AN EVALUATION OF MULTISPECTRAL AND MULTI-EMULSION AERIAL PHOTOGRAPHY FOR SOILS, VEGETATION AND LAND USE MAPPING

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October 1975

SUMMARY

This thesis evaluated multispectral and multi-emulsion (i.e. false colour, true colour and panchromatic) photography for various types of earth resources survey, primarily soil survey. Two test areas in upland Britain were used, one in Cumbria and one in North Yorkshire.

Only one set of multispectral photographs became available, covering the area in Cumbria, at 1:15,000 scale. False colour vertical aerial photographs of both areas were taken at two different seasons (October/ November 1973 and May 1974), also at 1:15,000. The available panchromatic photographs were at different scales and dates. The multispectral photography was analysed using a stereocope, and an additive viewer, and false colour photography was analysed using a stereoscope. Attempts were made to analyse the tones on the multispectral photography by densitometry, and on the false colour photography by densitometry and by the ISCC-NBS centroid colour charts. The lack of success of these experiments indicated that the methods could not be considered operational.

It was found that soils could not be mapped directly from aerial photographs, whatever type of emulsion was used, ant it was recommended that panchromatic aerial photography be continued to be used for soil surveying. The multispectral photography had too many disadvantages to be of use for many types of survey and it is possible that these defects are inherent in the multispectral system. False colour photography was found to be useful and, on the whole, superior to both panchromatic and multispectral emulsions for vegetation and land use mapping. However, it is important to choose the appropriate time of year for aerial photography and the use of ground photography is recommended to help predict the correct time of year for aerial survey and to monitor closely changes in crops and vegetation.

ACKNOWLEDGEMENTS

I wish to record my thanks to Dr. W.G. Collins of the Remote Sensing Unit, University of Aston, and to D.M. Carroll of the Soil Survey of England and Wales, who supervised this study.

I would also like to thank V.C. Bendelow and R. Hartnup of the Soil Survey for assistance with field work and my colleagues in the Remote Sensing Unit for advice and co-operation. I am particularly indebted to N. Henson of the Department of Biological Sciences, University of Aston, for his invaluable help with field work, and to G. Sinclair of the 2nd. Land Use Survey. W.A. Robinson, farmer, was of immense help in surveys of the Sedgwick area and I am grateful to J.L. Hughes and the 6th Form boys of Kendal Grammar School, without whom the ground photography project could not have been done.

D. Forsyth and L. Allen, photogrammetrists, and J. Pope, Department of Civil Engineering, University of Aston, assisted with the preparation of maps and I. Sabell of the same department supplied many of the plates. I am very grateful to Miss B. Bardell for typing this thesis, and finally, I would like to thank R.J. Davies for assistance with field work and proof-reading, and for constant encouragement throughout.

Huntings Surveys and Prof. J.K.S. St.Joseph, Committee for Aerial Photography, University of Cambridge, supplied the aerial photography used for this thesis.

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Chapter 1: INTRODUCTION

1.1 Remote sensing

Remote sensors are information-gathering devices not in contact with the subject under discussion (Estes, 1966), these include the conventional camera and the human eye, as well as infra-red, ultra-violet, radar and radio frequency scanners, gravity meters, magnetometers, scintillometers and γ and β ray spectometers. More specifically, remote sensing can be defined as "the identification and analysis of phenomena at, above or below the surface of the earth, using devices that are normally carried in aircraft or space craft" (Cooke and Harris, 1970).

Energy within the electromagnetic spectrum is sampled by these sensors and there are different sensors for the various parts of the spectrum. Photographic film, with which this thesis is concerned, is sensitive to only the visible light and near (reflected) infra-red regions. Photographic systems are passive sensing systems, using reflected solar energy and not emitting their own energy which is then reflected and sensed, as in radar systems. Photographic systems need good weather as they are dependent on solar energy and the factors affecting it, unlike radar which is an active sensing system, using its own energy and therefore independent of daylight and weather conditions.

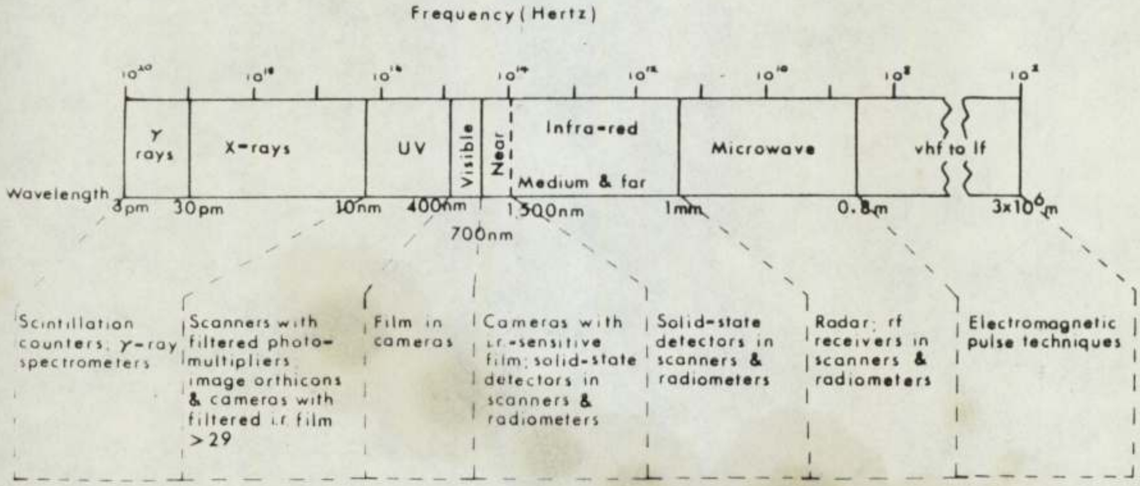

Fig. 1. Remote sensors for the electro-magnetic spectrum, (after Holz, 1973).

All energy detected by remote sensing systems undergoes certain fundamental processes. Radiation, usually solar radiation, is propagated through the atmosphere, will interact with a target, be re-emitted and pass back through the atmosphere before being sensed by any system (see fig. 2). Variations in the atmosphere may affect the speed of the radiation, its frequency, intensity, spectral distribution and direction.

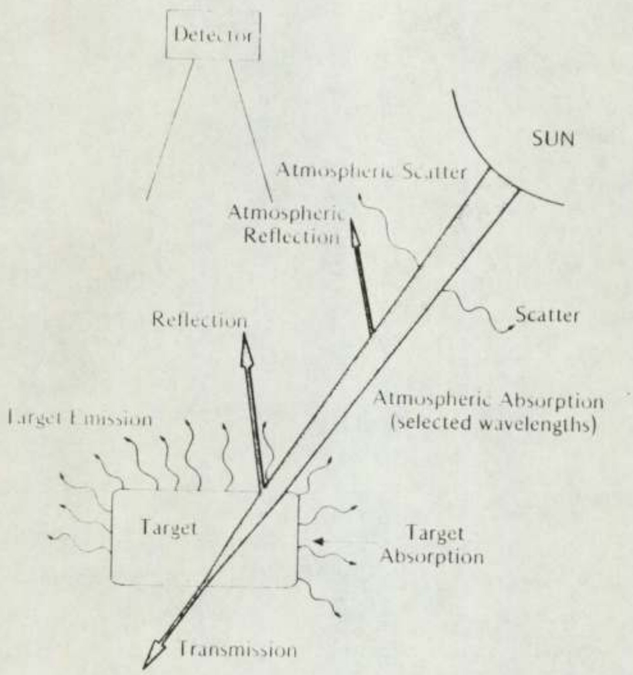

Fig. 2. Generalised diagram of energy flow for a passive sensor system. (after Holz, 1973).

It is therefore an important consideration in remote sensing to choose the appropriate filter or sensor systems, in order to prevent degradation of the image under certain conditions or to accomplish special effects.

One very serious effect is that of scattering of radiation by atmospheric particles. The direction of scattering is unpredictable unlike that of reflection, which is predictable. The shorter the wavelength, the greater the scattering e.g. within the visible part of the spectrum, blue light is scattered six times as much as red, therefore the longer wavelengths are more useful for aerial reconnaissance of any sort.

Certain wavelengths are also affected by absorption, especially the infra-red region and those shorter than visible light, which are affected more by absorption than scattering. The atmosphere selectively blocks transmission of certain proportions of the electromagnetic spectrum, mainly by absorption due to water vapour, carbon dioxide, carbon monoxide, nitrous oxide and ozone (see fig. 3). Some of the regions are almost completely opaque so efficient is the absorption, leaving the other parts as radiation windows in which sensing is easier. As atmospheric moisture, gaseous and particle content increases, energy absorption and scattering increase even in the windows, so consideration of meteorological conditions in a remote sensing mission is always important.

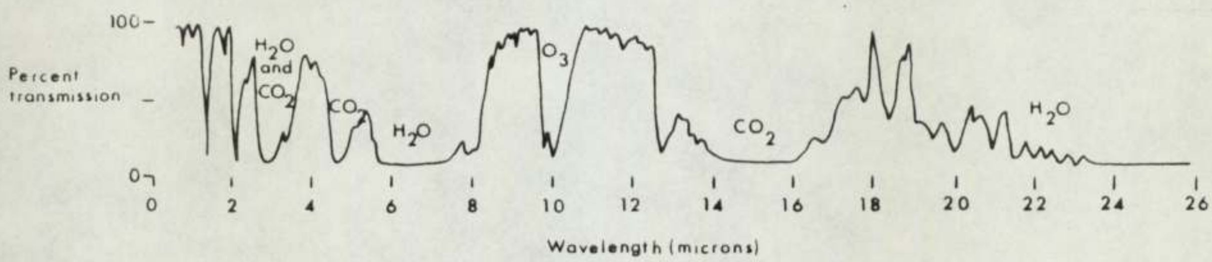

Fig. 3. In the ultraviolet region of the electromagnetic spectrum, atmospheric absorption of radiation is nearly complete out to about 0.3μ The small window in the adjacent visible region (0.4 - 0.7μ) is relatively free from absorption, but there is still considerable scattering by atmospheric particles. In the infrared, up to 25 μ there are many absorption bands of water vapour, carbon dioxide, carbon monoxide, nitrous oxide, and ozone. So complete is the absorption in some of these regions that they are, for all practical purposes, opaque. Absorption by water vapour virtually closes the atmosphere from 25μ to the more-or-less arbitrary start of the microwave region at 1000μ . (after Holz, 1973).

Proportions of incident radiation involved in reflection, absorption and transmission of a target depend on the radiant spectral distribution, the angle of incidence, the optical properties of the target and the thickness of the target. The amount of energy received by the camera is also affected by the instruments properties.

Thus the basic theory is that everything has its own unique distribution of reflected, emitted and absorbed radiation. If the spectral characteristics of an object are known, then one can pick the appropriate sensor to be used to distinguish the object or obtain information about its shape, size and other properties (Parker and Wolff, 1973). However, it is not as simple, as there are many other factors to be considered including the emissivity of the object, weather and atmospheric conditions (see ch. 2).

1.2 Aerial photography

Some of the first successful aerial photographs were taken from balloons in the U.S.A. in 1860 and were used for military reconnaissance during the Civil War. The first aerial photographs from an aircraft were not taken until 1909 but during the 1st World War aerial photography became very important for military reconnaissance. After the war came the development of photogrammetry for making topographic maps, and advances in scientific and commercial uses of aerial photography. However, the greatest stimulus to the use of remote sensing, in both civil and military fields, came with the 2nd World War when improvements in equipment and techniques made possible the use of parts of the spectrum other than the photographic region, and the field of remote sensing, of which aerial photography is a part, was established.

As already mentioned, aerial photography is a passive remote sensing system, utilising reflected solar energy. Photographic systems use wavelenths short enough to differentiate small features but long enough not to be scattered, and not so long that they cannot be recorded photographically (Strandberg, 1967). Various platforms are used in aerial photography including scaffolding, balloons, helicopters, rockets and satellites as well as aircraft. These provide a wide range of scales, from cameras suspended on large tripods only a few feet from the ground, to monitor detailed vegetational changes, to satellites which give very small scale imagery in the range of about 1:3M, providing synoptic views over large areas, which are useful for large scale tectonic features too large to be seen on the ground or even from aircraft. There are variations in information content with image scale; certain classes of data disappear and others appear with change in scale.

Olson (1973) states that a photograph is a graphic record of energy intensities, representing energy in parts of the spectrum. Aerial photographs are permanent records of an area at one instant in time, and are most useful in their ability to produce a three-dimensional model of an area when overlapping photographs are used under a stereoscope.

Various types of camera systems produce various types of photography, usually vertical photographs, either as prints or transparencies. Most photographs are rectified to remove geometric distortions and electronically 'dodged' to lighten areas of shadow and darken areas of high reflectance or glare. The use of filters, selecting one particular part of the spectrum to be photographed, is known as multispectral photography and will be discussed in the next chapter. Filters are normally used with any photographic system to penetrate through haze. The change from one part of the energy spectrum to another influences the nature of the records produced but not the basic elements so therefore the principles of interpretation for conventional panchromatic photography generally apply to other forms of imagery.

Each different film type that can be used has its advantages and disadvantages. Normal panchromatic (black and white) photographs are generally used, as the film has a wider exposure latitude than any other, which makes it particularly useful in areas such as Britain where photographic missions are likely to be affected by poor weather conditions. Colour photography provides more refined imagery than panchromatic as it is nearer to the view seen by the human eye. However, colour film needs better weather and light conditions, and is more difficult to process. Infra-red film has a better haze penetration because it senses at slightly longer wavelengths than panchromatic and colour films, and is less subject to scattering by atmospheric particles. Black and white infra-red film is very useful for delineating bodies of water, as water completely absorbs infra-red radiation and thus shows up absolutely black on the photograph, and for forestry purposes, distinguishing between coniferous and deciduous species. However, it is no more useful than panchromatic photography for any other feature and there are also difficulties in handling the film as it has to be loaded and unloaded in total darkness. Infra-red colour or false colour film (also known as camouflage detection film) is very useful. Cooke and Harris (op.cit.) consider it best for imaging the rural environment and agricultural phenomena, because it records reflected radiation from the near infra-red region and thus is significant for features that strongly reflect in this region, such as vegetation. Black and white infra-red film also records in this region but is more difficult to interpret as the hues are grey tones not colour. Reflectance and separation of curves is greater in the near infra-red region than in the visible spectrum because of the differing response of leaves to the incoming radiation (see fig.4).

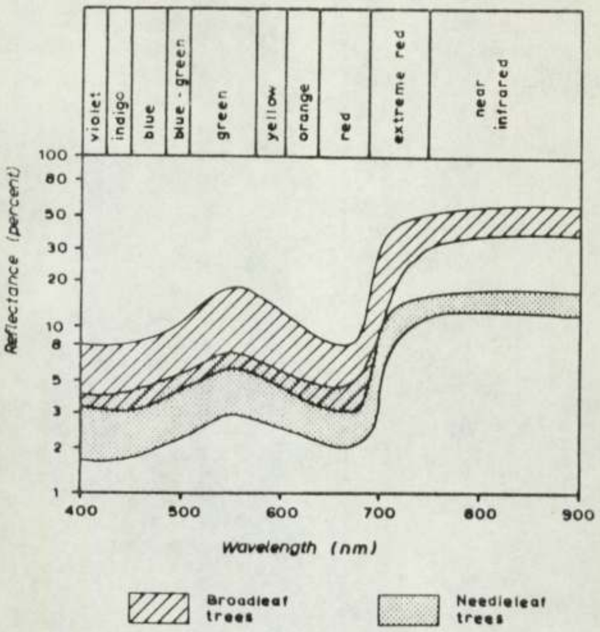

Fig. 4. Light reflectance as a function of wavelength for the foliage of representative broadleaf and needleleaf trees (after Colwell et al , 1963).

It is thought that the spongy mesophyll layer in the leaf reflects infra-red radiation and, therefore, variations in this tissue due to plant vigour, species type etc., will produce variations in infra-red reflectance. It has been thought that plant disease and growth failure can be detected by infra-red photography before it can be seen by the naked eye, due to loss of infra-red reflectance, but an experiment by Totterdell and Blair Rains (1973) shows that this is not always so. In fact, in the early stages of disease, because of increased physiological activity, infra-red reflectance is increased, thus making the plant look extremely healthy. False colour is probably the most versatile and potentially valuable type of photography but it has its limitations of narrow exposure limit, weather requirements (i.e. clear bright conditions are necessary), expense, more critical control in processing and less stable emulsion.

1.3 Aerial photo-interpretation

Aerial photo-interpretation is defined by the American Society of Photogrammetry (1960) as "the act of examining photographic images for the purpose of identifying objects and judging their significance".

Stone (1956) lays down general rules for aerial photo-interpretation (A.P.I.) as follows:

i) interpretation should be methodical

ii) interpretation should be made from general items to specific items

iii) interpretation should be done from known to unknown features

iv) the photography should be analysed for its photographic qualities alone, i.e. graininess, contrast, sharpness etc.

A.P.I. involves the recognition of visual contrasts on the photograph which are a function of the geometrical attributes of the images and other properties. It involves a conscious or unconscious consideration of the following elements:

1. size
2. shape
3. tone or colour
4. shadow (profile shape)
5. pattern
6. texture
7. site and situation
8. association

A.P.I. needs careful stereoscopic examination of all these elements of the aerial photograph; it consists of making a choice between essential and non-essential features on the photo-image. Evaluation of all elements of the landscape is necessary, both of individual landscape features and collections of features, including such things as landform, surface drainage network, vegetation and cultural details. Knowledge of terrain subjects e.g. agriculture, botany, geology and their inter-relationships is necessary, as well as formal training in A.P.I. practice and theory. A.P.I. provides a broad framework of qualitative data within which a framework of quantitative data can be erected (Lueder, 1959). Ground data such as maps and literature must not be ignored, and some field work is nearly always necessary to check the accuracy of the interpretation. It is important to choose the appropriate camera system, film, scale, season and time of day for the information required. As can be seen from the diagram from Vink (1967) (fig.5), the quality of the photo-interpreter, i.e. perception, mental acuity and experience, is important in the final assessment of the photo-analysis as well as the factors affecting the photography itself.

Air photo-keys may be useful for the beginner though they have too many limitations for general use. An air photo-key is defined by Stone (op. cit.) as a "systematic listing of observable distinguishing characteristics of an element of a landscape". They consist of illustrations, i.e. annotated photographs. They are limited, however, as the standardisation of the key forms is difficult, texture is difficult to describe and keys are often useful only for specific photography because of differences in developing, printing, scale, etc. Although interpretation is usually by stereoscopic viewing of overlapping pairs of photographs, mosaics and print-lay-downs are useful also, to provide a wider, overall view of the area to be studied.

The methods of A.P.I. for different disciplines are described in many publications and especially useful is the Manual of Photographic Interpretation (1960) which includes descriptions of A.P.I. methods for geology, soils, engineering, forestry, wildlife and range management, hydrology, agriculture, archaeology, geography and urban area analysis. A typical approach is that described by Vink (op.cit.) who describes a type of systematic

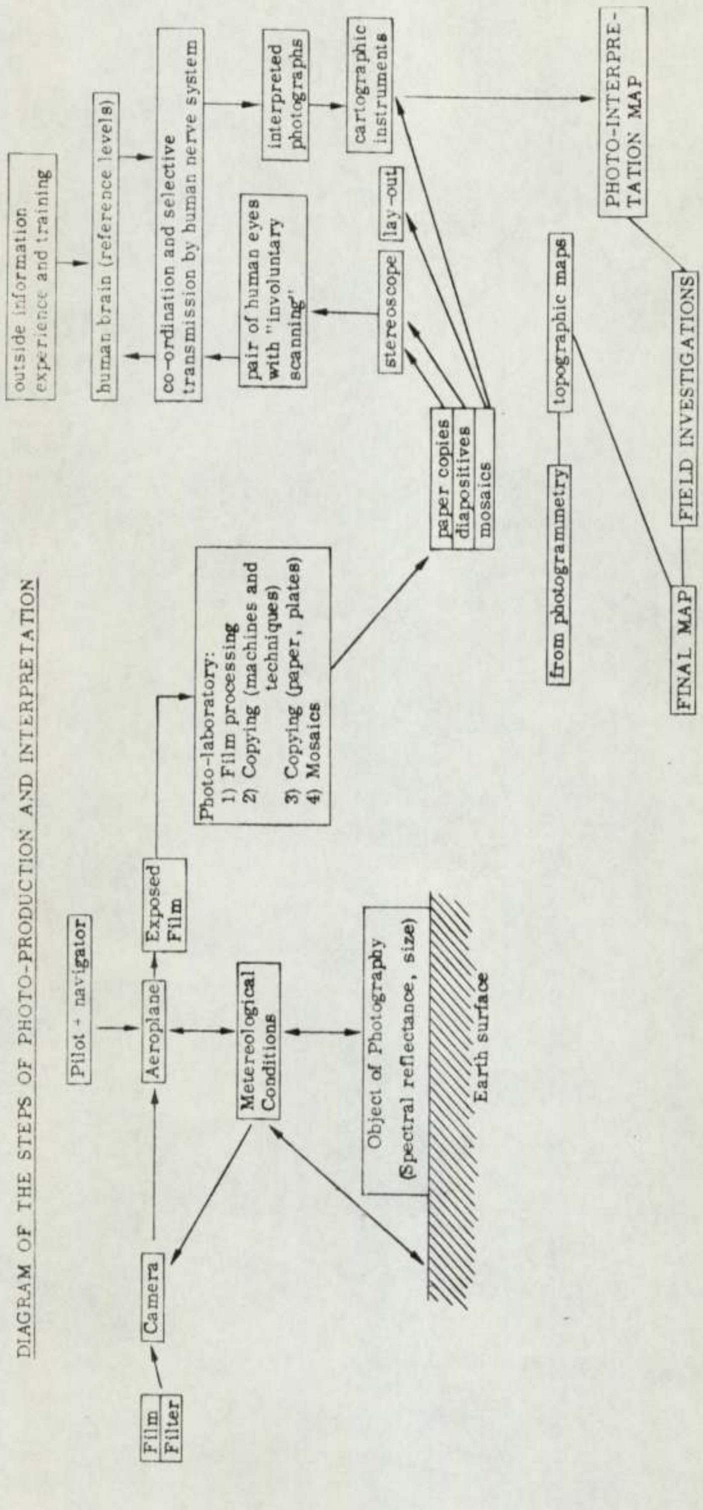

Fig. 5 Diagram of the steps of photo-production and interpretation (after Vink, 1967).

analysis of aerial photographs developed by Buringh (1960) for soil surveying, which is useful in other disciplines such as geology and geomorphology. It is an empirical approach to the problem of carrying out successful A.P.I. of a totally unknown region, in which no known individual phenomena can be recognised. This method consists of the systematic analysis of photo-patterns, basically those of morphology and vegetation because these are clearly seen covering the earth's surface and are closely related to soil, rock, land use etc. patterns.

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Chapter 2: MULTISPECTRAL PHOTOGRAPHY

2.1 Introduction

Remote sensing techniques depend on sampling the radiant energy within the electromagnetic spectrum and photography is a passive sensing method, using the visible and near infra-red (reflected infra-red) regions of the spectrum. Transmission, reflection, absorption, emission and scattering of light are selective with regard to wavelength and are specific for a particular type of material, depending on its atomic and molecular structure. Therefore, one can, in principle, identify a target from its wavelength plot. Earth materials have distinctive 'signatures' in terms of their reaction to electromagnetic energy, of which emission and reflection are the most important. Because this energy is reflected differently over the photographic spectrum, by selecting the appropriate film-filter combinations, it should be possible to record in areas of the spectrum where maximum differential energy reflectance occurs thus enhancing the contrast between the objects of interest and the background. Orr (1968) defines multispectral photography as "isolating the electromagnetic energy reflected from a surface in a number of given wavelength bands and recording each spectral band separately on black and white film".

The amount of energy an object reflects within a spectral band produces the tone on the image-forming medium; objects may produce the same tone in the same spectral band at that particular time of photography but it is very unlikely that objects will reflect exactly the same amount of energy in all spectral bands at all times, therefore they can be differentiated if photographed in properly selected spectral bands and at the proper times. This is a very simple theory with great potential but unfortunately, in practice it is much more complicated as there are so many factors to be taken into consideration. Unique reflectance spectra should give unique total appearances, though Yost and Wenderoth (1971) remark that "a unique spectra produces a unique colour.....but the same colour may be made by an infinite number of reflectance spectra". However, if one is comparing objects then there is likely to be a spectral band where they differ and where identification can be made easily (Legault and Polcyn, 1965). The aim is to provide the greatest amount of contrast between target features and their background while still providing enough data to make identification possible in ambiguous circumstances.

Although most landscape features have distinctive signatures these signatures will vary as the properties of the features vary with time e.g. seasonal and diurnal variations in vegetation, and as the dynamic variables of the environment vary e.g. the amount of illumination falling on the features may change and produce distortion of the spectral signatures of these features. Although spectral signatures can be obtained for many materials and environmental parameters by the use of a spectrophotometer, both in the field and in the laboratory, it is the dynamic, often unpredictable, variables in the environment which cause distortion and are difficult to take into account. Instrumentation errors are also likely to cause distortion. Lack of basic information on the environment causes problems in the use of multispectral reconnaissance as the environment is so variable in space, time and scale. Simonett (1971) argues that multispectral sensing can be split into a true multispectral component and a false multispectral component derived from time-related variations in the object to be sensed. Time should be regarded as another dimension in multispectral sensing, an independent variable. Compensation for some dynamic variables is possible and in some cases the exposure of each spectral band used can be controlled independently to compensate for the amount of solar radiation falling on the objects to be sensed (Yost and Wenderoth, op. cit.). The environmental variables should be calibrated as far as possible when multispectral reconnaissance is being performed; calibration of the characteristics of the films and filters being used and of the instruments being used is also important.

There are several types of multispectral sensing devices but we are concerned only with passive, photographic devices and not with multi-spectral scanners which can utilise wavelengths beyond those of the photographic regions. There are several different multispectral photographic systems in use, one of which uses several different cameras (usually four), exposed simultaneously, which is often called multi-emulsion photography as several different film emulsions are used. Another system uses a multi-lens camera, the imagery being recorded on a common film base. The camera lenses may be three, four, nine, sixteen or more in number and each one will be covered by a different filter, thus recording different portions of the spectrum on one film. This system ensures consistent processing of the imagery, by using only one film. These multi-lens cameras are known as multispectral or multi-band* sensors. A third type of multispectral photographic system uses a single lens and a multiple focal plane; a system of beam splitters is positioned inside the camera so that multiple images are formed, each one being spectrally filtered.

The basic considerations in multispectral photography must include the following factors which influence the photographic results:

i) atmospheric effects and the physical properties of earth materials
ii) the photographic collection system
iii) films, filters and processing

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*'Multiband' is usually preferred to 'multispectral' as there is only one spectrum which has certain wavebands in which sensing takes place. However, the original photography used in the project is known as multispectral photography, so the word 'multispectral' has been used throughout this thesis.

2.2 Atmospheric effects and the physical properties of earth materials

The atmosphere consists of a mixture of gases and particles, and solar energy must penetrate through this mixture in order to reach the earth's surface. The complex interaction between incoming electromagnetic energy and earth materials, including atmospheric constituents, results in transmission, reflection, absorption, emission and scattering of the energy. Chemical composition, optical properties, surface texture, opacity and arrangement of the materials are all variables involved in determining the type, degree and wavelength dependence of this interaction. The major adverse effect of the atmosphere is attenuation of recorded data, caused by scattering. The type and amount of scatter depends on the size, number and distribution of the particles, the wavelength of the radiation and the energy of the particles. Scattering and visible wavelengths affects the shorter, blue part of the spectrum the most, causing the blue colour of the sky. Blue and green records on multispectral photographs have less contrast than others. Atmospheric aerosols such as dust and haze are also scattering materials which affect the longer wavelenths, giving the sky a white to red appearance. Aerosols vary with time and place, in size, mixture and concentration, which cannot be predicted or measured. As haze affects the recording of lower radiance values more than the higher, a distorted reproduction curve is produced (fig.1.). Unpredictable atmospheric haze effects differ between spectral bands according to the nature and concentration of aerosols. Scattering factors are important in aerial photographic missions, especially those at high altitude; colour photography from space often has an overall blue cast. Sun angle during the time of photography, spectral characteristics of solar illumination, selective absorption, polarisation of light and amount of cloud cover also affect the photographic record.

Densitometry, by recording relative photographic density and therefore relative spectral reflectance, can be used to estimate the effects of the atmosphere on each image in the set, and estimate more closely the relative spectral reflectance values of objects. However, unless data on the condition of the atmosphere at the time of photography are available, then complex mathematical corrections from one of several models of the atmosphere, with certain parameters, must be made. Ross (1973) proposes a different method of correcting for atmospheric conditions, needing only spectral sensitometric response curves for the film used and known or estimated ground-level reflectance values for two or more objects normally found on multispectral photographs. One can also try to compensate for attenuation by utilising Tupper and Nelson's (1955) graph which shows the theoretical distorting effects of various amounts of haze on the tonal reproduction of photographs, modifications having been introduced to account for atmospheric absorption effects. Atmospheric effects can also be evaluated by using grey-scale target panels from which film response curves are plotted against recorded densities of the step images (fig.2.). Ideally, spectral radiometric or reflectance measurements should be made in the field at the time of the flight, to give reference areas. Alternatively, spectral reflectance measurements found in the literature can be used but care must then be taken to account for sun angle, relief of the terrain and seasonal factors.

Physical properties of earth materials are important in the way in which light is reflected from them to the imaging sensor. Surface texture and condition (e.g. wet and dry soils), colour, size, shape and arrangement of the objects with relation to the incident sunlight all combine to reflect light in a particular way. Seasonal and diurnal changes in earth materials must be included here.

2.3 The photographic collection system

As the multispectral camera system must record subtle differences in

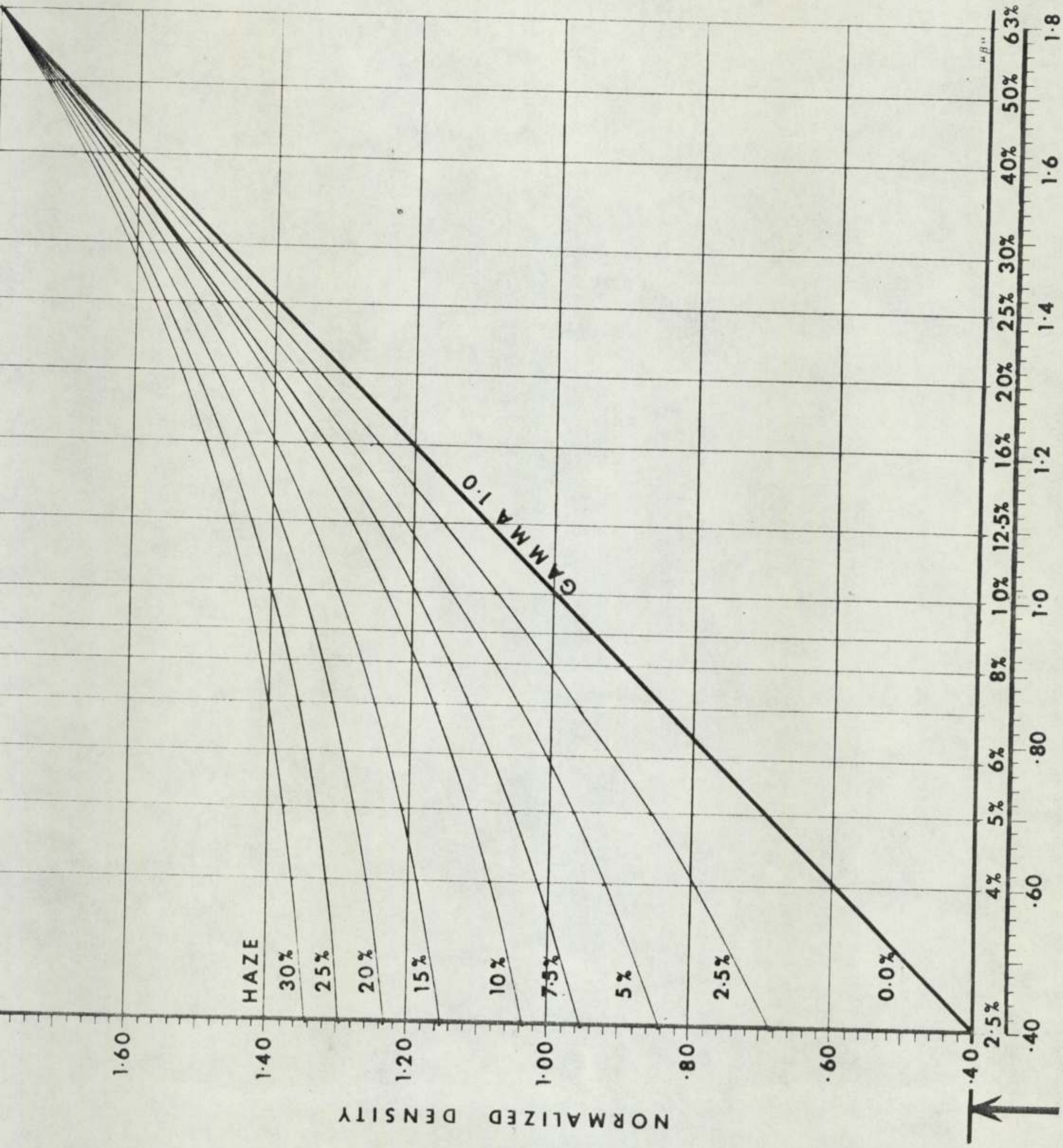


Fig.1. Curves illustrating effects of different amounts of atmospheric haze in distorting the linear reproduction of scene radiances (after Ross, 1973).

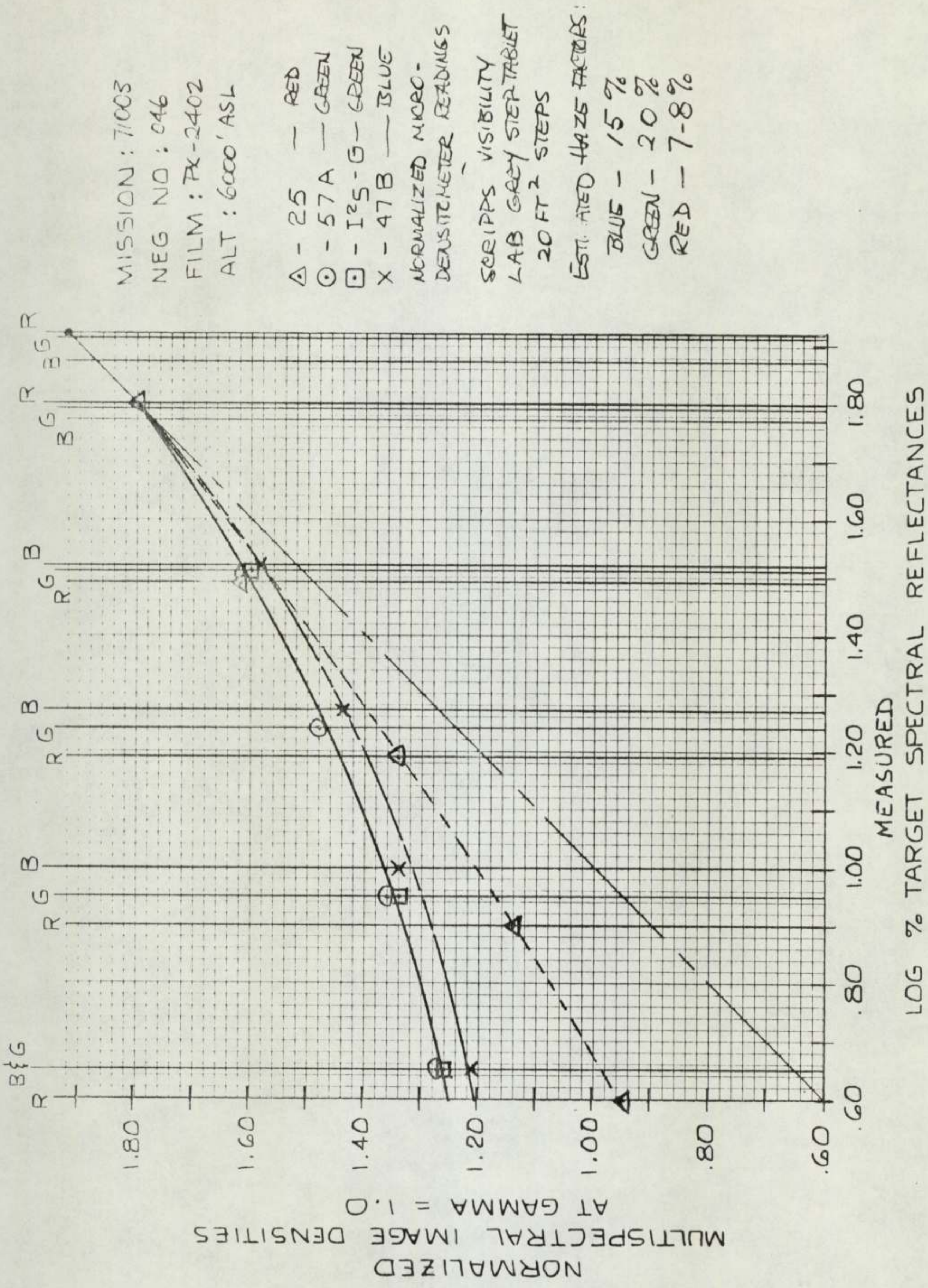


Fig.2. Estimated haze effects in blue, green and red spectral bands, determined from aerial photograph images of a grey step tablet on the ground (after Ross, 1973).

spectral reflectances, precise control and calibration of the system is important. The type of system used is important as each system has its advantages and disadvantages, and which system will be best suited depends on the information required by the user. The lens of the camera must be fully colour corrected and have low distortion, high resolution and anti-vignetting properties. Sharpness of focus should be optimal over the spectral bands to be recorded and the appropriate focal length should be selected to record the required information. Data on camera characteristics are often necessary for analysis of the results, as variations in instrumentation are likely. Therefore, instrument calibration before the photography is taken, is an advantage.

2.4 Films, filters and processing

Selection of a suitable film type depends on the energy available to achieve proper exposure. The energy available at the film plane of the camera is a function of the intensity of reflected light which varies with wavelength, filter factors, lens transmission efficiency, effective aperture and shutter speed. The type of film chosen depends on the type of information required, for example, black and white infra-red film is useful for mapping shorelines and bodies of water but for reconnaissance of crop conditions infra-red colour film may be more useful. The stability of the film base is also of importance, especially if precise densitometric measurements are to be made or if additive colour displays are required. Filters must be chosen for the spectral bands wanted and also to suit the film type used, e.g. false colour film must be used with a yellow filter to absorb the blue light to which the film is very sensitive. Precision in processing is another factor which must not be ignored; control of processing chemistry, temperature, pressure and development time is needed if image tones are to be consistent. The relationship of film density (tone) on both negatives and positive transparencies, to exposing energy, is critical in analysis of the data. Multispectral negative film should be properly exposed and processed to a γ of 1.0 (γ = photographic contrast), which represents a 1:1 ratio between film density and apparent colour of ground objects (Ross, op. cit.). However, frequently a γ of above unity (1.0) is needed in order to distinguish chromatically between objects which have similar reflectance spectra i.e. to enhance density differences. Differential printing of positives must match the γ (Yost and Wenderoth, op.cit.). It is impossible to have a perfect photographic recording system as there are always differences in processing, film batches, filters etc. To allow for these differences it is wise to expose spectral sensitometric control step tablets on the original film, through each filter type used, by a light source equivalent to daylight. The control exposures should be made as close as possible to the time of photography to avoid latent image failure effects, and the exposure should be of the same order as that of the camera. Often it is best to determine which part of the spectrum to use for identifying objects by using a spectrophotometer to obtain spectral signatures. Because of the great spectral variability, statistical analyses of spectral data are to be preferred to visual inspection, in order to determine which portions of the spectrum are best used under various conditions, to produce maximum contrast (Colwell, 1967).

2.5 Image analysis and display techniques

Multispectral photographic systems have great flexibility in that techniques have been developed for analysis and display, which provide a basis for multidisciplinary applications (Orr, op. cit.). Analysis techniques range from standard air photo-interpretation to automatic scanning. Image enhancement techniques such as density slicing, masking, density differencing, colour coding and additive colour viewing can be applied to multispectral photography with far greater ease than to other types of photography.

2.6 Digitisation techniques

These techniques convert the photographic image into a set of numbers which can be processed by a computer. This is done by measuring the photographic density of a very small area of the image (typically $50\mu m \times 50\mu m$) and converting it to a number. For example, the darkest part of the photograph is given the number 255 and the lightest part the number 0, all shades of grey in between are given a number in the range 0 to 255. An image size 20cm x 20cm digitised at $50\mu m$ intervals results in 16×10^6 numbers. Digitisation is performed by flying spot scanners, TV cameras or microdensitometers. The data they produce is either fed directly to a computer or stored on magnetic tape for processing.

2.7 Computer processing techniques

The aim of computer processing is to reduce these millions of numbers into a few numbers that have some meaning, in terms of identification of objects in the image. The main stages of this process are:

a) pre-processing to remove radiometric and geometric distortions.

b) feature extraction to extract features of the image such as texture, colour and shape.

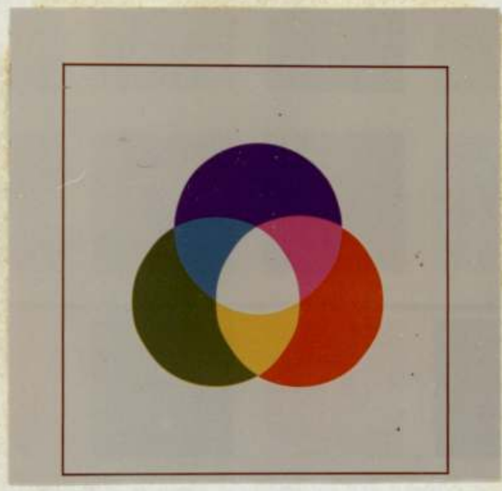
c) classification of the object, using the features extracted.

This process can be achieved by full or semi-automation. In fully automated systems the numbers representing the image go into the computer and a map emerges showing how the computer has classified each part of the image. The classification is done using either supervised or unsupervised techniques which are explained in non-mathematical terms in a paper by Preston (1974). The semi-automated method involves the digitised image displayed on a TV screen, and an interpreter with a light pen operates interactively with the computer. The computer performs the analysis using the same techniques as above, the interpreter merely controls the operation. He does no (or very little) interpretation since the image is mono i.e. not stereoscopic,and of low resolution.

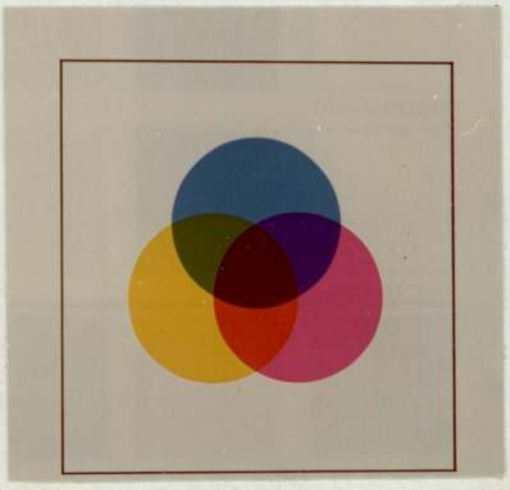
2.8 Additive colour techniques

The most widely used method for the production of colour images on photographs is the three-layer colour film. When white light illuminates the colour print some wavelengths are absorbed and others are reflected, producing the colours. This deletion of unwanted colours is called subtractive colour. The other method is that of additive colour where three or more photographs are taken simultaneously onto black and white film, each using a different filter (see fig. 3). Precise development of this film is necessary to produce positive transparencies; it must be specially processed to achieve the same relationship of exposure to density in all spectral bands. These positive transparencies are then projected, superimposed on each other in accurate registration, while each one is illuminated with a different coloured light. If three positive transparencies from a four-lens camera system are projected in registration and illuminated with blue, green and red light, then a true colour rendition of the photograph should result. The filters used in the multispectral camera should produce a total film/filter response similar to that of the human eye in order to give a true colour rendition. If a fourth, infra-red image is used (as in most multispectral systems) then false colour composite images can be produced, using many combinations of colours. It is best to use a special additive viewer which controls the brightness of illumination and the apparent hue and saturation of colours, although a lantern slide projector can be used if accurate registration is not required.

Additive colour techniques can distinguish subtle density differences, especially when complex colour combinations occur. Two different spectral reflectance curves (a and b) can produce the same visual colour and have



Colors illustrating additive mixture of the red, blue, and green combination combined in pairs. These colors produce magenta, cyan, yellow. When all three colors are combined, white light is produced. This is only achieved through light and cannot be accompanied with paint pigments.



The mixture of subtractive colors. Magenta, cyan and yellow when combined produces red, green and blue and a mixture of all three subtractive colors produce black.

Fig. 3. Illustrations of additive and subtractive colour. (from Manual of Color Aerial Photography, 1968).

the same chromaticity co-ordinates (calculated from spectrophotometric data, using spectral response curves of the Standard Observer (Judd and Wyszecki, 1963) and plotted on a chromaticity diagram which is a mathematical method of colour representation) and the same brightness,but these curves can be differentiated using additive colour techniques which permit discrimination in several spectral bands (see fig. 4).

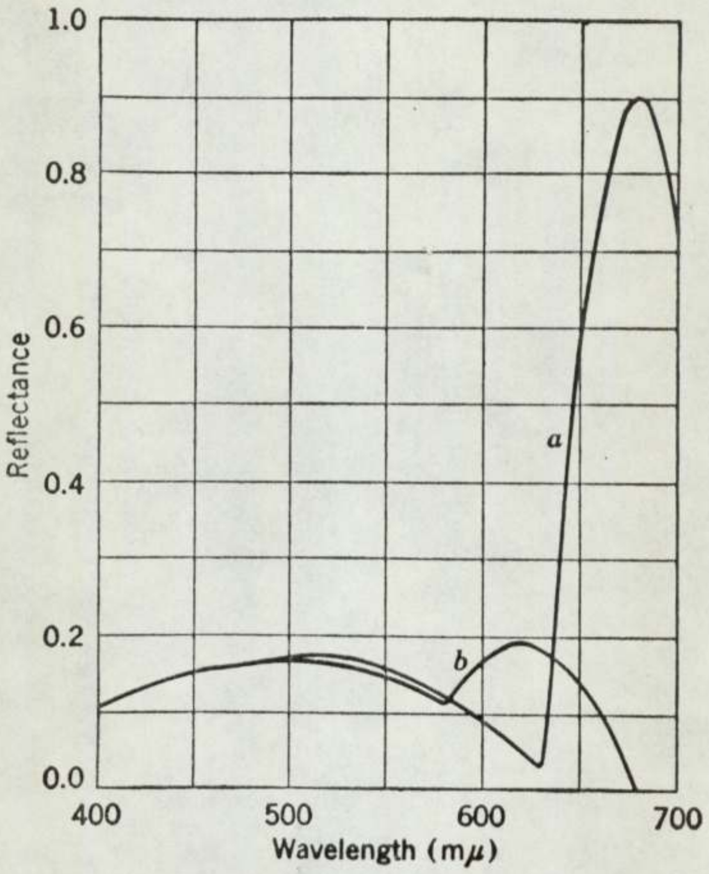


Fig. 4. Discrimination, by multispectral additive colour techniques, of two spectral reflectance curves which produce the same visual colour and have the same brightness and chromaticity co-ordinates (from Manual of Color Aerial Photography, 1968).

Thus, detection of an object with a nearly identical background is possible. If the object and its background show only small differences in reflectivity, which cannot be detected on panchromatic or three-layer colour film because of their wide band filtration (see fig. 5) they will be separated by additive colour photography.

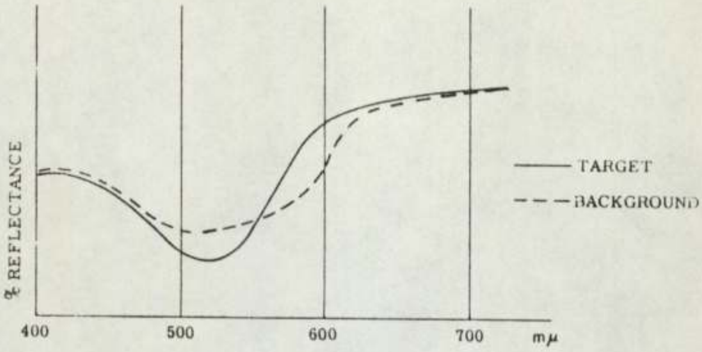


Fig. 5. Spectral reflectance curves of a target and background which are only slightly different in two spectral bands. (from Manual of Color Aerial Photography, 1968).

Colwell, Draeger, Lent and Thorley (1966) found additive colour viewing very useful as vegetation types can be identified on the basis of colour, as differences between them were not evident on the original black and white image. Yost and Wenderoth (op. cit.) claim that distortion of image colour due to solar illumination and atomospheric attenuation can be corrected when using an additive viewer.

When viewing additive colour, the optical design of the viewer must allow accurate registration and must be free of colour errors. The controls of the colour variables of hue, brightness and saturation must be calibrated and must not be distorted by shifts in the colour temperature of the illuminant as the brightness of the projection lamps is altered.

However, there are several disadvantages in the use of additive colour viewing. Colwell (op. cit.) points out that interpretation of multi-spectral imagery needs laborious cross-referencing of tone values and there is no permanent record available of the colour enhanced view unless it is photographed. Carroll (1973) also makes the point that one cannot compare different images on an additive viewer and that only a subjective assessment of the image is possible. Precise registration of several images is difficult and there are problems in controlling and keeping uniform the films and the processing which limit their quantitative use. Even so, this method is preferred to using conventional colour films because these have a fixed spectral sensitivity, a fixed relative exposure for each dye layer and inadequate exposure latitude for many purposes. Processing this material is also more complex and it does not produce significant colour differences between objects with slight spectral differences. Black and white photographs are also better to use in automatic data analysis because there are no problems due to the densities of the dye layers, as in colour photography. The wavebands chosen for multispectral photography should not be too broad or overlap too much as this defeats the purpose of multispectral sensing i.e. differentiation of objects by sensing in narrow wavebands.

2.9 Uses of multispectral photography

There have been many experiments in earth resources sensing using multispectral photography but only a few will be mentioned here. Colwell et al (op.cit.) conducted an experiment based on statistical analysis of spectrometric data. They analysed various terrain features such as clear, muddy and foamy water, wet and dry soil samples, granite, concrete, dead trees and healthy trees in order to predict their theoretical tone values on various film-filter combinations and to determine the theoretical contrast values between pairs of terrain features with each film-filter combination. They hoped to be able to produce multispectral tone signatures and optimum film-filter combinations for use in multispectral photography. Spectrometric measurements, film sensitivity data and film transmittance curves were used but they still found inconsistencies in the statistical tests, due to some unknown relationships interacting with the basic premise that each object has a unique spectral signature. The texture of the target was found to be important. The experiment also included tests on features at different slopes and aspects; here they found that relative tone values vary with aspect. Correlation between theoretical and actual tone values was found by densitometric analysis of the negatives. Image enhancement by additive colour viewing was used and this was found to be very useful, avoiding the confusion of interpreting four black and white images separately. Colour and false colour images were, on the whole, more useful for interpretation than black and white.

Yost and Wenderoth (op.cit.) used extensive ground control in their experiment, to obtain unique spectral signatures for species of agricultural crops and trees. The ground control consisted of grey-scale and colour target panels, measurement of incident solar radiation spectra, spectro-radiometric measurement of the radiation reflected by the ground targets and colourimetric measurement of the target panels. Flight altitudes for the photography varied from 1,000-30,000 ft. to include atmospheric effects. They had hoped to obtain spectral signatures for environment parameters but dynamic variables in the environment produced distortion, as did instrumentation errors. They also discovered that chromatic characteristics of the multispectral image formed by the additive colour method are significantly affected by processing techniques. They concluded that the 600-900 nm band is best for producing unique chromatic differences in images of living vegetation.

The Laboratory for Agricultural Remote Sensing of Purdue University, Indiana (L.A.R.S.) publishes research bulletins containing details of experiments using remote sensing methods for agricultural surveys. Research Bulletin 832 (1967) is concerned with multispectral photography. A qualitative analysis of such imagery showed that there was much tonal variation within a given crop species and that the differences between crops are more marked at certain times of the growing season and in certain wavebands. The primary variables listed are:

i) variety of crop

ii) relative maturity of crop

iii) geometry of crop (including plant height and growth characteristics, density, planting configuration)

iv) cultural practices e.g. fertilization

v) soil type

Other variables are past and present weather conditions, time of day, photo-angle and instrumentation variables. Some of these can be corrected or allowed for but the amount of variation in the response to photography must be studied in detail using multispectral data from many crop studies. Large quantities of data are needed to determine the statistical variation. The bulletin states that phenomena can be detected through a single waveband but identification can only be carried out through multispectral photography.

Other studies include those of Wiegand et al (1971) who conclude that multispectral and multiemulsion photography are about equally useful for crop and soil condition determination; Yost and Wenderoth (1969) and Hoffer and Johannsen (1969) who showed the potential of multispectral methods in ecology, Witmer (1968) who used multispectral photography for coastal studies and Colwell (1965) who pointed out the potential of multispectral photography for land use studies. Bell (1972) used two-band (panchromatic and black and white infra-red) multispectral analysis for crops and crop diseases but Anuta and McDonald (1971) concluded that the spectral bands they had used for crop surveys were too broad to be of much use. Cole and Owen-Jones (1972) have used multispectral photography for mineral exploration in Australia. Experiments with high altitude rocket photography have used multiemulsion methods - panchromatic film with yellow, red and green filters, and false colour film (Savigear et al, 1973; Hardy and Ridgway, 1973).

An extensive study of multispectral photography was carried out by the Natural Environment Research Council (N.E.R.C., 1974) in Britain. Two test areas were chosen; one around Thetford in East Anglia for crop, forestry and soil studies using a four-lens camera system of multispectral photography, the other of Gairloch in Scotland using multiemulsion photography for geological, hydrographical, ecological, soil, vegetation, land use and coastal surveys. The photography of the Thetford area showed that crop identification was possible using this method but that further studies using repeated flights for seasonal and annual variations were needed. Densitometric studies suggested that band 3 (red) was most useful in this case, while band 4 (infra-red) was good for some forestry purposes. Bands 3 and 4 were the most useful for soil surveying. Unfortunately, this system had very poor resolution, especially on band 1 (blue). No extra information was gained through additive colour enhancement though the technique usefully emphasised some features. Analysis of the Gairloch area showed that false colour was the most useful photography for vegetation and water resources studies, and marginally better for geological purposes. True colour was more useful for underwater features, soil survey, some aspects of forestry, agriculture and land use surveys, and ecological survey.

Several disadvantages of multispectral photography have already been mentioned; Carroll (op. cit.) criticises the four-lens camera system, as used by Yost (1969) and Yost and Wenderoth (1967), especially the difficulties of using the additive viewer. The blue waveband of this system is unsuitable because of loss of contrast and detail caused by scattering by haze and dust particles, and the green waveband shows only very subdued tonal changes, due to insensitivity of infra-red film in the green part of the spectrum. The ground detail is seen best in the red waveband or in ordinary panchromatic photography. On the whole, black and white infra-red is not good for general interpretation. The standard system uses wavebands that are too broad and that overlap. Brooner and Simonett (1971) who experimented with false colour photography, splitting the image into the three component dye layers by use of filters, could not distinguish clearly between various crops as there was so much variation within one single crop (see fig.6), often more than between two different crops. They state that there were "very few cases when individual crop types had unique spectral signatures" which undermines the whole multispectral concept.

Simonett (op.cit.) says that as the environment is so variable in space, time and scale, one will often come up against lack of information about the environment which remote sensing was intended to avoid obtaining. This is especially true in the use of training sets as these are not necessarily a representative sample. There are too many assumptions and it is necessary to criticise:

i) the multispectral concept itself

ii) that remote sensing provides a uniform data base

iii) that spatial, spectral and radiometric resolutions, which are tradeable quantities in instrument design, are also tradeable in environmental analysis

iv) time as an independent variable.

Carroll (op.cit.) also writes about the disadvantages of multispectral methods using photographic sensors. Photographic systems cover only the visible and near infra-red parts of the spectrum, much more information is available from the thermal infra-red and microwave regions. Photography needs sunlight, clear cloudless weather, and photographic filters are quite dense, requiring longer exposures which leads to loss of resolution. There are problems in controlling and keeping uniform both films and processing, which limit the quantitative use of photography. Also photography does not lend itself to automatic analysis; other sensors have an output that can be recorded directly onto magnetic tape as well as displayed visually. Other

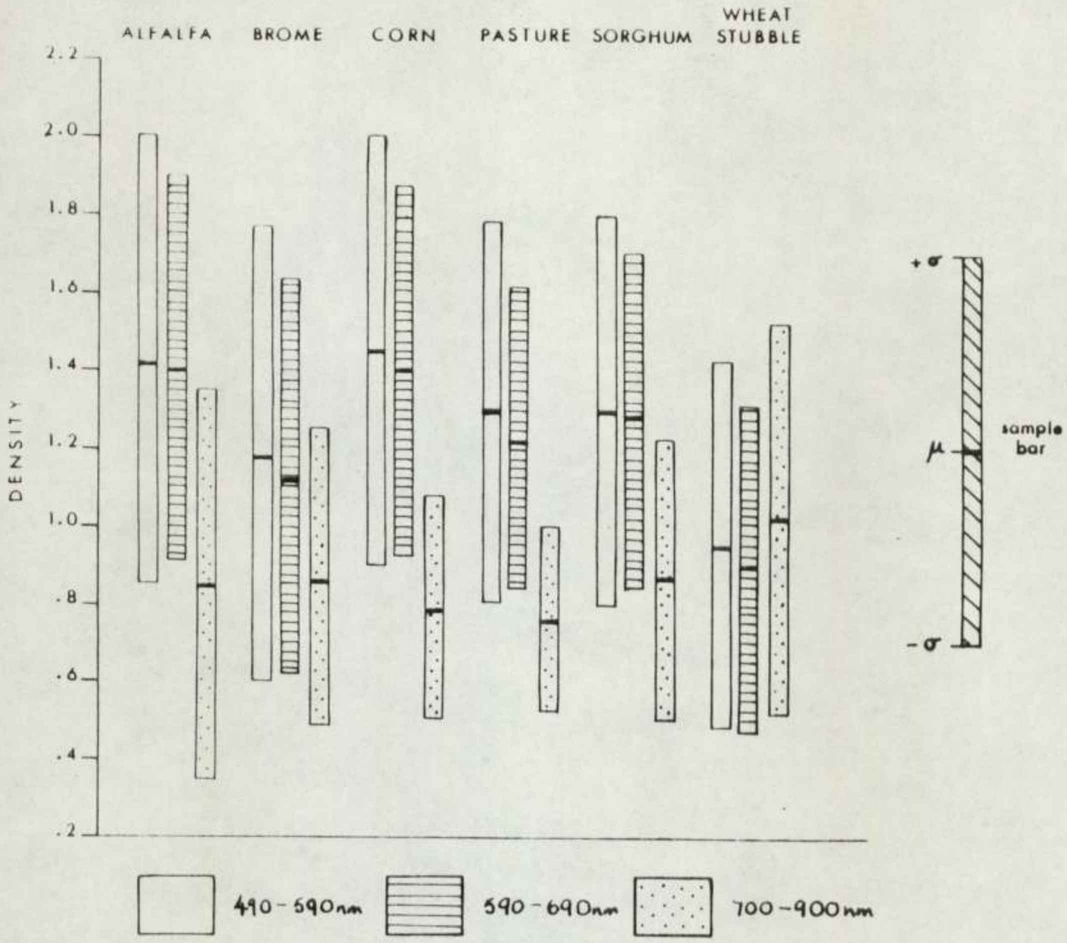


Fig. 6. Three-dimensional probability distribution of the densitometric data for the six most commonly occuring crops. The bars refer to the spectrally sensitive layers of the color infrared film from which the densitometric measurements were respectively obtained. Each bar shows the mean and one standard deviation around the mean for the measurements in each layer. Only at the tails of the distribution is it possible to get a clean discrimination for some crops. Not only are the means of the individual distributions very close together, but also the within-class variation greatly exceeds the between-class variation. (after Brooner & Simonett, 1971).

types of sensors e.g. ERTS multispectral scanner, have fewer attendant problems and for many purposes are much more useful and more versatile.

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Chapter 3: SOIL AND SOIL SURVEYS

3.1 Concepts of soil

There are many definitions of soil as 'soil' will mean different things to different people, depending on their interests, e.g. farmers, engineers and planners will all have their own definitions of soil, which will be different to that of a soil scientist.

Soil can be defined as the loose surface of the earth as distinguished from solid rock (Foth & Turk, 1972), or as what plants grow in (Jacks, 1956), or as the space-time continuum forming the upper part of the earth's crust (FitzPatrick, 1971). In the early days of soil science there were two schools of thought in the definition of soil, one chemical and one geological, e.g. Berzelius (1800) described soil as "the chemical laboratory of nature in whose bosom various chemical decomposition and synthesis reactions take place in a hidden manner", while pedologists with geological backgrounds thought of soil as comminuted rock with a certain amount of organic matter derived from the decomposition products of plants, e.g. Ramann (1911) described soil as "rocks that have been reduced to small fragments and have been more or less changed chemically, together with the remains of plants or animals that live in it or on it". Other definitions of soil are due to the work of Dokuchaev (1879) and Hilgard (1906) who related soils to climate, so that they could be described in broad, geographical zones which can be correlated with vegetation on a world scale - an environmental approach. Joffe (1949) offers the best detailed definition of soil as "a natural body of animal, mineral and organic constituents differentiated into horizons of variable depth which differ from the material below in morphology, physical make-up, chemical properties and composition, and biological characteristics". However, the simplest definition of soil, is a substance in which plants grow. This will include habitats such as the surface layers of a pond, mud at the bottom of a pond, solutions of plant food in a bottle or tank, in fact anything that contains air, water and plant food in a state in which plants can obtain them. Soil can be any material in which plants will grow, whether they do or not; there is much potential soil on the earth's surface, even though in many cases the environment will not support plant growth, e.g. bare rock on which lichens might grow. This simple definition is limited though because it does not take into account soil properties and characteristics produced by internal processes; Joffe's (op.cit.) definition covers the pedological characteristics of soil more fully.

3.2 The soil body

Soil is a three-dimensional continuum over the earth's surface that is continually changing. Each different type of soil is a natural body surrounded by and merging into other soils with differing properties; the area of an individual soil may vary from very much less than one acre to more than a hundred acres. Changes in soil type may be sharp or gradual and there are many intergrades between one soil type and another. This continual spatial variation of soils is very important and is regarded as a fundamental and distinctive characteristic. Because of it, lateral soil boundaries are usually very diffuse with transition zones between adjacent soils. Some boundaries may be sharp, e.g. changes in slope often bring about a change in soil type, therefore the sharper the change in slope the more abrupt the soil boundary. Differences in parent material or vegetation can also be responsible for relatively sharp lateral soil change.
The upper limit of a soil body is the earth's surface or the vegetation/soil interface while the lower boundary is the depth to which soil weathering is effective or the depth of root penetration, or both; this lower limit is not generally sharply defined. Because of the difficulty in finding precise lateral boundaries, soils must be mapped on the basis of

visible features or features with functional significance, e.g. pH, texture. Thus the basic unit of mapping is arbitrary and difficult to define, mainly because soil is really a four-dimensional continuum, if time is included as the fourth dimension, and does not occur in discrete units.

Although the soil body or mantle has this three-(or four-) dimensional form, the unit usually studied is a two-dimensional section or soil profile. The soil profile has horizontal sub-divisions or horizons produced by internal soil processes. These horizons are an expression of pedogenesis though they do not necessarily represent the current stage of development of the soil; they may be inherited from previous processes which are no longer operative. Soil profiles are not really a complete unit of study as they represent soil characteristics in a planar manner only but it is difficult to study the three-dimensional soil continuum as soils change continuously, both in space and time, therefore presenting problems in their study, designation and classification. Studies in both the laboratory and the field are necessary to the understanding of soils, though soils should basically be studied in the field because of the large role played by the environment in their development. It is more realistic to study a three-dimensional volumetric unit in the field than the two-dimensional profile and this volumetric unit of study can be called a pedon. A pedon is defined as "A three-dimensional body of soil with lateral dimensions large enough to permit the study of horizon shapes and relations" (U.S.D.A. 7th Approximation, 1960) and is usually less than 10 sq.m. which is not large enough to be a basic mapping unit. A pedon must have all the horizons of a vertical section present within its boundaries, which may be difficult to delimit laterally. Pedons are so small that they do not reflect important features of the larger soil body, ignoring the configuration of the surface, lateral changes etc. Therefore, a collection of pedons, known as a polypedon, is more acceptable as a soil individual. The polypedon is the smallest unit that can sensibly be mapped though the usual basic mapping unit, the soil series, is usually composed of more than one polypedon. The soil series is a taxonomic unit, a profile class with particular lithological characteristics. Its name may be used to identify a soil map unit. The map unit does not usually have clearly defined boundaries, more often there are transitional zones or intergrades.

Soil behaviour at one point i.e. the profile point, is a function of the soil forming factors which operate vertically within that plane, and the influence of relief and time in the development of soils cannot be taken into account at that point. Intergrades cannot be recognised this way. The use of a modal profile and variants about the profile can overcome these difficulties by accommodating intergrades and giving the soil profile three-dimensional qualities, i.e. producing a pedon. However, map boundaries are still arbitrary because soils merge into one another in most cases and sharp boundaries cannot be found. This concept of the modal profile is now widely used in mapping and classification.

3.3 Soil as a dynamic medium

Soil is a natural phenomenon with independent internal organisation and is formed by the interaction of other natural elements. Soil can be compared to other organisms as it is a dynamic medium, always changing and interacting with other soils and elements, even though the processes are often very slow. Soil develops by evolving through various stages until it reaches a slowly changing equilibrium with its environment. It is produced by the interaction of soil-forming factors throughout time.

Climate affects soil formation in at least four ways: by the weathering of parent material, the transportation of parent material, pedogenesis or the development of features by internal soil processes (e.g. leaching) and the erosion or physical removal of the soil body. In fact, climate is the major control on soil formation and development. Vegetation is very closely associated with climate, and with soil fauna, therefore its influence is extremely difficult to isolate. Plant matter is an integral part of the soil and its more important characteristics that influence soil type and development are the quantity and quality of plant cover and the annual rate of decay of plant litter. Biotic factors, i.e. animals and primitive plants, are involved in the decomposition of vegetable matter and the mixing of soil layers. Man is included here and can be very important as a soil modifier or even a soil former. Relief of the ground surface has mainly an indirect influence, working through other factors. Relief affects soil formation through aspect, altitude and surface morphology. Aspect and altitude tend to have indirect effects through their associated climate and vegetation types. Surface morphology has direct influence through drainage and may produce a clinosequence or toposequence of related soils, from the top of the slope to the bottom. Parent material influences soil formation in two main ways, weathering and pedogenesis, which are interdependent. Although climate is the major control in soil formation, locally parent material can control soil type much more closely; there are many areas in Britain where differences in parent material account for much of the spatial variation in soil. The influence of time in soil formation shows in the soil-forming processes tending towards a state of maturity which is, however, very difficult to define. Some soils may progress towards a minimal steady-state while others may attain early equilibrium with their environment. Some processes have an accelerating rate of change, e.g. the leaching of highly mobile materials which can reach steady-state only with the almost complete depletion of the leached material. On the other hand, processes such as organic decay reach equilibrium relatively early. Soil-forming processes do not operate at the same rate, therefore it is very difficult to identify the equilibrium or maturity state of a soil.

The processes of soil formation modify the already weathered parent material and give it the characteristics which distinguish soil from the parent material. These processes include podzolization, calcification, ferralitization, gleying, salinization, solodization and the formation of peat. None of these processes is mutually exclusive.

The soil formation system is an open system with soil-forming factors operating on different scales, though they are not usually independent of each other. The variety of soils on the earth's surface is always changing over space and time because there are so many types and intensities of the different soil-forming factors, and because each or all of the factors may change with time. It is not possible to classify the degree of inter-dependence of soil-forming factors over space as this inter-dependence will change as the relative influence of the soil-forming factors changes, and this change is also time dependent.

At various stages of the development of soil science different soil-forming factors have been given different emphasis. The early pedologists gave the most emphasis to parent material in soil formation, tending to think of soil as a geological formation. Then Dokuchaev (op. cit.) and his followers promoted climate as the dominant factor, having correlated soil and climatic zones across Russia. In Western Europe and the U.S.A. stress was laid on the physico-chemical aspects of parent material and on the time factor in soil genesis. Climate is still recognised as the major influence in soil formation on a broad scale, though locally other factors may be dominant. The factorial approach to soil formation has many drawbacks though, the soil 'equation' cannot be solved for any soil as other factors will come into the soil-forming process, e.g. soil mixing by fauna, freeze-thaw effects and soil creep. Using the factorial approach little insight into soil, as a natural phenomenon, is gained, only insight into soil-forming factors.

3.4 Soil classification

As stated previously, soils are natural phenomena, independent natural bodies with distinct morphologies, and, in order to be studied, need to be organised and therefore classified. The purpose of any classification is to organise knowledge so that the properties of the objects to be classified may be remembered and the relationships between them more easily understood. A classification is a basis for scientific enquiry and thus tends to reflect the present condition of a science.

Traditionally, soils have been classified in a similar way to plants and animals by a hierarchical system based on logical division (Linnéan system) but this tends to fail as soil individuals are not discrete bodies; they form a continuum and any classification of soils must therefore allow for intergrades. The application of the classification system and its interpretations to specific areas is made through soil maps. The system of classification used must provide for orderly generalisation by grouping and subdivision, and an orderly, non-ambiguous nomenclature should be used. Types of soil to be shown on a map must be accurately defined in terms of their characteristics within the classification. Many soil scientists, e.g. Comber (1960), Gedroits (1927) have postulated that an effective scheme of soil classification must be based on the characteristics of the soil itself and not on environmental or genetic factors, unless these can be directly and invariably connected with the soil form. Soil classification criteria should serve the intrinsic properties and features of the soil, not the soil-forming factors. Currently, morphogenetic systems are used for soil classification, which are based on intrinsic soil properties and make use of soil genesis where appropriate.

The unit of classification is relatively well defined vertically, forming the soil profile but its horizontal limits are very vague. The soil series is the lowest category in a classification as a polypedon is too small to be included when mapping. Knowledge of soil properties and their relationships is still limited and so any classification of soils will be incomplete. The method of ordering in a classification can never be natural and without synthesis, but is an adequate means of studying nature. A good classification system should be flexible and able to develop with increase in knowledge. The Linnéan system applied to soils is not very successful because soils are so different to plants and animals. There are fewer usable criteria for the classification of soils and one cannot list soil properties in order of importance, though one can have various combinations of properties, and there must be some order of importance but there is much confusion and disagreement over this. Northcote (1965) has developed a concept for listing and coding the principal profile forms of Australian soils, which is also a type of classification, as a basis for a key for a soils atlas.

Jones (1959) says that the theoretical and practical errors of soil classification are associated with the use of the soil profile as a working tool and basis for classification schemes. The planar characteristics of the profile are unsuited for depicting four-dimensional soil qualitites. However, the concept of the modal profile should encourage a 'calculus' approach to soil classification, i.e. structuring the classification from an infinite number of finite units to produce a classification where the interval between each finite unit is regarded as so small that eventually the final structure will have a quality of continuity. The use of the modal profile introduces the three-dimensional quality of soil into a classification scheme and thus intergrades can be accommodated but it can produce much complexity into a scheme, as eventually it becomes impossible, in the lowest categoric order, to recognise the extremes of modal quality or even the modal expression itself. Soil properties are continuously merging so they must have arbitrary lines drawn between them for classification and mapping purposes. Classification involves the systematic organisation of individual units and since soil bodies are not discrete individuals it is questionable whether systematics can be applied to soils.

The main purpose of a soil classification is usually ordering the soil units for mapping and not to show their genetic relationships. Soil is a multidimensional system in space and time, therefore several types of soil classification must exist at any one time, depending on the classifier's particular viewpoint (Manil, 1959). However, it is possible to link most classifications at a certain reference level, especially at the soil series level.

A comprehensive classification for all soils should be multicategoric and limited to a number of easily understood and remembered categories. The system must also be flexible. The classification of the Soil Survey Staff of U.S.D.A. (U.S.D.A. 7th Approximation, 1960) has attempted this using the concept of the modal individual. However, the resulting scheme demands an impossible degree of precision in classifying and its exactly defined, mutually exclusive classes lead to inconsistencies and absurdities. A hierarchical structure, using logical division, is used while the dispersed nature of soil makes the application of a hierarchy ridiculous, therefore producing an unsatisfactory system, though it is much used throughout the world. E.A.FitzPatrick (op.cit.) has tried a new approach, examining soils as distinct phenomena at the horizon level, establishing features common to all soils and using these features to construct a classification system. He concludes that a fundamental system of soil classification is not possible because one cannot order soils above the level of their constituent horizons because one cannot then consider intergrades, thus ignoring the spatial continuum. FitzPatrick uses standard horizons and horizon symbols which give a formula for each soil type. It is a versatile system but has confusing nomenclature and it is very difficult to use in the field because of the large number of horizons.

Classifications are still necessary even so, as the soil continuum must be divided up into arbitrary units for ease of communicating information, though hierarchical systems would seem to be of little use.

3.5 Soil classification in the Soil Survey of England and Wales.

In 1932 G.W.Robinson published a variation of Marbut's (1928) soil classification to be used for soil surveying in England and Wales. It was a simple, genetic system based on the division of soil-forming environments and including the degree of leaching, state of drainage and type of surface humus.

Soils with free drainage	Completely leached (pedalfers)	Presence of raw humus	1. Humus podsols
			2. Iron podsols
		Absence of raw humus	3. Brown earths
			4. Degraded chernozems
			5. Prairie soils
			6. Yellow podsolic soils
			7. Red podsolic soils
			8. Tropical red loams
			9. Ferrallites
	Incompletely leached (pedocals)		10. Chernozems
			11. Chestnut soils
			12. Brown desert soils
			13. Grey desert soils
Soils with impeded drainage	Absence of soluble salts	Sub-artic	14. Tundra
		Temperate	15. Gley soils
			16. Gley podsols
			17. Peat podsols
			18. Peat soils
		Sub-tropical and tropical	19. Vlei soils
	Presence of soluble salts		20. Saline soils
			21. Alkaline soils
			22. Soloti soils

Table 1. Provisional classification of soils by Robinson (1932).

Robinson (1943) introduced the soil series as a mapping unit, described as "a group of soils similar in the character and arrangement of the horizons of the profile, and developed under similar conditions from one type of parent material". The soil series is now conceived as a profile class with particular lithologic characteristics, within a broader group based primarily on character or arrangement of horizons (Avery, 1973). Definitions of major groups and subgroups were first compiled by a small committee of soil scientists (Clarke, 1940) and subsequently modified to give a system similar to those used in France, (Duchaufour, 1970) and Germany (Mückenhausen, 1965). There is a need for a better classification using specific soil properties to define class limits.

The most recent classification scheme is by B.W.Avery (op.cit.). The aim of this classification is to provide a nationally uniform, systematic basis for legends of soil maps, made to aid land use in England and Wales. For this purpose soil is considered to include any unconsolidated material directly below ground surface and the classification is based on horizons within the upper 1.5 m. The soil profiles classified are considered as three-dimensional for the purpose, with lateral dimensions large enough to evaluate the diagnostic properties of soil horizons in any one place. These are similar to the pedon in definition but are limited in volume to about $1m^3$ so they can be described and sampled as single entities. Classes are defined by properties that can be measured and observed in the field or inferred, within limits, from field examination by comparison with analysed samples, and that are relatively permanent. Properties of thin surface layers that can be easily destroyed by cultivation,or chemical properties that are difficult to assess in the field are, therefore, excluded as differentiating characteristics.

There are four levels of abstraction by progressive division, including the three higher categories of major groups, groups and sub-groups with the soil series being the fourth level. The classes in the higher categories are differentiated firstly by combinations of the composition of the soil material within specified depths and the presence or absence of diagnostic horizons generally reflecting degree or kind of alteration of the original material. The soil series is differentiated by profile characteristics, mainly lithological, that are not differentiating at subgroup level and are identified either by geographical name referring to the location of the type profile or by appending terms denoting series - differentiating characteristics to the appropriate subgroup name. (See Appendix).

3.6 Soil surveys

Soil is an extremely important, very extensive resource, and with a growing world population needing more and more food it is important that soils should be productively used. The most fertile soils should remain under agricultural production and only the poorer soils put to other uses. It is therefore necessary to know about the different types of soils and their behaviour, and to know where they are to be found. Thus soil surveys are important to resource planning of any kind.

Before 1914, in Britain, only the topsoil type was mapped, in broad categories such as sandy, stony, rich loam, etc. and geological maps were often the basis for these surveys. Rothamsted Experimental Station for soil research was established in 1843 but the Soil Survey of England and Wales was not formally recognised until 1939. After the 1st World War uniform methods of describing and mapping soils were evolved as more soil surveys were made. Several classifications and variations of classifications were used, and a new classification for use by the Soil Survey has recently been introduced (Avery, op. cit.).

3.7 The study of the soil in the field

A soil must always be studied in the field, so that detailed accurate observations can be made of the soil in relation to its environment. Laboratory study is an essential addition but it is not a study of the 'living soil' however, as not all information can be obtained by a lab study. Soil in laboratory analysis is a dead 'chemical' sample and this type of analysis cannot alone solve problems of fertility etc.

The form of the soil is recorded in the field by means of the soil profile, a two-dimensional slice in a pit or cutting. Much information on soil development and growth can be obtained from these profiles, which are basic to soil surveying. Notice should be taken of the environment of the soil, the soil-forming factors or site characteristics; if these factors are known, it may be possible to predict some soil profile characteristics.

The soil profile and site should be described in a uniform manner and there are three ways of doing this: by writing a full description of the data, by recording the data on a portable tape recorder or by noting the data on standard soil description cards (fig.1.). These cards are to be used by experienced soil surveyors; inexperienced surveyors should write a full description of the soil. However, the description cards are easy to use and time-saving. A full description of the site would also include notes on any flooding or tendency to flooding and a description of the soil surface or vegetated surface form and condition. A full profile description would note the following:

1. Horizon depth and thickness.
2. Colour.
3. Mottling.
4. Organic matter status.
5. Particle size class.

6. Stoniness - size, shape, abundance and lithology.

7. Soil-water state.

8. Soil structure - shape and size of peds, degree of ped development, voids, fissures, pores etc.

9. Consistence - strength, cementation, stickiness,plasticity.

10. Roots, other soil flora and plant remains including the nature of peaty horizons.

11. Fauna.

12. Carbonates.

13. Features of pedogenic origin - crystals, nodules, concretions and soft concentrations.

14. Boundaries - distinctness and form.

15. Soil reaction - pH.

16. Lithology of rocks and stones.

(Hodgson, 1974).

The soil profile pit is the basis of a soil survey and this is supplemented by auger pits, made where necessary for boundary mapping. Soil samples are taken throughout the profile, especially from the arable layers as these may vary from field to field, even though the soil belongs to the same series. Laboratory tests are more accurate than field tests especially for $CaCO_3$ and pH determinations. Other chemical properties may be tested, also moisture content, organic matter content, pore space and particle size distribution.

3.8 Soil mapping

Soil survey is the link between theoretical and applied pedology (Vink, 1963) and soil survey interpretation is part of land classification, grouping soils from the point of view of the user of the soil. The objective of a soil survey is to delimit soil units, and as soil is spatially

PROFILE NO.:

GRID REFERENCE:

SOIL SERIES:

SOIL GROUP AND SUBGROUP:

DESCRIBED BY:

DATE:

WEATHER BEFORE SAMPLING:

LOCALITY:

ELEVATION:

RELIEF: Regional:

Local:

Slope and Aspect:

Microrelief:

SOIL EROSION AND DEPOSITION:

ROCK OUTCROPS:

LAND USE AND VEGETATION:

SOIL SURFACE:

SOIL MOISTURE REGIME CLASS:

SUPPLEMENTARY INFORMATION:

SAMPLE DEPTH:

	PARTICLE SIZE	PHYSICAL DETERMINATION	MICROMORPHOLOGY STUDIES
1.			
2.			
3.			
4.			
5.			
6.			

Fig. 1. Soil description sheet.

variable, it would seem that it is highly mappable. However, this is not so as lateral changes in soils are usually diffuse and the different types of soil merge into each other and are thus very hard to define by lines on maps.

Soils are inspected by digging pits and augering, usually up to one metre in depth. The spacing of these inspection holes is related to the minimum size of the map unit that can be depicted and the scale of the final map. In many surveys, the spacing is also controlled by distance from a probable soil boundary; holes are dug more frequently where a soil change is expected or suggested, so that the boundary line can be accurate. Some soil properties can be correlated with external characteristics, such as slope, so some boundaries can be easily plotted. Even so, many boundary lines are arbitrary. According to Vink (op.cit.) the decision on where to put a soil boundary depends on the publishing scale of the map, the field characteristics of the boundary as determined by the soil surveyors (it is obviously senseless to put in a boundary from theoretical knowledge that cannot be located accurately in the field), the influence of other soil characteristics and of climate and site on the relative importance of the boundary, the agricultural significance of the boundary and the importance of the surface area of the soil units on both sides of the boundary. The boundaries between soil units should remain, even though the classification and terminology used change.

Soil surveying should start with an intensive investigation of terrain conditions in the area to be mapped. Geology and land use maps, and other sources of information e.g. aerial photographs, should be considered first before any field work starts, and then the initial field work should concentrate on surveys of the parent material, climate, vegetation cover and drainage conditions of the area, so that the surveyors become familiar with the local soil-forming environments. Cruickshank (1972) says it should be possible to draw a generalised soil map at this stage. Actual, detailed soil surveying is always necessary though. After the general conditions of the area have been studied, it is often useful to lay out traverses, to select the routes from which offsets can be made and to plan the rest of the field work. Difficult country e.g. a clay vale in southern England where there is little external expression of soil change may need more detailed mapping and the addition of other details e.g. topographic details.

There are three main groups of soil survey methods, differing mainly in the extent to which the mapped boundaries are based on observations of the actual soil, by augering, or on observations of the external and associated properties of the soil (Beckett, 1968).

1. Grid survey: this is the simplest but also the most laborious method. Observations are made at regular intervals along regularly spaced traverse lines, often on a grid pattern; these observations are of the soil properties apparent on auger sampling. Often the spacing of observations is varied according to visible changes in the soil surface or environment. As the intricacy of the landscape increases, or when the permitted intra-unit variability decreases, the spacing of the grid points must be reduced and the map scale increased. At smaller scales (wider grid) however, the precision of soil units mapped by grid survey only falls off more sharply with scale than the precision of those mapped by other procedures. But for estimation of proportions of different soils in an area, rather than their distribution, this method is the most economical whatever the scale. This method is the most economical whatever the scale. This method, being the simplest, calls for the least amount of skill on the part of the soil surveyor and is thus useful to those who have little experience of soil surveying.

2. Free survey: this is Steur's (1961) term for the mapping of soils by their boundaries and is the procedure generally used for detailed soil mapping in Europe and North America (e.g. U.S.D.A., 1951). A preliminary examination of the landscape is made to determine the mean or modal properties of the units to be mapped and to define their precision. The map legend then established, boundaries are located and followed over the area of their association with external properties such as land form, vegetation, etc., making the minimum number of soil observations necessary to confirm the association and to verify the position of the boundary. This way, the boundaries will be accurate, although small inliers of one soil in another may be overlooked. For this type of survey, the soils must have some external expression in the landscape, and the amount of experience the surveyor has had is very important. Free surveying at very large scales, where many types of soil will not have any external expression, is less precise than grid surveying. Also, at small scales when the location of boundaries depends increasingly on unchecked interpolation, free surveying will be less accurate than physiographic mapping.

3. Physiographic survey: boundaries are drawn, with little ground checking, on external properties of the soil and landscape usually as seen on aerial photographs or other forms of remote sensing imagery. Field observations are necessary to identify the soils within the boundaries. Soils can only be mapped if they have some external expression and if the association between this external expression and the soil is constant. This is likely at small scales, so the precision of the map may be equivalent to or superior than free surveying at these small scales and will require fewer observations (fig.2.).

In practice, normal detailed survey combines elements from all three types of survey, the proportions depending on the nature and complexity of the area being mapped. Free survey usually predominates. Aerial photographs can be used to varying degrees with all these types of survey.

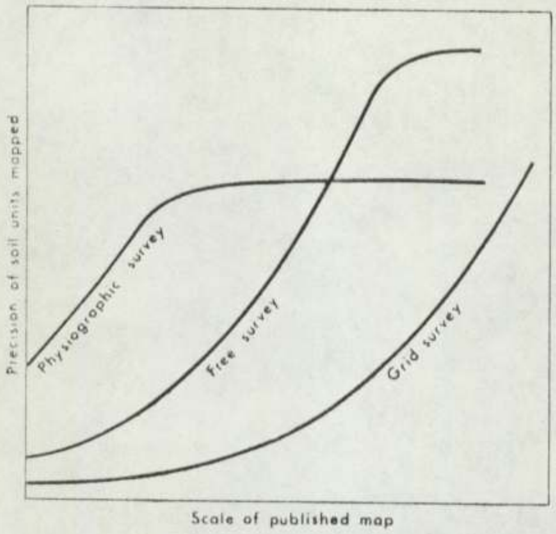

Fig. 2. Precision of soil mapping methods in relation to scale. (Beckett,1968).

Soil survey procedures as to how many observations will be necessary will also differ according to the scale of the published map. The detail of the field work is affected by the scale of the final map. Soil surveys can be classified as schematic or exploratory, general, reconnaissance, semi-detailed, detailed and intensive (tables 2 and 3).

Name of the soil map	Area of the basic soil unit in ha	Average scale of the final map	Variations in scale of the map
Special soil map	< 0,1	1 : 5,000	up to 1 : 7,500
Detailed soil map	0,1—0,5	1 :10,000	1 : 7,500—1 : 17,000
Semi-detailed soil map	0,5—3,0	1 :25,000	1 : 17,000—1 : 35,000
Reconnaissance soil map	3,0—15	1 :50,000	1 : 35,000—1 : 75,000
General soil map	15—60	1 :100,000	1 : 75,000 1 : 250,000
Schematic soil map	> 60	1 :500,000(?)	smaller than 1 : 250,000

Table 2. Types of soil map. (after Buringh, Steur & Vink,1962).

Kind of units to be distinguished on maps[1]) (see SSM p. 277 and 303)[2])	Publishing scale of map	Main purpose of map (SSM p. 15/19)[2])	General category of map (SSM p. 15/19)[2])	Approximate average number of observations per km²/100 ha		Approx. scale of sample areas	Approx. scale of aerial photographs
				without api[3])	with api[3])		
t ≈ m	1: 2.500	farm surveys very detailed projects	very detailed	500-4000	500-4000	–	1: 10.00
t ≈ m	1: 10.000	research surveys, sample areas surveys for detailed projects surveys for large farms	detailed	100-500	100-500	–	1: 10.00
t ≈ m C_t (a)	1: 25.000	research surveys, sample areas surveys for detailed projects	detailed to semi-detailed	1-100	10-50	–	1: 20.00
(t ≈ m) C_t a_1 (a_2)	1: 50.000	surveys for projects regional surveys	semi-detailed	12-25	1-3	1: 20.000	1: 20.00
a_1 a (a_3)	1:100.000	reconnaissance surveys for large projects regional surveys	detailed-reconnaissance	2-45	[illegible]	1: 20.000	1: 20.00
(a_1) a_2 a_3	1:200.000	national surveys reconnaissance surveys for very large projects	reconnaissance to generalized	[illegible]	0,5-1	1: 20.000 1: 50.000	1: 20.000 1: 50.000
a_2	1:400.000	national reconnaissance surveys (general inventory of areas)	generalized to schematic		–	1: 50.000 1:100.000	1: 20.000 1: 70.000
a_2 a_3	1:600.000	national reconnaissance surveys (general inventory of areas)	generalized to exploratory or schematic		–	1: 50.000 1:100.000	1: 40.000 1: 70.000
a_3	1:1000.000	schematic maps of national areas Comparison of areas on international level	schematic or exploratory		–	1: 50.000 1:200.000	1:500.000 1: 70.000
a_3	less than 1:1000.000	schematic maps of continents; comparison of areas on international level	schematic or exploratory		–	1:200.000 1:400.000	1: 70.000

[1]) Apart from phases that can be shown on all kinds of maps (Soil Survey Manual, p.289).
[2]) SSM: Soil Survey Manual.
[3]) api: Systematic air photo interpretation following the I.T.C. method.

EXPLANATION OF TABLE 2

t = taxonomic unit (= unit of the soil classification, based on general genetic and morphological principles)

m = mapping unit

a = association

- a_1 = a of series
- a_2 = a of family
- a_3 = a of groups (undiff. group)

m if at least (70% of the surface area of m = t)
(85%: SSM, p. 277).

In this case if it is considered necessary, m may be called the same as t, although in general this is not thought advisable.

Density of boundaries C_t = well defined complexes of (t ≈ m) – units on published map: 2,5 mm for oblongs, 5 mm for square and round forms (circular).

Taxonomic classification: 7th approximation (U.S. Soil Conservation Service, 1960)

Order	VII	on morphological and genetical principles (international, stable)	Family	III	on morphological and applied (agricultural) principles (national, flexible)
Suborder	VI		Series	II	
Group	V		Pedon	I	
Subgroup	IV				

detailed projects : 100 km²   large projects : 500-5000 km²

projects : 100-500 km²   very large projects : 5000 km²

Table 3. Some data on mapping scale and field observations. (Vink, 1963).

Because of the limitations of map scale and survey method the soil map represents the surveyor's simplified interpretation of the actual situation. The experience of the surveyor is obviously very important as soil surveying does tend to be subjective. The efficiency i.e. the speed and accuracy, of the survey in relation to its cost is influenced by many factors. The costs can be broken down into field costs and laboratory costs which will include the cartographic preparation of the map. Field costs tend to be proportional to the number of soil observations made and the number of observations per unit area mapped is proportional to the square of the map scale (Beckett, op.cit.). There are three different types of observations to be considered, classification observations, plotting observations and special observations. Obviously it is the plotting observations which will occupy most of the surveyor's time and any method is useful which will enable him to cut down on these, without loss of accuracy. Steur (op.cit.) suggests that observations be made as follows:

16 observations per ha. for scales of 1:5,000

4 " " " " " " 1:10,000

$\frac{2}{3}$ " " " " " " 1:25,000

1/6 " " " " " " 1:50,000

At map scales where both physiographic mapping and free survey are possible, field costs are less for physiographic mapping. The relationships between cost and precision of a survey and scale of the published map can be seen on the graphs by Beckett (figs. 3 and 4).

The cost of the survey is influenced greatly by the nature of the landscape being mapped and the ease of access to it. Land use also has some influence; lowland mapping in Britain is usually much slower than upland mapping as during the field season much land is likely to be under crops and therefore not accessible to the surveyor. Also external expressions of soils are likely to be less clear than in upland areas,

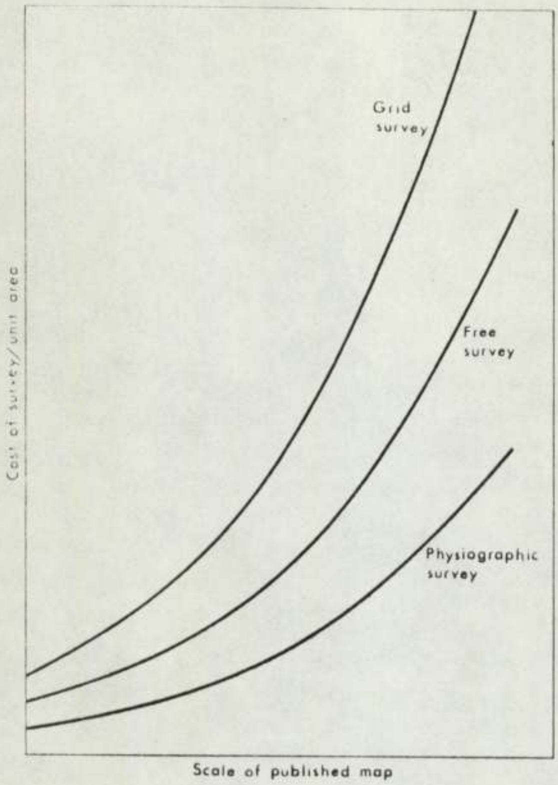

Fig. 3. The relationship between cost and scale of a survey (Beckett, 1968).

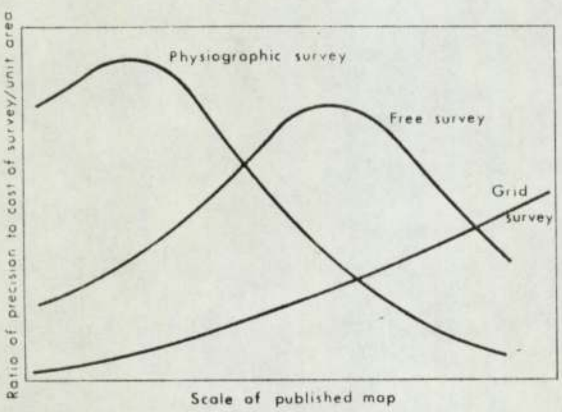

Fig. 4. The relationship between cost-effectiveness (assessed by precision/ cost per unit area mapped) and scale of a survey (Beckett, 1968).

due to more intensive management of the land in lowland districts. The length of the field season, the weather conditions, the distance of the field area from the surveyor's base, the amount of sampling needed and farm size (i.e. the time needed to visit farmers to gain access; this can be difficult if using preselected sites and where there are no maps of farm boundaries or ownership) all have influence on the time taken and cost of the survey. Douglas (1974) has listed the factors affecting the cost and time of soil surveys:

physical factors:-	complexity of soil pattern
	intricacy of soil boundaries
	relief, or lack of it
	weather conditions
	percentage of arable : pasture/moorland
	nature of land tenure
	accessibility
human factors:-	size of soil survey staff
	salaries of soil survey staff
	expenses of soil survey staff
	approach of surveyor (general v. detail)
	skill and experience of surveyor
	attitude of farmers

3.9 The map unit.

The basic mapping unit in England and Wales is the soil series, which is a map unit uniform in parent material and soil profile class. Soil series variation can be shown adequately on 1: 10,000 scale maps, whereas the soil phase is more useful in larger scale mapping. Soil phase is a variation of the soil mapping unit due to degree of erosion, stoniness, depth, salinity, etc. Special properties of agricultural interest are also described as soil phases, though a 1:10,000 scale map is not necessary as 1:20,000 scale will usually show field scale variation quite well.

The purpose of mapping is to make precise statements about particular parts of an area that one could not say about the whole (Webster and Beckett, 1968). Compared to that of previous maps, the maximum reduction in within-class variance is wanted by the surveyors and map users. Classes are needed that are homogeneous enough for predictions. The choice and definition of the map unit affects the reliability and utility of the map to a considerable extent, since the most vaguely defined units are only reliable within a broad definition. Webster and Beckett (op.cit.) state that it would be of value to the user if not only the mean or modal values of the properties of each class were stated but also variances or standard deviations. In areas where there are large variations in soil type over short distances, e.g. deep soil with rock outcrops, then the individual areas will probably be too small to manage separately and the area will be mapped as a complex, and the different soils within it described. Soil series mapping units are usually only about 50% pure (Cruickshank, op.cit.), however, this impurity may not be identifiable or mappable in the field and may be only minor property variation that does not affect management.

The United States Department of Agriculture uses the soil series as a basic mapping unit and attempts to have no more than 15% impurity within the unit, though this is very difficult because of the gradual nature of most soil boundaries and the subjectiveness of soil surveying. Soil complexes are often necessary and it is useful to know the percentage of different taxonomic units within a complex. U.S.D.A. consider the soil association the most important concept for all soil surveys at scales smaller than 1:25,000. The soil association is a group of defined and named taxonomic soil units, regularly geographically associated in a defined proportional pattern. In England soil associations are used more at small scale reconnaissance level mapping than at any other scale because of frequent local variations in parent material and the complex landscape history. The purity of the mapping unit at a more detailed level (e.g. 1:10,000 - 1:20,000) varies from country to country; in the United States they aim for 80%-90% purity, in Britain 85% (Findlay, 1965) and in the Netherlands 70%, because there many soils show deviations within short distances. If the purity of the unit is 30% or less, it is designated a soil complex when mapping at a detailed level. Special purpose soil maps may pay less attention to cartographic uniformity. The undifferentiated soil group is also useful; the component profile classes are not consistently associated in every delineation and are not necessarily dissimilar.

The size of the basic mapping unit in a conventional soil survey is determined by the smallest area in which at least one observation can be made; this is usually taken as 0.25 sq. cm. on the final map, which produces a density of four observations per square centimetre (Vink, op.cit.). If the amount is less then the basic mapping unit should be proportionally enlarged. In other types of survey, e.g. with air photo-interpretation, the size of the mapping unit depends on the detail and accuracy of the aerial photo-interpretation (if used), the reliability of the interpretation in the field and the number of field observations. Taking 0.25 sq.cm. as the smallest area that can be indicated on the final soil map, an area of 1 sq. cm. represents about 9 observations, therefore the distance between the points of observation would be about 3mm. The number of observations per sq.cm. varies according to the type of map being produced, e.g. the French use 1-2 observations per sq.cm. for soil maps of various parts of the world; with a detailed survey using the rigid grid method, at 1:50,000 or larger scales, 9 observations per square centimetre are usual and for a semi-detailed map with a scale not smaller than 1:250,000, 4-9 observations are used.

5.10 Quality and usefulness of soil maps

Cruickshank (op.cit.) regards a soil map as the expression of the natural environment of an area. Published soil maps can be used for teaching, land evaluation, engineering, forestry, agriculture, planning, etc., (Bartelli et al., 1966). Special soil maps, e.g. soil quality, soil suitability, land classification, may be made from the basic soil map. Reconnaissance scale soil maps are useful in developing countries, often as part of an overall resources survey. Special soil surveys, e.g. for development projects, which often stem from reconnaissance surveys, must be carried out with regard to the practical needs of the project and will not necessarily be the same as standard soil surveys. Many organisations publish maps on scales from 1:50,000 - 1:125,000; for England and Wales the soil maps are surveyed at 1: 10,560 and usually published at 1:63,360 scale, with some areas now published at 1:25,000, overprinted on Ordnance Survey base maps. These areas, of 100 sq. km. each, are chosen on a county basis for their pedological and agricultural interest and as being typical of that region. Each map is accompanied by an explanatory handbook. The remainder of the county will then be covered by a reconnaissance survey and a map published at 1:250,000, together with an explanatory booklet. This new programme has been in existence since 1966 and it is hoped the country will be covered more quickly than by the previous surveys for 1:63,360 scale maps. Agricultural land tends to be mapped first as farmers and agricultural advisers are the main users of soil maps but these can be difficult to interpret from the point of view of agricultural productivity and farm management practices. All current surveys include a land capability assessment map, and soil drainage maps are also made in certain areas.

A soil map serves as a key to available information for a particular part of an area, especially as soil boundaries are often drawn on the visual appearance in the field, i.e. in relation to relief or vegetation patterns. Good soil information is necessary for reliable land use prediction. The amount of variation within the soil causes problems here, as sufficiently precise statements must be made about the soil classes for the map to be of any use. Webster and Beckett (op.cit.) would like statements of variance and intraclass correlation present on the soil maps but these would be very time-consuming to supply.

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Chapter 4 : SOIL SURVEYS USING AERIAL PHOTO-INTERPRETATION

4.1 Introduction

Soil surveying by traditional methods takes a long time to cover even a small area of land and many countries are far from completing their soil mapping programmes. In Britain only 20% of the country is covered by published soil maps. Pasto (1953) quotes a House Document (1950) which states that soil maps are needed for 2,200,000 sq. miles in the U.S.A. and that surveying by field methods would take 13,900 man years, or 433 soil surveyors over 30 years. There are three basic ways in which soil mapping can be speeded up: by employing more surveyors, which is unlikely because of the cost and time involved in training them; by making less detailed maps, which is happening in England and Wales (see p. 61) by adopting a smaller scale; by using faster techniques of mapping, such as the use of aerial photo-interpretation (A.P.I.) methods.

The earliest reference to using aerial photographs for soil surveying was made in 1923 by Cobb, who said that the airplane would enable soil surveyors to make direct observations from the air and that air photo maps could be used in the preparation of base maps and for reference during the survey. Bushnell (1929) also advocated the use of aerial photographs as base maps for soil surveys and said that ".......the photo gives a better idea of how a map of the land should look, than you can get from actual viewing of the land itself from the ground". He further stated that "In many cases when a soil surveyor knows the soils, a better soil map could be made by tracing directly from aerial photos than the ordinary field work". A few years later, in 1932, Bushnell mentions stereoscopic methods for examining aerial photographs.

Since then much has changed, including the techniques of soil mapping and of photo-interpretation, and there has also been the introduction of new methods of remote sensing which may do much to aid soil surveying.

Aerial photographs are now used very extensively in some countries, often also as base maps for field work. As long ago as 1950, Simonson stated that the application of aerial photographs was one of the major advances in soil surveying during the last 20 years.

Aerial photo-interpretation for soil surveys is based on the fact that out of six main soil forming factors (climate, parent material, relief, living matter, time and man (Vink, 1964)) five (all except climate) are intimately connected with phenomena which can be seen on the aerial photograph. A systematic analysis i.e. the analysis of the various elements forming the image of the landscape, and classification of these will produce many boundaries which are probable soil boundaries. The use of aerial photographs for soil survey is comparable to the use a soil surveyor makes of correlative indications in the field; soils are landscapes as well as profiles (Goosen, 1967). Obvious advantages of using aerial photographs are: the possibility of analysing systematically the whole area, the point of view over the whole area is approximately the same (when using vertical photography) and the whole countryside can be viewed at once. It is also much easier to plan field work in advance, using the indications of soil type apparent on the photograph (Vink, 1962). However, the success of mapping using aerial photography depends on the knowledge and ability of the interpreter, and on accompanying field work. Buringh (1960a) points out that one should not expect more from A.P.I. than aerial photography can provide, and field work is <u>always</u> necessary.

The staff of the International Training Centre for Aerial Survey (I.T.C.) in Delft, the Netherlands, were among the first people to develop a method of using aerial photographs for mapping soils, by using the physiographic features visible on the photographs. The soils in the Netherlands are well suited to this and methods of systematic photo-analysis were developed. The methods of extrapolation and interpolation as described by Buringh

(1954) are based on aerial photo-deduction. Aerial photo-deduction can be defined as "dealing with the combination of careful observations on aerial photographs and knowledge from other sources, in order to obtain information that cannot directly be observed on the photo-image itself" (Buringh, 1960a). This is distinct from the A.P.I. of real facts, that are directly observable on the photo-image.

Interpretation of aerial photographs by interpolation is employed only in areas where the soil conditions of much of the area are known from both field and laboratory studies; the conditions in unknown parts can be deduced by A.P.I. This is a combination of photo-analysis and field work of two types. At a scale of 1:50,000 all distinguished units are checked by field work but at scales of 1:100,000 - 1:200,000 the survey work is shortened by restricting field work to key areas (Veenenbos, 1957), which must be regularly distributed over the terrain, on the basis of data indicated on the photo-analytical map. Photo-interpretation in other areas consists of interpolation and correlation between the soil conditions or land classes and the image as seen in the key areas. Using the method of extrapolation, the interpreter can use knowledge gained from the photographs plus his experience as a soil surveyor, for land that has not been studied in the field at all, or only to a small extent. The area will probably be classified into simple land units, which should provide information about the physical soil conditions of a large area. The pedological data are collected by field methods after the A.P.I. and land unit classification have been carried out, though Veenenbos (op.cit.) says it is best to obtain knowledge of the terrain before-hand, if possible. Buringh (1954) says that both the extrapolation and interpolation methods can only be applied to reconnaissance survey and general land classification surveys, and the extrapolation method is likely to be used at smaller scales (1:250,000 or less) than the interpolation method.

The mapping units obtained by means of pedological photo-analysis are mainly soil associations, complexes and phases, especially slope and erosion phases. Buringh (1954) and Jarvis (1962) believe there is little point in using photo-analysis for detailed soils maps of scales of 1:25,000 or 1:10,000 as field work is more important. However, aerial photographs can be of some help as some of the more important soil boundaries can be plotted before field work takes place. Certain features, e.g. landform, slope, on the photographs may point to great differences in soil conditions, while others e.g. vegetation, may indicate only slight differences. For photo-analysis using these features both geological and geomorphological background knowledge is necessary for accurate interpretation (Smit Siebinga, 1948). Buringh (1954) believes that "field experience is a primary requisite for the execution of a pedological photoanalysis". Hydrological elements can also be important, while vegetation is never very important or precise, as sometimes striking variations in vegetation are of only small pedological significance (Wieslander and Storie, 1953).

4.2 Advantages of A.P.I. in soil surveys

Aerial photographs are a valuable aid in collecting data as quickly as possible, even if used only as field maps, but they are of more value when photo-interpreation methods are employed.

Field investigations in soil survey are normally carried out with three objectives (Vink, 1964):

1. Classification observations: the description of soils and soil profiles.
2. Plotting observations: the control and possible modification of tentative boundaries already established.
3. Special observations, depending onthe needs of a project (hydrology, permeability, etc.)

Both 1 and 3 are made without A.P.I. and will require field study. However, plotting observations can be much reduced in number when using A.P.I., compared with a conventional soil survey of the same accuracy. Vink (1962) says 80% of all the observations in a soil survey are for locating boundaries and only 20% for describing the soils. By using A.P.I. the amount of field work necessary for locating boundaries can be reduced to about 10%, thus the total number of observations can be reduced to 30% of those of a traditional survey. The efficiency of soil surveys with A.P.I. can therefore be about three times as high as a conventional survey, depending on scale, the complexity of the soil units etc. Buringh (1954) writes that by using A.P.I., a soil survey at a 1:50,000 scale can be carried out in a quarter the time of a survey without aerial photographs, which means 800-1,000 ha. per working day can be mapped. Another advantage of pedological photo-analysis is the improved topographical accuracy of the soil boundaries.

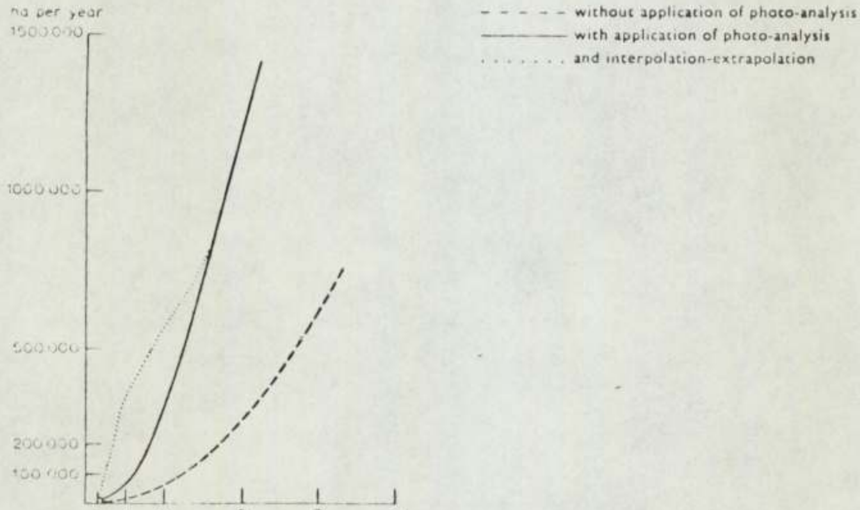


Fig.1. The relationship between aerial photo-interpretation and soil survey production (Veenenbos, 1957).

Buringh (1960b) has made a comparison of five methods of soil surveying:

A. a reconnaissance survey.

B. a detailed survey.

C. a semi-detailed survey with aerial photographs used as field maps only.

D. a semi-detailed survey combining A.P.I. and field work, with field checking of the whole area.

E. a semi-detailed survey using the method of interpolation.

That the methods using A.P.I. (D. and E.) are the most efficient is clearly seen in figure 2.

The advantages of using systematic A.P.I. methods have been summarised by Buringh (1954) as follows:

1. analysis can be carried out in a short time, before field work begins and therefore the conditions of the area are already known and field work can be planned.
2. mapping is done more easily and quickly and the accuracy of the boundaries is greater.
3. a saving in time, by up to 75%, also means a saving in cost.
4. less time is spent on routine mapping so there is more time to devote to the study of the soils.

The costs of preparing a photo-analytical map are only a small part of the total. Costs vary according to differences in terrain conditions, the total areas of each map unit, the distances to travel, the quality of the aerial photography and the currency and standard of living in the country concerned.

A breakdown of the cost of a semi-detailed soil survey covering 215,000 ha. in Iraq is given below by Buringh. In this case the cost of A.P.I. is relatively high because it included the cost of training assistants.

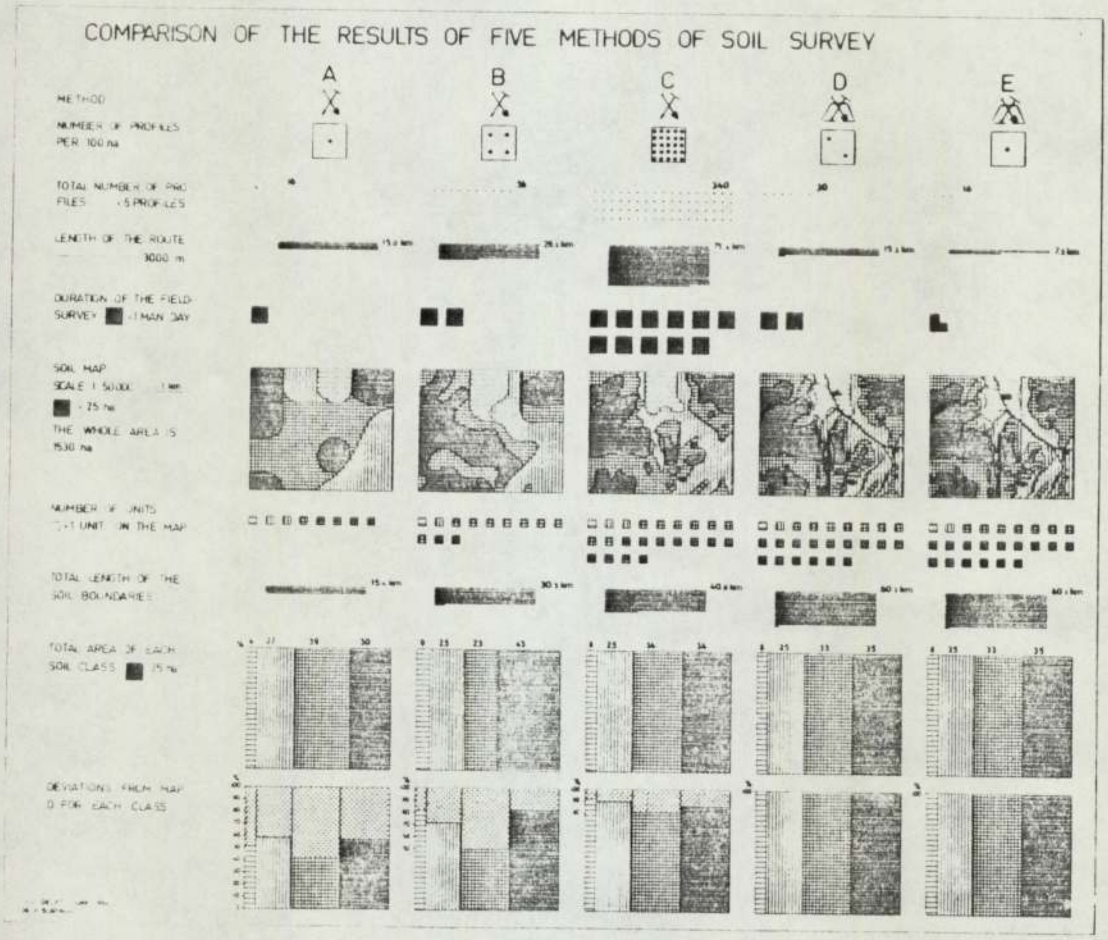


Fig.2. Comparison of the results of five methods of soil survey (Buringh, 1954).

The cost of transportation is also high because of the rough terrain conditions encountered.

	*Total cost, in f. per ha.**	*% cost soil survey*	*% cost of planning*	*% cost of project*
Aerial survey	f. 0.16	4	0.6	0.01
Preliminary field investigations	f. 0.16	4	0.6	
Aerial photo interpretation	f. 0.12	3	0.5	
Field work:				
salaries, allowances etc.	f. 1.65	46	6.3	
transportation and camping	f. 0.95	26	3.7	
laboratory investigations	f. 0.20	6	0.8	
reports	f. 0.20	6	0.8	
drawing maps	f. 0.16	5	0.6	
Total soil mapping	f. 3.60	100	13.9	0.3
Soil capability classification	f. 0.40		1.5	
Soil drainability classification	f. 2.00		7.7	
Total soil survey	f. 6.00		23.1	
Overhead	f. 2.32		9.0	
Total	f. 8.32		32.1	0.7
Other investigations (irrigation, drainage, leveling etc.)	f. 17.68		68	
Total planning costs	f. 26.—		100	2.2
Project costs, total	f.1200.—			100

* f. = Dutch Guilders; ha. = hectares. (One dollar = approx. 3.7f; one ha. = 2.471 acres.)

Table 1. Costs of soil surveying using A.P.I. (Buringh, 1960b).

For surveys at 1:50,000 or 1:100,000 about 6,000-8,000 ha. can be analysed per day while even more can be covered at smaller scales (Veenenbos, op. cit.). The efficiency of a survey using A.P.I. depends on the nature of the terrain, and the quality of the photographs, which itself depends on such things as the type of camera, the photo-scale, the type of photography and printing, the quality of the navigation and, especially, the time of year. At a scale of 1:50,000 an area three times larger can be mapped using aerial photographs than with a conventional soil survey (in the Netherlands, i.e. a physiographic survey), and at 1:100,000 an area five times larger can be mapped.

4.3 Limitations and problems of using A.P.I. for soil surveys

There is a limit to the use of aerial photography for soil surveying, because the soil profile, which is the principal object of study, is not

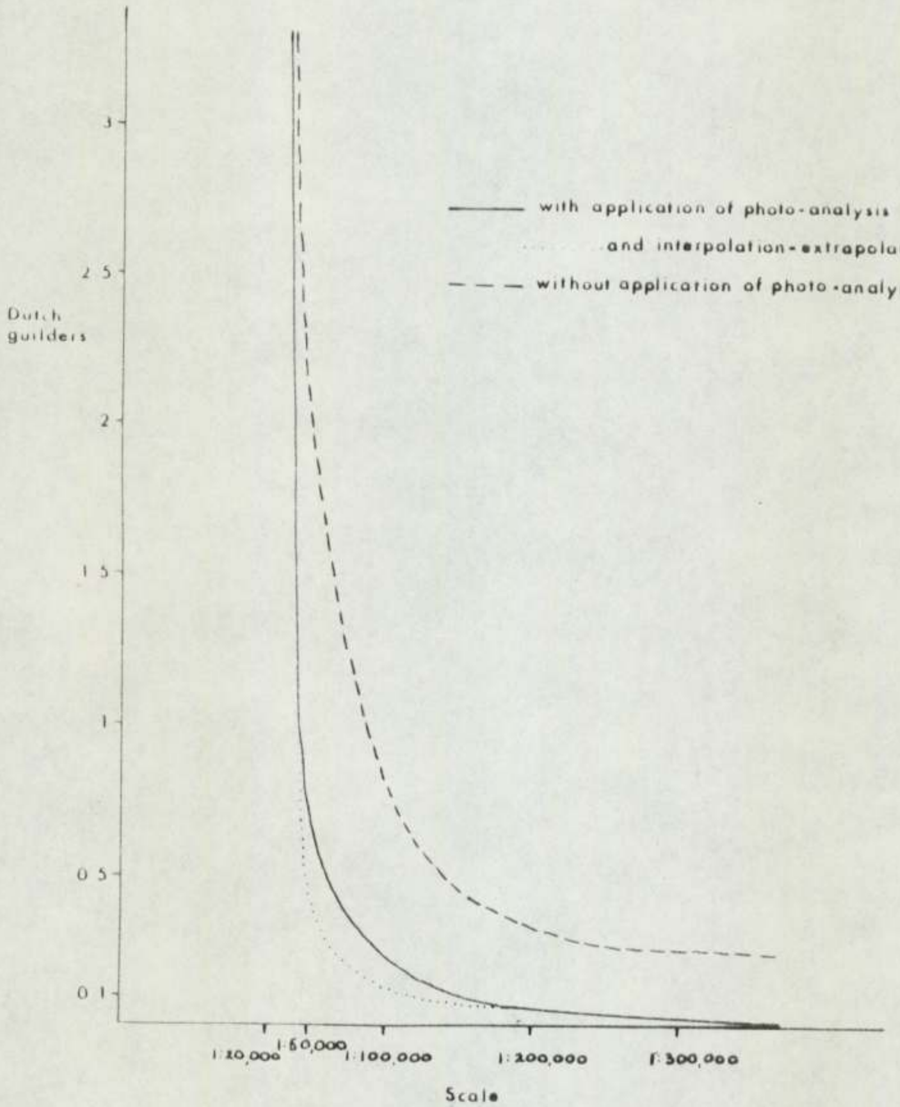
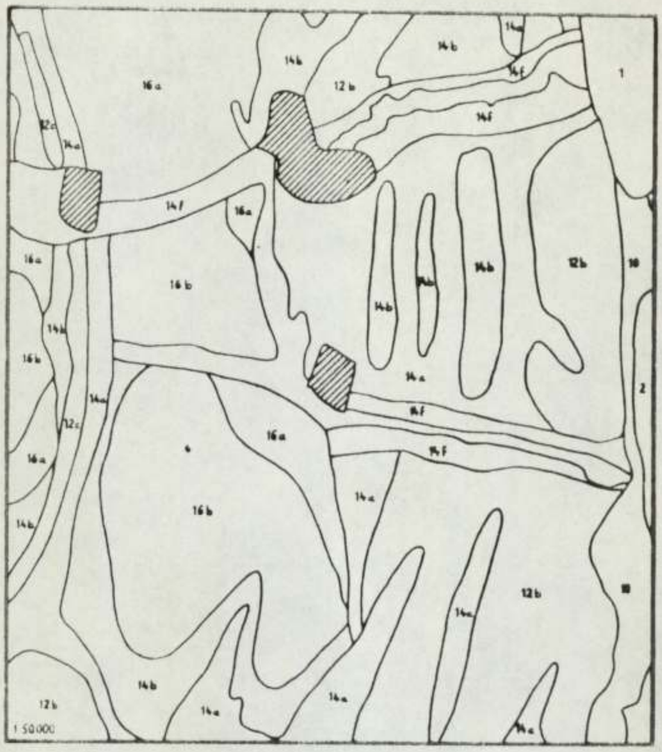


Fig. 3. Average prices per hectare of soil surveys (expressed in Dutch guilders) (Veenenbos, 1957).



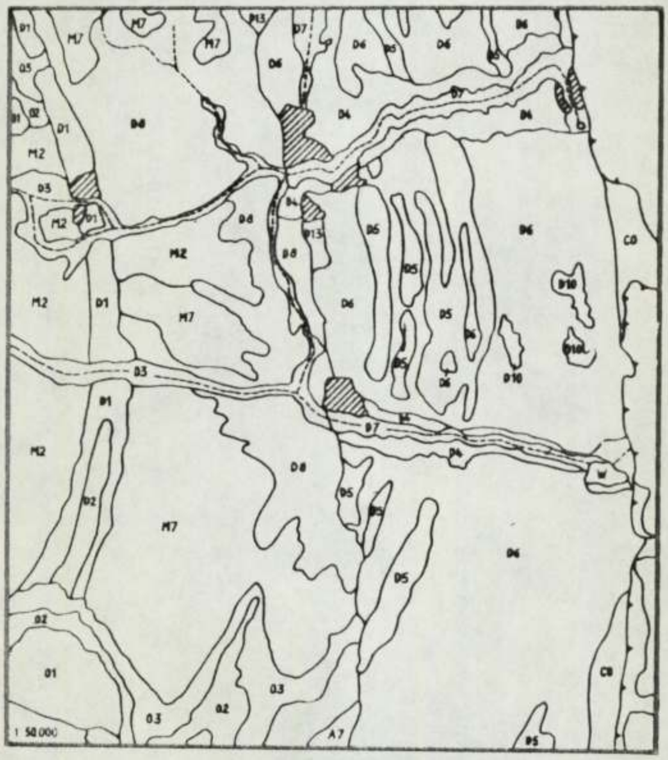


Fig.4. Results of field surveying (top) and photo-analysis (bottom) (Veenenbos, 1957).

visible on the photographs. Certain characteristics can be deduced but not all of them, and it is impossible to make any quantitive statements about soil properties. Therefore, photographic interpretation in the strict sense (*see bottom of page) cannot be applied in soil science (Buringh, 1954), although in the general sense, it can be very useful. Differences between soil phases and series are not always visible on the earth's surface and therefore will not be reflected on aerial photographs, especially where many different physiographic processes have been active. A.P.I. has limited value for detailed soil surveys. Some aspects of soil can be studied advantageously on aerial photographs e.g. relief, slope, position with respect to other soils, relative drainage. Often features may be obscured, by vegetation, for example, and study of the distribution of the soils needs to be done through knowledge of existing relationships between soil and vegetation, and physical and cultural features.

The procedure to be followed for combination of field work and A.P.I. should be decided at an early stage according to:

1. available knowledge of the area.
2. size of the area.
3. time available for the survey.
4. publishing scale of the final map.
5. distance of the area from the soil survey centre.
6. seasons suitable for field work.

Then the choice should be made from the following time sequences:

1. A.P.I. - field work - adjustment of A.P.I. - final field work (photo-preparation and adjusted field work).

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*Photographic interpretation is the science of examining the photographic images of objects for the purpose of identifying those objects and deducing their significance (President of Commission VII (Photographic Interpretation) of the International Society of Photogrammetry).

2. field reconnaissance - A.P.I. - final field work (pre-interpretation reconnaissance).

3. A.P.I. - field work (interpretation with full check).

4. A.P.I. - partial field work (interpolation and extrapolation procedures).

Vink (1964) gives the following table to indicate the steps necessary in soil surveying with A.P.I. - a gradual grouping of A.P.I., field observations and deductive knowledge, to form a soil map and report of good quality and practical value. The table also demonstrates that the legend should be made during field work.

Place	Phase	Result
OFFICE	1. air photo interpretation	photo interpretation map with (physiographic) "classification"
FIELD	2. first field reconnaissance	first draft legend of the soil map
	3. mapping of sample areas or catenas	second draft legend of the soil map + first partial draft of the soil map
	4. first field survey	checked field legend made final + second partial draft of soil map
	5. second field survey	remainder of the survey carried out with final field legend + first general draft of soil map + additional notes on dubious points
	6. third field survey (revisions survey)	spot visits on dubious points (where possible) lead to final draft soil map + revised field legend
OFFICE	7. map editing + draft report	final polishing of map + careful editing of the final survey legend+ the survey report which is as essential as the soil map itself
	8. soil survey interpretation + final report	all notes and observations on quality and suitability of the soils are combined to give the final report + soil survey interpretation maps.

Table 2. Steps in a soil survey using A.P.I. (Vink, 1964).

The combination of field observations with A.P.I. leads to special problems, which are not always understood by either the surveyor or the users of the resulting map. These problems have been summarised by Vink (1964):

1. The total number of field observations is a lot less than in a conventional survey, therefore the value of each observation is much greater, therefore the choice of its location and its description and classification are much more critical.
2. The field legend of the survey must be made at an early stage during the field work, i.e. when the total number of field observations is still small, therefore the "mental effort" required for this is greater.
3. More 'brains' and less routine work is needed, therefore more careful training is necessary for the personnel.

Buringh (1955) says that there have been many erroneous uses of aerial photographs in soil survey, leading to poor quality soil maps and disbelief in the usefulness of A.P.I. This is because some surveys have been based on A.P.I. only and there has been no examination of the soils in the field. Obviously, attempts to deduce detailed information on soil conditions from aerial photographs will fail (Pomerening and Cline, 1953). Aerial photographs give detailed information on the physical conditions of the earth's surface but they will never provide all the details regarding soil conditions. Aerial photographs must always be used by experts in soil science, not by beginners, and these soil scientists have to be trained in A.P.I. Soils must be studied in the field and in the laboratory, there is no time-saving method for this. If any of these conditions are not observed great mistakes may be made. Thus, A.P.I. is only an aid - but a very important one - to soil mapping.

4.4 Methodology

There are three principal methods of photo-interpretation for soil surveys: pattern analysis, element or feature analysis and physiographic analysis. This distinction between the three approaches is somewhat artificial as they overlap each other and in many cases a mixture of the three will be used. The amount to which any one of these methods is used depends, among other things, on the way in which the soil survey is executed, the detail necessary and the type of terrain involved.

Pattern analysis

The whole region is first studied on a mosaic or print-lay-down, and large regional patterns related to physiography, geology and climate are identified. These major landscape units are then divided into smaller units and local patterns, which are examined, in detail, under the stereoscope. Each pattern element suggests certain soil conditions; pattern elements which are indicative of surface and sub-surface conditions are landform, drainage, erosional features, vegetation, photo-tone and cultural features (Frost et al, 1960). Each element should be studied separately and the results combined to identify and describe the soils, e.g. a volcano often has radial drainage and therefore a radial drainage pattern might suggest a volcano, and thus volcanic soils. Patterns must always be studied in relation to their surroundings. This method requires a good knowledge of geomorphology or adequate representation of the landforms in a guide or key. Any literature or maps available should be used and field work is always necessary to investigate more fully the relationship between soil properties and elements of the natural landscape. Converging evidence (Lueder, 1959) may be used, where two or more patterns point to the same unit. Two patterns may be alike and even be caused by the same process but the related soils may not be alike, a combination of pattern elements may not be uniquely typical for certain soil conditions but may be 'poly-interpretable' (Goosen, 1967). Pattern analysis is most useful in areas of known geomorphological history and when conditions not visible on the photograph, such as climate and time, are more or less equal.

Element analysis

This type of analysis is based on the fact that most features of the earth's surface are connected in some way with soil conditions. There are basically two types of elements, those that are closely and systematically correlated with soil bodies, e.g. relief, and those which only indicate a change in soils and do not coincide with soil bodies, e.g. vegetation. Vink (1962) divides the photo-elements into four main categories:

1. Geomorphological elements, e.g. slope, drainage conditions and patterns, parent material.
2. Vegetation and land use elements.
3. Colour, tone and texture elements; the tone and hue of soils on aerial photographs depends on such factors as drainage conditions, salinity and humus content.
4. Cultural and human elements, e.g. settlement patterns, road patterns.

Buringh (1960b) gives a complete list of elements:

1. slope	physical elements
2. landform	
3. land type (complex of different landforms)	
4. gullies	
5. gully pattern	
6. drainage pattern	
7. watershed or spur pattern	
8. rivers, streams and creeks	
9. stratigraphy/parent material	
10. water and drainage conditions	
11. colour of earth's surface	

12. specific trees

13. natural/semi-natural vegetation

} - natural elements

14. land use

15. ditches and canals

16. parcelling

17. dykes

18. roads

19. settlement patterns

20. archaeological objects

} - cultural elements

Each of these elements can be characterised by variations in:

1. grade or density

2. type or shape

3. size

4. regularity

5. site or geographical position,

and classifications are based on similarities or differences in these elements or their variations.

First the appropriate elements must be chosen from a knowledge of local conditions; for instance, the land use element is of little value when surveying mid-West U.S.A., as the pattern of land use was set out according to a regular grid, and is not related in any way to the soil pattern. Then the elements are established in order of importance. The I.T.C. (Vink, 1963) uses the following categories to establish the relative weight of these elements, listed in order of decreasing importance:

1. elements with positive, direct relation to one or more aspects of soil themselves, e.g. clearly waterlogged soils.
2. elements related to the general morphology of the terrain, e.g. land type, relief form, drainage pattern.
3. elements related to special aspects of terrain, e.g. stratigraphy,

gully form, colour of surface.

4. elements related to vegetation cover, including land use.

5. elements related to specific human aspects, e.g. road, archaeological objects, settlement patterns.

6. inferred elements or elements based on converging evidence, e.g. water and drainage conditions, micro-relief.

In the following example (fig.5) six elements were chosen for the area to be analysed. The first analysis was carried out according to differences in land type, which produces a map of large physiographic units, then for differences in slope, as seen under the stereoscope. Similar analyses were made for drainage conditions, gully and drainage patterns, parent material, vegetation and land use. It was assumed that the value of each element was equal, for correlation with soil boundaries, and all the element maps were combined to produce a value of photo-interpretation map. The boundary lines were given values according to the number of various analyses of individual elements in which they appeared; therefore, a line occurring six times is most likely to correlate with a soil boundary. A boundary line occurring only once needs a special field check because it is very uncertain, especially if it occurs only on the vegetation or land use maps. A photo-interpretation map for soil survey purposes, based on these considerations, is the end result and is the basis for field work. Systematic traverses and sample areas for field work are also chosen from this interpretation map.

A systematic analysis of this type was carried out by the author, of a small area around Marsden, West Yorkshire. In this area the geology is simple, consisting of Millstone Grit overlying Carboniferous shales and mudstones. The grits form level or gently sloping plateau surfaces which often terminate in lines of steep crags or as isolated rocks. The softer shales and mudstones form concave slopes and marshy areas between the

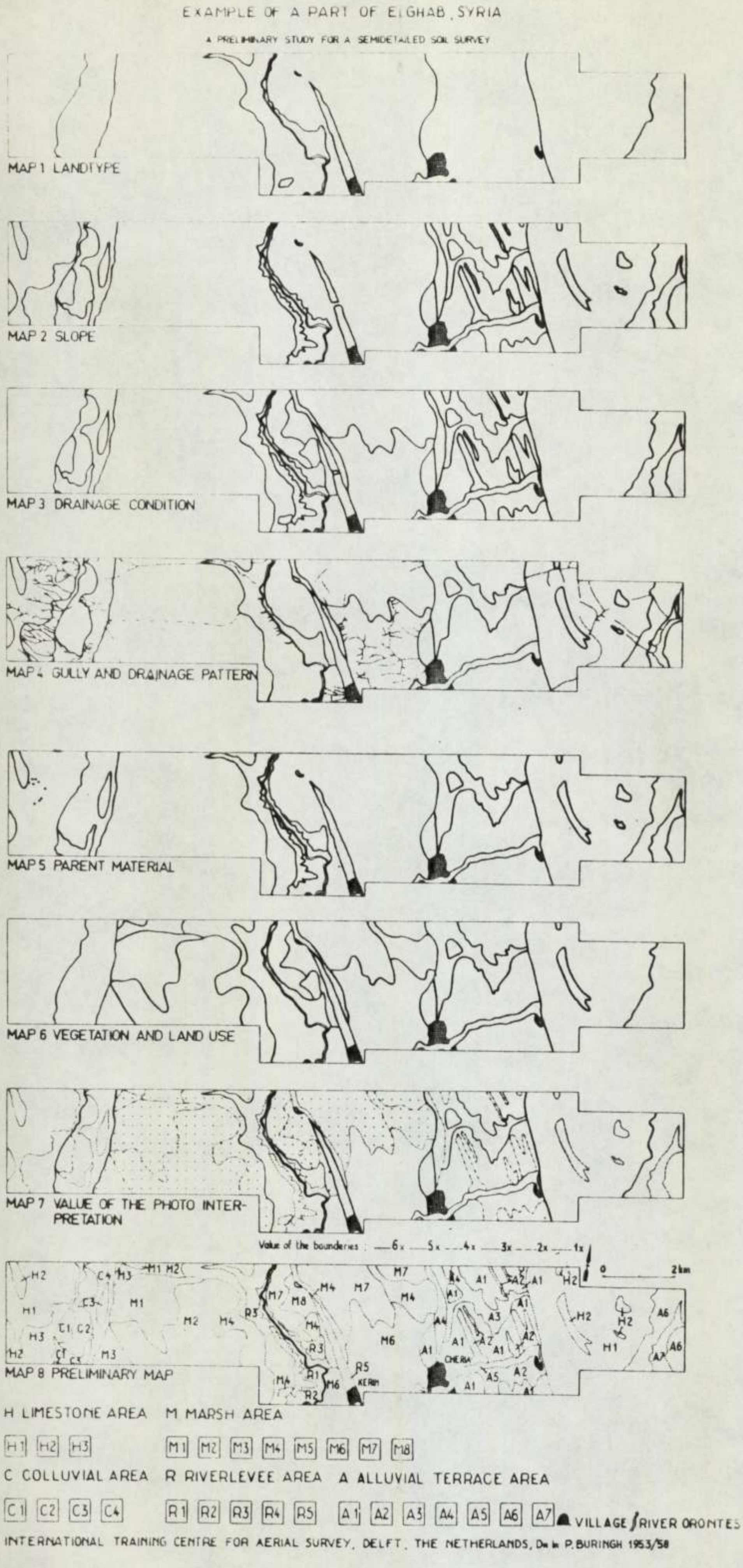


Fig. 5. Instruction maps for an A.P.I. exercise (Buringh, 1958).

	Visibility in stereo image	Relation to soil condition	Coincidence with soil boundaries
Landtype	High	High	High
Relief	High	High	High
Slopeform	High	High	High
Drainage conditions	Medium	High	Medium
Constructional drainage system	High	High	High
Destructional drainage system	High	High	Medium
Natural vegetation	High	High	Medium
Parent material	Low	High	High
Colour	High	Low	Low
Land use	High	Medium	Low

This table gives general rules. Local conditions may change the qualifications.

Table 3. Importance of photo-interpretation elements for soil surveys (Goosen, 1967).

plateaus. The river valleys have very steep sides because of the hard gritstone capping the soft, easily erodible shales underneath, which produce unstable slopes at high angles and has resulted in several landslips. The flat plateaus are covered with deep peat, formed because of high rainfall and flat topography. Streams issue from the junction of the peat and Millstone Grit at the edges of the plateaus. Land use reflects the topography and drainage; fields are found only in the valleys or sometimes up the valley sides where the slopes are less steep and unstable. Settlements are found only in the valleys; Marsden is a mill town which has grown up around a fast-flowing stream of soft water. Soil associations, as mapped by the Soil Survey of England and Wales, are basically differentiated by parent material and relief, and are subdivided by position in the area of the association e.g. the Scammonden Association, which is found on steep valley sides (at 340-420m), is divided into five types:

a) complex on steep slopes

b) complex on landslipped areas

c) peaty rankers on valley benches

d) peaty gleys on valley floor

e) organic soils

This area would seem to be ideal for element analysis as there is a close relationship between geology, relief and drainage. There were seven useful elements:

decreasing importance ↓

1. geology/parent material
2. slope and relief form
3. drainage
4. vegetation
5. tone and texture of the photograph
6. land use
7. settlement pattern

The analysis was not very successful, mainly because the scale of the photographs (1:10,500) was too large and the differentiation of soils aimed for was too detailed.

A full element analysis is very time-consuming and more often the more experienced interpreter will make up a list of elements on the basis of which he arrives at a classification of terrain units, each characterised by a certain combination of elements. Then using this classification, the photographs are analysed to produce, directly, a photo-interpretation map for soil survey purposes (Goosen, 1967).

Physiographic analysis

Physiographic analysis is based on a thorough knowledge of the relationships between physiography and soils, and the recognition of dynamic processes rather than static elements. The elements are used in a different manner to those in element analysis; they are not used primarily for drawing boundaries but as basic material in constructing an understanding of physiographic relationships in the landscape. It is an analysis of processes rather than phenomena. Vink (1962) says that the I.T.C. prefer to use physiographic analysis for soil surveys, as far as possible, rather than element analysis. A physiographic analysis will result in a map of terrain units; these terrain units are not soil series, which represent a finer subdivision of the landscape, but are more likely to be equivalent to soil associations. According to Areola (1969) one advantage of the physiographic landscape approach is that each unit mapped has the quality of reproducibility, which is where "a component as defined in one locality will have the same attributes elsewhere" (Mabbutt, 1968). Therefore, it is possible to extrapolate from a known to an unknown site. Terrain units must not be too small, because they will then become less reproducible and more unique, and therefore more difficult to identify.

Terrain analysis is used by several organisations, including the Australian C.S.I.R.O. Division of Land Research and Regional Survey (L.R.R.S.) and the British Directorate of Overseas Surveys, Land Resources Division (D.O.S.). The L.R.R.S. use terrain analysis for surveying the whole range of land use interests, including agriculture, forestry, water supply, fisheries, scenery etc. as well as soils. The surveys are based on land systems and land units (Christian and Stewart, 1968) which are recognisable on aerial photographs. D.O.S. use similar methods for planning the agricultural development of large unsurveyed regions. These surveys are usually small scale, often 1:250,000 or smaller. The land systems approach is not in itself used as a basis for soil surveys and is normally used to produce agronomic information. Also, in many such surveys, the approach tends to be more like pattern analysis than physiographic analysis.

Another method of terrain evaluation has been developed by the Military Engineering Experimental Establishment (M.E.X.E.) and the Department of Agriculture, Oxford University, with the object of gathering terrain information of all kinds, that would be useful for civil and military purposes, both intensive and extensive. This survey is on a larger scale than those of the D.O.S. and L.R.R.S. and a terrain evaluation map of the Oxford region has been produced at 1:63,360, with land facets and recurrent landscape patterns being the map units (Beckett and Webster, 1965).

Jarvis (1969) used Beckett and Webster's (op.cit.) Terrain Classification Map and surveyed,in the field, three 9 sq. km. areas covered by the map, producing tables showing the differences between the two maps. He says that terrain maps are the most useful in mapping soil associations, although in the areas covered by the Terrain Classification Map, drift deposits occur very frequently, which would prevent the aerial photographs from being fully used. He criticises the fact that the terrain units were classified with very little ground check and shows that the definition of the facets, in terms of soil, is broad; the facets tend to reflect soil site conditions rather than the type of soil. Variations in lithology and thickness of superficial deposits can be associated with contrasting soils without influencing landform. Apart from the work at Oxford, little has been published on the use of physiographic methods for soil surveying in this country, though Webster (1965) has produced a short paper describing a survey of soils in the Cotswolds, where the soils were mapped as landscape units. Here the soils are closely related to relief, so physiographic A.P.I. methods are useful.

Pattern analysis can only be used in areas where much is already known about relationships between the photo-image and local soil conditions, and where good photo-keys are available. Pattern analysis can be applied in semi-detailed surveys and sometimes in detailed surveys but it is restricted because of its heavy dependence on photo-keys. This method can be described as a reference method.

Element analysis is more useful as it can be applied universally by surveyors who have yet to build up a high reference level. The major disadvantage is that field checking of boundaries remains a significant part of the survey, and also the proper selection of elements and the assignment of weight to the different elements is not easy. This can be called a pragmatic approach (Goosen, 1967).

The physiographic method is also universally applicable but can only be applied by surveyors with a very high reference level of A.P.I. It is mainly mapping of boundaries, which will not need to be changed as the result of subsequent field work. Goosen describes this as a genetic approach.

4.5 Scales of photography used for soil surveys

The scale of photography used will depend on the scale of the actual soil survey. Buringh (1960b) says that most surveys use 1:20,000 or 1:25,000 scale photography and reconnaissance soil surveys of very large areas will use 1:40,000 or 1:50,000 scale photography. Simakova (1959), describing Russian work, says that detailed soil surveys will usually use 1:10,000, 1:25,000 or 1:50,000 scale photography while intermediate (less detailed) scale surveys will use 1:100,000 or 1:200,000 photography. She points out that for 1:10,000 scale mapping it is best to use photographs of the same scale and not a larger scale because excess detail makes interpretation difficult, and that smaller scales between 1:12,000 and 1:17,000 could be used. For 1:25,000 scale surveys it is also best to use contact scale photographs. In a mapping exercise, in a complex soil area in the Caspian region, photographs at 1:25,000 provided abundant detail and were of high interpretive quality; 1:10,000 scale photographs were also used to map the area but it was found that there was an insignificant increase in interpretive quality with an increase in scale. Jarvis (1969) believes that scales larger than 1:25,000 are of less value for A.P.I. and Tytherleigh (1967) points out that large scale (1:12,000) photographs are difficult to relate to each other, although it depends on the feature being mapped e.g. for mapping hillform patterns, small scale (1:20,000 - 1:30,000) photographs should be used.

The Soil Survey of England and Wales prefer a scale of 1:15,000 for A.P.I., as this provides enough detail to aid ground surveying but a good overall view can still be seen. The author's experience suggests that 1:20,000 is a better scale, plenty of ground detail e.g. individual trees can be seen but there is a wider, better view than with 1:15,000 photographs.

4.6 Timing of aerial surveys for soil mapping

There is little information available on the correct timing of aerial photography for soil surveys. This is probably because it is usually accepted that photographs will be taken in summer when light and weather conditions are most favourable. However, the photography should also be taken at a suitable time for recording soil patterns, in order to make the maximum use of aerial photography.

Aerial photographs record soil variability as shown either by tonal differences in bare soil or in differential crop growth, therefore there must be two good seasons for recording those patterns. Soil tone patterns are best recorded in winter and spring, with March and April being the best months. Crop patterns are best recorded in July and early August, just before harvesting. However, the most suitable conditions for aerial photography are found during the months from April to September, therefore planning is necessary when ordering photographs for a soil survey. Weather conditions, including the amount of haze and/or air pollution, especially over industrial areas, can severely restrict the number of days when good quality photography, of medium and large scales, can be taken in Britain (Evans, 1972a). It is difficult to assess accurately the number of suitable days in a year but it is probably less than one in two over the whole country and in many places it may be less than one in four. Winter photography is often better than summer photography because there is usually less haze but light levels are lower and the amount of daylight is less, restricting flying time. Autumn is the worst time for photography because of poor visibility and persistent cloud cover. Colour and false colour photography have even more critical requirements.

Evans (1972b) experimented with panchromatic photography, taken in all seasons, for recording soil patterns useful for soil mapping in lowland England e.g. stripes and polygons, polygonal pseudomorph ice-wedge patterns, creek patterns in peat.

He found that the three most important patterns, the stripe and polygon pattern, the silted creek pattern and the valley floor pattern, were best photographed in March and April (fig.6) but the pseudomorph frost wedge pattern was recorded only in June and July, the bedrock jointing pattern in January and July and the parallel lineation pattern in February and March. Different patterns show at different times of the year, e.g. fen patterns are not seen in summer when the crops are high but pseudomorph ice-wedge patterns do not show when the ground is bare of crops. Most of the patterns showed up best in March and April because there was much bare ground at that time. 70% of all the patterns showed when there were no crops in the field and only 24% when the fields were

Pattern	Percentage of all photographs on which patterns appear	
(A) Upland patterns		
Stripes and polygons		
Stripes + polygons	25.9	40.9
Stripes only	9.5	
Polygons only	5.5	
Circular and vermiform pattern, possibly two types (hummock and hollow)		15.4
Valley floor		8.8
Polygonal pseudomorph ice-wedge pattern		1.5
Rectangular bedrock jointing pattern		1.3
Parallel lineations (probably due to a rapidly alternating lithological sequence)		0.9
Linear pattern (probably due to widening of fissures by frost wedging)		0.3
(B) Coastal and fen patterns		
Creek pattern in silt fen		20.3
Creek pattern in peat		
Fen	4.5	10.4
Coastal	5.9	

Table 4. Soil patterns as seen on oblique air photographs (Evans, 1972b).

	Jan.	Feb.	March	April	May	June
Percentage of all photographs	2.0	0.5	39.3	25.9	7.8	15.0
	July	Aug.	Sept.	Oct.	Nov.	Dec.
Percentage of all photographs	4.3	1.1	1.3	1.0	1.3	0.6

Table 5. Months when soil patterns are recorded on aerial photographs (Evans, 1972b).

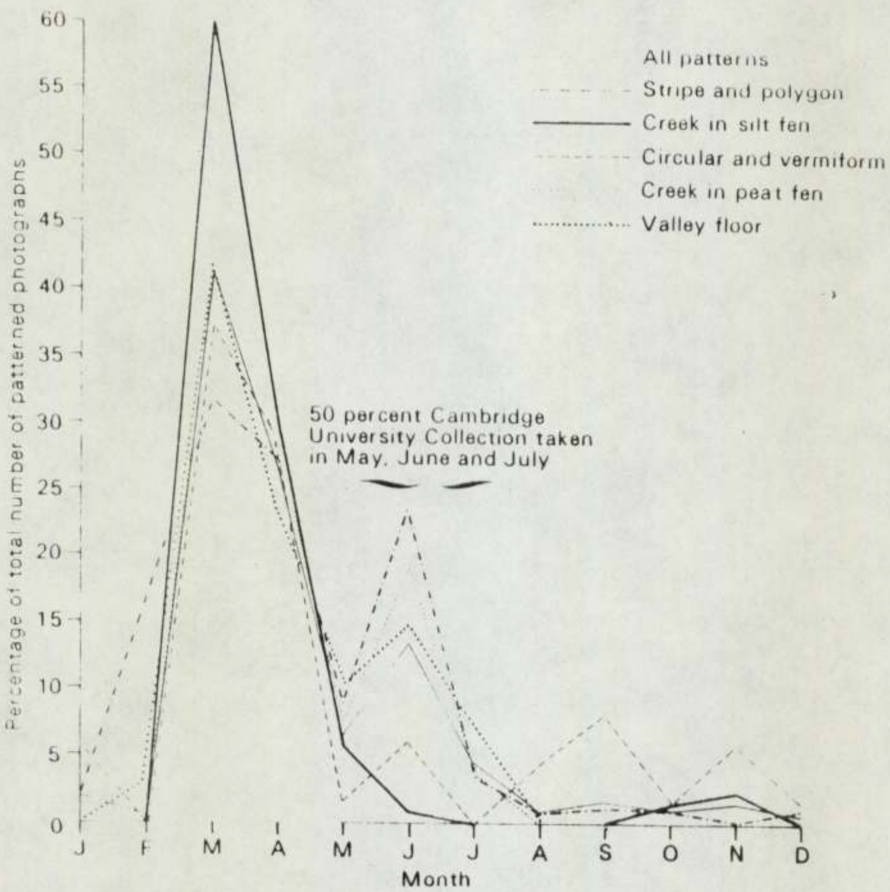


Fig. 6. Proportions of aerial photographs showing soil patterns, in different months (Evans, 1972b).

under crops. Patterns in vegetation accounted for only 5.2% of all the photographs actually recording patterns.

Factors which complicate interpretation should be eliminated as far as possible, so approximate dates of harvesting, sowing, crop rotations etc., should be known as these will vary from area to area. The type of crop in the field will show varying amounts of bare ground, e.g. cereals will show very little bare ground compared to crops such as turnips and sugar beet. Differential growth in cereals is only really seen in the mature and ripening stages, not when the crop is young because then there are too many minor tone differences, which may not be due to soil differences, making interpretation difficult. Stubble left after harvesting obscures any soil tone changes but in areas where winter sown cereals are dominant, the fields are ploughed immediately after harvesting so useful photographs may be taken then. Photographs should not be taken when the ratio between cropped and bare fields is low, as tone patterns cannot then be traced between fields without a break. Evans (1972a) found that tone changes on aerial photographs, which directly reflect soil changes, are common. These changes are often related to changes in lithology or parent material and are usually obscured by crop growth. April was considered the best month for both climatic conditions and soil tone changes.

There is even less said about the best time for photography for soil surveys of upland areas. One reference (Carroll and Evans, 1971) mentions that moorland and mountain areas are best photographed during early autumn when differential growth of vegetation is at its greatest, producing contrasting patterns. This opinion is also held by many experts on upland vegetation surveying (see chapter 6) but it does assume that soil changes are reflected in the vegetation, which is not always so (Wieslander and Storie, op.cit.).

4.7 Different emulsion types used for soil survey photography

Panchromatic photography is the most widely available type of photography, and is used by most soil survey organisations because of the difficulty and expense of obtaining other types of photography (mainly colour and false colour - see chapter 1). However, some experiments have been made to determine the usefulness of these other emulsions.

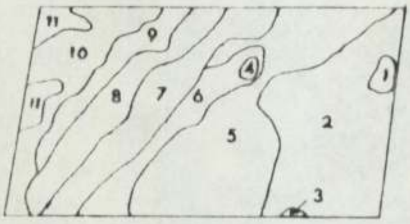
Anson (1966) reports an experiment in which a series of test flights were made to obtain both quantitative and qualitative information regarding the role of colour and false colour films for mapping applications. Colour and false colour photographs were compared to panchromatic photographs. Each film was exposed over the same target areas, under identical conditions of camera, vehicle and personnel. Information on vegetation (tree height, spacing, species, ground cover, etc.,) soil type (gravel, sand, rock, clay, silt), moisture content, surface drainage and crop type was required. Interpreters prepared vegetation, drainage, land use, cultural features and soils maps, using the photographs together with a small scale, general map of the area and the appropriate geological memoirs but no field work was carried out. It was found that false colour was superior to both colour and panchromatic photography for mapping drainage and vegetation, and colour was best for soils, land use and cultural features. The panchromatic photography was inferior for all uses. Colour photography provides a more accurate, rapid means of identifying cultural features and land use; it allows greater soil differentiation and crop identification and gives the interpreter more confidence in his decisions. Anson remarks also that colour film is best for soils with dry surfaces, while false colour is best for freshly cultivated soils with moist surfaces.

Parry, Cowan and Heginbottom (1969) tested bare soils using colour photographs taken in November and May. As colour has many more hues and chromas than grey tones, colour photography should be an advantage for interpretation. The soil colours were assessed in the field under wet (field capacity) and dry conditions, using the Munsell colour notation, to show variations between and within soil types. Surface colours only were recorded. In the areas chosen the soils had a fairly limited range of colour and, on the whole, moist soils were darker. Colour value could change by as much as two or three steps on the Munsell scale, depending on the position of the soil on the photograph, due to the different amounts of reflected light directed at the camera. The measurements were, therefore, made only when the soil was in the middle of the frame. They concluded that it is unlikely that specific colour signatures can be obtained from aerial photographs, at the soil series or soil group level, where the soils had developed under similar conditions from parent materials of the same general origin. However, colour photographs were superior to panchromatic photographs for identifying and plotting soil boundaries, differentiating soil types within the series and distinguishing changes within a single soil type, resulting from differences in moisture or organic matter content. Gerbermann et al (1971) also experimented with bare soils but in the laboratory, using twelve samples of different air-dried soils. These soils were photographed and optical density measurements made on transparencies, which used red, green, blue and white-light band-pass filters. Statistical tests showed that the soils could be separated into two groups, those with a low chroma which are distinguished best on false colour film, and soils with a high chroma, which are distinguished best with colour film.

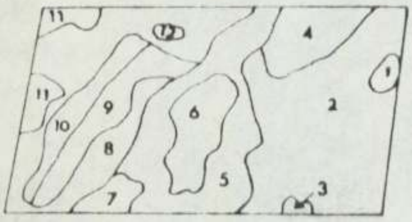
An investigation to determine if colour and infra-red photographs were superior to panchromatic for selected soil characteristics, was carried out by Kuhl (1970). The accuracy of the interpretations was measured against a map made in the field. Three sites in glacial till uplands were chosen (sites 1, 2 and 3) and two sites of alluvium, outwash and lacustrine sediments in a glacial through-valley (sites 4 and 5). Each site was examined on panchromatic, infra-red and colour photographs, on single photographs and on stereo pairs, and maps produced as overlays. Soil drainage, parent material, soil depth, erosion and slope were interpreted. A dot counter was used to compare the overlays with the control map. On average the colour stereo photographs were best for interpreting soil drainage and slope. The difference in accuracy of interpreting the photographs was not statistically significant however, and the results showed only a trend in favour of colour and infra-red photography (see fig.7 and tables 6 and 7).

Valentine et al (1971) carried out an experiment in Canada using 1:36,000 scale photographs of the podzolic zone of the mountains and of a valley with complex patterns of outwash, deltaic, marine and alluvial deposits. Rock, skeletal soils and till were found in the mountains. Panchromatic, infra-red, colour and false colour films were used. Using panchromatic photography the soils were mapped to an accuracy of 72%, this was increased to 80% (82% in the mountains) by using colour prints. They state that panchromatic photography is adequate for soil and terrain information from specific sites in the mountains, though the accuracy is only 50%-60%. For similar information in the valley, colour photographs were best, with an accuracy of 75%-83%. Black and white infra-red was difficult to see in stereo after a while and so was not used much. The best all round film was colour film but it did not produce much increase in amount or accuracy of information compared to panchromatic photography. False colour film gave disappointing results, probably because of lack of familiarity of the interpreter with the film.

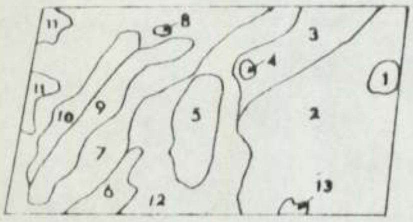
Site 2 -- Control Soils Map



Map 10 -- Black & White Stereo



Map 11 -- Infrared Stereo



Map 12 Colour Stereo

Fig.7. Site 2 soils map and stereo interpretation maps (Kuhl, 1970).

Interpretation Sequence	Photography	Stereo Maps	
		Drainage Accuracy	Slope Accuracy
Site 1			
1	Black & White	40%	60%
2	Infrared	21%	57%
3	Color	37%	61%
Site 2			
1	Black & White	69%	57%
2	Infrared	74%	68%
3	Color	74%	72%
Site 3			
1	Infrared	59%	41%
2	Black & White	50%	38%
3	Color	53%	41%
Site 4			
1	Color	49%	67%
2	Infrared	44%	42%
3	Black & White	47%	50%
Site 5			
1	Infrared	30%	88%
2	Color	39%	93%
3	Black & White	31%	84%

Table 6 Photo Interpretation Sequence and Accuracy.

Kind of Photography	Percent Accuracy and Percent Deviation													
	Drainage							Slope						
	-3	-2	-1	0	+1	+2	+3	-3	-2	-1	0	+1	+2	+3
B&W		8.7	11.6	36.4	35.2	6.8	1.3							
Infrared	1.4	8.6	13.8	41.0	23.8	10.6	.8							
Color	1.3	7.2	11.8	41.8	24.1	12.3	1.5							
B&W stereo	1.9	6.2	13.8	43.2	23.5	10.6	.8	.2	.5	14.6	57.9	24.9	1.1	.7
Infrared stereo	1.3	4.4	13.3	47.1	23.3	9.6	.9	.2	1.5	11.3	60.4	24.6	1.3	.7
Color stereo	1.8	2.5	13.2	40.4	22.5	9.7	.9	.4	.8	11.6	68.2	16.9	1.3	.8

Table 7. Summary Data of all Sites.

The marked superiority of colour film in mapping the valley was probably due to the type of vegetation present; the mountains had dense stands of mature hemlock and red cedar, while the valley had been logged and had smaller secondary growth, which reflected rather than masked the surface conditions. Vermeer (1968) has also carried out experiments, in a region in S.E.Netherlands, using panchromatic, infra-red and false colour photographs. Additional images were made by copying the three layers of the false colour film, separately and together, on to panchromatic film, to produce a type of multispectral imagery. There were seven images altogether, and seven areas were interpreted by seven interpreters who used the images in a cyclic fashion so that each of the interpreters interpreted seven different images of seven areas. These interpretations were evaluated against an ideal interpretation and given statistical treatment. The result was that panchromatic photography was found to be the most suitable for soil survey A.P.I.

In summary, the results of these experiments are rather inconclusive and conflicting. However, the difficulty of obtaining and handling colour and false colour film will probably ensure that panchromatic photography will continue to be used for soil survey A.P.I.

4.8 Quantitative aspects of soil surveying from aerial photography

Little quantitative work on the 'goodness' of soils interpretation has been done. Pomerening and Cline (op.cit.) have made a subjective comparison of A.P.I. maps and a 'best' map of the same area, made by combining the methods used, while Webster and Beckett (1964) have assessed the goodness of interpretation from the point of view of the user of soil maps, i.e. the farmer. They assessed the uniformity of physiographic A.P.I. units with respect to several chemical and physical properties of the soil. The study area was in Oxfordshire and was mapped using aerial photographs to their fullest extent, with only 10% ground check. In defining their physiographic units, greatest weight was given to fundamental characteristics of the landscape thought to combine most effectively recognisability, control of non-recognisable attributes (e.g. chemical properties) and homogeneity. Thus, morphology, surficial materials and water regime were used and classified on a geological basis, to give the A.P.I. units. The means, standard deviations, coefficients of variation and 90% confidence intervals, within the A.P.I. units, were given for each of the properties measured.

	Number of determinations	Mean	Standard deviation	Coefficient of variation %	90% Confidence interval ±
organic matter	709	9.8%	3.11%	31.7	5.13%
pH	1 694	7.09	0.57	8.1	0.94
P	1 728	0.031%	0.0338%	109	0.0557%
K	1 726	0.013%	0.0097%	74.5	0.0160%
$CaCO_3$	1 449	8.5%	12.3%	144	20.3%
Clay	83	36.9%	9.4%	25.5	15.9%
Cone Index	147	163	33.2	20.4	54.8

Table 8. Means, Standard Deviations, Coefficients of Variation and 90% Confidence Intervals of A.P.I. Mapping Units (Webster & Beckett 1964).

An analysis of variance was done for all the available data on the soils developed on solid geological formations, and it was found that where the soils were grouped either physiographically or geologically, variation in all properties was significantly reduced compared to the landscape as a whole. They concluded that soil classifications based either on geology or physiography gave mapping units more homogeneity, with respect to agronomic properties, than the landscape as a whole.

In young landscapes of variable geology, physiographic mapping was marginally less advantageous than geological mapping but map units defined on both physiographic and geological characteristics were best. However, the variability of some attributes was still very high, e.g. $CaCO_3$ content.

Webster and Wong (1969) tested the 'goodness of fit' of soil boundaries. Their A.P.I. of the soils was subjective but they gave it objective tests. Soil properties of interest can be combined by component analysis into a single variable that expresses a large percentage of available information. This variable, the first principle component, can be used as a quantitative measure of the soil. Variations in the lateral rate of change of the soil properties' boundaries lie along lines where the rate of change of this component is maximal or minimal. The positions of these lines can be found statistically by minimising variances within and maximising differences between classes of sampling points on either side of each line. The lines or points thus found may be used as standards, against which recognised soil boundaries may be compared. They found that lines representing maximum lateral rates of change are easy to map and agree closely with soil boundaries, determined independently as above, but the feasibility depends very much on there being some change in slope or land form accompanying other changes in the photo-image.

Beckett (1972) would like to see objective evaluations of A.P.I. methods. Assessment of the efficiency of these methods, by cost, time and accuracy is possible. He suggests a comparison of different A.P.I. procedures by several people and then these would be compared by rank correlation methods, providing the subjective assessments are relevant.

4.9 Methods used by the Air Photo Unit of the Soil Survey of England and Wales

The Soil Survey use a method very similar to element analysis, which they find especially useful in a new area, unknown to the surveyor. As the surveyor gains more experience of an area, then a more physiographic approach is used. The method used depends on the scale of the photography, the complexity of the soil pattern in the area and the surveyor's experience of the area or similar areas. The more experience a surveyor has, the more short cuts he can take in applying element analysis. The amount of field checking of the interpretation depends on the scale of the mapping; for reconnaissance maps (1:250,000), 1-4 spot checks per square kilometre are usually made (Carroll, personal communication).

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Chapter 5: LAND USE SURVEYS USING AERIAL PHOTO-INTERPRETATION

5.1 Land use surveys

Land use has been defined as "the end to which land is allocated, assuming a conscious decision to use it for a desired end" (Clawson, 1960). Definitions of both land and use will vary slightly according to the purpose for which a land use survey is carried out. The National Land Use Classification System (N.L.U.C.S.) (L.A.M.S.A.C., 1972) defines land as including not only the ground surface but all surfaces and spaces on and in which human activity occurs, so that activity on, for example, upper floors of buildings can be taken into account. They found that use was a little more difficult to define but eventually use was defined as the activity taking place on a piece of land. These activities could be defined in the N.L.U.C.S. in broad groups, e.g. residential, industrial, or described precisely e.g. chocolate factory. Concepts such as ownership, land capability and occupancy were not included in the N.L.U.C.S., although these are aspects of land use and it is usually easier to gather as much data as possible at once, rather than do separate surveys.

Land use surveys are carried out for various reasons; information about land use is essential for many purposes such as the preparation of development plans (agricultural and urban), development control, transportation studies, socio-economic assessments. For instance, the Countryside Commission have the responsibility to keep under review all matters relating to "the conservation and enhancement of the natural amenity of the countryside" (Countryside Act, 1968). Detailed information on the countryside could be used to make more authoratative statements about landscape conservation, help suggest regional priorities for grant-aiding local authorities and be of help to other types of rural survey. On a wider scale, up-to-date information on major land uses throughout the world is a basic need, especially information on the acreage and distribution of food crops. Land use data are essential for efficient management of agricultural resources in both developed and developing countries, especially as the world's population increases and the amount of food needed is greater. In many countries land is under great pressure from competing uses and thus efficient development planning and management is essential. Very often in the past decisions about land use were subjective assessments by individuals, based on incomplete information.

To overcome this lack of data Stamp organised the 1st Land Use Survey. He had been interested in the geography of Britain as a whole, and found that although there had been several regional studies of land utilization, only a small part of the country was covered by them and the data were not always comparable. Ordnance Survey maps gave little information on many aspects of land use and the state of cultivation of the land, and in many cases were out of date. There were serious gaps in knowledge of the British Isles and this was to become more apparent during the war years when planning, especially agricultural planning, became necessary. The aims of the 1st Land Use Survey were to survey the land utilization of the whole of Britain, on a field-to-field basis, so that rapid changes in the country could be assessed. It was to be "a modern Domesday Book".

The field work for the survey was done on 1:10,560 scale maps and the final maps were published at 1:63,360, with reports for each county. The work was done on a voluntary basis, mainly by school children, and the complete survey took seventeen years, from 1930-1947. Six simple classes were mapped:

1. forest and woodland
2. meadowland and permanent grass
3. arable

4. heathland, moorland, commons and rough pasture

5. gardens, allotments, orchards and nurseries

6. agriculturally unproductive land

Forest and woodland were further classified according to the species of tree and the state of the woodland, e.g. coppice, scrub, and arable land could also be classified according to the type of crop growing. Unproductive land included buildings, mines, cemetaries, waste land, etc., and it was asked that a note should be made stating the character of all considerable areas of this class. Differences in interpretation of some terms, such as rough grazing, led to difficulties and some sheets had to be edited before publication. Two maps at 1:625,000 were published to cover the whole of the country, summarising the findings of the survey, while the complete survey was described and the results discussed by Stamp (1962). These maps were very useful during the war, especially for planning the ploughing campaign, and it became apparent that data on land use were necessary for national planning. The need for national planning was brought home to the government of the time, when they found that British agriculture was in a poor state, totally unprepared for war, with much land disused or derelict (agriculturally sub-marginal).

The 2nd Land Use Survey of Britain was started in 1960. Stamp had prepared a general scheme for a world land use survey for the International Geographical Union, who had realised that an inventory of world land use was necessary because of the problems of population and world food supply. The 1st Land Use Survey maps were no longer valid because conditions in Britain had changed so much since the 2nd World War, with rapid industrial and agricultural expansion. An increase in detail was needed so the maps were surveyed at a scale of 1:10,560 and published at 1:25,000. The basic classification is the same as the 1st Land Use Survey but each class is divided into subclasses, to produce two levels of generalisation and 64 categories.

The field survey is carried out in a similar manner but there is greater differentiation of crops and other uses, (figs. 1 and 2). Volunteers are used for the field mapping, which is supposed to be done as rapidly and as completely as possible because crop rotations can quickly change the land use pattern. There are eleven major and two minor groups:

1. settlement (residential and commercial)
2. industry
3. transport
4. derelict land
5. open spaces
6. grass
7. arable
8. market gardening
9. orchards
10. woodland
11. heath and rough land
12. water and marsh)
    - minor categories
13. unvegetated land)

Each of these groups is subdivided into different categories. The handbook (Coleman and Maggs, 1965) gives the explanation of the symbols, the method of field surveying and a quick guide to the identification of crops. Large areas of heath and rough land are mapped by their constituent vegetation communities, e.g. bracken, grass moor (3 types), heather and bilberry, Sphagnum, but these vegetation surveys may be mapped at a 1:25,000 scale.

Other land use surveys of Britain include the N.L.U.C.S. (op.cit.) which is primarily for the use of local authority planning departments.

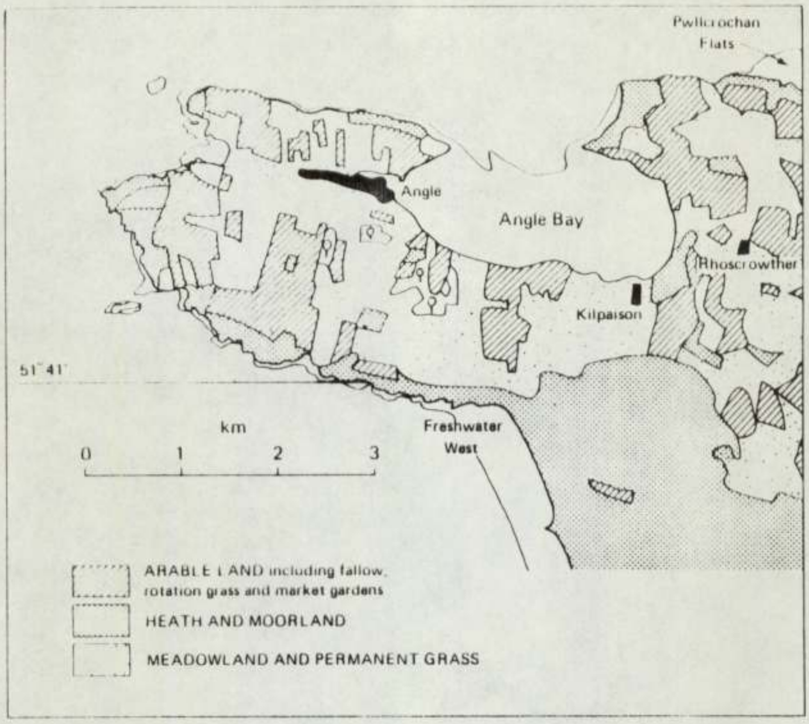


Fig.1. An example of a land use map by the 1st Land Use Survey. Part of the Pembroke and Tenby sheet.

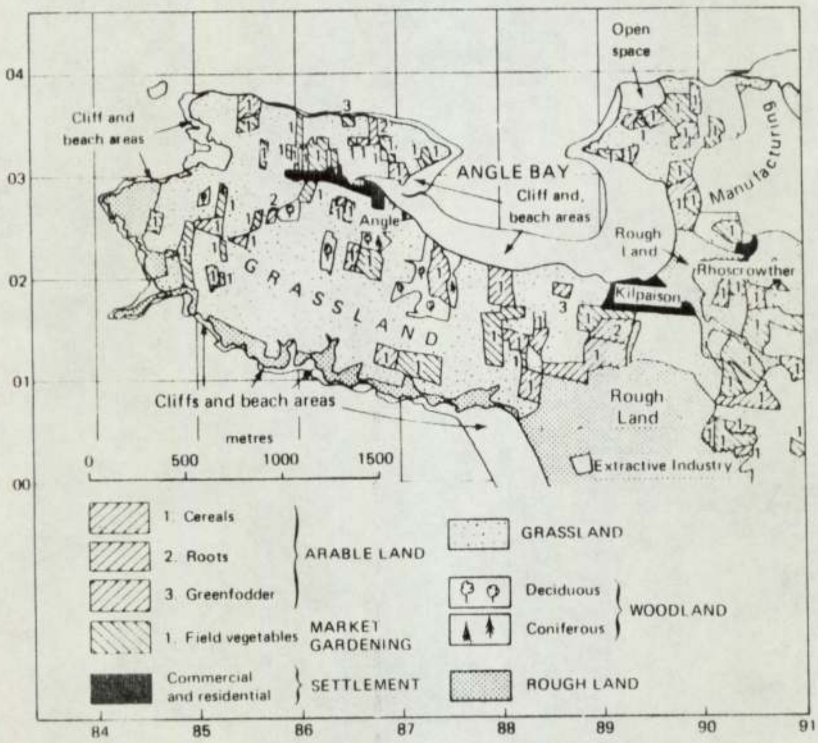


Fig.2. An example of a land use map by the 2nd Land Use Survey. Part of the Milford Haven sheet.

They needed a universally accepted, national land classification to provide an aid to making decisions about land use, and they found that existing classifications and surveys did not meet their needs, mainly because varying interpretations of land use terms and different classifications meant that these studies could not be related to each other and the land use data could not be used reliably in other studies. The N.L.U.C.S. is "a medium for collecting, classifying, displaying and disseminating land use data" and is thus a land management aid. It has a four tier structure, is based on the theme of human activity and is ordered in its hierarchy by this criterion. The Countryside Commission (1971) also found that existing land use data were unsuitable for their needs and carried out their own survey. This was a survey of rural landscapes rather than land use, and information on such aspects of countryside as the type of field boundary, e.g. wall, fence, hedge, were wanted. Continuing changes in rural land use, the expansion of towns, afforestation etc., alter the landscape but there is no reliable data on the type, extent and rate of landscape changes, e.g. the rate of loss of hedgerows in Britain was estimated at less than 1,000 miles per year by the M.A.F.F. in 1969 and over 7,000 miles per year by the Nature Conservancy in 1968. This survey of the changing countryside failed, however, because it was too complex and the definitions of terms were not strict enough. Information on various aspects of land use are needed for surveys of other types e.g. surveys of countryside resources for outdoor recreation (Coppock, Duffield and Owen, 1973), surveys for conservation assessment of certain areas of great interest (Nature Conservancy, 1965), types of farming surveys (Anderson and Coppock, 1972), land quality surveys (Stapledon and Davies,1936; Stapledon, 1937; M.A.F.F., 1968).

Surveys of the agricultural value and potential of land are not strictly land use surveys but may often use land use data as a basis.

Coppock (1963) remarks that land use may be related to land quality as certain crops, e.g. cherries which require rich, well-drained loamy soils, can be used as an index to land quality, but many other factors, such as the type of farm management, should be assessed also. In the broad view, the hypothesis that land use pattern is related to land quality is valid but there are many differences in detail. Bibby and Mackney (1969) have a scheme for land capability assessments where the land is graded according to its potentialities and limitations. Land capability is assessed from known relationships between the growth and management of crops, and the physical factors of soil, site and climate. The classification is primarily for agricultural purposes and the land is assessed for capability under a moderately high level of management and not necessarily on its present use. The M.A.F.F. (1968) also have an agricultural land classification which is similar. Land is graded according to the degree to which physical characteristics impose long term limitations on agricultural use; these limitations may operate in several principal ways: they may affect the range of crops which can be grown, the level of yield, the consistency of the yield and the cost of obtaining it. Morgan (1968) says that this type of classification may be more useful than land use surveys, as the emphasis is on long term factors and the permanent physical properties of the land which influence crop production are included in the classification.

The two most common problems in land use classification and the interpretation of data are:

1. the incompatible and inconsistent use of terminology e.g. arable, cultivated and cropland can all mean the same thing (see Table 1).

Munn, McClelland and Philpotts	Board	Stridas	Avery
horticulture		horticulture	
cropland	cultivated land	cropland	cultivated land
orchards and vineyards	orchards and vineyards	trees and other perennials	
improved pasture and range	grassland	improved permanent pasture	
		grassland and scrub	
productive woodland	clumps and unplanned woodland	woodland	pine forest
unproductive woodland	unplanned forest and dense bush		hardwood forest
unproductive	scattered bush	unused	idle
swamp, marsh and bog		swamp and marsh	water

Table 1. Land use classes (after Nunnally and Witmer, 1968).

2. developing useful and comparable classification systems.

Nunnally and Witmer (1970) carried out an experiment where very detailed land use data were necessary and various classification systems were used. The system which was specifically designed for the problem, came out best in the tests but they found that it was very difficult to standardise classifications and that there was no single system suited to all purposes. The N.L.U.C.S. was set up for this reason and also the Countryside Commission survey. The N.L.U.C.S. is based on human activity on the land and problems associated with this include defining the dominant activity and designating sequential use. Sequential use is usually defined as multiple use. If there is more than one dominant activity the most important ones are chosen so the land parcel will be marked as multiple use, e.g. water storage and recreation. All activities are taken into account if it is difficult to decide which is dominant. However, such definitions are for planning purposes and are not necessarily suitable for any other purpose.

5.2 Land use surveys and aerial photo-interpretation

Historically, land use data were compiled by census, interview or field survey and usually took a very long time. Aerial surveys are a much faster method and provide up-to-date information, usually for one point in time (Luney and Dill, 1970), as data can be acquired in the same season and/or even on the same day. The interpretation of the photographs and the production of maps will take longer than the collection of the imagery but the time taken will still be less than the traditional land use survey. Brunt (1961) shows that aerial photographs are very useful to the agriculturalist because they present a bird's-eye view of ground conditions and are useful field documents, as more topographic detail is shown than on a map. At this time there had been no controlled tests on time and accuracy to compare ground survey methods with A.P.I. methods but Brunt carried out a detailed land use and vegetation survey of 2,000 sq. miles in Gambia, at 1: 25,000 scale, which took one man-year using A.P.I. methods; he estimated that by ground methods this survey would have taken five years at least. A similar survey was carried out in Kenya, where a three-man team completed a survey of 20,000 sq. miles, at 1:50,000, in one year. It was estimated that the work would have taken three times as long without aerial photographs. These figures do need qualification because the amount of time taken on a survey depends on the experience of the people doing the work, the complexity of the features being surveyed, the ease of communications etc. In the tropics information on areas of crops grown is often scanty or non-existent and where agricultural development is important, lack of this information can be a serious handicap. In Gambia, A.P.I. was the only way of making a historical assessment for a survey of changes in rice acreage. Brunt concludes that the use of A.P.I. will usually speed up surveys and reduce the cost and therefore prevent mistakes in development programmes.

At first, aerial photographs were used purely as base maps for land use classification projects, although land use was sometimes mapped directly from aerial photographs with little or no field checking. Marschner (1958) produced land use maps of the U.S.A. in this manner, at a scale of 1:5M, showing very broad land use categories. Aerial photographs rapidly became more widely used for land use surveys and other related surveys. The U.S. Department of Agriculture has surveyed land use from aerial photographs for determining the acreage of crop types, for land classification in conjunction with soil studies, for watershed and flood plain studies and for assessing sites for outdoor recreation (U.S.D.A., 1962). For studies of changing land use, aerial photographs provide useful historical documents (Wagner, 1963; Avery, 1965). Some other types of land use studies using A.P.I. include an analysis of farming types (Ryerson and Wood, 1971), a survey of erosional hazards for agricultural development (Jones, 1969), urban data collection (Moore and Wellar, 1969; Wellar, 1973) and derelict land studies (Collins and Bush, 1971; Gibson, 1974).

Nunnally and Witmer (1968) discuss some problems associated with interpretation of land use from aerial photographs. There are three basic problems, two of which have already been mentioned (see p.111-112) as they are problems associated with land use mapping as a whole, not specifically with the use of aerial photographs. The problems are:

1. those associated with the definition of terms.
2. those associated with the development of classification systems.
3. those associated with image perception.

Problems associated with the perception of the image on an aerial photograph stem from the definition of land use in terms of function, which can rarely be directly deduced from the image. Land use is dynamic, with many cyclic changes, e.g. crop rotations, but only the observed image at one point in time can be recorded by the survey. Sequential photography, at carefully selected seasons, could be used to show the dynamic aspects of land use. Nunnally and Witmer (1968) argue that deductively derived (by logical division) land use classifications are not appropriate for surveying land use by A.P.I. An inductive approach, producing hierarchical categories by grouping related or similar land uses, at first in detail, then into progressively larger, more comprehensive groups, is more flexible and can be expanded as new uses are identified (see tables 2 and 3). Table 2 shows an inductive classification of land uses classes as they might be grouped for urban planning studies, while table 3 shows the same classes grouped for agricultural purposes. A three-fold strategy for land use surveying with aerial photographs was proposed:

1. Interpret and record land use data on maps in as great detail as possible. Land use existing at the time of photography should be recorded only, and nothing inferred.
2. Establish a classification system by grouping interpreted individuals into land use classes.
3. Data handling; coding, storing and tabulating the data.

This strategy using the proposed inductive classification was tested by Nunnally and Witmer (1970) against other systems. It gave the most

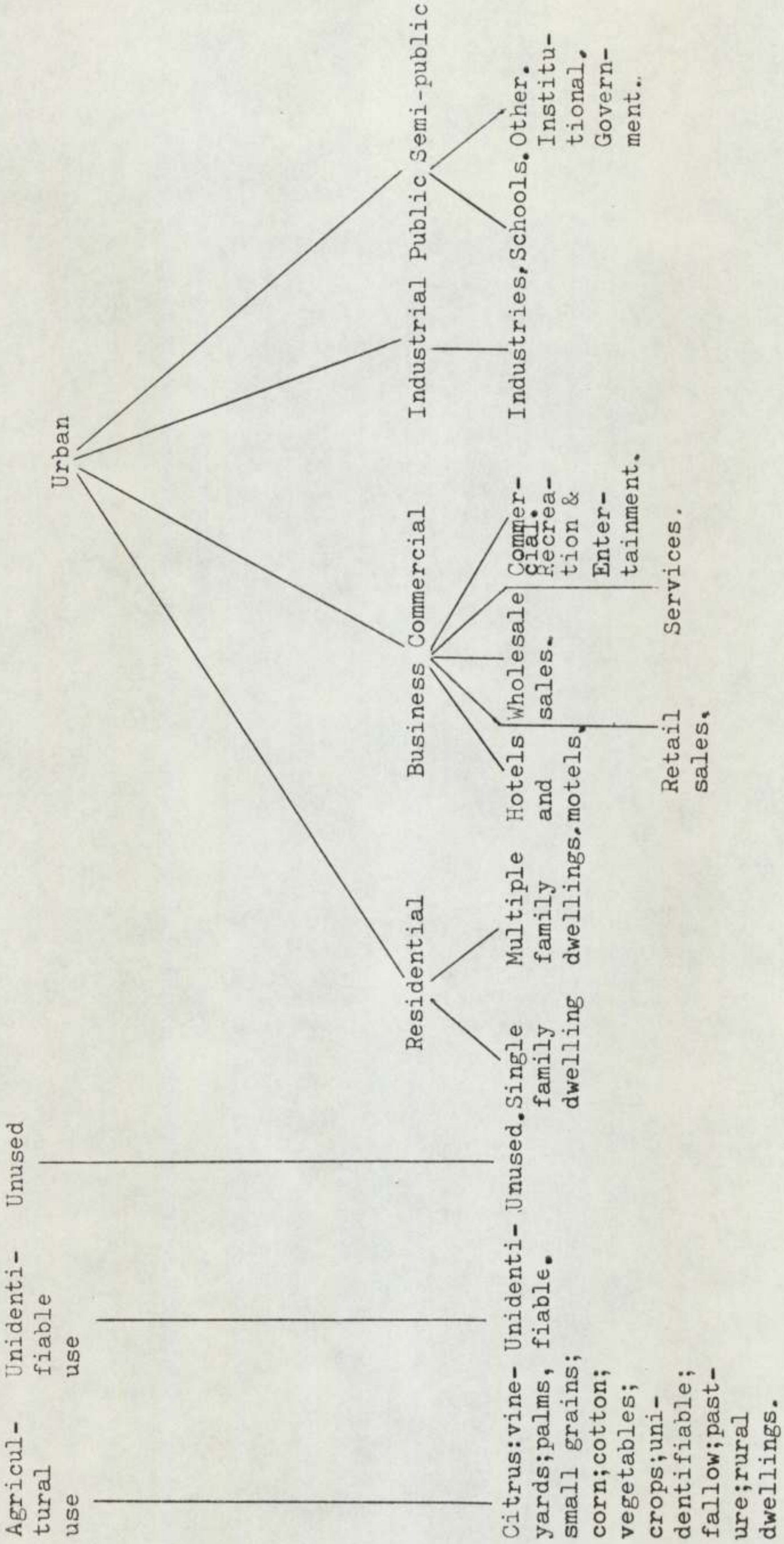


Table 2. Land use classes for urban planning (Nunnally and Witmer 1968).

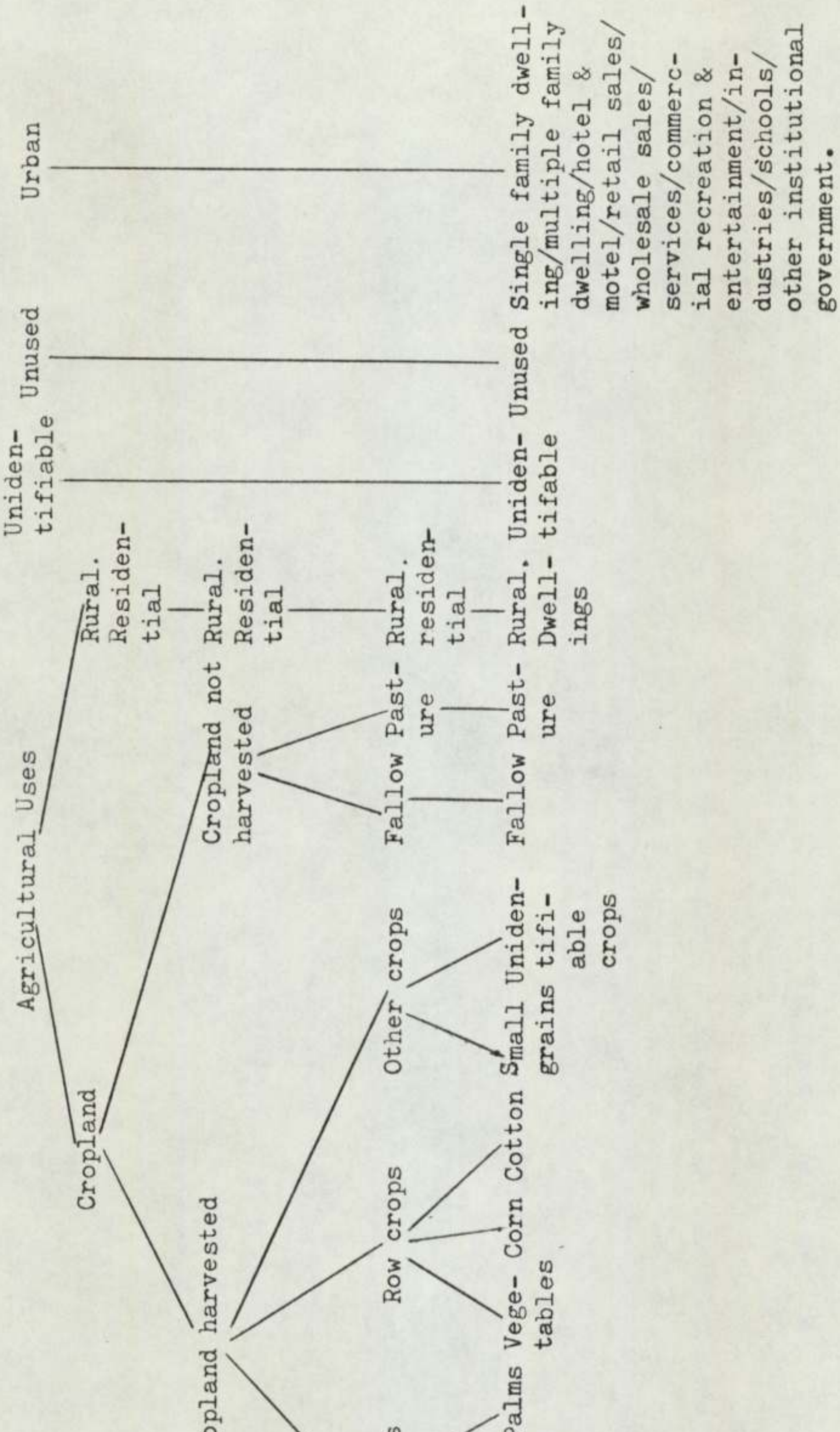


Table 3. Land use classes for agricultural planning (Nunnally and Witmer, 1968).

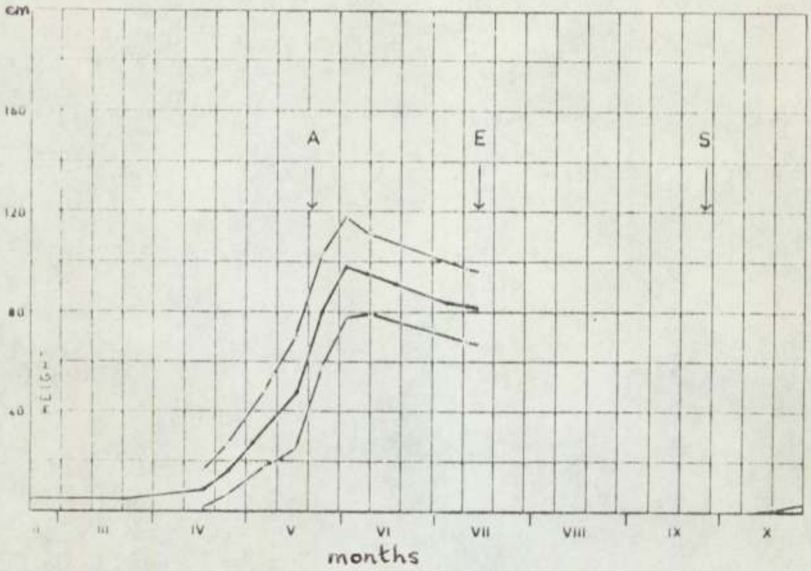
accurate and most detailed result. They believe that this type of classification interpretation system is applicable to all scales and types of remote sensing imagery.

5.3 Timing of aerial surveys for land use mapping

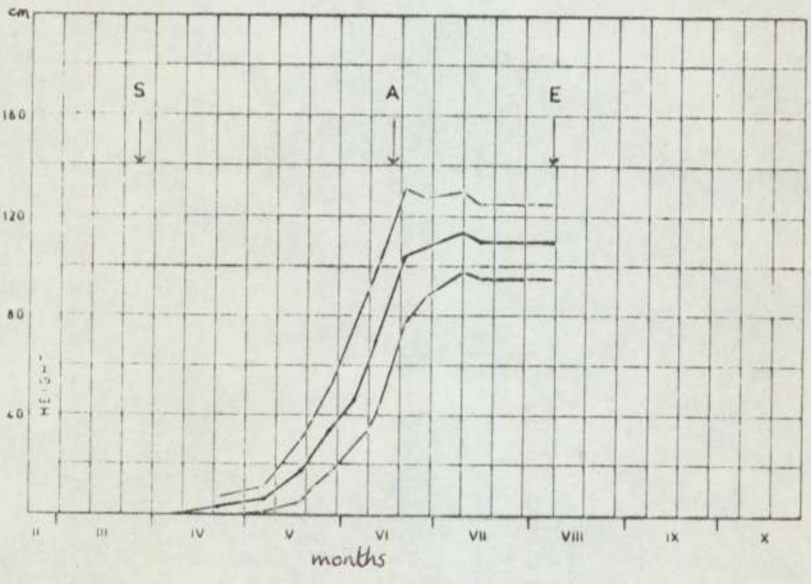
The timing of aerial surveys is extremely important for rural land use surveys. Rapid changes in the vegetation cover during the growing period mean that the A.P.I. of rural land use presents special problems. Surveys for urban land use mapping or for special aspects of land use, such as derelict land mapping, may not require such consideration of season.

However, the study of seasonal changes is a prerequisite for planning flying programmes for rural land use surveys. Steiner (1966) says that the problem of studying these seasonal changes can be tackled in two ways: prognostically and experimentally.

1. The prognostic method involves making field observations on the ground and drawing conclusions about the probable ease of interpretation of aerial photographs taken at corresponding times. Photographic tone, texture and height are the most important characteristics of a crop, as shown on an aerial photograph. The tone (colour) of a crop in the field can be measured using the spectral reflectance of the vegetation, though it is much more difficult to describe texture objectively. The collection of phenological records of vegetation is important as these show the stages of growth of the vegetation (fig.3) and indicate the most important times of year e.g. the emergence of the crop (fields becoming green), flowering (change in colour), beginning of ripening (fields turning yellow or brown). Growing cycles may repeat themselves within a year, e.g. in hay fields. This method is more flexible than the experimental method but the value of the results is limited because of the



a) Winter barley



b) Spring wheat

Fig.3.Phenological observations of winter barley and spring wheat, including average growth height ± 2 standard deviations and average dates of sowing (S), heading (A) and harvest (E), valid for the Zurich area, Switzerland (Steiner, 1966).

theoretical nature of any predictions made.

2. The experimental method uses aerial photography, taken at intervals during the growing season, to decide on the appropriate time. Tone, texture and height are again used as the most important characteristics. Tone can be measured from the photographs using a grey scale or the Munsell colour notation, or by a microdensitometer, although there are many factors other than the actual colour of the vegetation which influence tone on a photograph (see chapter 2). Also there tends to be a large amount of variation within crops. Texture is again difficult to describe, although crop height is easy to measure. Probably the best way to overcome these problems is through a sample survey and photo-interpretation. The results of the A.P.I. can be checked in the field and mistakes corrected before carrying out the whole survey. This method is more expensive and is applicable only in fine weather, so the photography is likely to be at irregular intervals, so it is possible to miss important aspects of the growing cycle. Ideally both the prognostic approach and the experimental approach should be combined.

Steiner (op. cit.) also discusses some results of research into seasonal effects in various regions. In intensively cultivated, temperate and subtropical areas he reports that most authors find it difficult to identify crop types on panchromatic photographs but crops can be separated into groups, e.g. grains, row crops. Variations from region to region are related to the complexity of land use, and any conclusions about the affects of season and its influence on A.P.I. have a strictly regional (or even local) value. Many crops can be recognised from factors other than colour, texture and height, such as the different types of harvesting pattern or machine (Ryerson and Wood, op. cit.) e.g. hay crops. Certain crops, e.g. rice, can be easily recognised at any time because of its characteristic field pattern and topographic occurrence. In non-intensively cultivated, temperate and subtropical regions, there may be sharp seasonal contrasts between components of the vegetation cover, due to differences in soil type and land management. In these areas mapping the vegetation cover is usually a fairly simple task.

In tropical areas, Steiner reports that land use mapping from aerial photographs is more difficult because of shifting cultivation practices, mixed cropping (e.g. coffee under banana trees), small fields, succession cropping and the similarity of the main crops (e.g. millet and guinea corn in Western Africa). However, work undertaken for this thesis has shown that the problems of small fields, mixed cropping and succession cropping are probably as common in intensively cultivated temperate areas such as Britain, as in the tropics. In the area studied, many farmers practised crop rotation; one of the major crops is kale, which is sown in July and will be cut by December at the latest but is usually cut in October or November, so there is no sign at all of this crop for seven months of the year or longer. Often one crop will be undersown with another which ripens at a different time, e.g. barley undersown with vetch, and then the field may be left to reseed itself with grass. Many crops, both grain and root crops, are used green, as fodder, and it can thus be impossible to distinguish between them. However, detailed differentiation was possible in this area for some crops, for example it is local practice to sow swedes broadcast and to sow turnips in rows, so these two similar crops can be distinguished. Thus, information on local and regional farming practices may be necessary for accurate land use interpretation. The economic situation in the country may cause rapid change in the types of crops grown, at any time, as well as normal rotation practices, e.g. in the study area, the change over twelve months (October 1973-October 1974) showed that an increasing amount of grassland was being turned to arable crops, mostly fodder crops, in response to the increase in the price of imported animal feed. Multi-seasonal or sequential photography may be the answer to these problems of changing land use (permanent and rotation changes) but this can be very costly.

The Laboratory for Agricultural Remote Sensing (L.A.R.S., 1967) state that the key to remote sensing for crop identification appears to lie in obtaining data at the appropriate periods of crop development, and throughout the growing season. They also remark that adequate background knowledge of agriculture and knowledge of current agricultural conditions in the places of interest is important in determining the causes of variation in the photo-image.

5.4 Different emulsion types used for land use surveying

There have been several experiments using different emulsions for land use A.P.I. Blair Rains and Brunt (1971) have assessed the usefulness of true colour, false colour and panchromatic aerial photography for land use surveys in Africa. In tests on true colour photography, for land use analysis in Malawi, the improvement in correct identification of land use classes rose from 82% on the panchromatic photography, to 94% on the true colour photographs. Certain crops, e.g. cassava, which were often mistakenly identified on the panchromatic photography, were easily and correctly identified on the true colour photographs (Table 4).

PHOTOGRAPHY	SCALE	VIEWING	% CORRECT IDENTIFICATION
Black and White	1:10,000	Non stereo	65
Black and White	1:40,000	Stereo	82
Ektachrome true colour (8442)	1:40,000	Stereo	94

Table 4. Malawi: air photograph interpretation trials for land use identification (Blair Rains and Brunt, 1971).

Trials using different emulsion types for surveying parts of Kenya were designed to investigate the best type of aerial photography for teams of scientists investigating different parts of the environment, including land use, and these indicated that true or false colour photography had an advantage over panchromatic, especially for the identification of natural vegetation and crops. Unfortunately, for extensive land resource surveys, the cost of obtaining colour photography is very high, so panchromatic imagery will continue to be used.

Other studies have used several, simultaneously exposed, emulsions; Bell (1972) has used panchromatic and black and white infra-red photographs for the identification of crops and crop diseases; Witmer (1968) analysed a coastal area in Florida using panchromatic, black and white infra-red and colour infra-red photographs; Ryerson and Wood (op.cit.) suggest that false colour and true colour are better emulsions for land use interpretations. L.A.R.S. (op.cit.) have used multispectral photography for land use interpretation and have found it useful, although work by the author suggests that false colour photography is more useful (chapter 8).

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Chapter 6: VEGETATION SURVEYS USING AERIAL PHOTO-INTERPRETATION

6.1 Vegetation surveys

Vegetation was first depicted on maps around the sixteenth century, when, for instance, areas of forest would be shown by drawings of trees. Later, during the seventeenth century, cultural vegetation was increasingly shown, e.g. vineyards, olive groves. Modern Ordnance Survey maps distinguish several types of vegetation, including marsh, furze, reeds, rough pasture, heath and moor, and forest species (coniferous or deciduous). One of the earliest vegetation maps was made by Sendtner (1854) who mapped the geographical distribution of "Sphagnetum with Pinus pumilio". Since then there have been many attempts at mapping vegetation, more often the vegetation of a whole country rather than the distribution of one or two individual species. Much of the United States was mapped during the nineteenth century, while mapping in Europe developed more slowly. The development of ecology and phytocenology led to the production of many vegetation maps in Europe, often at large scales, and various methods for vegetation surveying have been developed. The success of vegetation mapping in Europe rests on very clear and precise definitions and classifications of phytocenoses (Küchler, 1967). Phytocenology is the study of vegetation, which consists of phytocenoses or plant communities.

For mapping purposes, vegetation can be defined as "the mosaic of plant communities in the landscape" (Küchler, op. cit.). It is better not to separate the plants from their environments, but to treat the combination of plant community and its environment as a whole, named an 'ecosystem' by Tansley (1935). Maps showing only the geographical extent of one or several species are area maps referring to floristic regions and are not strictly vegetation maps. There is a variety of classification systems; plant communites have so many characteristic features that it is impossible to use them all for classification, so it depends on the purpose of the mapping exercise and the particular area, which features are used in the classification. According to Küchler (op. cit.) the relationship between classifying and mapping vegetation is very intimate and he lists some of the more well-known classification systems:

physiognomic systems (using the outward appearance and structure of the vegetation)

ecological systems

physiognomic-ecological systems

dynamic - floristic (species type) systems

physiognomic - floristic systems

Classifications can also be hierarchical or non-hierarchical.

Vegetation surveys are needed for many purposes; for instance the Nature Conservancy (Goodier and Grimes, 1970) require vegetation maps for the selection of research areas, the study of animals in relation to their habitats, resource management for planning integration of wildlife conservation with other forms of land use, inventories of resources in nature reserves, and for land use planning, to indicate the relative importance of various habitats in any area. Matthews (1939) says that "vegetation maps are essential as a record of the existing vegetation of a country and should form a basis for future land utilisation". Mitchell (1973) points out that vegetation is often a very important key for the recognition of terrain types when mapping land resources, while Viktorov et al (1964) show the need for vegetation maps in the peat industry in Russia and for agricultural purposes, e.g. land reclamation, pasture improvement. Vegetation surveys can be of use to geological and mineral surveys, certain plants indicating the occurrence of various mineral ores.

6.2 Methods of vegetation survey

The basic tool in vegetation surveys is the quadrat, which is a square frame, usually of metal and often one metre square, divided into smaller sections by pieces of string. This is used either to map the total vegetation occurring within a larger quadrat or to map samples of a particular vegetation community. Quadrats of a much larger size can be constructed using poles and tapes, often 10m square quadrats will be used for a woodland survey and 2m square quadrats for a grassland survey. Other ways of mapping or sampling are by transects, which show graphically the changes in the vegetation composition along selected lines. The belt transect, a strip rather than a line, is normally used. A profile chart is similar to a belt transect and is usually recorded along the same line. It is a plan of the vertical aspect of the vegetation. Quadrat data are amenable to quantitative analysis but there is another method which is also amenable to quantification without the use of a quadrat. This is valence analysis, which has been used by the author for the vegetation surveys of Ingleborough Hill. This type of analysis shows the occurrence of species composing random samples; the random samples can be chosen by any method but the usual one is to toss an object (possibly but not necessarily, a quadrat) down onto the ground and to study the vegetation in the area in which it falls. As with quadrat analysis, the size of the area subjected to analysis may vary, according to the nature of the vegetation. The species and their occurrence in each throw are recorded (see table 1) and the total number of occurrences of each species is counted up, expressed as a percentage of 100 trial areas and grouped into the following groups:

Group A 0-20%

B 21-40%

Table 1. Valence survey.

INGLEBOROUGH VEGETATION SURVEY

AREA: Little Knott - limestone grassland.
MAP REFERENCE: 742713.
DATE: 7th August 1975.

SPECIES	1	2	3	4	5	6	7	8	9	10
Festuca ovina/rubra	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Achillea millefolium	✓			✓		✓	✓			
Poa trivialis	✓						✓			
Trifolium repens	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Thymus drucei	✓	✓	✓		✓		✓	✓		✓
Cerastium glomeratum	✓	✓		✓	✓				✓	
Luzula campestris	✓	✓	✓		✓		✓	✓	✓	✓
Sesleria caerulea	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cirsium acaulon	✓	✓	✓			✓	✓	✓	✓	✓
Prunella vulgaris		✓	✓				✓		✓	
Galium sterneri				✓						
Euphrasia confusa					✓			✓	✓	
Urtica dioica						✓				
Lotus corniculatus							✓	✓		
Viola riviniana								✓		✓
Agrostis tenuis										✓

C 41-60%

D 61-80%

E 81-100%

A histogram is made from the results (see fig.1). This gives a clear idea of the composition of the vegetation; species in group E are regarded as dominants and co-dominants, while those in group A are regarded as accidentals. As well as surveying the vegetation areally, the abundance of each species, the percentage cover, the sociability, i.e. the relation of individuals of a species to each other, and the stratification of the vegetation are often noted (McLean and Ivimey-Cook, 1950). Many other methods of vegetation survey exist but it is not necessary to mention them here.

6.3 Reconnaissance vegetation mapping

Vegetation surveys can be classified according to their scale. Many surveys are at large scales and show the vegetation in great detail, often as it occurs in nature, with little generalisation. Other surveys are small scale and are suitable for atlases or maps of whole countries. In between these scales is reconnaissance mapping, which is often a preliminary step to more intensive mapping. There is no strict definition of reconnaissance: Küchler (op.cit.) regards 1:100,000 - 1:500,000 as reconnaissance scales, whereas Tivy (1954) used 1:25,000 scale for reconnaissance maps. Reconnaissance mapping generally calls for a rapid and not a detailed mapping method, whatever scale is used.

There have been few recent botanical surveys in Britain with the exception of the Grassland Survey of England and Wales (Stapledon and Davies, 1936), the 1st Land Utilisation Survey (Stamp, 1962) and Ratcliffe's (1959) survey of the vegetation of the Carneddau in North Wales. Modern plant ecologists have tended to concentrate on smaller and smaller

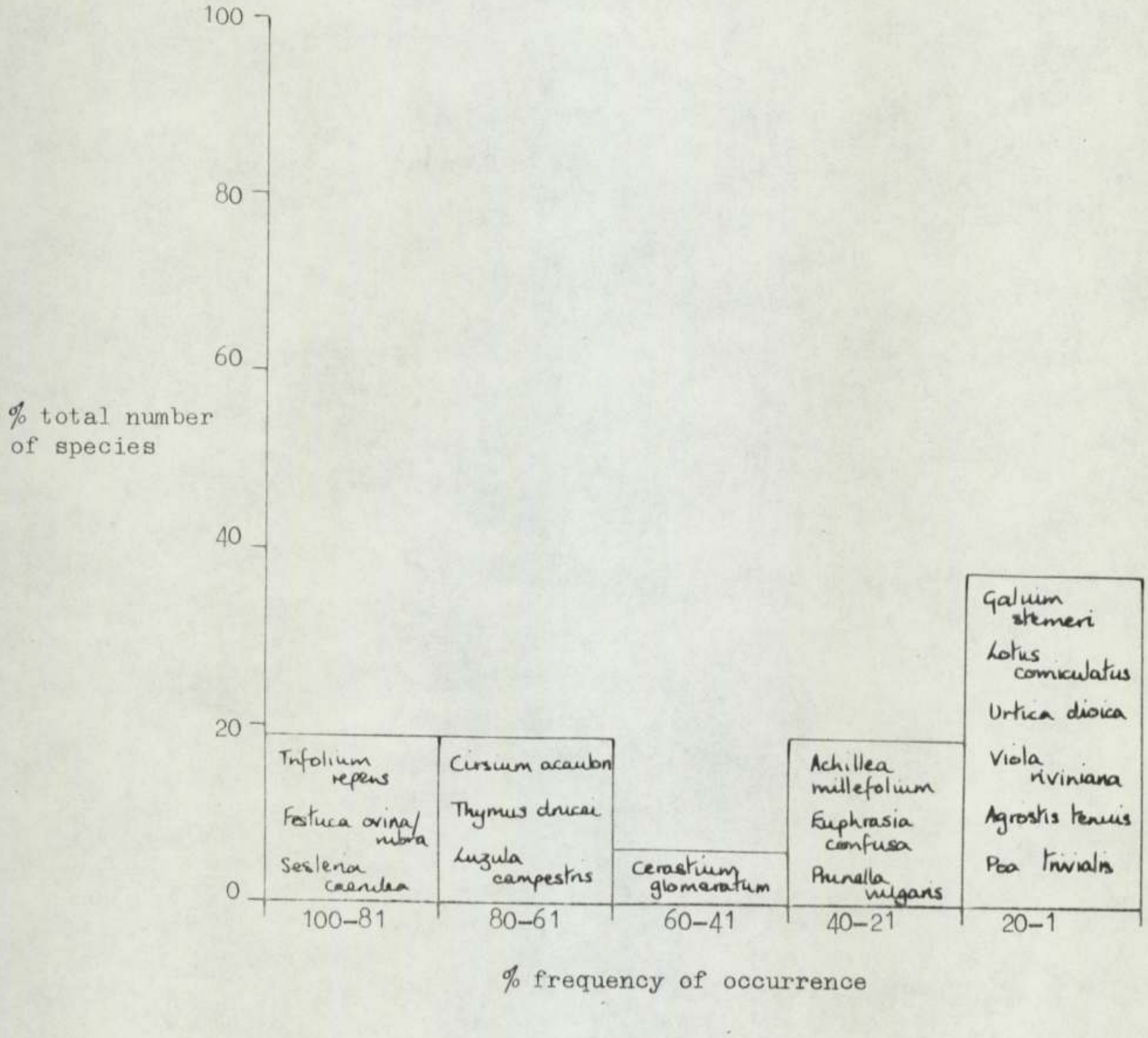

Fig. 1. Valence analysis of the Little Knott area, Ingleborough Hill.

areas in increasing detail and there is more emphasis on plant-habitat relationships and plant physiology than on primary or reconnaissance vegetation survey. Any maps thus produced were confined to very localised areas.

Tivy (op.cit.) carried out a reconnaissance vegetation survey of parts of the southern uplands of Scotland, in an attempt to assess the effect of physical factors on vegetation and land use. The plant associations reflect the dynamic nature of their habitats, the inter-relationships of climate, soil, relief and human activities. The surveying was done on foot, using units consisting of a burn and its watersheds. The main species were analysed where a noticeable change occurred in the vegetation, and the position and extent of the associations plotted on a map. The limits of the association were not defined systematically since measuring features such as slopes was too time-consuming. These measurements should not be included in a reconnaissance survey but can be added afterwards if necessary. After the mapping had been done, the associations were classified, defined and delimited on 1:25,000 scale maps. The moorland vegetation of this area is a biotic climax with regional subdivisions due to the influence of landform (especially drainage and slope), altitude and climate, and with smaller divisions due to local variations in physical and biotic factors. The associations mapped included types such as mixed grass heath, dry heather moorland and Scirpus moor.

The vegetation survey of Wales (Taylor, 1968) is a reconnaissance survey which recorded the vegetation pattern of non-agricultural areas, i.e. moorland, as a bsis for land use studies. These areas are 'man-adapted ecosystems' which show evidence of post-glacial climatic succession and which include "many ecological margins at low altitudes which are sensitive to and therefore indicative of, contemporary socio-economic, ecological and pedological trends". The vegetation patterns can be related to:

i) altitude - slope - aspect - hydrology,

ii) parent material - soil - hydrology,

iii) hill climate - topo-climate - micro-climate - soil climate,

iv) historical and modern land use trends including variations in types and intensities of grazing, present dominance of sheep, afforestation, etc.

The field methods of this survey were based on visual observation, and the recording of all significant and characteristic vegetation units mappable on a 1:10,560 scale. This included every species of 10% or more cover, with an average range of 2-5 dominants per association. Quadrats were used to determine the dominants and discontinuities i.e. boundaries, and they were also taken at ramdom and at the centres of characteristic and extensive vegetation units. On average, at least one quadrat per 3sq.miles was analysed. All species within the quadrat with over 10% cover were recorded, plus significant minor species with less than 10% cover, (see table 2 and fig.2).

Taylor describes his survey as neither purely botanical nor purely ecological: the survey mapped the relatively dominant species per unit. One problem in vegetation survey is the fact that in many areas there is an almost continuous variation in plant distribution, so it can be very difficult to place a boundary. McVean and Ratcliffe (1962) used a nodal method for surveying in the Scottish Highlands; they selected reference points or noda adequate in number and type to represent the range of variation. Taylor considers that the field method of the vegetation survey of Wales is parallel in principle to these nodal studies. This problem of continuous variation, and the nodal method solution is similar to the major problem in soil surveying, where discrete units must be

Vegetation Survey of Wales: a specimen quadrat

Map:
Radnorshire 32 S.W.
Aspect: West.

Map reference:
SO. 048469.

Height:
1,400' O.D.
Date: 1st November, 1964.

Throw	Quadrats 1	2	3	4	5	6	7	8	9	10	% Cover
Species:											
Calluna vulgaris	2	1	3	1		4	3	3		5	22
Erica tetralix	2	3		2	1	4		3	3	2	20
Erica cinerea			+			+	1				1
Vaccinium myrtillus			+		+				1		1
Potentilla erecta			+						+		
Eriophorum vaginatum	3	3	1			+	3	2			12
Carex binervis	+				1						1
Nardus stricta	1	1	3	4	2		2	1	2	2	18
Molinia caerulea						+					
Juncus squarrosus				2	3						5
Trichophorum } *Scirpus caespitosus*					1				1		2
Hypnum cupressiforme	1		2	1					2		6
Sphagnum tenellum		2			2					+	4
Pleurozium schreberi	+		1	+					1		2
Aulacomnium palustre							+				
Dicranum scoparium	1		+							1	2
Acrocladium cuspidatum		+									
Cladonia arbuscula						1	1	1		1	4
Cladonia pyxidata						1					1

Derived quadrat symbol — ÇyEtNEry

The area analysed by quadrats is on a plateau at *circa* 1,500' O.D., south of Builth Wells, Breconshire. Both the steep, northwest scarp slope and the southern dip slope were covered by bracken (*Pteridium aquilinum*) below 1,300' O.D. Much of the bracken (*Pteridium aquilinum*) on the dip slope had been mown to provide winter bedding for the cattle on the nearby farms.

The vegetation covering most of the plateau was a *Nardus stricta/Juncus squarrosus* association, grazed intensively by sheep, but there were also three very boggy regions each about 400 square yards in area and each drained by a stream. These supported large, robust tussocks of *Eriophorum vaginatum* in the extremely wet parts, and *Calluna vulgaris*, *Erica tetralix* and typical bog bryophytes such as *Sphagnum tenellum*, *Aulacomnium palustre*, and *Acrocladium cuspidatum* on the surrounding land which was not quite as waterlogged.

An interesting feature was that the *Calluna vulgaris* roots in this habitat were confined to the surface peat, and did not penetrate to any appreciable depth as is usual on drier ground.

(*Field Surveyor:* Caryl Travess.)

Table 2. The vegetation survey of Wales: a specimen quadrat (Taylor, 1968).

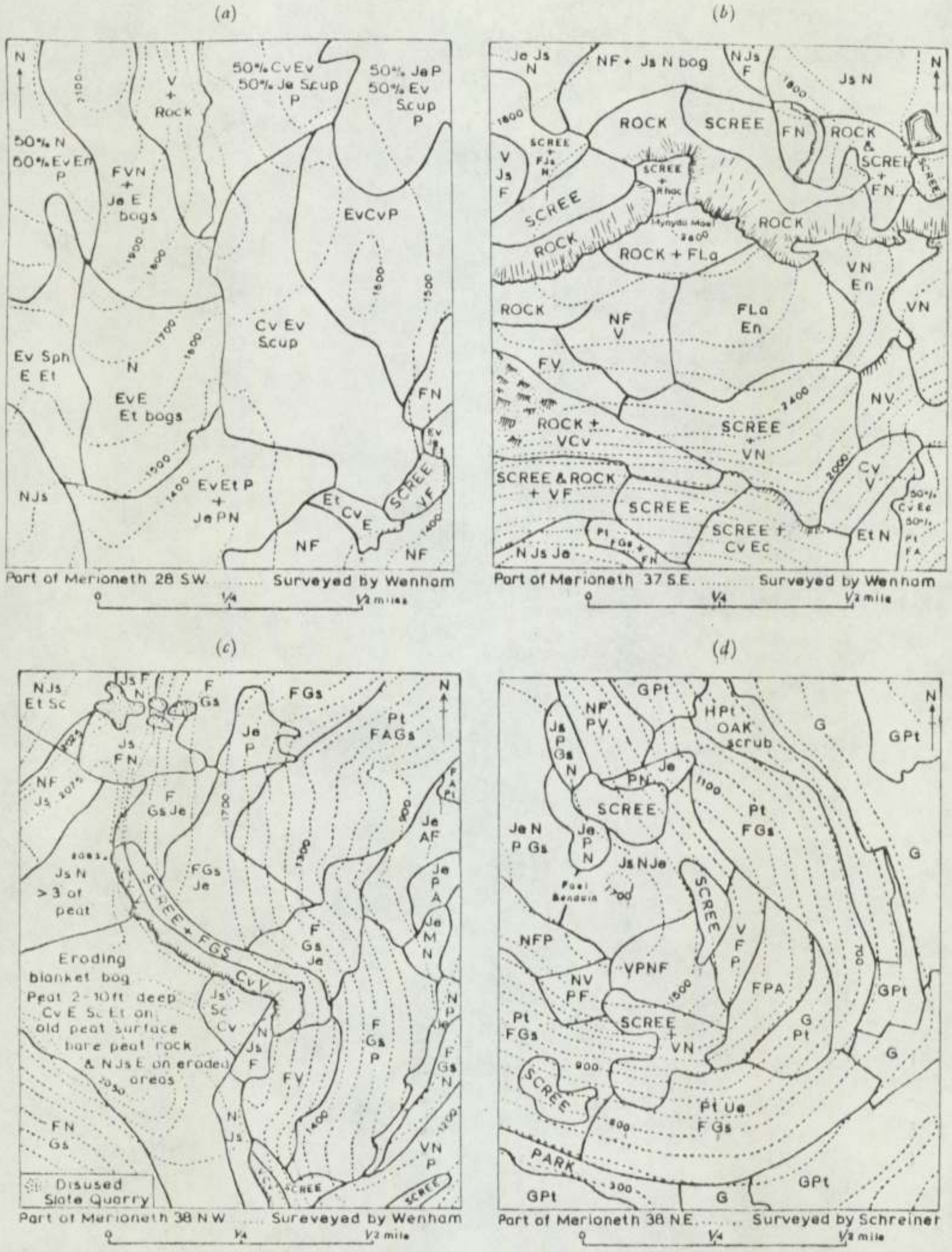

Fig.2. The vegetation survey of Wales: selected extracts from the 1:10560 field maps of Merioneth (Taylor, 1968).

established on continuously variable material (see p. 39).

The very similar 2nd Land Use Survey covers all areas of moorland and mountain pasture in England and in parts of Wales (Coleman and Sinclair, in preparation). The vegetation was mapped at 1:25,000 scale by community and by visual dominance within the community. The dominant species had to be always visible and relevant to land use potential. Wherever possible, the community was specified by a single dominant, e.g. Juncus squarrosus, Molinia caerulea, otherwise it was specified by co-dominants, e.g. 'fescue-bent grasses' consisted of various species of Festuca and/or Agrostis. The surveying was carried out on foot; each association was botanically examined at close quarters and thereafter by derived physical characteristics discernable at a distance, such as overall colour and texture. Dominants, co-dominants and subdominants were mapped, any species of less than 10% of the mass of the association was a subordinate species and not mapped.

6.4 Seasonal effects on vegetation mapping

Many surveys, especially those that employ visual methods rather than quantitative methods, mention that the different plant communities and associations have specific colours and textures. Stapledon and Davies (op.cit.) in their grassland survey of Wales, mention that the major associations show obvious wide contrasts in form, growth and colour, and that relatively minor ecological differences can be determined, where they are associated with plants that show a distinctive colouring. From a distance, the contrast between different associations is based largely on different shades of colour. These colours are emphasised during the autumn when the vegetation is dying back. Tivy (op.cit.) says that in her survey the classification of associations "..... is dependent mainly on the presence and combination of several dominant moorland species giving, especially in late summer and early autumn, a distinctive colouring to a particular association which can, in turn, generally be related to a particular physical habitat". Taylor (op.cit.) also remarks how useful the colour differentiation of vegetation can be and this characteristic is also used by the 2nd Land Use Survey (see table 3).

Certain species may be present or absent at different times of the year. Some species are likely to be misplaced in an ordinal sequence of dominants, subdominants and subordinates because they are more conspicuous at certain times of the year. They may be masked by other species or appear prevalent when they are not, e.g. Vaccinium myrtillus is very obvious in summer but in winter it is very difficult to find, Pteridium aquilinium shoots do not appear above ground until June but by August will mask any other growth. Küchler (op.cit.) points out that understanding the seasonal aspects of vegetation are basic to the study of landscape, and that phenological records are very useful in many cases. Other reasons for 'false dominants' in a vegetation association can be due to management practices, e.g. where Calluna vulgaris is burnt periodically to promote its growth, such as on a grouse moor, in such a case where Vaccinium myrtillus is sub-dominant normally, it may become dominant in a sudden flush of growth when the Calluna is removed.

6.5 Vegetation as an indicator of physical conditions.

Vegetation can often be related to various aspects of the landscape such as altitude, drainage and soil type. All plant species differ in their tolerance of habitat conditions and thus those with a limited tolerance are good indicators of site conditions. Indicator species, as such, are not always of use when mapping vegetation, especially at

Table 3. Tabular summary of colours of common moorland species (after Coleman and Sinclair).

Species	Jan.,	Feb.,	Mar.,	April,	May,	June,	July,	Aug.,	Sept.,	Oct.,	Nov.,	Dec.,
1. Sphagnum species	Very little seasonal change colours slightly						brighter in summer. Red, yellow, pale and rich greens.					
2. Eriophorum vaginatum	Dull brownish green					dull mid-dark green white cottons		dull dark green with low angle sheen			dull brownish green	
3. Eriophorum angustifolium	Becoming intense reddish ochre					mid-dark green white cottons		dark green with reddish tips			increasingly reddish brown-green	
4. Tricophorum caespitosum	Reddish orange with yellow tips					temporarily bright light green then mid dark green			variable buff-orange-yellow.		reddish orange with yellow tips	
5. Juncus species	Buff fawn with some dull dark green					dark shiny green becoming duller, some pale buff dead growth					becoming buff-fawn from tips downwards.	
6. Juncus squarrosus	Dull greenish bronze and buff					dark green increasingly olive green				olive bronze green		dull bronze and buff
7. Molinia caerulea	Pale fawn or straw changing erratically to					bright mid-green	full bluish-green with increasing purple sheen				dark red-orange	paler fawn-orange
8. Nardus stricta	Off-white to white					pale green with purple sheen		dull, pale green, off white		dirty, dull off-white		
9. Festuca/ Agrostis species	Pale dull green and pale buff				mid green (Agrostis brighter) gradually fading							pale dull green and pale buff

Continued........

Species	Jan.,	Feb.,	Mar.,	April,	May,	June,	July,	Aug.,	Sept.,	Oct.,	Nov.,	Dec.,
10. Calluna vulgaris	Dark olive green-brown becoming browner				deep olive green			purplish-mauve (flowers) becoming paler				dark olive green-brown
11. Erica tetralix	Green olive grey							pale pinkish - mauve (flowers)				pale grey-olive green
12. Vaccinium myrtillus	Olive brown (twigs)				variable red yellow bronze and brilliant green		bright mid-green			rust red and tawny olive		olive brown (twigs)
13. Pteridium aquilinium	Orange brown					bright pale green	deep mid-dark green			blackened by first frost then yellow/ orange with green patches		deep russet-orange brown
14. Ulex galli	Dark green											
15. Ulex europaeus	Under foliage dead grey				dark green						under foliage dead grey	

SPECIES	CLIMATE	VEGETATION TYPE	SOIL TYPE	pH.	BASE STATUS
Scirpus caespitosus (Deer Grass)	Uniformly wet, atlantic	Blanket Bog	Wholly organic, water-logged peats, generally deep	Most usual range: 3.3–3.8. Normal limits: 2.8–4.1. Very acid	Very low
Eriophorum vaginatum (Cotton Grass)	Ditto; slightly less wet	Blanket or Raised Bog	Similar, generally over 2 ft. deep, slightly dryer	Most usual range: 3.2–4.0. Normal limits: 2.8–4.8. Very acid	Very low
Eriophorum angustifolium (Cotton Grass)	Ditto	Ditto	Similar, but very wet, generally where free water collects	Most usual range: 3.0–4.5. Normal limits: 2.8–6.7. Acid—Neutral	Low—increasing
Calluna vulgaris (Heather, Ling)	Oceanic, moist but not extremely wet	Heath and Moor	Abundant on dryer peats and raw humus, deep or shallow, and on sandy soils. Often indicates **free drainage.** Present, but does not flourish on waterlogged peats.	Most usual range: 3.4–5.9. Normal limits: 3.0–7.0. Acid – Neutral (**Not alkaline**)	Variable not high
Molinia caerulea (Purple Heath-Grass)	Similar to *Calluna*	Acidic grassland, heath, moor and fen	Damp peats or humus, especially flushes where water well aerated by movement. Will not tolerate stagnant water	3.0—alkaline. Wide tolerance	Tolerant, may be rather low or high
Nardus stricta (Moor Mat Grass)	Dryer	Acidic grassland, heath, moor	Moist (but not wet) peat or humus. Especially on peat which has been redistributed by water, wind, etc., and on soils with higher mineral content	Acid: generally about 3.5	Rather low
Deschampsia flexuosa (Wavy Hair Grass)	Similar to *Nardus*	Acidic grassland, heath, moor	Thin sandy peat, moist or dry humus or light soils, free drainage, especially on slopes	Acid; most usual range 3.5–6.0	Rather low
Agrostis tenuis (Bent Grass)	Ditto	Acidic grassland, grass-heath, heath	Thin humus, and more fertile soils, freely drained and light	Acid, but often less so than the above species	Increasing
Festuca ovina (Sheep's Fescue)	Ditto	Grass-heath, acidic, neutral and basic grasslands	Light soils, wide fertility range	Acid—alkaline. Wide tolerance	Generally higher than the above species
Pteridium aquilinum (Bracken)	Widely tolerant	Grassland, grass-heath, heath, moor, woodlands, etc.	Tolerant, but **not of waterlogged soil,** though sometimes indicating slightly impeded drainage (esp. when appearing as a belt below heather on a hillside). Generally on lighter or sandy soils of some depth	Tolerant, normally on the acid side	Variable

Table 4. Conditions under which some common species of hill-land normally occur (after Gimingham, 1949).

reconnaissance scales, because the particular species may not invariably be present in the corresponding habitat, intermediate habitats may not possess indicator species and the indicator species may be too small or there may be too few individuals in a community to be of use when mapping by visual dominance. However, associations of vegetation, such as those mapped by Tivy (op. cit.) will give general indications of the type of habitat, and Tivy found correlations between the vegetation associations and aspects of landform such as slope, aspect and drainage. In the classification the associations were related to physical conditions, e.g. the Scirpus moor association was described as being dominant on thick peat, accompanied by Calluna vulgaris, Erica tetralix, Sphagnum, etc., found on gently sloping, ill-drained areas where peat had formed over glacial moraines. Gimingham (1949) investigated the grazing values of grasslands and discovered that information could be obtained by using the presence or absence of certain indicator species, by considering the relative percentage of the more important species in the community and by examining the performance and general morphology of the more important species. Table 4 shows the conditions under which the more common hill-land species occur. Other species are also valuable in indicating conditions, e.g. Erica tetralix is a good indicator of impeded drainage and usually occurs on a gley or peat soil. A combination of species indicates a combination of conditions. Management practices can introduce changes into the community, e.g. sheep grazing may convert a Calluna vulgaris dominated community into Agrostis-Festuca grassland and improve the base status of the soil. These changes can be considerable, causing problems in evaluation of the habitats, especially where there are relic species from previous communities. Some species or associations such as bracken (Pteridium aquilinium) are not suitable indicators as they grow over a very wide range of habitats.

Many other surveys relate the vegetation to environmental conditions. Viktorov et al (op. cit.) describe geobotanical maps which depict the distribution of plant communities in connection with environmental conditions and the terms used to describe the map units define both the vegetation type and the corresponding type of landscape, e.g. Stipa steppe, Artemisia semi-desert. Stapledon and Davies (op.cit.) relate their pasture categories to environmental conditions as do Duffey et al (1974), e.g. Nardus grassland typically has peaty podzols or peaty gleyed soils. Mitchell (op.cit.) mentions the usefulness of vegetation as an indicator of terrain type, even in cultivated areas, though Wieslander and Storie (1953) and Kelly (1960) emphasise that vegetation is only an indicator of conditions, the correlation is not always good and can be with a range of factors, not always soil or drainage, as is sometimes presumed. Habitat boundaries are not always reflected in the vegetation as other factors may be dominant, e.g. grazing. However, most vegetation associations indicate land use potential and can be related to the average grazing or tree planting potential etc.

Upland areas have great potential for grass production, as grass responds strongly to moisture and the rainfall during the growing season in most of lowland Britain is well below the optimum for grass production (Crompton, 1958). The overall agricultural output of the hill-lands could be increased by improving the soils and converting vegetation species to more palatable types. This has been done in some areas by the application of fertilizers and other surface treatments in conjunction with controlled grazing. There are still large areas that could be improved, and one of the first steps towards improvement is mapping the distribution of the various vegetation types present in the uplands.

6.6 Vegetation surveys and aerial photo-interpretation

Aerial photographs can be of great help in vegetation surveys, especially those that are based on visual observation of species and associations. Vegetation is clearly seen on aerial photographs and many of the surveys already mentioned used aerial photographs to some extent (Tivy, Taylor, Wieslander and Storie, Mitchell, Viktorov et al and Küchler: op.cit.). Aerial photographs are probably of little use for very detailed vegetation mapping, although with very large scale photographs, such as those taken by a camera suspended from a frame, extreme detail can be seen. Only the uppermost layer of the vegetation cover can be seen on an aerial photograph but often clues to the type of understorey can be gained from careful examination of the vegetation imaged. Sometimes, careful choice of the season of photography can be of help, e.g. in a deciduous forest the ground layer can be seen through the tree branches in winter.

Burks and Wilson pointed out the advantage, as long ago as 1939, of a vertical view of the ground as on an aerial photograph, over the 'vantage point' method of mapping vegetation from the tops of hills, ridges, etc. Fenton (1951) was one of the first British botanists to draw attention to the usefulness of aerial photographs in identifying and mapping vegetation. He remarks that different groups of plants show different shades of green, and other tints, especially in autumn when many colours are present. Since then aerial photographs have been used increasingly for mapping vegetation in this country, especially by such bodies as the Nature Conservancy, e.g. for coastal vegetation surveys (Hubbard and Grimes, 1972). Goodier and Grimes (op.cit.) remark that aerial photo-interpretation for vegetation survey and identification is "....a field which we recognise as being both actually and potentially of immense aid in understanding and recording the environments with which we are concerned."

Some surveys have used aerial photographs to a small extent only, for instance, in Taylor's (op.cit.) vegetation survey of Wales aerial photographs were only used for checking the limits of species which were more obvious on the photographs, i.e. the Ericaceous species and bracken, while the 2nd Land Use Survey (Coleman and Sinclair, op.cit.) decided not to use aerial photographs at all. They felt that the terrain itself could yield a more detailed collection of data than could photographs and it was not possible to distinguish on the photographs all the vegetation categories in which the Survey was interested. They also felt that although the survey might take longer by ground methods, a truer, multidimensional knowledge of the plant communities would be gained as observations would be made from varying distances, at all seasons and in different weather conditions.

It should be emphasised that, as with soil surveys using A.P.I., a photo-interpretation alone is not sufficient. Field work must always be carried out to check the validity of boundaries, to confirm the correctness of the interpretation and to determine the detailed composition of the vegetation units. In one exercise by the Nature Conservancy (Ward et al, 1971) on Dartmoor, they used 210 of the original 216 vegetation samples as spot-checks after interpretation. They found that 186 out of 210 samples had been correctly or acceptably interpreted, an accuracy of 88.5%, which is described as extremely high.

An important problem in the use of A.P.I. for vegetation surveying is the choice of classification system to be used. Goodier and Grimes (op.cit.) discuss this in relation to their work on mountain vegetation in North Wales. Should an <u>a priori</u> classification, i.e. a classification constructed before A.P.I., or an <u>a posteriori</u> classification, i.e. a classification constructed after A.P.I., be used? Or should a classification specially suited to A.P.I. be used? Three different classification methods were tried:

i) by initial photo-interpretation.

ii) by grouping the stand data derived from field sampling, by physiognomy and then by dominant and characteristic species (phytosociological approach).

iii) by grouping the stand data on the basis of species presence or absence (association analysis).

Attempts to relate the phytosociological and the association analysis classifications to the units mapped from the aerial photographs were not successful. This is because the areas delineated on the photographs as distinguishable plant communities cannot be defined only on the basis of species presence and physiognomy but are the result of complex interactions between the visual effects of geomorphology, soil type and moisture content, and the vegetation. Association analysis does not produce a classification of immediate use to photo-interpreters and derived groups have to be recombined to achieve equivalence with certain phytosociological units (Ivimey-Cook and Proctor, 1966; Edgell, 1969). The a posteriori approach, which is similar to Küchler's (op.cit.) comprehensive method, involves the delineation of areas on aerial photographs and then each delineated area is visited in the field and vegetation data obtained. This is very time-consuming and does not make full use of the aerial photography. Goodier and Grimes came to the conclusion that a classification especially suited to A.P.I. is the most practicable. They also think that "....it is a mistake to allow aerial photo-interpretation to become bogged down in an attempt to make mapping units and plant community units correspond". Map units tend to represent complexes of plant communities rather than plant communities themselves, and are recognised on the basis of gross physiognomy and topography. Goodier and Grimes and Ward et al (op.cit.) advocate the development of photo-ecology as a field in its own right; this type of approach would take into account the close association between plant ecology and geomorphology. Russian workers follow this approach (Komarov, 1968; Viktorov et al, op.cit.) and the work is being systematised by the production of photo-keys, which Ward et al regard as being very useful and they hope that photo-keys for British work will be developed.

6.7 Scales and cost of aerial photography for vegetation surveys

The choice of scale depends on the area to be covered and the details required, and therefore on the type of survey to be done. Williams (1971) suggests that for general resources studies, including vegetation, the scale should be between 1:7,500 and 1:40,000 depending on the detail necessary, and for medium scale work the range of 1:7,500 - 1:25,000. A good general scale is 1:10,000. Komarov (op.cit.) states that the scales used for work in the U.S.S.R. are between 1:3,000 and 1:30,000. With smaller scales, although the vegetation boundaries are visible, interpretation of the composition of the map units is poor. However, photo-mosaics at these scales or smaller (up to 1:80,000) might be useful for the recognition of boundaries which would be lost in detail at larger scales. Komarov concludes that 1:10,000 is the optimum scale for discernment of composition and boundaries but that for medium scale work 1:20,000 is probably best. Goodier and Grimes (op.cit.) used 1:10,000 and 1:5,000 scale photographs for work in the Rhinog mountains in North Wales. The 1:10,000 scale photographs related well to the size of the vegetation units of the main plant communities, in the context of mapping either at the contact scale or reducing to 1:25,000. They found that although the 1:5,000 scale photography was useful in resolving certain A.P.I. problems, especially in mire community complexes, and led to some improvement of community boundary definition, there was too much intra-community complexity revealed and the large number of prints to be examined was inconvenient. However, a study on Dartmoor by Jones (Ward et al, op.cit.)

showed that too much complexity within the mapping categories was revealed by 1:10,000 scale photography and that a smaller scale such as 1:15,000 would be better.

Stellingwerf (1969a) comments that for reconnaissance surveys, mainly of forest areas, scales from 1:30,000 to 1:70,000 are used. These give a good overall view and gregarious groups of species can be identified, e.g. in Brazil 1:70,000 scale photography was used to locate Parana pines. He has also used 1:50,000 scales for distinguishing different forest types, though for timber exploitation surveys, which require greater detail, 1:20,000 scale is used, as individual trees can be seen. However, in Britain, scales of 1:25,000 - 1:10,000 are probably optimum, as very large areas are not usually mapped and the mapping is usually of smaller species such as grasses.

Costs of aerial photography are usually difficult to assess because of unknown factors such as weather. An example of costs of four sets of photography commissioned by the Nature Conservancy is shown below:

SURVEY	Dartmoor	Rhinogau		Snowdonia
PHOTOGRAPHY SPECIALLY COMMISSIONED (- for specific time, etc.)	Yes	No		No
scale	1:10,000	1:10,000	1:5,000	1:10,000
COLOUR/MONOCHROME	Colour	Monochrome	Monochrome	Monochrome
NO. OF PRINTS	482	12	45	147
COST OF SURVEY	£1,466	£125		£338
COST PER PRINT	£3.04	£2.19		£2.30

Table 5. Costs of aerial photography (after the Nature Conservancy, 1971).

The cost per print is generally less the greater the area flown.

Mapping by A.P.I. is cheaper and quicker than mapping by ground survey in most cases, even if expensive colour photography is used.

6.8 Timing of aerial surveys for vegetation mapping

The time of year when photography is flown can greatly affect the interpretation. As mentioned earlier in this chapter (p.137), when mapping vegetation by visual observation there can be great differences in the colour of the vegetation and the visual dominance of a community throughout the year. Therefore, great care must be taken not to over-map or under-map particular species. There are optimum times for mapping vegetation types, depending on the particular vegetation type and its locality. An experiment by Joy et al (1960) concluded that colour photography of California in early May showed the greatest contrast in montane herbaceous vegetation, whereas photographs taken at other times appeared rather uniform. Williams (op. cit.) mentioned that for the interpretation of chalk grasslands, the maximum contrast in tone and texture occurs in late June and early July, when most grass species are in flower. For upland vegetation, autumn is the best time of year for maximum colour contrast. Many species assume characteristic tints at this time, e.g. Nardus stricta - white, Eriophorum angustifolium - red, Juncus squarrosus - tawny/chestnut. Goodier and Grimes (op.cit.) comment on the advantage of late season photography and also on the fact that their study of the Rhinog mountains was carried out in June, before the bracken had emerged and it was impossible to interpret the extent of the Festuca - Agrostis grasslands which were subject to invasion by bracken.

Photography is difficult to obtain in the autumn in Britain because of loss of light intensity and decreasing day length. Komarov (op.cit.) suggests that photography of the same area should be obtained at different times of the year, so that comparative photography is available for interpretation purposes and the optimum season may be determined. He also adds that the best time of day should be chosen and that it has been found that for forest vegetation or hilly country elevation of the sun between 25° and 55° is best, and for level steppe and deserts 10° - 20° is best.

6.9 Different emulsion types used for vegetation surveying

The most widely used type of film for aerial photography is panchromatic film but it is restricted in its usefulness by the fact that colours in nature are reproduced as a limited number of grey shades. Colour film is superior for many types of A.P.I. but especially for A.P.I. of vegetation. Küchler (op. cit.) indicated that it is inevitable that colour photographs should save time and effort in correct interpretation, while Heller et al (1964) found that colour was superior to panchromatic film for identification of individual tree types. A study of vegetation on Norfolk Island in the South Pacific (Benson, 1974) concluded that vegetation mapping was made easier by using colour aerial photography but that additional costs were incurred; however, depending on the area to be covered and the complexity of the vegetation, colour photography should be seriously considered in vegetation mapping projects.

Transparencies are superior to prints for interpretation (Welch, 1968; Jones, 1971) but colour transparencies are expensive to duplicate and can be difficult to handle, i.e. a light table is necessary for viewing. The Nature Conservancy have used colour photography in many studies and have found it very useful. False colour photography has also been used in similar studies, although it is stated that the unreal appearance of the landscape can be a serious disadvantage (Goldsmith, 1972). For certain studies, false colour is superior to true colour e.g. in grazing pressure studies, where false colour accentuates the differences between overgrazed and healthy ungrazed vegetation. Goldsmith (op.cit.) in a vegetation mapping exercise in the Gairloch Conservation Unit in Scotland, found that true colour and false colour gave overall better results than panchromatic and infra-red panchromatic film. True colour was found to be best for woodland, Calluna-Molinia communities and bracken, while false colour was best for the interpretation of agricultural land, Tricophorum-Eriophorum communities and Calluna. Cooke and Harris (1970) found that false colour was overall better than true colour for identifying any vegetation type.

False colour film has been used with limited success in forestry work, in mapping diseased trees. There is some controversy over the ability of false colour film to detect plant disease before it becomes visible to the eye. Benson and Sims (1970) state that they "have not been able to detect any differences in photographic appearance which could be interpreted as previsual symptoms" (of disease in plants). This is contrary to much earlier work (Stellingwerf, 1969b)(see also p. 7). However, Hildebrandt and Kenneweg (1970) find false colour photographs superior to colour for the detection of defoliated trees, and work on Forestry Commission woodlands in parts of Cardiganshire supports this conclusion (Jones, op.cit.).

The usefulness of multispectral photography for vegetation studies is uncertain and very little work has been carried out using multispectral photography for this purpose (Wenderoth et al, 1974). Experience by the author suggests that multispectral photography is of very little use in vegetation studies and may be inferior to panchromatic photography in some cases (see p. 184).

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Chapter 7: THE PROJECT AND THE STUDY AREAS

7.1 The aims of the project

The aim of the project was to investigate the application of a new type of remote sensing system to terrain resource mapping in general, and soil surveying in particular. The remote sensing system used was multispectral photography, where a four lens camera produces four spectrally filtered images onto panchromatic infra-red film. These images can be analysed separately, and in combination, by using an additive viewer which recombines the photographic images to produce enhanced colour images. Multispectral imagery is also amenable to automatic data analysis, such as densitometry. The theory that each object has a unique spectral signature and that by sensing in specific wavebands, objects can be easily distinguished (see p. 13), would seem to have important applications for soil survey, especially if soils could be mapped by automatic analysis of spectral signatures.

The Soil Survey of England and Wales has been investigating the use of different types of remote sensing imagery, including multispectral photography, for soil surveying, especially in upland regions where there are large, inaccessible areas to be mapped. This project evaluated both the multispectral photography and colour infra-red photography for ease and efficiency of soil surveying, and also for obtaining other types of terrain information i.e. land use and vegetation patterns. Four test areas in upland Britain were chosen, each with a soil pattern that was typical of the surrounding countryside and that correlated with other features such as parent material and relief. These areas were:

Area A: Ingleborough, in the western Pennines, which is a mountainous area of limestone soils and features.

Area B: Sedgwick, near Kendal, Cumbria, an area of drumlins and other glacial features in the lowlands bordering the Lake District.

Area C: Marsden, covering part of the Millstone Grit plateau of the southern Pennines.

Area D: Penistone, an area of dip and scarp topography of the Lower Carboniferous sandstones and shales, north of Sheffield.

A ground photography project was set up in the Sedgwick area in an attempt to discover the best time of photography for soil surveying. False colour and infra-red panchromatic 35 mm. films were used. Sixteen different sites, covering twelve different soils, were chosen and these were photographed once a month, at approximately the same time, for twelve months.

7.2 Problems

The first and major problem was the late arrival of the aerial photography. The multispectral photography should have been taken in the summer of 1971 in order to be available when the project started in October 1971. However, the first set of photography did not arrive until June 1973, almost two years late. Another major problem was that we had asked to be informed when the photography was being flown, or within seven days of the flight, so that ground truth data could be collected. This is very important as conditions can change rapidly. The best time for data collection is during the actual flight as there may be ephemeral features present, such as dew, which may not be seen on other occasions, and also measurements of soil temperature, humidity etc. can be related precisely to tones on the photography. In order to assess, as precisely as possible, the effect of atmospheric conditions on the photography, very localised knowledge of weather conditions is necessary and data from a local weather station are not normally adequate unless it is situated in the study area. Thus, meteorological data should be collected at the same time as ground truth data. If it is not possible to collect ground truth data during the time of the flight, general ground conditions, e.g. crop growth and soil moisture, are likely to remain approximately the same within about a week of the photography. However, after this period, conditions will have changed too much for any data collected to be relevant, especially during the crop growing season. The multispectral photography was taken on 17th May, but this was not known until the photography arrived in mid-June. This was too late for any field work on soils and thus ground truth work had to be postponed until May of the following year, when conditions were approximately the same.

The next problem was the quality of the photography obtained; the photographs had been processed wrongly to a γ of visual density instead of to a γ of 1, which meant that densitometric analysis was difficult as there was no fixed base against which the grey tones could be measured i.e. white would tend to have a hue, and therefore was not a constant measurement. The blue band (band I) was very hazy, and although the photographs had been dodged there was still a noticeable increase in density towards the edge of each frame. Some photographs had a large amount of tilt which produced distortion and a flattening-out of relief on the stereo model. As relief is an important feature in soil surveying with aerial photography these photographs were of limited use. Another disadvantage was the large amount of photographs to be handled; each frame covered only a small area and had a large amount of overlap (72%). 66 photographs were needed to cover the 25 sq.km. of the study area at 1:15,000 scale. The imagery came in the form of transparencies (diapositives) so a light table was necessary for viewing. A light table had to be specially constructed as the ordinary light tables used in the drawing office were not strong enough to support a stereoscope.

The additive viewer which was to be used for analysis of the multispectral photography was situated near London, while most of the research work was being carried out in Birmingham. Thus, every time an enhanced colour image of the photography was required, a visit to London was necessary; this was very time-consuming and expensive, so little work was done using the additive viewer. Other disadvantages became obvious during work with the viewer. There were problems with handling the photographs as the edges had to be trimmed so they would fit into the machine and it took a long time to set up each image, as each of the four frames on the photograph had to be in registration with the others. Only one enhanced image could be seen at a time, so stereo-viewing was impossible and there was no permanent record of the enhanced colour image unless it was photographed. This was again expensive and time-consuming. There was a large amount of fall-off in illumination away from the centre of the image due to the centre illumination of the viewer screen combining with the lens fall-off on the photographs. The colour images produced were also rather blurred, probably because of the amount of enlargement from the original frame to the screen, which was about 2½ times.

The contractors were only able to produce one set of multispectral photographs, covering the Sedgwick area, so eventually false colour photography of the Sedgwick area and of the nearby Ingleborough area was specially commissioned, to cover both areas at two different seasons. The first set of false colour photographs was taken in October and November 1973, and arrived in February 1974. Colour prints had also been taken during this flight, with a hand-held camera. Unfortunately, again we were not informed as to the date of the flight so no field work could be done at the appropriate time. The second set of photographs was taken in late May 1974 and although we were not informed about the flight, by a lucky coincidence, field work had been done in the Sedgwick area only six days before-hand. These sets of photography were of very good quality, very clear and sharp, though unfortunately there is too much overlap, resulting in a very small base line on any stereo model, which led to difficulties when plotting boundaries from the photographs (see p. 249). There were the same problems with handling this photography as with the multi-spectral photography, as it was in the form of transparencies; however, this was not a disadvantage as a light table had already been constructed. The false colour transparencies were delicate and so a transparent cover had to be made for each photograph to prevent the emulsion from being scratched. As there were only eleven photographs covering each area at each season this was possible and proved useful as boundaries etc. could be drawn on the covers and wiped off if necessary, without damaging the photographs.

Originally, the project had intended to evaluate the photography for soil surveying but after some work had been done on this topic, it was obvious that soil could not be mapped directly from aerial photographs while land use and vegetation types could. Thus, the emphasis of the project changed to include vegetation and land use surveying. Land use was mapped in the Sedgwick area and semi-natural moorland vegetation mapped in the Ingleborough area.

The ground photography project also encountered some difficulties mainly because it was carried out by assistants, from Kendal, and the author was in Birmingham. Problems encountered could not be dealt with immediately and practical problems arose, such as the conveyance of materials and equipment from Kendal to Birmingham and vice versa. The panchromatic infra-red film used was very sensitive to light and had to be loaded and unloaded in total darkness; this was extremely difficult to do and often resulted in parts of the film being exposed and fogged. Also, this type of film is very experimental and there is little guidance to the length of exposure necessary. A Zorki 4 camera was used for the black and white infra-red film and a Zenit E for the false colour film.

The late arrival of the material meant that the project was delayed by nearly two years. Mapping land use and vegetation is seasonal work and thus could not be completed in the time left for the project, so it was extended by one year. Most of the practical work has had to be carried out in only eighteen months; it would have been better if there had been more time available so that seasons over several years could be studied to show the changes in vegetation and land use. The project would also have been more detailed if there had been more time, as many problems have come to light since the interpretation of the photographs and the field work has been done.

7.3 The Sedgwick area

This area covers 25 sq.km. around the villages of Sedgwick and Endmoor, a few miles south of Kendal, Cumbria (fig.1).

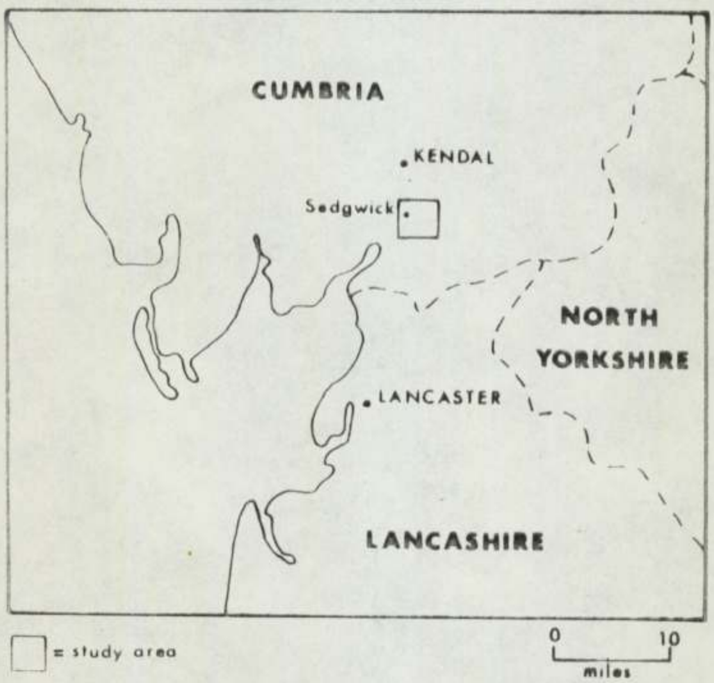

Fig.1. Location of the Sedgwick area.

This area was chosen because the soils of the area had been recently mapped and published at 1:25,000 scale, and the surveyors did not use aerial photo-interpretation except for checking boundaries in areas of rugged relief. This is a heavily glaciated area of drumlins which produce rolling relief of fairly small, steep-sided hills, ranging in height from under 30m. to over 180m. (photo. 1). Drainage is predominately towards the south-west and shows features of rejuvenation such as small gorges and steep-sided river valleys. Where the underlying rock is exposed, it forms areas of higher, more rugged topography than the surrounding glacial drift. The solid geology consists of Silurian slates, flagstones and greywackes in the east and Carboniferous Limestone in the west, a major fault separating the two and running south from Kendal (see fig.2). The Lake District till forms the drumlins and is greyish-brown in colour, and very stony with a silt loam or silty clay loam matrix. This till is locally derived, probably from the nearby Howgill Fells to the north-east, thus soils on the exposed rock are very similar in composition to those formed on the drift. Some fluvio-glacial deposition is evident as small mounds of coarser texture till with lenses of sand and gravel. Peat occurs in small areas, mainly in flush sites and poorly drained hollows between the drumlins. Alluvium is found on the flood plains of the rivers (fig.3).

The climate of the region is typical of north-west England, very much influenced by the sea, and a prevailing south-westerly wind results in a cool, wet climate with heavy orographic rainfall, the average rainfall being 1386mm. (54.6") p.a. The land use of the area reflects the high rainfall and the soil type. Permanent pasture covers 95% of the area with occasional ley grasses, root and grain crops. Most of the crops are for animal fodder and dairying is the main concern with sheep rearing as an important subsidiary, though beef cattle are common also.

The soils of the area (see fig. 4) consist of the following series:

Photo. 1. Part of the Sedgwick area, showing drumlins in the background.

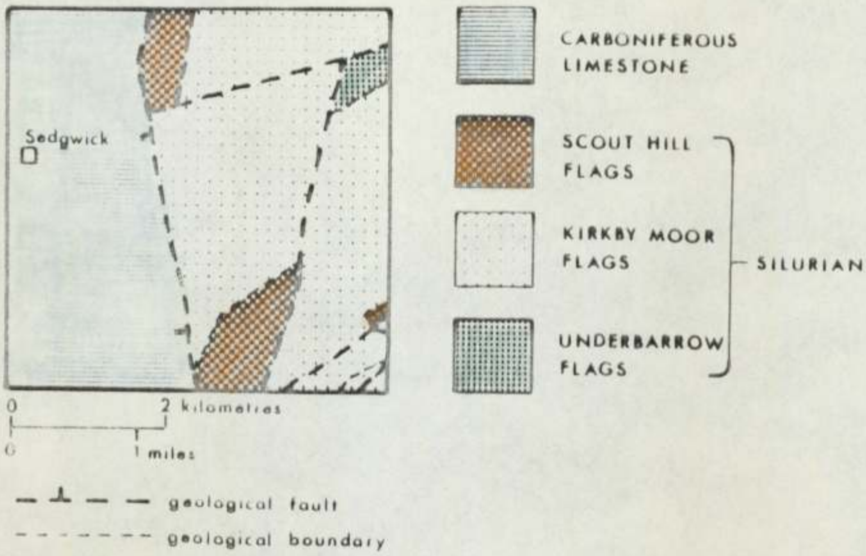

Fig.2. Solid geology of the Sedgwick area.

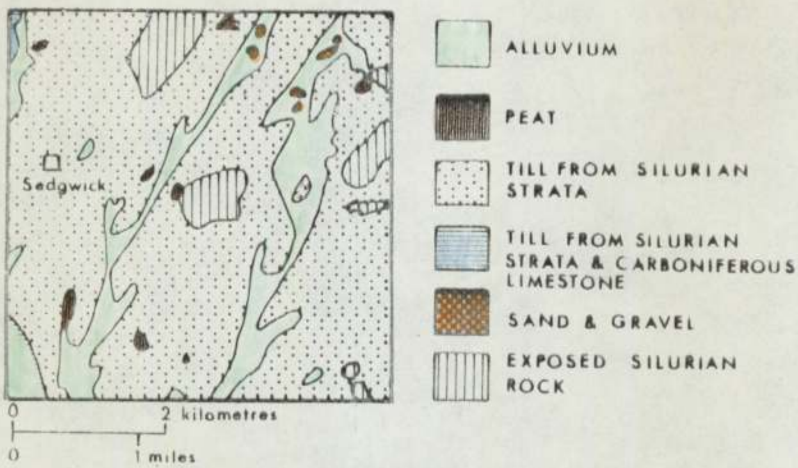

Fig.3. Drift geology and soil parent materials (based entirely on soil survey information).

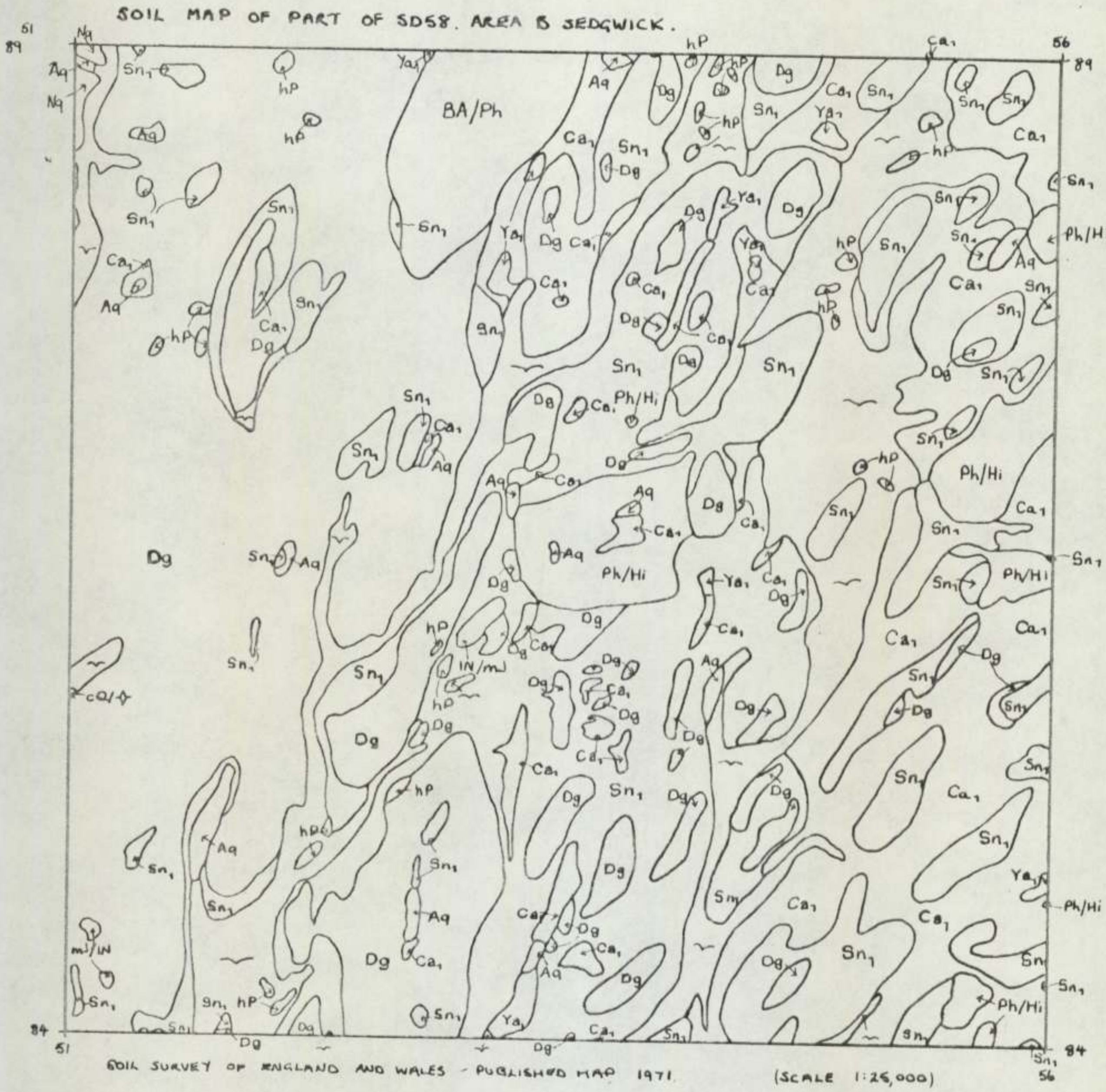

Fig.4. Soils of the Sedgwick area (scale approx. 1:44,000).

Table 1. Soils of the Sedgwick area

hp Hincaster Series: typical brown earths, silty (loamy)-skeletal, parent material till derived from Silurian shales and Carboniferous Limestone.

Dg Denbigh Series: typical brown earths, fine silty, parent material till from Silurian shales and sandstones.

Sn_1 Sannan Series: stagnogleyic (gleyed) brown earths, silty-skeletal, parent material till from Silurian shales and sandstones.

Ca_1 Cegin Series: cambic stagnogley (non-calcareous surface-water gley) soils, silty-skeletal, parent material till from Silurian shales and sandstones.

Ya_1 Ynys Series: cambic stagnohumic gley (peaty gley) soils, silty-skeletal, parent material till from Silurian shales and sandstones.

Aq Altcar Series: raw oligo-fibrous peat soils, fen carr or reedswamp peat.

Ph/Hi Powys-Hiraethog Complex: humic rankers, fine silty, ironpan stagnopodzol (peaty gleyed podzol), peaty gleys, gleys and some bare rock, over Silurian shales and sandstones.

BA/Ph Brantwood-Powys Complex: humic rankers, fine silty, typical brown podzolic soils; peaty gley soils and some bare rock over Silurian shales and sandstones.

IN/mJ Lonsdale-Malham Complex: fine silty ironpan stagnopodzol, brown earths and some bare rock, parent material mixed stoneless drift with limestone resideu over limestone.

mJ/IN Malham-Lonsdale Complex: fine silty typical brown earths, brown calcareous soils, rendzinas and much limestone pavement, parent material mixed stoneless drift with limestone residue over limestone.

Nq Natland Series: typical brown calcareous soils, parent material coarse silty drift over limestone.

~ Downholland Association: undifferentiated alluvial soils.

As the parent material is the same over much of the area, the soil pattern reflects the drainage regimes of the drumlins. There is a relationship between the Denbigh, Sannan, Cegin and Ynys series, from the well-drained acid brown earths and the gleyed brown earths on the drumlins, to the surface-water gleys and poorly drained peaty gleys on level ground and in hollows between the drumlins.

7.4 The Ingleborough area.

This 25 sq.km. area covers most of Ingleborough Hill which occupies a prominent position on the valley of the upper Ribble, in the Craven Pennines west of Settle (fig.5).

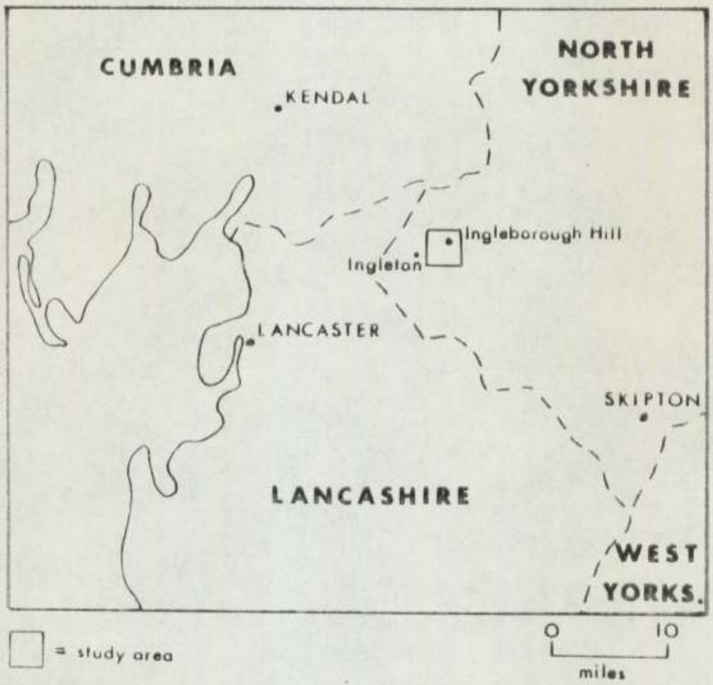

Fig. 5. Location of the Ingleborough area.

As with the Sedgwick area, Ingleborough was chosen for the study as the soils had been mapped without the use of aerial photographs, although the map was not published. Aerial photographs of the area were available only after the mapping had been done and thus were of little use to the survey. Ingleborough Hill is bounded by the river Greta on the western side and by the river Ribble on the east. The mountain has a flat top at 733m with the smaller peak of Simon Fell (635m) to the immediate north-east. These two features are linked by a saddle, and form the central high mass. The land falls away in precipitous slopes to the west and north-west and more gradually in a series of extensive terraces or platforms to the east. To the north-east Simon Fell extends in a broad spur and to the south Ingleborough Fell slopes more moderately to prominent limestone bluffs at Grey Scars. In the extreme north-west a series of cliffs drops from the limestone pavement at 419m to 259m in the gorge-like valley of the river Greta. Much of the land is over 300m and shows typical karst features, with potholes, caves and much limestone pavement. The drainage is also typical of a limestone area with many small streams and springs disappearing and re-appearing through the internal drainage systems.

Ingleborough consists essentially of Carboniferous rocks except in the Greta valley where underlying Silurian rocks are exposed. 183m of massive, almost horizontally bedded Carboniferous Limestone lies on top of the Silurian rocks and produces striking limestone scenery. Interbedded shales, sandstones and limestones of the Yoredale Series overlie the Carboniferous Limestone and are capped by the Main Limestone and a block of Millstone Grit at the summit (fig.6). The Main Limestone and Millstone Grit are resistant to weathering and produce marked crags but the softer Yoredale Series below have weathered back from the Carboniferous Limestone scarp to give an unusual and distinctive profile (photo.2). Glacial drift is found on the east, south and west sides of Ingleborough, especially on the lower slopes of the Yoredales, and poorly developed drumlins are found on Hurnel Moss, on the south-eastern side of the hill. There are two types of drift on Ingleborough; the older is sandier and is found only in a few relatively protected localities while the newer drift covers much of

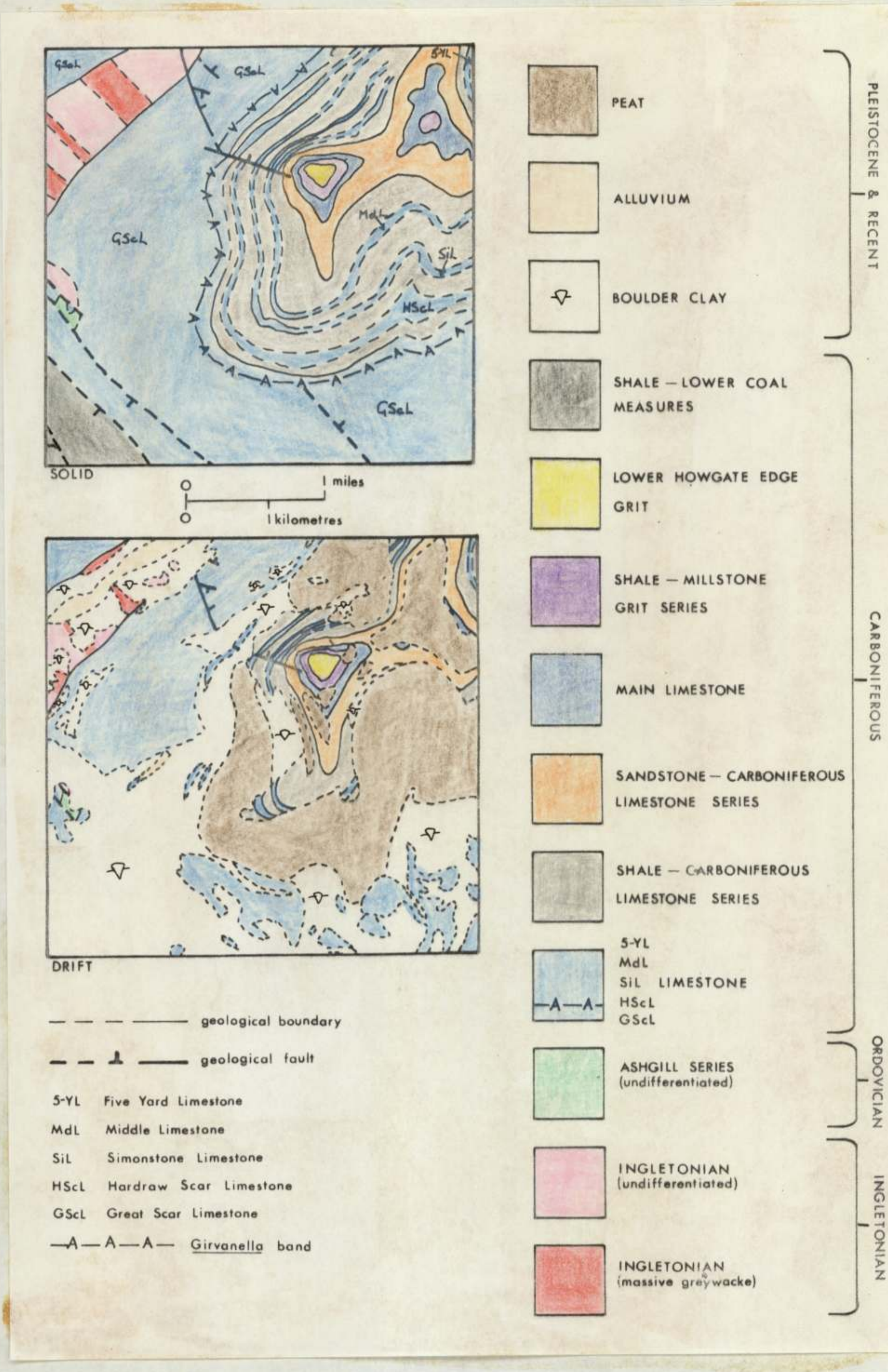

Fig. 6. Solid and drift geology of the Ingleborough area.

Photo.2. The distinctive profile of Ingleborough Hill.

the area except where the limestone is exposed. This drift is very stony and is typical of this part of the Pennines (Sweeting, 1974). There are other indications of glacial activity e.g. erratic boulders of Millstone Grit on the limestone pavements.

It is very difficult to make a general statement about the climate of Ingleborough as the climate in this region is determined largely by altitude and aspect, and the weather on the high fells is liable to rapid change and extremes. Ingleborough probably has a similar range of temperature and rainfall to Malham Tarn (380m) where the mean monthly temperature ranges from 1°C to 15°C, with extremes of 27.5°C maximum and -10°C minimum (Manley, 1957). January, February and March have mean daily minima below freezing. The temperature on Ingleborough is very much influenced by its exposed position and it is subject to persistently strong winds throughout the year, predominantly from the south-west. The rainfall distribution is very variable and discontinuous. The annual rainfall at Ribblehead (about 300m), immediately to the north of the study area, is estimated at 1915mm (75.5") p.a. and the number of rain days (when 0.01" or more of rain falls) as about 225 p.a. Malham Tarn records show the part played by snow in making up the total rainfall, where, on average, snow falls on 40 days of the year and is lying at 9a.m. on 32 days of the year.

The land has been traditionally used for common grazing and so much of it is unenclosed. The agriculture of the region is predominantly hill-sheep farming and much of the area has been, and is being overgrazed, leading to growth of coarse, unpalatable vegetation and problems of soil impoverishment. Dairy cattle are grazed in enclosed fields, mainly on better soils and at lower altitudes. The bottom land in the river valleys is usually given over to hay production or to provide better quality grazing, for both cattle and sheep, but the major part of the study area is used for rough grazing.

The soils of the area are listed in the following table. Some of the soils are as yet unnamed and so they have been numbered.

Table 2. Soils of the Ingleborough area.

Rankers

Unit 1. Revidge Series: humic ranker, sandy, over gritstone.

Rendzinas

2. Humic ranker, loamy, over limestone.

3. Humic rendzina (Marian Series), humic ranker (Wetton Series), loamy and silty, and shallow brown earths, fine silty, (Lulsgate Series) over limestone scree and with limestone pavement.

4. Marian Series: rendzina, loamy, over limestone with limestone pavement.

5. Marian Series: rendzina, loamy, over limestone, with till hummocks and peaty gley podzols and peaty gleys.

Brown earths

6. Malham Series: typical brown earths, fine silty, parent material drift over limestone.

7. Denbigh/Cegin Series with some Sannan Series: loamy, parent material till from Silurian shales and sandstones.

8. Wharfe Series: typical brown alluvial soil, loamy, parent material riverine alluvium.

Gleyed brown earths

9. Gleyed brown earths, coarse to fine loamy, in complex with stagnogleys and alluvium, often peaty in hollows, parent material fluvio-glacial and morainic drift with limestone. Similar to the Charnock Association mapped in Lancashire but with a higher proportion of less gleyed soils.

Surface-water gleys

10. Brickfield Association: cambic stagnogleyic soils, fine loamy (Brickfield Series) to clayey (Hallsworth Series), parent material till and head from

Carboniferous sandstones and shales.

Peaty gleys

11. Wilcocks Association: cambic stagnohumic gleys, fine loamy (Wilcocks Series) to clayey (Roddlesworth Series) with some limestone outcrop, patches of peat and stagnopodzols around swallow holes, parent material till from Carboniferous sandstones and shales.

12. Complex of fine loamy to clayey (Onecote Series) stagnohumic gley soils, parent material Yoredale shales and related drifts.

Organic soils

13. Basin peat, raw oligo-fibrous peat soil.

14. Deep peat, cambic stagnohumic gley soil, fine loamy or clayey, parent material Yoredale shales and related drifts.

15. Winter Hill Series: raw oligo-fibrous peat soil, deep hill peat.

Peaty gley podzols

16. Belmont Series: ironpan stagnopodzol in complex with rankers and shallow brown earths, loamy-skeletal, parent material head and till from Carboniferous sandstones and shales.

These soils (fig.7) are typical of those generally found in areas of Carboniferous Limestone but are modified by the presence of drift. Apart from parent material, the main factors determining the soil type are climate, topography and vegetation. High rainfall and low evapotranspiration lead to rapid leaching of nutrients and the presence of acid drift accelerates this. There is a general degradation of limestone soils toward increasingly acid types, as shown by the increase in Nardus grassland, though other factors, such as grazing, complicate this. Four main types of soil can be recognised, which often have typical vegetation e.g. acid brown earths are dominated by Nardus. The main types of soil are:

i. rendzinas, which develop over limestone.

ii. brown calcareous soils, which develop in limestone areas wherever the

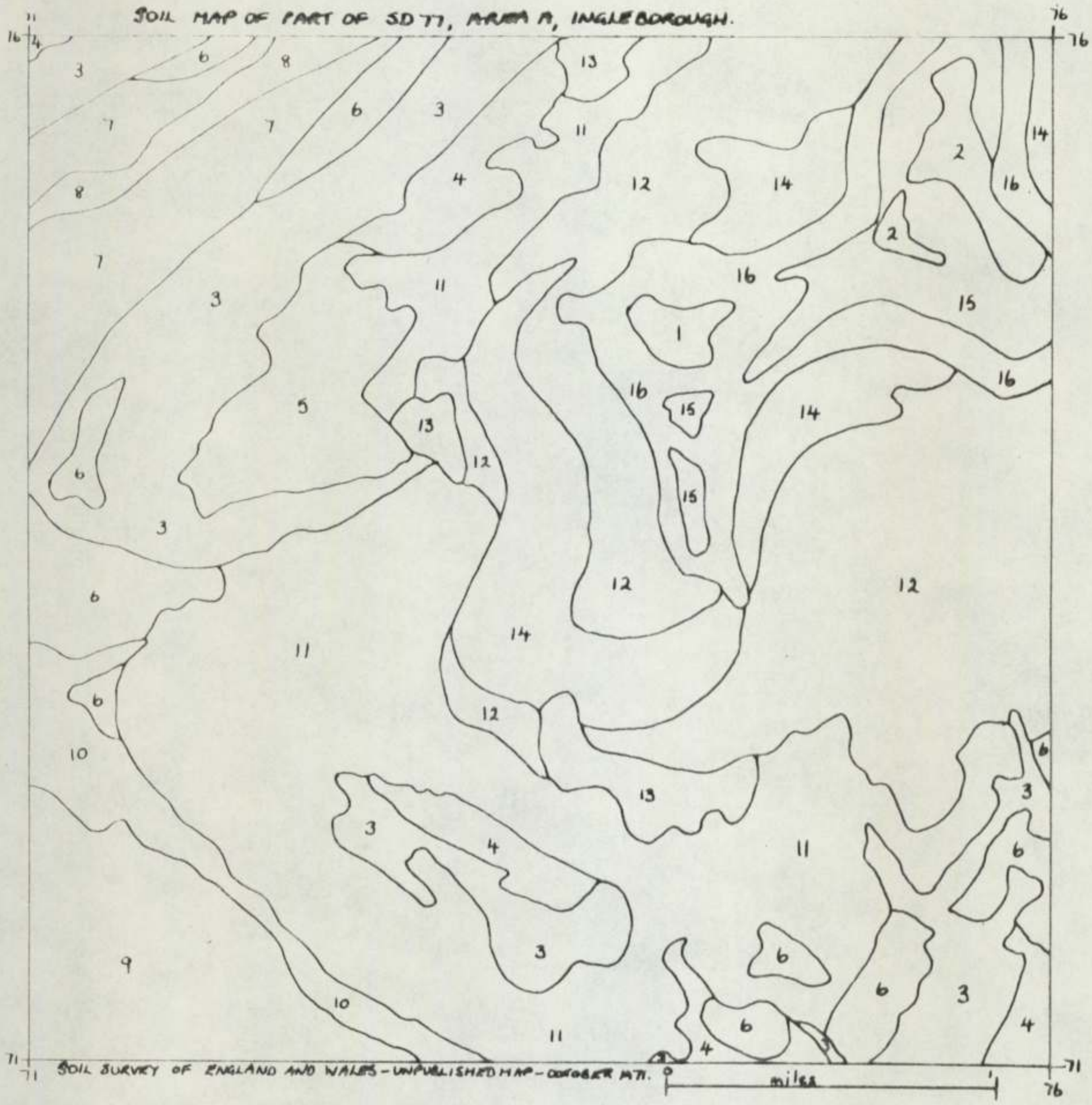

Fig.7. Soils of the Ingleborough area (scale approx. 1:44,000).

parent material is some distance below the surface (usually about 30 cm).

iii. acid brown earths, which tend towards brown podzolic soils and develop over solid limestone which occurs well below the surface or on drift overlain by silt.

iv. stagnopodzols, which are confined to the wetter areas which may be waterlogged for much of the year.

7.5 Material available for the study

Aerial photographs: these consisted of the following vertical photographs and oblique true colour prints of Ingleborough, taken with a hand-held camera on 26th November, 1973.

Multispectral	photography	of	Sedgwick	at	1:15,000,	taken on	17th May,1973
False colour	"	"	"	"	"	"	" 29th Oct.1973
" "	"	"	"	"	"	"	" 30th May,1974
Panchromatic	"	"	"	"	1:20,000	"	" 6th and 14th Oct. 1971
False colour	"	"	Ingleborough		1:15,000	"	" 26th Nov.1973
" "	"	"	"		"	"	" 30th May,1974
Panchromatic	"	"	"		1:10,500	"	" 14th June,1968

Maps: 1:10,560 and 1:25,000 scale Ordnance Survey maps were used as base maps in the study. Soil maps of recent date (1971) were available at 1:25,000 scale and published geological maps were available at 1:63,360 scale. The field sheets, at 1:10,560, of both the solid and drift geology of Ingleborough were copied although these were rather old, having been surveyed in 1851 and revised in 1909. The 1:63,360 sheets were redrawn from the original maps and amended. The geological map covering the Sedgwick area was also old (1892) but better information was available from the Soil Survey publication on Sedgwick, although not at a large scale. The field sheets of the 2nd Land Use Survey (1:10,560) were available and a copy of the land use of the Sedgwick area in 1964 was made. At the same time the field sheets (at 1:25,000) of the 2nd Land Use Survey vegetation survey were consulted and a copy made of the sheet covering Ingleborough (1967).

Literature: soil survey information for the Sedgwick area was available from the Soil Survey's handbook (Furness and King, 1972) which accompanied the map and additional information on the new soil classification from the Soil Survey Air Photo Unit at Harrogate (D.Carroll, personal communication). The handbook also contained useful notes on the geology of the area and a small map of the drift geology. Land use information came from the Soil Survey handbook and information on land use survey methods was found in the Land Use Survey handbook (Coleman and Maggs, 1965), and provided by a surveyor (G.Sinclair, personal communication). More detailed land use data were provided by the local Ministry of Agriculture advisory service and by several local farmers around Sedgwick. A survey of seven farms in the area by the Grassland Research Institute (personal communication) provided detailed data on farm acreage, sward age, cover crop, time of sowing, type of seed mixture sown, dominant species etc., and various soil factors.

The soil survey information on the Ingleborough area came from several sources as the Soil Survey's map has not yet been published. The map and a legend came from the Soil Survey Air Photo Unit in Harrogate, with additions from the Soil Survey's publication onthe soils of Lancashire (Hall and Folland, 1970) and papers on the soils of the Malham area (Bullock, 1964, 1971). The Soil Survey record for the Sedgwick area (op.cit.) was also useful. Geological information also came from several sources including the Geological Survey Memoirs (Dakyns et al., 1890) for the area, publications by Sweeting (1950, op.cit.) and Hicks (1959), and from a book by the Nature Conservancy (1965) describing the Ingleborough Site of Special Scientific Interest. This book was very useful and covered land use, vegetation, climate, history and soils of the area, as well as the geology. Some general information on the agriculture of the area was published by Williams (1963), while information on the vegetation came from the 2nd Land Use Survey (G.Sinclair, personal communication) and papers describing similar vegetation associations at Malham Tarn (Sinker, 1960; Proctor, 1974).

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Chapter 8: SURVEYS OF THE SEDGWICK AREA

8.1 Introduction

In this area both soil surveys and land use surveys were attempted but only the land use surveys were successful. Soils could not be mapped directly as over much of the area there was a permanent vegetation cover. This was, for the most part, not natural or semi-natural vegetation but managed grassland, and thus did not respond to changing soil conditions unless these conditions were extreme e.g. in very wet areas that had not been drained where the presence of *Juncus* species indicated waterlogging.

8.2 Multispectral photography

This photography was taken using a multi-lens camera which recorded four images simultaneously on black and white infra-red film. This produced four 3.5" x 3.5" images on a 9" x 9" format (photo. 1). Each image was filtered to cover a chosen waveband: band I used a blue filter (47B), band II a green filter (57A), band III a red filter (25) and band IV a visually opaque filter (88A). Thus the wavebands transmitting light were:

Band I 380-500nm - green, red, ultra-violet absorbed.

Band II 440-620nm - red, blue absorbed.

Band III 600-900nm - blue, green, ultra-violet absorbed.

Band IV 720nm + - all visible light absorbed.

Infra-red blocking filters were used with bands I, II and III. The lens had a focal length of 100mm and the exposures were as follows:

Band I f4 at $\frac{1}{350}$th sec.

Band II f2.8 " " "

Band III f.2.8 " "

Band IV f8$\pm$0.5 " "

Photo.1. An example of multispectral photography, bands I and II.

Bands III and IV.

Since little bare soil was visible on the photographs it was not possible to map soil types and the boundaries between them. In some cases the vegetation type indicated conditions, e.g. the poorly drained Cegin soils are subject to Juncus infestation if badly managed but management was so varied that this proved an unreliable indicator. Soils of the Hincaster Series, which are acid brown earths developed on sandy fluvioglacial moraines forming small mounds on the alluvial soils, also show a vegetational difference where they are adjacent to very poorly drained soils. If such land has not been improved by the farmer, then there tends to be Juncus in the wet places and gorse bushes and heath type vegetation on the sandy soils, e.g. in a field on the alluvial soils of St.Sunday's Beck (542885), these differences can be seen but the adjoining field, which has the same soils, has been managed better and there is little difference to be seen in the vegetation. Most of the poorly drained soils were drained in the last century so there is now little indication of soil type from the vegetation, unless the drains have proved inadequate.

The Downholland Association of alluvial soils can be picked out fairly easily on the photographs from their lack of relief rather than their tone. Occasionally, patches of peaty soils in this association can be seen on the photographs as they are often in small hollows where flooding is frequent and drainage is poor e.g. a large field on the floodplain of Peasey Beck (552868) which had been sown with a grain crop; growth of the young crop was more advanced in the small, wet hollows. Abandoned stream channels can be seen in one large, very wet area of alluvial soils.

The complex of soils associated with the Silurian rocks could be picked out easily on the photographs, as these areas have often been left as common land with heath or moorland vegetation because of the difficulty in managing such soils. The relief is usually more broken than that of the drumlins, with steep slopes and exposures of rock. The vegetation consists of heath grasses (e.g. Agrostis canina) with gorse and much bracken, which produces distinctive tones and textures on the photography. However, these regions can be successfully integrated into permanent pasture as can be seen on the Helm (531887), where the western side is common land with heath vegetation but the eastern side is fairly good permanent pasture belonging to a nearby farm, including pasture grasses such as Lolium perenne. It is difficult to pick out the precise boundaries of these areas although the broken topography gives some indication.

It is impossible to distinguish, on the photographs, the Altcar Series (peat soils) from the Ynys Series (peaty gley soils) or from badly drained Cegin Series (surface water gleys) in the numerous wet patches on level ground and in hollows. These wet patches can be picked out very easily on the photographs from the vegetation type but many are too small to be included in the Soil Survey's map.

Small areas of brown calcareous soils, e.g. Natland Series, are found in the western part of the area, around exposures of Carboniferous Limestone. These soils cannot be separated from other soil types on the photographs, even though the rock exposure can be clearly seen. It is difficult to distinguish the limestone from the Silurian greywackes as the exposures are so small; it is even difficult to tell rock exposures from bare soil on footpaths, etc.

Boundaries between the soils on the drumlins were impossible to find also. There was no indication on the photographs, of the sequence of Denbigh, Sannan, Cegin and Ynys soils except in extremely wet areas, as already mentioned. Approximately 50% of the arable fields were found on the better drained Sannan Series, 20% each on the Denbigh and Cegin Series, although arable fields were found on all the other types of soil except the Hincaster soils and the complex soils where topography would preclude ploughing. The few areas of bare soil visible on the photographs show almost no tonal differences between soil types as the colours of their surface horizons are very similar. In one field of bare soil, where a boundary between the Sannan and the Cegin Series is located, there is a very slight tonal difference between the two types of soil, that is easy to miss unless known to be there.

Confusing tones can be produced by such practices as muck or fertilizer spreading; muck gives dark tones when recently spread while fertilizer application causes better crop growth, which also results in darker tones. Strip grazing using electric fences is a normal practice in this area, resulting in fields that have been closely grazed in one part with comparatively lush growth in the ungrazed part; the ungrazed side of the fence has dark tones and the grazed side light tones. Areas of sparse vegetation can also cause confusion, e.g. the western tip on one drumlin (544883) has a steep slope which is a favourite place for sheep to lie; soil and vegetation is eroded and a crescent-shaped pale patch on the photograph produced, which could easily be mistaken for a different soil type. Only careful examination under the stereoscope and a visit to that field showed the patch for what it was. Mottled vegetation patterns are often caused by poor management and the growth of weeds such as thistles, nettles and rushes, rather than soil type, although differential crop growth can indicate small areas of differing soil types.

Stereoscopic examination of the photography band by band found that bands I and II were of little use while band III was the most useful with band IV almost as useful.

Band I (blue filter) shows up patterns on the fields left by muck-spreading and hay-cutting but it was impossible to tell which was which.

Fertilized fields cannot be distinguished from unfertilized and the difference between two types of conifer in a plantation (larch and spruce) cannot be seen either. This band is the least clear of the four; the tones are all very similar, giving a hazy appearance.

Band II (green filter) is slightly clearer than band I but is again hazy and although it shows as many differences in tone as on band III, it is more difficult to work with as the tones are so similar Fertilized fields can be distinguished with some difficulty, although the muck-spreading patterns show up well and it is easy to distinguish between the two types of conifer in the plantation.

Band III (red filter) is the most useful, especially for vegetational differences. Stages of crop growth can be seen very clearly and fertilized fields also stand out well. Fields that have a lush growth of grass due to fertilizer application give dark tones on bands I, II and III compared with the paler tones of those that have not had a recent application of fertilizer or those that have been grazed. Patterns of strip grazing, muck-spreading and hay-cutting show up most clearly on this band. Areas of bare soil or where the vegetation cover is sparse, as on footpaths, and also bare rock, show up clearly. However, no difference between larch and spruce can be detected.

Band IV, the infra-red band, was found to be very useful, especially when viewed in conjunction with band III. Vegetational differences are not as clear as on band III, for instance, a ploughed field gives a completely blank, smooth white tone on band IV but on band III the young, sprouting crop can be seen. It is difficult to distinguish between bare ground such as a ploughed field, and grazed land. Areas of semi-natural vegetation stand out well, as do the wet patches. These patches are clearly visible on all bands but are especially clear on band IV. The mottled patterns of vegetation in the fields, caused by thistles, nettles and hummocky grass, cannot be seen at all and only with difficulty can fertilized fields be seen. However, strip grazing and muck-spreading patterns are clearly seen, as are patches of bare ground and exposures of rock. The two types of conifer are easy to distinguish and blossom on the hawthorn trees in the hedge-rows shows up best on this band. Drainage channels show up very clearly. It was not easy to view relief on the infra-red band through a stereoscope, possibly because the tones on this band are the opposite to what one would expect - the vegetation gives light tones rather like those of a photographic negative.

The additive viewer was used to give true and false colour images of the multispectral photography (photos. 2 and 3). The true colour image was produced by projecting blue through channel I (band I) at an illumination intensity of 7 (on a 1-9 scale), green through channel II at an illumination of 9 and red through channel III at an illumination of 5. The infra-red band was not used. This combination produced a fairly good colour rendition although the image was rather blurred, probably because of the great amount of enlargement (2½ times). Eight different tones of green were distinguished, although they were difficult to separate as they tended to grade into each other. A tracing of the tone boundaries was made from the image (fig.1).

A false colour image was made by projecting green through channel II, blue on channel III and red on channel IV. The illumination was at its highest intensity. This gave a range of seven tones from light blue and blue to dark red. This combination of colours was found easier to work with than any other, as the contrast was greatest. A trace over-lay was made from this image (fig.2) and compared with the true colour overlay and with the ground truth data, in the form of land use and soils maps, and some field work.

Photo. 2. Part of a true colour composite on the additive viewer.

Photo.3. Part of a false colour composite on the additive viewer.

It is difficult to reproduce the colour tones as seen on the additive viewer, and when these photographs were taken, the illumination of the viewer was faulty, resulting in a red cast over part of the screen.

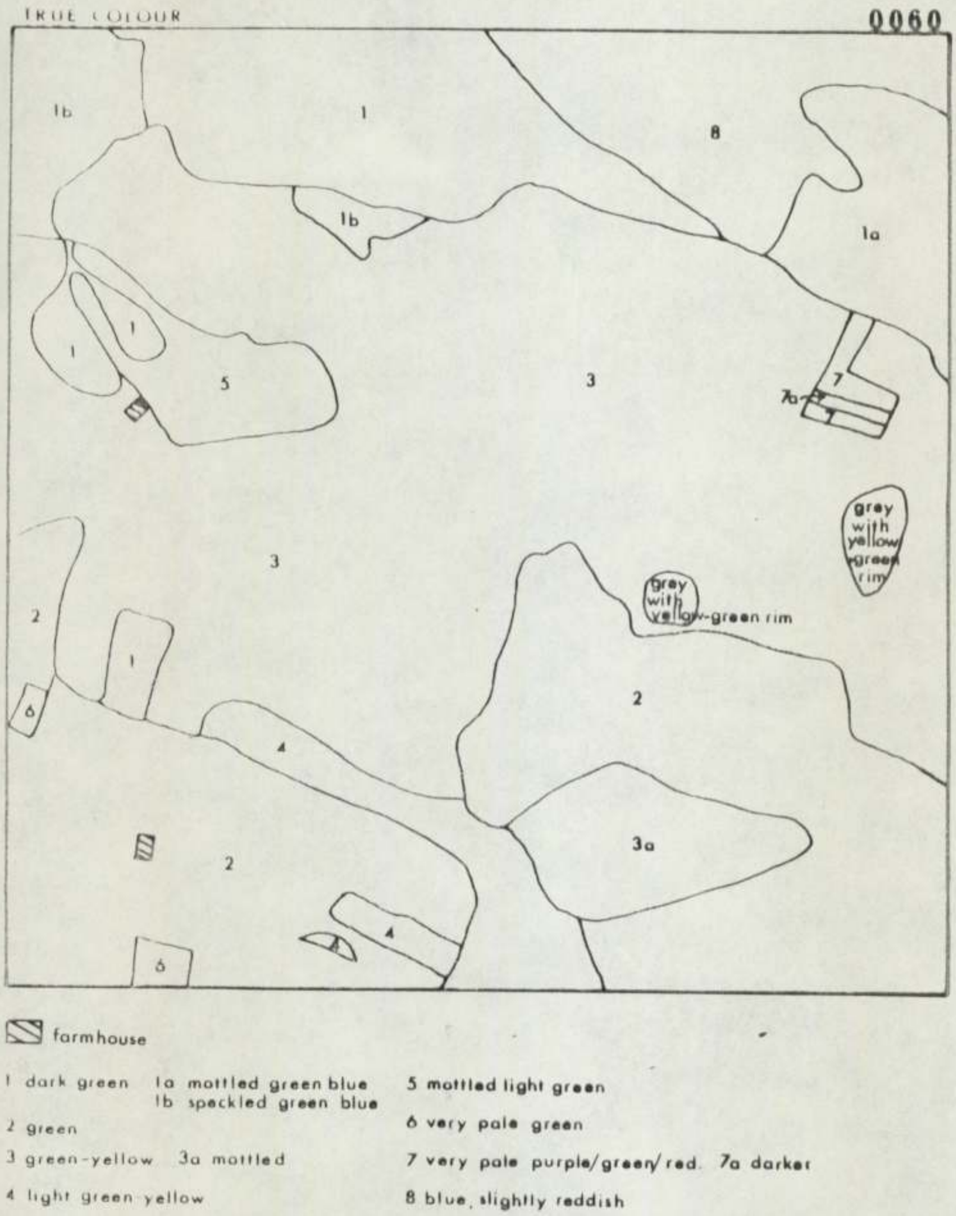

Fig.1. A tracing of tone boundaries from the true colour composite. (scale approx. 1:10,000).

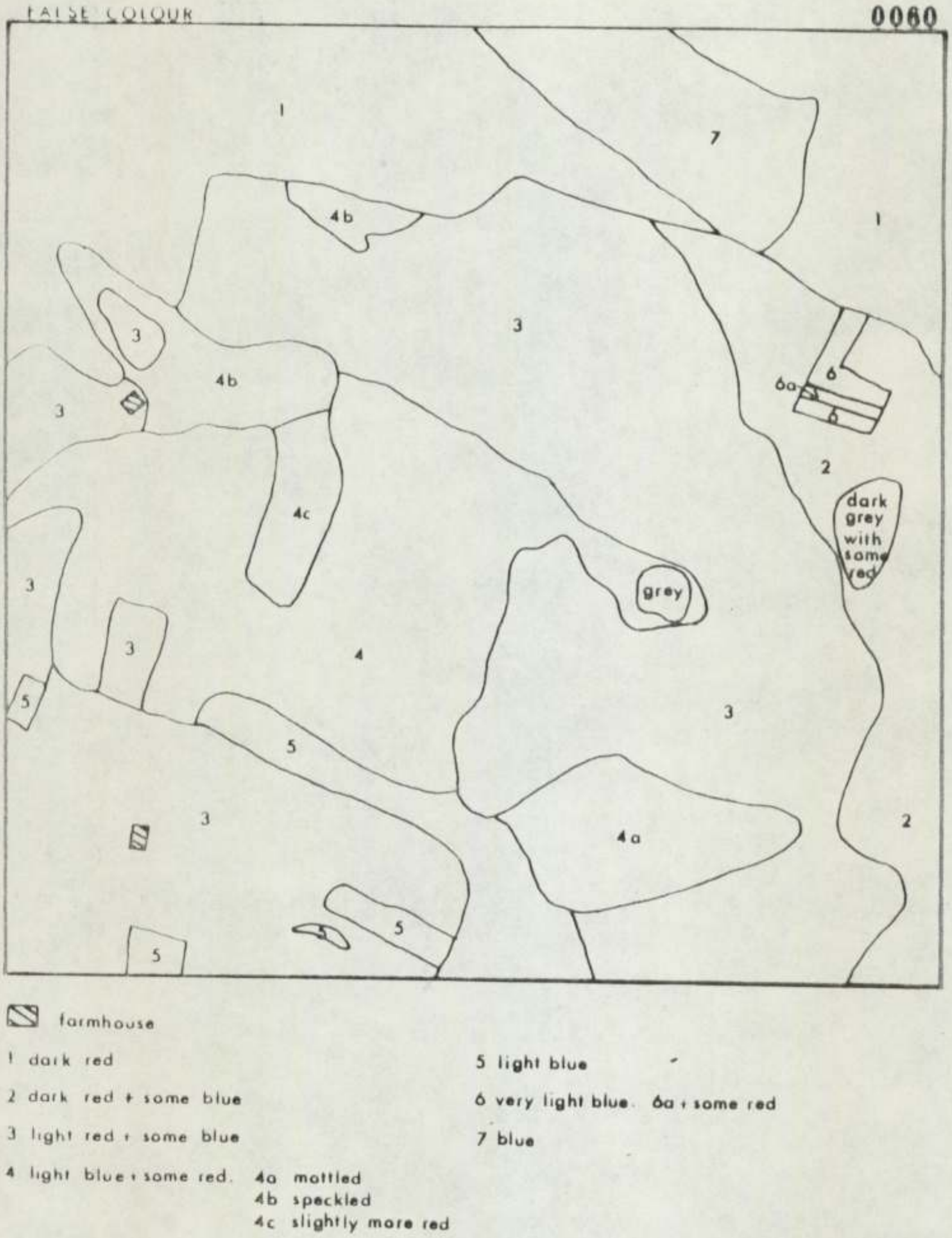

Fig.2. A tracing of tone boundaries from the false colour composite. (scale approx. 1:10,000).

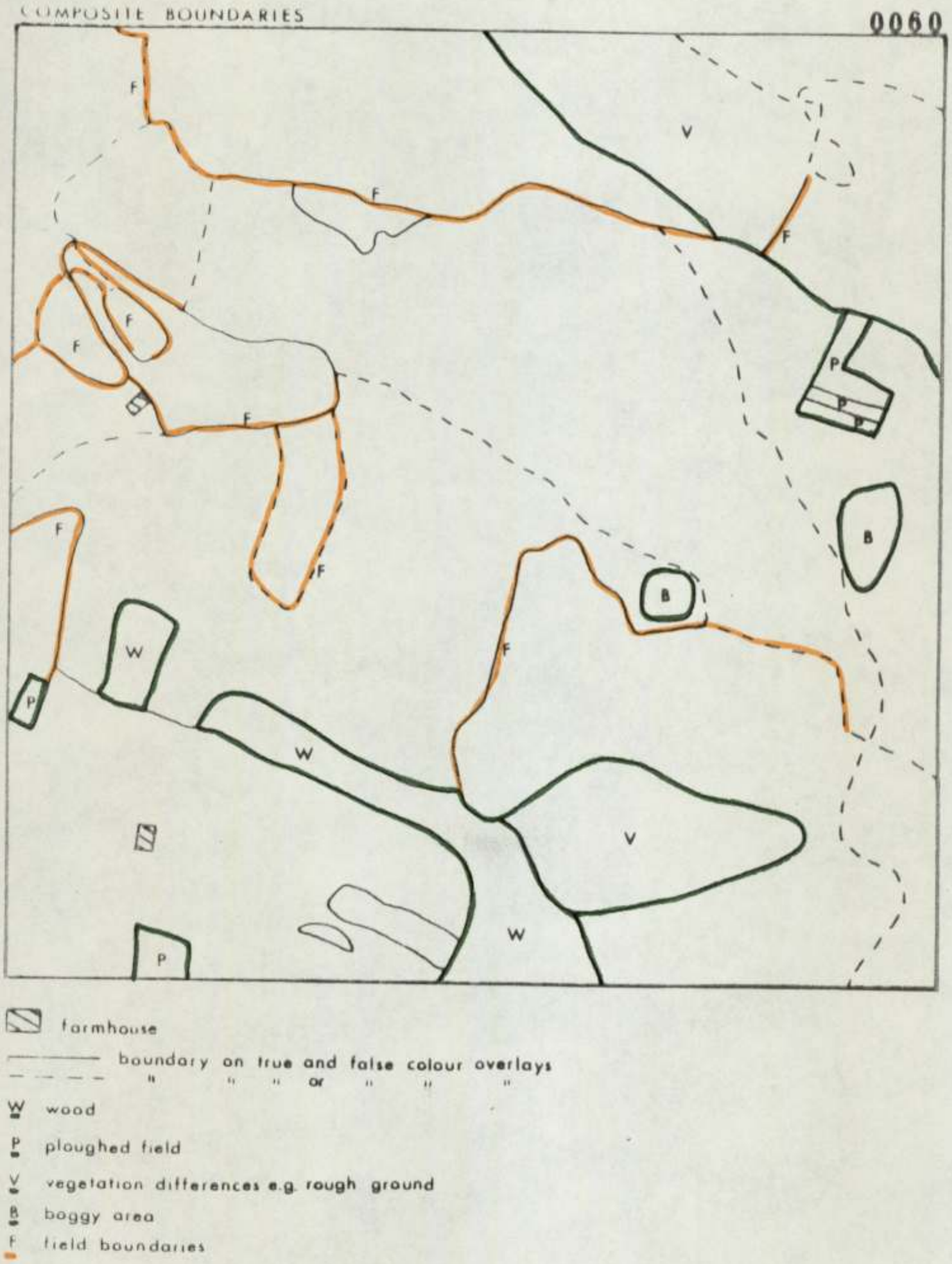

Fig.3. Composite map made from figs.1 and 2, showing boundaries that appeared on both figures. (scale approx. 1:10,000).

The two overlays were very similar; there were only three discrepancies in the boundaries, one of which was probably due to fall-off in illumination towards the edge of the image. A composite map was made from the two overlays showing lines that appeared on both (fig.3). Only two boundaries showed actual soil differences, where there were two very wet flush areas, where the vegetation is mainly species of Juncus. These soils are peats and peaty gleys, though it is impossible to tell between the two. These areas are prominent on the panchromatic images also. The other lines on the overlays can be explained by various farm management practices, such as strip grazing and the use of fertilizer, causing differences in the vegetation growth and type. Most of the boundaries coincided with field boundaries and thus with vegetation differences. All the boundaries can be seen without using an additive viewer although the viewer did show these differences more clearly.

8.3 False colour photography

The colours on this type of photography consist mainly of shades of magenta and turquoise blue or cyan. Green, healthy vegetation produces shades of magenta, and dead vegetation, road surfaces, rock exposures, bare soil etc. show as shades of turquoise ranging from very pale turquoise (dead vegetation) to blue-green (bare soil). Other colours found are green, which is produced by orange-brown colours in true colour e.g. dead bracken, and very dark red or green colours, which can be almost black e.g. gorse bushes are very dark green, and conifers are dark purple-red. The false colour photography is very clear and sharp as it cuts through haze very well, and thus textures tend to be important also. The wider range of tones or colours picks out patterns more clearly than on the black and white multispectral image, and also more clearly than can be seen in the field (i.e. a true colour oblique view) but this may not be so when viewing a true colour vertical aerial photograph because of the different angles of view. True colour oblique aerial photographs were available to compare true colours with the unfamiliar shades of the false colour photographs but although very useful, these were not as sharp as the false colour photographs.

8.4 Soils

Soil surveying using false colour photography suffered from the same disadvantages as using the multispectral photography i.e. that little actual soil is visible on the photographs and visible features may not relate well to soils. The vegetation of the area does not correlate well with the soils as it is not natural or semi-natural, and what soil is visible cannot be differentiated as the colours of the surface horizons of most of the soils in the area are very similar. Colour photography, both true and false colour, will give a better differentiation of the vegetation cover than will panchromatic photography of any type, but this is of little use if the vegetation does not correlate with soil. Therefore, soils could not be adequately mapped using the false colour photographs but the vegetation could be, so land use maps were produced instead of soil maps. For both soil and land use mapping the October photography was found to be better than the May photography, as autumn is a good season for colour differentiation in vegetation (p.137) and the more subtle tones in the fields were easier to differentiate than the bright magenta colours on the May photography. Also, relief could be picked out well by shadows, as the angle of the sun is lower in October (photos.4 and 5).

Two more attempts were made at mapping the soils from the false colour photography, by using relief features. Break in slope, taken where the break is the sharpest, was mapped and it was found that certain soil associations could be easily delimited in this manner.

Photo.4. False colour aerial photograph of the Sedgwick area, October 1973 (reduced from 9" x 9").

Photo.5. False colour aerial photograph of the Sedgwick area, May 1974. (reduced from 9" x 9").

The alluvial soils (Downholland Association) were very easy to pick out as the drainage of the Sedgwick area shows rejuvenation features and most of the drainage channels have been cut quite deeply into the underlying till and have been infilled with alluvial material, producing flat-bottomed valleys. Mounds of fluvio-glacial moraine and their associated soils (Hincaster Series) are usually situated on alluvium and therefore stand out well; in some cases the shape and location of these areas on the A.P.I. map was more accurate than on the Soil Survey map. However, where these mounds are situated on other soils, mainly on the drumlin soils (Lowick Association), they are more difficult to see. Areas of complex soils on Silurian rocks can be picked out because of broken topography and rock exposures but it is difficult to find the exact boundaries. Drumlins can be easily seen but it is impossible to differentiate between their component soils except for certain poorly-drained areas at the bottom of the drumlins; vegetation is the most useful indicator here as these areas are rather small to be picked out from their lack of relief. The calcareous soils (Warton Association) cannot be picked out by their topographic expression even though the limestone rock can be seen. The peat soils (Altcar Association) can be picked out because they occur in flat, poorly-drained places but again vegetation is the main indicator and these soils cannot be differentiated from other poorly-drained soils (Ynys Series) belonging to a different association. Relief is a very useful aid to soil surveying by aerial photographs but it is as easily seen on panchromatic photographs as on false colour, true colour or multispectral photographs, though the false colour photographs are good because they are so clear.

A separation was attempted between soils of the Lowick Assocation: the Denbigh, Sannan, Cegin and Ynys Series - a related sequence of soils on the same parent material, differing because of drainage. No indication of this difference was found through tone/colour or texture as the vegetation was usually uniform. Mapping the slope in detail was tried, to see if the change in soil type was accompanied by a change in slope, however slight. Two drumlins were chosen, consisting of Denbigh soils on the tops of the drumlins, surrounded by Sannan soils, with Cegin soils in the valley between. A map, at 1:5,000 scale, of contours at 10 foot intervals was drawn using a Wild A7 Stereoplotter (fig.4). Even at this large scale no obvious/continuous break in slope can be detected, although the two drumlins and the valley between them are obvious. The soils of the drumlins would seem to have little or no external expression in either relief or vegetation type so they could not be mapped from aerial photographs, and as these soils cover the major part of the Sedgwick area, the soil mapping exercise failed.

8.6 Land use

Survey Method: two land use maps of the Sedgwick area were produced by A.P.I. methods, one map showing land use in October and one showing land use in the following May. First, A.P.I. training samples were selected from typical farms in the area, chosen with help from the local Ministry of Agriculture officers. These areas were mapped in the field and consisted of six farms, covering approximately 15% of the area. The survey by the Grassland Research Institute was useful here as it covered three of the farms and gave detailed information on crop types, grass species etc. The field work was carried out in May 1974, so the farmers had to be interviewed to obtain information on the type of crop growing in their fields during the previous October and May, to coincide with the dates of the multispectral photography and the first set of false colour photography. Questionnaires were used (fig.5) in conjunction with a 1:10,560 Ordnance Survey map. These interviews were not

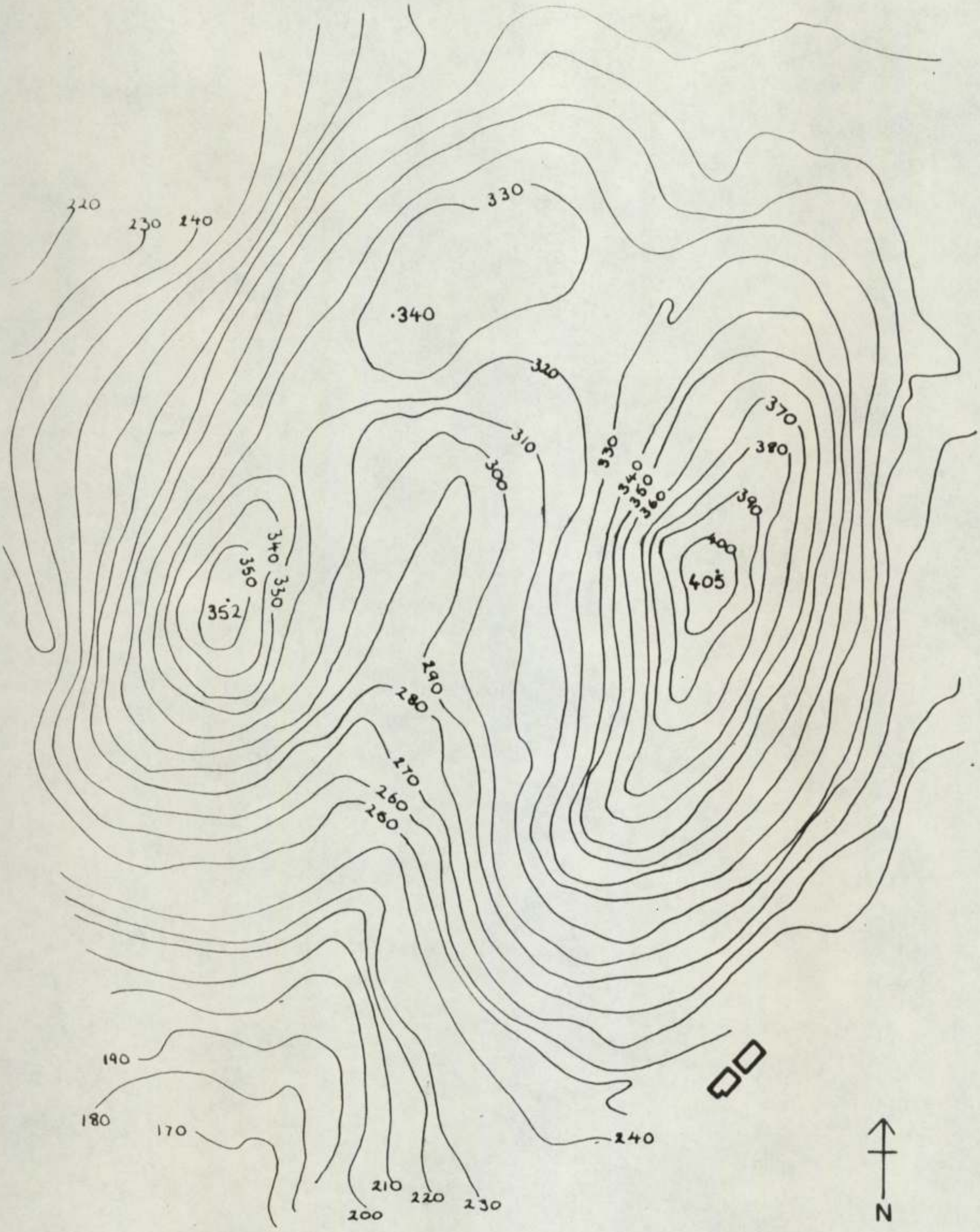

Fig.4. The area around Stubb Farm (536851) and Deer Park (532848) mapped in detail at 1:5,000, with contours every 10 feet.

Fig.5. LAND USE SURVEY: SEDGWICK, WESTMORLAND

FARM: Bradley Farm, Hincaster. MAP REF: 512847

FARMER: J. Pickthall.

a = May 1974 b = ~~December~~ OCTOBER 1973 c = May 17th 1973

FIELD NO.	CROP TYPE	OTHER REMARKS
	a ploughed	for potatoes
19	b bare earth, potatoes just lifted	
	c potatoes	
	a permanent grass	arable up to 6 years ago. Resown with intention of permanent grass
20	b resown with grass May / June 1973	
	c permanent grass	
	a permanent grass	false colour - light colour is wet area
21	b " + muck-spreading	
	c "	
	a permanent grass	
22	b "	
	c "	
	a permanent grass	
23	b "	
	c "	
	a permanent grass	
24	b "	
	c "	

always successful, so a small amount of the information may be incorrect. This field work also included a general tour of the whole area, to become familiar with the land, its soils, relief and farming types. After this field work had been completed, aerial photo-interpretation maps were made using the land use categories of the 2nd Land Use Survey (Coleman and Maggs, 1965) so that they could be compared with the 2nd Land Use Survey map of 1964. The A.P.I. maps were checked using random sampling and a 10% sample was chosen, i.e. 100 fields were to be checked. The sample sites were chosen using random number tables and marked on a grid placed over the map. Out of 100 samples, 14 fell in ground truth areas and did not need checking, 11 samples fell in the same fields as others and 3 numbers were repeated, so only 72 fields were checked. Only one sample was found to have been wrongly identified; it had been classed as a grain crop and was instead a good growth of grass. This field checking was carried out in October 1974 but any field that was thought to have changed since the photography had been flown was checked with the farmer. A check was made also on unknown vegetation types e.g. where raspberries were grown, and the final maps were then produced. Valence analysis was carried out on the heath and moorland vegetation of the Helm, where there were three different areas - grazed, grazed and managed, and ungrazed.

The land use categories mapped were:

1. residential/industrial
2. natural vegetation
3. woodland
4. orchards
5. nurseries and allotments
6. grassland
7. arable land
8. wet areas

1. Residential/industrial: these two categories were not differentiated as there is very little industry in this area and in some cases industry has taken over a residence e.g. a mansion now housing a furniture factory. This category was very easy to map and easy to plot. The Ordnance Surey map was found to be very out of date in its representation of buildings, as several new housing estates have been built, as well as individual houses.

2. Natural vegetation: this consists of heathland, moorland and rough grazing, mostly unenclosed land receiving little or no deliberate management. It is characteristically semi-natural vegetation kept in an arrested stage of development by extensive grazing, burning, liming or natural conditions. There are not many areas of this category in Sedgwick but they stand out well on the photographs and are a great contrast to the healthy grass crop in the rest of the area, as they are not grazed intensively and thus have taller vegetation with much dead material present, giving a different colour. Weeds such as bracken and gorse are characteristic and can cover large areas. Fields infested with bracken, gorse, rushes etc. were not included in this category unless the invading vegetation covered over 50% of the field. The component vegetation of these heath areas was mapped e.g. heath grasses (Hg), bracken (Pt). The main area of this type is the Helm, a rugged hill of Silurian rocks. The eastern side is grazed and managed, permanent pasture consisting mainly of pasture grasses such as Agrostis tenuis, Holcus lanatus and Lolium perenne, with many rock exposures and shallow stony soils with sparse vegetation. The exposed rock and soil show as turquoise blue on the photographs while the wetter areas of deeper soil in between have a better growth of vegetation and show as magenta. The western side of the Helm is grazed occasionally and the bracken is cleared occasionally but it is common land and is mostly left

as rough grazing. There is much bracken (photo.6) and gorse is also present, showing up as dark green dots. The heath grasses usually show as a pale blue colour, as there is much dead material. At the summit, rock is exposed and at the southern tip of the hill bracken has recently been cleared. The vegetation types give the best contrast on the October photography, when they are dying back, e.g. dead bracken gives a distinctive green colour on the aerial photographs, whereas in May it shows only as an indistinct green-blue. The rock exposures show up best on the May photography but this is possible only because the weather had been abnormally dry. It was easy to confuse rock exposure with patches of bare soil such as footpaths. Areas of rough land were difficult to delimit except where the area was enclosed, as they tend to merge with the better land, and it was also difficult to map fields infested by heath grasses unless they were accompanied by more easily recognisable species such as rushes, bracken or gorse.

3. Woodland: this category was differentiated into coniferous, deciduous and coppiced woodland where possible. Deciduous trees are most common in this area but there are two plantations of conifers. The difference between the woodland types could be seen by crown shape and size, and by colour. It was also found that larch could be distinguished from other conifers as it tended to have a lighter magenta colour although not as light as deciduous species. There was not a great difference, however, and individual larch trees could not be detected although a whole stand could. In October the deciduous trees were losing their leaves and thus produced many shades on the photographs - green, blue-green, pale blue, almost white, and magenta where the leaves were not yet dead. The conifers remained purplish-red on both sets of photography except for the larch trees which were losing their needles and changing colour in October,

Photo.6. The Helm, a rugged hill of Silurian rocks, with a vegetation cover of heath grasses and bracken.

showing up as green. On the May photographs the deciduous trees are shades of magenta and are whitish where there is blossom, e.g. on the hawthorn trees in the hedgerows. Copper beech trees stand out as bright orange on the May photographs but are no different to other deciduous species on the October photographs.

4. Orchards: these can be distinguished because of their location and texture. They are often next to a house or farm, enclosed, and the trees are all approximately the same size and shape, and usually widely spaced, unlike a plantation. It was difficult to tell the exact type of tree, although most were apple orchards.

5. Nurseries and allotments: these can also be picked out because of their shape and location, and nurseries usually have some glass houses. The allotments are small strips of different vegetation, usually near a residential area.

6. Grassland: both temporary and permanent grassland were included in this category as it was found impossible to tell the difference between the two, even in the field, though a short ley may often have a high percentage of Lolium multiflorum and a longer ley will include Lolium perenne, Dactylis glomerata, Phleum pratense and less L.multiflorum. Buttercups are good indicators of old pastures, so some indication of age can be obtained, but in Sedgwick ley grasses tend not to form part of a rotation system. Permanent pasture can be picked out definitely but it is difficult to tell whether a good growth of grass indicates a temporary ley crop, a recently reseeded area or a good hay crop. Mottled textures in the fields often indicate an old pasture and may be because of hummocks of different grass types, especially D.glomerata, or thistles, nettles or rushes. Farmers in this area tend to plough up and reseed a field every 20 years or so, depending on the state of the pasture, and

then the field will probably be used to grow an arable crop for the first year and subsequnetly be planted with grass, which is not grazed but cut for silage. The presence of plough lines in a field does not mean that the grass is temporary, e.g. on Dreamland Farm plough lines can be clearly seen in a field that has not been ploughed for over 80 years. The colour of grassland on the false colour photographs varies from light blue to deep magenta, depending on the health of the grass and the amount of dead material present, which will depend on management and grazing practices. In the October photography, the grass is mainly blue toned as growth is not vigorous at that time of year, while in May it is usually bright magenta. Grazing patterns can be confusing; strip grazing using an electric fence (which cannot be seen on the photographs) is common and produces fields with one part closely grazed, showing pale blue and the other part ungrazed, showing a magenta colour. Reseeded areas tend to look like areas that have been recently strip grazed, especially if only part of a field has been reseeded; the boundaries can be seen up to two years later. A similar pattern is produced by areas that have been under arable crops and have been put back to grass, as often only parts of a field will be ploughed up for the crop. Fertilizer applications can be seen as the growth of the grass will be very lush, and if the machine does not spread the fertilizer evenly, a clear pattern is seen. Muck spreading produces a similar result and cannot be separated from fertilized areas except where the muck is still lying on the surface, when it produces a dark green-blue colour. The October photography has subtle tones of blue, pale magenta and purple, which were found easier to work with than the bright magenta colours on the May photography. 'Zero grazing' where as grass crop is cut very close to the ground so that about only 2cm of vegetation is left, was seen on the May photography. This was confusing as the remaining vegetation, being the yellow, non-photosynthetic parts of the plant, looked dead and gave a turquoise colour, though with a very few magenta patches where the grass had begun to grow again. As the texture was even, the field looked like ploughed land with a young crop just beginning to sprout.

7. Arable: very few arable crops are grown in the Sedgwick area and most of what is grown is for silage or fodder crops, not human consumption. The bare earth category was included here as these could be fields ploughed for a crop. Bare earth shows as green-blue with possibly some dead vegetation on it showing up as white. Kale (marrowstem kale) is the major fodder crop and is easy to detect on the photographs. It is a bright magenta colour, fairly tall (about 1.25m) when mature, and has a characteristic, often uneven, texture which looks like pile on velvet. Kale is sown broadcast so the plants are close together. It is usually cut in strips (photo.7), rather than grazed, producing a characteristic pattern. The kale is usually sown in July and cut in October, although it may be left in the fields up to the end of December. Thus, it would not often be seen on the May photographs but would be very obvious on the October photographs. Where a mixture of crops is sown, such as kale and grass, it is difficult to distinguish and may not have a characteristic harvesting pattern. Root crops of swedes, turnips and potatoes tend to look similar to each other and similar to kale, with almost the same colour and texture, although they are all shorter than kale. Potatoes are often harvested in October, leaving fields of bare earth often with the unwanted, dead parts of the plants lying on the surface and boxes and sacks lying by the edge of the field. Usually just small strips of land are used for potato crops, not many whole fields, as the potatoes are for home consumption only or for sale in the local market or, in one case, on a milk round. Most of the bare fields on the October photography are potato fields. It is difficult to tell which are potato fields on

Photo. 7. A true colour, low oblique aerial photograph of the Sedgwick area (October 1973), showing kale-cutting near Gatebeck (547855) (from the Cambridge University Collection).

the May photographs as the crop would just have been sown and could be potatoes, swedes or turnips, or even kale. Swedes and turnips are very similar but can be distinguished when mature, i.e. in October, because swedes are larger and are usually sown broadcast, whereas turnips are smaller and row sown. Swedes also have slightly darker leaves than turnips. Turnips are often used as sheep fodder and eaten in the fields when quite small. However, it is difficult to tell between these two crops, and to distinguish them from immature kale or potatoes, or possibly tussocky grass, when they are immature. The two grain crops in the area are barley and oats. Barley is a light magenta colour when unripe, with a close, even texture like tall grass. Oats are darker magenta with a bluish tinge when unripe and usually have a less even texture than barley. The grain crops are usually grown in whole fields but they are occasionally grown in small strips like potatoes. They are very difficult to distinguish from each other in May, and from a tall crop of grass, however, later in the season it is easier to see the difference. In this area grain crops are often cut green for silage, so completely ripe crops were not seen. By October, most grain crops had been harvested and there was confusion over areas where grain crops had been; the straw had been left in the ground but grass was already beginning to show through. Cabbage is grown for home consumption, as are the potatoes, and can be confused with swedes etc. Raspberry canes, are in rows but could be mistaken for peas, beans etc., except that they are present, unchanged, on both the October and May photographs.

8. Wet areas: these are not strictly a land use category but were identified for the soil map. Their vegetation is very obvious however, and so they were included in the land use survey. These areas consist mainly of *Juncus* species and have dark, peaty soils. They show up

more clearly on the May photographs, as more detail can be seen, but this may possibly be because of the very dry weather which would have dried out the soil surface and thus altered its colour. The tones (light vs. dark) are the same on both sets of photographs but the colours are different: red in May and dark blue-green in October. Most areas are a blue-black colour in May (with a magenta tinge) which probably comes from the Juncus species but one area has a lush growth of other meadow plants as well, and is a dark red colour in May. The wet areas are generally darker than the surrounding vegetation whatever the colour.

This work shows the difference between the two seasons of photography. May is not a suitable season for vegetation and land use mapping (see p.118 and 137) as there are very few differences in colour in the vegetation at this time. Also, as it is the middle of the growing season there are few clues e.g. harvesting patterns, to the type of crop, except where hay is cut. October is a much better month for this type of mapping, as the vegetation is dying back, giving characteristic colours, crops are being cut or have recently been cut and the crops in the ground are mature showing obvious differences in height, colour and texture. Some crops are visible at this time of year that are not visible in the Spring, e.g. kale, although some crops will have been harvested before October and all traces of them will have disappeared. Mid-June to mid-August is the best time for land use mapping in Britain (G. Sinclair, personal communication) as this is an overlap period and will include nearly all the crops grown. August is probably the best month as the crops will be mature but this will depend on the climate of the area, e.g. Sedgwick will have a later start to the growing season than areas further south or east.

8.6 Assessment of the panchromatic photography

1:20,000 scale photographs were used, taken in October. On the whole, texture is important when using panchromatic photographs as there are less colours and the grey tones are all similar; however, textures were more difficult to see as the scale of the panchromatic photography was smaller than that of the false colour photography. More careful A.P.I. is needed, with a knowledge of local farming practices or experience of A.P.I. of a similar area. The residential and industrial category was as obvious on the panchromatic photographs as on the false colour photographs. The natural vegetation was easy to pick out on the panchromatic photographs because of its rough texture but the differences between the vegetation types were not so easy to see. On the whole, pale tones were grass, darker tones were bracken and the gorse was dark dots. Woodland is again an obvious category, though the difference between coniferous and deciduous species was more difficult to see and interpretation depended mainly on crown shape and size. Orchards, nurseries and allotments were easy to detect because of their shape, texture and location. Grass was very easy to confuse with other crops and it was impossible to tell the difference between a good growth of grass and a grain crop. Mottling of old pastures could be detected. Strip grazing shows up only as faint lines where the darker and lighter tones meet but animals can be seen on some of the grazed parts. It was also impossible to tell which fields had been fertilized. Bare earth shows up as a darker area with a rather smooth texture and sometimes plough lines can be seen. Kale is easy to see but it is also easy to confuse with a potato crop; kale is slightly taller and darker and has a different texture however, and sowing patterns differ. Kale cutting patterns are easy to see, as are potatoes being harvested. Grain crops are extremely difficult to pick out as the tones are similar to those of grass but the texture is different, and they are easy to distinguish if they are being harvested. Oats have a slightly rougher texture than barley but this was very difficult to see. The raspberry canes have a distinguishing texture and the wet areas are easy to pick out from their dark tones, although they could be mistaken for areas of bare earth.

8.7 Comparison of the land use maps and the methods of mapping

Land use maps were made from both sets of false colour photography, showing the land use of the Sedgwick area in October 1973 and May 1974. These were then compared with the map made by the 2nd Land Use Survey in May-August 1964. There is more differentiation of categories on the 1964 map because the grassland is divided into temporary and permanent grassland and the residential and industrial areas are separated. The changes in land use over ten years and from one season to another can be seen by studying these maps. In 1964 there was over four times as much arable land (162.2 ha.) than in 1973 (33.2 ha.), though the crops were very similar, being mainly fodder crops - kale, potatoes, swedes, mangolds and oats. However, the grain crop in 1964 was almost exclusively oats (oats 70.2 ha., barley 3.7 ha.) whereas in 1973/74 the crop was approximately 50% oats and 50% barley (oats 19.1 ha., barley 14.3 ha.). The amount of arable land increased from 33.2 ha. October 1973 to 54.4 ha. in May 1974 and this probably reflects the increasing price of animal feeds, rather than a normal seasonal change. As would be expected, there has been an increase in the residential category since 1964; this is mainly two housing estates though several individual dwellings have been built also. There are less allotments and no nurseries on the 1973/74 maps (8.6 ha. in 1964, 3.6 ha. in 1973/74). The amount of land under orchards remains the same but there is less woodland, as several plantations have been cut, although some areas have been replanted with conifers. The areas marked as coppice are no longer kept as coppice and are thus rather overgrown.

The times taken for the survey are as follows:

October photography: 30 minutes scanning, 60 minutes plotting (all residential and woodland areas and all allotments, nurseries and orchards, were plotted from these photographs but for the May photography they remained the same and were thus transferred directly from one map to another).

May photography: 30 minutes scanning, 30 minutes plotting.
Panchromatic photography: 30 minutes scanning, no plotting done.

These times show only the amount of time taken for A.P.I. and do not include time taken in scanning the whole area and becoming familiar with it, selecting training samples etc. These other times were not noted but would probably greatly increase the overall time devoted to A.P.I. Probably a whole working day would be necessary to scan and interpret the photographs and plot the information. This would not be carried out all at once, as some work must be done before the training areas are visited, some before the field check and some after the field check, when the final maps are made.

The field work took longer than the A.P.I. Approximately four days were spent in mapping the training samples and visiting the farmers. One day was spent checking the random samples and one and a half days checking the unknown vegetation types and carrying out the valence analyses of the Helm. This field work was carried out on foot and by bicycle, so work done by car would be quicker. The total exercise took 7½ days but more time was actually taken because the surveyor was not familiar with land use mapping by A.P.I. and more time was also taken to become familiar with the area. This method is quicker than that of the 2nd Land Use Survey, as they took approximately 10 days to do the field work, by walking and driving and more time would be necessary for plotting the final map.

8.8 Ground photography project

This project was carried out to determine the best time of year for taking aerial photographs for soil surveys and land use surveys. The photographs were taken using 35mm false colour and black and white infra-red films. Sixteen sites were chosen, covering twelve soil types and all these areas were grass covered except for one; in each case a view of the site and the surrounding area was obtained from a vantage point such as the top of a hill or wall (photos. 8 and 9). The photographs were taken every month over a year and during the middle of each month, between the 7th and 21st. Even though two weeks in every month was allowed, conditions were not always suitable; no photographs could be taken during January and in November and December the results were not good due to the low levels of light intensity and the few hours of day-light. The black and white infra-red film (photo. 10) was found to be very difficult to handle and to evaluate and no results were possible. The false colour film was easy to handle and extremely good photographs were taken in bright sunlight. When each photograph had been taken a sheet (fig.6) was filled in, so that differences between light conditions and exposures were noted and could be related to differences in tone on the slides. Cloud shadows tended to produce very peculiar colour effects. The false colour photographs showed very little in the way of soil conditions even on the bare soil site where a soil boundary runs across the field. However, these photographs were very useful for showing differences in vegetation growth over the year, especially where a crop had been sown on the bare soil site. It was found that colours on the oblique false colour views were not always the same as on the

Photo.8. Site for ground photography project, showing a bare field of Sannan and Cegin soils.

Photo.9. Site for ground photography project, showing a grass field of alluvial soils with a mound of Hincaster soils.

Photo.10. An example of black and white infra-red photography taken for the ground photography project.

Fig.6. SEDGWICK PHOTOGRAPHY 7th – 21st OCT.

Date: 20th October 1974

Weather: Cloudy, bright periods

Weather on Previous Day: Cloudy, heavy rain in evening.

Type of Photography: False colour.

SITE	TIME	WEATHER/LIGHT CONDITIONS	EXPOSURE
hp	10.40	bright, 40% cloud.	1/500 at f2
BA/Ph	11.40	" 20% " (taken into sun)	" f16
Ya_1	12.15	" " "	" f5.6
Sn_1 (b)	12.35	" 50% "	" "
~ (b)	12.50	becoming cloudier, 60% "	" f4
Ph/Hi	13.05	rain shower, 80% "	" f8
Aq	13.23	" " 90% "	" f5.6
Ca_1 (a)	13.45	" " + sunshine 80% cloud	" "
Sn_1 (a)	14.10	60% "	" f8
Dg (b)	14.30	rain shower, 70% "	" "
bare soil (now grass)	14.45	" " 80% "	" f4
~ (a)	15.25	60% "	" f16
Dg (a)	15.45	70% "	" f8
mJ/iN	16.25	50% "	" f4
Nq	17.05	60% "	" f2.8

vertical aerial photographs e.g. bare soil is dark blue on the ground photography but a pale blue-green on the aerial photographs. This is probably because the ploughed surface produces a different angle of reflection, and also because of the effects of the atmosphere. On the whole, the reproduction of colour was good, especially where vegetation was photographed rather than bare soil or rock. The amount of vegetation cover, its height, vigour, stage of growth, etc. are all shown on these photographs; these are features which are difficult to see on an aerial photograph because of its smaller scale. Differences in crop growth were seen on the ground photographs that were missed on the aerial photographs, e.g. the bare field site was planted with barley and the crop was just beginning to show in April. By May, there was a lush growth of the crop with no bare ground visible in between the plants, and by July the crop was ripening, shown by a paler pink colour. The barley was cut in between the July photograph and the August photograph, as on the August one the field is now a lush crop of vetch. By September the vetch had disappeared, either cut or grazed, and the field consists of grass. On the A.P.I. map this area was marked as a barley crop but it was, in fact, barley undersown with vetch and grass. As the ground photography is much less expensive than the aerial photography, it is a useful exercise to carry out monthly ground photography to determine the optimum time for aerial photography.

References:

COLEMAN, A. & MAGGS, K.R.A. 1965. Land use survey handbook. 4th edition.

Chapter 9: SURVEYS OF THE INGLEBOROUGH AREA

9.1 Introduction

As the Ingleborough area is almost entirely in rough grazing, a vegetation rather than a land use survey was attempted, and this survey related to the soil survey.

9.2 Vegetation survey method

Inspection of both sets of photography revealed that the winter (November) photographs were clearer and showed more vegetation boundaries than the May photographs (photos. 1 and 2), even though some areas were obscured by shadow, so the November photographs were used to make the basic vegetation map.

The photographs were carefully scanned under the stereoscope and boundaries were drawn around areas of the same colour, which were described by their colour and texture. Traverses for field work were then chosen and marked on the Ordnance Survey base map, and vegetation boundaries were marked with chinagraph pencil on the panchromatic photographs. The field work consisted of following the traverse lines and sampling the different vegetation associations for valence analysis. Areas of uncertain vegetation were also checked. The boundaries on the photographs were then altered if necessary, the boundaries plotted on to the Ordnance Survey map and the areas designated. Three main vegetation associations were distinguished: blanket bog, limestone grassland and drift grassland, and seven subordinate categories: woodland, Festuca-Agrostis grassland, Sphagnum bog, bracken, scree, limestone outcrop and sandstone outcrop.

1. Blanket bog: this consists mainly of Eriophorum vaginatum (cotton-grass) and its associates. This plant is usually a dull dark green, often with a silvery grey tinge where there is dead material, and in

Photo.1. False colour aerial photograph of Ingleborough, November 1973, (reduced from 9" x 9").

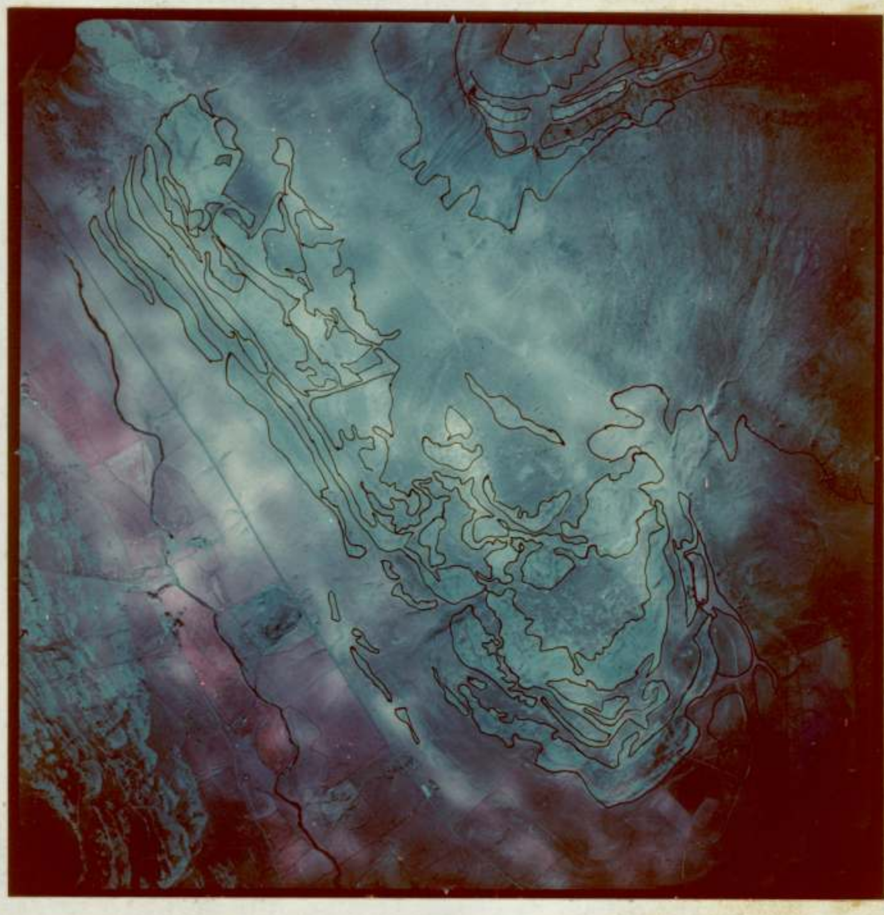

Photo.2. False colour aerial photograph of Ingleborough, May 1974 (reduced from 9" x 9"), with vegetation boundaries marked on.

autumn it turns a brownish-green colour, which shows as dark green on the false colour photographs. This contrasts with the surrounding pale areas and the association is extremely easy to distinguish. It has a rough texture as E.vaginatum has a tussocky habit (up to 0.5m high), which protects the growing points of the plant from overgrazing, and these areas occur on drift overlying the limestone, so the bog is raised slightly, adding to the rough texture (photo.3). Blanket bog occurs all over the lower slopes of Ingleborough summit and over much of the plateau of the Great Scar Limestone. The lower boundary is very distinct as it ends in a line of pot-holes (subsidence cones) where the limestone is near the surface and the drift thins out. The line of pot-holes will sometimes be 5-8m in from the actual vegetation boundary as there seems to be a critical depth of drift for the formation of pot-holes, which are formed by solution of limestone by acidic waters under the drift cover, which then collapses into the holes. The size of the pot-hole is dependent on the depth of the overburden and they are very frequent where the thickness is 2-3m but are rare where the drift cover is over 10m in thickness (Sweeting, 1974). Although these pot-holes are a feature of drift deposits, they are also concentrated along the buried shale-limestone boundary, which corresponds approximately to the lower boundary of the major part of the blanket bog. The boundary between the blanket bog and surrounding grassland is often obvious, with a ditch between the two areas (fig.1).

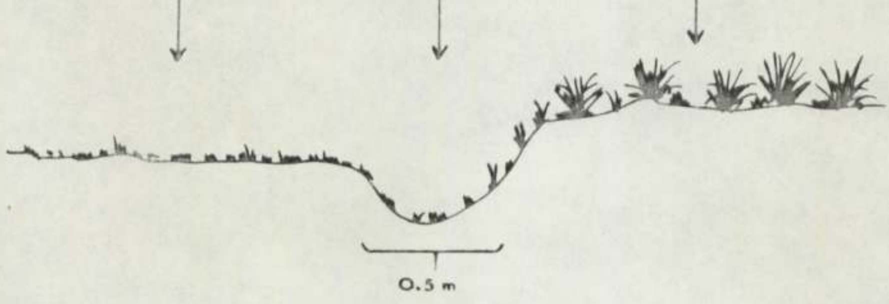

Fig.1. Boundary between the blanket bog and the drift grassland.

Photo. 3. Blanket bog on Ingleborough, showing the tussocky habit of *Eriophorum vaginatum*.

The upper boundary of the blanket bog is less distinct, merging, where the slopes get steeper, into Nardus stricta - Juncus squarrosus associations. Valence analysis (fig.2) shows that Eriophorum vaginatum is the dominant species with Juncus squarrosus as the subdominant. The relatively dry tussocks of E.vaginatum provide a rooting medium for heath species and in this case Vaccinium myrtillus and Deschampsia flexuosa are frequently found growing on the tussocks. Vaccinium occurs only as small plants without woody stems. J.Squarrosus, Polytrichum commune, Carex species, Sphagnum species and Eriophorum angustifolium are found in the wetter areas between tussocks. Very wet areas occur within the blanket bog community, which consist mainly of Sphagnum species, and have pools of stagnant water. One area of blanket bog, north of Rayside Plantation (751715), has a rather different type of bog vegetation, more like that of a raised bog, containing Calluna vulgaris, Erica tetralix and Tricophorum caespitosum, but this cannot be picked out on the photographs. This is an area which is subject to less intensive grazing than the rest of Ingleborough, which probably accounts for the difference in vegetation. Also, there is an area at the eastern end of Grey Scars (735720) where there are the remains of a Vaccinium heath. Cushions of Vaccinium occur on both the blanket bog areas and the surrounding drift grassland, and are seen on the photographs as a small, green-black, reticulate pattern but this pattern is dispersed and cannot be separated from the other areas.

Only the flattest parts of the blanket bog have a uniform cover of E.vaginatum, the steeper areas have drier hummocks on which Nardus stricta and other species grow and the many streams tend to have borders of Juncus species (probably J. effusus), as do pot-holes. Thus, the blanket bog can have a rather mottled pattern. Parts of the area mapped as blanket bog around Clapham Bottoms (752719) were found to be stands of almost uniform J. squarrosus (fig.3). J.squarrosus has a very similar colour

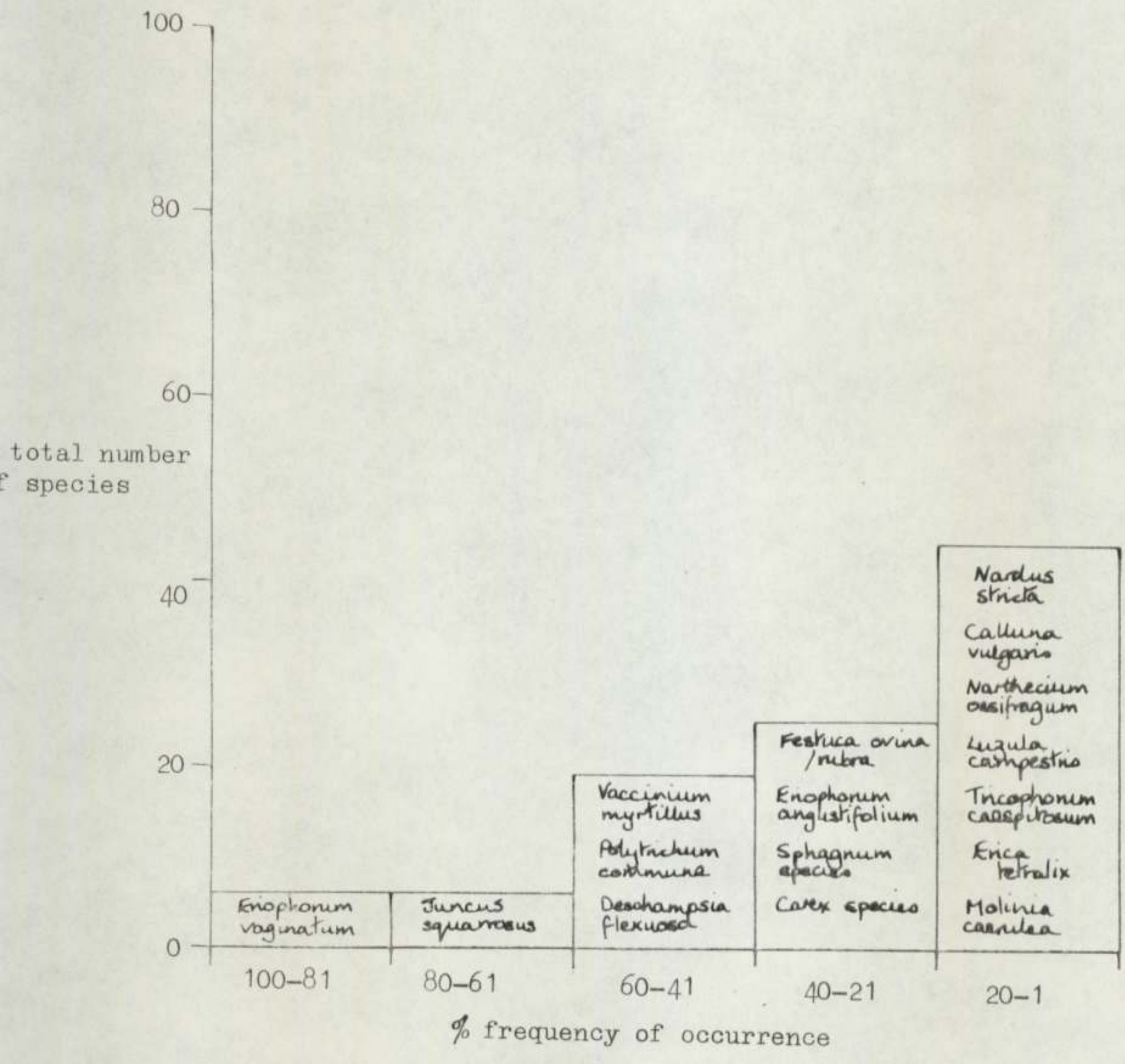

Fig.2. Valence analysis of the blanket bog on Ingleborough.

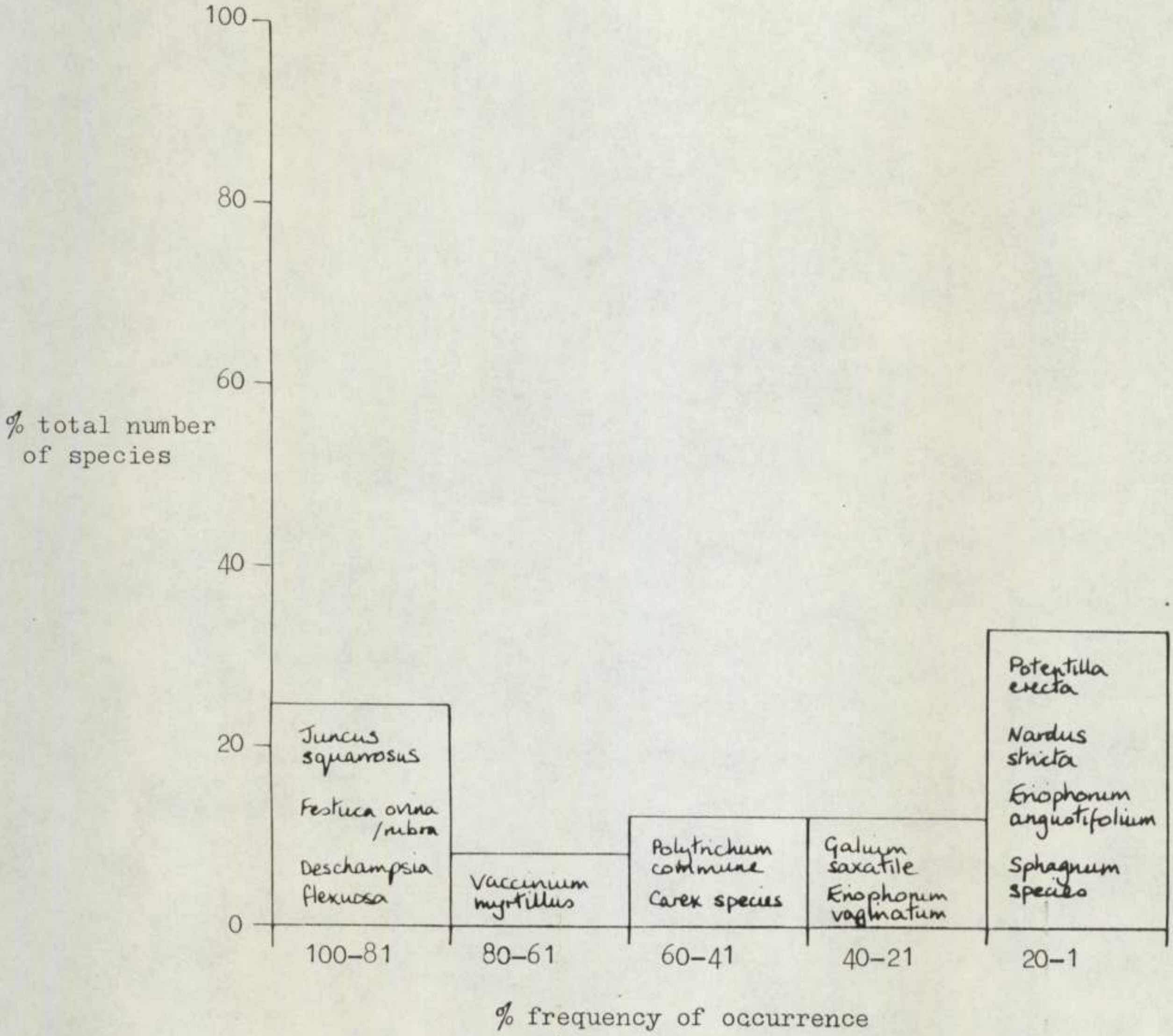

Fig.3. Valence analysis of the Juncus squarrosus heath on Ingleborough.

to E. vaginatum and could not be distinguished from it, even though in autumn J.squarrosus turns a chestnut brown colour. The texture of the J. squarrosus heath is different, as the plant does not have a tussocky habit but this was not easy to see as it still has a rough texture. These areas could be picked out topographically as they occur on higher ground (possibly poorly developed drumlins) within the blanket bog but the boundaries are not clear, so they have been included within the blanket bog category.

2. Limestone grassland: these areas produce a purple-magenta tone on the November photography and have a smooth texture. This is because the flora is rich in nutrients, as the base status of the soil is high, and thus is intensively grazed. The vegetation is always cropped short and so there is very little dead material present to alter the tone from that of green, healthy vegetation. In areas such as these, that are being intensively grazed, dwarf varieties of many species occur, so the vegetation will never grow tall in any case. Very often limestone is exposed, and sometimes the pattern of clints and grikes can be seen through the vegetation cover. The dominant species are Festuca ovina and F.rubra, Thymus drucei and Trifolium repens, with Sesleria caerulea as subdominant. Many other species are present also, including some extremely rare types, and thus this type of grassland is nutrient rich. Figure 4 shows a valence analysis of parts of the limestone grassland; 35 species were found in this exercise, though many more are present and are fully documented in the report by the Nature Conservancy (1965). There are some areas of slightly deeper calcareous soils and these have a similar flora, sometimes slightly taller than the rest of the limestone grassland. Molehills are often seen in these areas, indicating a fairly deep soil and good drainage. Limestone grassland occurs on the plateau of the Great Scar Limestone, wherever there is no drift cover (photos.4 and 5).

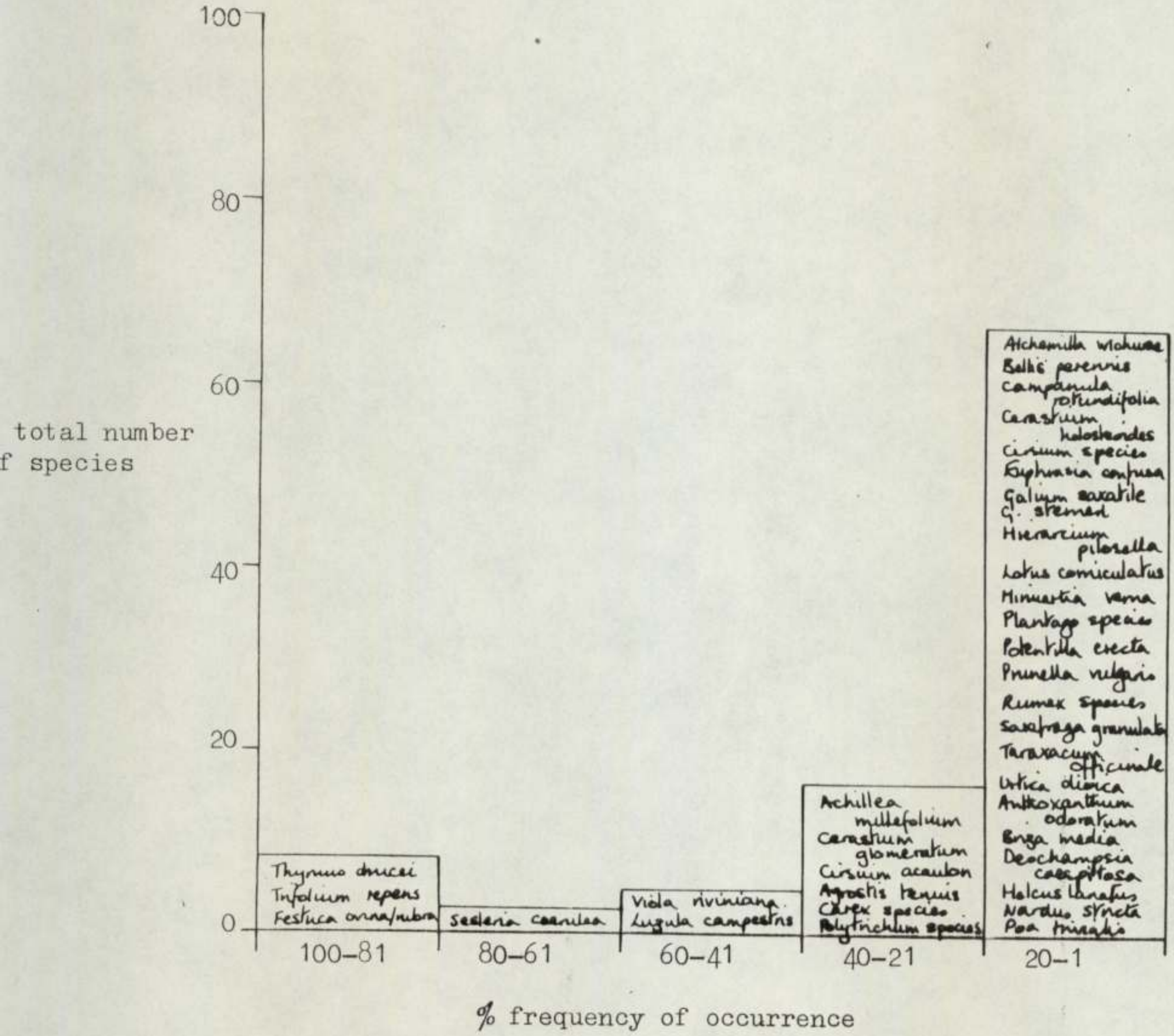

Fig.4. Valence analysis of limestone grassland on Ingleborough.

Photo.4. Areas of limestone grassland among limestone pavement on White Scars (720740).

Photo.5. An area of limestone grassland within the blanket bog on Ingleborough. The vegetation on the limestone is brown and scorched due to a long period of very dry weather.

3. Drift grassland: these areas produce shades of turquoise blue on the photographs, and have a fairly rough texture with tufts up to 25 cm in height, smaller than the tussocks of E.vaginatum. They consist of Nardus stricta which is a tufted perennial and this tussocky character is accentuated by the selective grazing of sheep, who normally avoid it. When it dies back after flowering, most of the leaves and the inflorescences turn a bleached white colour which produces the distinctive pale blue colour on false colour photographs, and there is a very large amount of dead material present. Nardus is associated with Festuca rubra, F.ovina and Juncus squarrosus. This association is a Nardus-Juncus squarrosus type rather than a pure Nardus association (fig.5). J.squarrosus can be dominant in places and produces a dark green colour on the photographs. Usually it is scattered throughout the Nardus and this produces a mottled pattern. There are large areas of more uniform J.squarrosus occurrence in the drift grassland which have been mapped separately wherever possible; they can easily be confused with blanket bog vegetation. Some small areas of Molinia caerulea occur, e.g. Clapdale Scars (747713), in better drained areas within the blanket bog, such as on the slopes of pot-holes. A larger area of Molinia occurs just above Trow Gill (753717) and which is associated with Deschampsia flexuosa and F. rubra. When it dies off in autumn, Molinia is a light orange colour which shows up as pale blue on the photographs and cannot be separated from the areas of Nardus.

Drift grassland occurs mainly on steeper slopes which are not enriched by flushing from the limestone areas, and in many places the vegetation can be almost pure Nardus, a species-poor association. J. squarrosus tends to occur on flush sites on hillsides while Sphagnum and other Juncus species occur in wet, flatter places where the water is stagnant or slow moving. Drift grassland occurs on the drift areas which have too great a slope for blanket bog to form (over 15^{o}). Many

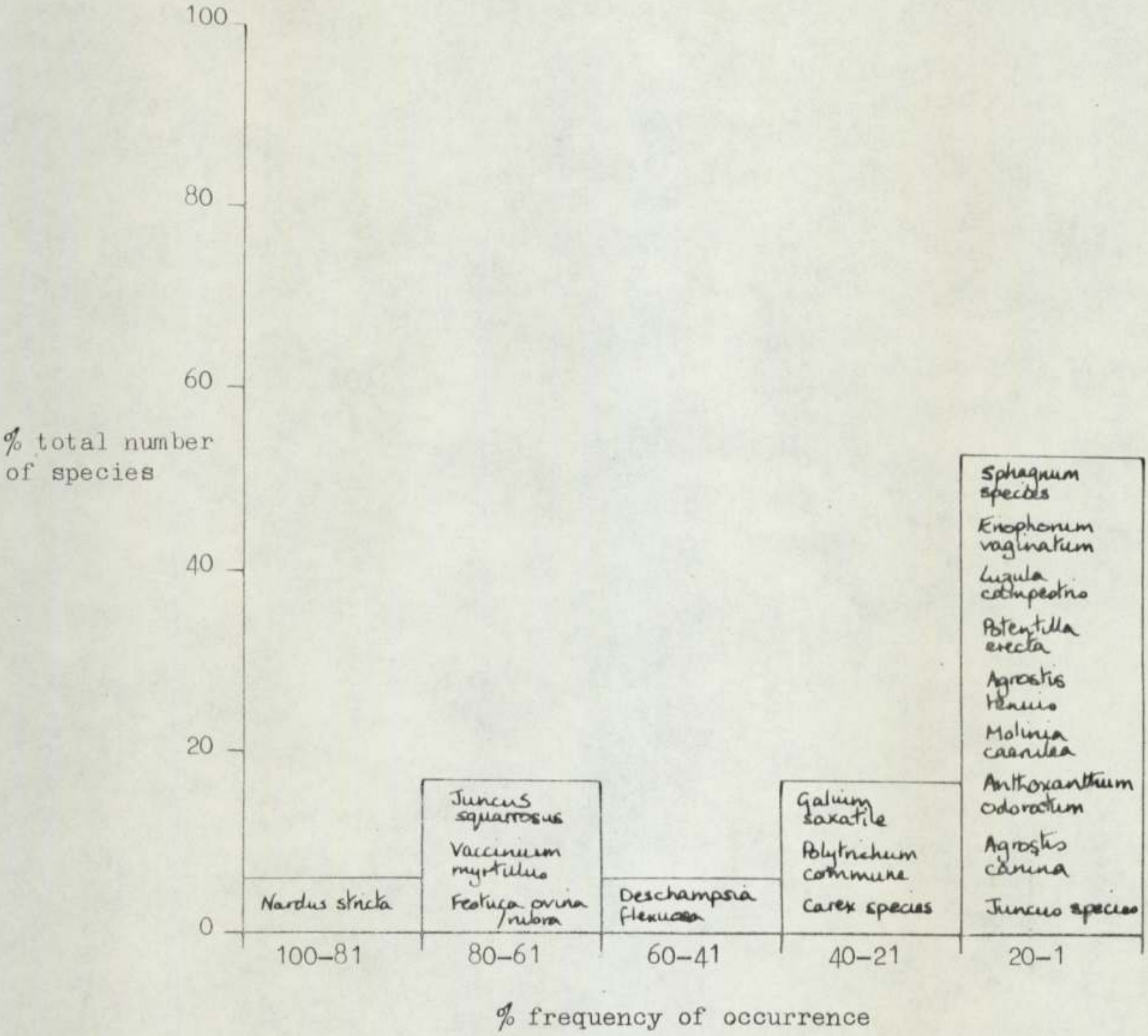

Fig.5. Valence analysis of drift grassland on Ingleborough.

areas are probably underlain by limestone, providing better underdrainage than shale. All the lower slopes of Ingleborough below the blanket bog are drift grassland, except where the limestone outcrops, and it also covers the steep slopes above the blanket bog where it is very patchy, producing a mottled pattern with darker patches of J. squarrosus. Most of the outcrop of Millstone Grit, including the summit of Ingleborough, is also covered with this type of vegetation. Small mounds of drift sometimes overlie the limestone pavement, eg. White Scars (720740) and Lead Mine Moss (725742), which often have almost pure Nardus cover.

4. Woodland: there is little woodland on Ingleborough Hill and the two major areas are the valley of Clapham Beck (756715) and Rayside Plantation (751714), just above the valley. The plantation consists of beech, ash and coniferous species, mainly larch, whereas in the valley there is typical limestone woodland, consisting mainly of ash trees with some hawthorn, oak and beech, associated with a species-rich ground flora. A few individual trees are found, often growing out of pot-holes or similar places inaccessible to sheep. These are usually ash, and a few stunted hawthorn trees are found on White Scars limestone pavement. The coniferous trees are a purple colour on the photography while the deciduous trees are magenta if they still have their leaves, or black if not. The species can be separated by crown size and shape.

5. Festuca-Agrostis grassland: this is an area by Crina Bottom (722735) which consists of alluvium washed down from the slopes of Ingleborough and deposited in a small valley. There is now a stream for only part of the course. The area stands out from the surrounding drift grassland as it is a magenta colour. The vegetation was obviously palatable

to sheep as they have grazed the turf closely, producing a smooth texture. Investigations (fig.6) showed that this was an area of Festuca-Agrostis grassland, not as species-rich as the Limestone grassland but preferable to the drift grassland for grazing sheep. A few other areas were found to be of the same type of vegetation and most of the enclosed fields on the lowest slopes of Ingleborough are Festuca-Agrostis type. This grassland resembles limestone grassland in colour and texture, although there are no exposures of limestone. They were therefore mapped together, except for the alluvial area which can be separated by its position and flatness.

6. Sphagnum bog: there are many very small areas of Sphagnum bog in amongst the larger area of blanket bog. They occur on the flattest areas where drainage is impeded and consist mainly of Sphagnum species often with Eriophorum angustifolium. The Sphagnum has a bright green colour and on the photographs it shows up as a very bright, almost fluorescent purple. There are two large areas of Sphagnum bog: one which drains into pot-holes known as Boggart's Roaring Holes (729729), where there are pools of water with E.angustifolium as well as much Sphagnum, and one area which drains into a pot-hole by Red Gait Head (730740). This area has a large amount of E. angustifolium (fig.7) which turns a bright red colour in autumn, as well as Sphagnum. This red colour shows up on the photographs as a bright green but it is not a strong contrast to the tone of the surrounding blanket bog on the photographs as the individual plants are too dispersed.

7. Bracken: one area on the photographs had been invaded by bracken (Pteridium aquilinium); this area is not strictly in the vegetation mapping area as it is an enclosed field (limestone pasture) but under the 2nd Land Use Survey classification (Coleman and Maggs, 1965) it

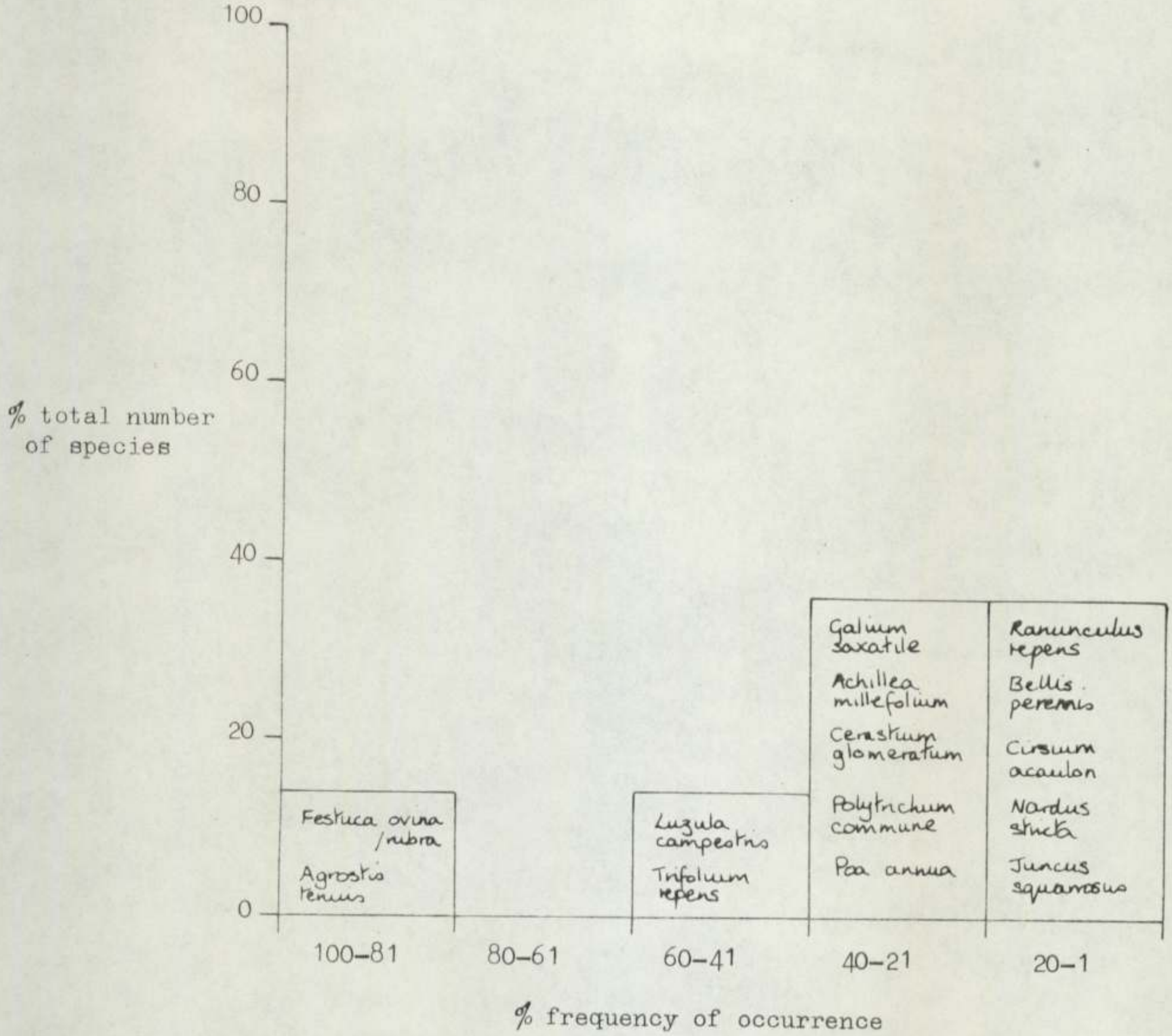

Fig.6. Valence analysis of Festuca-Agrostis grassland on Ingleborough.

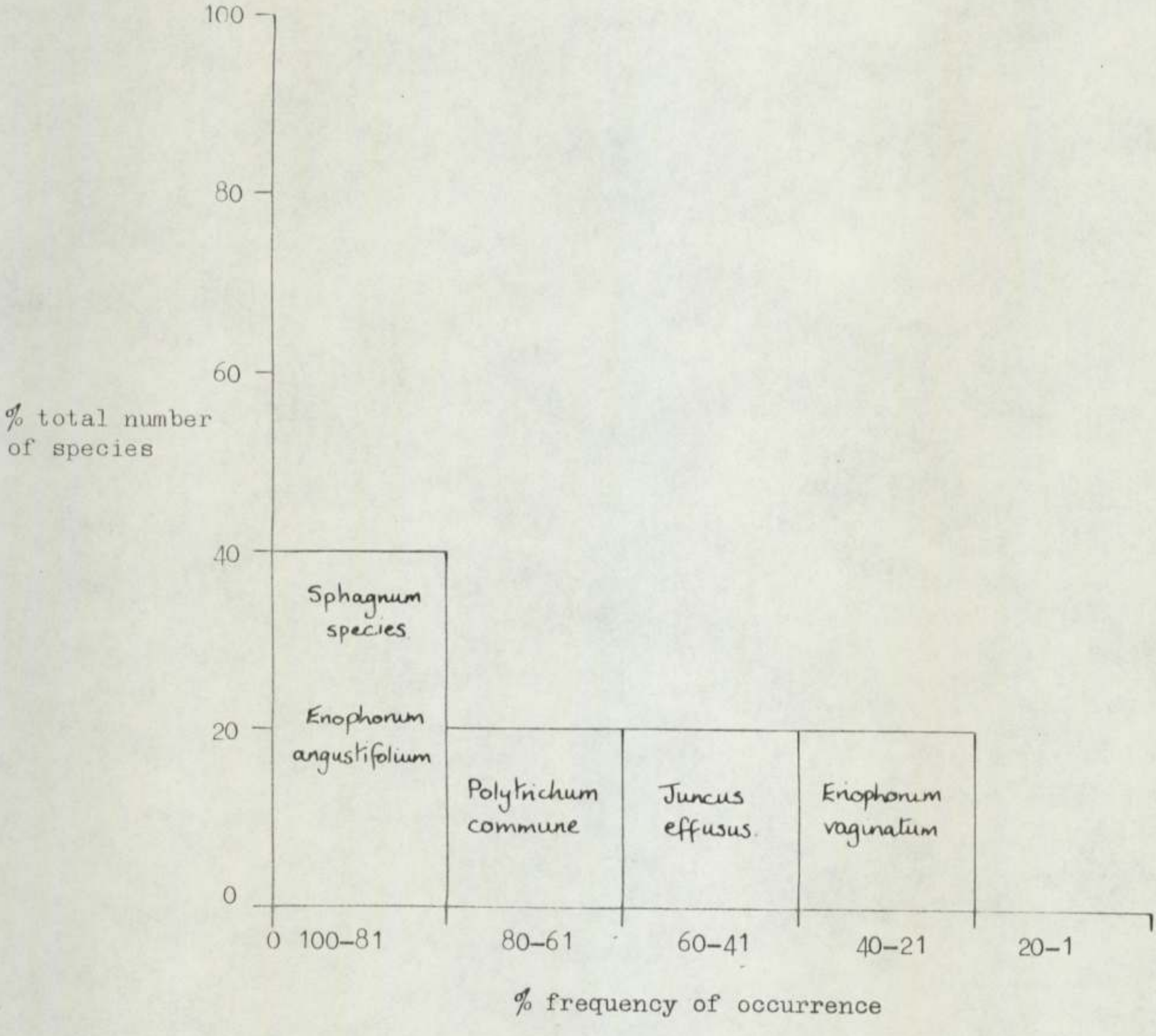

Fig.7. Valence analysis of a Sphagnum bog on Ingleborough.

would be included as semi-natural vegetation as bracken covers 50% of the field. There is only this one occurrence of bracken on Ingleborough. It has a characteristic green colour on the November photographs and a characteristic close texture. The pasture consists mainly of Holcus lanatus and Agrostis species with other grasses and herbs. Where the bracken had invaded, the number of species was reduced and Poa trivialis became dominant under the bracken cover with Rumex acetosa (figs. 8 and 9).

8. Scree: limestone scree stands out well as pale blue areas below outcrops of limestone. Sandstone scree is a bright blue colour and is easily recognised; it also has a different texture to limestone scree as it is more blocky. Both types of scree will support some vegetation growth but not enough to influence the tone on the photographs.

9. Limestone outcrop: this includes cliffs or scars of limestone and limestone pavement. Limestone pavement is a pale blue colour on the photographs, very similar to limestone scree, and the pattern of clints and grikes can be clearly seen. Limestone cliffs have a smoother texture than the pavement and are often a lighter colour, almost white, depending on the position of the sun when the photograph was taken. Limestone pavement supports a woodland type of vegetation in the grikes but only a few mosses and lichens on the clints, if there is any vegetation at all. The vegetation in the grikes cannot be seen on the photographs but it probably contributes towards the texture of the pavements by adding to the contrasting tone of the grikes.

10. Sandstone outcrop: there is very little sandstone outcrop on Ingleborough, only the cliffs of Millstone Grit on the summit. These have very little vegetation and can be identified by their darkish blue

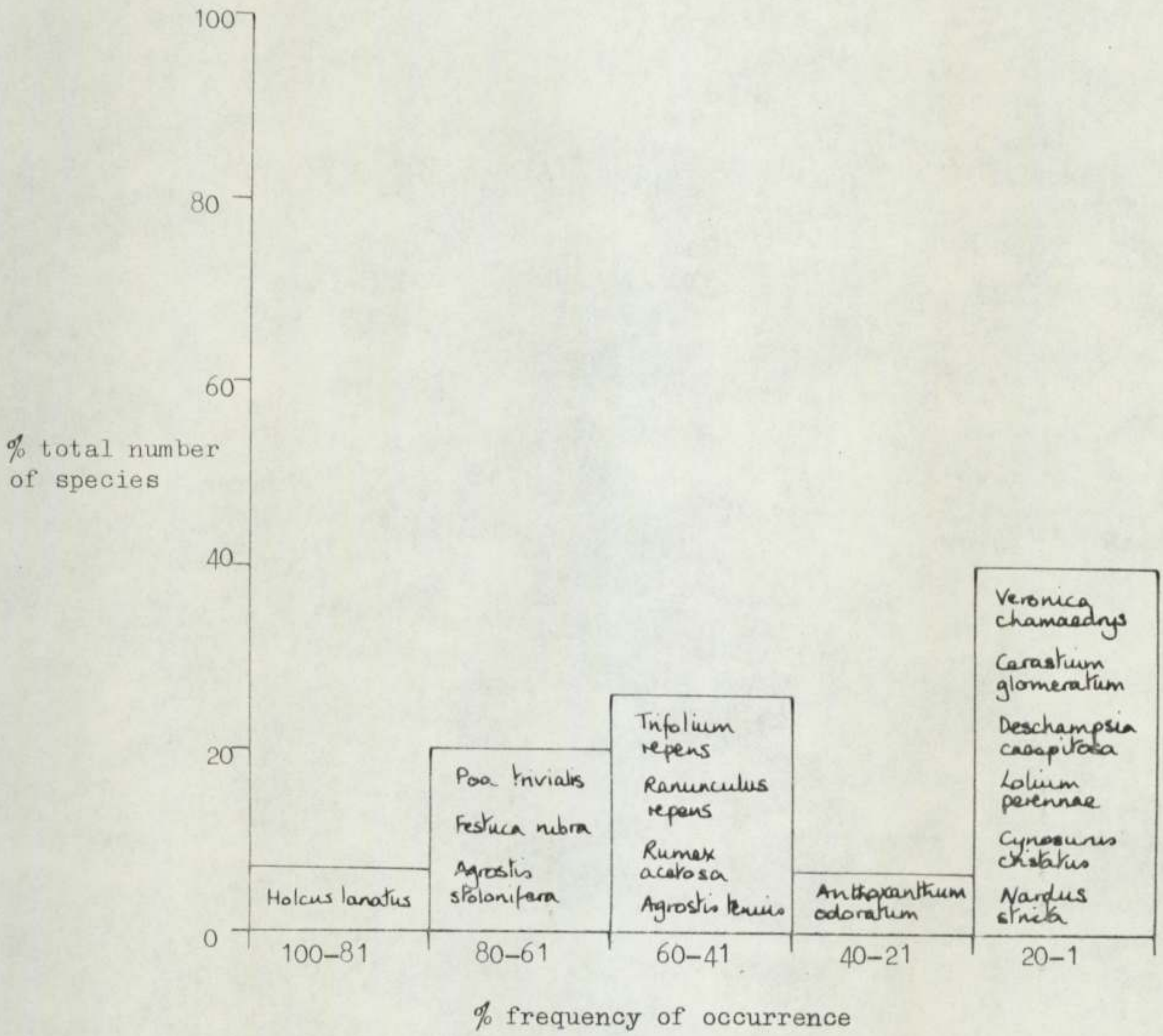

Fig.8. Valence analysis of limestone pasture on Ingleborough.

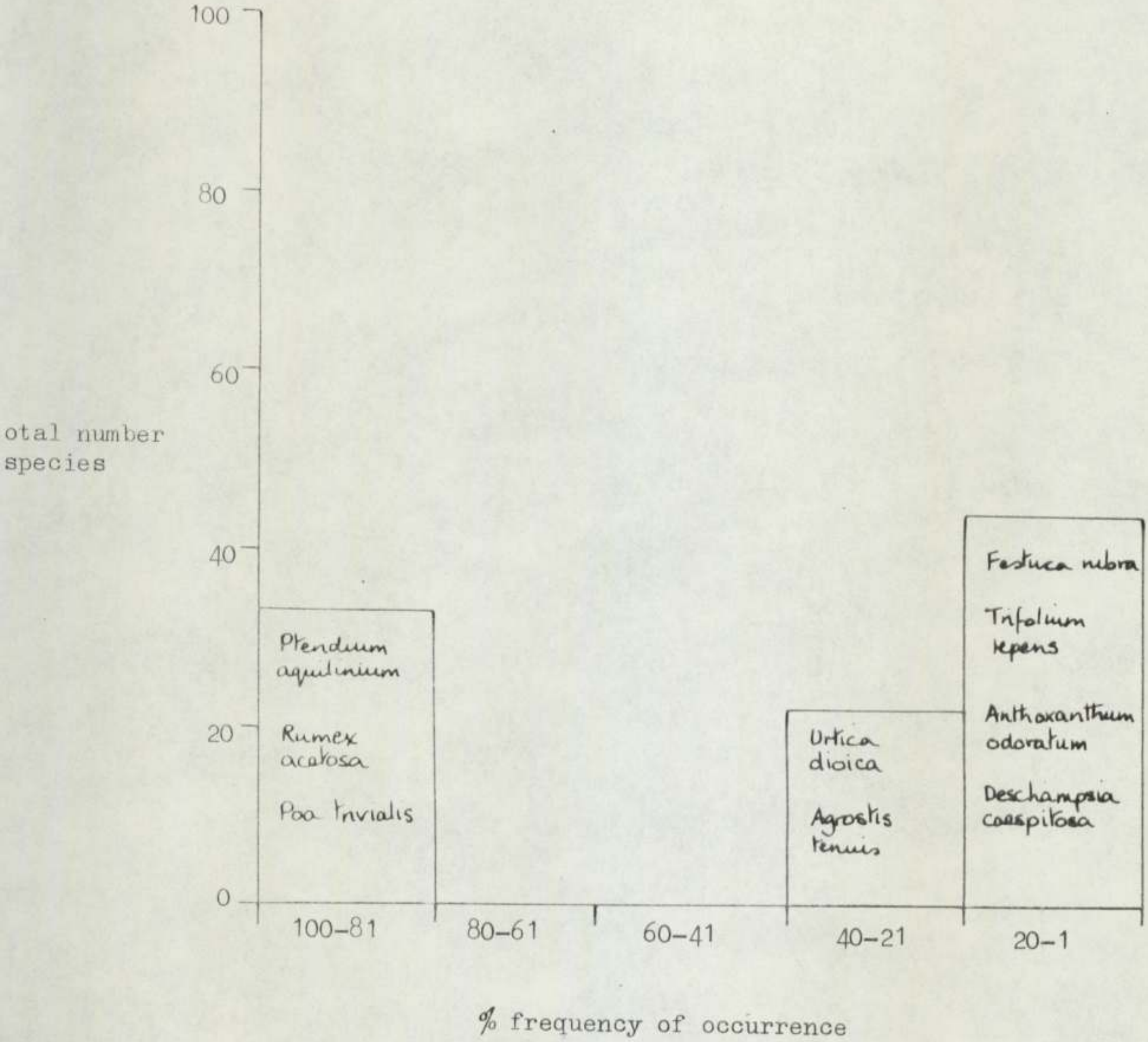

Fig.9. Valence analysis of limestone pasture invaded by bracken, on Ingleborough.

colour and the presence of scree below. A freshly exposed face of sandstone has a pale blue colour.

9.3 Comparison of the two seasons of photography

The winter photography showed more and clearer vegetation boundaries due to the distinctive colouring of semi-natural vegetation as it dies back in the autumn. In comparison, the May false colour photography was difficult to use as these colours are not seen and all vegetation tends to be a similar green colour (photos.6 and 7). It was difficult to find the lower boundary of the blanket bog, which is clear on the winter photographs. The boundary can be seen if looked for carefully as the pot-holes are there and there is a very slight colour difference but it is difficult to pick out straight away. The drift grassland can be easily confused with the blanket bog unless there are very boggy areas with pools of water or deep peat that is suffering from erosion and therefore exposing areas of bare peat (photo.8). *Sphagnum* bog areas, e.g. Boggart's Roaring Holes, can be seen as they are paler but they are not obvious. Limestone grassland and limestone pavement are obvious because of their colour and texture. Sandstone scree and outcrop stand out well on both sets of photographs as do wooded areas. It is occasionally difficult to distinguish between the limestone grassland and the drift grassland, unless much *J. squarrosus* is present which produces a darker colour. There is also the problem of certain species having not yet appeared in May e.g. bracken and *Molinia caerulea*. *Molinia* does not appear until later in the year, it flowers in August and then turns a pale orange colour. No *Molinia* was found by Trow Gill in July because it was only a few inches high and did not appear above the rest of the vegetation, but a month later it was very obvious, forming an almost uniform stand and masking most of the other species present.

Photo.6. Crina Bottom (722735) area in early July: very few colour differences can be seen in the vegetation.

Photo.7. Crina Bottom (722735) area in September: the vegetation shows clear differences in colour.

Photo.8. Peat erosion on Simon Fell (757748): these areas of bare peat show up well on aerial photographs and the vegetation type (blanket bog) can easily be distinguished.

The colours on the May photographs are generally not clear. Cultivated grassland shows as shades of bright magenta, limestone grassland is slightly paler shades of magenta, with a smooth texture, and drift grassland is mottled grey-blue and magenta. Blanket bog is also a grey-blue but slightly lighter, with patches of pale magenta. However, the summer photography has some advantages over the winter set, because the angle of the sun is higher and there is therefore no shadow. The November photographs have very deep shadow in some places, which totally obscures the vegetation, but the low angle of the sun picks out relief well, and because of this and the better differentiation of colours of the vegetation, the basic vegetation map (Map 5) was made from the November photographs and the supporting map (Map 6) from the May photographs which showed less boundaries.

9.4 Assessment of the panchromatic photography

The panchromatic photographs were unsatisfactory as their scale is larger and it was more difficult to see the overall patterns. They were taken in June, which is a poor time of the year for vegetation mapping, and they were lacking in contrast. Limestone outcrop and scree stand out well as white tones and the limestone grassland can be seen but not consistently recognised, as paler, smoother patches than the other vegetation types. *Sphagnum* bog areas look similar to limestone grassland but are whiter and not so smooth, and pools of water can be seen. No difference between the blanket bog and drift grassland can be detected; they are both mottled, medium grey tones, except where there is peat erosion, and also the drainage pattern suggests the type of vegetation. Dark patches on the drift grassland are *J. squarrosus* but there are also dark patches on the blanket bog. The sandstone scree shows up as darker patches and could easily be mistaken for a different type of vegetation. This type of photography could have been used to make the survey but it would have been more difficult, especially because of the poor contrast, large scale and wrong season.

9.5 Relationship of the vegetation types to soil types

Indications of soil conditions such as depth, drainage and pH can be gained by studying the vegetation types present (see p.138) and the vegetation associations of Ingleborough were investigated to discover how good this correlation between soil and vegetation types was.

The blanket bog association consists mainly of *Eriophorum vaginatum* which occurs in areas of permanently high water table. It is usually on deep peat (0.6-9m) and in very acid conditions (pH 3.2-4.0) with a very low base status. *E. vaginatum* will grow over a wide range of moisture conditions but is a dominant component of peat communities that have a surface water table in spring but become drier in summer, and it is usually in areas of stagnant rather than moving water which may flood the hollows between the tussocks in winter (Wein, 1973). Depending on the amount of peat present the soil may be classified as an organic soil or a peaty gleyed soil. The parent material is often impermeable but formation of blanket bog requires the slope of the land to be less than 15°.

The drift grassland, with *Nardus stricta* and *Juncus squarrosus*, often occurs on gentle, moderately drained slopes below peat moors. *Nardus* is found on a variety of parent materials, on brown earths, podzols, gleys, peaty podzols and peat, usually where the substrate is calcium-deficient, so the base status is low with a pH generally about 3.5 (Chadwick, 1960). It does not occur on wet peat and is not present in areas of low rainfall (< 20"p.a.). *J. squarrosus* is associated with both blanket bog and drift grassland, and occurs in moist or wet places on a variety of acidic soils or peats, often on podzols with acid humus or on peaty gleys. It is confined to acid soils or peat as it is slow-growing and cannot withstand competition from the faster growing species on base rich soils. It can withstand complete waterlogging but not submergence and it is much dwarfed or absent on dry soils. The Nardus-J. squarrosus association is usually found on gley soils whereas J. squarrosus-Sphagnum association forms in wetter flush areas on slopes (Welch, 1966). It can form a continuous mat about one foot high over large areas.

Limestone grassland occurs on thin, calcareous soils directly over limestone which are dry, well drained and with a moderately high base status (pH 6-7). Festuca-Agrostis grassland is found in similar areas, well drained open sites, usually on deeper soils with no peaty mat and a pH which may be acid or alkaline. The soils are not necessarily calcareous but will have a higher base status than those of the drift grassland. These soils are often invaded by bracken and gorse (Stapledon and Davies, 1936); the bracken indicates that the soil is deep enough for sound tree growth.

Sphagnum species tend to occur in very wet, waterlogged places, as does E. angustifolium which prefers wetter conditions than E.vaginatum and is often found growing in pools of peaty water.

These relationships between soil conditions and vegetation types were tested in the field. The soils at several sites within each vegetation association were inspected. The blanket bog was found to have varying depths of peat, depending usually on the degree of slope, with the flatter areas having a greater depth of peat. Most of the soils consisted of about 30-60cm of predominantly semi-fibrous peat. The parent material was usually a grey clay, derived from the Yoredale Series. This soils is a shallow phase of a raw peat soil which grades into a cambic stagnohumic gley. Sphagnum bog has a deep, very fibrous raw peat soil.

The drift grassland covered a wide variety of soils, which were all better drained and with a thinner peaty surface horizon than the soils under the blanket bog. Both the Belmont Series and the Wilcocks Association had a cover of Nardus stricta and Juncus squarrosus. These are ironpan stagnopodzols and cambic stagnohumic gleys, and other soils occur also e.g. podzols without any ironpan or iron concentrations. The parent material is mixed drift from the Yoredales and the composition of this drift will influence the soil as some drift will be sandier than the rest. These differences cannot be picked out by vegetation type as there is only a difference in the degree of change, not the type of change.

Limestone grassland occurs on humic rankers and humic rendzinas, and on shallow mesotropic brown earths, which are moderately acid. Both types of soils are acid to certain degrees because of leaching and there are great variations in depth, with occasional ironpan formation. However, these soils have a higher base status than the other types, so the vegetation is more heavily grazed and thus kept green and very short throughout the winter. These areas are easy to pick out and correspond well with the soil type. In some places, however, overgrazing has led to degradation of the pasture and Nardus has become established on the more acid limestone soils, thus leading to increased acidification of the soils. The brown calcareous soils may have a cover of Nardus rather than of the palatable limestone species. Festuca-Agrostis grassland occurs on brown earths and on the Belmont Association which consists of stagnopodzols, although the drainage of most areas is probably good. In many cases the vegetation of these areas is prevented from reverting to Nardus type by relatively heavy grazing and manuring by the grazing sheep, e.g. an area of Festuca-Agrostis grassland is present by a wall near

Crina Bottom (719733); the wall gives shelter to the sheep which concentrate in this area and graze nearby, heavily manuring the ground at the same time. This grassland passes into an area of almost pure Nardus which has an ironpan stagnopodzol soil in similar material and it is probably only the heavier grazing which keeps the Festuca-Agrostis grassland and its associated brown earth as it is.

Scree soils are complex, with various kinds of podzolic and shallow soils. Limestone scree usually has humic rankers. These scree soils are included in the Belmont Association which often has a vegetation cover of the Nardus type.

This work showed that vegetation does not reflect soil type directly although it is a useful guide to some of the soil conditions. Soil boundaries cannot be mapped as vegetation boundaries as many factors other than soil type affect vegetation distribution., e.g. grazing pressure. The rock exposures, including screes and their associated vegetation, were easy to pick out and produced more complex boundaries when plotted than those on the soil survey map. Limestone grassland and limestone soils could be plotted fairly accurately but there were many small areas present which were too small to be plotted on the soil survey map. This method of mapping produced much more complex boundaries than those on the soil survey map which are very generalised, and so in certain cases the boundaries are more accurate, but some major boundaries were not seen at all, e.g. between the Wilcocks and the Belmont Series, and differences in soils under the blanket bog peat could not be distinguished e.g. between units 15 and 12. There is a general correlation between soil type and vegetation type but it is not good enough when surveying on this scale (1:10,560) and at this detail.

9.6 Comparison of the two vegetation survey methods and results

The method used by the 2nd Land Use Survey (Coleman and Sinclair, in preparation) has already been described (p.137) and it was estimated by the surveyor that the field work necessary to map Ingleborough took 3-4 days, assuming it was done as part of a larger work pattern (G. Sinclair, personal communication). The time taken for A.P.I. of the false colour photographs was 1 hour 45 minutes, which included drawing the boundaries on the photographs, and the field work took 4 days, with another day devoted to soil examination. However, the field work was intensive as Ingleborough was the only area being mapped, and if the author had been more experienced in vegetation mapping and the survey had been part of a larger exercise, the amount of field work would have been cut by probably 50%. The A.P.I. method is quicker than the ground survey method but it is not as detailed.

Comparison of the two vegetation maps made by the different methods showed that the boundaries on the A.P.I. map are more complex and less generalised than those of the ground survey map and are therefore more accurate. However, the ground survey has mapped more detail, for instance, areas of blanket bog have been split up into types where J. squarrosus is dominant and E.vaginatum subdominant, where E. vaginatum is dominant with J. squarrosus subdominant and where E. vaginatum has J. squarrosus, N. stricta and Calluna/Erica as subdominants (see Map 4). The drift grassland has been divided depending on whether Festuca or Nardus is dominant. However, less detail appears on the areas of limestone pavement with drift, and many rock exposures have not been mapped. Certain areas have been separated that are visible on the photographs but that were thought to be part of the surrounding vegetation association, e.g. on the blanket bog where Juncus species are locally dominant; these areas were generally too small to have been separated in any case.

One large area of _J. squarrosus_ heath, within the blanket bog, has been mapped by the ground survey method but these areas cannot be separated by colour on the photographs although it is possible to separate them by relief. However, not all small hills and rises within the blanket bog have the same association so the vegetation cannot invariably be mapped by relief. It is interesting to note that there is another, fairly large area of _J. squarrosus_ heath not far from the one that was mapped but this has not been mapped by the ground survey. As the ground survey mapped by visual dominance and could not cover all the area on foot, this vegetation association was not mapped, as it cannot be picked out by colour on the ground, so visual dominance methods suffer from similar disadvantages to photographic methods.

The 2nd Land Use Survey mention that they did not use aerial photographs for mapping because certain categories could not be distinguished, i.e. most mixed grass communities and well grazed areas. This is true, as it was found impossible in most cases to distinguish _Festuca-Agrostis_ grassland from limestone grassland on the photographs but the Land Use Survey map does not distinguish these categories either, except in some areas where it is marked as _Festuca-Agrostis_ grassland on limestone, with no unvegetated surfaces, and _Festuca-Agrostis_ with limestone exposures. This may be only a difference in opinion as what to call these grasslands but the Nature Conservancy (op. cit.) do distinguish between limestone grassland over shallow rendzina soils, dominated by _Festuca_ and _Sesleria caerulea_, and _Festuca-Agrostis_ grassland which occurs on rather deeper, leached soils which are often on glacial drift in areas of lime-rich soil water. The _Festuca-Agrostis_, no unvegetated surfaces, category includes both the limestone pavement areas and the enclosed fields on the slopes below Raven Scar, whereas it was possible to separate these on the A.P.I. map and this would have been done if the enclosed fields had been included in the survey.

As the 2nd Land Use Survey map was made seven years before the false colour photographs were taken, the vegetation boundaries and associations have probably changed, which accounts for some of the differences between the two maps. The Calluna/Erica category has been mapped as sub-dominant in several places, e.g. within the blanket bog association, east of Lead Mine Moss, but Calluna was found only once or twice in the recent survey (see fig.2). Sheep prefer Calluna to many other species which probably accounts for its disappearance as a subdominant. In fact, Calluna was very much more common on Ingleborough 20 years ago and has declined dramatically through overgrazing by sheep, being replaced by Nardus and J. squarrosus (Nature Conservancy, op. cit.). The 2nd. Land Use Survey map was also compared with the soil map but less correlation was found with soil type than on the A.P.I. map. This vegetation map shows more detail and this is not related to soil type but more to biotic factors, i.e. grazing pressure.

9.7 The use of vegetation maps in the Ingleborough area

Apart from being useful in depicting the vegetation types of a moorland area, these maps can be of use in agricultural planning and development as the quality of the pastures and the possibilities for their improvement are indicated.

Stapledon (1937) lists several species in order of their grazing value:

high ↑

grazing value

Agrostis species

*Festuca ovina**

Eriophorum vaginatum

Molinia caerulea

Juncus squarrosus

Tricophorum caespitosum

Nardus stricta

low

Festuca-Agrostis pastures are of high grazing value and act as a link between vegetation of the uplands and that of the lowlands. They are capable of great improvement but are subject to invasion by *Nardus*. Increasing the fertility will produce heavier grazing because of the better grasses, which leads to more fertilization and a better grass growth. This holds true for all types of vegetation. Limestone pasture, especially where there is a large amount of *Sesleria caerulea*, is very valuable, especially at high altitudes. *E. vaginatum* is normally rich in mineral nutrients (usually phosphates and nitrogen) which concentrate under ombrogenous conditions, and which are present in the basal sheaths. It is grazed by sheep throughout the winter to March, and provides a valuable early spring bite. Sheep also eat the flower buds and in some areas e.g. northern Pennines, *E. vaginatum* has two peaks of flower production, May, and September to October. However, it is often associated with less valuable plants such as *J. squarrosus* and *T. caespitosum*. *Molinia* provides fodder for sheep in late summer when it starts growing but it grows so rapidly that sheep cannot keep

*Both *F. rubra* and *F.ovina* were found on Ingleborough but always together, so they were mapped as *Festuca*. *F. rubra* has a higher grazing value than *F. ovina*, and on the whole, there was more *F. rubra* on Ingleborough, so the pastures were not always as poor as they might seem.

pace with it so about 90% of the growth is wasted on sheep grazing land. Also, it loses its leaves completely in the autumn so has no grazing value for the winter and spring, although it can be cut for 'bog' hay (Stapledon, op. cit.).

J. squarrosus is intolerant of shade both in the seedling stage and when mature, and is therefore favoured by grazing. It is not a good food, however, being tough and fibrous but it is eaten in winter and early spring when other food is scarce. The developing inflorescence is also eaten by sheep. Its presence is due entirely to biotic factors and it often invades blanket bog when Calluna is removed. It has low competitive ability because of its slow growth and light requirement but it is little affected by grazing, burning or treading. Its growth starts in March and is rapid in April and May.

Biotic factors, usually sheep grazing, are also responsible for the presence of Nardus. The general degradation of calcareous soils to increasingly acid types, due to climate, is aggravated by overgrazing which leads to Nardus invasion of pastures. On soils with limestone at depths greater than 50cm, the plant association significantly influences the direction of soil development. These areas are normally dominated by Nardus which is unpalatable to sheep and therefore not grazed. It is also unpalatable to soil fauna so residues break down slowly and a mat of more or less decomposed Nardus sheaths quickly builds up. This thickens and causes waterlogging which produces a peaty layer with incipient gleying beneath - a brown earth with surface gleying. As the peaty humus becomes more pronounced, the area becomes wetter and moisture loving Carex species and J. squarrosus appear, and the soil develops towards a peaty gleyed podzol (Bullock, 1971). Nardus is not normally grazed but can provide some winter sustenance and the value of these areas is increased where J. squarrosus shares the dominance.

Calluna is an important food for sheep and for grouse, especially from February to April for sheep, but excessive grazing can eliminate it and cause *Nardus* to invade.

9.8 Transfer of data from the photographs to the map.

The first problem was to decide how general the boundaries for the vegetation map should be. A tracing of boundaries, of a small area on Raven Scar (727752), was done using the November photographs and the x3 binoculars on the stereoscope. All boundaries that could be seen and plotted easily were drawn. This produced a very complex map (fig.10) which is too complicated to be depicted accurately and it would have been too time-consuming to cover the whole of the area in such detail. Another tracing was done over the same area using the stereoscope without the binoculars and this produced a much clearer map (fig.11), although some areas were too small to be strictly included. The final map used slightly more generalised boundaries and the smallest area depicted was approximately 0.5 cm in diameter on the 1:10,560 map, 52.5m on the ground, which gives an area of approximately 0.25 sq.ha. There was also a tendency to generalise the boundaries when transferring them from the photographs to the map. Some boundaries were not clear on the photographs, for instance, where the blanket bog merges with drift grassland on the upper slopes of Ingleborough, and so the boundaries in these cases tended to be arbitrary. They were placed where there seemed to be 50% of one association and 50% of another. Boundaries of this type, where there is a transition area or ecotone, are common and so boundaries on many vegetation maps will be arbitrary to a certain extent.

The second problem was to transfer the boundaries from the photographs to the map, and as accuracy was important it was decided to do this photogrammetrically, using a Wild A7 stereoplotter. However, this proved

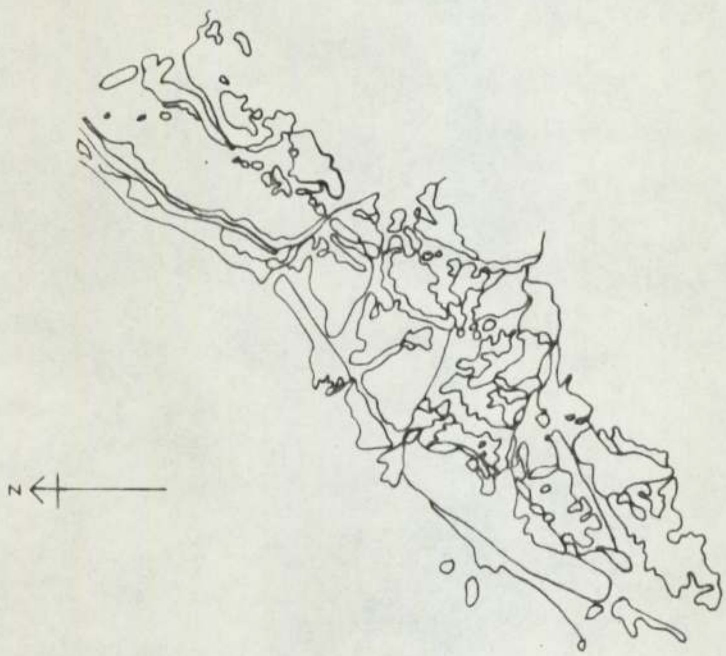

Fig.10. An A.P.I. map of vegetation boundaries on Raven Scar (727752), drawn using the x3 binoculars on the stereoscope. 1:15,000 approx.

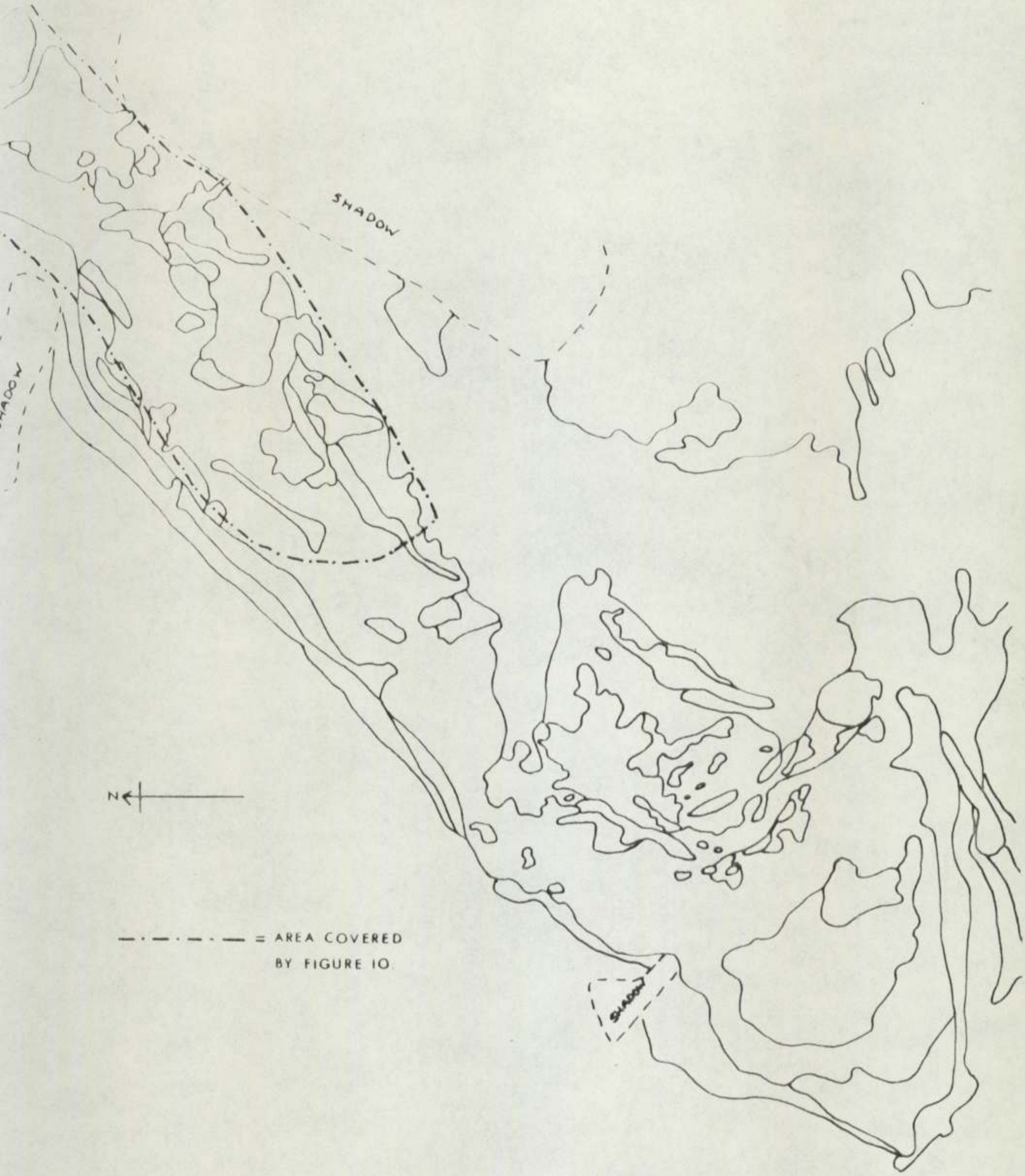

Fig.11. An A.P.I. map of vegetation boundaries on Raven Scar (727752) and White Scars (720740), drawn without using binoculars on the stereoscope. 1:15,000 approx.

impossible as the black floating marks were invisible against the very dark diapositives (November photography), so that even a relative orientation was impossible. Panchromatic contact prints (negative prints) were made from the false colour transparencies that had the boundaries drawn on (photo.9) so that they could be used in a radial-line plotter but lack of ground control on the Ordnance Survey base map meant that the radial-line plotter could not be oriented and fixed on the plotting map. These prints were then used with a sketch-master but this required a transparent plotting map if the map detail was to be seen as the prints were so dark and this was not available. The prints were next used in a Wild B8 stereoplotter but this failed also because the photography has too large an overlap, resulting in a very small base on any stereo model. Such a small base could only have been accommodated on the B8 if a reduction pantograph had been available. A Watts stereosketch was also used in an attempt to transfer the boundaries from the photographs to the map but this was impossible because there was too much relief distortion on the photographs and not enough control points on the base map. Plotting on to a 1:25,000 base map was also tried with the stereo-sketch but although the distortion was reduced because of the smaller scale, there was still too much to map accurate boundaries. A pair of adjustable dividers was used but they were only adjustable to an approximate difference and again there was too much relief distortion and not enough control points for the method to be satisfactory.

Eventually, a method for the approximate transfer of boundaries was devised. Transfer of boundaries by eye was too difficult because of the lack of control points on the base map, so 35mm slides were made from the false colour transparencies with boundaries on, and these were projected through a photographic enlarger on to the map, and the boundaries drawn on the map. Again some boundaries were not correct

Photo.9. Part of a negative contact print, made from a false colour photograph of Ingleborough, showing vegetation boundaries drawn in.

because of the relief distortion but the major boundaries could be drawn in and the others filled in by eye. In this way a map was made from the boundaries on the November photographs. The May photographs are much lighter in overall colour and it was possible to use them in the A7 stereoplotter. Some boundaries were difficult to plot because the edges of the photographs tend to be darker than the centres but a map was produced. The major boundaries from the May photographs are therefore very accurate, as they have been plotted photogrammetrically, so these boundaries could be used for the map made from the winter photographs, as long as the same boundary on both sets of photographs is in the same position.

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Chapter 10: OTHER EXPERIMENTS WITH THE PHOTOGRAPHY

10.1 Introduction

Two other experiments were tried with both the multispectral and the false colour photography. Analysis of multispectral and false colour photographs was attempted using a microdensitometer and an attempt to quantify the colours found on the false colour photography was made, so that the variation in colour within and between crops could be stated.

10.2 Densitometer work

The densitometer used was a Joyce Loebl automatic recording microdensitometer, model MK 111C. It scanned a single line across a photograph with an aperture of 200μ, covering 3m on the ground. The densities were recorded in a graphical manner. A neutral density wedge, which measures the relative density of the photographic tones, was used and various coloured filters could be used to filter out certain wavebands so that just a narrow part of the spectrum could be recorded. The scan was on a 1:1 ratio so features could be distinguished by measuring how far a peak or dip was from the frame edge on the graph and measuring the same distance on the photograph.

The multispectral photography was scanned, the same scan lines being used over all four frames to ensure the same area was scanned. It was found that there was the most variation in band III, little variation in bands I and II, and the most contrast in band IV with the trace maxima and minima being reversed (figs. 1 and 2). This is what would be expected, from visual examination of the photography (p.183) - bands I and II are of little use, band III shows the most variation in vegetation types, while band IV is useful for distinguishing other features such as bodies of water, but does not show so much variation in vegetation. Field boundaries i.e. hedges and walls, can be picked out easily on the

Key

V = natural vegetation/rough pasture

R = road

W = wet area, with Juncus species

B = field boundary, usually a hedge

P = footpath

S = stream

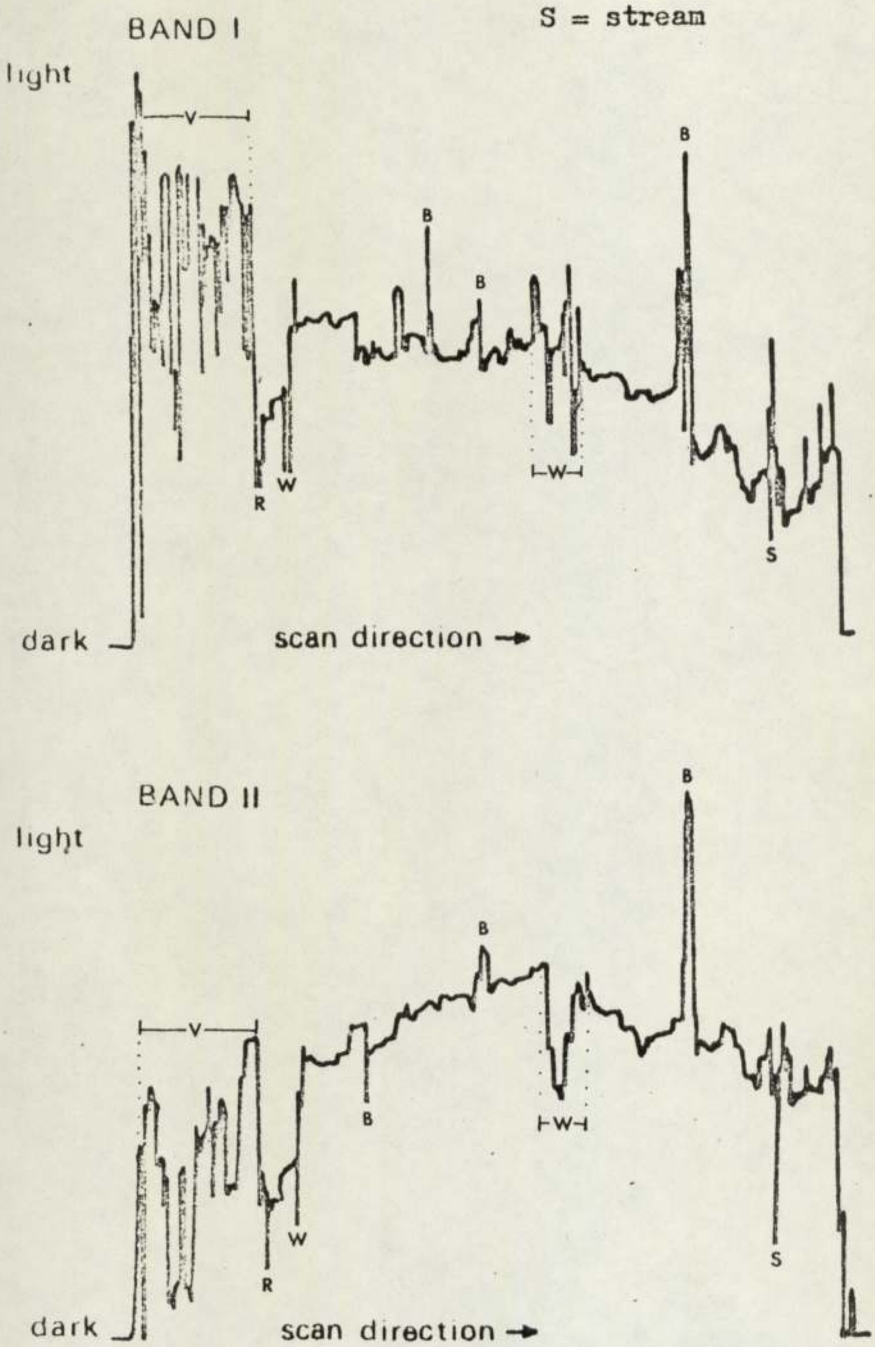

Fig.1.Densitometer scans of multispectral photography: bands I and II.

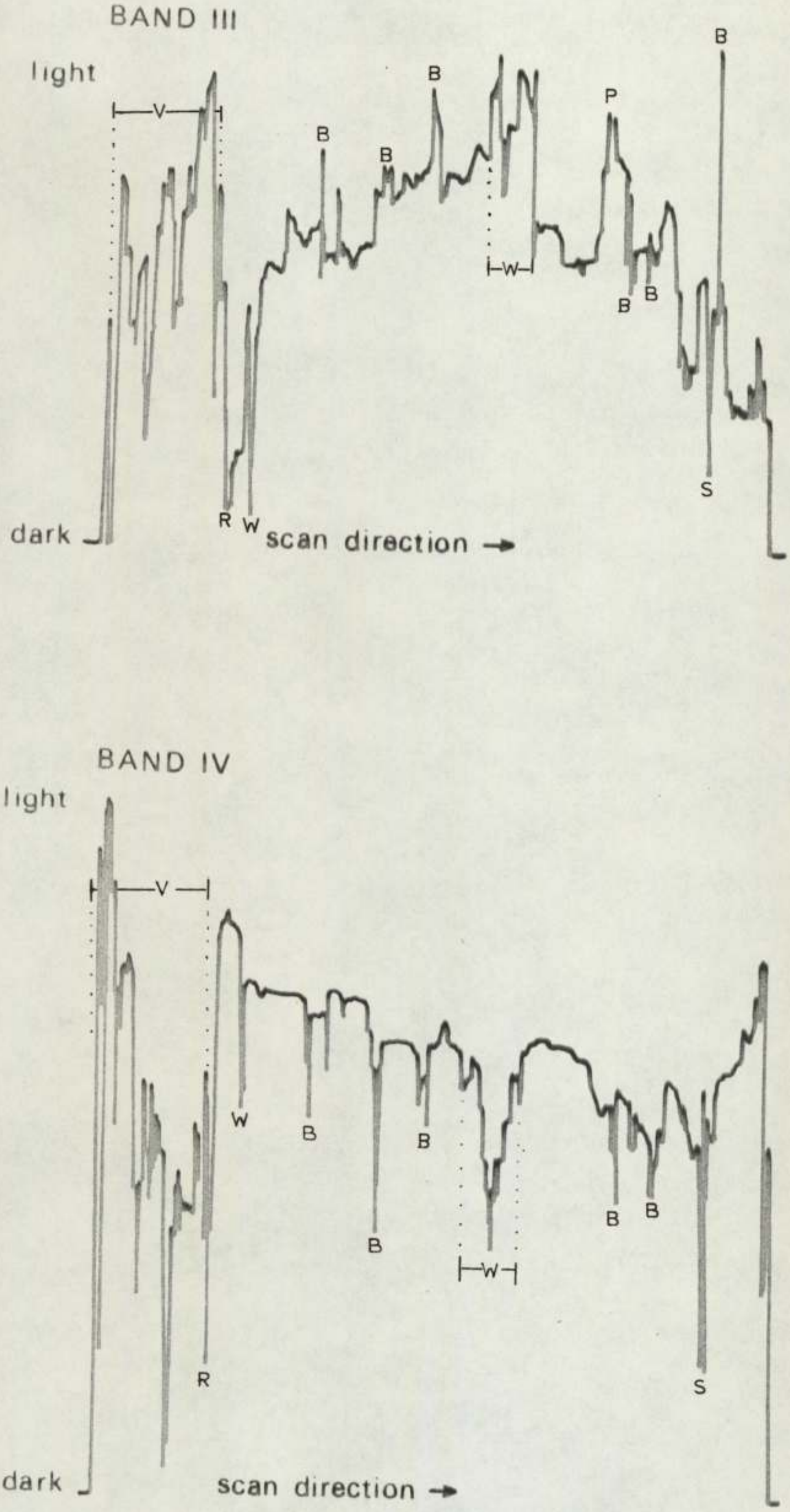

Fig.2. Densitometer scans of multispectral photography: bands III and IV.

trace from band IV while the band III scan was very complex and it was difficult to pick out features. A similar scan was found on all bands with roads streams, walls, etc. being dark and vegetation lighter, except on band IV where the vegetation was very light.

The Sedgwick and the Ingleborough areas were scanned, using a sample of the winter false colour photography and a sample of the spring false colour photography for each area. The different filters - blue, magenta, dark blue, green-turquoise, red, orange and green, were used. On the May photography very little could be seen in the Sedgwick area, as with the Ingleborough area, though here the limestone pavement stands out well as does the river (fig.3). However, variations in vegetation, scree and the limestone terraces produce similar peaks so they could not be distinguished from each other. On the winter photograph of Sedgwick there was even less variation than on the May scan but the Ingleborough winter photograph produced large amounts of variation, leading to much confusion. The area scanned on the Ingleborough photographs was across the river Greta, eastwards over Raven Scar and the limestone pavements. This type of relief had many areas in shadow on the winter photograph which would produce great variations in density. It was found that the limestone pavements and cliffs were generally distinguishable from vegetation on this scan. Using the filters produced little more data, as a similar scan was produced, often with peaks and dips in the same position and usually of the same magnitude, though further down the scale of brightness, depending on the particular filter (fig.4).

The major problem with this experiment was making sure that exactly the same line was being scanned every time, otherwise different features would be covered and the scans could not be compared with each other or with the features on the photographs. Also, the densitometer converts the false colours to grey tones, which is a disadvantage. Another

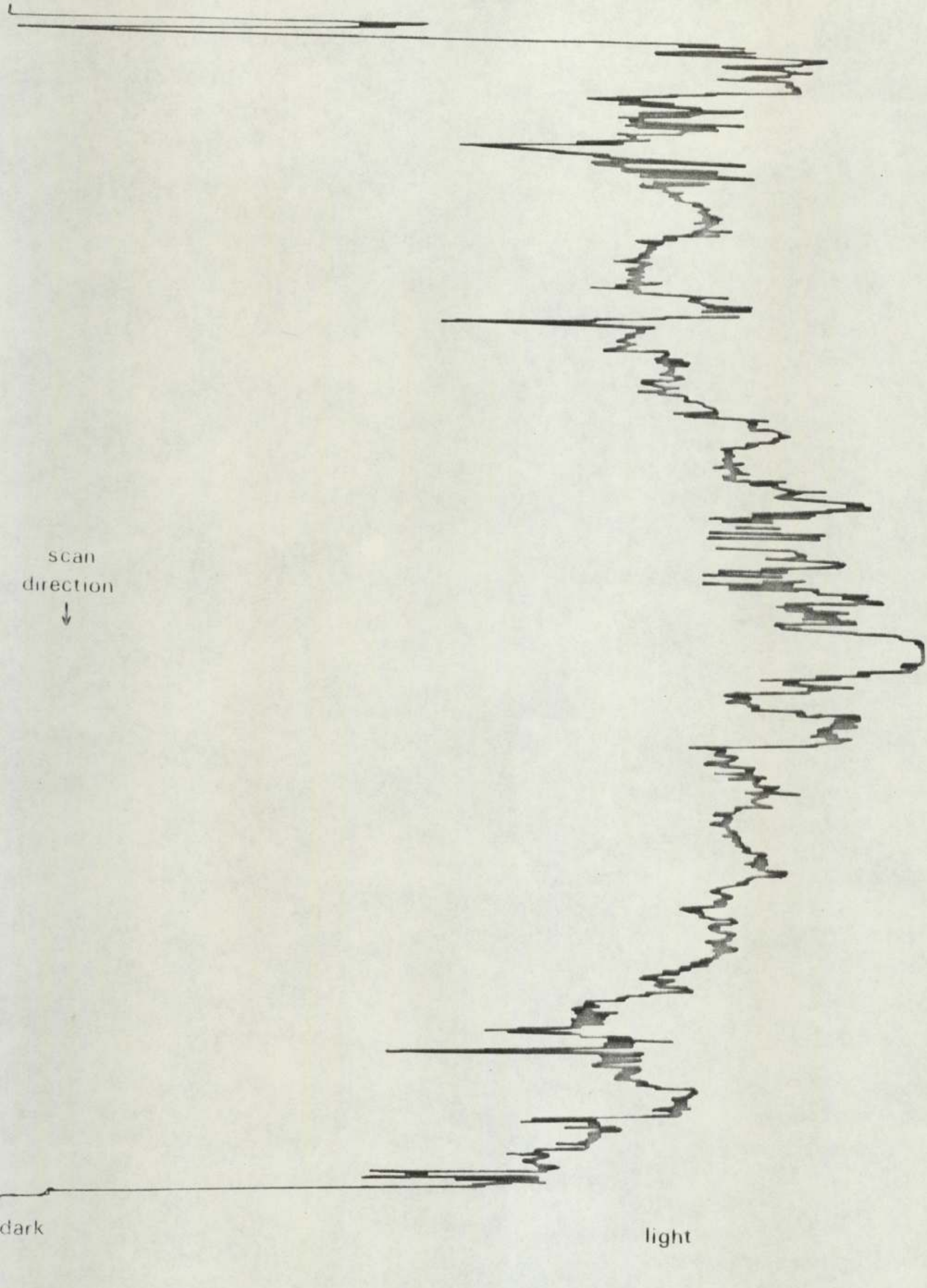

Fig.3. Densitometer scan across a false colour photograph of Ingleborough (May, 1974).

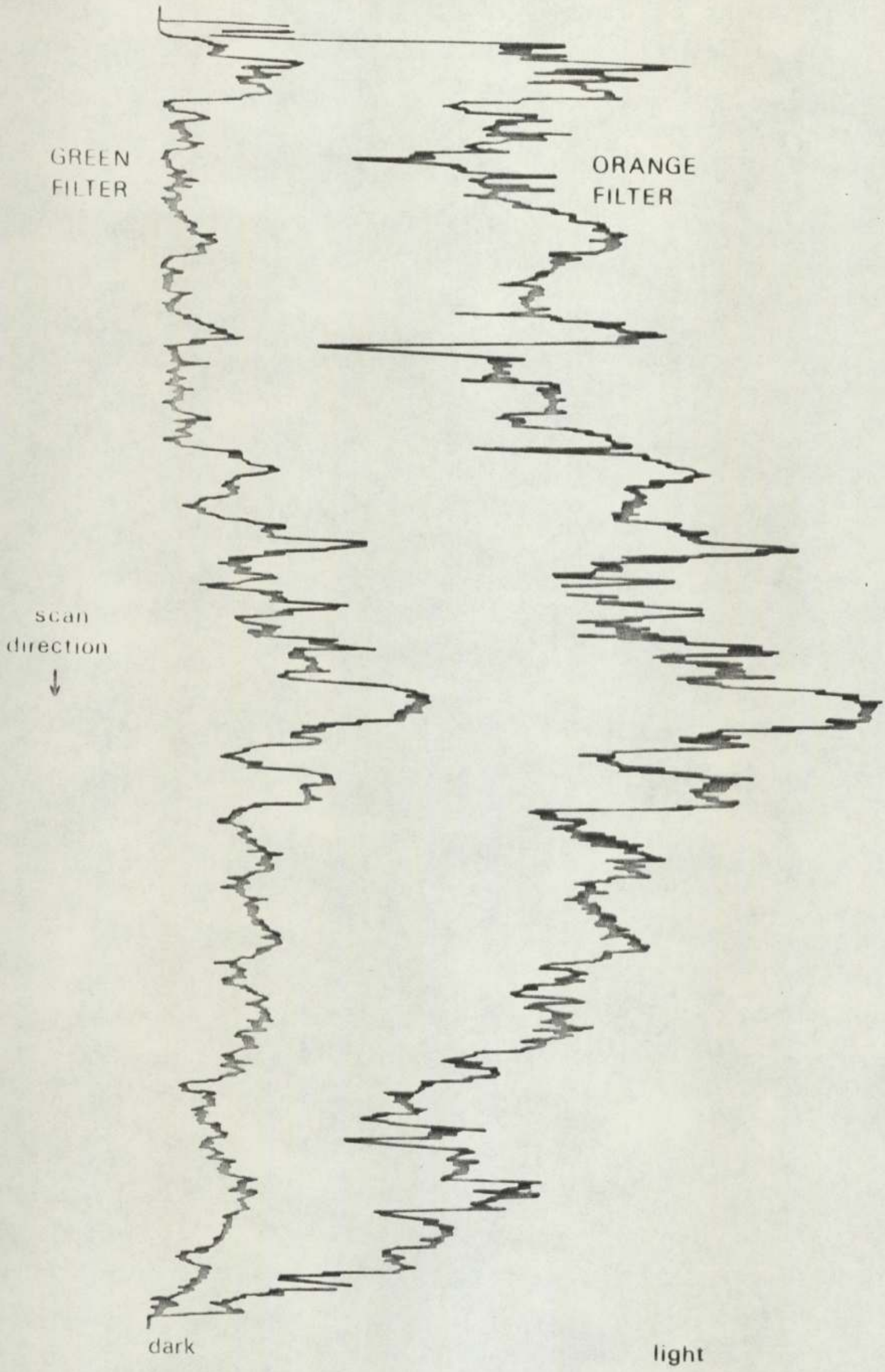

Fig.4. Densitometer scans across a false colour photograph of Ingleborough (May, 1974) using various filters.

disadvantage was that the record of the photographic densities was produced as a single line and so the shape and size of a feature could not be used for identification, e.g. a sheep and a limestone wall have very similar densities and cannot be distinguished on the scan because their shape is unknown; the shape (and size) of these two objects immediately distinguishes them on the photographs. A densitometer scan in the form of a map would have been far more useful.

10.3 Colour designation

The Inter-Society Colour Council-National Bureau of Standards (ISCC-NBS) centroid colour charts were used in this experiment. This method of designating colour contains 267 colour names and it has been possible to produce 251 of these colours in glossy paints. The charts contain one inch square samples of each colour, fixed to a variable grey background so that each colour is on a neutral background of approximately its own lightness. It was hoped that the colour(s) of a crop or vegetation type could be precisely described by this system as with the designation of soil colour by the Munsell colour system. However, the colour chips could not be used with the false colour photographs as the photographs are transparencies and not prints. If transparent colour samples had been available it might have been possible to carry out the experiment. Further reasons for the failure of this experiment were: the fact that the photographs are all much darker around the edges than in the centres; the angle of the sun on the winter photography tends to alter the colour of the vegetation, depending on whether a slope is facing towards or away from the sun; and on the May photography faint cloud shadows change the tone of the vegetation. The colour tone can be changed considerably by shadow, even very faint shadow. On the winter photographs this effect is especially pronounced, with areas of turquoise blue, drift grassland on one side of a valley being very pale, almost white, where they received direct sunlight, but the other side of the valley being darker blue, or green in one case. This was confusing during the interpretation as some areas looked as though they were a different vegetation association and a visit in the field was necessary to show that this was not so. Colwell et al (1966) also found these effects of slope and aspect; their experiments showed that an eastern aspect caused a decrease in transmission of radiation and a western aspect caused an increase, depending on the colour of the target. Apart from these disadvantages, the ISCC-NBS colour chips did not cover a wide enough range of tones, especially of magenta and turquoise-blue, to be of any use; it would probably have been better to use the Munsell Colour Book which contains 1450 different colours, although none are in a transparent form.

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Chapter 11: DISCUSSION AND CONCLUSIONS

11.1 Soil surveying

Aerial photo-interpretation methods are useful for soil surveying and the Soil Survey of England and Wales has made increasing use of A.P.I. methods as an aid to surveying since 1968. Various remote sensing systems have been recently developed which may possibly prove to be further aids to soil surveying. This project investigated the use of multispectral and false colour photography in soil surveys. The continual spatial variation of soils is a problem in soil mapping as boundaries which are normally diffuse have to be depicted as sharp lines. Soils are classified according to the various horizons comprising the profile, so it is therefore impossible to classify soils on a detailed basis by A.P.I., as only the surface of the profile is visible on a photograph. Over much of the country not even the surface of the soil is visible as it has a permanent vegetation cover. Therefore, if soils are to be mapped using aerial photographs, use must be made of the external characteristics of the landscape which correlate with soil conditions. A.P.I. is only an aid to mapping and soils must always be studied in the field.

Goosen (1967) lists a number of important features which are visible on aerial photographs and which correlate with soil type to a greater or lesser extent (table 1). These criteria were applied to the Ingleborough area and several changes in the importance of the elements were apparent. Land-type and land use were included in the list of features, but these were not strictly relevant to the Ingleborough study as the scale of mapping was too large. Also, the relationship of drainage systems (constructional and destructional) to soil conditions in Britain is not close. Goosen mentions that local conditions will change the

	Visibility in stereo image	Relation to soil condition	Coincidence with soil boundaries
Landtype	High	High	High
Relief	High	High	High
Slopeform	High	High	High
Drainage conditions	Medium	High	Medium
Constructional drainage system	High	High	High
Destructional drainage system	High	High	Medium
Natural vegetation	High	High	Medium
Parent material	Low	High	High
Colour	High	Low	Low
Land use	High	Medium	Low

Table 1. Importance of photo-interpretation elements for soil surveys (Goosen, 1967). This table gives general rules. Local conditions may change the qualifications.

qualifications and for Ingleborough relief, slopeform and natural vegetation were less important. Parent material has a very strong influence on soil type in this area and relief and slopeform also have a marked influence but are not clear enough to map soils by. Drainage conditions (rather than systems) are important and are closely related to the parent material. The vegetation cover is not natural, as it has been greatly modified by man's activities, and does not invariably reflect the underlying soil conditions. The area of the study is too small and the scale of the photographs too large for these criteria to be successfully applied. Goosen's approach is ideal for semi-detailed or reconnaissance mapping, where soil associations rather than soil series are mapped. Buringh (1954) and Jarvis (1962) also mention that the usefulness of A.P.I. methods depends on scale and that at a large scale (1:25,000 - 1:10,000) field work is more important than A.P.I., though A.P.I. is still useful. The scale used in this project was 1:15,000, which is preferred by the Soil Survey, but this was not really suitable; 1:20,000 or 1:25,000 scale would have been more useful and would probably have produced as much detail, especially if the Surveyor was familiar with the area. The results of the element analysis of the Marsden area (p.80) also showed that the scale of the photographs was too large and that too much detail was required to be able to make full use of A.P.I. methods. However, climatic conditions are worse the higher the aircraft (smaller scale) and at 1:20,000 or smaller scales it becomes difficult to locate oneself precisely, so that the photographs are much less useful for any detailed mapping necessary. The saving in time and therefore cost by using A.P.I. depends very much on the scale of the photographs and of the mapping exercise, and also on the nature of the terrain and soils, the available knowledge of the area and the quality of the photographs.

Another important consideration when mapping soils by A.P.I. is the timing of the flight. For lowland areas, Evans (1972) suggests that April is the best month for photographing patterns related to soil conditions, as there is much bare soil at that time, and that July is the best month for photographing soil patterns visible in cropland. However, this was not relevant to either of the study areas as they are both upland areas with very little arable farming and hence little bare soil and grain crops. The vegetation cover in upland areas can indicate soil conditions but the vegetation must be natural or semi-natural, as managed vegetation, such as the permanent grassland around Sedgwick, does not normally correlate well with the underlying soil conditions. For mapping semi-natural vegetation autumn is the best time of year as the vegetation is dying back, producing distinctive colours. However, flying conditions are not always good in either April or autumn and this must be borne in mind when planning an aerial survey. Some of the photography used in the soil mapping exercises was taken in May and some in October, so they could be compared to see which was more suitable for soil mapping. It was found that the winter photography was the more suitable, as there was more differentiation of vegetation, both in semi-natural vegetation and in crops.

All emulsions have the same basic disadvantage for soil survey A.P.I., i.e. that only the soil surface is seen on the photographs. However, some emulsions are more useful than others for mapping soils by correlation with features visible on aerial photographs. Multispectral and false colour photographs were compared with each other and with panchromatic photographs, to assess their use in soil mapping.

The spectral signature theory, i.e. that all earth materials have distinctive, unique spectral signatures and that if they are imaged in the appropriate wavelengths, the difference between the images of the objects and their backgrounds can be enhanced, would seem to have great potential for A.P.I. of all types. Multispectral sensing can be carried out photographically in the visible and near infra-red wavelengths or by an electronic scanner which can use longer wavelengths as well. Photographic multispectral sensing was used in this study. Although the theory seems promising, spectral signatures can be very variable due to time, the spectral quality of solar illumination and dynamic variables in the atmosphere e.g. haze, which alter the photographic record. Although some of these variables are predictable or measureable, many are unpredictable and distort the spectral responses of objects. Brooner and Simonett (1971) found very few cases where the individual crop types they had photographed had unique spectral signatures, and that the variation within one crop was usually greater than the variation between crops. Evans (1975) says that further investigation is needed of the factors which govern image response and he also states that the multiband signature technique appears to have little application for soil mapping and classification. Kristof and Zachary (1974) found that the results obtained when mapping soils by multispectral methods were very local because of differences in illumination of two areas, in surface roughness, texture, colour and differences in instrumentation when imaging different areas. They state that the multispectral technique can be expected only to augment and not replace traditional soil mapping. Colwell et al (1966) point out that multispectral photography should use properly selected spectral bands but Carroll (1973) says that the standard multispectral photographic system uses wavelengths that are too broad and that overlap. The wavelengths should be chosen specifically for the object to be sensed.

The experiment with multispectral photography in the Sedgwick area had all these problems and also the film had been processed wrongly which meant that densitometric analysis of the photography was difficult. Soil mapping using vegetation correlations was attempted and it was found that band III, the red band, was the best for this, as did Evans (1975), because it penetrates haze well and red light is absorbed by chlorophyll which produces a greater contrast between vegetation and other features (Gates et al, 1965). The infra-red band (band IV) was also useful (Evans, 1975; Brack, 1975) but not as useful as the red band, and it is not good for general interpretation (Carroll, op.cit.). However, Evans points out that the red band requires a longer exposure than panchromatic photography and that it is not always possible to take photographs in this band. The blue and green bands (bands I and II) were inferior, lacking in contrast and clarity of detail due to scattering of that end of the spectrum by haze. The multispectral photography used for this thesis was inferior to the panchromatic photography for all types of interpretation, though this may not always be so, as the multi-spectral photographs used in the study were of poor quality. Additive viewing had very little effect on the quality and quantity of the A.P.I. There are many disadvantages in using an additive viewer, especially the fact that there is no permanent record of the enhanced image; therefore, as the images cannot be compared, only a subjective assessment of the image can be made, and there is no stereo-view. The N.E.R.C. study (1974) also found that no extra information could be gained through using an additive viewer. The inherent defects in multispectral sensing, i.e. the probability that there are no unique spectral signatures and that the unpredictable variables in the atmosphere, which influence the recorded image, make this system unsuitable for A.P.I. of any type, including that for soil survey. Although multispectral scanners may be more useful as they are more flexible and sense in a greater part of the spectrum than do the photographic sensors, they also suffer from these disadvantages, and thus the basic premise of multispectral sensing is questionable.

The false colour photography proved to be far more useful than the multispectral photography and it was a very useful aid in mapping vegetation. The differences between vegetation types are emphasised on this type of emulsion because of the high reflectance of vegetation in the near infra-red region. Parry et al (1969) consider colour photography superior to black and white photography for interpretation, because of the greater range of colour tones than of grey tones, and Cooke and Harris (1970) consider false colour the best type of film for imaging the rural environment and agricultural phenomena. Some authors think that false colour may be inferior to panchromatic photography for interpretation because of the unfamiliar colours (Goldsmith, 1972; Valentine et al,1971) but this was not found in the project. The false colour photographs were also of very good quality and very clear because of the haze-cutting qualities of the film. Land use was mapped in the Sedgwick area and vegetation in the Ingleborough area and the resulting maps were compared with the soil maps to discover if there was any correlation between land use, vegetation and soils. The false colour photography was found to be superior to panchromatic photography for both land use and vegetation mapping, as vegetation differentiation was poor on the panchromatic photography especially on the Ingleborough photographs which had been taken at the wrong season and had too large a scale.

11.2 Land use surveying

Land use mapping should be done as rapidly as possible (Coleman and Maggs, 1965) because crop rotations can quickly change the pattern of land use. Aerial photographs can therefore be a great help to land use surveys as they are usually taken over a very short period of time and thus give a view of an area at one point during the year. The 2nd Land Use Survey took a period of time over four months to complete the Sedgwick map by ground survey methods, although the surveying probably took only ten days in all. Brunt (1961) says that A.P.I. can cut the time taken for a survey by 66% but this depends on the scale of the survey and of the photographs, the complexity of the area, the time of year, the type of information required, etc. The Sedgwick A.P.I. survey took approximately 75% of the time taken by the ground survey although this could probably have been cut to 50% if the author had been more experienced and the area had been part of a larger survey. The map made by A.P.I. methods was less detailed than the ground survey map because some crops, e.g. temporary grass, were difficult to identify; however, it could have been more detailed, as the residential/industrial category could have been split. A.P.I. is a rapid method for land use surveying and can be detailed if necessary although this adds to the amount of time taken for the survey. Certain categories cannot be mapped at all by A.P.I., e.g. industry that has taken over a residence, so some field work is still necessary. The distribution of land use types was found not to be influenced by soil conditions in most cases and so soils could not be mapped by vegetation differentiation in this area. However, relief was some guide to the broad soil type.

One major problem is that the dynamic aspect of land use cannot be seen on aerial photographs, but on the other hand it is rarely depicted on maps either. Sequential photography is useful to show this type of change and as the project used photography taken in October 1973 and May 1974, the changes over five months can be seen on the maps (Maps 2 and 3). Short term changes such as rotations were evident and also a longer term change due to economic pressure, e.g. the growing of more fodder crops due to price rises of imported animal food. It was also interesting to see the changes over a ten year period, from 1964-1974, by comparing the A.P.I. maps with the 2nd Land Use Survey map (Map 1). Other problems in land use mapping are difficulties in identification due to small fields, mixed cropping and succession cropping. Steiner (1966) regards these as being problems of tropical areas but this project has shown these to exist in Britain also (p. 121).

Another important aspect of land use surveying by A.P.I. is the correct timing of the flight, as there are rapid changes in the aspect of the vegetation cover during the growing period, which can affect the interpretation. The two seasons of photography were compared with each other and it was found that the May photographs were inferior as many crops were immature at that time and could not be identified. On the October photographs the crops were mature and more easily identifiable, also the more subtle colour tones were easier to work with. It has been suggested by an experienced land use surveyor that photographs should be taken during the overlap period for crops (mid-June to mid-August) which covers most rotations although autumn is a useful period in parts of the country where fodder crops are grown rather than grain crops, as they tend to be harvested later. However, any conclusions about seasonal changes in vegetation and their relationship to land use mapping have a strictly regional or local value, as Steiner (op.cit.) has pointed out.

The correct timing of aerial photography can be achieved by the study of the vegetation/crop changes in the area so that the optimum time of year for identification can be discovered before the photography is flown. L.A.R.S. (1967) state that the key to remote sensing for crop identification lies in obtaining data at proper periods of crop development and at intervals throughout the growing season while Steiner recommends that phenological records for crops and other vegetation types should be studied and also states that photography in the field, during the growing season, is useful. Curtis and Hooper (1974) write that ground photography can be very useful for choosing the best time of year or day for aerial photography, and that it is also useful for collecting ground truth data at the time of flight, especially data on site morphology, crop/vegetation cover characteristics and cultivation and husbandry features. Special attention should be paid to the rate of change and aerial photography is generally too expensive for such detailed monitoring of crop changes and the recording of transient features. Blair Rains and Brunt (1971) state that timely and adequate ground observations are generally essential for evaluation of aerial photographs and that permanent records of features both from the air and the ground are useful. The ground photography project in the Sedgwick area confirmed these statements and shows that even monthly photography may miss some important events during the growing season of a crop (p.215). False colour photography is probably the most useful here as it will show detailed changes in the vegetation and is also an indicator of plant vigour.

11.3 Vegetation surveying

Most of Ingleborough consists of one land use type, rough grazing; so rather than mapping land use, the vegetation associations making up the area were mapped. Reconnaissance vegetation surveys require a rapid method of mapping which does not produce a detailed map. Observational methods are normally used, occasionally with a small amount of quadrat surveying to obtain quantitative data in order to confirm the visual observations (Taylor, 1968; Tivy, 1954; Coleman and Sinclair, in preparation). Vegetation surveying has a similar problem to soil surveying in that the boundaries are usually diffuse as vegetation varies continuously. Thus, the boundaries on a map are usually arbitrary to a certain degree. In certain parts of the study area there was much variation within a very short distance and it was impossible to map every association present, so the map boundaries are general and do not fully show the situation that exists in the field.

Although the vegetation units are difficult to define, vegetation is clearly seen on aerial photographs, and for reconnaissance mapping A.P.I. is extremely useful. Goodier and Grimes (1970) remark that A.P.I. is of immense aid in understanding and recording plant environments and they advocate the development of photo-ecology as a field in its own right. A.P.I. is usually much quicker than ground methods; the amount of time taken was approximately the same as the time taken by the ground survey of the 2nd Land Use Survey (Coleman and Sinclair, op. cit.) but if the author had been more experienced and the work had been as part of a larger survey, the time taken by A.P.I. methods would probably have been only 50% of that taken by the ground survey. The associations mapped by A.P.I. methods may be quite different to those mapped by ground methods. Goodier and Grimes (op.cit.) state that a classification suited to A.P.I. should be used as the areas delineated on the photographs are defined not only on the basis of species presence and physiognomy but are the result of complex interactions between visual effects, geomorphology, soil type and moisture content, and the vegetation. The A.P.I. map units are complexes of plant communities, recognised on the basis of gross physiognomy and topography. The units mapped in the Ingleborough study are less detailed than those mapped by the 2nd Land Use Survey but the same basic divisions are shown (p.244). The boundaries of the A.P.I. map are more accurate and less generalised than those of the ground survey but, as both methods rely on visual observations from a distance, where an association cannot be distinguished by colour and texture (and where it has not been found by walking over it on the ground survey), it will not be recorded. The 2nd Land Use

Survey did not use aerial photographs for their vegetation survey as they decided that certain categories could not be distinguished adequately, i.e. most mixed grass communities and well grazed areas; however, if these cannot be distinguished on aerial photographs they are unlikely to be distinguished by observation, from a distance, in the field. A visit in the field to these communities would be essential in both types of survey.

The scale of photography used in vegetation surveys has an effect on the amount of information that can be obtained, and aerial photographs would probably not be used in very detailed surveys. Komarov (1968) suggested that 1:10,000 is the optimum scale for distinguishing composition and boundaries, but that 1:20,000 is probably best for medium scale work. Work on Dartmoor by Jones (Ward et al, 1971) showed that 1:10,000 scale photographys revealed too much complexity within the vegetation mapping categories and made it difficult to work with them. The panchromatic photographs of Ingleborough were of a similar scale (1:10,500) which was also found to be too large and even the 1:15,000 scale of the false colour photographs was rather large. It was not necessary to use the binoculars on the stereoscope when delineating the map units, as the boundaries were too complex, so a smaller scale of photography (1:20,000-1:25,000) would have been more suitable.

As with land use surveying, the timing of the photography in vegetation surveys is very important. Many authors mention that vegetation communities often have distinctive colours and textures which are emphasised in the autumn when the vegetation is dying back (Stapledon and Davies, 1936; Fenton, 1951; Tivy, op.cit.). This characteristic is extremely useful as could be seen by comparison of the two seasons of false colour photography. The May photography was difficult to use, with only slight differences in colour between the associations, whereas the different associations were very distinct on the November photography (p.236). There can also be problems of some species not appearing until late in the season, e.g. Molinia caerulea, which was not apparent until August, although some spring-flowering species may not be seen in autumn. Phenological records can be useful in such cases and Ashley and Rea (1975) state that knowledge of times when crop and forest vegetation experience seasonally related changes in development is important in understanding growth and yield relationships. September to October is usually the best time of year and the colours of the dead vegetation may remain throughout the winter. However, autumn is not usually a good time of year for aerial photography, especially if colour or false colour film is to be used.

There is a general relationship between semi-natural vegetation and habitat type but this is not always specific enough to use for soil survey. Association type often indicates drainage conditions, pH and sometimes type of parent material but many associations grow over a wide range of habitats, e.g. Nardus stricta communities, and although broad correlations can be made, they are not detailed enough to map soil series. There can be problems in interpreting the plant associations as management may produce false dominants or leave relic species from other associations, and often habitat boundaries may not be reflected in the vegetation because of management (Wieslander and Storie, 1953; Kelly, 1960). The vegetation associations on Ingleborough reflect broad changes in soil type and sometimes are specific for a particular soil, e.g. the limestone grassland with limestone pavement has humic rendzinas of the Marian Series, but on the whole they are not specific enough to map in the detail required by the Soil Survey. Bullock (1971), when mapping the soils of the Malham Tarn area, also found that the tonal pattern of the vegetation did not correspond to the distribution of individual soil type. The area is not natural vegetation but semi-natural vegetation, which has been heavily grazed and tends to reflect biotic factors, e.g. grazing pressure, as much as soil conditions. This type of broad correlation of soils with vegetation would be useful in a reconnaissance soil survey.

The semi-natural plant associations of the area do, however, indicate land use potential. An increase in agricultural output of the hill-lands in Britain, by improving the soil and vegetation types, is possible as these areas have great potential for grass production (Crompton, 1958) but at present many are badly managed and overgrazed. Ingleborough has suffered very badly from overgrazing, especially in recent years due to the increase in sheep stocking, e.g. the Enclosure Awards of 1809 regulate the number of sheep at one per 15 acres but the density in 1965 was one sheep per acre. This is only a theoretical density as sheep concentrate in more accessible and favoured areas, which will have an even higher density. The observable effects of overgrazing are the reduction and impoverishment of the better areas, and the decline in Calluna and its replacement by coarse herbage, i.e. Nardus and J. squarrosus. This decline in Calluna is confirmed by the decline in grouse shooting: in 1909 295 brace were shot, only 7 brace in 1939 and now the area is no longer used for grouse shooting (Nature Conservancy, 1965). Also, the present trend to slaughter sheep at earlier stages of their lives means that the sheep on the moors are less heavy and therefore cannot break down the plants by trampling. Often sheep are not grazed all year round on the moorland, only April to October, and they then select the more palatable herbage, whereas the coarse herbage would be eaten during October to March (Chadwick, 1960). Sheep are also responsible for the retardation of tree and shrub growth, which would improve shelter conditions. Some pastures on Ingleborough are now so impoverished that the best method for recuperation would be to withdraw sheep completely for a period of years.

Other methods of improving the grasslands would be to introduce cattle, as they are not so restricted in their tastes and tend to trample vegetation, thus maintaining a good proportion of palatable pasture. Burning can reduce some unwanted species but in the case of Nardus it stands up well to burning because of its tussocky habit and strong rhizome systems, and burning also has little effect on J. squarrosus. The most effective method to reduce both these species would be to heavily fertilise the areas and encourage the growth of base rich species which would lead to heavier grazing, more manuring and therefore better growth of grasses. As both J. squarrosus and Nardus are slow growing they cannot complete with faster growing species in more fertile habitats; increased fertility increases the palatability of Nardus which is eventually grazed away, while J. squarrosus cannot tolerate shading by taller, faster growing species. The Nature Conservancy also suggest that, apart from massive fertiliser applications, the only other effective way of improving and reclaiming poor pastures is by the establishment of a vigorous plant growth capable of tapping the bases of the limestone below, i.e. recolonisation by woodland species, which is prevented by sheep grazing at the moment. However, agricultural improvement would be difficult in such an area because of the numerous swallow holes in the less well drained areas and the rocky nature of the otherwise favourable soils.

11.4 Conclusions

This thesis has attempted to assess the value of multispectral and false colour film for various types of earth resources surveying. Few quantitative data were obtained to support the results although attempts were made to measure the tonal values for the crop and vegetation types appearing on the photographs, in order to quantify the differences between their images on the different types of photography. A micro-densitometer was used to record the density values but for various reasons (p.259) the results were meaningless, and an attempt to designate the colours on the false colour photographs, by comparison with standard colours, also failed. Many different factors are involved in producing the image on a photograph (see ch.2) and field spectra having a solar energy origin involve factors such as reflectance from multiple leaf layers, soil background radiance, slope and aspect effects, as well as atmospheric absorption and scattering factors. Other factors are involved when imaging the field spectra, e.g. instrumentation effects, film processing. Myers et al (1970) rightly state that "much research is still needed to establish the characteristic colour signatures that will permit identification of crop varieties and the colour tone of each, which might be affected by various soil and crop conditions".

The conclusions reached in this study are:

(1) That soil surveying using aerial photographs cannot be done directly because often the actual soil is not visible and if it is visible, then only the surface is seen, not the whole profile, which is the basis of soil identification and classification. Therefore, indicator features, which are visible on the photographs, must be used to map soils and if a soil has no such external expression then it cannot be mapped by using aerial photographs. This is true for all types of emulsion as no photographic system can record what lies below the soil or vegetation cover. The appropriate scale and season of photography must be chosen if A.P.I. is to be an effective aid to soil survey.

(2) Multispectral photography suffers from too many disadvantages to be useful for soil surveying or some other types of survey. There is

probably an inherent defect in the multispectral system as the basic theory of the system, i.e. that spectral signatures are unique, is now in doubt.

(3) False colour photography is useful and, on the whole, superior to panchromatic and multispectral photography for surveying vegetation types. The time taken for both land use and vegetation surveys is reduced and also more accurate boundaries produced. Therefore, it is more efficient than multispectral and panchromatic photography, and surveys with it are more efficient than ground survey, although it may not be as accurate in identification. It is important to remember that the classification and mapping units will not necessarily be the same as those of a ground survey.

(4) A major problem is the collection of ground truth data, for comparison with the image on an aerial photograph. This collection of data should be made at the same time as the aerial photography is flown, if at all possible. It was found that some of this data was best collected by ground photography, especially using false colour film. Monitoring of vegetation or crop changes over a period of time could also be done in this way, and the results used to predict the best time of year and/or day for aerial photography.

(5) The recommendations for soil survey are that multispectral photography should not be used and that false colour photography could be used but as it is more expensive and is more difficult to take, panchromatic photography is overall the best emulsion for soil survey. A.P.I. is essential in reconnaissance scale surveys and valuable for all types of survey, though at the scale and detail of survey required in the project, field work is more important.

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APPENDIX

Soil classification in England and Wales (Avery, 1973). Classes in higher categories:

*Classes in higher categories**

Major group	*Group*	*Subgroup*
1 *Terrestrial raw soils* Mineral soils with no diagnostic pedogenic horizons or disturbed fragments of such horizons, unless buried beneath a recent deposit more than 30 cm thick	1.1 *Raw sands* Non-alluvial, sandy (mainly dune sands)	
	1.2 *Raw alluvial soils* In recent alluvium, normally coarse textured	
	1.3 *Raw skeletal soils* With bedrock or non-alluvial fragmental material at 30 cm or less	
	1.4 *Raw earths* In naturally occurring, unconsolidated, non-alluvial loamy, clayey or marly material	
	1.5 *Man-made raw soils* In artificially disturbed material, e.g. mining spoil	
2 *Hydric raw soils* (Raw gley soils) Gleyed mineral soils, normally in very recent marine or estuarine alluvium, with no distinct topsoil, and/or ripened no deeper than 20 cm	2.1 *Raw sandy gley soils* In sandy material	
	2.2 *Unripened gley soils* In loamy or clayey alluvium, with a ripened topsoil less than 20 cm thick	
3 *Lithomorphic (A/C) soils* With distinct, humose or organic topsoil over C horizon or bedrock at 40 cm or less, and no diagnostic B or gleyed horizon within that depth	3.1 *Rankers* With non-calcareous topsoil over bedrock (including massive limestone) or non-calcareous, non-alluvial C horizon (excluding sands)	3.11 humic ranker 3.12 grey (non-humic) ranker 3.13 brown (non-humic) ranker 3.14 podzolic ranker (with greyish E) 3.15 stagnogleyic (fragic) ranker
	3.2 *Sand-rankers* With non-calcareous, non-alluvial sandy C horizon	3.21 typical sand-ranker 3.22 podzolic sand-ranker 3.23 gleyic sand-ranker
	3.3 *Ranker-like alluvial soils* In non-calcareous recent alluvium (usually coarse textured)	3.31 typical ranker-like alluvial soil 3.32 gleyic ranker-like alluvial soil
	3.4 *Rendzinas* Over extremely calcareous non-alluvial C horizon fragmentary limestone or chalk	3.41 humic rendzina 3.42 grey (non-humic) rendzina 3.43 brown (non-humic) rendzina 3.44 colluvial (non-humic) rendzina 3.45 gleyic rendzina 3.46 humic gleyic rendzina
	3.5 *Pararendzinas* With moderately calcareous non-alluvial C horizon (excluding sands)	3.51 typical (non-humic) pararendzina 3.52 humic pararendzina 3.53 colluvial pararendzina 3.54 stagnogleyic pararendzina 3.55 gleyic pararendzina
	3.6 *Sand-pararendzinas* With calcareous sandy C horizon	3.61 typical sand-pararendzina
	3.7 *Rendzina-like alluvial soils* In recent alluvium	3.71 typical rendzina-like alluvial soil 3.72 gleyic rendzina-like alluvial soil
4 *Pelosols* Slowly permeable (when wet), non-alluvial clayey soils with B or BC horizon showing vertic features and no E, non-calcareous Bg or paleo-argillic horizon	4.1 *Calcareous pelosols* Without argillic horizon	4.11 typical (stagnogleyic) calcareous pelosol
	4.2 *Non-calcareous pelosols* Without argillic horizon	4.21 typical (stagnogleyic) non-calcareous pelosol
	4.3 *Argillic pelosols* With argillic horizon	4.31 typical (stagnogleyic) argillic pelosol

* Names in parenthesis are alternative or explanatory.

Major group	*Group*	*Subgroup*
5 *Brown soils* Soils, excluding pelosols, with weathered, argillic or paleo-argillic B and no diagnostic gleyed horizon at 40 cm or less	5.1 *Brown calcareous earths* Non-alluvial, loamy or clayey, without argillic horizon	5.11 typical brown calcareous earth 5.12 gleyic brown calcareous earth 5.13 stagnogleyic brown calcareous earth
	5.2 *Brown calcareous sands* Non-alluvial, sandy, without argillic horizon	5.21 typical brown calcareous sand 5.22 gleyic brown calcareous sand
	5.3 *Brown calcareous alluvial soils* In recent alluvium	5.31 typical brown calcareous alluvial soil 5.32 gleyic brown calcareous alluvial soil
	5.4 *Brown earths (sensu stricto)* Non-alluvial, non-calcareous, loamy or clayey, without argillic horizon	5.41 typical brown earth 5.42 stagnogleyic brown earth 5.43 gleyic brown earth 5.44 ferritic brown earth 5.45 stagnogleyic ferritic brown earth
	5.5 *Brown sands* Non-alluvial, sandy or sandy gravelly	5.51 typical brown sand 5.52 gleyic brown sand 5.53 stagnogleyic brown sand 5.54 argillic brown sand 5.55 gleyic argillic brown sand
	5.6 *Brown alluvial soils* Non-calcareous, in recent alluvium	5.61 typical brown alluvial soil 5.62 gleyic brown alluvial soil
	5.7 *Argillic brown earths* Loamy or clayey, with ordinary argillic B	5.71 typical argillic brown earth 5.72 stagnogleyic argillic brown earth 5.73 gleyic argillic brown earth
	5.8 *Paleo-argillic brown earths* Loamy or clayey, with paleo-argillic B	5.81 typical paleoargillic brown earth 5.82 stagnogleyic paleo-argillic brown earth
6 *Podzolic soils* With podzolic B	6.1 *Brown podzolic soils* (podzolic brown earths) With Bs below an Ap or 15 cm, and no continuous albic E, thin ironpan, distinct Bhs with coated grains, or gleyed horizon at 40 cm or less	6.11 typical (non-humic) brown podzolic soil 6.12 humic brown podzolic soil 6.13 paleo-argillic brown podzolic soil 6.14 stagnogleyic brown podzolic soil 6.15 gleyic brown podzolic soil
	6.2 *Humic cryptopodzols* (Humic podzolic rankers) With very dark humose Bhs more than 10 cm thick and no peaty topsoil, thin ironpan, continuous albic E, Bs, or gleyed horizon	6.21 typical humic crypto-podzol
	6.3 *Podzols (sensu stricto)* With continuous albic E and/or distinct Bh or Bhs with coated grains and no peaty topsoil, bleached hardpan or gleyed horizon above, in or directly below the podzolic B or at less than 50 cm	6.31 typical (humo-ferric) podzol 6.32 humus podzol 6.33 ferric podzol 6.34 paleo-argillic (humo-ferric) podzol 6.35 ferri-humic podzol
	6.4 *Gley-podzols* With continuous albic E and/or distinct Bh or Bhs, gleyed horizon directly below the podzolic B or at less than 50 cm, and no continuous thin ironpan or bleached hardpan	6.41 typical (humus) gley-podzol 6.42 humo-ferric gley-podzol 6.43 stagnogley-podzol 6.44 humic (peaty) gley-podzol
	6.5 *Stagnopodzols* With peaty topsoil and/or gleyed E or bleached hardpan over thin ironpan or Bs horizon (wet above a podzolic B)	6.51 ironpan stagnopodzol 6.52 humus-ironpan stagno-podzol 6.53 hardpan stagnopodzol 6.54 ferric stagnopodzol

Major group	Group	Subgroup
7 *Surface-water gley soils* (Stagnogley *sensu lato*) Non-alluvial soils with distinct, humose or peaty topsoil, non-calcareous Eg and/or Bg or Btg horizon, and no G or relatively pervious Cg horizon affected by free groundwater	7.1 *Stagnogley soils (sensu stricto ≈ Pseudogley)* With distinct topsoil	7.11 typical (argillic) stagnogley soil 7.12 pelo-stagnogley soil 7.13 cambic stagnogley soil 7.14 paleo-argillic stagnogley soil 7.15 sandy stagnogley soil
	7.2 *Stagnohumic gley soils* With humose or peaty topsoil	7.21 cambic stagnohumic gley soil 7.22 argillic stagnohumic gley soil 7.23 paleo-argillic stagnohumic gley soil 7.24 sandy stagnohumic gley soil
8 *Ground-water gley soils* With distinct, humose or peaty topsoil and diagnostic gleyed horizon at less than 40 cm, in recent alluvium ripened to more than 20 cm, and/or with G or relatively pervious Cg horizon affected by free ground water	8.1 *Alluvial gley soils* With distinct topsoil, in loamy or clayey recent alluvium	8.11 typical (non-calcareous) alluvial gley soil 8.12 calcareous alluvial gley soil 8.13 pelo-(vertic)alluvial gley soil 8.14 pelo-calcareous alluvial gley soil 8.15 sulphuric alluvial gley soil
	8.2 *Sandy gley soils* Sandy, with distinct topsoil and without argillic horizon	8.21 typical (non-calcareous) sandy gley soil 8.22 calcareous sandy gley soil
	8.3 *Cambic gley soils* Non-alluvial, with distinct topsoil, loamy or clayey Bg horizon and relatively pervious Cg or G horizon	8.31 typical (non-calcareous) cambic gley soil 8.32 calcaro-cambic gley soil 8.33 pelo-(vertic) cambic gley soil
	8.4 *Argillic gley soils* With distinct topsoil and argillic (Btg) horizon over relatively pervious Cg	8.41 typical argillic gley soil 8.42 sandy-argillic gley soil
	8.5 *Humic-alluvial gley soils* With humose or peaty topsoil, in loamy or clayey recent alluvium	8.51 typical (non-calcareous) humic-alluvial gley soil 8.52 calcareous humic-alluvial gley soil 8.53 sulphuric humic-alluvial gley soil
	8.6 *Humic-sandy gley soils* Sandy, with humose or peaty topsoil and no argillic horizon	8.61 typical humic-sandy gley soil
	8.7 *Humic gley soils (sensu stricto)* Non-alluvial, loamy or clayey, with humose or peaty topsoil	8.71 typical (non-calcareous) humic gley soil 8.72 calcareous humic gley soil 8.73 argillic humic gley soil
9 *Man-made soils* With thick man-made A horizon or disturbed soil (including material recognizably derived from pedogenic horizons) more than 40 cm thick	9.1 *Man-made humus soils* With thick man-made A horizon, including Plaggen soils	9.11 sandy man-made humus soil 9.12 earthy man-made humus soil
	9.2 *Disturbed soils* Without thick man-made A horizon	
10 *Peat (organic) soils*	10.1 *Raw peat soils* Without earthy topsoil or ripened mineral surface layer	10.11 raw oligo-fibrous peat soil 10.12 raw eu-fibrous peat soil 10.13 raw (unripened) oligo-amorphous peat soil 10.14 raw (unripened) eutro-amorphous peat soil
	10.2 *Earthy peat soils* With earthy topsoil or ripened mineral surface layer	10.21 earthy oligo-fibrous peat soil 10.22 earthy eu-fibrous peat soil 10.23 earthy oligo-amorphous peat soil 10.24 earthy eutro-amorphous peat soil 10.25 earthy sulphuric peat soil

Ordnance Survey

Ingleborough Hill

Sheet SD 77

1:25 000 First Series **45p**

An index to the
1:25,000 First Series is
printed on the reverse
side of the map

The National Grid and Reference System

All modern Ordnance Survey maps show the National Grid. This is simply a series of squares with sides parallel and at right angles to the straight line that represents the central meridian of the projection of Ordnance Survey mapping. For convenience this grid system is sub-divided into 100 kilometre squares which are identified by two letters as shown on the index to the 1:25,000 First Series printed on the reverse of the map. These 100 kilometre squares are further sub-divided and are shown on the 1:25,000 maps at one kilometre intervals, thus providing a simple means of giving an accurate reference to any place on the map.

To give a reference proceed as follows:

(1) Identify the south-west corner of the square in which the place falls.

(2) At this intersection read off the grid number of the vertical (Eastings) line in the north and south margins and the grid number of the horizontal (Northings) line in the east or west margins.

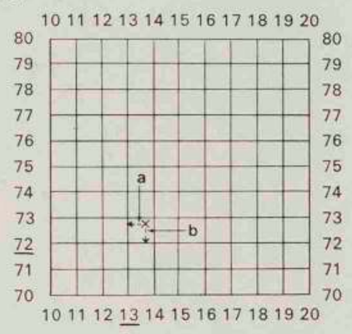
(3) The four figure grid reference of the square in which the place falls is obtained by combining the former with the latter. A more accurate six figure reference can be obtained by estimating the distance in tenths east and north of the point of intersection.

To make this reference into a unique one for the whole country it should be prefixed by the two letters representing the 100 kilometre square in which the place falls.

Example:

Sheet No. TQ 17

On sheet TQ 17 the grid reference for the point X is TQ 137728 and is made up as follows:



100 kilometre square	**TQ**	
Eastings - -	**137**	Grid number 13 shown in north and south margins and an estimated distance of 7 tenths (see (a) on diagram) east of grid line 13.
Northings - -	**728**	Grid number 72 shown in east and west margins and an estimated distance of 8 tenths (see (b) on diagram) north of grid line 72.

When giving a reference the "Eastings" should always be given before the "Northings".

A full description of the National Grid and Reference System is explained in the booklet "An Introduction to the Projection for Ordnance Survey Maps and Plans and the National Reference System" (Code 62-1028-0-68), which can be obtained from H.M. Stationery Office, 49 High Holborn, London, W.C.1, from Government Bookshops or through any bookseller.

Conventional Signs

Note:- Road fillings and numbers are shown in orange on the map.

Motorway, Trunk and Main Road (Dual Carriageway) — M 4 or A 6(M) — A 123 or A 123(T)

Trunk & Main Road — A 123 or A 123(T)

Secondary Road — Fenced — B 2314 — Unfenced

Road Under Construction

Other Roads — Good, metalled — Poor, or unmetalled

Footpaths — FP Fenced — FP Unfenced

Railways, Multiple Track — Station — Sidings — Road over — Cutting — Tunnel — FB (Footbridge)

" Single Track — Viaduct — Level Crossing — Embankment — Road under

" Narrow Gauge

LTE & Glasgow District Subway Stations — *Interchange Stations*

Aerial Ropeway — Aerial Ropeway

Boundaries — *County or County Borough*; *" " County of City (in Scotland)*; *" " " " " " with Parish*; *" Parish*

Pipe Line (Oil, Water) — Pipe Line

Electricity Transmission Lines (Pylons shown at bends and spaced conventionally)

Post Offices (In Villages & Rural Areas only) P — *Town Hall* TH — *Public House* PH

Church or Chapel with Tower — *Church or Chapel with Spire* — *Church or Chapel without either*

Triangulation Station — *on Church with Tower* — *without Tower*

Intersected Point on Chy — *on Church with Spire* — *without Spire* — *on Building*

Guide Post GP. *Mile Post* MP. *Mile Stone* MS. *Boundary Stone* BS *Boundary Post* BP

Youth Hostel Y *Telephone Call Box (Public)* T *(AA)* A *(RAC)* R *Antiquity (site of)*

Public Buildings — *Glasshouses*

Quarry & Gravel Pit — *Orchard*

National Trust Area (Sheen Common NT) — *Furze*

" " " Scotland NTS — *Rough Pasture Heath & Moor*

Osier Bed — *Marsh*

Reeds — *Well* W

Park, Fenced — *Spring* Spr

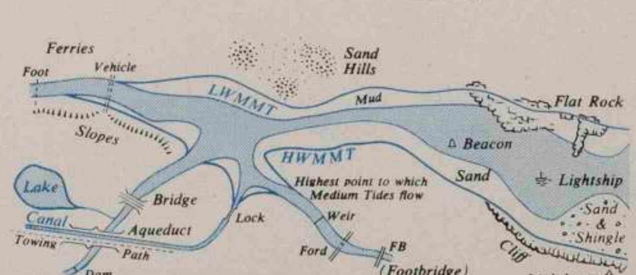
Wood, Coniferous, Fenced — *Wind Pump* Wd Pp.

Wood, Non-Coniferous Unfenced

Brushwood, Fenced & Unfenced

Contours are at 25 feet vertical interval, shown in Orange.

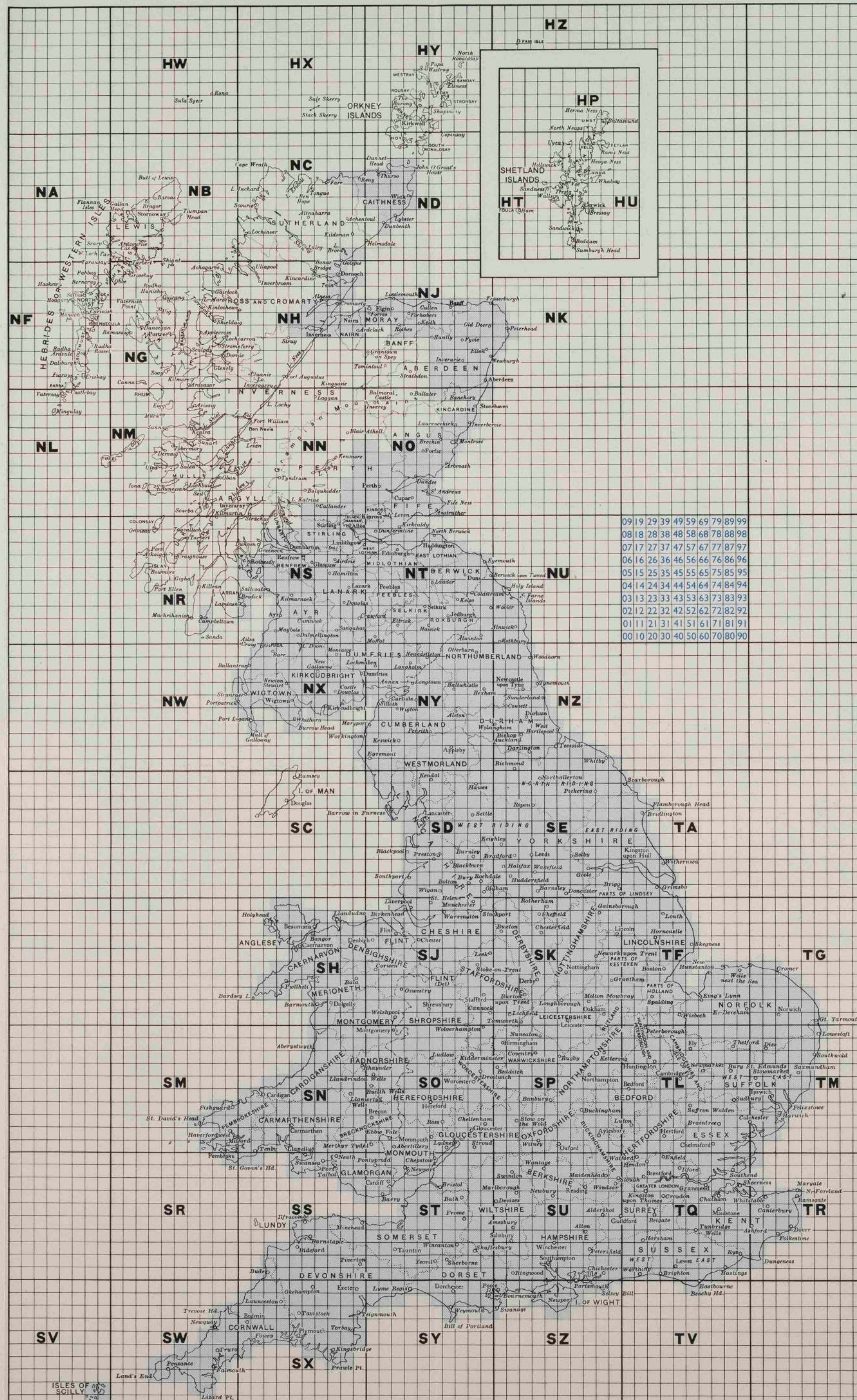
Spot Height 123·



(High & Low Water Mark of Ordinary Spring Tides, in Scotland)

Note:- Sand is shown as an orange stipple on the map. Sand and shingle are shown in orange, and mud as a combined blue and orange stipple.

1:25,000 FIRST SERIES (Provisional Edition) AVAILABILITY DIAGRAM



The bold black letters denote the 100 kilometre square of the National Grid. The blue tint shows the full extent of the 1:25,000 First Series (Provisional Edition) covering Great Britain. It is not intended to publish any further sheets covering West Scotland and the Highlands in this Edition.

The bold blue figures at the north-east quadrant of the diagram show the incidence of the sheet numbers within each 100 kilometre square. When ordering 1:25,000 sheets please quote 100 kilometre prefix letters shown as capital letters on the diagram, followed by the appropriate 10 kilometre numerals as shown by the bold blue figure. Say also which style is required, i.e. coloured flat or folded. Outline, flat only.

Examples

The sheets covering Bristol and Edinburgh are ST 57 and NT 27 respectively.

An index to the 1:25 000 First Series is printed on the reverse side of the map

1:25 000 First Series 45p

Ingleborough Hill

Sheet SD 77

Ordnance Survey

1:25,000 First Series (Provisional Edition)

This series covers the whole of Great Britain apart from the Highlands and Islands of Scotland at the 1:25,000 scale, approximately two and a half inches to one mile. The series was first produced during the Second World War from pre-war six-inch mapping, but all sheets have since been revised. No further systematic revision will be carried out, but important changes, e.g. motorways, by-pass roads, large reservoirs are added whenever a sheet is re-printed. Most sheets represent an area 10 kilometres square, but some coastal sheets are larger. Its detailed depiction of the country makes the series invaluable for professional, educational and recreational purposes. It carries the National Grid at one kilometre intervals.

All sheets are available in coloured and outline styles.

An index to the series is printed on the back of the map.

1:25,000 Second Series

A new Second Series is being produced to replace the First Series. It will be derived from post-war 1:1250, 1:2500, 1:10,000 or 1:10,560 mapping, whichever is the largest scale available. Each sheet represents an area of 20 kilometres east to west, by 10 kilometres north to south, but there may be variations along the coast. In general the Second Series shows the same detail as the First Series, though in a more attractive and colourful form, but in addition the England and Wales sheets show public rights of way if the information is available when the sheet is prepared. An index to the new series and information about sheets currently available may be obtained from the Ordnance Survey, Southampton. All sheets in the new series will be published in coloured and outline styles.

One-inch Series

The 189 sheets in this series give a detailed and readily understood topographical picture of the country. All roads are shown and colours are used to indicate Ministry of Transport classifications types of surface and width. The sheets are revised regularly and important road changes are added whenever a sheet is reprinted.

Tourist and other Special Maps

These maps cover some of the main tourist areas. The style and content of the Tourist maps is much the same as the one-inch maps, but on most sheets various combinations of colour and hill shading give an excellent general impression of the area. Some sheets also show special information such as places of interest, viewpoints, camping sites, etc. The following maps, mainly at the one inch to one mile scale, are currently available.

- Ben Nevis and Glen Coe
- Cairngorms
- Dartmoor
- Exmoor
- Greater London
- Lake District
- Loch Lomond and the Trossachs
- New Forest
- North York Moors
- Peak District
- Snowdonia National Park (Half inch to one mile scale)
- Wales and the Marches (Quarter inch to one mile scale)

These maps are obtainable from Ordnance Survey agents and most booksellers

Made and published by the Director General of the Ordnance Survey, Southampton

Ordnance Survey

Sedgwick

Sheet SD 58

1:25 000 First Series 45p

An index to the
1:25 000 First Series is
printed on the reverse
side of the map

C.

The representation on this map of a Road, Track, or Footpath, is no evidence of the existence of a right of way.

SHEET SD58

Grid North at the centre of this sheet is 0° 33' 39" W. of True North.
Magnetic Variation is 9° 30' W. of Grid North for June 1960.
Annual Change 7' E.

INDEX TO ADJOINING SHEETS

SD 49	SD 59	SD 69
SD 48	SD 58	SD 68
SD 47	SD 57	SD 67

The GRID lines on this sheet are at 1 Kilometre interval.
Heights are in feet above Mean Sea Level at Newlyn.

1 square inch on this map represents 99·639 acres on the ground.

Compiled from 6'' sheets last revised 1910-12.
Other partial systematic revision 1938-51 has been incorporated.
Major roads revised 1971.

Made and published by the Director General of the Ordnance Survey, Southampton.
Reprinted with the addition of new major roads

SHEET SD58

The National Grid and Reference System

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To give a reference proceed as follows:

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To make this reference into a unique one for the whole country it should be prefixed by the two letters representing the 100 kilometre square in which the place falls.

Example:

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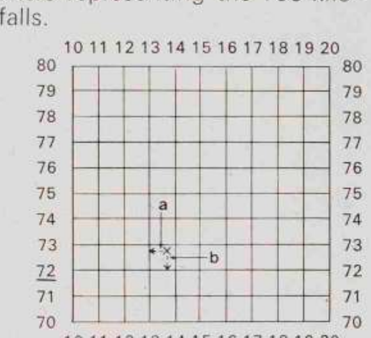

100 kilometre square	**TQ**	
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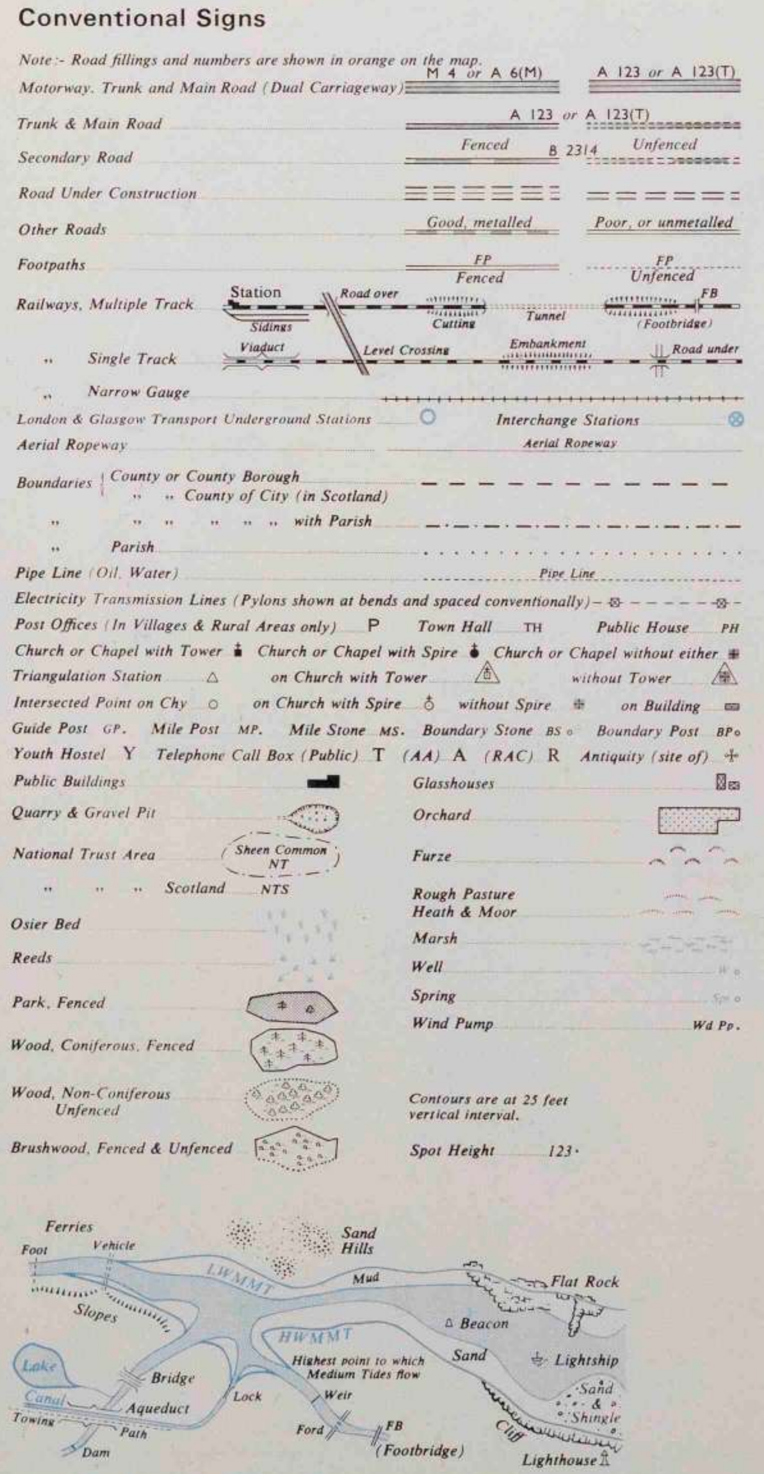
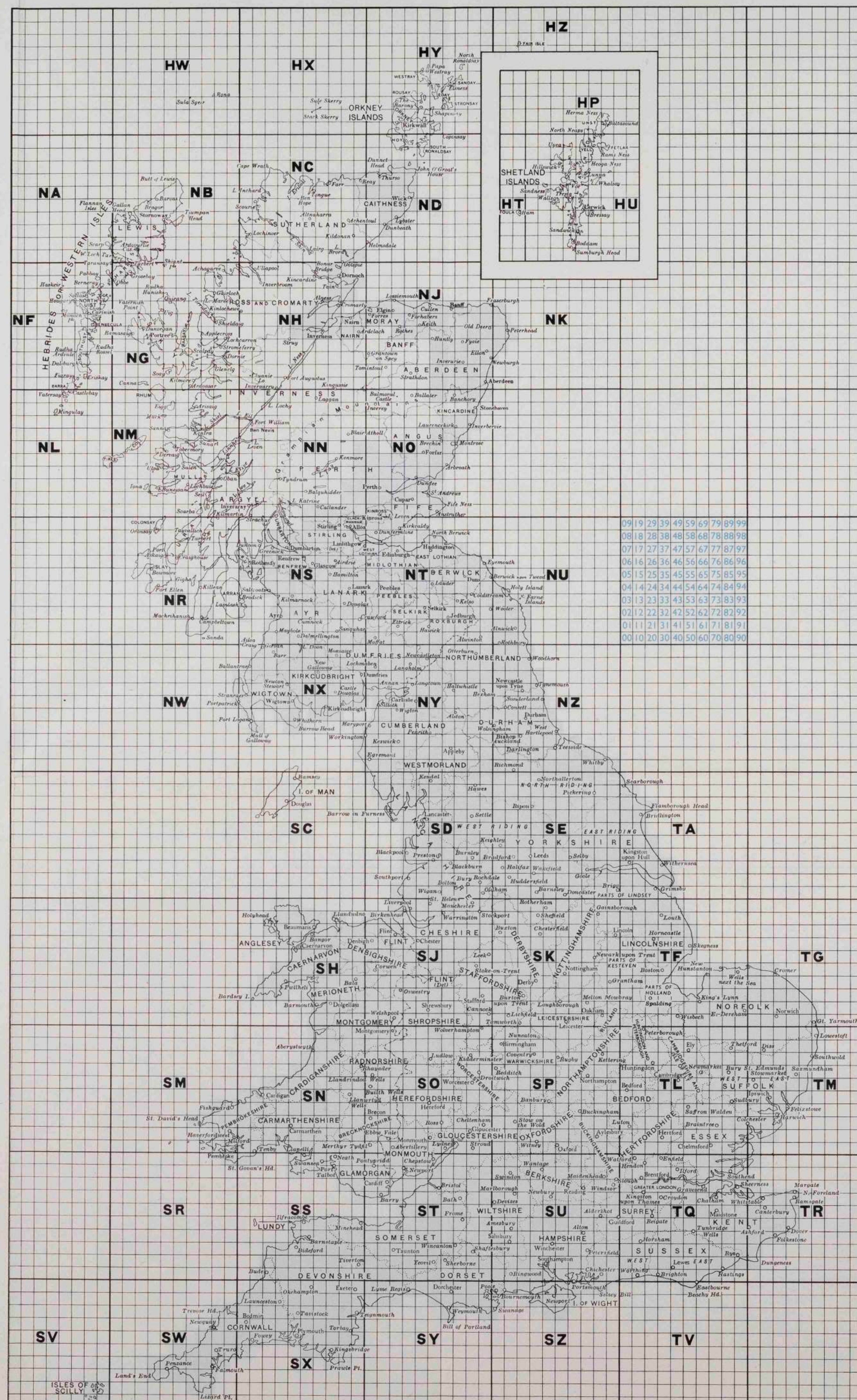
Conventional Signs



Note:- Sand is shown as an orange stipple on the map. Sand and shingle are shown in orange, and mud as a combined blue and orange stipple.

INDEX FOR 1:25 000 FIRST SERIES (Provisional Edition) - See Notes below



The black bold letters denote each 100 kilometre square of the National Grid. The blue tint shows the part of Great Britain which has been covered by the 1:25 000 First Series (Provisional Edition); it is not intended to publish any further new sheets of this Series outside this area. First Series (Provisional Edition) sheets are being withdrawn when the corresponding Second Series sheets are published.

The blue figures at the north-east quadrant of the diagram show the incidence of the sheet numbers within each 100 kilometre square. When ordering 1:25 000 sheets please quote 100 kilometre prefix letters shown as capital letters on the diagram, followed by the appropriate 10 kilometre numerals as shown by the blue figures. Say also which style is required, i.e. coloured flat or folded: outline, flat only.

Examples

The sheets covering Bristol and Glasgow are ST 57 and NS 56 respectively.

An index to the 1:25 000 First Series is printed on the reverse side of the map

1:25 000 First Series 45p

Sheet SD 58

Sedgwick

Ordnance Survey

This map is one of the 1:25 000 First Series (Provisional Edition)

The 1:25 000 First Series (Provisional Edition)

This series (the scale is about two and a half inches to one mile), based upon pre-1939 six-inch mapping, was completely revised for major changes from 1948 to 1965. No further systematic revision is being carried out but major changes in communications and in building development are incorporated on reprint. Each of these maps normally covers an area of 10 km. square (there are variations along the coast) and sets out to show, with much other detail, all roads, tracks and footpaths (although not designated rights of way) and contours at 25ft. vertical intervals.

The 1:25 000 Second Series

These maps normally cover an area of 20 km. x 10 km. (again there are variations along the coast). They are gradually replacing the maps of the 1:25 000 First Series (Provisional Edition), but are unlikely to supersede them completely for many years. The Second Series maps are derived from the latest large scale surveys and give an even more detailed picture of the countryside than do the popular one-inch maps. In addition to the main roads, they show tracks, footpaths and a wealth of other topographical information which makes them invaluable for recreational, educational and business purposes. Contours are shown at 25ft. vertical intervals but these will eventually be replaced by metric contours. The specification provides for public rights of way to be shown on the maps of England and Wales where these have been established by the local authority.

Particulars of the limited number of sheets which have so far been published in this series may be obtained from the Director General, Ordnance Survey, at the address below.

Sheet Numbering

The reference number of a Second Series map, for example SP 24/34, is generally made up from the reference numbers of the relevant two First Series (Provisional Edition) maps. In this example the First Series sheet numbers are SP24 (the western sheet) and SP34 (the eastern sheet).

A Map Catalogue

describing all Ordnance Survey small scale maps is available from the Director General, Ordnance Survey, Romsey Road, Maybush, Southampton SO9 4DH.

Ordnance Survey maps are obtainable from Ordnance Survey agents and most booksellers

Made and published by the Director General of the Ordnance Survey, Southampton