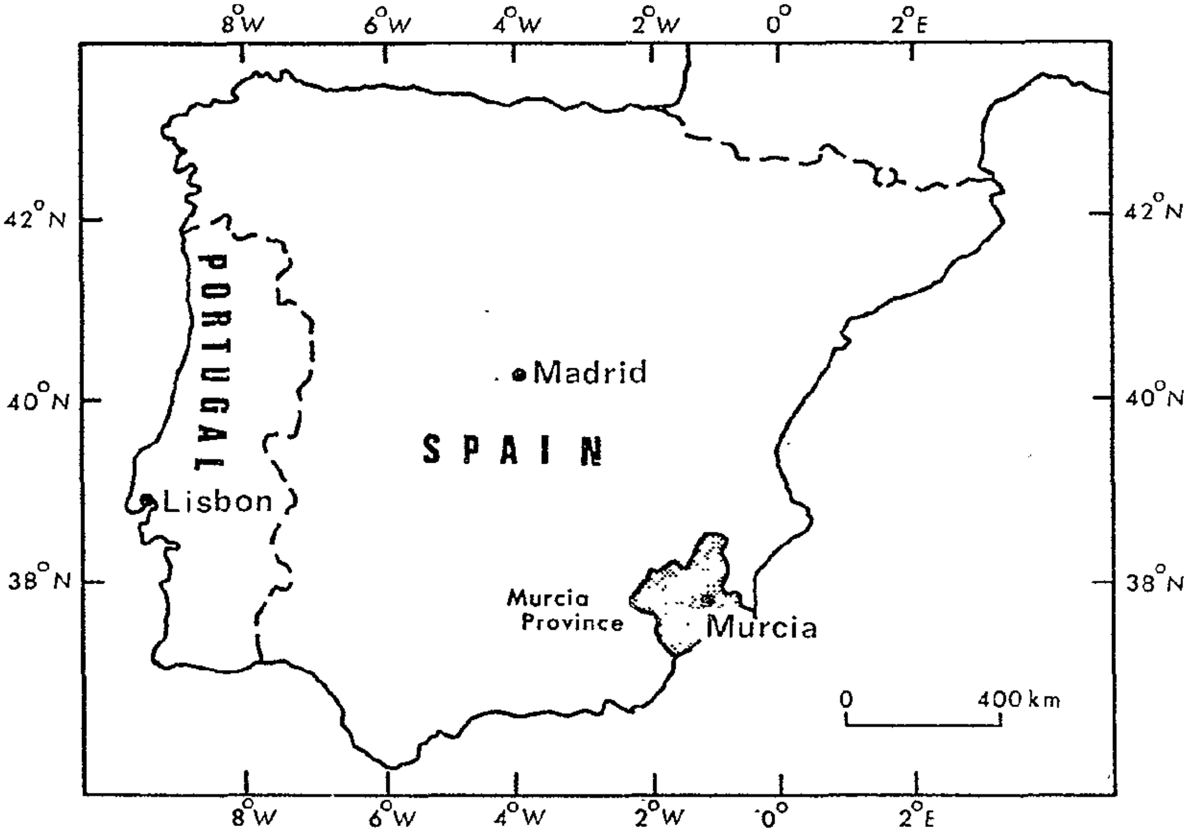


Figure 5.1 GENERAL LOCATION MAP OF FIELD STUDY AREA

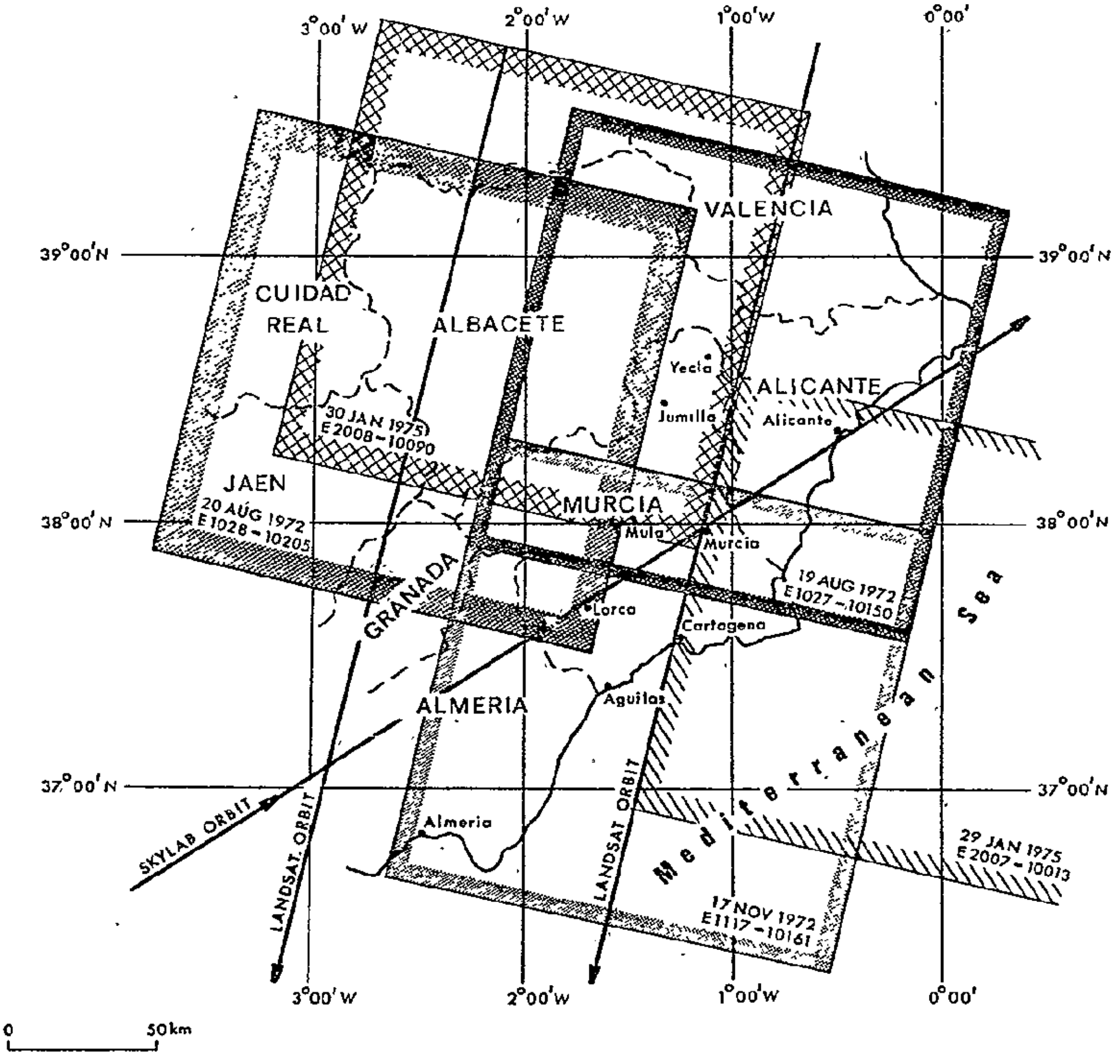


Figure 5.2 MAP SHOWING APPROXIMATE AREAL COVERAGE OF LANDSAT IMAGERY

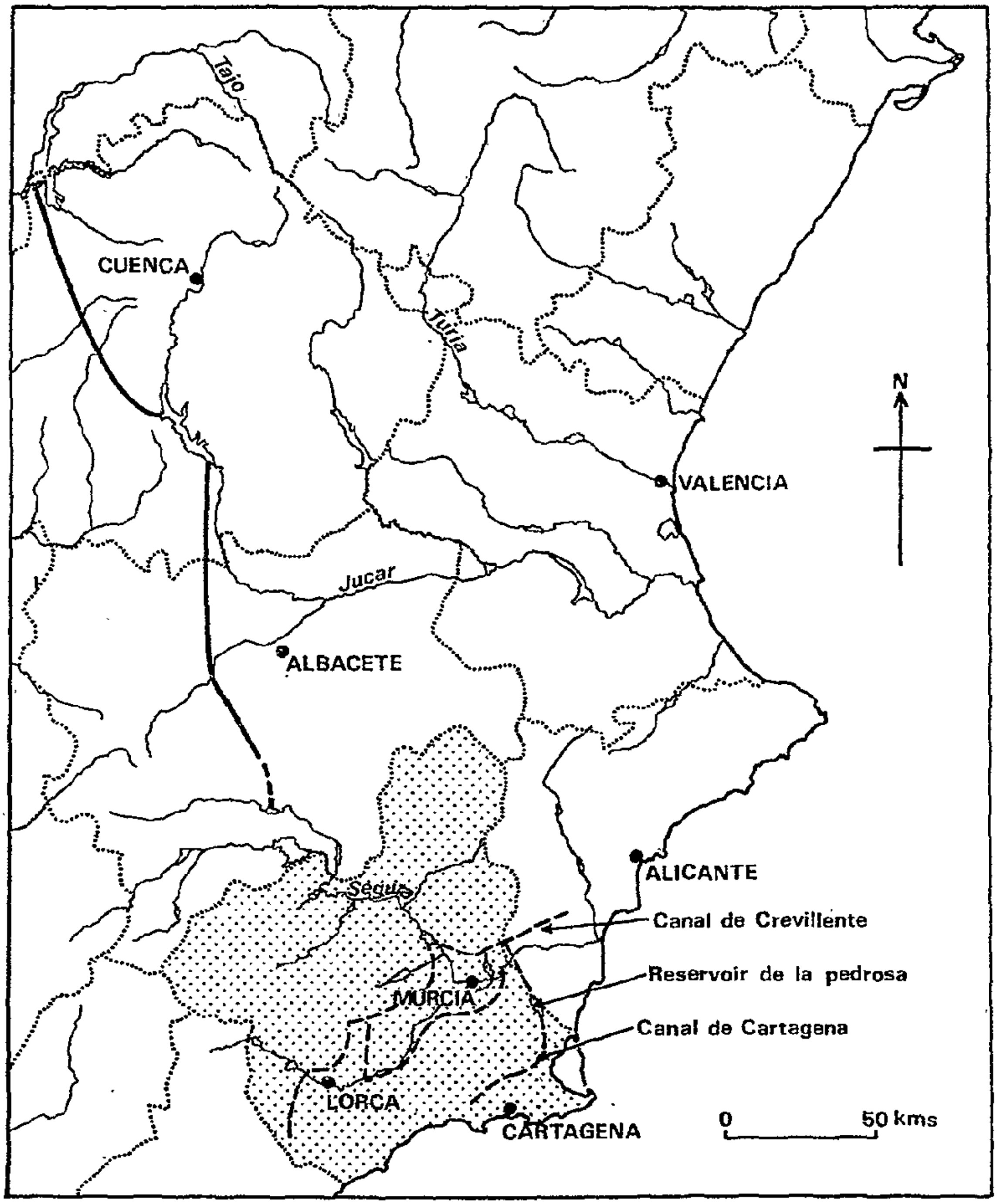


Figure 5.3 PROPOSED TAGE-SEGURA DEVELOPMENT SCHEME
(from Lopez-Bermudez, 1975)

reports, etc.which have been obtained on previous field excursions to the region was available.

Situated in South East Spain, Murcia Province has an area of approximately, 11,000 square kilometres and is dominated by the Segura River and its associated lowlands. The physiography of the remainder of the Province consists basically of a series of parallel mountain ranges with intervening plains. The region is semi-arid and lies within the rain-shadow of the Meseta. It is one of the driest areas of Spain with a mean annual rainfall of 309 mm. (1862-1971) received mainly in autumn and spring and often in sudden, heavy downpours. Mean monthly temperature rise from 10°C in January to a maximum of 27°C in August (see Figures 5.6, 5.7) . Generally, the rainfall is insufficient for widespread agriculture and cultivation is mainly confined to the vicinity of streams or located in areas served by irrigation schemes (see Figure 5.8.) Mean annual temperature decreases and mean annual rainfall increases towards the North West of the Province.

The main agricultural products of the Province include olives, almonds, oranges,lemons,grapes,apricots,peaches, vegetables and cereals. Several different types of agricultural practices are carried out and have been summarised under the following categories :-

1) irrigated tree crops, e.g. citrus, peaches, apricots (see Photograph 5.1)
2) irrigated inter-cropping with many different combinations of crops e.g. fruit trees and vegetables (see Photograph 5.2.)
3) non-irrigated inter-cropping, e.g. almonds and cereals.

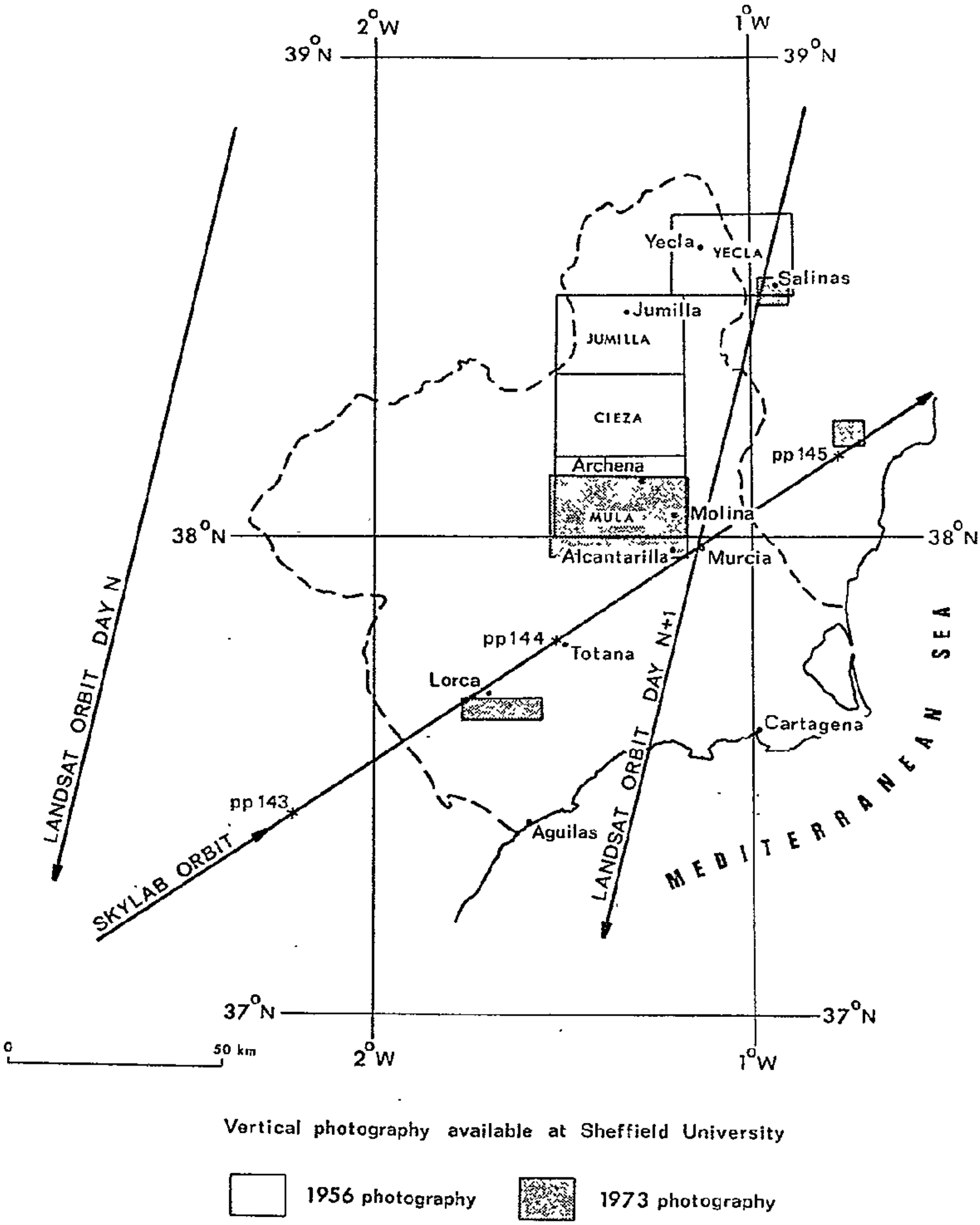


Figure 5.4 Map showing approximate Landsat and Skylab orbits and available aerial photography

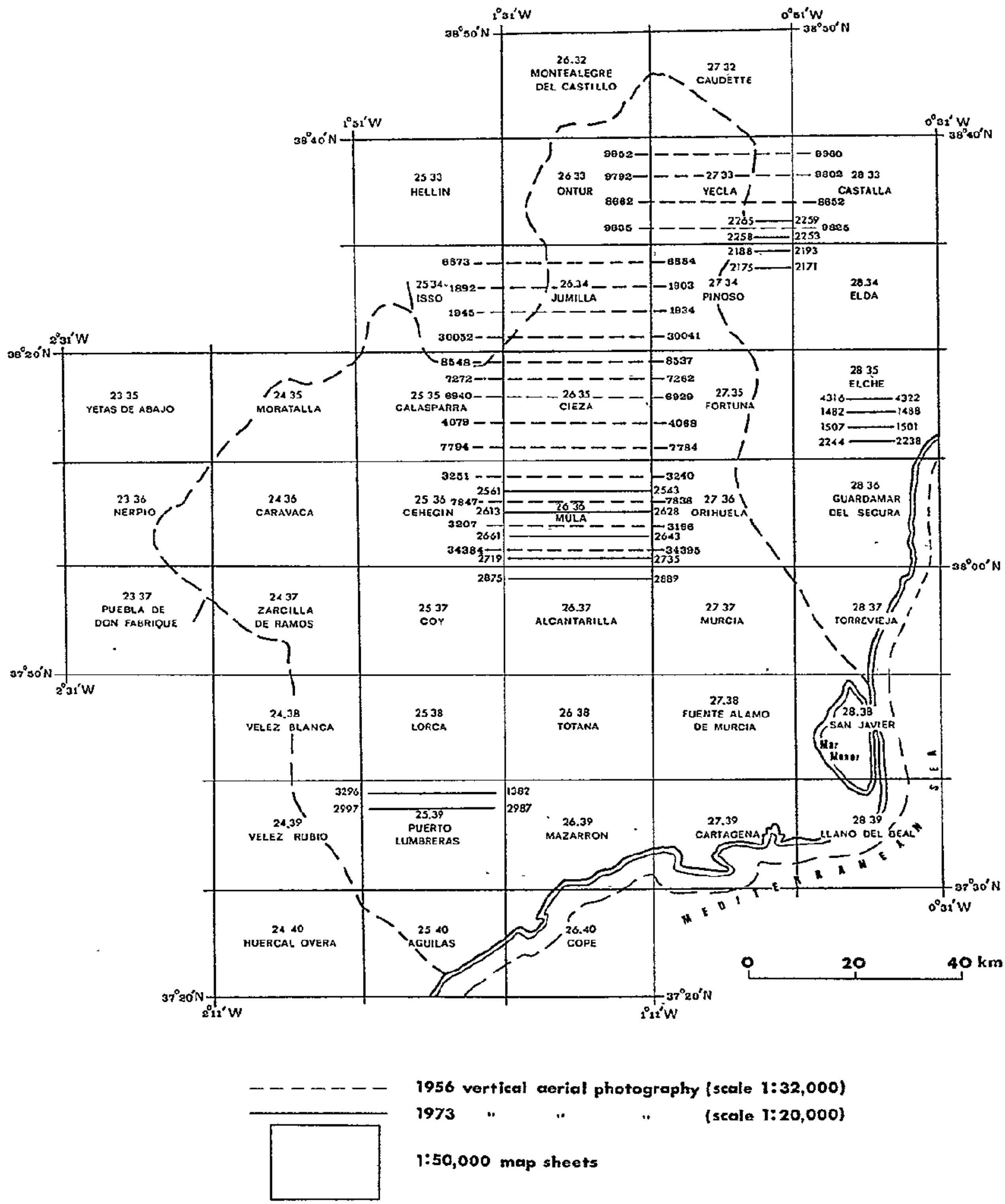
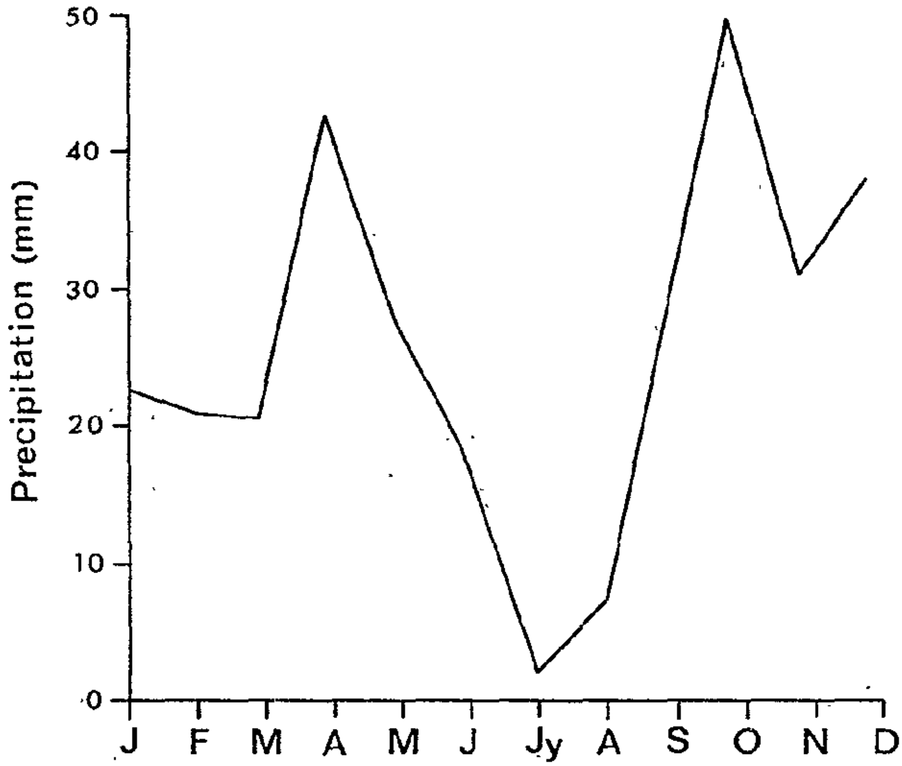
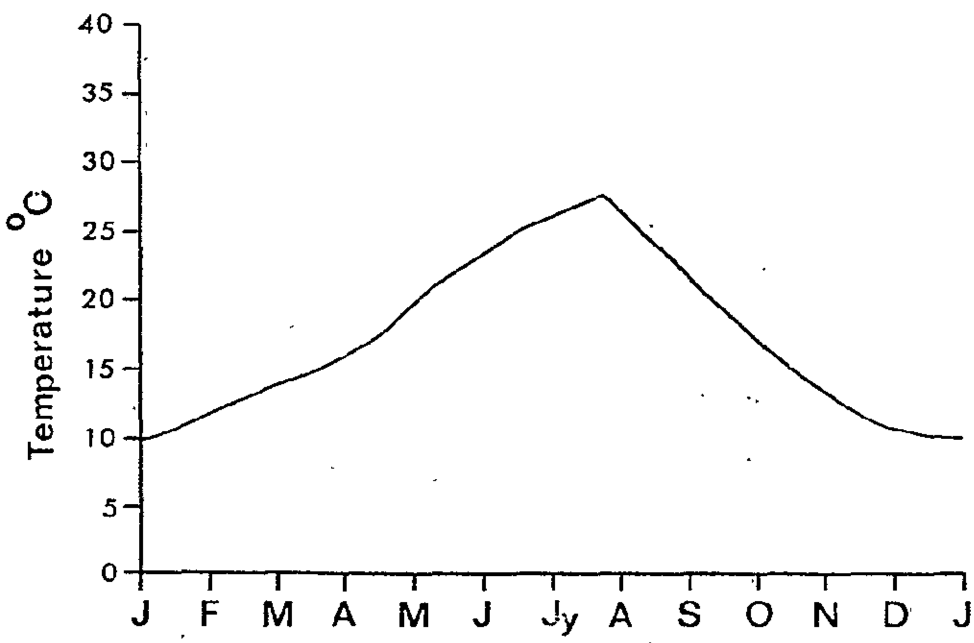


Figure 5.5 FLIGHT PLANS OF VERTICAL AERIAL PHOTOGRAPHY, MURCIA PROVINCE, SOUTH EAST SPAIN.



Mean monthly rainfall for Murcia (1941-71)



Mean monthly temperature for Murcia (1919-59)

Figure 5.6: CLIMATOLOGICAL DATA

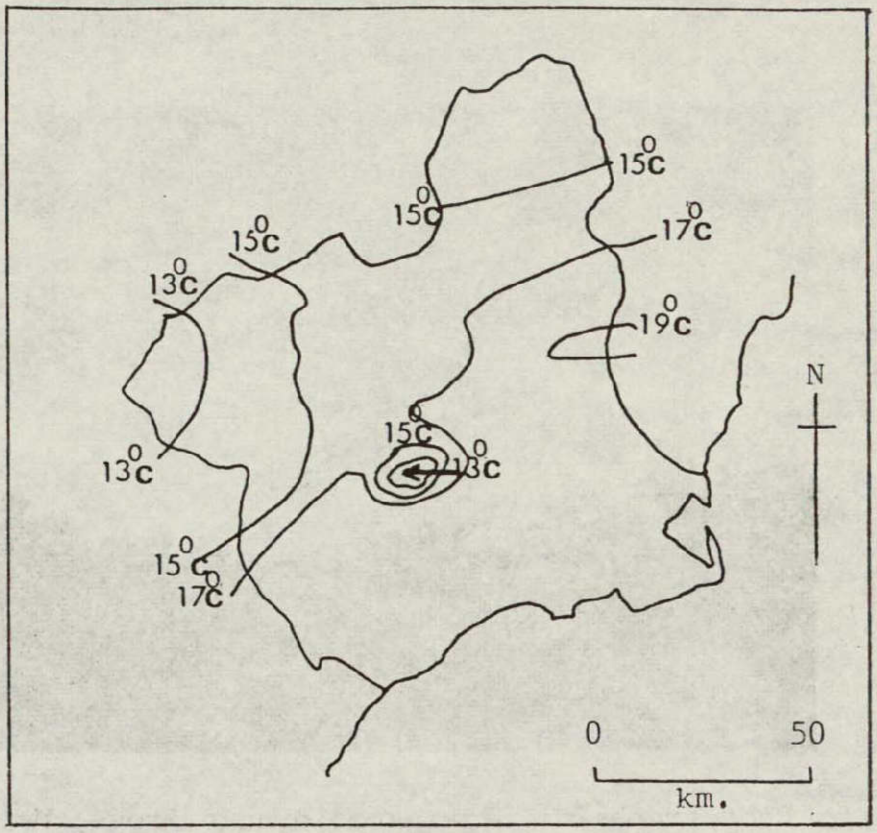


Fig 5.7 Murcia Province: Annual Isotherms

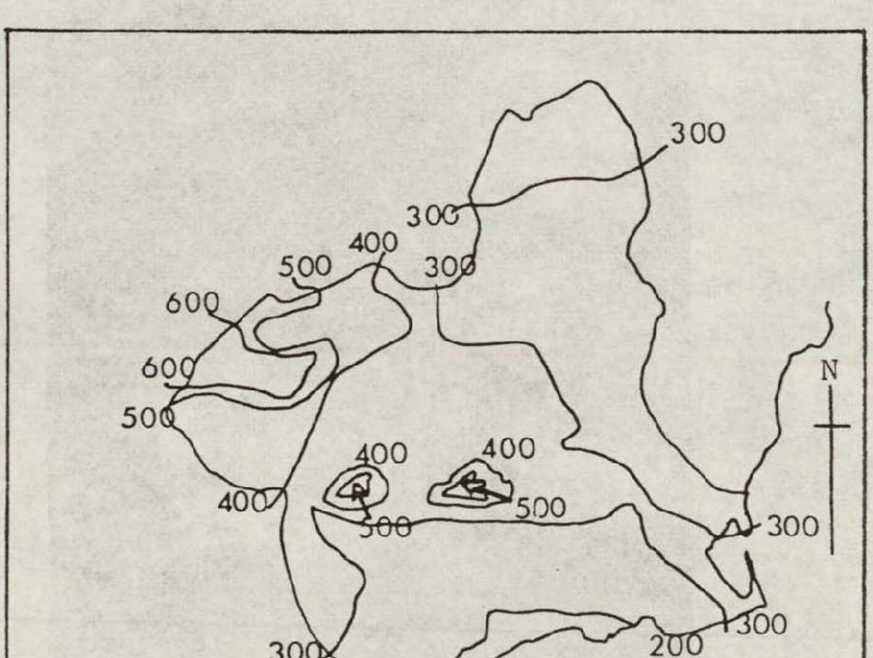
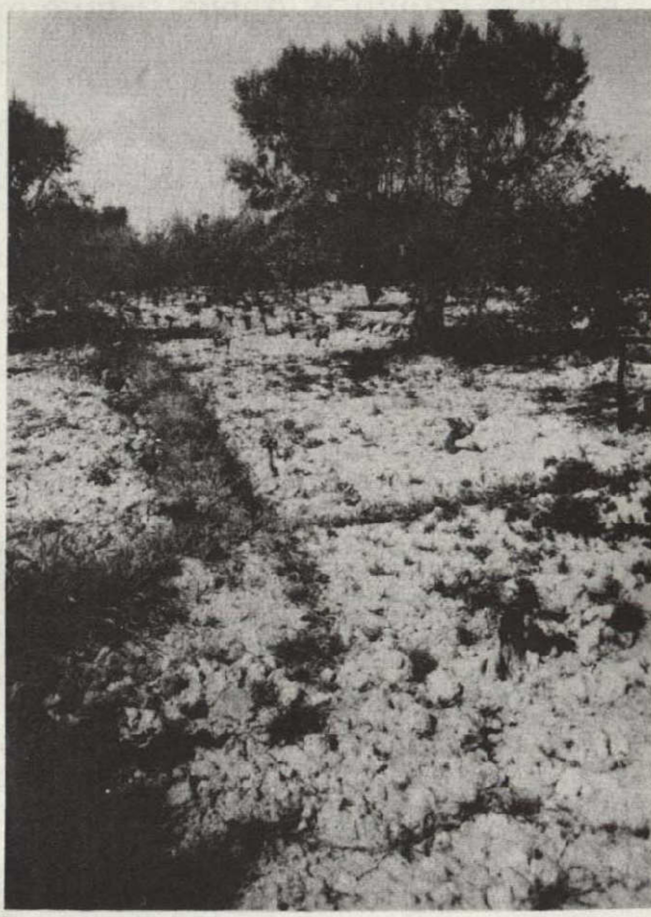


Fig 5.8 Murcia Province: Mean Annual Precipitation (mm.)

Photograph 5.1 Irrigated orange grove, Mula



Photograph 5.2 Irrigated inter-cropping of olives, vines and cereals, Murcia.

(see Photograph 5.3.)

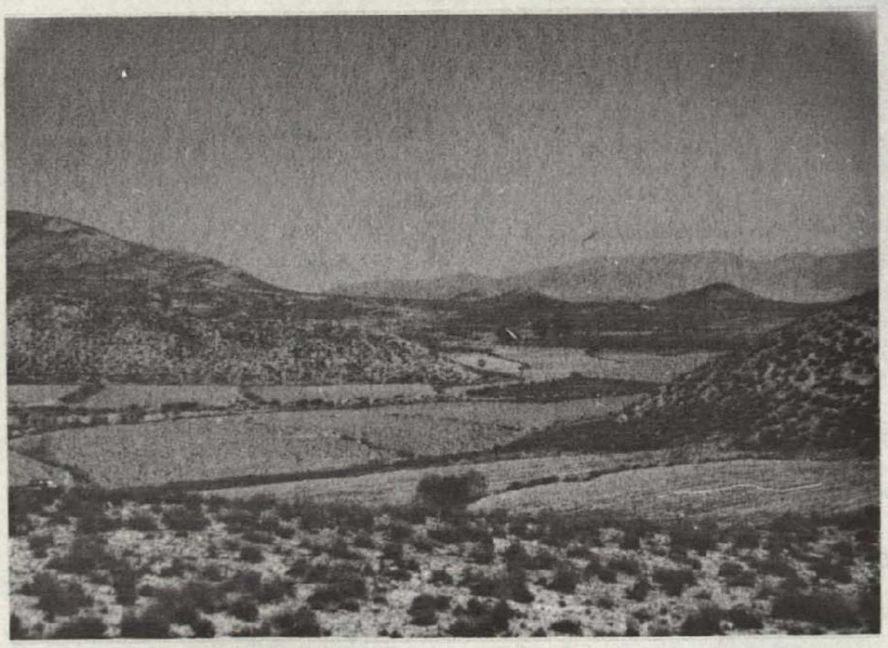
4) monoculture in non-irrigated areas. Predominantly cereals although some large areas of vines in the North East and some smaller areas of olives are scattered throughout the Province. (see Photograph 5.4.)

The Province is characterised by a wide variety of field shapes and sizes ranging from approximately ¼ acre (0.1 hectares) in irrigated areas to 20 acres (8 hectares) or larger in the dryland areas (see Photographs 5.5,5.6).

The natural vegetation of the Province can be divided into two broad groups, viz: evergreen forests and matorral. The evergreen forests mainly include <u>Pinus pinaster</u>, <u>Pinus halepenis</u>,<u>Quercus rotundifolia</u> and <u>Juniperus thurifera</u> and are mainly found on the middle and upper levels of the steep north-facing slopes of the mountain ranges where lower temperatures and lower rates of evaporation result in denser vegetation.. Matorral is a Spanish term that has been used to describe Mediterranean scrub communities and includes the relatively tall "maquis" and the shorter "garrigue" (or "garigue") (Polunin and Smythies, 1973). Opinions differ amongst botanists about an adequate separation between the two. The problem has been due to a combination of physiognomic, biotic and edaphic factors as well as the additional effects of man and animals.

In Murcia Province there are few areas of maquis as defined above, and garrigue has been accepted as the overall descriptive term for the low scrub community. The garrigue throughout the Province displays a comparatively large

Photograph 5.3 Non-irrigated inter-cropping of almonds and cereals, Alcantarilla.



Photograph 5.4 Cereals in non-irrigated area, Calasparra. Note garrigue on steeper slopes.

Photograph 5.5 Small irrigated fields near Cehegin.

Photograph 5.6 Large non-irrigated fields near Moratalla.

geographical variation in floristic composition and vegetation height. Some of the most common include *Teucrium polium*, *Rosmarinus officinalis*, *Periploca laevigata*, *Pistacia lentiscus*, *Quercus coccifera* and species of *Thymus*, *Artemisia*, *Thymelaea*, *Erica*.

More detailed descriptions of the vegetation, soils and geology of the Province are provided in two official publications of the Centro de Edafologia y Biologia Aplica del Segura, viz. "Estudio Edafologico y Agro biologico de la Provincia de Murcia", 1966 and 1968 which were prepared by the Instituto de Orientacion y Asistencia Tecnica del Sureste, Murcia.

A bibliography containing articles about the physical geography of the Province has been compiled by Lopez-Bermudez (1973a). Other recent articles on relevant topics are :-

1. Climate - Lopez-Bermudez (1971,1973b)
2. Agriculture - Garcia-Tornel (1968,1971b), Bel (1973)
3. Development projects - Garcia-Tornel (1968,1971a), Lopez-Bermudez (1975)

5.3. STAGES OF PRODUCTION OF MURCIA PROVINCE RURAL LAND USE MAP

5.3.1. PREPARATION OF PRE-PROCESSED MATERIALS

Pre-processing in this investigation refers to the transformation of imagery into the most appropriate form for interpretation. It involved the careful selection from the range of standard pre-processed imagery produced by EROS Data Center as well as a knowledge of other methods which could be used to transform the standard imagery into other formats. The extent of the "in-house" pre-processing was purposely restricted to simple photographic processing and relied on only basic visual interpretation equipment.

Due to the wide range of opinions that have been expressed about the optimum combination of scale,resolution and format of the imagery and interpretation techniques (see Section4.2) it was decided to assess them independently and most of the standard pre-processed imagery covering the Province was obtained from EROS Data Center. It was envisaged that this would provide a satisfactory data base for further "in-house" pre-processing as the evaluation of the imagery and interpretation techniques progressed. Also, attempts were made to select imagery from different seasons but many frames were not satisfactory for use in this study due to excessive cloud cover. The most useful frames were obtained from orbits on 19,20 August, 1972; 17 November, 1972, 19,30 January 1975, and 29,30 November, 1975 (see Figure 5.2)

The main type of "in-house" pre-processing was the black and white enlargement of portions of selected bands of the frames. These were produced in the form of opaque prints and/or transparencies at various scales up to 1:100,000.

Other black and white photographic techniques e.g. contrast printing, edge enhancement, density slicing and image addition were not considered feasible due to cost and time factors. Furthermore, there was little evidence to show that interpreters had benefitted by their use in operational surveys (see Section 4.2).

Additional pre-processing involved the preparation of different forms of transparencies of the black and white imagery and colour composites for use with commonly used visual enhancement equipment which had been recommended by researchers.

TABLE 5.1 LANDSAT MSS PRODUCTS OBTAINED FROM EROS DATA CENTER OF MURCIA PROVINCE

Black and White imagery

Image Size	Scale	Format
2.2 inch	1:3,369,000	Film positive for bands 4,5,6,7
2.2 "	1:3,369,000	Film negative for bands 4,5,6,7
7.3 "	1:1,000,000	Film positive for bands 4,5,6,7
7.3. "	1:1,000,000	Paper print positive for bands 4,5,6,7
14.6 "	1:500,000	Paper print positive for bands 4,5,6,7
29.2 "	1:250,000	Paper print positive for bands 4,5,6,7

Colour composite imagery

7.3 inch	1:1,000,000	Film combination of bands 4,5,7
7.3 "	1:1,000,000	Opaque print of combination of bands 4,5,7
29.2 "	1:250,000	Opaque print of combination of bands 4,5,7

(see Section 4.3.4). They included 35mm and 70mm slide projectors, microfiche readers and microfilm readers.

The advantages of low cost and simplicity of production of colour composites by the Diazo process stressed by several groups of researchers led to experimentation with different exposure times (see Section 3.2.3). Colour composites of all the selected frames were prepared using yellow, cyan and magenta diazo film for bands 4,5 and 7 respectively. Standard 1:1,000,000 positive transparencies of each band were individually placed in a vacuum frame with the appropriate film and exposed. The film was then run through a dyeline machine to reveal the particular colour. The three coloured films representing bands 4,5 and 7 were super- imposed in correct register and joined together. During the procedure it became apparent that the major problem associated with the Diazo process was the correct selection of exposure time but, once this was determined, good quality colour composites were produced. It was found that, after experimentation with different products, the best results were obtained by using Ozalid esochrome •003" polyester film base exposed to a 500 watt mercury vapour UV light in a vacuum frame for approximately 20 seconds depending on the density of the LANDSAT MSS positive transparency. The best registration of the superimposed colour films was achieved when standard LANDSAT MSS film transparencies were used rather than producing "in-house" enlargements of the 1:3,369,000 standard film chips.

Supplementary data in the form of uncontrolled mosaics of the 1956 pan-chromatic aerial photographs of the Mula Cieza, Jumilla and Yecla 1:50,000 topographic map sheets were also utilised in the identification and classification of patterns on the LANDSAT MSS imagery. One uncontrolled mosaic of the Mula 1:50,000 topographic map sheet was prepared for examination using 1973 aerial photographs (1:20,000) and reductions of the previous by constructed mosaics of Cieza, Mula, Jumilla and Yecla at approximately 1:143,000 and 1:250,000 were also used in the investigation.

5.3.2. SELECTION OF VISUAL INTERPRETATION TECHNIQUES

The basic objective of designing a methodology based on inexpensive and unsophisticated methods has controlled the extent to which interpretation techniques could be used in the preparation of the rural land use map of the Murcia Province. Most of the conventional visual equipment that was reviewed in Chapter 4 was available for evaluation. They included mirror stereoscopes with magnification up to 8 times, monocular magnifiers with varying levels of magnification, microfiche readers, microfilm readers, overhead projectors, 35 mm and 70 mm slide projectors and light tables. The exceptions were colour additive viewers and rear projection screens. The different types of pre-processed imagery available for assessment has been listed in Section 5.3.1.

The difficulties associated with evaluating the relative interpretability of remote sensor imagery have been expressed by various researchers and no satisfactory method has been developed to assess them in a strictly objective manner (see Section 4.3.2)The main problem is that many factors affect the level of interpretability especially image resolution and scale, tonal contrast, quality of colour and the availability and standard of interpretation equipment. Many of these aspects are closely inter-related and researchers have found that it is very difficult to isolate and identify their relative importance in the interpretation process. Consequently, the assessment and selection of LANDSAT MSS imagery and interpretation techniques in this investigation was essentially subjective and involved the systematic application of various combinations of imagery and equipment. One major problem was concerned with the possibility of incorrectly rejecting a technique due to the interpreter's initial lack of familiarity with the images, the equipment and the region. This problem was recognised and constantly checked by considering the various combinations of imagery and equipment several times during the selection stage as well as later in the investigation.

Before the programme of assessment could commence a satisfactory understanding of the surface features of the region and their possible effects on the imagery was required. This involved the collection and evaluation of appropriate collateral material of the region (see Section 4.3.4.4). As no satisfactory land use map of the region had been produced the most appropriate alternative was to consider other maps which could be used to compare the spectral responses on the imagery with the areal distribution of other surface phenomena. The only thematic maps of the Province that were published at a suitable scale were the potential natural vegetation, geology and soils maps (see Section 5.2). Of the three, the vegetation map provided the most correlation and a transparent overlay was prepared at map scale (i.e. 1:250,000). This was then placed over the standard 1:250,000 black and white enlargements of each spectral band as well as the enlarged colour composite and attempts were made to identify various portions of the imagery in order to provide bases from which further possible identification could be made.

As a basis for the extrapolation of image identities several other methods were used. A land use map of the Mula 1:50,000 topographic map sheet was prepared from the 1:20,000 mosaic using conventional air photo-interpretation techniques. Information from various unpublished reports on the Mula region provided supplementary background information during the interpretation of the aerial photography. The broad land use patterns on the map were then compared with the spectral responses on the appropriate portions of the black and white and colour LANDSAT MSS imagery. In addition, a single detailed 1:50,000 published land use map of the irrigated lands near the city of Murcia was used to assist in the positive identification of spectral responses associated with irrigated agriculture (Garcia-Tornel, 1971 b). Finally, reductions of the air photo mosaics of Mula, Cieza, Jumilla and Yecla 1:50,000 topographic map sheets at scales of approximately 1:143,000 and 1:250,000 were compared with the LANDSAT MSS imagery as another method of identifying the land use patterns (see Figures 5.9, 5.10,5.11,5.12).

After the period of familiarisation with the imagery, a more detailed assessment was undertaken using the different types of visual enhancement techniques with the full range of pre-processed imagery. During the first stage of the assessment, monocular magnifiers of increasing power up to 8x were used with black and white transparencies and paper prints of each band enlarged to various scales.

C3

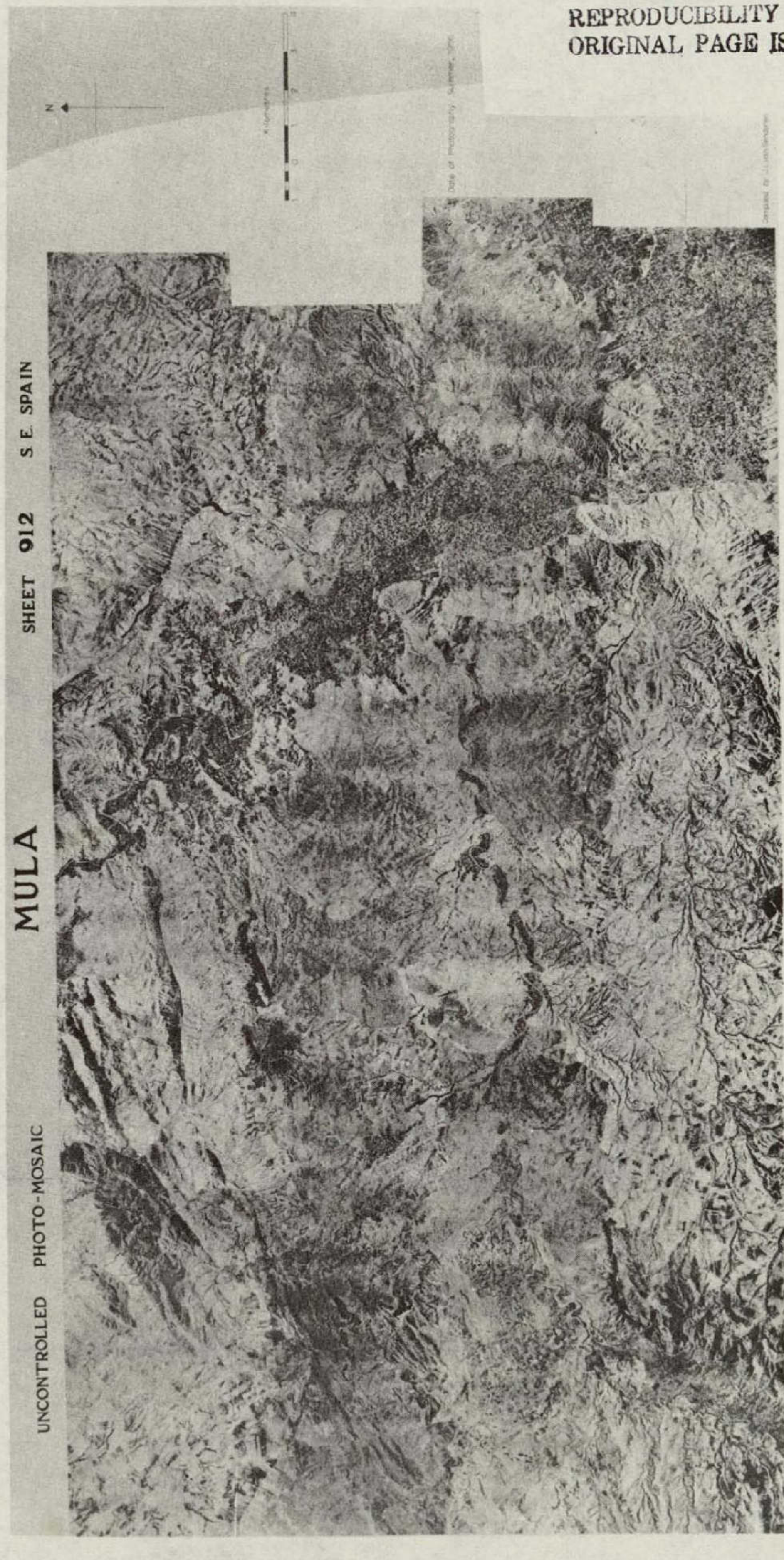


Figure 5.9 Uncontrolled photo-mosaic Mula 1:50,000 topographic sheet (scale approx1:143,000).

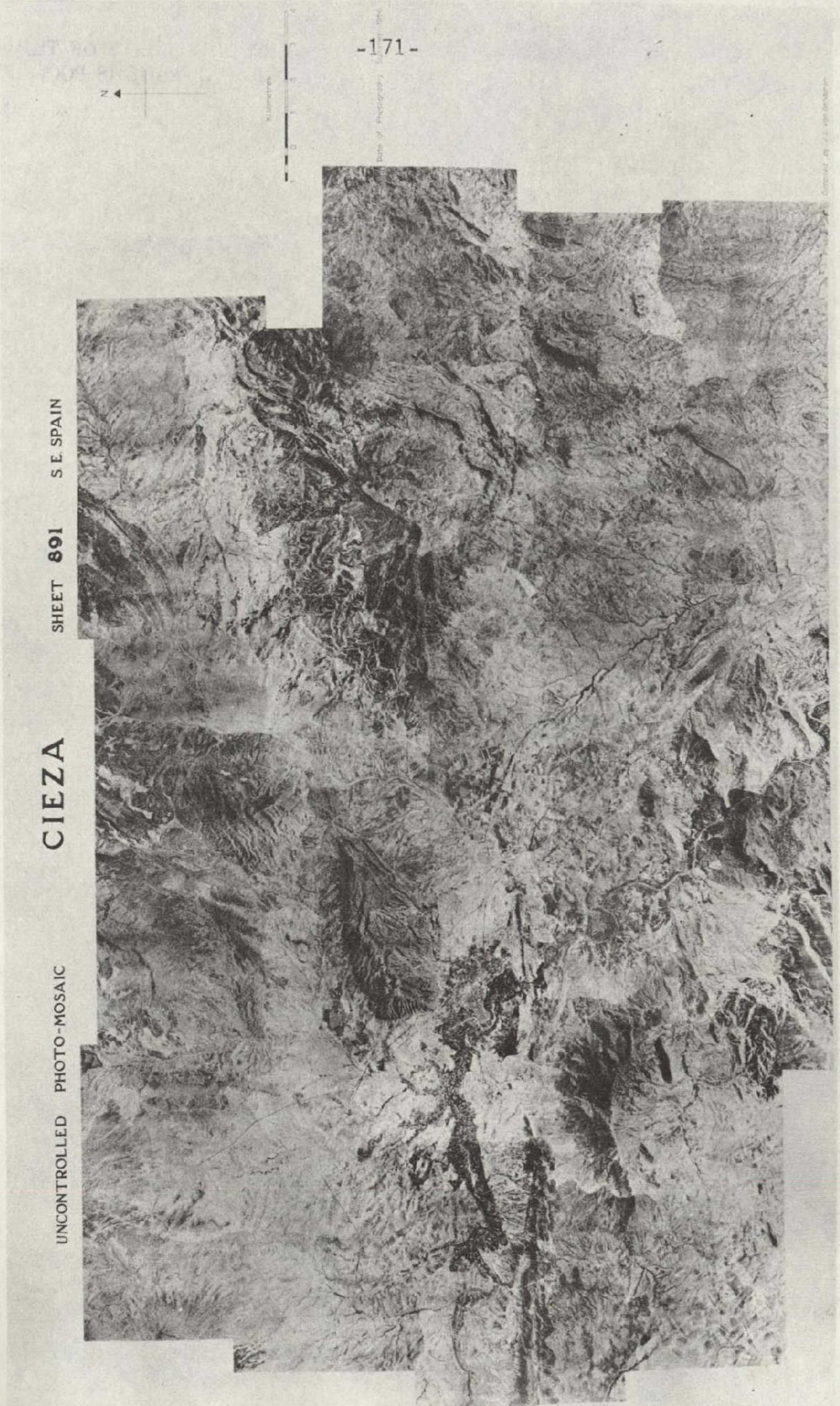


Figure 5.10 Uncontrolled photo-mosaic of Cieza 1:50,000 topographic sheet (scale approx. 1:143,000).

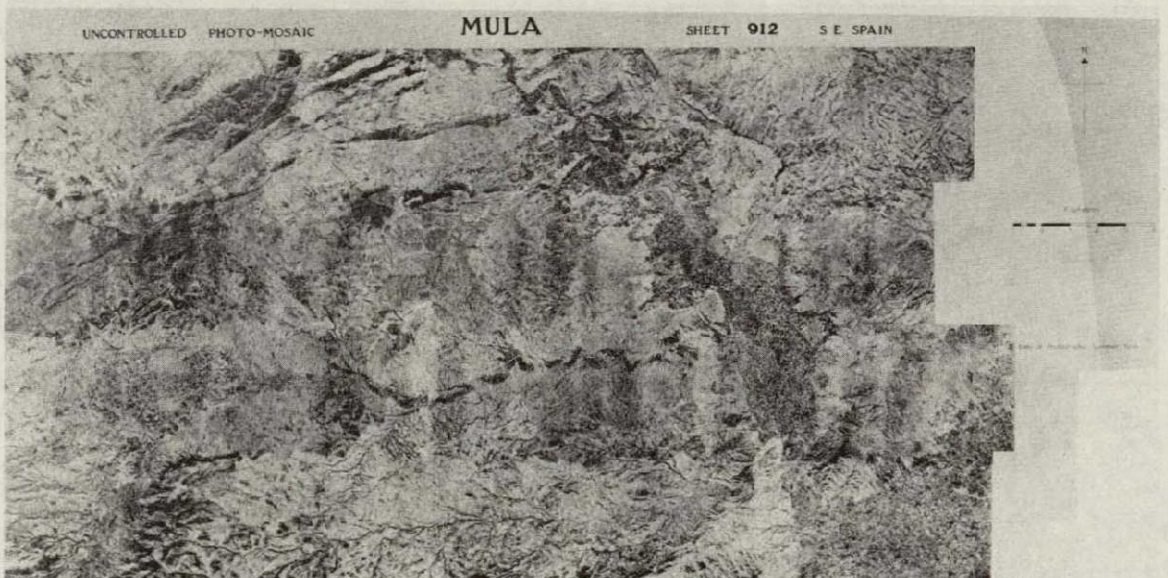
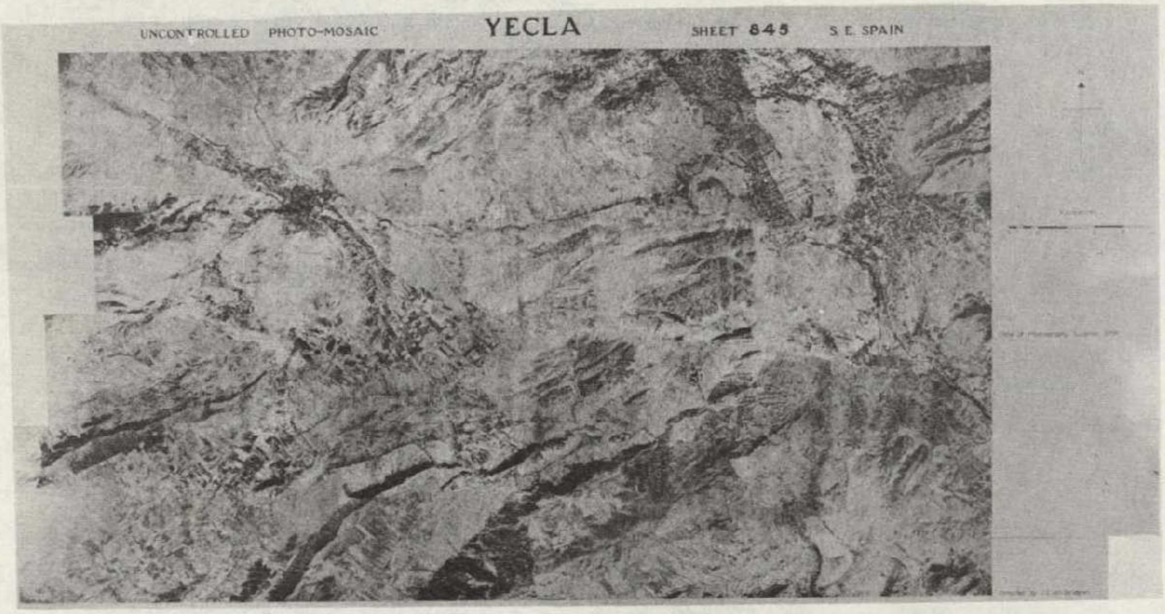


Figure 5.11 Uncontrolled photo-mosaics of Cieza and Mula 1:50,000 topographic sheets(scale approx.1:250,000).



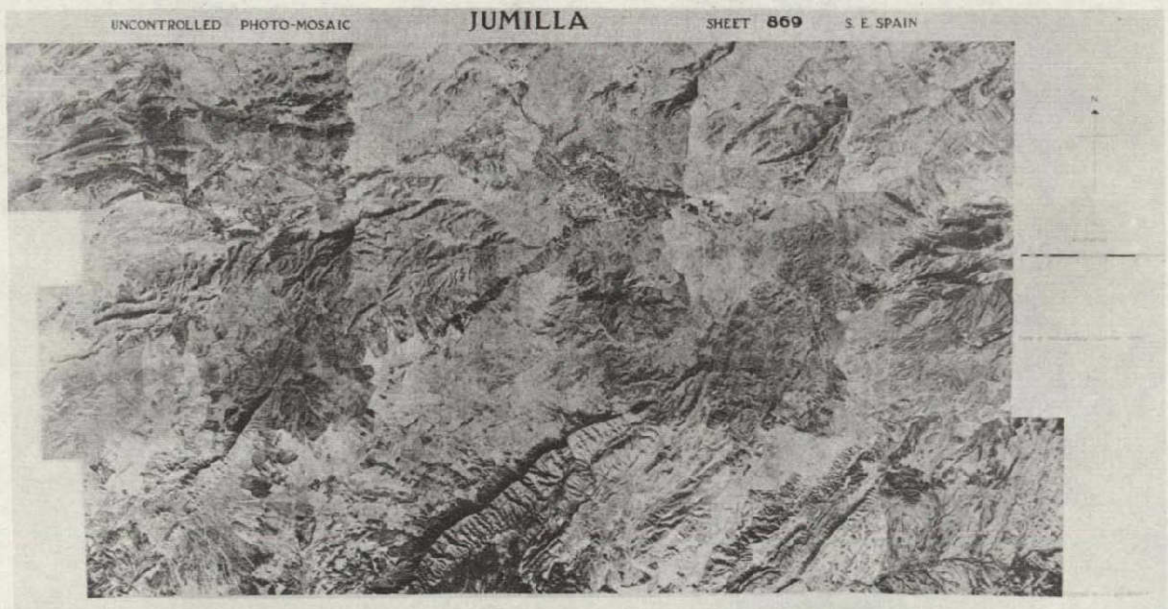


Figure 5.11 Uncontrolled photo-mosaics of Cieza and Mula 1:50,000 topographic sheets(scale approx.1:250,000).

With each combination an attempt was made to assess the relative importance of the accepted elements of image interpretation, i.e. size, shape, shadow, tone, texture, patterns and site (see Section 4.3.2). It was found that the image interpretation elements that aided identification were tone, texture, site and pattern. In addition, the effects of photographic enlargement on the resolution of the imagery were compared with that obtained by visual optical enlargement produced by the monocular magnifiers. For example, a black and white paper print-enlargement of band 5 enlarged to 1:250,000 was compared with a 1:1,000,000 paper print or transparency of the same band but enlarged by means of a 4x monocular magnifier. The sharpest definition was obtained by using the monocular magnifier and the 1:1,000,000 transparencies using rear illumination from a light table.

Detailed subjective assessment of the standard colour composite transparencies and opaque prints (see Photograph 5.7) at a scale of 1:1,000,000 through different levels of monocular magnification, also indicated that light transmitted through the transparencies provided better image definition than when reflected from opaque prints. When the 1:250,000 standard opaque prints of the colour composites were examined it was discovered that there was a marked decline in image resolution and colour contrast when they were compared with the 1:1,000,000 transparencies and opaque prints. In addition, there were more distinct differences in colour between adjacent frames of the 1:250,000 colour composite print.

Diazo colour composite transparencies produced at a scale of 1:1,000,000 (see Section 4.2.2.2 and Appendix VIII)

Photograph 5.7 Reproduction of the standard colour composite of LANDSAT MSS frame, 17 Nov., 1972. (scale approx. 1:2,000,000).
Note : The quality of this reproduction is poor when compared with the standard colour composite transparency.

were compared with the standard colour composite transparencies of the scale and were found to compare very favourably in all aspects of interpretation. The assessment verified the claims that diazo colour composites offer very good alternatives to the more expensive colour composites available from EROS Data Center. (see Section 3.2.3). The cost differential becomes much more pronounced if it happens to be the first colour composite produced covering a particular frame as the Data Center charge for the initial generation as well as the cost of the print.

Although the identification of many different types of land use was attempted in the early stages of the investigation it was felt that some restrictions should be placed on the level and type of identification that was to be attempted. The extent to which the interpretation should be attempted should remain within the limitations imposed by the purpose of the map and the resolution of the imagery. It is apparent that some investigators have been too ambitious in their interpretations and have tried to identify objects in too much detail leading unbalanced or " ad hoc" classification systems (see Section 4.4). This may have been due to the interpreter's application of the "inductive" type of approach adopted in some land use studies based on air photo-interpretation. In this method as many objects as possible are identified and then grouped together to form a classification system. However, this approach is very time-consuming and often leads to the production of classification systems which cannot be satisfactorily compared with others produced in adjacent regions. Also, the interpreter may be particularly knowledgeable about certain aspects of the region and may tend to over-emphasise these in his classification system. This leads to difficulties if other interpreters become involved in the mapping at a later stage (see Section 4.4). Also, although it is possible to identify certain minor land use types in some cases, they should not be included as a separate category in a classification system, as there is no guarantee that all patches of such a land use type can and will be identified and mapped. This means that it is imperative to have land use categories which can be consistently and reliably identified and mapped at the 85-90% accuracy level. Consequently, in order to co-ordinate the assessment of objects on the imagery in this study, some initial guidelines were provided by a tentative classification system which was devised (see Section 5.3.3). Identification of specific types of crops or trees was not attempted as this was outside the scope of the mapping objectives and often beyond the resolution capabilities of the imagery. Instead, identification of some of the relatively broad categories of land use provided in the classification system was undertaken, i.e. forestland, garrigue, dryland agriculture, irrigated agriculture, reservoirs,etc.

The assessment of the imagery and interpretation equipment involved the comparison of spectral responses on each type of imagery with the respective areas of land use which could be easily identified from collateral material. It was found that, with black and white imagery and different levels of magnification, band 5 provided the best imagery for identifying and delineating forestland, dryland and irrigated agriculture.

As mentioned earlier the main image interpretation elements that aided interpretation of this type of land use were tone, texture, site and pattern. Band 4 was nearly as good but bands 6 and 7 were inadequate due to the lack of tonal contrast. (see Figures 5.13, 5.14, 5.15. and Appendix V). The spectral responses recorded on the imagery that corresponded with the known areas of garrigue were approximately the same on all bands. The tonal and textural characteristics of garrigue remained relatively constant and appeared as a smooth, light grey cover which tended to make it difficult to delineate from agricultural land in certain parts of the region. Band 7 proved to be the best band for delineating salt lakes and reservoirs with bands 6, 5 and 4 in declining order of importance. Black and white imagery from different seasons were also compared and it was found that the utilisation of carefully selected multi- date imagery could aid the identification and delineation of the agricultural areas in particular.

In general terms, band 5 proved to be the most versatile of the black and white imagery for this type of study. However, the problem of extrapolating away from known areas became difficult due to the limited tonal range and the similarity of patterns in a number of areas. This was particularly evident when trying to differentiate between dryland agriculture and garrigue and in some areas it was extremely difficult to draw boundaries to separate them (see Figures 5.13, 5.14, 5.15. and Appendix V).* This problem occassionally occurred between forest land and garrigue especially where the spectral responses were influenced by steep slopes. Irrigated land was reasonably easy to identify due to the combination of tone,

*The reproduction of the LANDSAT MSS imagery in these figures and appendices have much poorer image resolution than the original material used in the assessment.

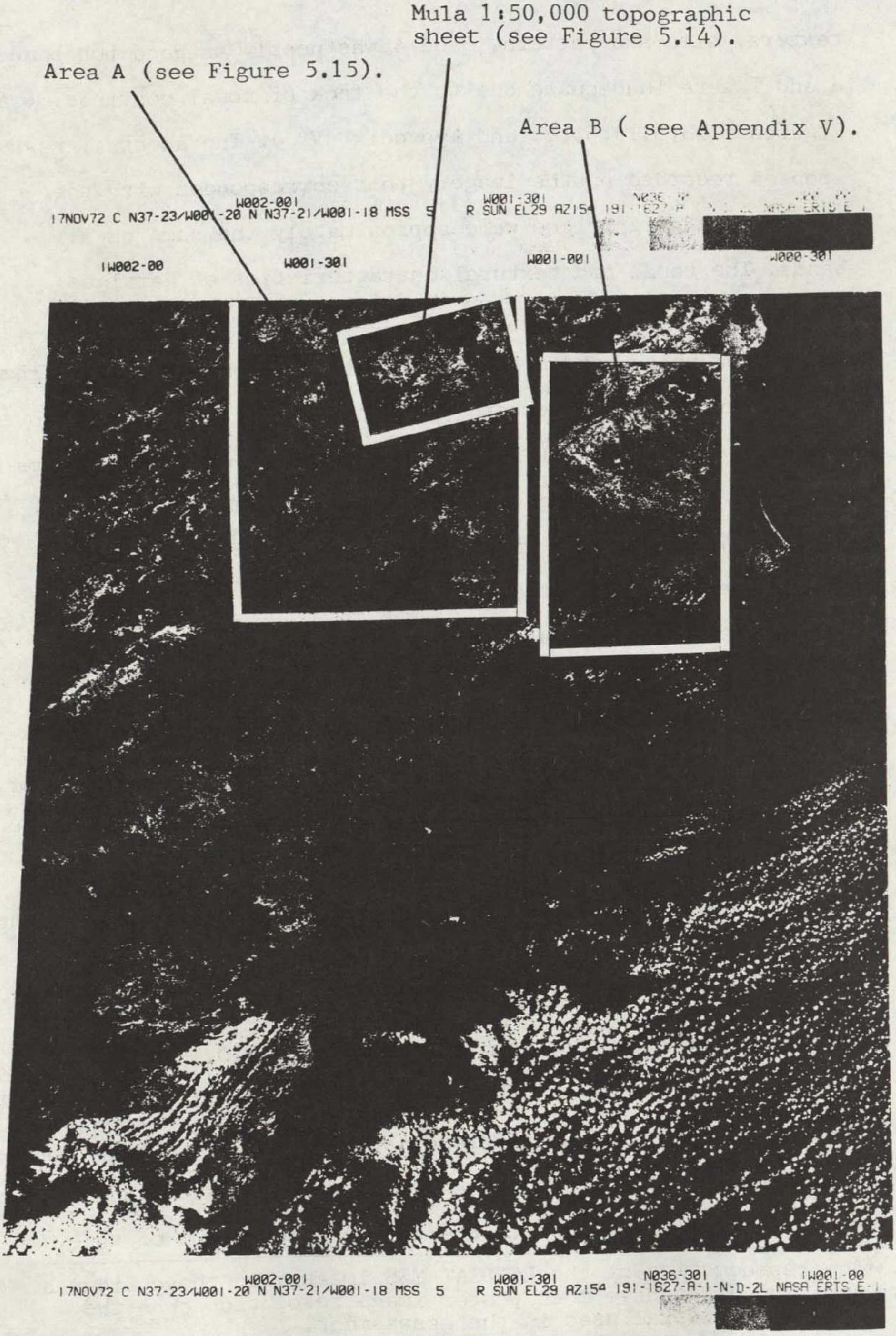
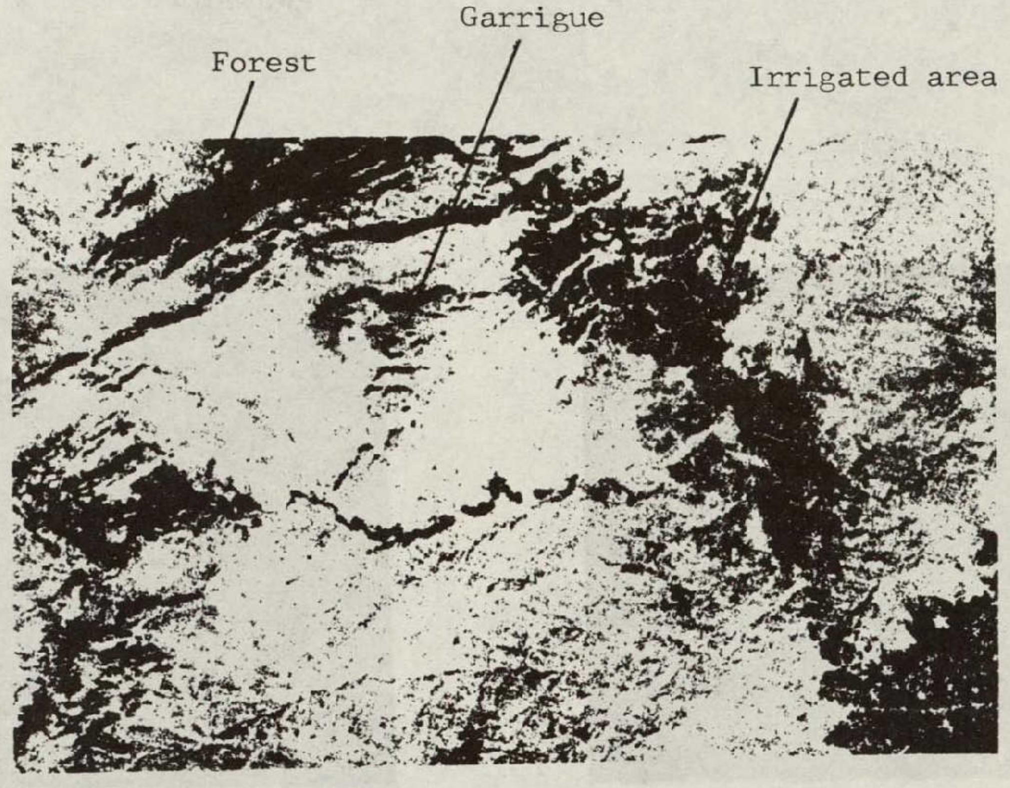
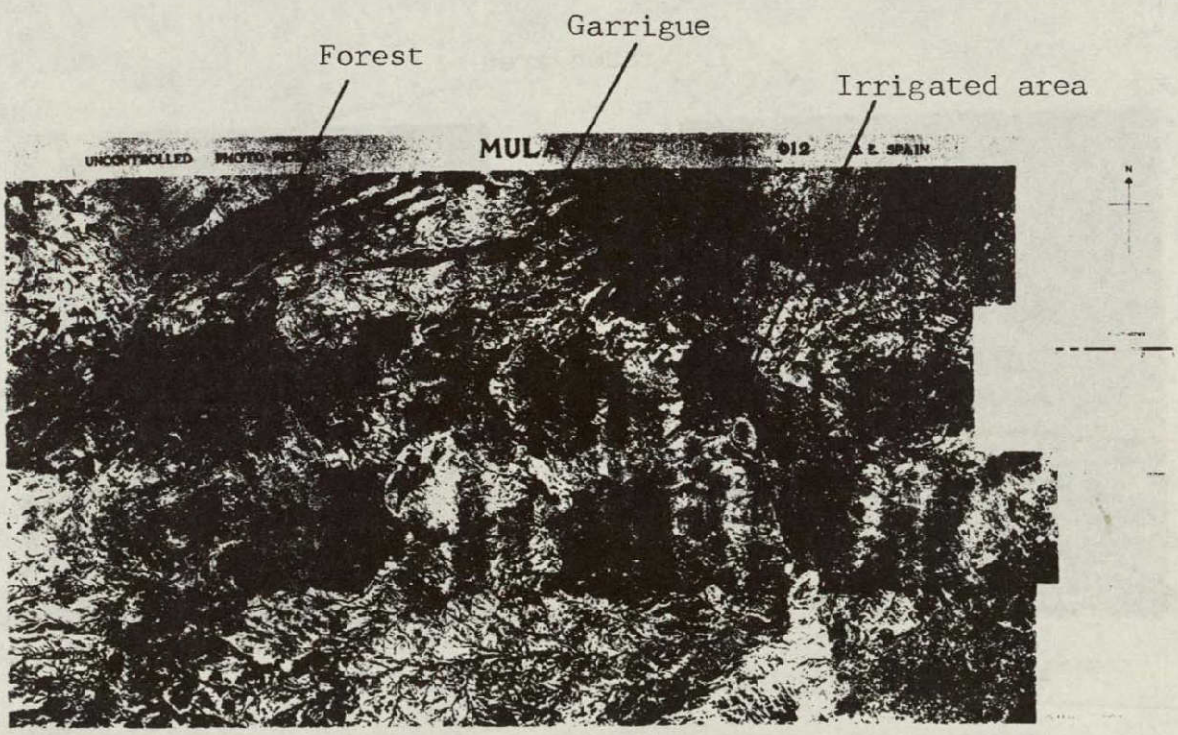


Figure 5.13 Areas of Murcia Province used for comparing the four spectral bands of LANDSAT MSS imagery (see Figures 5.14, 5.15 and Appendix V) Scale approx. 1:1,000,000.



LANDSAT MSS, Band 5, 17 November, 1972 (scale approx. 1:250,000).



Uncontrolled photo-mosaic of Mula 1:50,000 topographic sheet (scale approx. 1:250,000)

Figure 5.14 Comparison of LANDSAT MSS Band 5 and photo-mosaic.

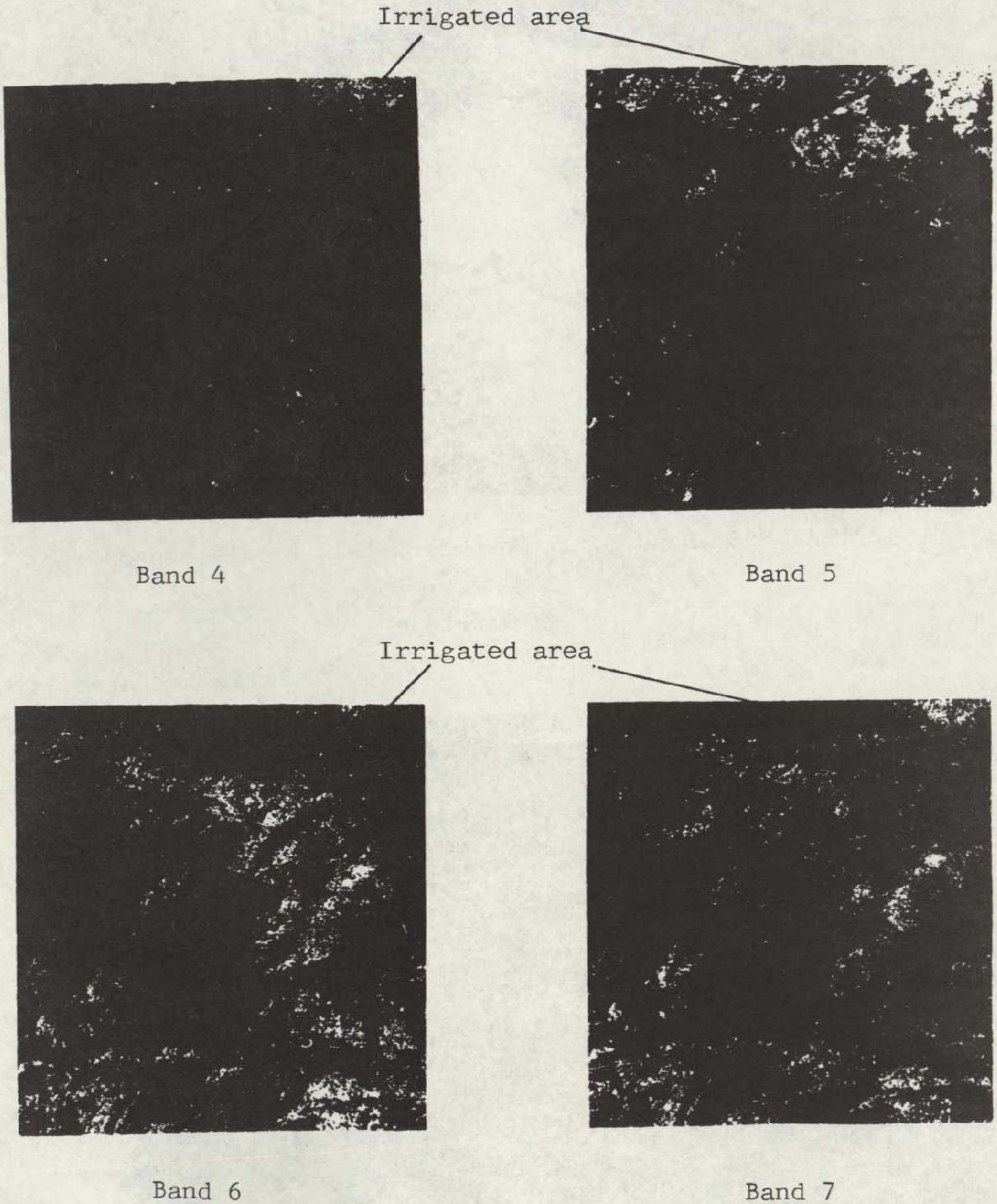


Figure 5.15 Comparison of the different spectral bands of LANDSAT MSS imagery, 17 Nov, 1972. (scale approx. 1:1,000,000). Area A. shown on Figure 5.13.

pattern and site elements but problems did occur in some areas where its dark tonal response was very similar to forest land.

The initial examination of the standard and diazo colour composites immediately showed that a much greater versatility in the interpretation of land use was possible than with any of the forms of black and white imagery. (see Photograph 5.7 and AppendixVII) *. Detection, recognition, delineation and classification became much easier as colour, with the additional characteristics of hue and chroma, allowed a much greater range of tonal contrasts than the 15 grey-scale steps on the black and white imagery. (see Section 4.2.2.2.). Areas of irrigated agriculture were easy to locate due to their characteristic red colour, their patterns and their site along rivers. Forest lands could also be identified quite easily due to their dark brown colour, their peculiar texture and their association with north-facing areas of the steep slopes of the mountain ranges. The separation of garrigue and dryland agricultural areas proved to be much easier than with the black and white imagery as the use of colour tended to increase the contrast between them as well as enhancing textural differences. Salt lakes and reservoirs became more obvious due to their colour contrast with surrounding areas. In all cases, extrapolation of identification away from known areas became much easier when the colour composites were used. The effect of different spectral responses on the imagery caused by seasonal changes in vegetation was most pronounced in irrigated agricult-

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* The reproduction of the LANDSAT MSS imagery in these figures and appendices have much poorer image resolution than the original material used in the assessment.

ural land and this was used to clarify boundaries in some areas.

Other visual enhancement techniques including image mixing, stereoscopy were also assessed. Image mixing using two different black and white bands in the form of transparencies or opaque prints with a stereoscope has been suggested by several researchers as a method of improving the interpretability of LANDSAT MSS imagery (see Section 4.3.4.2). This technique was tested using several different combinations of bands but it did not offer any advantages over the monocular magnification of colour composites and tended to produce effects which caused misinterpretations in some cases. Basically, it is not a suitable method for an operational programme because the increased time required to determine which combination of spectral bands should be utilised for interpreting particular types of land use is much longer than the time required to interpret colour composites. However, this method could be considered as a possible technique in the identification of land use types in difficult areas of the imagery if other methods prove to be unsatisfactory.

The operational use of the effect of stereoscopy was not considered to be feasible as a major interpretation technique in this type of study due to the small amount of side overlap of the frames. No forward overlap could be obtained due to the nature of the imaging system.

Slide projectors (35 mm and 70 mm), microfiche and microfilm readers and overhead projectors were also considered in the assessment but could not be considered as viable alternatives to monocular magnification. Although they proved to be useful in investigating some specific areas within the region, the problems of distortion and difficulties associated with the transference of data to base map eliminated them as adequate interpretation techniques in any operational survey.

After considering the different types of commonly available equipment and easily obtainable imagery, the interpretation techniques adopted for operational use in this study included colour composite transparencies (standard and diazo) at 1:1,000,000 in association with a monocular magnifier (approximately 4x) and a light table. Information was transferred to 1:250,000 colour composite enlargements although paper prints of the black and white enlargements of band 5 at the same scale could be considered as a reasonable alternative mapping base if the colour composite enlargements were unavailable due to cost or other reasons. Alternatively, if no standard colour composites exist for the region then a combination of "in-house" produced diazo colour composites at 1:1,000,000 and standard 1:250,000 enlargements of band 5 could be considered. Other visual enhancement techniques including the use of 70 mm. and 35 mm. slide projectors, microfiche readers and image mixing should only be considered when trying to interpret difficult areas on the imagery.

In order to aid the location of places on the enlarged colour composite, a transparent overlay showing relevant topographic information and the 1:50,000 topographic map boundaries was drawn at a scale of 1:250,000. It also served as a base map for the preliminary land use map and the production of the final land use map.

5.3.3. DEVELOPMENT OF LAND USE CLASSIFICATION SYSTEM

The problems associated with the development of a satisfactory rural land use classification system for use with small scale remote sensor imagery have been discussed, in detail in Section 4.4. Briefly, the evolution of a satisfactory system is mainly controlled by the overall objectives of the land use survey, the quality of the available imagery, the final mapping scale and regional land use characteristics. In addition, other pragmatic aspects of the system must also be considered, especially its ability to be used over a very wide area by a number of different interpreters with imagery acquired at different times of the year.

As mentioned in Section 4.4, general guidelines for the establishment of the classification scheme for use in the preparation of the rural land use map of Murcia Province have been provided in U.S. Geological Survey Circular 671. These guidelines include the need for the initial establishment of a basic set of criteria which the classification should meet. For the purpose of this study most of the criteria presented in Circular 671 were considered relevant and are presented below in slightly amended form:

1) the minimum level of accuracy in the interpretation of imagery should be about 85%. The accuracy of interpretation depends to a large extent upon the capabilities of the size of sample used to determine the accuracy level of the interpretation. This latter aspect has generally been neglected by researchers (see Section 4.5.2.2.).

2) the accuracy of interpretation for the different categories should be approximately the same level.
3) similar levels of accuracy should be obtained by different interpreters with imagery acquired at different times through the year.
4) the scheme should be useable over large areas.
5) the categorisation should permit vegetation and other types of land cover to be used as surrogates for activity.
6) the categories should be capable of further sub-categorisation so that information from other sources including larger scale imagery can be incorporated.
7) categories must be capable of collapsing into the next broader level.
8) the system should permit the comparison of land use information that has been compiled in the past or may be collected in the future.

On the basis of these criteria and the classification system outlined in Circular 671 as well as information obtained from collateral material , a preliminary classification scheme was devised for Murcia Province. The major aim of this initial scheme was to provide a framework which was as broad as possible and would cover all the possible types of land use within the Province that could be mapped within the limitations imposed by the prescribed criteria, the imagery and the mapping constraints. At this stage, the classification system was not intended to be final but was designed so that it contained all possible categories which might be encountered in the interpretation process.

The hierachical nature of the U.S.G.S. Circular 671 system with various levels of classification for use with different types of imagery was accepted as an appropriate organisational structure that would satisfy the adopted criteria. Hence, the only Level 1 categories that were relevant in Murcia Province were Urban and Built-up Land, Agricultural Land, Forestland, Rangeland, Water and Barren Land and all their subcategories at Level 2 were then closely examined with regard to their applicability within the Province (see Tables 3.1 and 3.2).

A large number of factors controlled the inclusion of Level 2 sub-categories within the land use classification system for Murcia Province. Possibly the most limiting aspect concerned the minimum size of each category or sub-category that can be effectively shown on the published map. Various researchers have suggested that the minimum size should be 2.5 hectares (approximately 6 acres) which can be represented by a square of 2 mm. by 2 mm. on a map produced at a scale of 1:250,000 (see Section 4.5.2.4.) Consequently, the sub-categories have been designed with this areal control in mind.

Another problem in the selection and description of subcategories was caused by the use of different names for the same types of vegetal cover. For example, the terms "matorral" and "garrigue" have been used interchangeably to describe similar types of vegetation by various authors. This aspect has been discussed in detail in Section 5.2 where garrigue was accepted as the common term for most of this type of vegetation within the Province. However, an allowance was made for the possibility of matorral being found during the field check by including it as a sub-category at Level 2.

Also, in many of the irrigated areas near the larger towns, intensive inter-cropping is practised with a wide variety of crops in small fields and this complexity of vegetal cover was initially included as the category of "Orchards, Groves, Vineyards, Horticulture". The underlying assumption during interpretation was that this category applied to permanently irrigated areas, i.e. the category was synonymous with the Spanish term "regadio".

A similar difficulty occurred when attempting to define an adequate title for a sub-category that would describe the vegetal cover of the very extensive areas of dryland agriculture in the Province. These areas have been predominantly devoted to cereal production but certain scattered areas of un-irrigated orchards and a large area of vineyards in the North of the Province. The sub-category of "cropland and pasture" was adopted initially with the knowledge that it could possibly be changed. The most appropriate alternative description was the Spanish term "secano" which has been used in a variety of forms.

Further sub-division was provided by Levels 3 and 4 which were added to the classification system and consisted of sub-categories which permitted the more accurate field identification of land use features that could not be identified on the LANDSAT MSS imagery. This information served several purposes including the provision of more detailed information that could assist in devising the most suitable descriptions for the various mappable land use categories. In addition, the information gained at these levels could provide information that could assist in determining reasons for mis-interpretation. This latter aspect has been considered in more detail in Section 4.4.

Finally, each category and sub-category was numbered so that a "short-hand" description of the land use type could be used during image interpretation (see Appendix III).

5.3.4. PRODUCTION OF PRELIMINARY MAP.

The interpretation of the rural land use of Murcia Province was mainly undertaken using 1:1,000,000 colour composite transparencies (standard and diazo) and 1:250,000 standard opaque enlargements of the appropriate LANDSAT 1 frames with the assistance of a 4x monocular magnifier. A series of extrapolations were carried out from known areas using a variety of techniques including the use of transparent overlays of the 1:250,000 vegetation and topographic base maps, generalised 1:50,000 topographic maps and mosaics. Colour was used as the main interpretation element in the detection, recognition and delineation of the various homogeneous regions which were categorised using the previously devised classification system. Other interpretation elements were utilised in varying degrees depending on the type of land use being identified. The extent to which these are applicable to various land use categories has been discussed in Section 5.3.2.

The area of the smallest, mappable area was taken as being 25 hectares (approximately 62 acres) which represents a square 500 m. by 500 m. on the ground or 2 mm. by 2 mm. on the map. In practical terms, however, there were a number of areas which were greater than 25 hectares in area but were very elongated in one direction and very narrow in cross-section. This occasionally occurred with thin strips of irrigated orchards along river valleys in areas that were pre-dominantly devoted to non-irrigated cereals. In these cases, the problem involved a decision about whether to include the area and over-exaggerate its width or to omit it. At a scale of 1:250,000 a boundary line of 0.3 mm. represents 75 metres on the ground i.e. approximately one pixel wide. Therefore, if two boundary lines and some reasonable width was given to the land use strip on the map then it could be in the order of 1-2 mm. wide which would represent 250-500 metres on the ground which is often considerably wider than the ground width. Consequently, strips of land use needed to be 250 metres or wider in order to be included in the map at their true width. In some cases, especially irrigated areas, some patches smaller than 25 hectares were identified very easily due to their characteristic colour and were included on the map.

Boundaries and appropriate classification numbers were drawn on the 1:250,000 opaque colour composite prints after identification on the 1:1,000,000 colour transparencies viewed through the monocular magnifier. The problem of locating the relevant position being investigated on both sets of imagery was overcome by using transparent overlays with graticules representing the 1:50,000 topographic maps. This system was also used in a checking procedure to ensure that the mappable land use in all areas had been delineated, identified and classified. In several areas where boundaries were difficult to define collateral material was consulted and, if it still could not be delineated it was left as a broken line so that more positive identification could be carried out in the field.

Thus, the major difficulties included the differentiation of several categories in certain areas e.g. garrigue and secano, forest and garrigue, and the decision about which small patches of land use should be included on the map. These problems were extended further in certain areas due to the inconsistency in colour and definition between the various opaque enlargements of the various frames used in the interpretation.

The preliminary land use map was prepared by tracing the boundaries and classifications onto a specially prepared 1:250,000 base map. This base map contained most of the topographic information that would provide an adequate background for the land use categories as well as providing a satisfactory data base when field checking the interpretations. Then, the preliminary map was coloured in order to differentiate the land use regions and to give a clearer indication of the areal distribution of the various types of land use. The colours selected for the various categories were similar to those suggested by Paludin (1973) for use with LANDSAT MSS imagery. It also served as a check to determine whether boundaries or classifications had been omitted. Another check was carried out using transparent overlays of the vegetation and soils maps of the Province.

TABLE 5.2. Colours suggested by Paludin (1973) for use with U.S.G.S. Circular 671 Land Use Classification System. (from Peterson, 1975)

Level 1

01	Urban and Built-up Land	-	Colour Red
02	Agricultural Land	-	Light Brown
03	Rangeland	-	Orange
04	Forestland	-	Green
05	Water	-	Light Blue
06	Nonforested Wetland	-	Dark Blue
07	Barrenland	-	Yellow
08	Tundra	-	Grey
09	Permanent Snow and Icefields		White

5.3.5. ESTABLISHMENT OF GROUND TRUTH

5.3.5.1. GENERAL

The difficulties associated with the establishment of a satisfactory ground truth procedure in which the results of the interpretation can be checked in the field have been discussed in Section 4.5. Essentially, the problems can be resolved into the main areas of sampling design, ground data collection, field survey procedure, and analysis of data.

5.3.5.2. SAMPLING DESIGN

The sampling design developed for use in this investigation involved the use of a stratified random sampling strategy in which the land use categories were adopted as the basic method of stratification. Then the pre-determined sample prints were randomly distributed within each stratum (see Section 4.5.2.2.). This was achieved by placing a large sheet of millimetre graph paper under the base map and using a random number table to generate the co-ordinates of the sample sites. By using the millimetre divisions, the graph paper provided approximately 30,000 possible sample sites representing the centres of squares with 250 metre sides. The graph paper was positioned so that the grid references of sites could eventually be transferred to the co-ordinate system used on the 1:50,000 and 1:200,000 topographic maps of the Province by means of corresponding known points. This was carried out so that the selected sample points could be accurately located in the field using the published 1:50,000 or 1:200,000 topographic maps.

The number of sites for each category was determined by considering the interpretation accuracy level prescribed in the criteria for adopting the classification system, viz 85%

and then consulting Tables 4.10 and 4.11. It was decided that the minimum number of sample sites for each main category should be at least forty. This would permit an interpretation error level of two (see Table 4.11) and allow for the possible exclusion of several sites due to difficulties in reaching them or possible mis-plotting. In addition, the first hundred sample points were maintained in order to obtain an approximate indication of the distribution of the categories and for the consideration of possible trends when the field work was completed. When these points had been recorded, categories which had reached the limit of forty were ignored. Although this method removed much of the subjectivity involved in the allocation of sample sites to each category, it did entail the generation of a large number of co-ordinates which had to be plotted in order to determine the categories in which they fell (see Appendix VI). After plotting 300 points, one category, viz 3.1. (forestland) still had not received the nominal 40 sample sites (see Table 5.3). In fact, only 15 sites had been generated for this category and to avoid continuing the sampling process for a long period it was resolved that this number of points would be accepted on the understanding that the probability of making incorrect interpretations at the 85% accuracy level would be high. (see Table 4.11). Alternatively, the specified interpretation accuracy level for this category could be reduced. An indication of the level to which the specified interpretation accuracy level should be reduced can be obtained by considering Table 4.10. For example, if a sample size of 15 is used then the interpretation accuracy level should be 80% with no errors to be within the normally accepted 5% probability level.

In the next step, all selected sample sites were plotted onto available 1:50,000 or 1:200,000 topographic map sheets ready for field work.

5.3.5.3. <u>GROUND DATA COLLECTION</u>

In order to verify the accuracy level of the interpretation of the LANDSAT MSS imagery and to identify possible reasons for misinterpretation, the selection of appropriate ground data was considered an essential stage in the production of the land use map. The necessary information had to be in a form that could be collected rapidly and did not involve complicated and time-consuming techniques. Consequently, a ground data collection sheet was designed so that as much relevant information as possible could be collected rapidly at each site in a manner that would facilitate subsequent data analysis.

The ground data collection sheets were divided into the four hierachical levels outlined in U.S.G.S. Circular 671. Details about the first two levels i.e. levels 1 and 2, which were designed for use with imagery obtained from satellites or high altitude air craft, have been discussed in the previous section (Section 5.3.5.1). But, basically, their roles on the sheets were to record the identification of the broad-scale land use at a site. The other two levels, i.e. Levels 3 and 4, permitted the identification and recording of land use characteristics that would normally be obtained by large scale aerial photography or field surveys. (see AppendixIII).

As stated previously, the aim of this initial classification system was to provide as many different categories as possible at each level, and this aspect has been reflected in the ground data collection sheets. This is particularly evident at Level 4 where many specific types of vegetation were listed so that the recording of the vegetation and its areal distribution at a site could be recorded quickly. All categories and sub-categories were numbered so that a brief numerical coding system could be used to identify the type of land use at a particular point, if required.

Details about other factors that could influence the spectral nature of the imagery were also collected on the data collection sheet. These factors included the amount of slope, the slope form, height and spatial distribution of the plants as well as surface colour and roughness. Also, as the imagery had been recorded at different times of the year to the fieldwork phase provision was made for comments about other aspects that could influence the land use at a particular site. Ground level photographs were taken at many sites, especially those located in positions near the boundaries of categories which caused interpretation difficulties.

Provision was also made for the adequate identification of each site by including site number, site random number, site co-ordinate, topographic map sheet name and number, and date of visit. (see Appendix III).

5.3.5.4. FIELD PROCEDURE

The ground data collection was carried out in Murcia Province during a four week period in late March and early April. It involved the development of an overall systematic plan so that all the selected sites could be visited and doubtful areas checked within a minimum time period.

In order to reduce excessive travelling each day, the Province was divided into a number of regions each surrounding a large town or city which served as a base for several days until all sites in the surrounding areas were visited. Daily routes were planned so that views from selected vantage points could provide additional checks on the interpretation. Other checks of boundaries and classification were made whilst travelling from one site to the next. Any queries were noted on the preliminary map for later verification.

Details of the land use within a 250 metre square in which the actual plotted position of the site was considered to be the centre were noted on a data collection sheet. The reasons for the selection of a 250 metre square as the appropriate size of a sample site have been discussed in Section 4.5.2.4. The identification of the land use classification allocated to the site was accepted as being correct if more than 50% of the site was covered by that type of land use. However, if uncertainty existed over the classification or, if it was incorrect then detailed notes and photographs of the site and surrounding area were taken for further consideration during the analysis of results and the production of the final map.

Several sites could not be reached due to bad weather conditions, bad tracks and a prohibited military area (see Table 5.4.). However, problems of this nature had been anticipated in the original selection of the sample size. Several sites with difficult access were accurately located and identified from a distance.

Table 5.3: Number of sites selected using random tables

1	2.1	2.2	3.1	4.2	5.1	5.2	6.1
2	50	40	15	42	1	-	-

Total 150

Table 5.4: Sites excluded from sample

Site number	Interpreted Classification	Reason for exclusion
85	2.1	Prohibited property could not gain view of site
113	3.1	Site could not be reached due to torrential rainful. Tracks impassable for several days
254	3.1	Site difficult to reach. Remote area-very sandy roads-car bogged
268	4.2	Point misplotted-could not re-locate

5.3.5.5. CONSIDERATION OF RESULTS

The ground data collection sheets were examined and several sites were excluded from the sample due to inaccessibility or misplotting (see Table 5.4). Then the sheets for the sites which were in-correctly interpreted were also examined and comments about possible reasons for mis-interpretation were listed (see Table 5.5). On-site photographs were used as additional data sources for isolating reasons for the incorrect interpretations. The predominant reason for mis-classification was that the sites were situated in a small area of a particular category which was located in a much larger area of another category. In these cases the size of the small patch was not large enough to meet the smallest mappable area requirements. One site was located in an area which was affected by very small patches of cloud and their shadows which produced unusual image responses on a small portion of one frame and made interpretation difficult.

Using the conventional technique of considering the number of correctly identified sites as a percentage of the total number of sites interpreted as a guide to the accuracy level of interpretation, then all major categories were interpreted at greater than 95% accuracy (see Table 5.6). However, this technique for establishing the interpretation accuracy level of surveys using remote sensor data and random sampling has not been accepted as a valid method in this study. Detailed reasons for its rejection and a description of the technique used in this study have been presented in Section 4.5.2.2 and the results of the ground truth survey will be discussed in the context of the new sampling procedure.

TABLE 5.5 Sample sites incorrectly interpreted

Site number	1:50,000 map sheet	Interpreted classification	Field identifcation	Comments
8	CEHEGIN	4.2	2.1	Site located in one of several comparatively small 2.1 areas located within a large area of 4.2
47	MAZARRON	2.1	4.2	Area around site covered by patches of cloud and shadow making identification difficult
49	CIEZA	2.1	2.1	Site located in a large area of 2.1,Other patches of 2.2 and 4.2 in area but too small to be mapped
75	CARAVACA	4.2	3.1	Site located in large area of 4.2. Comparatively small patches of 3.1 in area. Also, pines thinly spaced and, therefore, easily misinterpreted as 4.2
138	ALCANTARILLA	4.2	3.1	Patch of 3.1 too small to map. In a large area of 4.2

TABLE 5.6. Summary of results

Land use classification	1	2.1	2.2	3.1	4.2	5.1	5.2	6.1
Initial sample size	2	50	40	15	42	1	-	-
Sites excluded	-	1	-	2	1	-	-	-
Number of sites investigated	2	49	40	13	41	1	-	-
Incorrect interpretations	-	2	-	-	3	-	-	-
Interpretation accuracy expressed as a percentage	100	96	100	100	95	100	-	-

As no errors were made in the identification of the 2.2 category i.e. orchards, groves, vineyards and horticulture, the interpretation accuracy level of 85% could be accepted at the 5% probability level (see Tables 5.5, 5.6). Also, it can be seen that the number of incorrect interpretations made in categories 2.1 and 4.2 were 2 and 3 respectively. If these errors are considered in association with the prescribed interpretation accuracy level, i.e. 85%, then category 2.1 (cropland and pasture) with 49 sites investigated and 2 interpretation errors is well below the 5% probalility level (Tables 4.10, 4.11).

The 4.2 category (garrigue) with 41 sample sites and 3 interpretation errors is above the 5% probability level (approximately 8%). However, if the interpretation error caused by the shadow (Table 5.5) then the 85% interpretation accuracy level of the 4.2 category could be accepted at the 5% probability level.

Although no interpretation errors were found in the 3.1 category (forestland), the number of sample sites i.e. 13 was comparatively low and consequently, the probability of making incorrect interpretations was relatively high at the prescribed 85% interpretation accuracy level (i.e. over 10%). Therefore the accuracy of the interpretation of the forestland could not be treated with the same confidence as the other categories. However, if the required interpretation accuracy level was reduced to 80% then the results could be accepted at the 5% probability level.

In summary, three out of the four categories that were field tested by the sampling strategy i.e. 2.1, 2.2 and 4.2

Table 5.7 MATRIX SHOWING NUMBERS OF SITES IN ACTUAL AND INTERPRETED LAND USE CATEGORIES

LAND USE (on the ground)

LAND USE (Interpreted from imagery)	2.1	2.2	3.1	4.2	Sum
2.1	47	1	-	1	49
2.2	-	40	-	-	40
3.1	-	-	13	-	13
4.2	1	-	2	38	41
Sum	48	41	15	39	143

could be accepted at or near the 5% probability level using the pre-scribed 85% accuracy level. However. due to the combination of the small sample size and the pre-scribed 85% interpretation accuracy level, the 3.1 category could not be accepted at the 5% probability level even though no interpretation errors were recorded. Consequently, the results can be considered in two ways. Either the categories could be considered separately and, in this case, three of the four categories meet the accepted interpretation accuracy level at the 5% probability level and that the interpretation accuracy of the forest lands should not be treated with the same confidence. Alternatively, all categories could be accepted at the 5% probability level if the prescribed interpretation accuracy level was reduced to 80%. The first alternative was accepted for this study.

Finally, the low number and distribution of interpretation errors obtained in this study did not provide enough data to permit a valid statistical consideration of the types of interpretation problems outlined in Section 4.5.2.2.

5.3.6 FINAL MAP

Once the accuracy level, of the interpretation had been verified and the land use classification had been accepted in general terms, the completion of the final map commenced. The first stage involved the checking of comments noted during the traversing as well as additional remarks obtained at sample sites. Some minor changes were made after reviewing the imagery.

Then, modification of the classification system was undertaken and the initial broad scope used in the data collection sheets was reduced so that only categories of mappable size were included. The land use classification system adopted on the final map consisted of six Level 1 categories, viz. Urban and Built-up Land, Agricultural Land, Forestland, Rangeland, Water and Barren Land. Of these, only three had more than one Level 2 categories (see Appendix VII).

Urban and Built-up Land, originally designated "Developed" was sub-divided into 'Cities, Towns' and 'Tourist Development'. The latter category was designed to distinguish the recent and rapid development at La Manga Mar Menor from the other built-up areas in the Province. The 'Agricultural' category was initially divided into three sub-categories in the preliminary system and followed the U.S.G.S. Circular 671 system by using 'Cropland and Pasture' and Orchards, Groves, Vineyards and Horticulture'. The other sub-category designated 'other' was included to permit the recording of other types of agricultural land use if they existed in mappable dimensions. In the final classification, the Spanish word 'secano' was adopted as the most appropriate term to describe the vegetation cover of those areas of the Province that are predominantly devoted to non-irrigated agriculture. The crops are mainly cereals with scattered areas of olives and almonds as well as a large area of vineyards in the north. In addition, the Spanish word 'regadio' was used instead of 'Orchards, Groves, Vineyards, Horticulture' to describe the vegetation cover of the crops that are grown in areas served by permanent irrigation systems. The crops are predominantly fruit trees and vegetables and, in some areas, cereals. The 'Water' category also followed the U.S.G.S. Circular 671 sub-categorisation and incorporated the use of 'Lakes' and 'Reservoir' at Level 2.

This structure was maintained in the final classification.

In the 'Rangeland' category the only sub-category that was represented in mappable dimensions was 'garrigue' shorter, Meditteranean type scrub community (c.f. maquis). Also, within the 'Forestland' category only one sub-category was mapped at Level 2, viz. evergreen forests which predominantly consisted of several species of Pinus and, consequently 'coniferous' was adopted as the most appropriate descriptive term. Finally, the term 'Salt Flats' was accepted as the only sub-category of 'Barren Land' that existed in mappable size within the Province.

The numerical coding of all the accepted categories was then finalised and it was essentially based on the hierachical structure of the U.S.G.S. Circular 671 (see Appendix VII).

The colour scheme for use with LANDSAT MSS imagery that was suggested by Paluden (1973) and reported by Peterson (1975) was used as a guide for the selection of colours for the categories and sub-categories portrayed on the final map. (see Table 5.2). Finally, the normally accepted symbols for additional locational features e.g. roads, railways, rivers were added to the map and the other normal cartographic procedures including overall layout design were completed (see Appendix VII).

6. DETAILED METHODOLOGY FOR THE PRODUCTION OF SMALL SCALE LAND USE MAPS FROM LANDSAT MSS IMAGERY

6.1. INTRODUCTION

The major aim of this investigation has been to develop a viable methodology that may be adopted by researchers or organisations wishing to utilise LANDSAT MSS imagery to produce small scale rural land use maps. As mentioned previously, one of the main problems confronting the researcher in this type of study is the very wide range of articles dealing with various aspects of the application of LANDSAT MSS imagery in land use mapping. However, most authors have tended to concentrate on certain specific aspects rather than presenting descriptions of all stages involved in the production of the maps. Consequently, this methodology has been devised after reviewing and evaluating relatively in-expensive and unsophisticated pre-processing, interpretation, classification and ground truth methods in the operational production of a rural land use map of Murcia Province, South East Spain.

The methodology has been divided into two stages, viz. pre-operational and operational. Basically, the pre-operational stage involves the careful selection of the appropriate interpretation techniques and imagery that may be used in the operational stage where the actual land use map is produced. All aspects of both stages are considered to be particularly relevant and to achieve optimum results in the final map, adequate attention must be paid to the planning, selection and preparation of imagery and techniques before the interpretation process commences.

In order to assist the detailed explanation of the proposed methodology, a diagrammetric representation of the whole

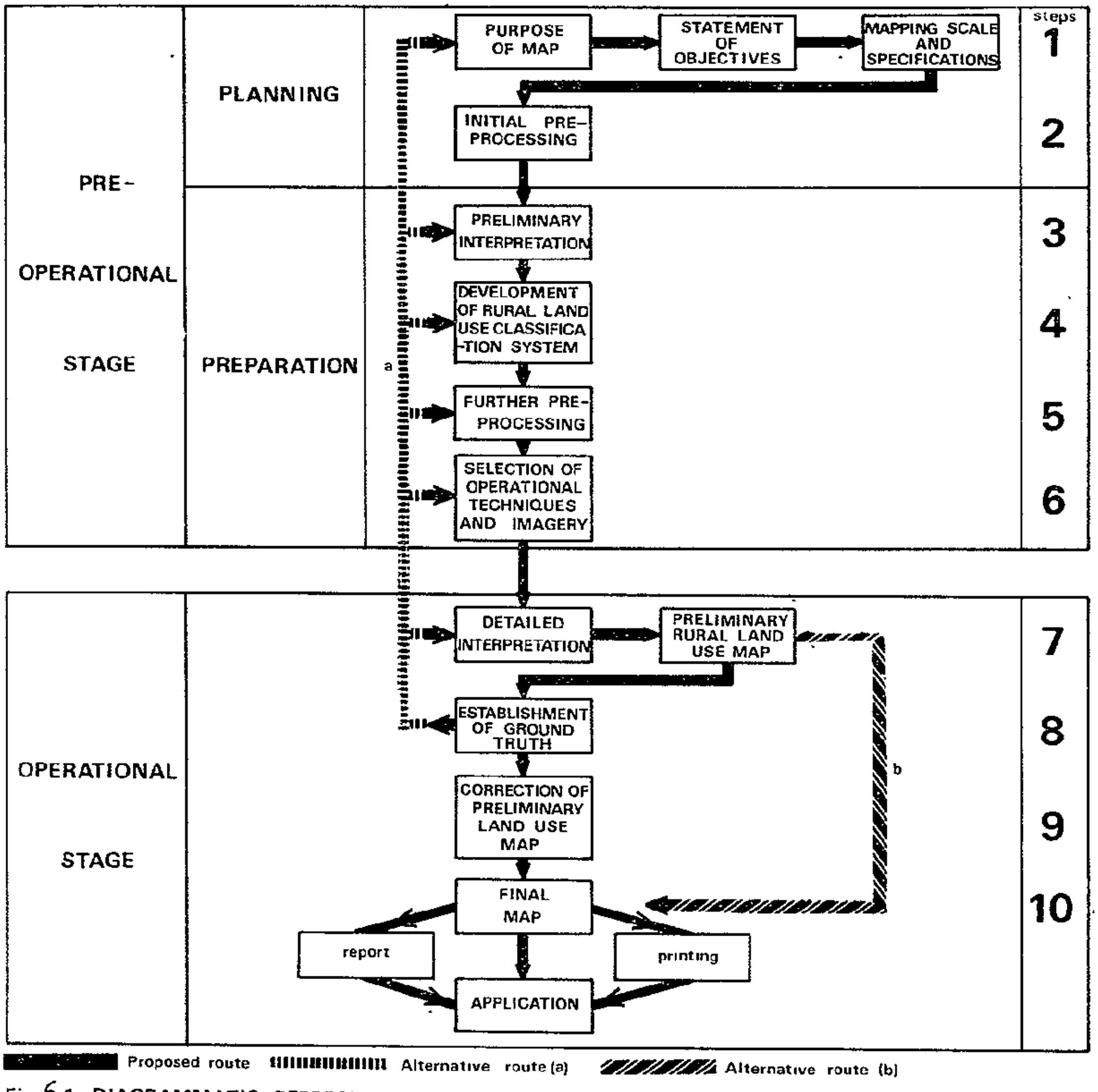

Fig 6.1 DIAGRAMMATIC REPRESENTATION OF A PROPOSED METHODOLOGY FOR THE PRODUCTION OF SMALL-SCALE RURAL LAND USE MAPS FROM LANDSAT MSS IMAGERY

NB THE METHOD ADOPTED IN THE PRODUCTION OF THE LAND USE MAP OF MURCIA PROVINCE WAS VERY SIMILAR TO THE PROPOSED ROUTE SHOWN IN THIS DIAGRAM procedure has been devised. Each main step has been numbered and further explanations and expanded diagrams have been presented (see Figure 6.1). Various alternatives are listed in several of these steps and it is possible for an investigator to select from these suggestions or he may adopt the recommended approval if he wishes.

The recommended route through the different steps in both the pre-operational and operational stages has been shown as a solid black line and several alternative routes have also been shown (see Figure 6.1). One of these routes (i.e. Route a) links the preliminary map and the final map and indicates the type of method adopted by some investigators who, for various reasons, do not check the accuracy of their interpretation in the field. Usually, they tend to adopt the preliminary map as the final map after making modifications. The other alternative route (i.e. Route b) indicates the possible choices available to an investigator if the results of field work suggest that the accuracy of image interpretation is not sufficient to justify the completion of the final map. The choices range from a re-interpretation of the imagery to an investigation of the purpose and objectives of the whole mapping operation.

6.2. PRE-OPERATIONAL STAGE

6.2.1. PLANNING

This initial phase of the methodology has been divided into two main steps which establish the basis for the whole mapping operation. The first step entails the detailed clarification of the purpose of the map and a statement of objectives that need to be fulfilled in order to produce the desired map.

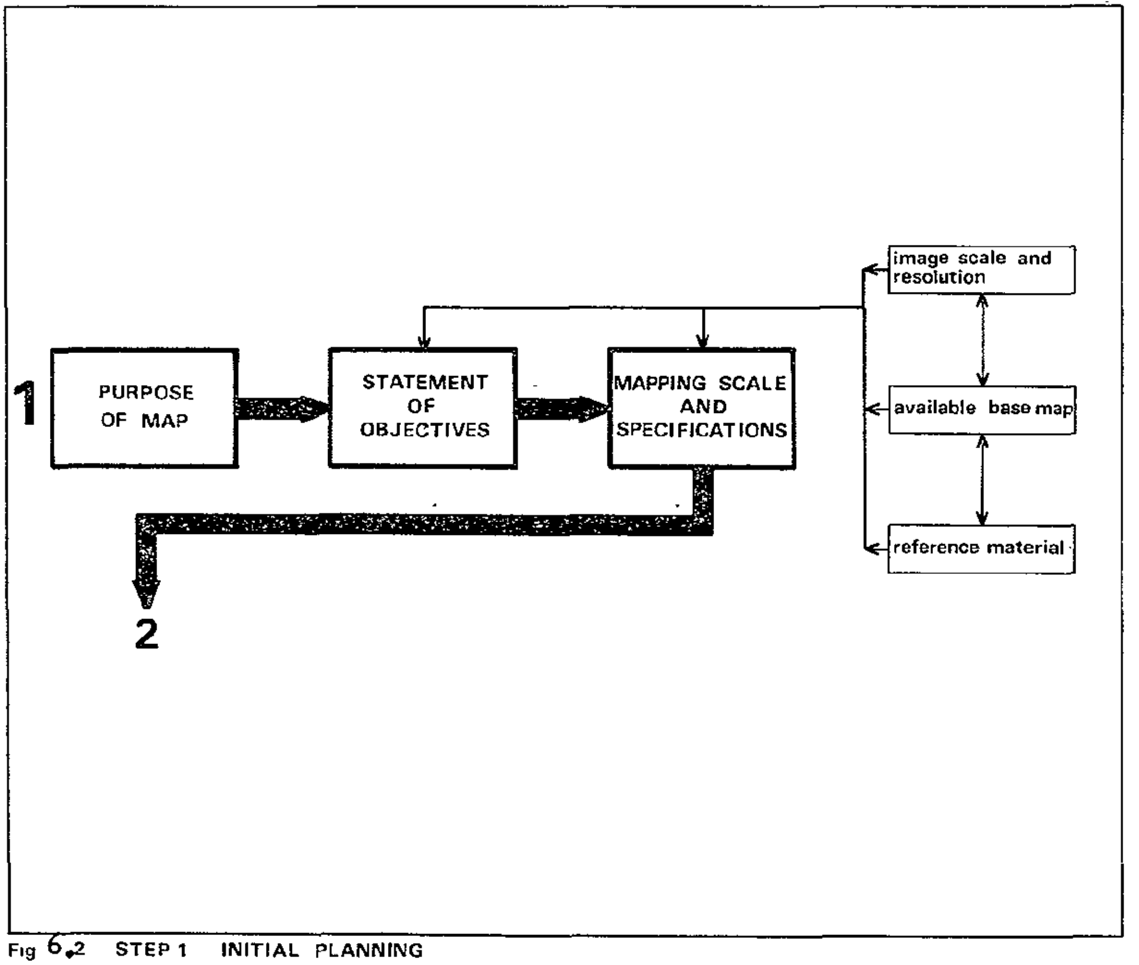

Fig 6.2 STEP 1 INITIAL PLANNING

These, in turn, influence decisions that must be made about the most appropriate scale and detailed specifications of the final map. The framing of the objectives and the final mapping scale and specifications requires a careful consideration of possible imagery, base maps and other reference material. Once the objectives have been defined, standard pre-processed LANDSAT MSS imagery can then be selected and purchased from EROS Data Center or any authorised organisation. However, this step can provide difficulties for investigators unfamiliar with the different types of LANDSAT MSS imagery as it can be obtained at four different scales, in four different black and white positive or negative spectral bands and in transparency or paper print format. In addition, colour composites are available as transparencies or opaque prints at various scales (see Figure 6.3). Obviously, this wide choice could lead to much unwarranted expense if guidance is unobtainable as imagery for each spectral band is not required in rural land use investigations (see Section 4.3.3.). In addition, imagery should be selected so that the seasonal variations in vegetation cover can be utilised in the accurate delineation and identification of landuse boundaries and categories (see Section 4.3.6).

The recommended standard pre-processed imagery of each LANDSAT MSS frame for rural land use mapping consists of one 1:1,000,000 false colour composite transparency, if available, or one each 1:1,000,000 black and white positive transparencies of bands 4,5 and 7 for producing colour composites by the diazo process. In addition, one 1:250.000 colour composite print or, if unavailable, one 1:250,000 paper print of band 5.

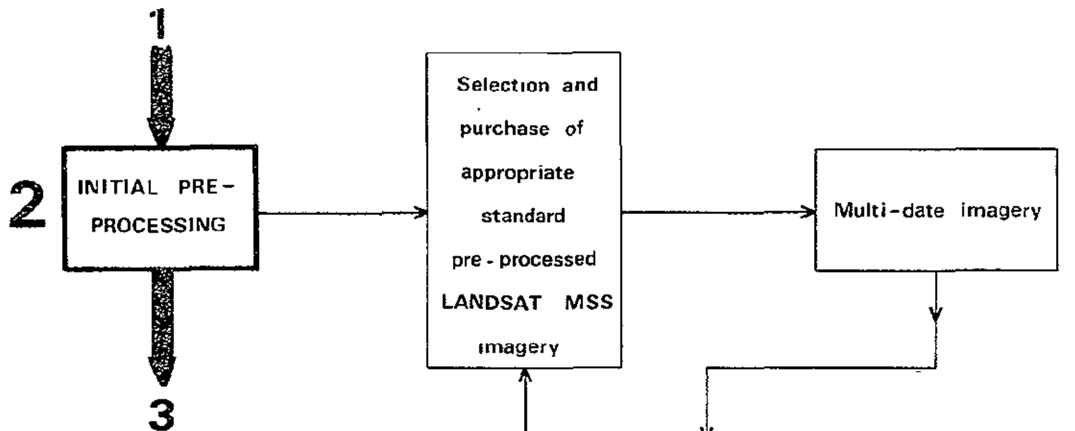

Image Size	Scale	Format	Black and White Unit Price US $	Colour Composite Unit Price US $
2·2 inch	1 3,369,000	Film positive	$ 3 00	$ N A
2·2 "	1:3,369,000	Film negative	4.00	N A
7 3 "	1:1,000,000	Film positive	5 00*	12.00
7·3 "	1 1,000,000	Film negative	6 00	N A
7·3 "	1.1,000,000	Paper	3 00	7.00
14·6 "	1·500,000	" "	8.00	20.00
29 2 "	1:250,000	" "	15.00	40 00

Information; USGS EROS Data Center, August 1975.

COLOUR COMPOSITE GENERATION (when not already available)

Image Size	Scale	Format	Unit Price
7·3 inch	1·1,000,000	printing master*	$ 50 US

* COST OF PRODUCT FROM THIS COMPOSITE MUST BE ADDED TO TOTAL COST

Fig 6.3 STEP 2 INITIAL PRE-PROCESSING

6.2.2. PREPARATION

This phase involves the procedures necessary to provide a satisfactory base for the detailed interpretation of the land use in the operational stage of mapping. The first step necessitates a preliminary interpretation of the purchased standard imagery in order to establish whether the imagery is appropriate for the task in that form or whether further "in-house" pre-processing is required. (Step 2, Figure 6.3). The quality of interpretation is not only affected by the quality and seasonality of the imagery but it is also a function of the interpreter's reference level, the collateral material available and the visual optical enhancement techniques that can be employed. Details of these aspects have been presented in Section 4.3.1 and they are summarised in Figure 6.4. Adequate care should be taken to ensure that the interpreter spends sufficient time in becoming familiar with the nature of the MSS imagery and the spectral responses of the region as the level of interpretation skill at this stage tends to influence the framing of the land use classification scheme, the selection of visual enhancement equipment and the type and amount of additional pre-processing. The familiarisation with the imagery should be achieved by considering relevant collateral data about the region as well as the methods used in acquiring and processing the LANDSAT MSS data.

Once the interpreter becomes accustomed to the imagery, a preliminary land use classification scheme can be evolved which should be as broad as possible within the limitations imposed by the final mapping scale, the image scale and resolution and the spectral responses of the vegetation cover (see Figure 6.5). In addition, it involves the integration of relevant collateral material, the interpreter's reference level and guidelines from other similar land use classification systems, especially the system outlined in the U.S. Geological Survey Circular 671. However, before the system is produced a set of criteria should be established which define the conditions which the system should meet. These criteria should reflect the scope of the mapping objectives and they should provide adequate guidelines for the development of a satisfactory classification system that will be appropriate for the region. Probably the most guidance with regard to the framing of criteria and designing of the structure of a land use classification system for use with LANDSAT MSS imagery can be obtained from U.S. Geological Survey Circular 671. This system basically consists of two levels of classification and both levels are based on a description of the land use which is expressed in terms of vegetation cover rather than an activity-oriented classification. Level 1 contains categories which express broader types of land use and it is more directly applicable for use with small scale orbital imagery. Level 2 categories are more detailed sub-classifications of Level 1 categories and they are designed for use with larger scale orbital and high altitude imagery. Further details about this system are provided in Section 4.4 and Tables 3.1 and 3.2.

As a result of the assessment of the imagery during the preliminary interpretation step and the development of the initial classification system, any further pre-processing that can assist in the operational interpretation should be undertaken. Essentially, this involves photographic enhancement

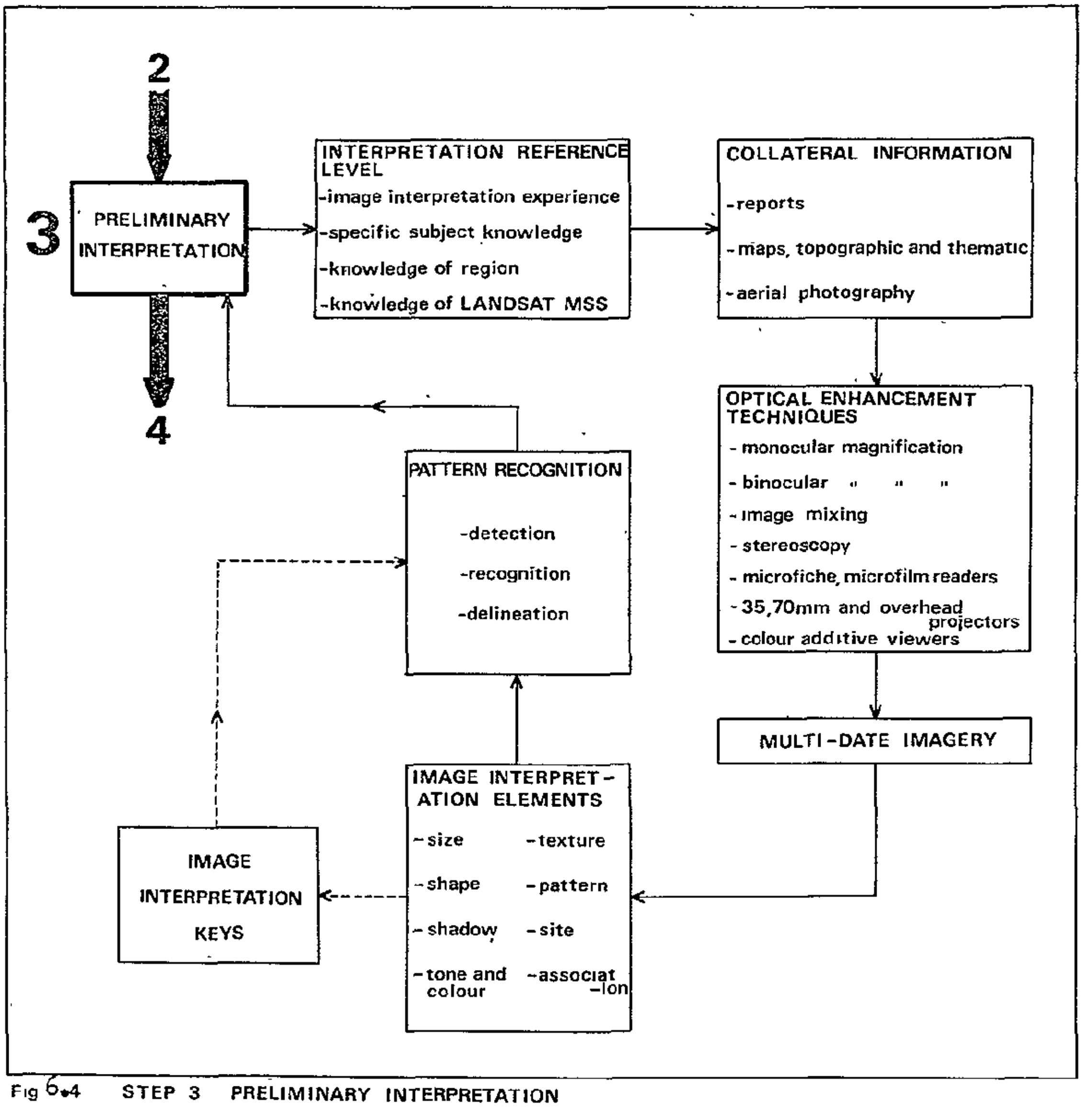

Fig 6.4 STEP 3 PRELIMINARY INTERPRETATION

of the standard LANDSAT MSS imagery and available aerial photography, especially enlargements and/or the use of the diazo process to produce colour composites (see Figure 6.6). In addition, some other pre-processing to produce imagery in 35 mm. or 70 mm. slide formats for certain parts of the region may be carried out.

After considering all available techniques and imagery, those most appropriate for use in the operational stage of the map production may then be selected. The approach that was adopted in the production of the land use map of Murcia Province and the one that is recommended for future use in operational rural land use surveys utilising LANDSAT MSS imagery is outlined in Figure 6.7 Essentially, it is a combination of monocular magnification and 1:1,000,000 colour composite transparencies for detailed viewing in the interpretation process with 1:250,000 prints for plotting boundaries. However, several choices of imagery are available. Instead of the expensive standard colour composites, diazo colour prints of bands 4,5 and 7 of each frame can be made from the black and white positives and super-imposed to produce satisfactory colour composites (see Section 4.2.2.2.). Also, an enlarged black and white positive print of band 5 at 1:250,000 could be used as an alternative to the standard opaque print of the colour composite at 1:250,000. In addition, other supplementary materials and equipment that may be used to assist interpretation include air photo mosaics at various scales, slides of portions of selected areas of LANDSAT MSS imagery for viewing with 35 mm. or 70 mm. projectors and relevant reports.

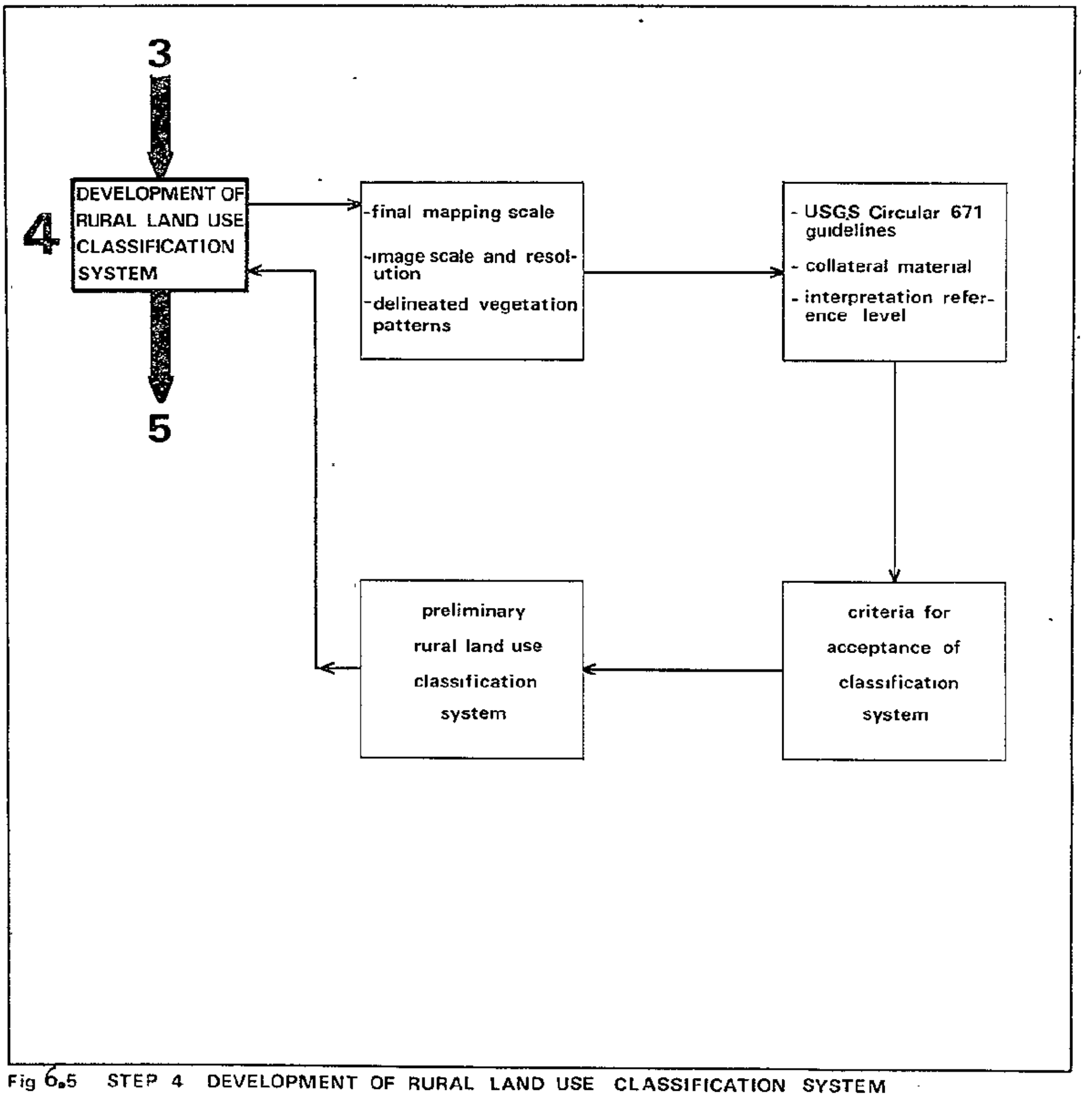

Fig 6.5 STEP 4 DEVELOPMENT OF RURAL LAND USE CLASSIFICATION SYSTEM

6.3. OPERATIONAL STAGE

6.3.1. DETAILED INTERPRETATION AND PRODUCTION OF PRELIMINARY RURAL LAND USE MAP (Step 7).

The first major step in the operational stage consists of the detailed interpretation of the selected LANDSAT MSS imagery and the production of the preliminary rural land use map. In the detailed interpretation, colour is used as the main image interpretation element in the detection, recognition, delineation and classification of the different land use categories. The other interpretation elements e.g. shape, size, texture, site, etc. are all used to varying degrees depending on the type of land use being investigated. Again, the potential accuracy level depends on the interpreter's reference level with regard to his training in image interpretation, his knowledge of the region, his background knowledge of specific related subjects and his familiarity with the spectral characteristics of the LANDSAT MSS imagery. Colour composite transparencies of each frame at a scale of 1:1,000,000 (either standard or diazo) with rear illumination from a light table are initially viewed under monocular magnification to detect areas of similar colour. Then, when familiar with the colour and resolution characteristics, areas of similar land use are identified by extrapolating away from the colours of areas of known land use. These areas can be identified from various sources including relevant reports, topographic and thematic maps of parts of the region and air-photo interpretation of available aerial photographs or mosaics. The location of the similar areas can be facilitated by the use of a specially prepared transparent base map containing selected topographic data at a scale of 1:250,000.

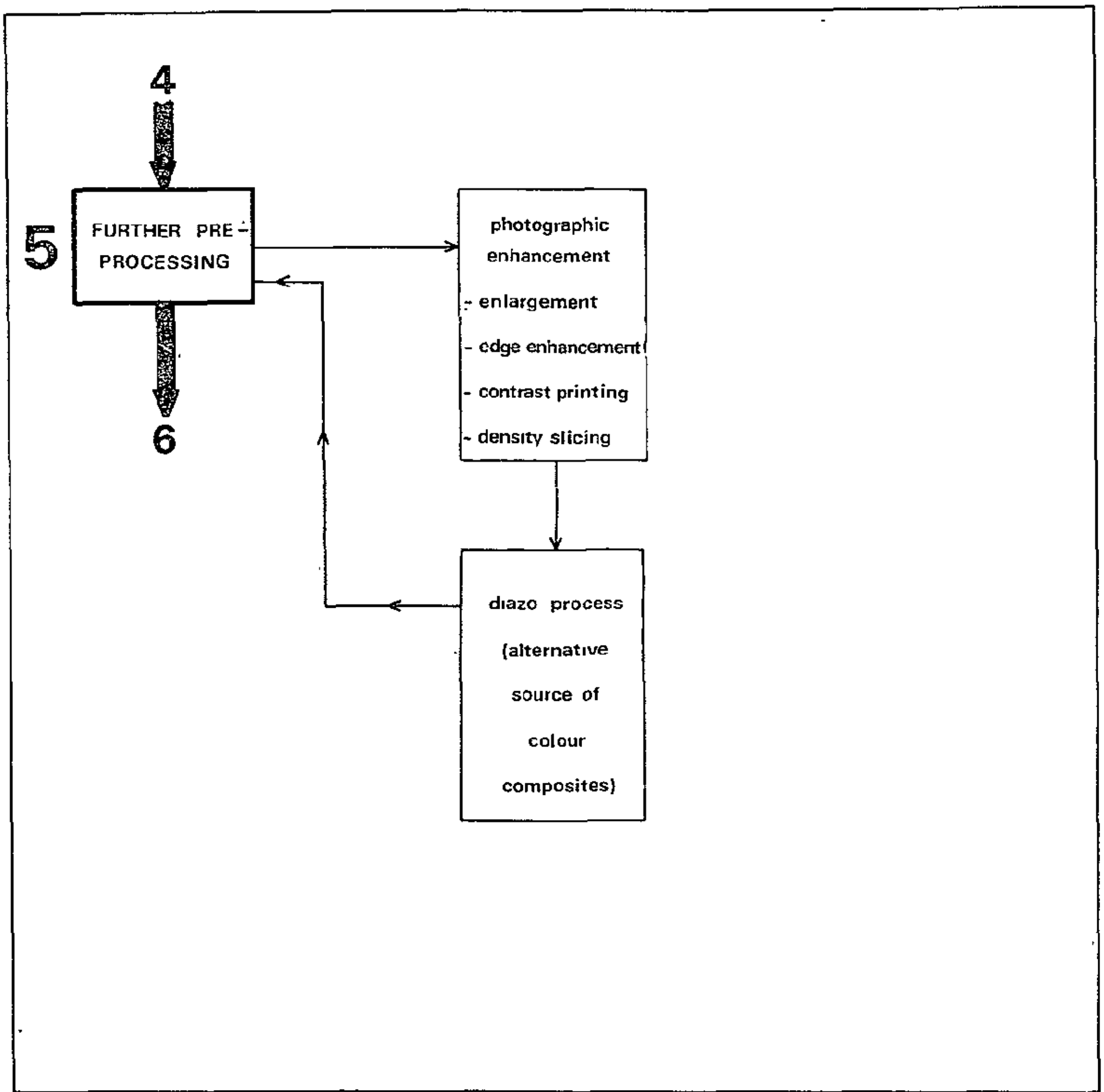

Fig 6.6 STEP 5; FURTHER PRE-PROCESSING

Further enhancement to aid the interpretation of difficult areas can be achieved by other optical enhancement techniques especially slide projectors, microfiche and micro-film readers which may be used to enlarge optically imagery of certain portions of the region that require further investigation. Also, the spectral responses recorded on imagery acquired during different seasons (multi-date imagery) should be viewed as an additional aid in clarifying boundaries and categories.

An adequate method should be devised to ensure that all areas of land use having areas greater than 25 hectares or larger have to be delineated and classified on the map. One satisfactory method utilises the grid pattern of the 1:50,000 topographic mapping system plotted onto a transparent overlay to provide a systematic framework for identifying areas on the map and on the imagery.

Once the interpretation has been completed the boundaries and categories can be transferred to the transparent base map from the 1:250,000 colour composite print or black and white enlargement of band 5. In this case, the recommended base map scale should be the same as the print containing the interpreted data, i.e. 1:250,000 and it should contain sufficient information to permit the location of land use boundaries in the field.

Other aspects involved in the preparation of the preliminary land use map include the determination of the minimum size of the area of categories that should be mapped. The generally accepted minimum size, based on a map scale of 1:250,000, is approximately 25 hectares (60 acres) which represents an area of 4 sq mm. on the map. As a consequence, areas of land

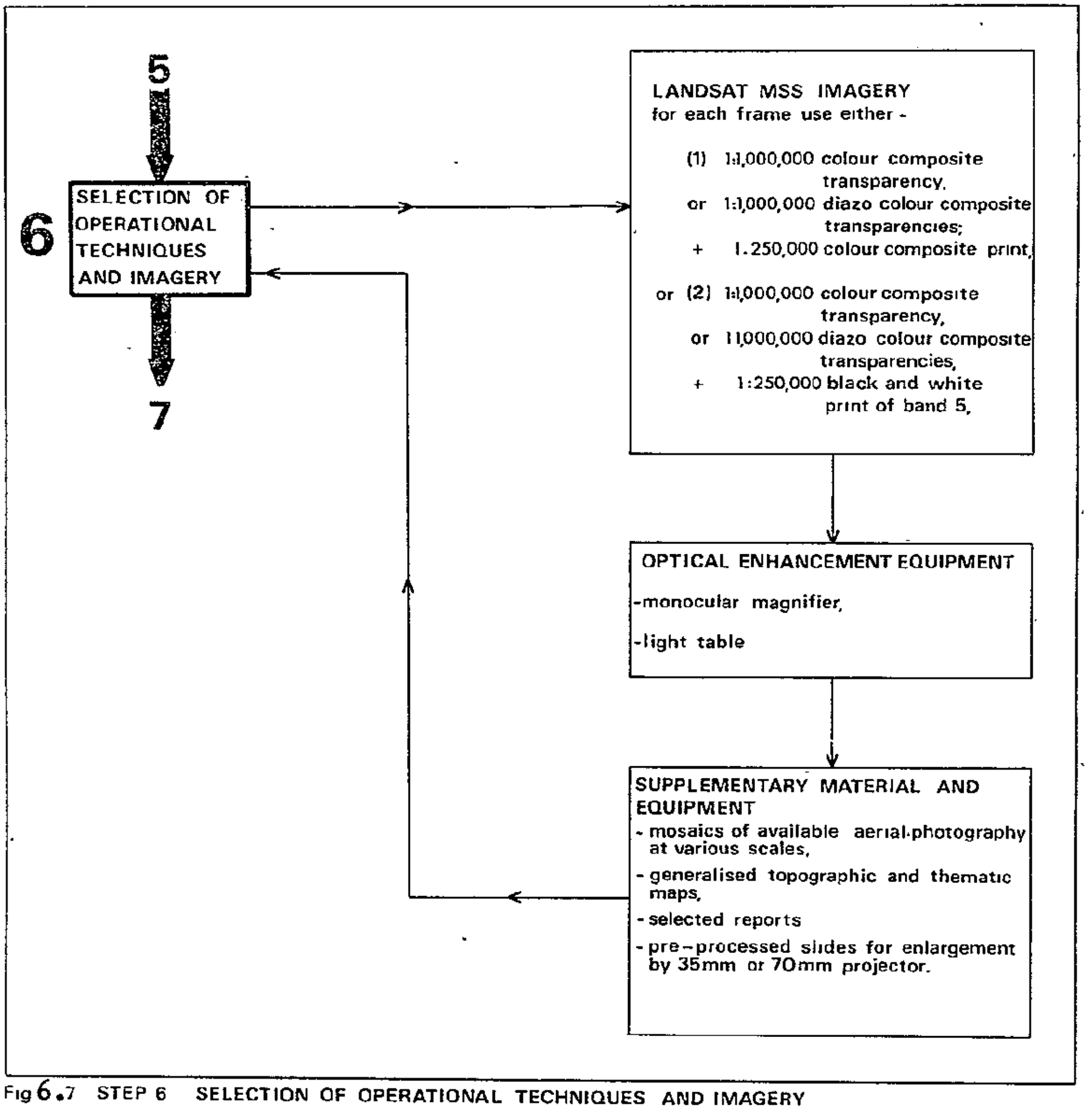

Fig 6.7 STEP 6 SELECTION OF OPERATIONAL TECHNIQUES AND IMAGERY

use smaller than this size should be absorbed within the surrounding category unless there are certain circumstances which necessitate their inclusion on the map. For example, certain areas of irrigated land may have special significance and may be easily identified and mapped. Then, appropriate symbols and colours for each category should be added to the map to enable easy identification of areas in the field. Finally, the map should be checked for omissions in the interpretation phase and in the process of transferring data to the base map. This can be achieved by first overlaying the transparent map onto the 1:250,000 print used in the interpretation and then systematically checking within each graticule of a selected grid system e.g. 1:50,000 topographic map system. .

6.3.2. ESTABLISHMENT OF GROUND TRUTH (Step 8)

The next step in the operation is one that is occassionally omitted from the overall mapping procedure (see Figure 6.1). It involves the establishment of ground truth or, in other words, it enables the accuracy of the interpretation of the land use from LANDSAT MSS to be assessed and, consequently, should form an important part of the mapping operation. The suggested method can be divided into three parts, viz: the sampling strategy, field data collection and the analysis of data (see Figure 6.9).

In the sampling strategy phase, a stratified random sampling technique has been found to be the most appropriate method available and stratification is achieved by using the different categories of the land use classification system. The number of points for each category is obtained by consulting Tables 4.10,4.11 and 4.12 which indicate the appropriate

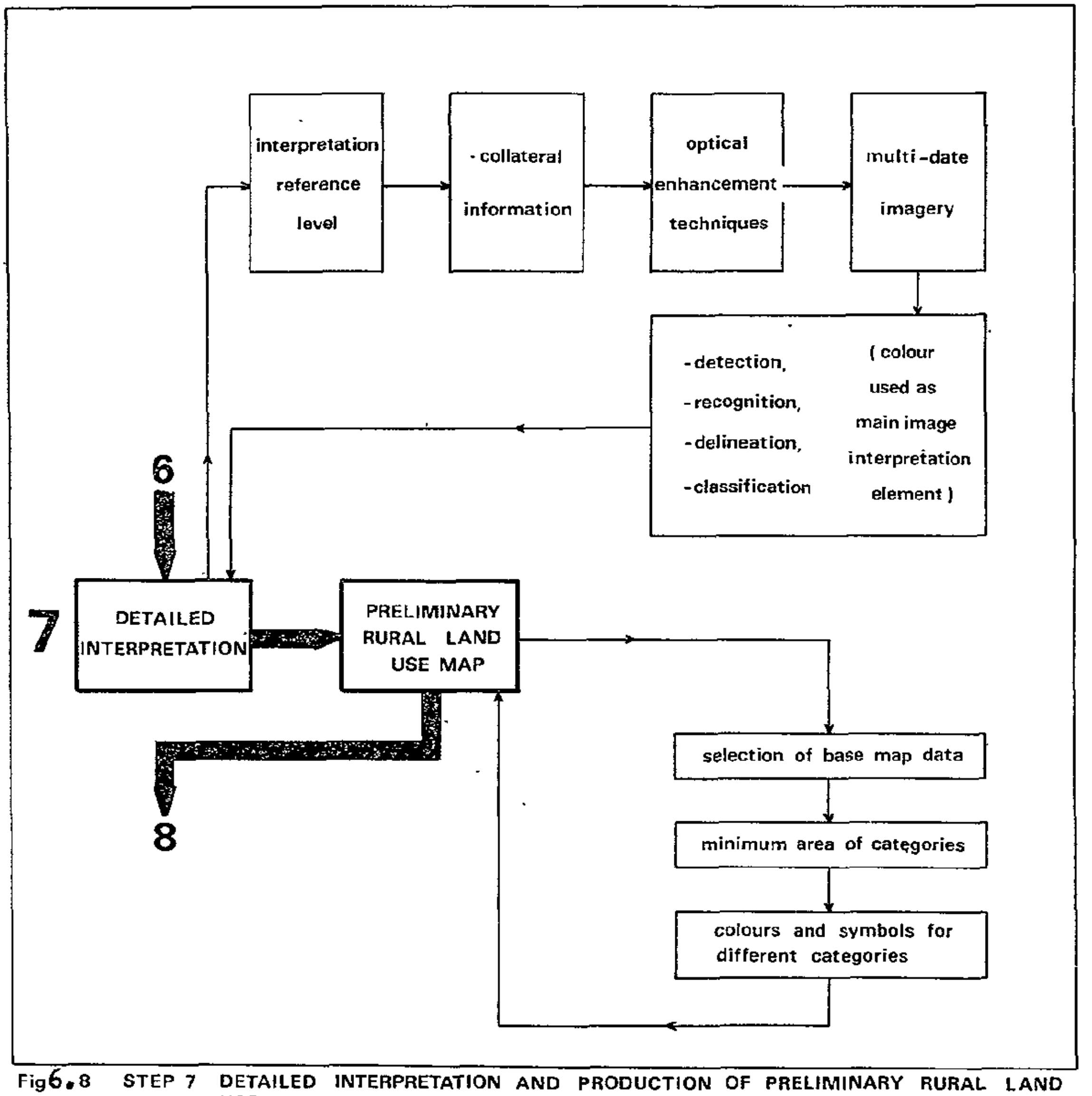

Fig 6.8 STEP 7 DETAILED INTERPRETATION AND PRODUCTION OF PRELIMINARY RURAL LAND USE MAP

number of sample points required for the pre-scribed interpretation accuracy level. In practice, the optimum sample size is obtained by adding several more sites to the value derived from the tables as certain factors, e.g. bad weather and prohibited access may prevent detail at certain sites from being recorded. Random sampling is then carried out over the whole area using co-ordinates generated from random number tables. These points are then plotted onto the preliminary land use map which overlays millimetre graph paper. Thus, the inter-sections of lines on this graph paper represent the centres of 250 m. squares on the ground. When the desired optimum number of points has been reached for a particular category no more random points are added to the list for that category. Ideally, random sampling continues until the optimum number is reached for each category. However, in practice, the areal distribution and coverage of some categories may be too small to permit the generation of enough random points. In these cases, several alternatives are open to satisfy the need of an adequate field check. For example, the investigator can decide to visit all the areas in that category whilst field checking other sites. Or, alternatively, he can use the number of sites that were generated after a reasonable period of random sampling and accept the fact that the accuracy level for that particular category may not meet the accepted level required for the survey. If these alternatives are not acceptable then the classification system may have to be re-adjusted so that these categories are sub-sumed into the next level of the classification.

To ensure that the sample sites can be accurately located

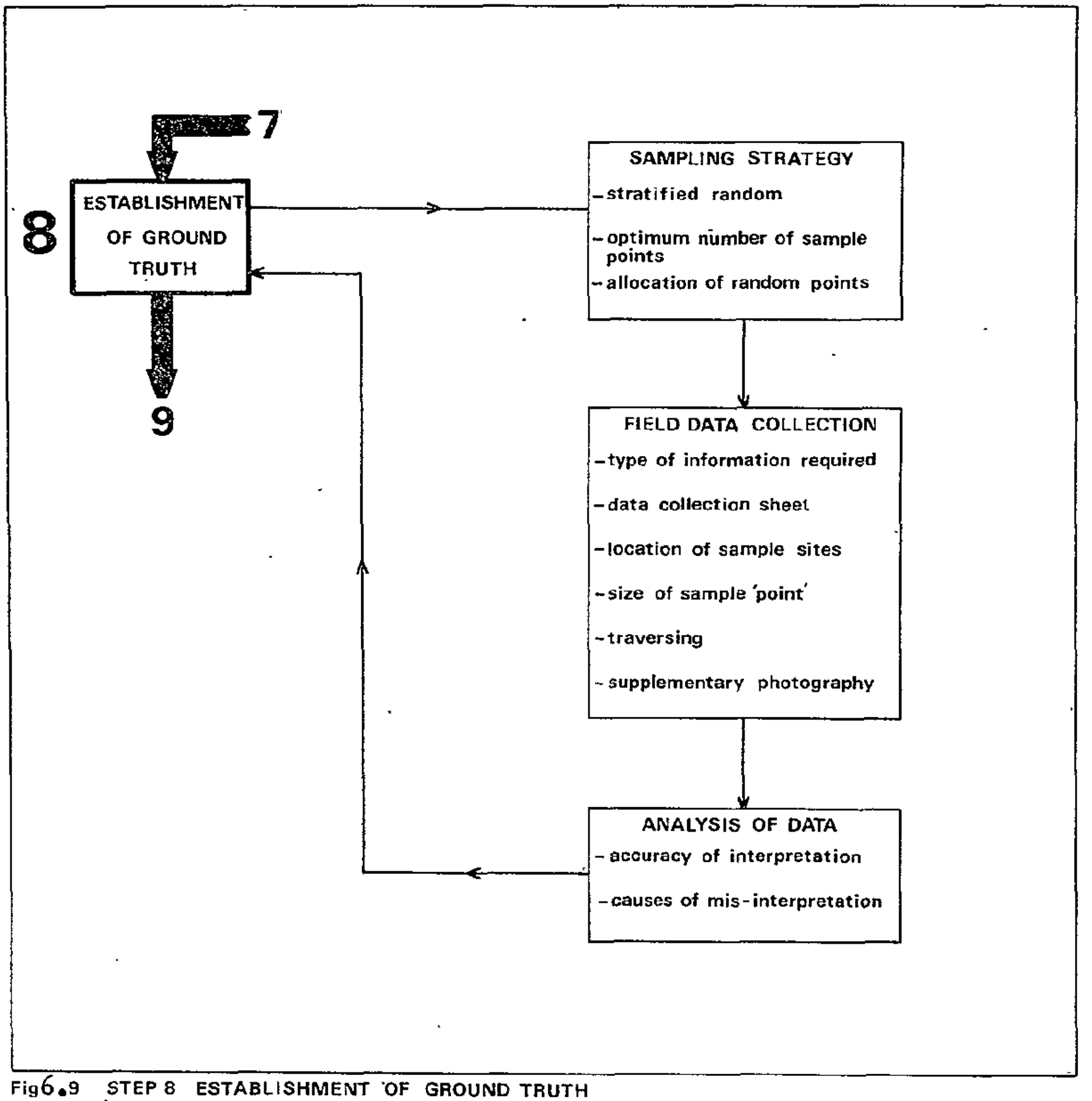

Fig6.9 STEP 8 ESTABLISHMENT OF GROUND TRUTH

in the field the millimetre graph paper should be aligned with the base map in such a way that the co-ordinates of known points on appropriate topographic maps can be transposed onto the graph paper, This permits the accurate determination of the co-ordinates of each sample point. The co-ordinate of each point can then be plotted onto the relevant topographic map for use in the field. Ideally, the larger the scale of the topographic map the easier it is to locate points in the field, but 1:50,000 and 1:250,000 topographic maps have been used successfully.

Field data collection requires careful planning to make certain that the appropriate data are collected as rapidly as possible and that the data will provide a satisfactory check on the level of interpretation as well as isolating possible reasons for mis-interpretation. This is best achieved in the field by using a data collection sheet designed for rapid recording and easy analysis of appropriate information (see Appendix III). To ensure that the land use at each site is recorded in a systematic manner the sheet should contain details about the possible land use, as typified by the vegetation cover, at each classification level i.e. Levels 1-4 which the observer can easily identify and record. The complexity of identification increases from a general description of overall land use at Level 1 e.g. agricultural land to a detailed description of the type of crop or plant species at Level 4 e.g. peaches. Provision for the recording of other aspects of land use, e.g. the distribution, colour and height of the crop should also be made. In addition, details of the surface characteristics, e.g. slope, colour, roughness, aspect should also be recorded as they may provide some guidance in establishing reasons for in-correct interpretations. Ground level photography of sites has been found to provide valuable assistance in analysing site data and provision for recording their location details should also be provided on the data collection sheet.

In the field, daily traverses should be carefully planned to make sure that sites are located with minimum travelling and the traverse should include a visit to all categories that did not have sufficient random sites generated e.g. reservoirs. In addition, local vantage points which can provide overall visual checks of the mapped land use should be incorporated. Further checks can be carried out along the routes between sites and any discrepancies should be noted on the land use map. At each site, the land use over an area of 250 m. x 250 m. should be recorded on the data collection sheet for each level of classification. For Levels 1 and 2, the land use should cover at least 50% of the site. Comments about unusual features evident on or near the site should also be recorded, e.g. new irrigation schemes, etc.

After all the sites have been visited, the data collection sheets should be analysed to determine whether the prescribed accuracy level of the interpretation of each land use category had been met. This can be achieved by referring back to Tables 4.10,4.11,4.12. If the number of errors for a particular sample size at 90% accuracy level is too great (Table 4.12), then the 85% accuracy level may have to be accepted (Table 4.11). If the errors are still too high either the accuracy level must be lowered further or the 85% level may be accepted with the knowledge that the probability of incorrect interpretations is going to be higher than the normally accepted 5% probability level.

Further investigation of the data collection sheets may permit subjective as well as statistical analyses of the types of interpretation errors that were made. If the accuracy level and reasons for mis-interpretation warrant it, then a re-assessment of the mapping operation may be required. This could possibly mean a complete review of the mapping objectives and specifications if the results are particularly bad. Or, it could mean a review at other steps in the overall methodology indicated by alternative route (a) shown on Figure 6.1.

6.3.3. CORRECTION OF PRELIMINARY RURAL LAND USE MAP

If the accuracy of interpretation as indicated by the ground truth investigation is accepted as sufficient, then corrections to the preliminary map can commence. Initially, any changes to the classification system should be carried out, i.e. any classification changes indicated by the field survey where certain categories should be collapsed due to the low interpretation accuracy at Level 2. The final classification system should then be devised with brief but adequate descriptions of each category and sub-category. Then, any specific queries noted on traverses or at sample sites should be checked on the imagery and relevant changes made to the map. This is particularly applicable to the location of boundaries between categories.

In order to prepare the preliminary map as a satisfactory base for the final rural land use map, several types of data generalisation are required. For example, the amount of

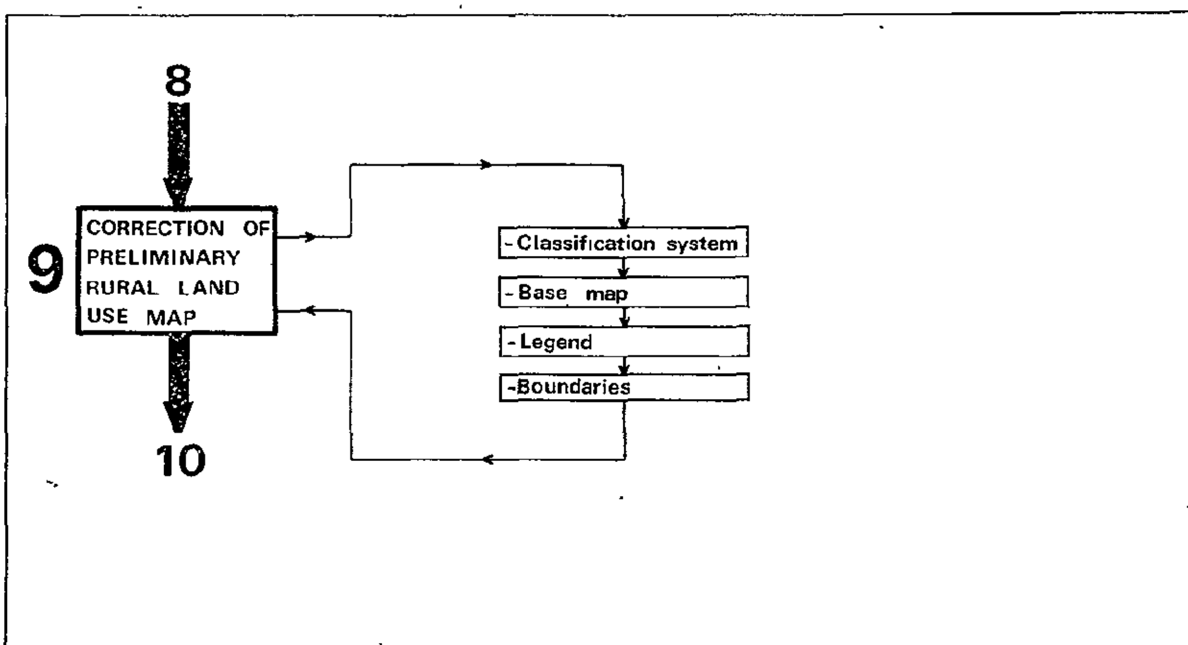

Fig 6.10 STEP 9; CORRECTION OF PRELIMINARY RURAL LAND USE MAP

topographic information should not be as detailed as that presented on the preliminary map when it was prepared for field work. However, it should provide sufficient locational information for the viewer. In addition, areas of certain categories may be considered to be too small to be adequately represented on the final map and, consequently, must be sub-sumed within the surrounding categories.

6.3.4. FINAL MAP

The production of the final map involves the presentation of the map in its completed state ready for application in the tasks for which it was designed. It entails the re-drawing of the corrected and generalised data shown on the preliminary map and it also includes the normal cartographic procedures of devising a satisfactory overall layout, the design of a legend incorporating the classification system, and the selection of lettering, symbols and colours. One suggestion regarding colours suitable for land use mapping with LANDSAT MSS imagery has been made by Paludan (1973); It is also outlined in Peterson (1975). The main aim of this colour scheme has been to make land use maps prepared from this data source as compatible as possible (see Table 5.2).

Once completed the final map can then be used as a final "colour rough" for colour printing or it may be used directly as the base map for further investigations within the region. An important addition to the final map should be a report detailing the purpose, objectives and specifications of the map as well as possible recommendations for potential map-users. It should also include explanations of the various pre-processing, interpretation, classification and ground truth procedures adopted during the production of the map.

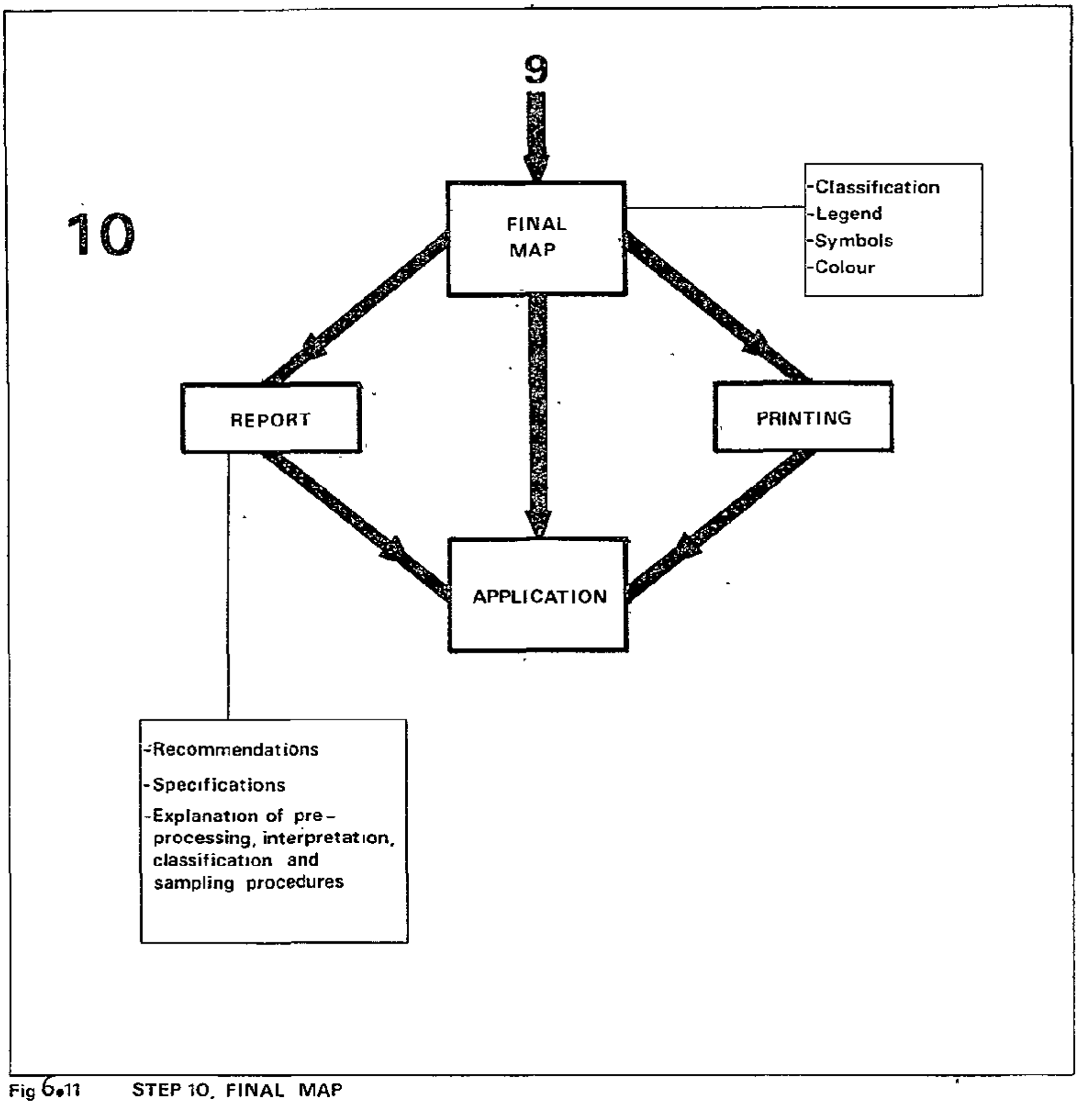

Fig 6.11 STEP 10. FINAL MAP

7. CONCLUSIONS

The results of this study have shown that it is feasible to design a methodology that can provide suitable guidelines for the operational production of small scale rural land use maps of semi-arid developing regions from LANDSAT MSS imagery using inexpensive and unsophisticated techniques. The suggested methodology should provide immediate practical benefits to map-makers attempting to produce land use maps in countries with limited budgets and equipment. As the LANDSAT MSS imagery system permits regular synoptic coverage of the Earth's surface, it provides an ideal method for establishing a satisfactory data base and further monitoring of land use changes over large areas. This task would be extremely time-consuming and expensive with conventional aerial photography.

One main advantage of the methodology is that it should considerably reduce the time spent by researchers in trying to locate and assess the different techniques involved in the various stages of map production that have been reported in numerous articles during the last few years. This has been achieved by presenting and evaluating the most appropriate pre-processing, interpretation, classification and ground truth procedures in a simplified and systematic manner. Initially, many pre-processing and interpretation techniques were considered and rejected on the grounds that they were in-appropriate mainly due to the high cost of the imagery and equipment or their inadequacy for use in the operational sense.

The suggested imagery and interpretation techniques consisting of colour composites and monocular magnification proved to be the simplest, fastest and most versatile method.

However, it should be recognised that the level of interpretation is also very dependent upon the interpreter's reference level and, in this type of mapping, it is particularly important that adequate steps should be taken to ensure that the interpreter has a satisfactory understanding of the MSS imaging system. This is necessary due to the unconventional type of imagery produced from the data acquired by the multispectral scanner. The interpreter should be aware of the nature of the image characteristics represented on the individual spectral bands or on combinations of the bands.

In order to maintain a standardised classification of land use, the criteria and hierachical structure presented in the U.S.G.S. Circular 671 were found to be acceptable as a general basis for researchers and organisations wishing to develop systems for their own regions. However, it should be stressed that these recommendations should only be used as guidelines for the development of an adequate system for a particular region.

As no satisfactory method could be located which provided directions for systematically analysing the results of the interpretation, a new scheme was devised and tested. This proved to be successful, in the operational sense, during the production of the land use map of Murcia Province. Although the system was based on the commonly-used stratified random strategy, one important aspect that was developed in this study was the method of determining the most appropriate sample size. However, the technique utilises interpretation accuracy levels that are lower than the normally accepted standards adopted in conventional surveys using air photo-interpretation methods.

This situation arises from the fact that the concept incorporates the probability of making incorrect interpretations at particular prescribed accuracy levels e.g. 85% or 90% for a certain number of errors e.g. 0,1,2,3 etc. for a particular sample size. This contrasts with the usual practice of expressing the interpretation errors as a percentage of a subjectively derived number of sample sites. Consequently, it is felt that this approach offers a more meaningful explanation of the interpretation accuracy level of the whole operation and within each category. Furthermore, it should prove to be very useful in other types of operational remote sensing projects where stringent specifications need to be met but, prior to this study it was not possible to check the accuracy of the work in any reliable, statistical manner.

In their applications, the suggested methodology and the land use map should be used in the context in which they were designed. Essentially, this means that they should be used to provide a data base for further study within the region or for monitoring land use changes over large areas. More detailed investigations in selected parts of the region should be under-taken using the larger scale imagery and relevant methodology.

In conclusion, it has been demonstrated that the proposed methodology can play an important role in providing a suitable link between the acquisition of the LANDSAT MSS data and its operational application in land use mapping using inexpensive techniques.

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INQUIRY FORM

GEOGRAPHIC COMPUTER SEARCH

EROS DATA CENTER

Sioux Falls, S.D. 57198
Phone: 605/594-6511 Ext. 151
FTS: 605/594-6151

Date ______________

NAME MR. MS. ______ (LAST) ______ (FIRST) ______ (INITIAL) ______ Previous Contact No. ______ (IF KNOWN)

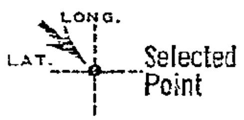
COMPANY ______________ Phone: (BUSINESS) ______

ADDRESS ______________ Phone: (HOME) ______

CITY ______ STATE ______ ZIP ______ Your Reference No. ______ (P.O., GOVT. ACCT. OR OTHER)

TO INITIATE AN INQUIRY AND COMPUTER GEOSEARCH, COMPLETE ONE OF THE FOLLOWING

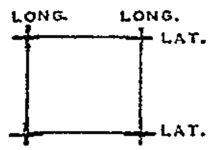
POINT SEARCH



Imagery with any coverage over the selected point will be included.

Latitude ______ ° ______ '
Longitude ______ ° ______ '

AREA RECTANGLE



Imagery with any coverage over the selected area will be included.

Latitude ______ ° ______ ' TO Latitude ______ ° ______ '
Longitude ______ ° ______ ' TO Longitude ______ ° ______ '

GEOGRAPHIC NAME AND LOCATION (INCLUDE A MAP IF POSSIBLE) ______________

INDICATE YOUR INTERESTS FOR EACH OF THE FOLLOWING:

TYPE OF COVERAGE
- ☐ LANDSAT
- ☐ SKYLAB
- ☐ NASA-AIRCRAFT
- ☐ AERIAL MAPPING PHOTOGRAPHY

TIME OF YEAR
- ☐ JAN-MAR
- ☐ APR-JUNE
- ☐ JULY-SEPT
- ☐ OCT-DEC
- ☐ SPECIFIC DATES ______

TYPE OF PRODUCT
- ☐ BLACK & WHITE
- ☐ COLOR OR COLOR INFRARED

MAXIMUM CLOUD COVER ACCEPTABLE

☐ 10% ☐ 30% ☐ 50% ☐ 80% ☐ 100%

MINIMUM QUALITY RATING ACCEPTABLE

☐ 0-2 (VERY POOR) ☐ 3-4 (POOR) ☐ 5-6 (FAIR) ☐ 7-9 (GOOD)

APPLICATION AND INTENDED USE ______________

APPENDIX I EROS Data Center : Inquiry form.

ORDER FORM
LANDSAT STANDARD PRODUCTS
EROS DATA CENTER

Sioux Falls, S.D. 57198
Phone: 605/594-6511 Ext. 151
FTS: 605/594-6151

Date

NAME MR. MS. (LAST) (FIRST) (INITIAL) Previous Contact No. (IF KNOWN)

COMPANY Phone (BUSINESS)

ADDRESS Phone (HOME)

CITY STATE ZIP Your Reference No. (PO OR GOVT ACCT OR OTHER)

PLEASE TYPE OR PRINT PLAINLY

SCENE IDENTIFICATION NO.	PRODUCT CODE	BAND 4	5	6	7	REMARKS	TOTAL BANDS	QTY.	UNIT PRICE	TOTAL PRICE

STANDARD PRODUCTS

BLACK AND WHITE

IMAGE SIZE	SCALE	FORMAT	UNIT PRICE	PRODUCT CODE
2.2 IN	1:3 369 000	FILM POSITIVE	3.00	11
2.2 IN.	1:3 369,000	FILM NEGATIVE	4.00	01
7.3 IN	1:1 000,000	FILM POSITIVE	5.00	13
7.3 IN	1:1,000 000	FILM NEGATIVE	6.00	03
7.3 IN.	1:1 000 000	PAPER	3.00	23
14.6 IN	1:500,000	PAPER	8.00	24
29.2 IN	1:250,000	PAPER	15.00	26

COLOR COMPOSITE GENERATION

7.3 IN.	1:1 000 000	PRINTING MASTER	50.00	59

NOTE PRINTING MASTER IS RETAINED BY EDC. COST OF PRODUCTS FROM THIS COMPOSITE MUST BE ADDED TO TOTAL COSTS

FALSE COLOR COMPOSITES

IMAGE SIZE	SCALE	FORMAT	UNIT PRICE	PRODUCT CODE
7.3 IN.	1:1,000,000	FILM POSITIVE	12.00	53
7.3 IN.	1:1,000,000	PAPER	7.00	63
14.6 IN	1:500,000	PAPER	20.00	64
29.2 IN	1:250,000	PAPER	40.00	66

COMPUTER COMPATIBLE TAPES (CCT)

TRACKS	BPI	FORMAT	SET PRICE	PRODUCT CODE
7	800	TAPE SET	200.00	82
9	800	TAPE SET	200.00	83
9	1600	TAPE SET	200.00	84

TOTAL ABOVE	A
TOTAL FROM PREVIOUS SHEETS	B
TOTAL COST	C

PAYMENT MADE BY:

- CHECK, MONEY ORDER ☐
- PURCHASE ORDER ☐
- GOVT. ACCOUNT ☐

COMMENTS: ______

APPENDIX II EROS Data Center : Order form.

HOW TO ORDER LANDSAT DATA

This order form is used to order all standard LANDSAT data. Necessary order information can normally be extracted from a computer listing of available data or from other LANDSAT references.

Please provide the following information in the indicated areas of the order form:

A. List your complete NAME, ADDRESS, ZIP CODE, and name of your COMPANY if applicable.

B. List a PHONE NUMBER where you can be contacted during business hours.

C. If you have had previous business with the Data Center and this order relates to that business, please list the previous CONTACT NUMBER if known.

D. Enter the complete SCENE IDENTIFICATION NUMBER. This number can be transcribed directly from the COMPUTER LISTING. If the source of information is from other than a computer listing, please specify the date the scene was recorded and the time taken.

E. Review the STANDARD PRODUCTS TABLE on the ORDER FORM and determine the type of product desired.

F. Enter the PRODUCT CODE of the type product being ordered from the STANDARD PRODUCTS TABLE.

G. Enter an indicator for the band(s) desired.

H. The REMARKS column is completed only when a CUSTOM PRODUCT is desired and you want to specify the parameters.

I. Enter the Total Number of Bands ordered.

J. Multiply the total bands ordered by the number of copies desired and enter the result in the QUANTITY column.

K. Enter the UNIT PRICE of the type product as reflected in the STANDARD PRODUCTS TABLE.

L. Multiply the figure in the QUANTITY column by the UNIT PRICE and enter the result in the TOTAL PRICE column.

M. Repeat the above for each product ordered.

N. TOTAL the costs of all products ordered on that order form and enter the net result in BLOCK A, TOTAL ABOVE.

O. If more than 1 order form is required, enter the sum of the figures in BLOCKS A in BLOCK B on the last order form.

P. Enter the SUM of BLOCK A and BLOCK B in BLOCK C, TOTAL COST.

Q. Indicate the TYPE of payment being made with a CHECK MARK. Make all drafts payable to U.S. GEOLOGICAL SURVEY. DO NOT SEND CASH.

R. Mail ORDER FORM(S) and PAYMENT to the address listed on the front side of this form.

APPENDIX II (continued).

APPENDIX III (i)

DATE

RANDOM NUMBER

SITE COORDINATES

1:50,000 SHEET

SITE NUMBER

INTERPRETED LAND USE

FIELD CHECK

correct

incorrect

SURFACE COLOUR

ASPECT

GRADIENT

flat			steep
0/5	5/15	15/30	>30

SLOPE FORM

concave

convex

linear

SURFACE ROUGHNESS

undulating

gullied

channelled

terraced

other

GROUND PHOTOGRAPHY

POSITION

DIRECTION

PHOTO No

OTHER COMMENTS

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
1 DEVELOPED			

LEVEL 1	LEVEL 2	LEVEL 3
2 AGRICULTURAL	1 CROPLAND AND PASTURE	1 IRRIGATED – PERENNIAL
	2 ORCHARDS, GROVES, VINEYARDS, HORTICULTURE	2 IRRIGATED – FLOODING
	3 OTHER	3 NON-IRRIGATED

LEVEL 4 (agricultural)

		o/o				o/o
1	CEREALS			8	VINES	
2	FALLOW			9	OLIVES	
3	PASTURE			10	PLUMS	
4	CITRUS			11	POME – GRANITE	
5	PEACHES			12	VEGE – TABLE	
6	APRICOTS			13	FIGS	
7	ALMONDS			14	OTHERS	

Average height of dominant crop

Crop spacing

Colour

COMMENTS

LEVEL 1	LEVEL 2	LEVEL 3
3 FORESTLAND	1 EVERGREEN (primary màquis)	1 CONIFEROUS
	2 OTHER	2 BROAD – LEAVED

LEVEL 4 (forestland)

		no				no
1	Pinus pinnaster			4	Quercus rotundifolia	
2	Pinus halepensis			5	Quercus ilex	
3	Juniperus thurifura			6	Other	

1	< 10 m	
2	10 – 20 m	
3	20 – 30 m	

SPACING

open ☐☐☐☐☐ closed

LEVEL 1	LEVEL 2	LEVEL 3
4 MATORRAL (rangeland)	1 MATORRAL	1 HIGH > 5m
	2 GARRIGUE	2 LOW

LEVEL 4 (matorral)

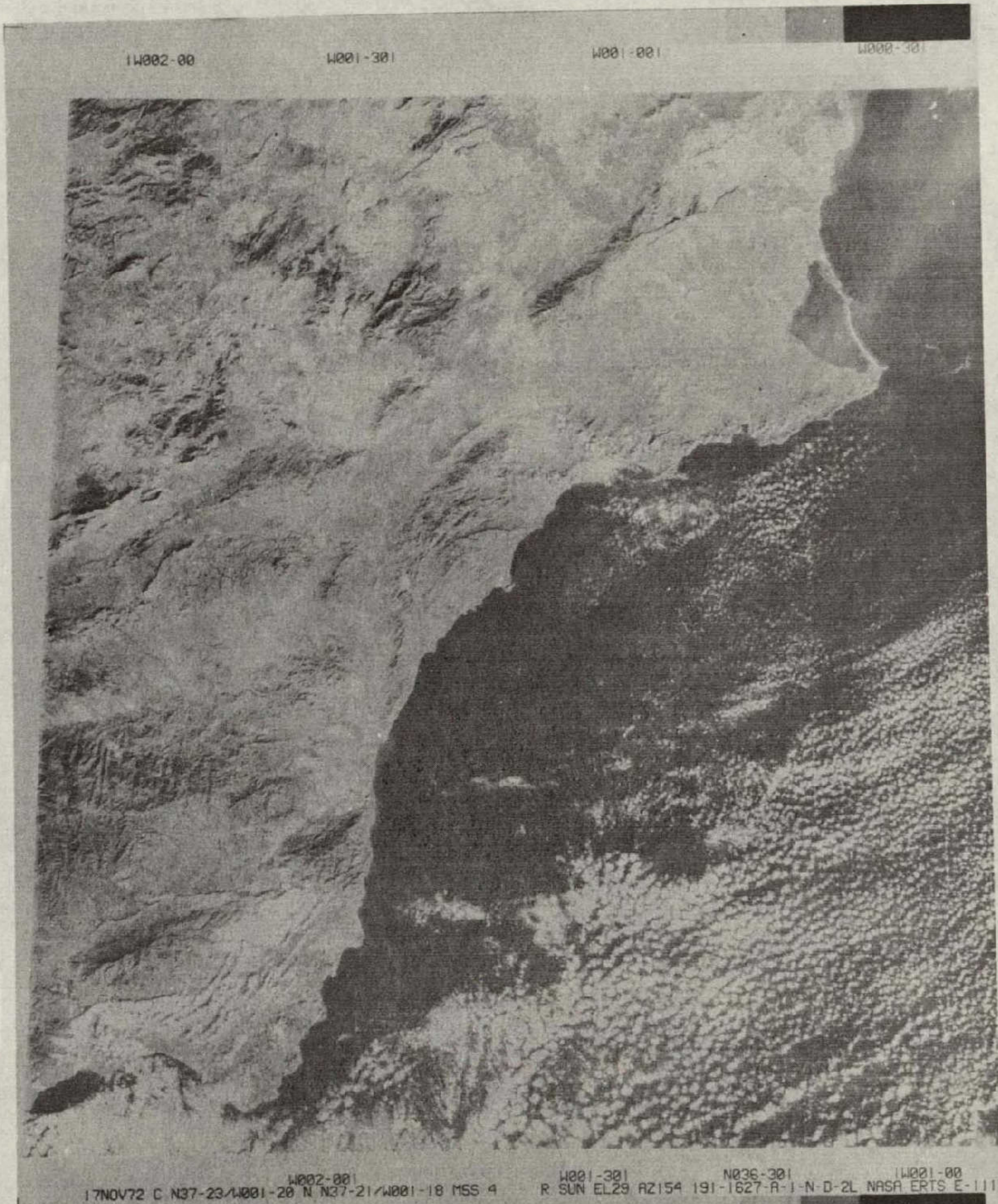
1	Q. ilex	9	Lentisk
2	P. halepensis	10	Buckthorn
3	Wild olive	11	Periploca
4	Carob	12	Tamarix
5	Juniper	13	Erica
6	Tree heather	14	Thyme
7	Q. coccifera	15	Theucrium
8	Rosemary	16	Others(sideritis)

1	< ½ m	
2	½ – 2 m	
3	2 – 5 m	
4	5 – 10 m	

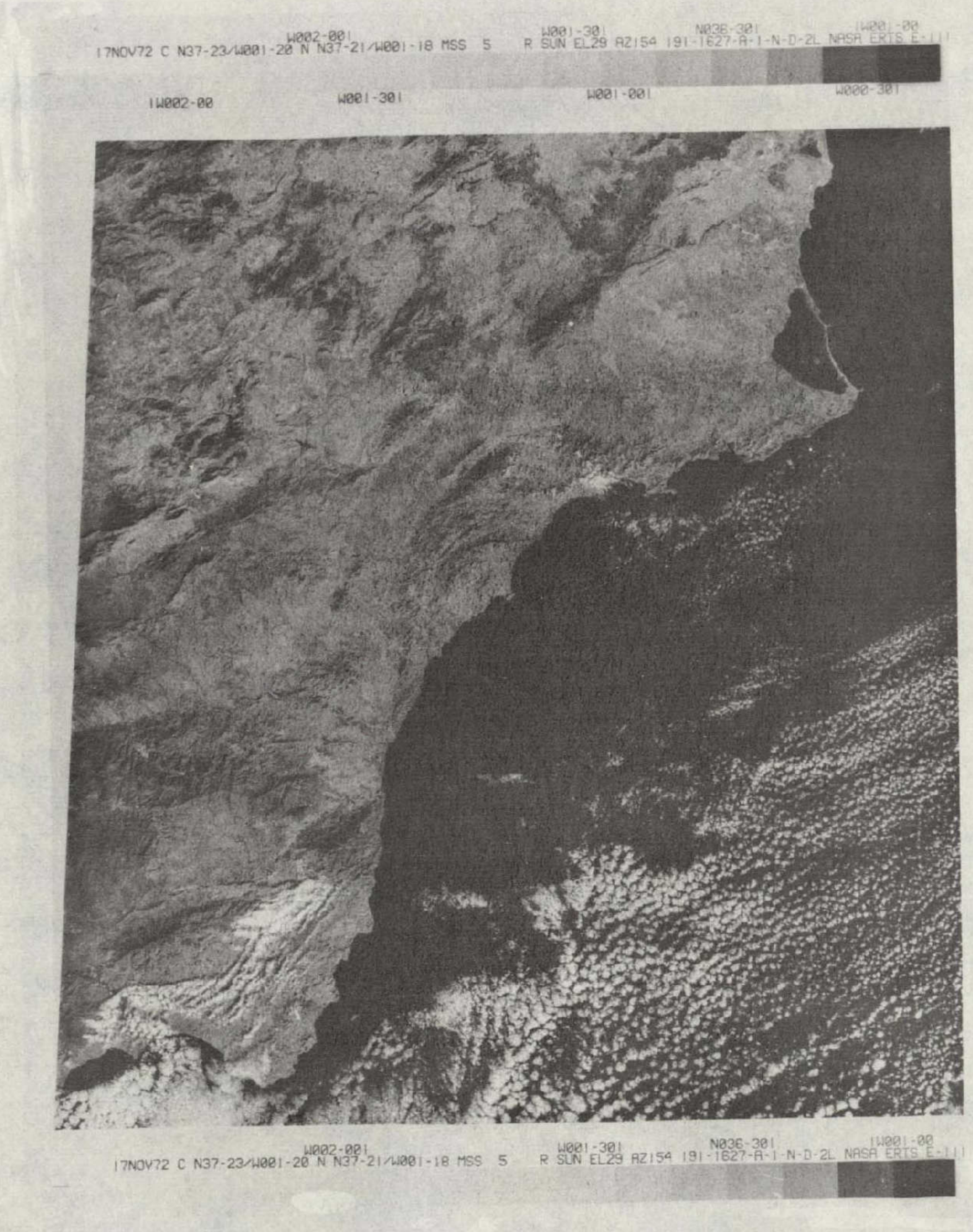
SPACING

open ☐☐☐☐☐ closed

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
5 WATER	1 LAKE		
	2 RESERVOIRS		
	3 OTHER		
6 BARREN LAND	1 SALT FLATS	1 SALT FLATS	1 FRANKENIA
	2 OTHER	2 OTHER	2 SALSOLA
			3 SALICORNIA
			4 OTHER

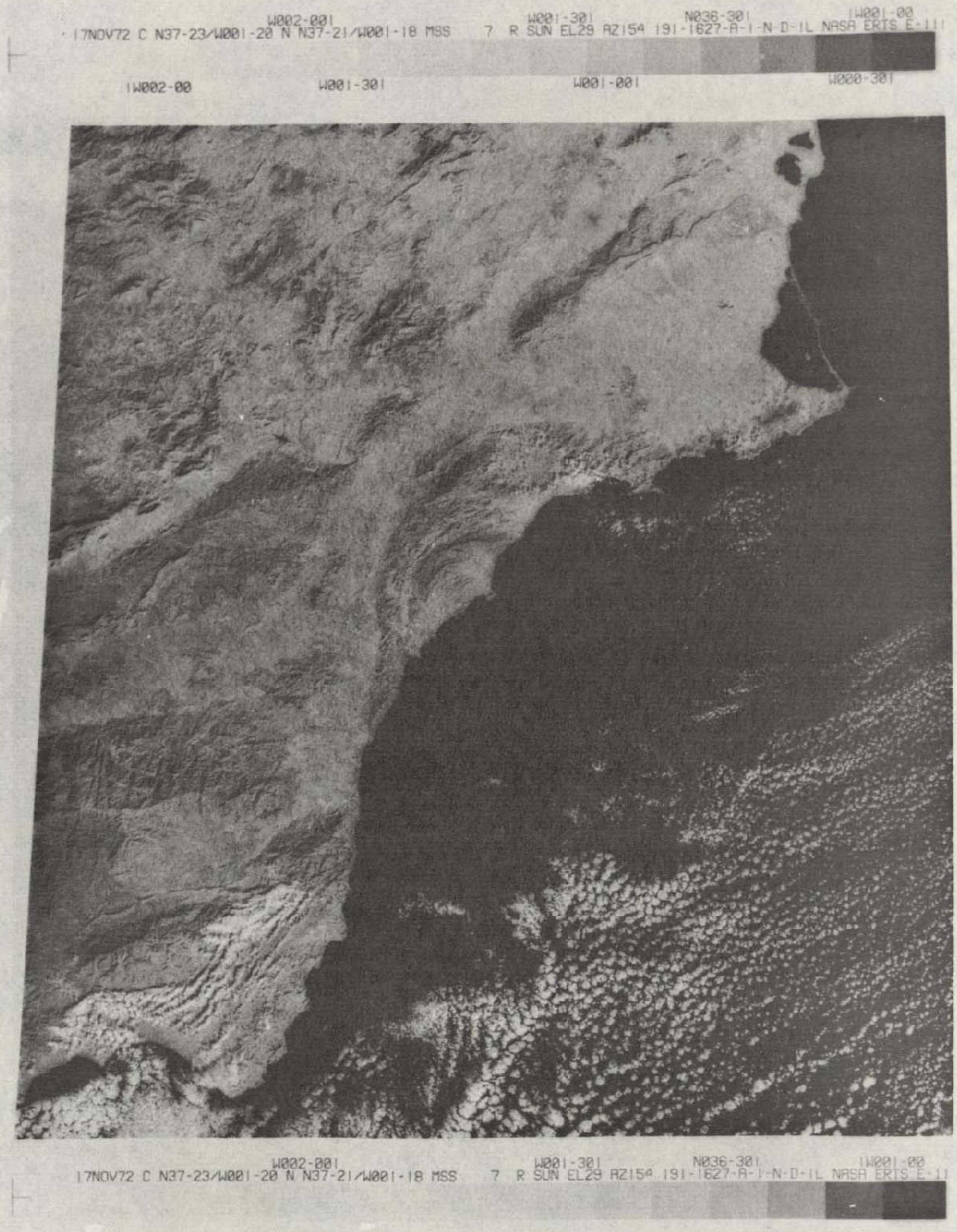


APPENDIX IV (i) LANDSAT MSS frame, Band 4, 17 Nov., 1972 (scale approx. 1:1,000,000).



APPENDIX IV (ii) LANDSAT MSS frame, Band 5, 17 Nov., 1972 (scale approx. 1:1,000,000).

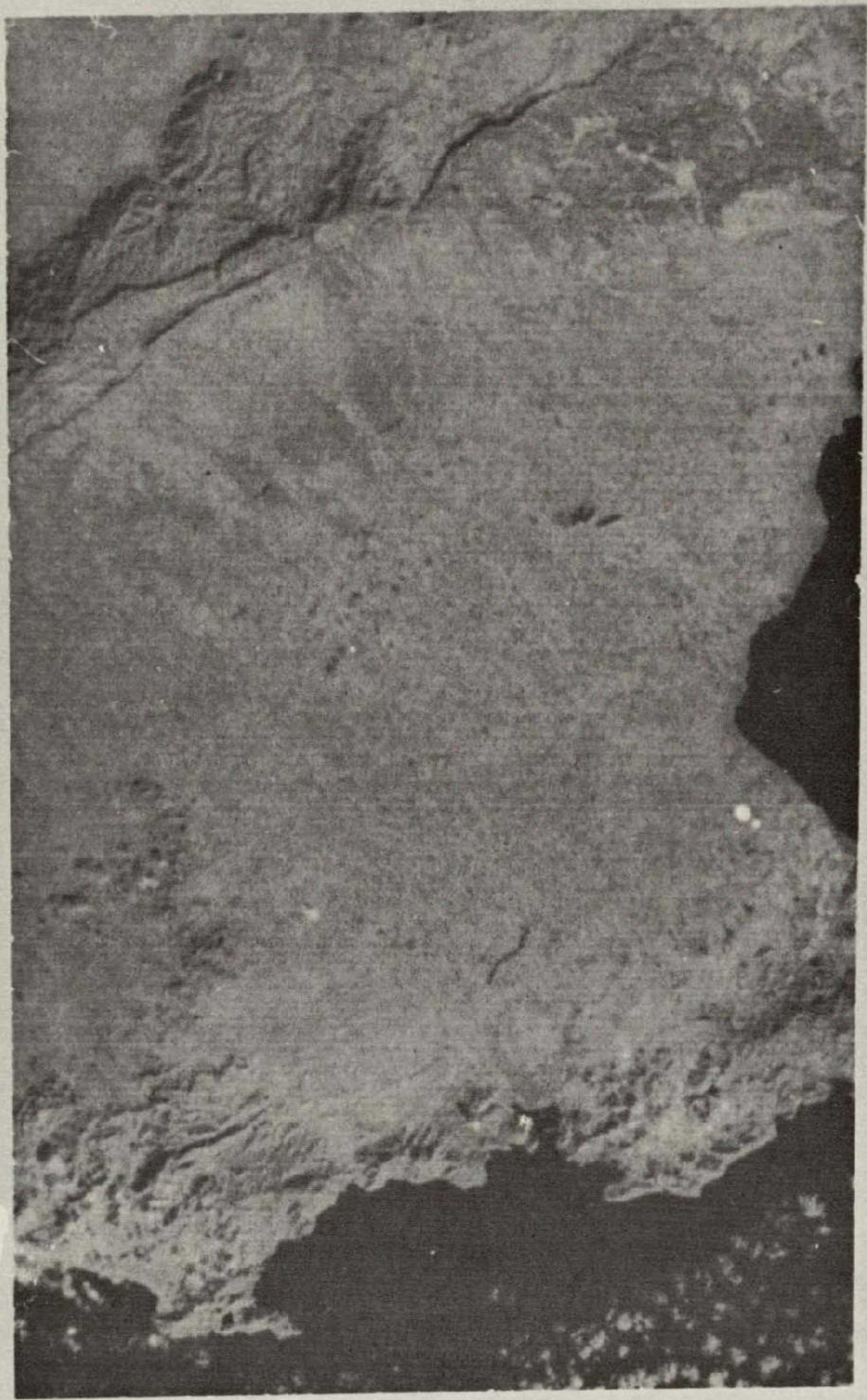
APPENDIX IV (iii) LANDSAT MSS frame, Band 6, 17 Nov., 1972 (scale approx. 1:1,000,000).



APPENDIX IV (iv) LANDSAT MSS frame, Band 7, 17 Nov., 1972
(scale approx. 1:1,000,000).

APPENDIX V (i) Enlargement of portion of LANDSAT MSS frame, 17 Nov., 1972 Band 4 (scale approx. 1:250,000).

APPENDIX V (ii) Enlargement of portion of LANDSAT MSS frame, 17 Nov., 1972 Band 5 (scale approx. 1:250,000).

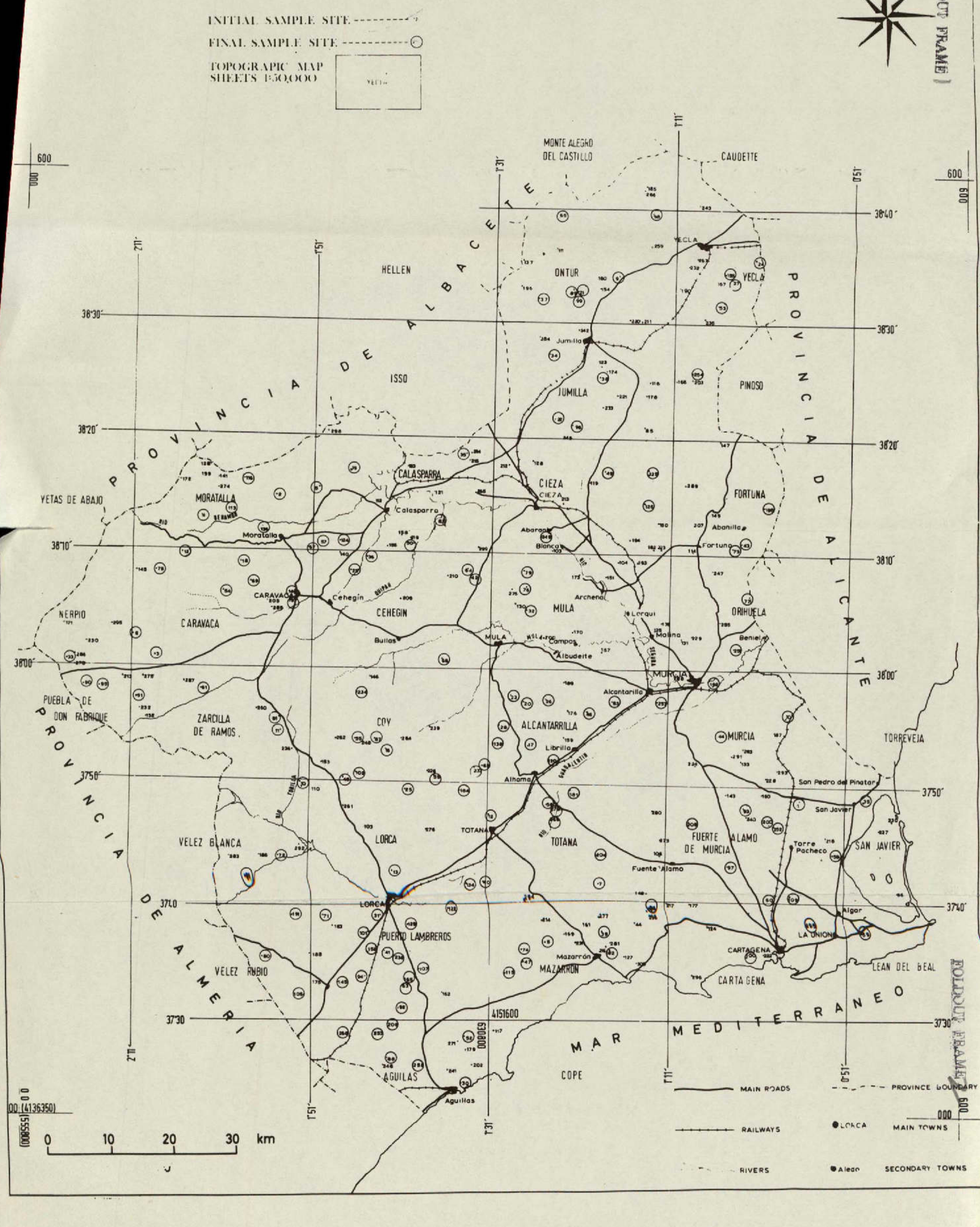


APPENDIX V (iii) Enlargement of portion of LANDSAT MSS frame, 17 Nov., 1972 Band 6 (scale approx. 1:250,000).

APPENDIX V (iv) Enlargement of portionof LANDSAT MSS frame, 17 Nov., 1972 Band 7 (scale approx. 1:250,000).

APPENDIX VI

MURCIA PROVINCE
LOCATION OF SAMPLE SITES

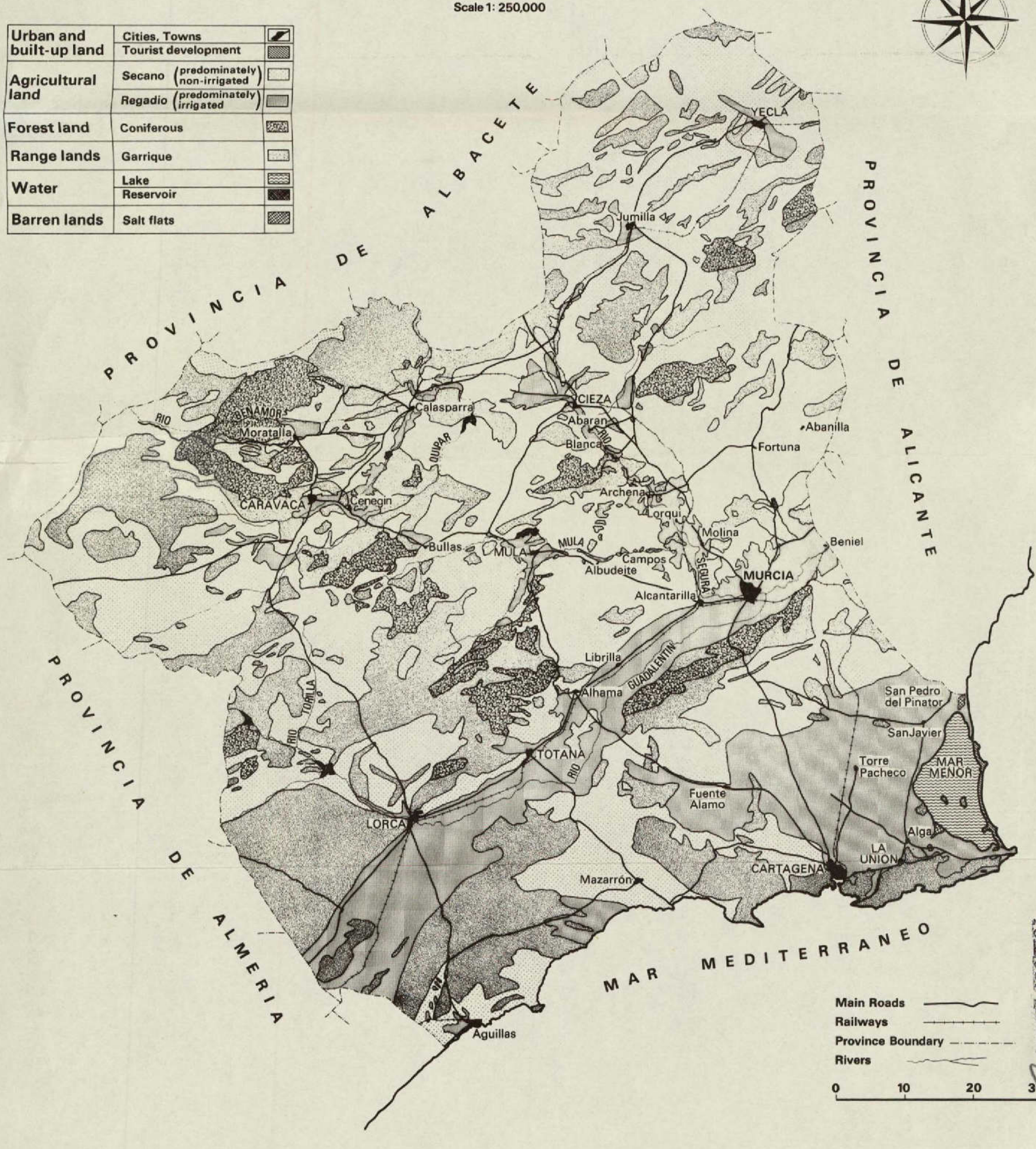


FOLDOUT FRAME 1

APPENDIX VII

Land use Map of Murcia Province

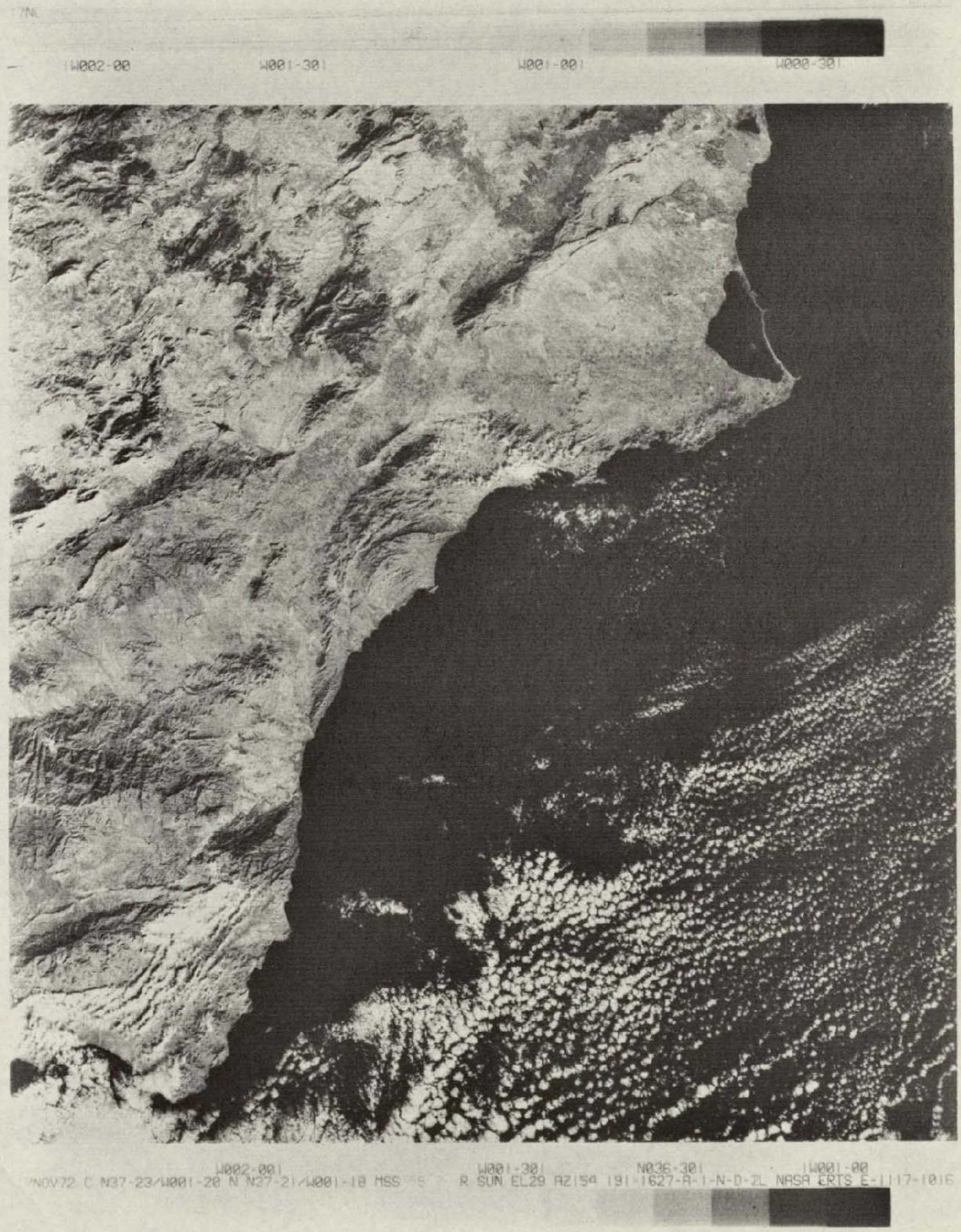
Scale 1: 250,000



285-A

285-B

FOLDOUT FRAME 2



APPENDIX VIII Diazo colour composite of LANDSAT MSS Frame, 17 Nov 1972

(scale approx. 1:1,000,000)

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