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I.	TITLE OF REPORT	: "An Evaluation of EREP (SKYLAB) and ERTS Imagery for Integrated Natural Resources Survey".
II.	PRINCIPAL INVESTIGATOR	: Dr J. L. van Genderen.
III.	ADDRESS OF ORGANIZATION	: Department of Geography, The University, SHEFFIELD, S10 2TN, United Kingdom.
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Summary of Significant Results

An experimental Procedure has been devised and is being tested for natural resource surveys. It has been found that extrapolation away from known ground conditions - a fundamental technique for mapping resources - is very effective when used on orbital imagery supported by field sampling. Meaningful boundary delimitations can be made on EREP images using various image enhancement techniques.

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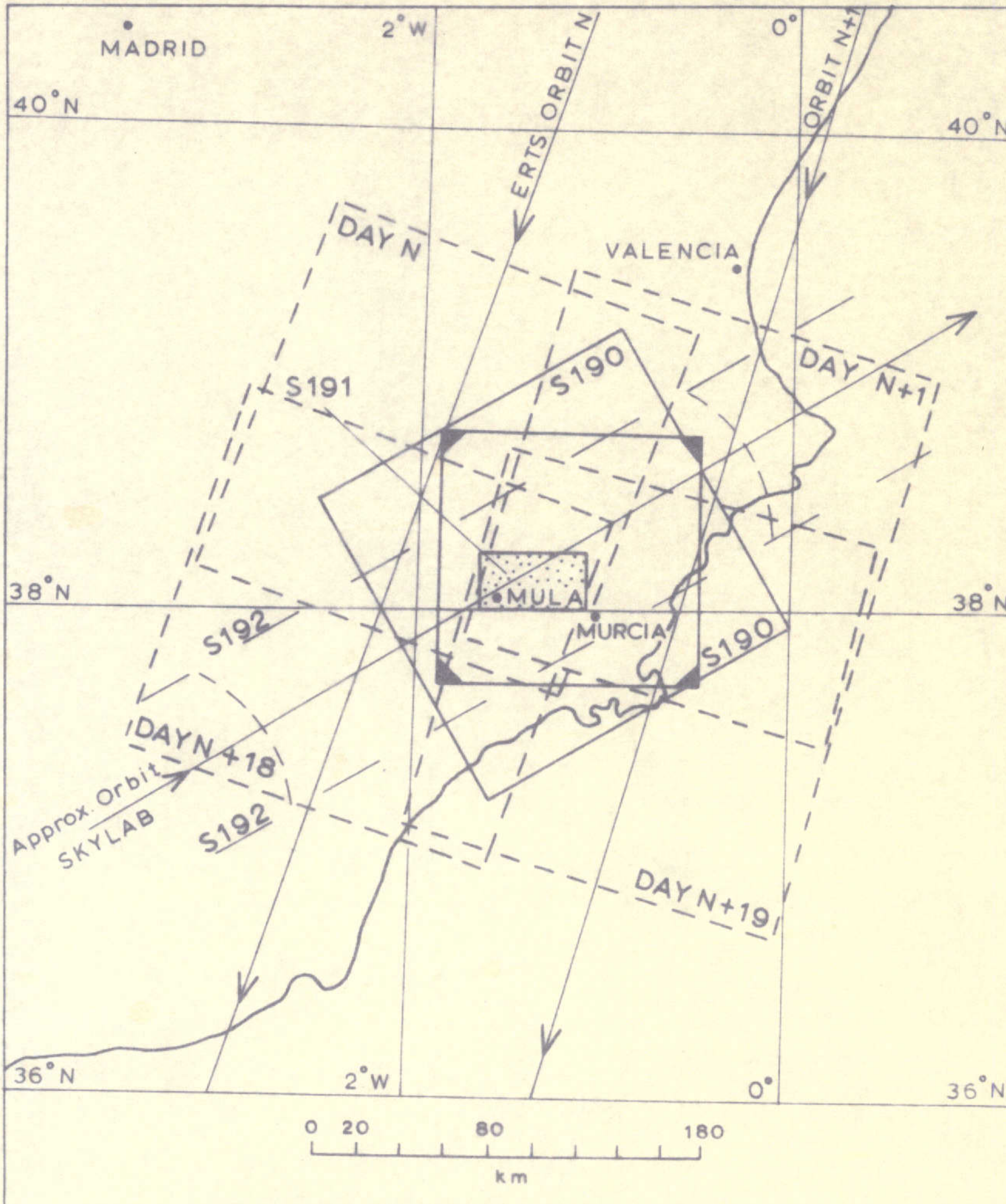
Abstract

An experimental procedure has been devised and is being tested for natural resource surveys to cope with the problems of interpreting and processing the large quantities of data provided by SKYLAB and ERTS. Some basic aspects of orbital imagery such as scale, the role of repetitive coverage, types of sensors, etc. are being examined in relation to integrated surveys of natural resources and regional development planning. Extrapolation away from known ground conditions - a fundamental technique for mapping resources - becomes very effective when used on orbital imagery supported by field sampling. Meaningful boundary delimitations can be made on orbital images using various image enhancement techniques. To meet the needs of many developing countries, this investigation into the use of satellite imagery for integrated resource surveys involves the analysis of the images by means of standard visual photo interpretation methods.

As a result of the UNESCO sponsored International Postgraduate Course in Applied Geomorphology and Natural Resources Research, an investigation is being carried out by staff members of the Department of Geography, University of Sheffield, on the methodology of integrated surveys of natural resources using orbital imagery in the Murcia Province, S.E. Spain. Figure 1 shows the location of the investigation area of approximately 30,000 km2. The detailed Mula test site within this has an area of slightly less than 2,000 km2. The Mula test site has been mapped and classified into 200 'land units', these being characterized by a narrow range of variation in landform, soil and vegetation. These land units are represented by a characteristic appearance on the vertical panchromatic aerial photographs (1:31,000). The land units were subsequently built up and grouped into 40 types of terrain 'land complexes' employing a modified version of the C.S.I.R.O's 'land systems' approach (C.S. Christian and G.A. Stewart: 1968). The recurrence of a number of units within a land complex in a regular pattern gives rise to the distinctive recurring tonal pattern on the aerial photographs. The recognition of these distinctive photo patterns is an integral part of the type of reconnaissance survey carried out. A very extensive literature exists on the subject of aerial photographic interpretation of natural resources (e.g. M.G. Bowden: 1967; J.J. Nossin: 1971; UNESCO: 1968; A.P.A. Vink: 1967; R.L. Wright: 1971). This paper confines itself to those aspects which are related to orbital image interpretation of integrated resource surveys at a regional reconnaissance level (P.C. Badgley and W.L. Vest: 1966; J.L. van Genderen: 1972; F.J. Wobber: 1972; R.A. van Zuidam: 1971).



Approx. Orbits on two consecutive days, every 18 day period

160 km² RBV Frames

Test Area - Murcia Province

Mula Test Site

Major Cities and Towns

SCALE

Scale is a most important element in the recognition of the terrain features used in resource surveys, as the scale of the image determines how large a particular feature will appear on the image, and also the number of images required to cover a given area. In many of the vast areas of Africa, Asia, Australia, Central and South America, photography at a scale of 1:40,000 to 1:80,000 has been used effectively for preliminary reconnaissance of the resources of the area. In S.E. Spain, aerial photographs at a scale of 1:31,000 were used. This scale has been found to be less satisfactory, because there are more photographs to handle at all stages, the area covered by each photograph is relatively small so that deductive interpretation is more difficult, and also, the air photo patterns are diffuse and not easily recognized and mapped. Some of the important advantages of the orbital imagery for mapping earth resources have been found to be, therefore:

(i) The synoptic view of large areas. The data provided by ERTS is in the form of images covering an area of 160 x 160 km. Thus one image covers almost the whole study area for which 1,000 aerial photographs would be needed (see Figure 1). This ability to observe large areas under relatively uniform conditions serves to reduce the number of variables that affect the interpretation and use of imagery, such as tonal changes between photographs, thereby facilitating extrapolation away from known ground truth areas - a fundamental technique for the rapid mapping of natural resources.

(ii) The reduced volume of data per unit area. A single synoptic image from either EREP (SKYLAB) or ERTS presents information contained in many hundreds of images from the conventional coverage of the area. Thus the handling and making of mosaics, a major cost factor in resource surveys is greatly reduced.

(iii) Accessibility to remote areas. The satellite images provide a means for the cyclic monitoring of large areas remote from human observation, so that areas which are difficult or impracticable to observe by other means, are brought into view for fuller understanding.

Since the objective of reconnaissance surveys is to make rapid inventories of the resources of large areas, the scale of mapping that was found to be most appropriate in this area was in the range of 1:100,000 to 1:250,000, although for larger areas scales as small as 1:500,000 have been used. The value of mapping earth resources from orbital images is therefore obvious. The average size of a land complex mapped in the Murcia area was 50 km2, so that all the land complexes are of sufficient size to be readily identifiable on orbital imagery, even that with a relatively low ground resolution. Many of the land units are also clearly defineable on orbital images. A definite advantage of the method of land complex mapping for resource surveys developed in Sheffield, is that it can be applied to orbital imagery, even though with small scale satellite images the size of the minimum area that can be mapped and recognized as a discrete unit becomes larger. This is so because the basic unit, the 'land unit' is recognized and measured in the field, and subsequently built up into the 'land complexes' which may be readily mapped on the orbital images. So, while it becomes almost impossible, for example, to discriminate between small fields - common in many developing countries, it is nevertheless possible to identify the whole complex of fields from the orbital images and map these, since the internal variations and characteristics of the land complex (such as the nature, shape and size of individual fields, slope, lithology and soil characteristics, etc.) have been obtained by field checking using standard statistical sampling methods and air photo extrapolation techniques. These methods have been developed because of the prohibitive costs of a complete inventory, as well as the long time that this would involve.

The field work area is located in a semi-arid environment which is, in many respects, similar to the Basin and Range province of southwestern U.S.A., especially the northern half of the project area. Here, dissected, isolated mountain ranges are girdled by extensive footslopes, with enclosed interior drainage basins, many having salines or playas in their centre. Thus, in preparing for the receipt of the orbital imagery of S.E. Spain, present research has been concentrated on the interpretation and analysis of orbital images (ERTS-A, APOLLO, GEMINI) of S.W. United States. Because of the similarity of environmental conditions in S.E. Spain and Arizona, it is anticipated that the images will be able to help in the analysis and planning for the extension of existing cultivated land and the opening up of new areas in the Murcia Province. On the basis of the results obtained from ERTS-1 all the new irrigation canals, pipelines, etc. under construction as part of a large development project to increase the irrigation capacity in the area, will be able to be identified and mapped using orbital imagery.

A basic aspect of orbital imagery which needs to be examined in relation to earth resource investigations is the role of repetitive coverage. This is a factor which has seldom been fully appreciated by those bodies concerned with physical resource inventories and management planning. The repetitive coverage of both ERTS and EREP sensors will allow an almost complete record of the changes in agriculture, seasonal run-off, soil moisture conditions, etc. to be accurately monitored. Repetition also makes possible the acquisition of data previously excluded for various reasons. In the Murcia area, the present investigation will trace and examine the developments and changes in the agricultural pattern. This is particularly valuable in semi-arid areas, as the agricultural potential here is limited by water-shortage. The effects of the irrigation projects underway to increase the irrigation capacity of the Murcia Province, by bringing water into the area over a distance of several hundred kilometres will, in this way, be under constant review.

To compensate for the small scale of the orbital images, emphasis in this project has been placed on those image enhancement techniques which lend themselves to magnification, such as the use of Agfa Contour Equidensity film, the Image Quantizer and the Isodensitracer. Second order Agfa contour pictures are easily magnified, as they consist only of black lines on a white background, so that the picture does not 'break up' as quickly as occurs when enlarging an original orbital image. The Image Quantizer recordings, which plot the various tonal densities of orbital images can also be greatly magnified without loss of detail, even though the original recording is made at a scale ratio of 1:1. The Isodensitracer has been found to be particularly useful for small scale orbital images, as this can magnify to the extent of 1,000 to 1.

TYPES OF SENSORS

Such an enormous amount of different image types of the same area will be available from the EREP (SKYLAB) and ERTS sensors (Table 1), that it is claimed that materials such as crops, lithologic types, soils, etc. can be recognized on the basis of characteristic spectra of electromagnetic radiation. Thus present field surveying techniques in the Murcia area include the collection of ground truth data (P. Chapman and P. Brennan: 1969) which is being incorporated in a data bank system so that computer print-outs can later be obtained separating, for example, wheat from other crops. One of the main problems being encountered at present is the difficulty in obtaining compatibility between the orbital image and the ground truth information. One of the reasons for the difficulties being encountered in correlating the imagery with the ground truth information is the problem of interpreting the tonal differences on the images. While these differences may be easily measured and mapped using the techniquess discussed below, areas with similar tonal values do not always represent areas with similar ground characteristics, and vice versa, so that appreciable errors in interpretation can arise, once again indicating the need for detailed field information. To overcome this problem to a certain degree, arrangements have been made with several Spanish research organizations in Murcia to record detailed ground data in carefully pre-selected sample areas on those days that the satellites pass over the area.

A study of several simulated multi-spectral orbital images provided by NASA has shown that for orbital surveying of the earth's resources to be fully utilized, it is necessary to pay special attention to such aspects of spectral resolution as the position and number of bands, width of bands, etc. Another factor to consider is the difference between the RBV and MSS images, for whilst the former has a central projection, the latter uses a line scan technique. On the basis of an examination of ERTS-A orbital photographs, it is considered that the ERTS' RBV images allow for the stereoscopic study of the images (Figure 1). Although the impression of relief is seldom great, the

SPACECRAFT : EREP (SKYLAB) - Earth Resources Experiment Package.

SENSOR : S 190 - Multispectral 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 (Hi Res. Colour)

SENSOR : S 191 - Infrared Spectrometer.
Spectral bands : 0.4 - 2.4 μ
6.2 - 15.5 μ

SENSOR : S 192 - 13 band multi-spectral scanner.
Spectral bands : 0.41 - 0.46 μ 0.98 - 1.08 μ
0.46 - 0.51 μ 1.09 - 1.19 μ
0.52 - 0.56 μ 1.20 - 1.30 μ
0.56 - 0.61 μ 1.55 - 1.75 μ
0.62 - 0.67 μ 2.10 - 2.35 μ
0.68 - 0.76 μ 10.2 - 12.5 μ
0.78 - 0.88 μ

SENSOR : S 193 - Microwave system.
Spectral band : 13.8 - 14.0 GHz

SPACECRAFT : ERTS - Earth Resources Technology Satellite.

SENSOR : RBV - multispectral TV camera system.
Spectral bands : 0.475 - 0.575 μ
0.580 - 0.680 μ
0.690 - 0.830 μ

SENSOR : MSS - Multispectral 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 1 : Types of Sensors with their Spectral Bands of EREP and ERTS Satellites.

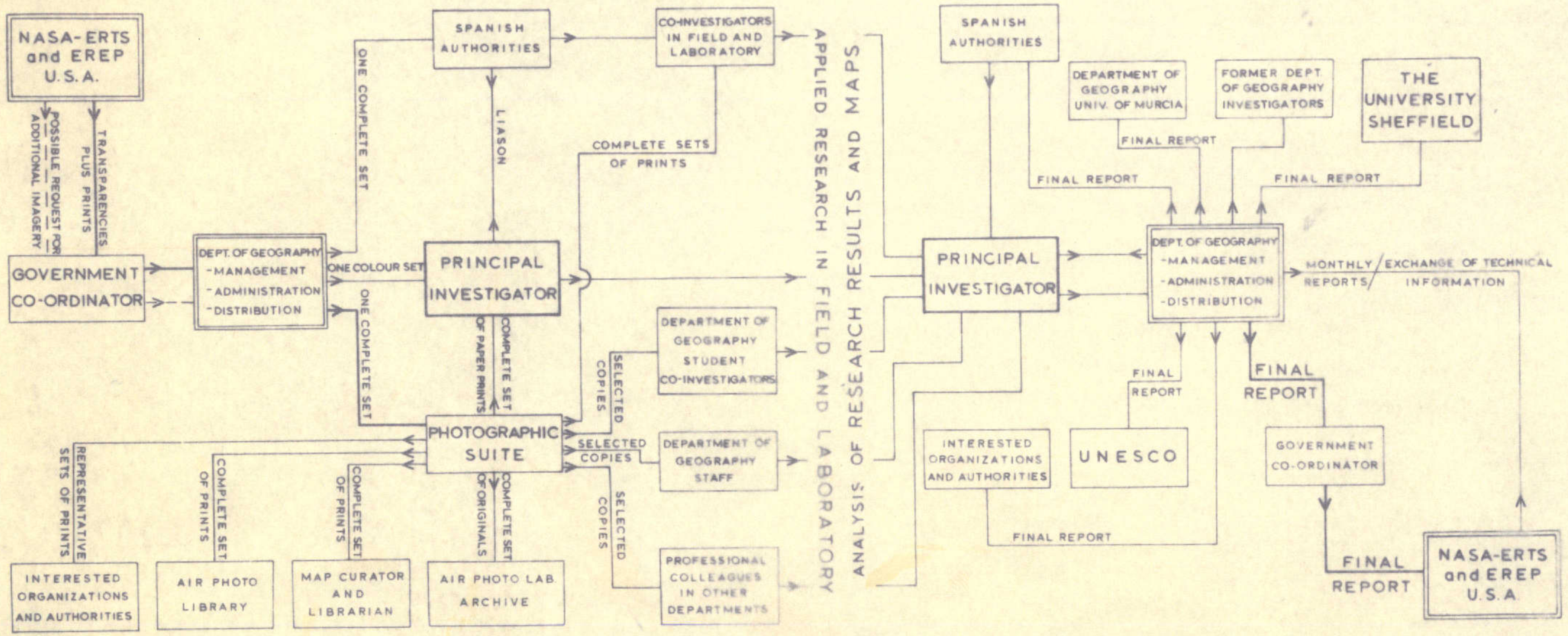
ability to view the images stereoscopically, or at least to obtain binocular fusion, greatly reduces the signal-to-noise ratio. This is so partly due to the use of twice as many silver grains to form the composite image, and partly to the benefits that result from 'binocular reinforcement' when assigning one good eye to the study of one image, and another to the study of its stereo mate. The excellent stereoscopic vision obtainable in low latitudes, from the ERTS' RBV camera system, and praised by many workers at the NASA meeting on the Evaluation of ERTS-1 capabilities, is due to the fact that the stereo-effect depends on latitude, in that near the tropics, where side overlap is minimal - due to the orbital characteristics of the satellite - relief displacement is greatest in this narrow overlapping zone. By contrast, in polar latitudes, where the overlap is much greater, the impression of stereo is markedly less, due to the change in the base-height ratio. Using the RBV images, allows much detailed interpretation to be carried out using simple mirror stereoscopes. Especially useful in this respect is the Zeiss Jena Interpretoscope, which, with its rotating optical axis (for orientation differences), zoom optics, differential magnification (up to x15), ability to view prints and transparencies, and ability to fuse several pairs of RBV images simultaneously, etc. is ideal for image mixing and is a cheap, fast, and effective method of image enhancement analysis.

DATA HANDLING AND PROCESSING

Despite a reduction in volume of data per unit area, the satellites will generate vast volumes of data of the Murcia area through their repetitive flights and many image types. Such a profusion of data will create new and complex problems of data handling, analysis and use (Figure 2), such as problems in sorting the useful data, monitoring changes, and the systematic recognition of objects and phenomena.

In order to prepare for this anticipated problem of handling and processing the data, an experimental procedure has been devised and tested for natural resource surveys, in that the new images, together with the need for some form of automation have led to the development of several new techniques to aid in the evaluation and mapping of resources.

FIG. 3: FLOW DIAGRAM NASA TO PRINCIPAL INVESTIGATOR, DEPT. OF GEOGRAPHY, UNIVERSITY OF SHEFFIELD, U.K., AND BACK TO NASA



Of great importance in this respect are the grey and colour tones, which can only be qualitatively assessed by eye. Hence Agfa Contour Equidensity film, an Image Quantizer and a three colour Isodensitracer have been used as well as a micro-densitometer, for the quantification of tonal values and the detection of spectral signatures, as these methods allow visual as well as quantitative interpretations to be made.

The fundamental image characteristics which the photo-interpreter uses for identification and analysis are tone, texture, pattern, shape, size, shadow, association and orientation. In photographic terms, variation in tone, or density, is the common factor which constitutes the whole image, thereby making possible the perception of the other image characteristics. Although microdensitometer readings from various targets in a given spectral region imaged on photographic film cannot be compared on an absolute basis with readings in another region, the relative ordering in each spectral region tends to be invariant. Experiments have shown this to hold true for natural targets such as soil, vegetation and rock type. This characteristic relative ordering furnishes a type of spectral signature which can be used as a discriminating functional property of great value to natural resources surveys of large areas from orbital imagery, especially because of the 13 narrow wavelength bands to be used in the MSS scanner of EREP. Experiments of simulated orbital imagery have shown that consistent reflectance differences were obtained only if very narrow wavelength intervals were used. There is still the need for much ground truth against which to establish these results.

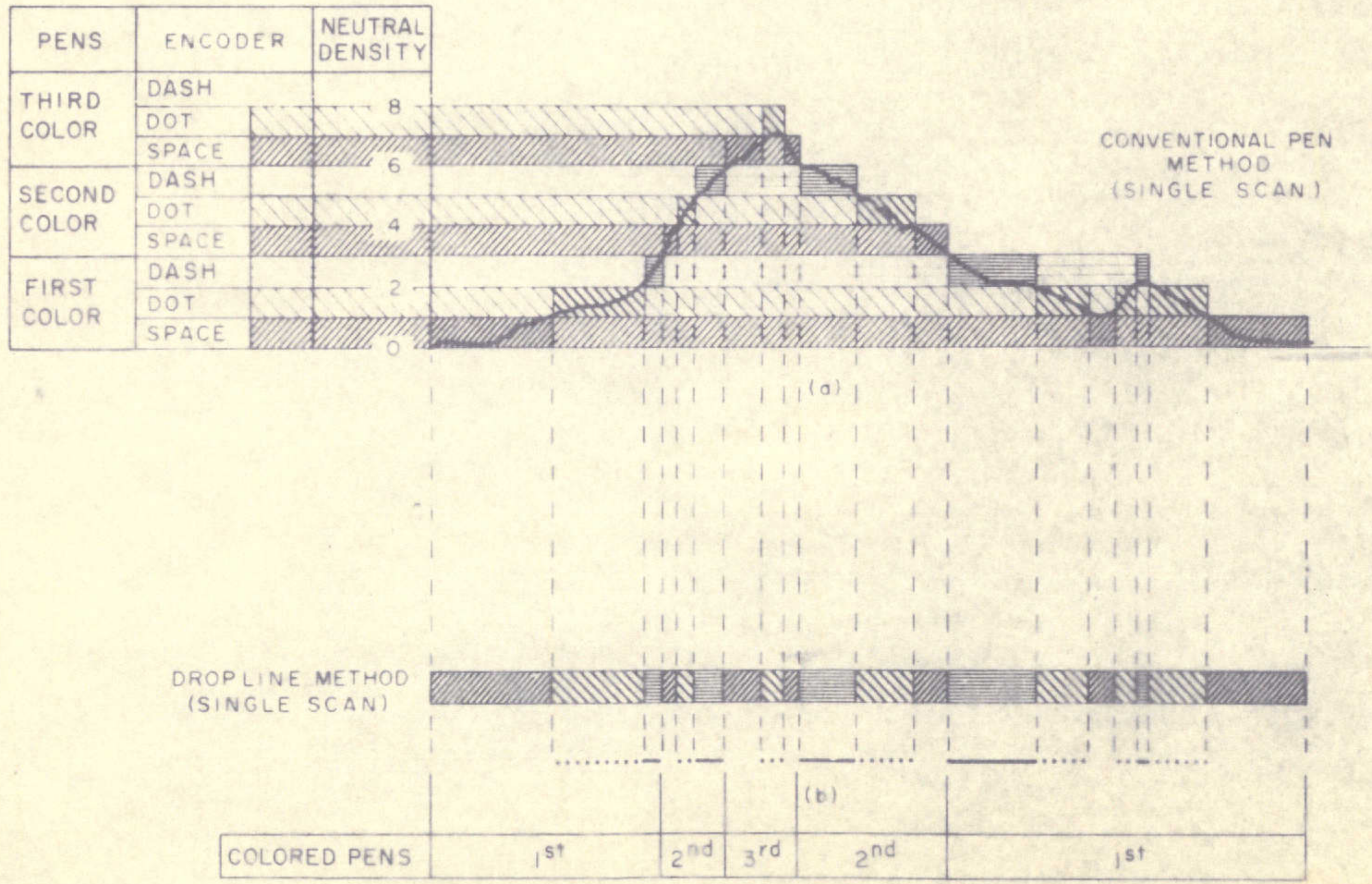
The principle, techniques and applications of Agfa Contour Equidensity film have been well described by E. Ranz and S. Schneider (1971) in a paper presented at the 7th International Symposium on Remote Sensing of Environment, so that these need not be discussed in this paper. Using

Agfa Contour, it is possible to examine the entire density distribution of an original by making several separate equidensities and arranging these subsequently in register to make a family of equidensities. However, in this study, it has been found that in many cases the increase in information obtained from a single first order equidensity (by making one copy of an original) is adequate, especially if a second order equidensity picture is made from the first order equidensity image. A whole series of equidensities taken with different exposure times therefore, especially when used with all or selected bands of the 13 band multi-spectral scanner in SKYLAB, will provide identification of various crop types.

One of the main methods of the approach used in Sheffield for integrated resource surveying is boundary delineation of photo patterns as a precursor to area typing for resource mapping. Boundaries of the land complexes are often more easily detected on orbital imagery than on photo mosaics. Most boundaries drawn on orbital imagery have been found to be indicators of real differences in environmental conditions, so that these may be used to select the field sample areas. While some boundaries are diffuse or transitional in terms of tonal density, Agfa Contour Equidensity film highlights these very subtle changes. However, while most boundaries drawn on orbital images no doubt result from changes in one or several terrain features, it has been observed that these boundaries are not always significant, and hence the boundaries should always be checked against the results of the field sampling and the land complex boundaries as plotted on the aerial photographs.

The Image Quantizer also provides useful data for reconnaissance surveys, as this instrument will plot the tonal density range of an image - both prints and transparencies up to 23 x 30 cms. in approximately 5 to 7 minutes. Up to 20 isodensity contours can be plotted, with the difference between isodensity contours continuously variable over the range 0.02D - 0.16D. This makes it ideal for rapid, preliminary examination of areas of interest. A similar effect to that obtained by taking single first or second order Agfa Contour Equidensity images can be obtained quickly by this instrument in that the recording threshold may be set to any level. The density range of the isodensity contours can be varied so that only objects of the required density are recorded, those with densities below or above these being eliminated, simplifying the image for subsequent interpretation.

A three-colour Isodensitracer has also been used for detailed examination of tonal differences, as this instrument can plot up to 50 different density contours. A four-colour Isodensitracer also exists which can plot up to 64 density contours for even greater image enhancement so vital for small scale orbital image analysis. The three-colour instrument automatically scans and measures the density of all points in a film transparency and plots the values as a quantitative, three-colour two-dimensional density map of the scanned area. The Isodensitracer uses the 'dropped line' technique, rather similar to that used in the production of orthophotographs. This technique is illustrated in comparison to a conventional pen method in Figure 3. This shows that as the density increases, the first coloured pen scribes a sequence of space, then dots, then dash. As the density continues to increase, the second coloured pen is activated and produces space, then dots, then dash and so on. When the density decreases, the above given sequence reverses. The pattern produced on the recording paper makes it obvious whether the density is increasing or decreasing as the write-out method changes. The large magnification ratios available make this instrument ideal for studying tonal variations on orbital images, as the visual recording lends itself to easy field checking to determine the significance of the tonal variations.



Comparison of Conventional and Dropline Write-Outs

-15-

More information is contained in an image than the normal interpreter is able to detect with accuracy and confidence within a reasonable time. Even though normal objects seldom exhaust the enormous recording capacity of the sensors, reduction of image information into useful, accurate data in a short time is most essential in the case of many earth resource subjects. With the enormous amount of imagery data that will be made available by the EREP and ERTS sensors, the need for quick and reliable processing of the image information, instrumentally if possible, assumes great significance. Hence in the present study, both a Freescan Digitizer and a Particle Size Analyzer are being used as well as the techniques outlined above, as these are considered to be most useful for earth resource surveys using orbital imagery. With the digitizer, the location and areas of the various mapping units can be quickly and quite accurately calculated. The digitizer is also considered to be invaluable in studying structural features on orbital images such as the gross pattern of structural lineaments of an area, as well as other types of linear features such as roads, irrigation canals, etc. Tests carried out show that the particle size analyzer can be very useful for measuring the individual particle sizes of objects (such as fields, land units, land complexes, etc.) and for determining their distribution, as the many images over many spectral bands contain thousands of objects which need to be measured. Using the particle size analyzer, the dimensions and areas of about 500 objects can be measured in half an hour. However, since the eye participates in the measuring process, the diameter of the object to be measured should not be less than 1 mm. The measuring range of 1.0 to 27.7 mm. has been found to be ideal for most objects on orbital images of relevance to natural resource investigations. If the object falls outside these limits, enlargement or reduction of the image has to be made. The rapid recording and monitoring of changes in agriculture, forest clearance, and other aspects of the landscape related to integrated resource surveys can, therefore, be made from orbital images.

As well as the many semi-automatic, quantitative image enhancement techniques, the Department's work involves understanding the needs of developing countries with regard to the use of orbital imagery for natural resource surveys. These countries, due to lack of funds and trained personnel, usually prefer simpler methods. Thus one of the main aspects of this investigation into the use of orbital imagery for integrated resource surveys involves the development of techniques of image analysis by means of standard visual interpretation methods, detailed examination of image characteristics, image mixing, and using various kinds of mirror, scanning and zoom stereoscopes.

The experimental procedure developed in Sheffield for the use of orbital imagery in integrated surveys of natural resources involves the following phases (Figure 2):

(i) Pre-field interpretation of the orbital images and aerial photographs of the Murcia area for planning the sampling and traversing procedure to be adopted in the field. Preliminary boundary delimitation of the image patterns.

(ii) The construction of orbital and aerial mosaics of the area for use as base maps during field work.

(iii) Field work. The measurement and collection of field data in selected sample areas for compiling the list of land units and land complexes, for the establishment of ground truth sites against which to calibrate the information provided by the imagery, and for the extrapolation of this information into surrounding areas.

(iv) Standard and semi-automatic interpretation techniques including the use of such instruments as various kinds of stereoscopes, a microdensitometer, an image quantizer, an isodensitracer, a freescan digitizer and a particle size analyzer to facilitate extrapolation and the marking of boundaries.

(v) Plotting the land complex boundaries on the orbital images or on enlarged sections thereof by using the Zeiss Jena Interpretoscope.

(vi) Final quantification of results, the compilation of the resource maps, management proposals, reports, etc.

These phases may, of course, be changed or others added as more experience is gained in handling and interpreting the orbital imagery. Using this procedure, orbital images provide a useful synoptic supplement to most of the established applications of aerial photography in the field of natural resource surveys. On the basis of the results obtained to date in experiments, the quantitative and image enhancement techniques, as well as the more elementary methods of steroscopic or binocular examination of the images, the mixing of different image types, etc. should all be able to provide the earth scientist using orbital imagery for his resource survey, with much useful data.

The territory of developing countries is usually strongly differentiated with respect to the spatial exploitation of known natural resources. One of the main features of developing countries is that they are characterized by having a dual economy, i.e. by a simultaneous existence of some modern and very backward sectors which display a different spatial pattern. The regional approach to national development, by utilizing data from ERTS and SKYLAB, makes it possible to deal with the differentiated regions and their problems individually without losing the national perspective which the orbital data also provides, and consequently, to apply the most effective measures for further development to each region.

As a pre-condition to accelerated growth, the developing countries must acquire a certain level of infrastructure in the forms of roads and railways, port and storage facilities, power sources, communication networks, water supply facilities, etc. Again, the location of these can be determined in the early stages of development using the orbital data provided by ERTS and SKYLAB, especially if this is done within the framework of a comprehensive regional development scheme such as outlined in this paper.

CONCLUSIONS

While the synoptic views of satellites have been shown to provide a major input into the recognition, exploration and management of resources, the demand for detailed data from conventional airborne surveys will increase rather than decrease with the use of space surveys. This is so because the interpretation of the EREP and ERTS data will require detailed knowledge of representative natural and cultural features on the surface of the earth in order to establish spectral signatures. The Mula test site in the Murcia province is one such test area being investigated by conventional field and air survey methods by the Geography Department in Sheffield, but many others remain to be identified. As applications to resource surveys for orbital data evolve, the need for such calibration or ground truth sites, as well as the essential ground and air surveys will increase. Thus future applications of remote sensing to resource development are considered to require a careful blending of space and airborne surveys to realize the goals of resource missions. However, as pointed out, their realization will be dependant upon the solution of the escalating problems of data retrieval, processing dissemination, and the determination of spectral signatures. An increasing number of techniques and procedures, several of which have been discussed in this paper, are now available to meet these problems.

Aerial and ground surveys, therefore, are essential to our understanding of the remote sensors and to the significance of the orbital observations. In the Murcia area, in preparation for the space flights, laboratory tests have been used to select and determine useful parameters for integrated surveys to assess and evaluate certain quantititative as well as qualitative techniques of interpretation and mapping, and to define applications. With this type of framework, it is considered that one will be able, systematically, to use aerial and ground surveys to follow up orbital data in the same way that one now uses field surveys to verify aerial observations.

ACKNOWLEDGEMENTS

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