MONITORING THE DEVELOPMENT OF LANDSLIDES USING ARCHIVAL PHOTOGRAPHY AND ANALYTICAL PHOTOGRAMMETRY

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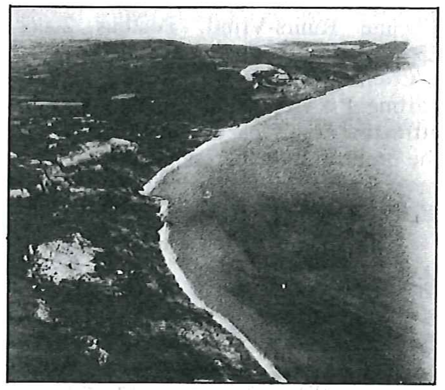


Figure 1. Oblique aerial photograph – Black Ven 1948. Photograph courtesy of University of Cambridge Committee for Aerial Photography.

Abstract

The principles of a technique which enables spatial data to be obtained from archival photography is outlined. The method is applied to a 42-year sequence of oblique and vertical aerial photography of the Black Ven landslide in Dorset, England.

The data processing options are discussed and illustrated by some results produced from historical photographs of the Dorset landslide.

1 Introduction

Geomorphology is the science which attempts to understand the landscape and the processes and factors controlling landform evolution. Photogrammetry can provide the spatial data representing landform efficiently, so close links between the two sciences would perhaps be expected.

One of the main problems in geomorphology has been estimation of process rates because they are characteristically slow (Thornes and Brunsden, 1977). Archival photographs can now be used to provide geomorphologists with accurate spatial data. With sufficient photography available to form a time-based sequence, the effect of processes can be accurately assessed and quantified. The recent Photogrammetric Society one-day symposium on photographic archives in the UK has shown the existence of a large quantity of historical photography. This represents an untapped data source that geomorphologists and other earth scientists can now employ in conjunction with analytical photogrammetry. The research that will be outlined is one approach, which has been called the 'archival photogrammetric technique'.

2 The problems

Several problems can be identified when historical photographs are used for photogrammetric measurement. There is likely to be an absence of camera calibration data and co-ordinated ground control points, so that conventional photogrammetry would be inconceivable. Secondly, in order to monitor the development of a feature it must be possible to obtain sufficient photography to form a sequence. This task would be easier if the photogrammetric techniques were universal, such that all aerial imagery, including obliques, could be used. Finally, in order to detect relevant differences, it is essential that a common datum is defined at all epochs.

3 The technique

The archival photogrammetric technique is based around computerised analytical procedures, primarily a *self calibrating bundle adjustment.* This computational procedure establishes digitally, the relationships between the photographs and a ground co-ordinate system. The replacement of the analogue stereoplotter with such a digital mathematical model is flexible and now well established (Ghosh, 1979). Photo pairs are still required, but these do not have to fulfil the tight rotational and positional requirements demanded by analogue instruments. The only photo requirement is some degree of overlap and a base/distance ratio greater than 1:10.

The whole technique can be simplified into several distinct sections, which are carried out sequentially.

3.1 Photo acquisition – Obviously suitable sequential contact diapositives must be acquired from one of the archive sources. Many of these sources are now making use of computerised registers, so searches are becoming quicker.

3.2 Identification and derivation of control – Co-ordinated points will generally be unavailable, but control can be scaled from a local large scale plan. Additional control can be provided by measurements between points. These can include 'natural' measurements, for example; zero height differences between points defining the boundary of a lake. The stochastic properties of all co-ordinates and measurements should be judged, as the measurements are weighted in the final adjustment.

3.3 Photo measurement – The image positions of control and pass points are measured using a stereo-comparator. Reference points such as corners or sides of the format can be used if suitable fiducials are not present.

3.4 Photogrammetric processing – consists of a suite of four programs. The self calibrating bundle adjustment is the last and this is used to estimate the exterior orientation parameters, or the positions and rotations of the cameras in the ground co-ordinate system. Elements of inner orientation, which model the internal geometry of the camera, are also estimated. Two groups can be identified:

(i) The primary inner orientation parameters, which model the displacement of the principal point relative to the reference marks and a correction to an approximate camera focal length.

(ii) Lens distortion parameters; one or three parameters of an even powered polynomial used to model radial lens distortion, and optionally two parameters used to model tangential lens distortion.

No explicit modelling for film deformation is included, as it is improbable that calibrated fiducial data are available.

The internal parameters can be included in various combinations, so that inestimable parameters can be dropped in an over parametised solution. Other important aspects of the program are the ability to include measurements between points, which enables unconventional control to be included. Also, as the stochastic nature of co-ordinates and measurements are taken into account, data of various precision can be used. The self-calibrating bundle adjustment overcomes rigorously many of the problems associated with historical photography.

3.5 Data extraction – When a satisfactory solution has been obtained, it is possible, using the estimated exterior and interior parameters, to extract the co-ordinates of new points anywhere on the site. This procedure can be carried out using a stereo-comparator, but is more effective if an analytical plotter is used. The City University has recently acquired the Intergraph 'InterMap Analytic' analytical plotter, which allows for two forms of data extraction:

(i) Feature coding – delineation of boundaries, with lines of varying colours, linetypes and thicknesses.

(ii) DTM collection – extraction of a grid DTM of any size and density.

Both of these programs enable high rates of data extraction, approaching 5,000 points per day.

3.6 Data processing/presentation and interpretation – All of these data are stored on computer file in a form that can be manipulated by a graphics workstation. Detailed map and plans can be produced anywhere of the site, at a scale controlled by the quality of the data. There are also other potentially more useful methods of processing these data.

4 Results

All new techniques must be applied in practice, in order to validate or modify the methodology. The case study chosen for this purpose was the Black Ven landslide in Dorset. This was selected because it is the most active complex of mudslides in the British Isles (Brunsden and Goudie, 1981), and has shown marked changes. Many of these have been recorded qualitatively by various geomorphologists and geologists in the past (Arber 1941, Brunsden 1969, Deness 1972, Conway 1974). It was felt that to quantify this early work and to include additional survey epochs would be of distinctive geomorphological importance.

A sequence of photographs of the site was obtained from a variety of sources and diapositives were made of the original negatives. Originally, the sequence began in 1946 and included epochs in 1948 (Figure 1), 1958, 1966 (Figure 2), 1969 and 1976. The sequence was completed in January and June of this year by hiring a light aircraft and using a hand-held Rollei 6006 large format camera. At present bundle adjustments have been computed for all photoepochs but positional data have been extracted only from the 1946, 1958, 1969, 1976 and 1988 surveys.

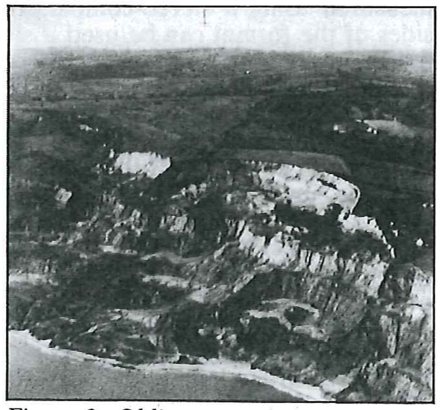


Figure 2. Oblique aerial photograph – Black Ven 1966. Photograph courtesy of University of Cambridge Committee for Aerial Photography.

The inclusion of a full stochastic model in the analytical photogrammetric solution is advantageous for several reasons, as illustrated by the 1958 bundle adjustment of Black Ven.

The inner orientation parameters need to be carefully selected in a self-calibrating bundle adjustment. A sufficient number must be included to model the systematic errors associated with a camera of unknown internal geometry. If too many are selected the solution becomes over-parameterised and unstable. The significance of a parameter can be determined statistically by using the relevant diagonal element of the covariance matrix and the estimated parameter to evaluate a test statistic. If this statistic shows, at a certain level of significance, that the parameter cannot be reliably estimated, it should be removed from the solution.

The covariance matrix can be used to determine the correlation between parameters. It was found that there was a correlation as significant as 0.99 between the displacement of the principal point in the y plate direction (yp) and the rotational elements of exterior orientation. This inner parameter was removed and the solution was stablised to the extent that as many as three lens parameters could be reliably estimated. Upon closer examination it was discovered that these lens parameters were also modelling a significant

proportion of the distortions associated with firm deformation. Similarly, it was found that the primary rotational elements of exterior orientation (Omega) were highly correlated with atmospheric refraction. For this reason it was unnecessary to model refraction explicitly.

The stochastic model also gives an indication of the quality of the co-ordinates that are finally extracted. The standard deviations of the spatial co-ordinates of typical points of detail were of the order of +/− 1 metre, which was similar to the precision of the control co-ordinates that were derived from the OS 1:2 500 large scale plan. This corresponds to a rms residual on the images of up to 10 microns, resulting from least squares estimation with about thirty degrees of freedom.

5 Data processing for geomorphology

In geomorphology, historical photographs are an example of an incidental observation (Thornes and Brunsden, 1977). Historical photographs were obtained for a variety of reasons, certainly without consideration of the frequency of observation necessary for a geomorphological survey. Consequently, there are dangers of inferring process from such a series of incidental observations, especially if a sequence is short and the time intervals between photographs are long.

The basic data unit used for all photogrammetrically-based methods is the co-ordinate. It is this unit which can be otained with a density and efficiency which is unobtainable by other techniques. Data extraction is greater, denser and with subsequent data processing, more powerful and flexible. The co-ordinate can be used to provide geomorphologists with a variety of graphical and numerical data. These include basic planimetry, direct profiles and contours, DTM data processing and movement vectors.

5.1 Maps and plans

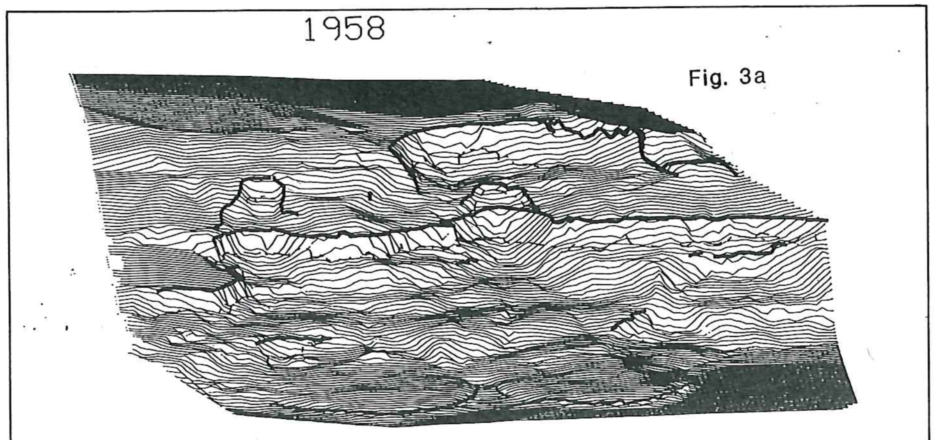
Delineation of boundaries between distinctive land units is a basic requirement in the production of both conventional and geomorphological maps. In geomorphology, the identification and categorisation of morphological boundaries is an important first step in the interpretation and understanding of process. A variety of geomorphological maps and coding systems are available (Cooke and Doornkamp, 1974) and important systems have been developed at the International Institute of Aerospace Survey and Earth Sciences (ITC) (van Zuidam, 1986) and also by Savigear (1965). Traditionally, geomorphological maps have been compiled by sketching detail onto a conventional large scale base map (van Zuidam, 1986). Techniques depend upon the map scale, but both field sketching and air photographs have been used. Non-rigorous or approximate photo-mapping techniques prevail, such as those used by geologists (Allum, 1965) and geographers (Lo, 1976).

The precise definition and coding of morphological boundaries by rigorous photogrammetric techniques combines the benefits of geomorphological interpretation with positional relevance. The visual comparison between plots at two widely differing epochs (Figure 3d) provides a basic tool that can be used to identify, quantify and interpret areas which display any degree of change.

5.2 Direct profiles and contours

The down-slope vertical profile and cross section are commonly used in geomorphology and engineering geology to illustrate the mechanisms of slope failure. They also provide the basic framework for subsequent slope stability analyses and for the design of remedial measures. Contours are widely used to represent relief and form on most topographic maps. Photogrammetry can be used to obtain both profiles and contours directly and provide the only practical means of obtaining high quality and high density data (Chandler *et al* 1987).

The measurement technique is 'non-contact' and retrospective; conse-



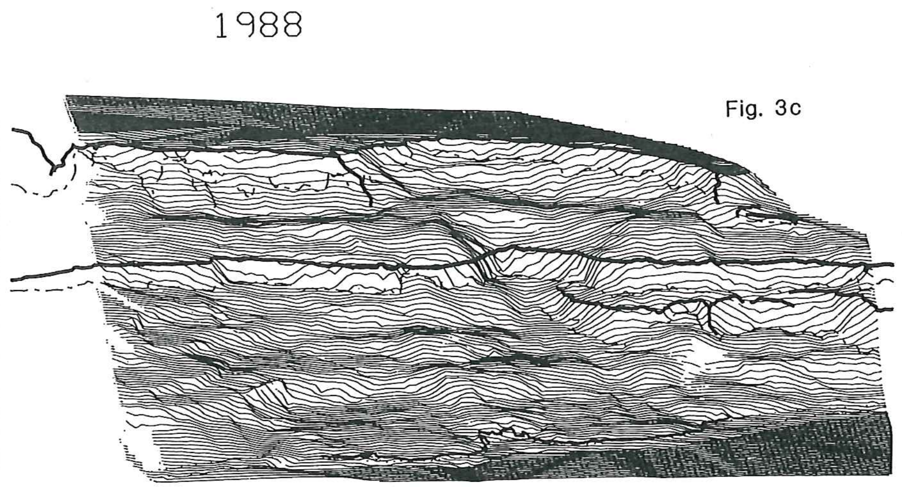


Figure 3a, b, c. Isometric views of grid (Black Ven 1958, 1969, 1988).

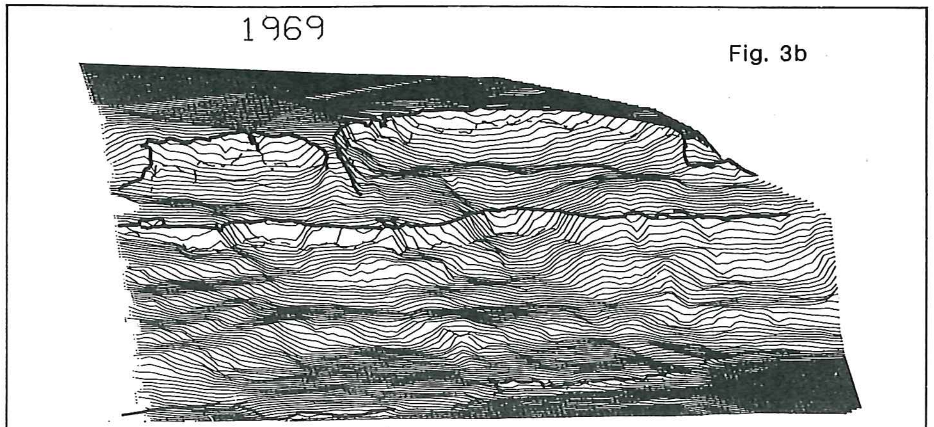
quently any plane can be measured with a density of data points that is variable. In the analytical plotter, measurement of data is controlled by interactive software and ensures only points representing the desired profile or contour are collected. Provided that the density of data points are high, an accurate representation of shape or form of the ground surface along the plane of interest can be displayed. The observation process can be repeated for the same plane, but using photography from a different epoch. A single plot combining these data will enable a direct and quantitative *morphogenetic* comparison between two widely separated epochs.

5.3 DTM data processing

The techniques that have been mentioned so far can all be regarded as two dimensional. Digital terrain modelling techniques use three dimensional data in order to provide either graphical or statistical forms of output. It is these techniques that really exploit the spatial quality of these data.

Several processing options are available, these and others are still being tested on the Black Ven case study. The techniques rely upon complex computing algorithms and require both a powerful computer and a comprehensive DTM software package.

5.3.1 Contour plots. Initial processing consists of triangulating the DTM co-



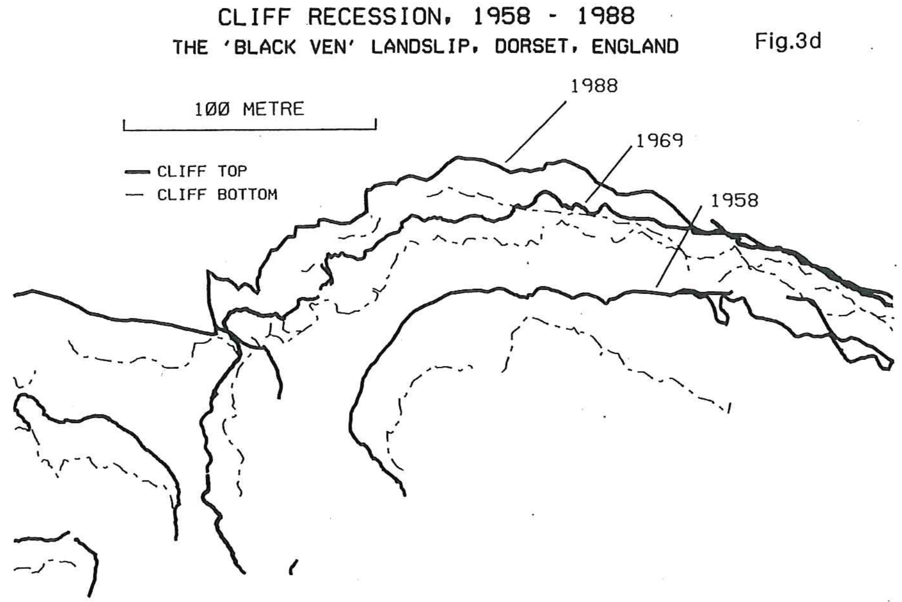


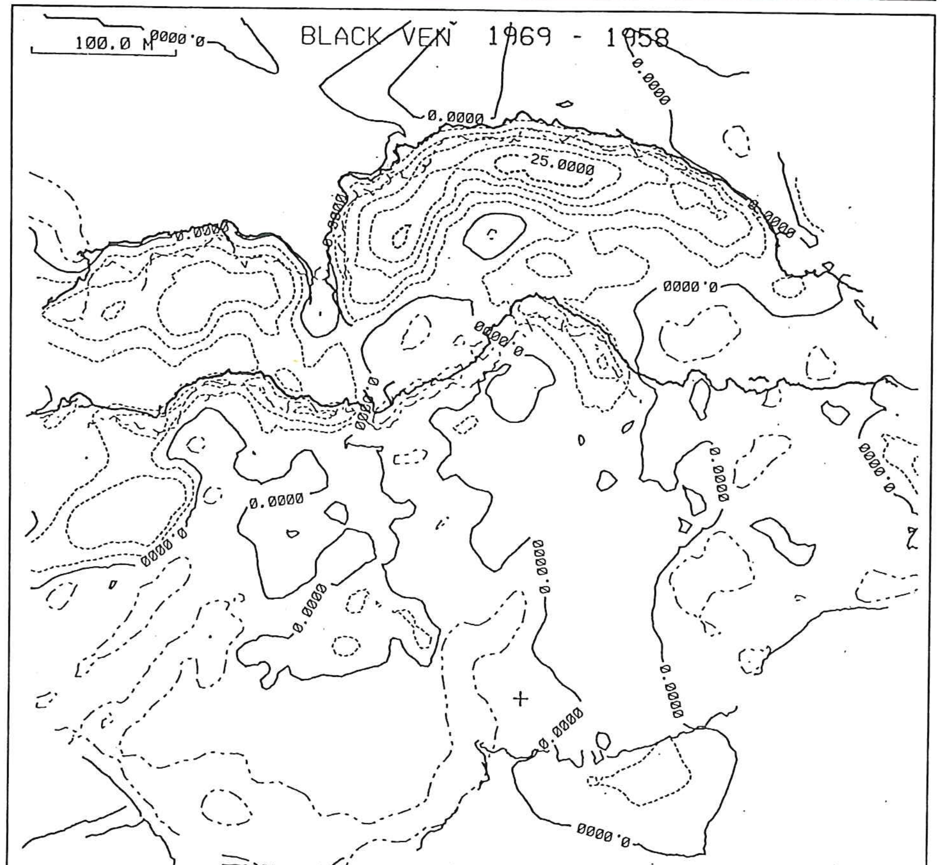
Figure 3d. Basic planimetric information (Black Ven 1958, 1969, 1988).

ordinates, so forming a faceted surface. This can be used to produce contours, portrayed by various symbologies. The contoured plot can give a reasonable representation of site morphology, indicating steep areas and breaks of slope. If a contour plot is overlain with morphological boundaries, the geomorphologist is provided with much of the spatial information necessary for interpretation.

5.3.2 Isometrics of grids (Figure 3a, 3b, 3c). A grid file can be produced from the triangulated surface and forms the basis for more advanced processing. The grid can be used to produce perspective and isometric plots which provide a good representation of site morphology.

The grid file can be used to provide cross sections and profiles anywhere on the site. This can be useful in identifying quantitatively areas which have experienced most change. It should be remembered that these sections can only be as accurate as the DTM itself, so a major factor is the density of the constituent DTM points. The best results can be obtained by measuring a profile directly (Section 5.2).

MAKING USE OF HISTORICAL PHOTOGRAPHS



KEY

ISOGRAMMES OF SURFACE DIFFERENCE (INTERVAL: 5.0M)

........MATERIAL LOSS —— NO CHANGE IN SURFACE LEVEL

– · – · –· MATERIAL GAIN

Figure 4. Surface of change (Black Ven 1969 – 1958).

5.3.3 Contours of difference (Figure 4). Although contour plans provide a full description of site morphology at the different epochs it is difficult to identify areas of change by mere visual inspection. One advanced technique consists of subtracting a grid surface produced at one epoch from a grid at an earlier epoch. This creates a grid surface which represents the change of form over the period defined by the photographs. This surface can be contoured, thus quantifying the effect of process. The interpreter must exercise caution as areas which appear to exhibit no change are not necessarily inactive regions. They can be areas where the input of material has equalled output, over the defined period. This problem can only be resolved by understanding the basic geomorphic processes.

By comparing two DTM's of difference, derived from three photographic epochs, it is possible to see the change in the distribution of geomorphic activity through time. This can be used for tentative predictions of future activity as it is possible to identify 'waves of aggression' which pass through a site. It is clear that this particular technique is illuminating and with careful interpretation can be very powerful.

5.3.4 Slope maps/histograms. Statistical forms of output can be useful also. The grid file can be used to create a grid file of slope angle. This can be contoured and used to produce a slope map, but can also be used to produce a histogram of the distribution of slope angle. This can be repeated for other photographic epochs and combined to show how the distribution changes with time (Figure 5). What is notable about the Black Ven landslide is that over the 42-year period in which the back scar has recessed by up to 100m, the distribution has changed remarkably little. The slope morphology has remained stable although the positions of the slopes have changed radically.

MAKING USE OF HISTORICAL PHOTOGRAPHS

5.3.5 Aspect maps/histograms. The standard grid file can also be used to produce aspect maps and slope orientation distributions. The former appear to be difficult to interpret but may be useful in the construction of a hazard map. The slope orientation distributions appear more useful as a notable shift in the distribution can indicate a change in the direction of activity.

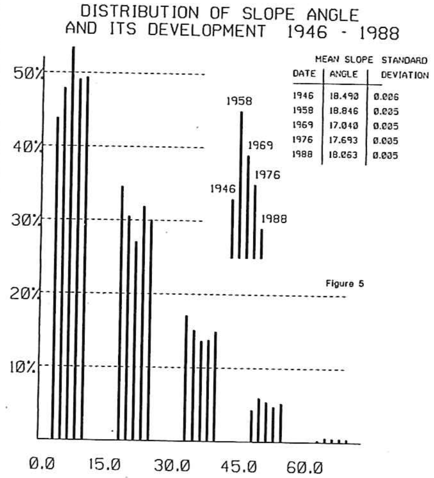


Figure 5. Distribution of slope angle and its development (Black Ven 1958, 1969, 1976, 1988).

5.3.6 Volume calculations. The real advantage of a DTM software package is the ability to produce information that in some way summarises the whole data set. The possibility of calculating volumes, from areas contained within a grid file, is one example. Volume calculations of the whole site between two epochs can be used to compute the volume of material that has been moved and lost from the system. The proper use of analytical photogrammetry with historical photographs enables a standard deviation to be associated with each co-ordinated point so it is possible to associate a standard deviation with the computed volume. This is obviously important when assessing the significance of a detected volumetric change.

5.3.7 Input/output analysis. By dividing the site into a series of systems, subsystems and units, volumes can be computed for each section. These can be combined to produce a volumetric analysis of the system components, known as a system budget. By knowing the morphological effects of each unit in the system, the geomorphologist can begin to understand the complex interrelationships and feedback between units in the subsystem and system as a whole.

5.3.8 Quantitative evolutionary models. The system budget can possibly be combined with mathematical models of process, which can theoretically enable the prediction of events. Such quantitative evolutionary models need to be extremely comprehensive in order to emulate the complex relationships between the factors controlling landform evolution. The Black Ven landslide is possibly too complicated to serve as a case study in these early stages of constructing such an evolutionary model.

5.4 Computation of displacement vectors

Analytical photogrammetry and historical photographs can be used to provide three dimensional vectors at specific points, these representing the rate of movement at these points. The vectors can be deduced by subtracting the three dimensional co-ordinate of a point at one epoch, from the co-ordinate of the same identifiable point at a subsequent epoch. This may be repeated for any number of points distributed over the whole site, so providing three dimensional vectors of displacement which are in their correct spatial relationship to each other. The sensitivity of the photogrammetric measurement can be increased by using alternative analytical procedures, providing suitable well defined targets can be measured.

With historical photography, points such as boulders, pieces of vegetation and prominent features on buildings must be used as targets. The main problem with these 'natural' targets is one of identifying the selected points at subsequent survey epochs. The retrospective quality of photogrammetry can help greatly with this problem. All photogrammetric measurement can be delayed until all of the historical photography has been acquired and only if points are identifiable on all sets of photographs.

The quantitative display of the pattern of movement is undoubtedly beneficial to the monitoring of a landslide. If failure does occur the sequence of photographs can be photogrammetrically re-examined, concentrating only upon the area of failure. Such a retrospective examination can establish the sequence of events prior to failure, so that the causal factors can possibly be identified.

6 Conclusion

One possible method of extracting positional data from historical photographs has been briefly outlined. The application of these techniques to a mudslide in Dorset has shown the potential of the method to provide geomorphologists with a variety of data. Initially, the method can be used to provide simple spatial data in a variety of conventional forms; map, contour, profile and isometric plots. More advanced data extraction and processing techniques can enable a quantitative analysis of the change in slope morphology and also the determination of movement vectors. The digital terrain modelling techniques are probably the most useful as they fully utilise the spatial quality of the photogrammetrically acquired co-ordinates.

It is important to realise that the approach is flexible and can be applied to any large scale photogrammetric survey using a hand held camera. The 1988 survey is an example of such an application.

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MARKET RESEARCH LAND INFORMATION SERVICES, SYSTEMS AND SUPPORT: AUGUST 1988

In the September issue of L&MS (Miscellany) *there was a brief story on the research commissioned by the Land Surveyors division of the RICS to examine the market for computerised land information systems and services. The research, conducted by John Rowley, managing consultant of Geobase, and Peter Shand, principal of Miles Arnold, was completed in August, and the Executive Statement is published below.*

A LAND INFORMATION SYSTEM IS . . .

1 An information system that includes data which is referenced to its location on the earth's surface using national grid co-ordinates, latitudes and longitudes, etc.

2 A system which links spatial referencing using co-ordinates to aspatial references such as addresses, post-codes, manhole numbers, legal document numbers, etc.

3 A system which gives the user alternative methods for viewing data using a text screen computer terminal or giving a map-reader's view at a graphics computer terminal.

4 A system that provides complete custom applications for every executive and clerical role without the inconvenience of manual-searching for bulky information such as maps.

5 A system that will record every class of environmental data, everything man-made, much about man himself, all unrelated except through spatial context: therefore the *only* way of answering complex questions about man and his environment.

LAND INFORMATION SYSTEMS YIELD BETTER DECISIONS ABOUT PEOPLE, PLACES & RESOURCES: SYSTEMS TO MAKE OUR LIVES BETTER THROUGH BETTER INFORMATION

The extent of the land information systems market-place

Market size

The market for LIS in the UK is substantial. Excluding maintenance and replacement systems, the LIS share of DP *capital* outlay is around £275m over a ten year forecast period. Adding in base-map supply, conversion of existing data, verification of data, configuration, networks, training, consultancy and project management the total LIS market over the same period will be in excess of £1.5b. Allowing for maintenance and replacement of systems and for the gradual assimilation of spatial data into the general market for information, continuing expenditure on all aspects is expected to run well beyond 2000.