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THE EXTRACTION OF POSITIONAL DATA FROM HISTORICAL PHOTOGRAPHS AND THEIR APPLICATION TO GEOMORPHOLOGY

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Abstract

A technique which enables spatial data to be obtained from historical photography is outlined. The method is applied to a 40 year sequence of oblique aerial photography of the Black Ven landslide in Dorset, England. Some of the possible data processing options are discussed and illustrated by some preliminary results produced from the Dorset landslide.

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 the estimation of process rates as these are characteristically slow (Thornes and Brunsden, 1977). If historical photography could be used to provide accurate spatial data and sufficient photography is available to form a time based sequence, then the effect of these processes could be accurately assessed and quantified. The symposium on photographic archives, held by the Photogrammetric Society on 29th March, 1988, showed the existence of a large supply of historical photography. This represents an untapped data source that geomorphologists and other earth scientists could use, provided that suitable photogrammetric techniques are developed. The research that will now be outlined is one such approach.

The Problems

Several problems can be identified when historical photographs are used for photogrammetric measurement:

(a) obtaining suitable photography for the sequence. This task would undoubtedly be easier if unconventional oblique imagery could be used;
(b) absence of conventional ground control;
(c) unknown internal geometry of camera; and
(d) definition of an identical datum at all epochs.

The Technique

The approach is based on computerised analytical procedures, primarily a self calibrating bundle adjustment. The replacement of the analogue stereoplotter with a digital mathematical model is flexible and now well established (Ghosh, 1979). Photographic pairs are still required, but these do not have to fulfill the tight rotational and positional requirements demanded by the analogue instrument. The photographic requirement is some degree of overlap and a reasonable base: distance ratio.

The whole technique can be simplified in several distinct sections (Fig. 1) which are carried out sequentially.

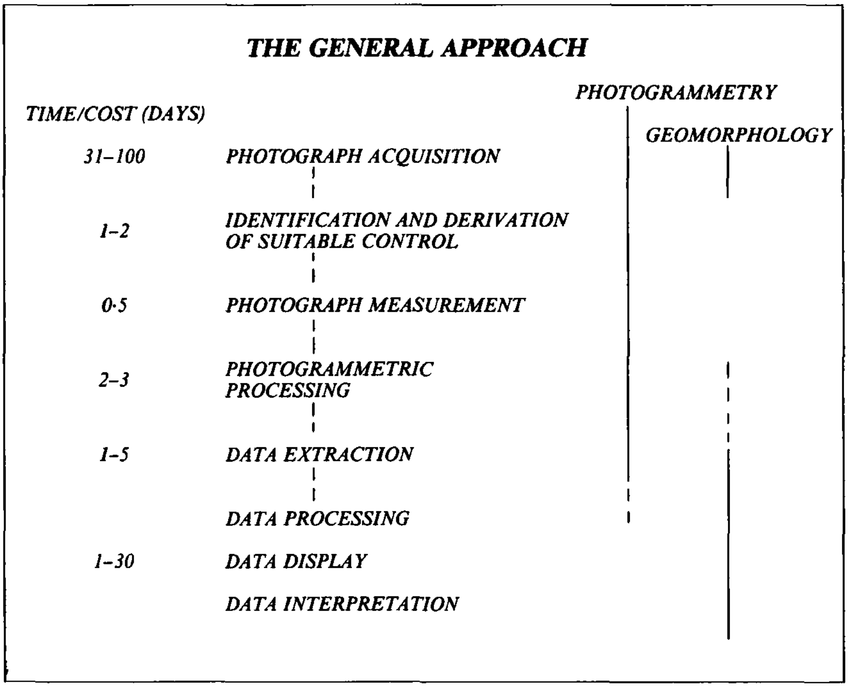

FIG 1.

Photograph Acquisition

Suitable sequential contact dispositives must be acquired from one of the archive sources. Many of these sources are now making use of computerised registers, so searches should become quicker.

Identification and Derivation of Control

Co-ordinated points will generally be unavailable, but control can be scaled from a large scale plan. Additional control can be provided by measurements between points. This can include natural information, such as zero height differences between points defining the boundary of a lake. The stochastic properties of all co-ordinates and measurements should be estimated, as the measurements are weighted in the final adjustment.

Photograph Measurement

The image positions of the control and pass points are measured using a stereocomparator. Reference points such as the corners or sides of the format can be used if suitable fiducial marks are not present.

Photogrammetric Processing

Processing consists of a suite of four programs, the fourth being the self calibrating bundle adjustment. In addition to estimating the exterior orientation parameters, this program enables the estimation of certain elements of inner orientation. Two groups can be identified:

(a) the primary inner orientation parameters, consisting of displacements of the principal point relative to the reference marks and a correction to an approximate camera principal distance; and
(b) the lens distortion parameters of an even powered polynomial which is used to model radial and 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. This is important as it enables inestimable parameters to be dropped in an over parameterised solution. Other important aspects of the program include the ability to use measurements between points. As the stochastic nature of co-ordinates and measurements is taken into account, data of various precision can be used. The adjustment overcomes rigorously many of the problems associated with historical photography.

Data Extraction

When a satisfactory adjustment 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 stereocomparator, but is more effective if an analytical stereoplotter is used. The Intergraph photogrammetric workstation at the City University allows two forms of data extraction. These are feature coding, involving the delineation of boundaries, with lines of selectable colours, linetypes and thicknesses, and digital terrain model (DTM) collection by extraction of a regular or grid DTM of varying size and density. Both of these programs enable high rates of data extraction, perhaps approaching 5000 points per day.

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 maps and plans can be produced anywhere of the site (Fig. 2), at a scale controlled by the quality of the data. There are also other potentially more useful methods of processing these data.

Case Study

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, Dorset. This was selected because it is the largest landslide complex in Europe and because it has shown marked changes in form over the last 50 years. Many of these changes have been recorded qualitatively by geomorphologists and geologists in the past (Arber, 1941; Brunsden, 1969; Conway, 1974). It was felt that to quantify this earlier work and to include additional survey epochs would be of distinct geomorphological importance.

A sequence of photography of the site was obtained and diapositives were made from the original negatives. The principal source was the University of Cambridge Committee for Aerial Photography and consisted mainly of small format oblique photographs. Originally the sequence began in 1948 and included epochs in 1958, 1966, 1969 and 1972. The sequence was completed in January 1988 by hiring a light aircraft and using a hand held Rollei 6006 camera. At present bundle adjustments have been computed for all the photograph epochs but positional data have only been extracted from the 1958, 1969 and 1988 surveys.

Results

One of the strengths of the analytical solution is the combination of a

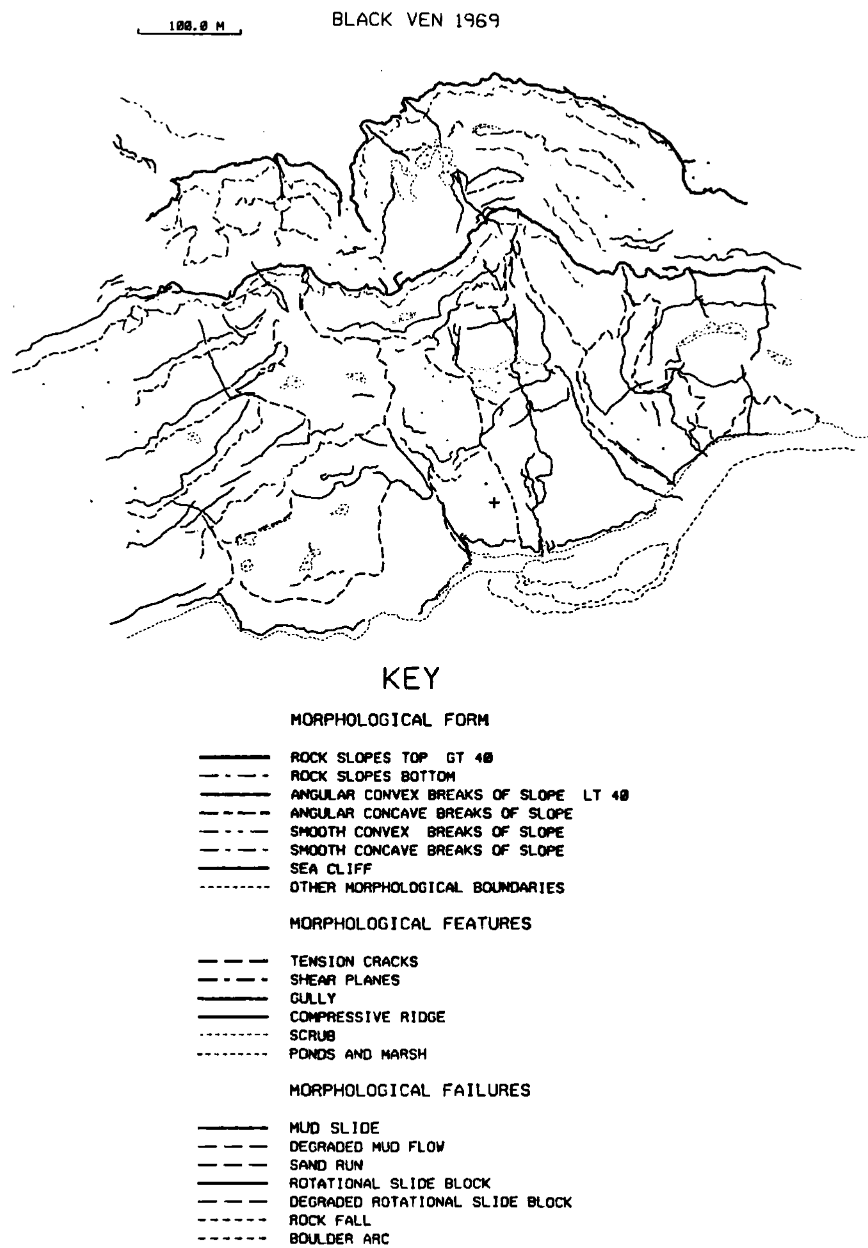

FIG. 2. Geomorphological site plan of Black Ven, 1969. The original plot was colour coded.

functional and stochastic model. During initial program execution reference to the residuals is important, as these indicate how well the measurements fit the functional model. Very large residuals indicate gross errors in either the plate measurements, the derivation of a survey measurement or in the scaling of the control co-ordinates. Smaller, non-random residuals indicate the presence of uncorrected systematic errors. If systematic errors are present, they can be detected by *a posteriori* analysis of the variance factor and a χ^2 goodness of fit test. This statistic also incorporates a global check on the stochastic model. If the residual errors are random in nature and the variance factor is significantly different from the *a priori* value, then incorrect standard errors might have been assigned to either the plate measurements, the co-ordinates or the survey measurements.

When the functional and stochastic models are deemed correct, an assessment of the quality of the final solution can be made. Principally this is in the form of an analysis of the standard errors of the estimated interior and exterior orientation parameters. Perhaps most importantly, the standard errors of the co-ordinates of points in the object space are also computed. It is apparent that the precision of these co-ordinated points varies throughout the site, depending upon the geometry. However, a global average for this case study would be approximately $\pm 1{\cdot}0$ m.

Further analysis of the solution can include the correlation between the parameters and the determination of internal and external reliability. These parameters can be useful for finding an optimum solution for the selected camera and measurement configuration.

Use of the bundle program does require some practice and understanding. It also has to be executed several times with slight modifications to the raw data files and the number of internal parameters that are selected. Different combinations of the internal parameters can be more effective in the modelling of the internal geometry. In addition, if there is insufficient redundancy, only a limited number of the internal parameters can be determined reliably. The use of the iterative self calibrating adjustment is to an extent iterative itself.

Data Processing for Geomorphology

As mentioned previously, maps and plans can be produced at any scale and of any section of the site. Relevant morphometric measurements can be obtained and therefore erosion rates can begin to be estimated (Chandler *et al.*, 1987). Although this is of some use to the geomorphologist, the full three dimensional quality of the data is being unused. Digital terrain modelling uses full spatial data in order to provide either graphical or statistical forms of output.

Several processing options are available (Fig. 3); these and others are still being explored. Most rely upon complex computing algorithms and so require both a powerful computer and a comprehensive software package.

Contour Plots

Initial processing consists of triangulating the raw co-ordinates, so forming a faceted surface. This can be used to produce contours, portrayed by various methods and symbologies.

Isometrics of Grids

A grid file can be produced from the triangulated surface, this file forming the basis for more advanced processing. The grid can be used to produce perspective and isometric plots, though these can only be of qualitative interest (Fig. 4).

Contours of Difference

One advanced technique consists of subtracting a grid surface at one epoch from a grid at an earlier epoch. This produces a grid surface which represents the change of form over the period defined by the photographs. By contouring this surface, the effect of process can be quantified and with careful interpretation can be very powerful (Fig. 5).

Slope Maps and Histograms

The vertical derivative with respect to height produces a grid of slope angle. This can be used to produce a slope map, but can also be used to produce a histogram of the distribution of slope angle at each epoch. These can be compared and correlated with process (Fig. 6).

Aspect Maps and Histograms

Similarly, the first horizontal derivative with respect to height produces a grid of facet orientation. Aspect maps and slope orientation distributions can then be produced.

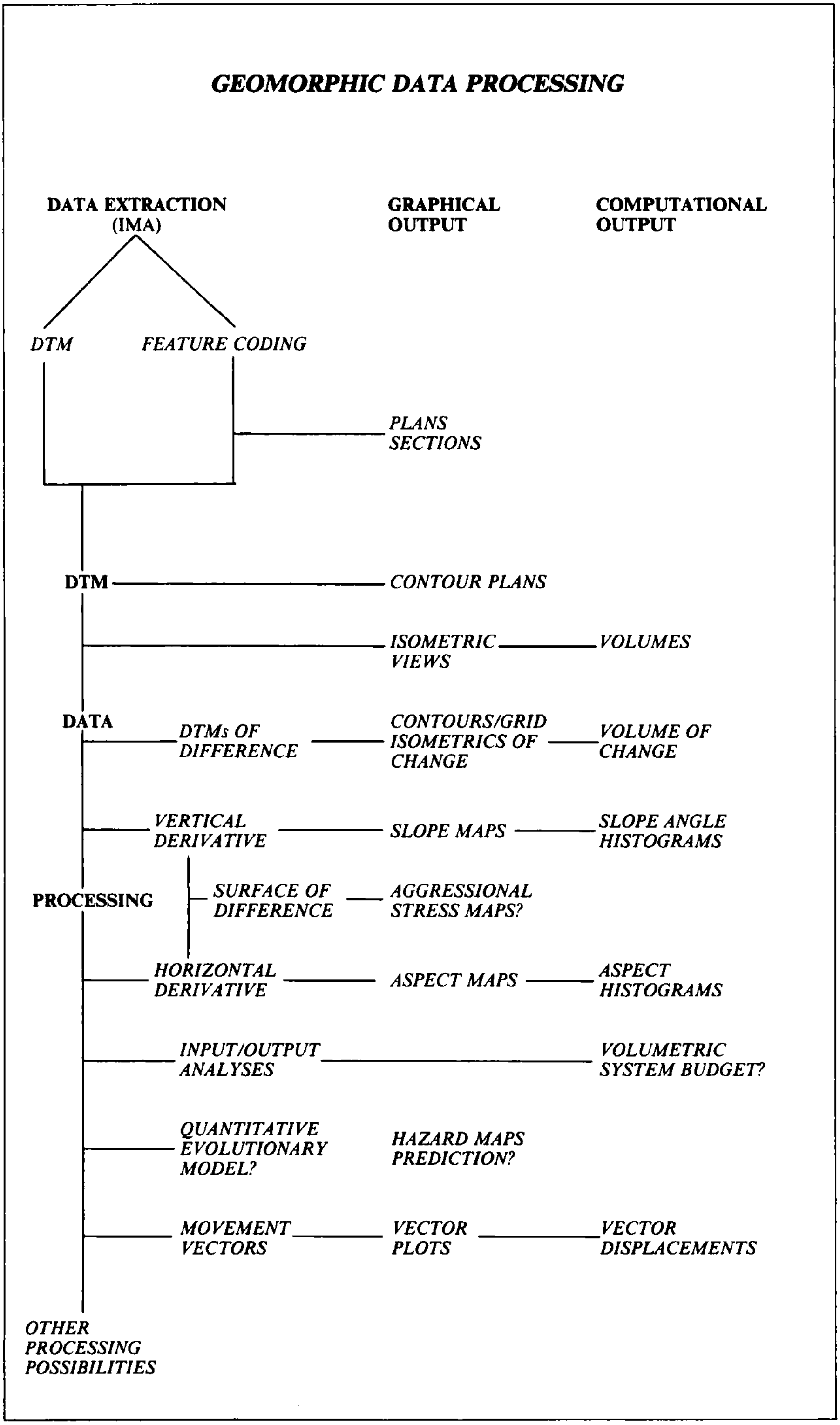
GEOMORPHIC DATA PROCESSING
DATA EXTRACTION (IMA)
GRAPHICAL OUTPUT
COMPUTATIONAL OUTPUT
DTM
FEATURE CODING
PLANS SECTIONS
DTM
CONTOUR PLANS
ISOMETRIC VIEWS
VOLUMES
DATA
DTMs OF DIFFERENCE
CONTOURS/GRID ISOMETRICS OF CHANGE
VOLUME OF CHANGE
VERTICAL DERIVATIVE
SLOPE MAPS
SLOPE ANGLE HISTOGRAMS
PROCESSING
SURFACE OF DIFFERENCE
AGGRESSIONAL STRESS MAPS?
HORIZONTAL DERIVATIVE
ASPECT MAPS
ASPECT HISTOGRAMS
INPUT/OUTPUT ANALYSES
VOLUMETRIC SYSTEM BUDGET?
QUANTITATIVE EVOLUTIONARY MODEL?
HAZARD MAPS PREDICTION?
MOVEMENT VECTORS
VECTOR PLOTS
VECTOR DISPLACEMENTS
OTHER PROCESSING POSSIBILITIES

FIG. 3.

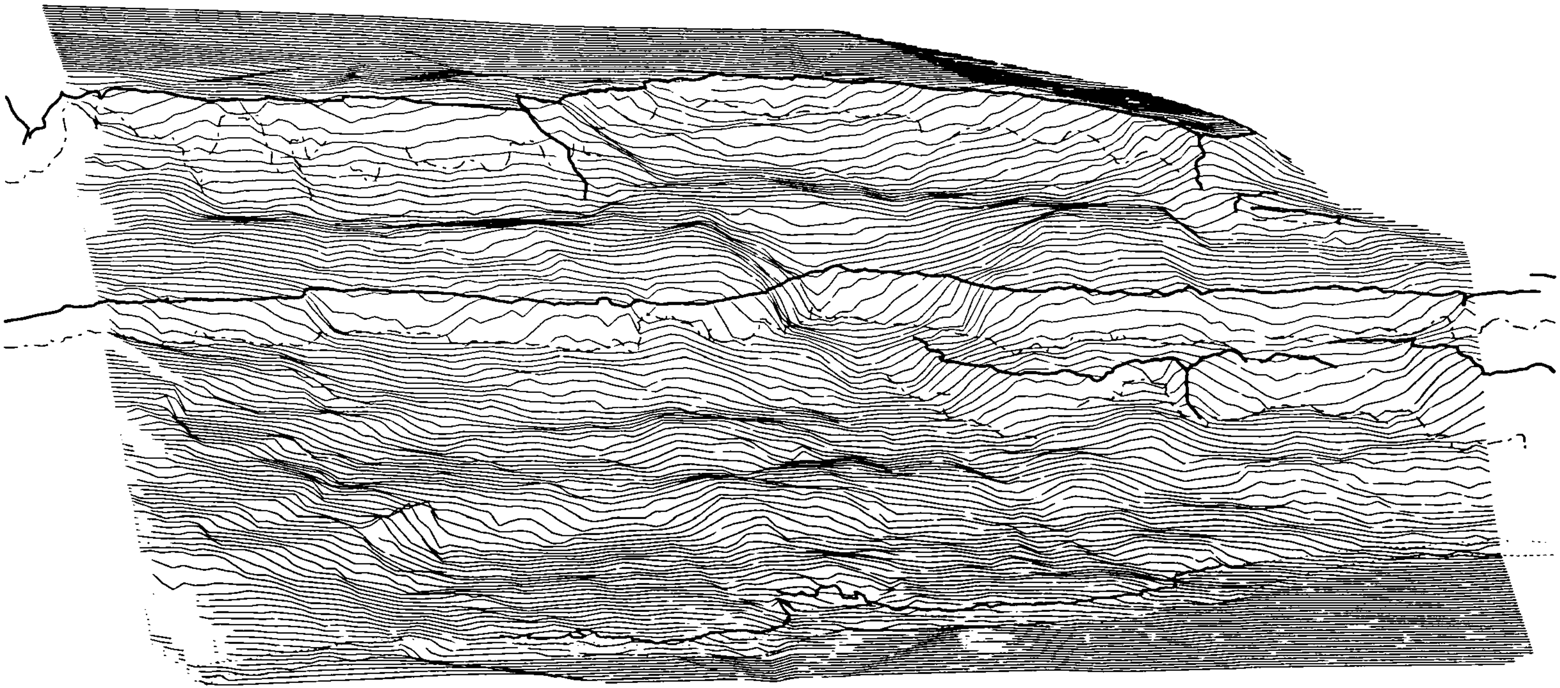

FIG. 4. Isometric view of Black Ven, 1988.

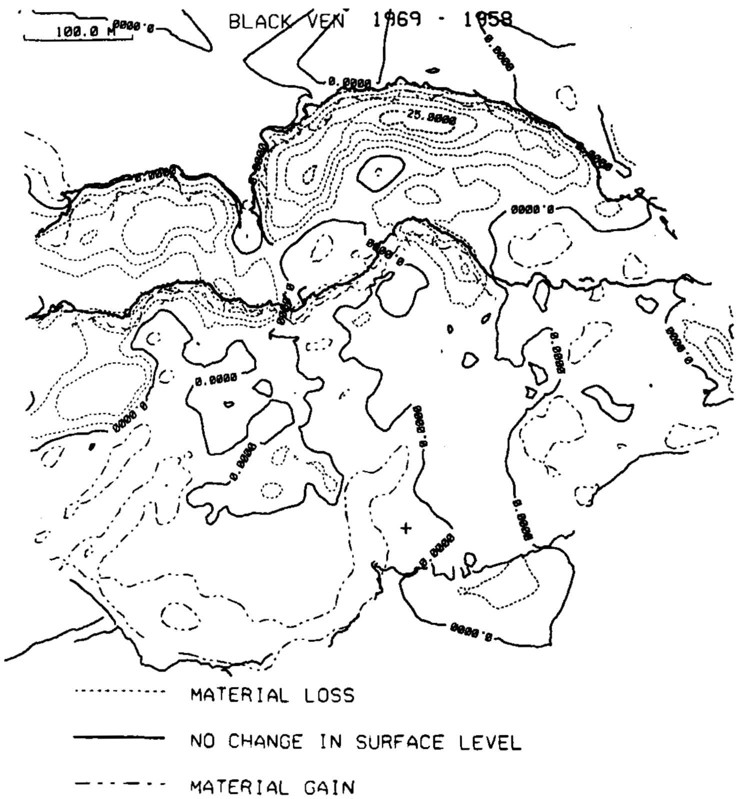

FIG. 5. Surface of change between Black Ven in 1969 and 1958.

Volume Calculations

One of the major advantages of the DTM method is the ability to compute summarising statistics. One such statistic is the volume, which can be computed from an area contained within a grid file. Theoretically it is possible to associate a standard error with the computed volume. This is obviously important when assessing the significance of a detected volumetric change.

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.

Quantitative Evolutionary Models

The system budget can possibly be combined with models of process, so forming a quantitative evolutionary model. This can then possibly be used for prediction.

CONCLUSION

One possible method of extracting positional data from historical photographs has been outlined briefly. The application of these techniques to a landslide in Dorset has shown the potential of the method, especially when used in conjunction with digital terrain modelling techniques. 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.

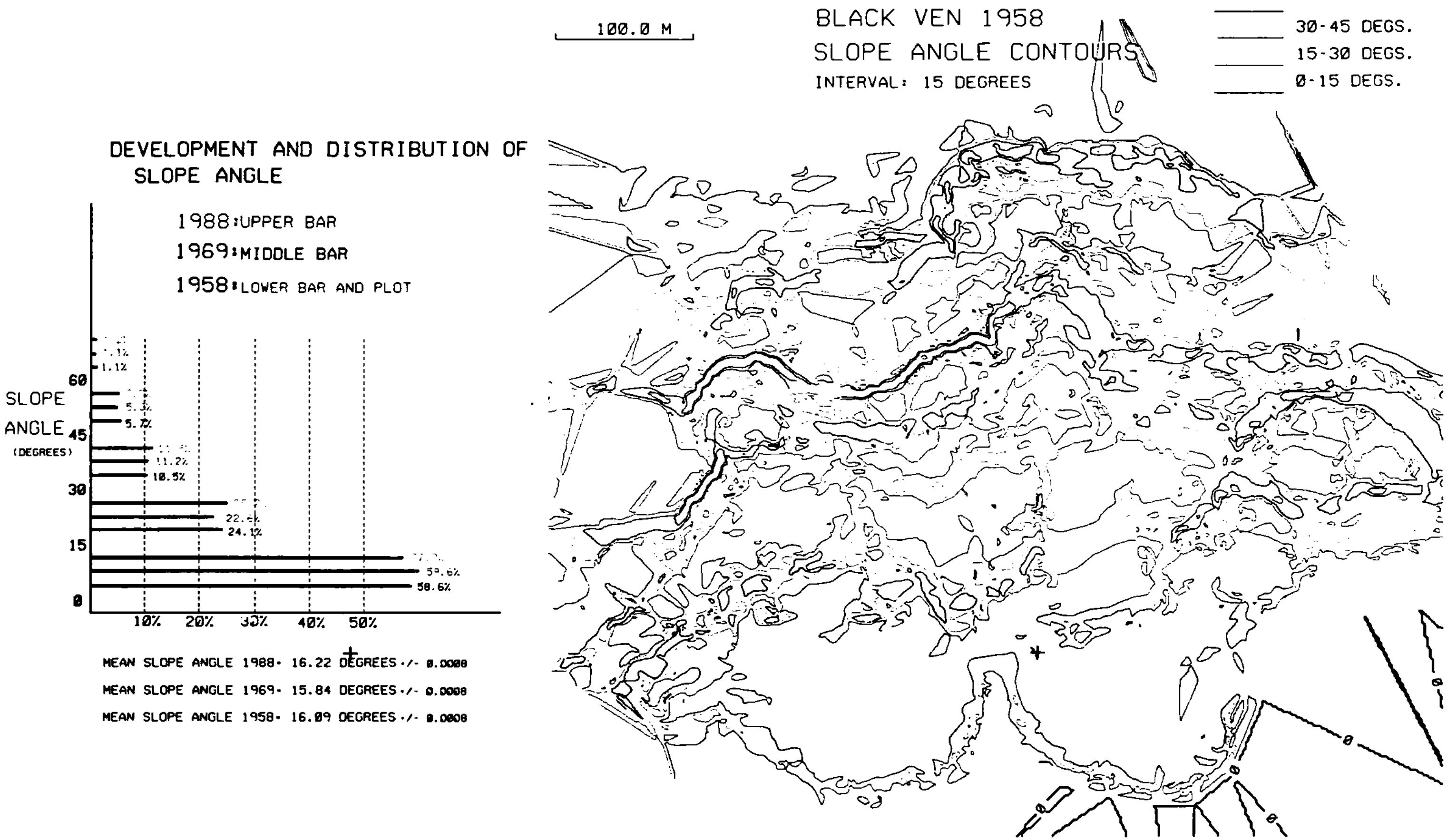

FIG. 6. Slope map and time based histogram for Black Ven in 1958, 1969 and 1988. The original plot was colour coded.

REFERENCES

ARBER, M. A., 1941. The coastal landslips of west Dorset. *Proceedings of the Geologists' Association*, 52(3): 273–283.

BRUNSDEN, D., 1969. Moving cliffs of Black Ven. *Geographical Magazine*, 41(5): 372–374.

CHANDLER, J. H., CLARK, J. S., COOPER, M. A. R. and STIRLING, D. M., 1987. Analytical photogrammetry applied to Nepalese slope morphology. *Photogrammetric Record*, 12(70): 443–458.

CONWAY, B. W., 1974. *The Black Ven landslip, Charmouth, Dorset.* NERC Institute of Geological Sciences Report No. 74/3. H.M.S.O., London. 16 pages.

GHOSH, S. K., 1979. *Analytical photogrammetry.* Pergamon Press, New York. 203 pages.

THORNES, J. B. and BRUNSDEN, D., 1977. *Geomorphology and time.* Methuen and Co. Ltd., London. 208 pages.

Résumé

On présente un procédé qui permet d'obtenir des données géographiques localisées à partir de photographies anciennes. On a appliqué la méthode au glissement de terrain de Black Ven, au Dorset (Angleterre), en se servant d'une séquence de prise de vues aériennes obliques échelonnées sur 40 ans. On examine quelques possibilités de traitement des données en les illustrant des résultats préliminaires obtenus sur le glissement du Dorset.

Zusammenfassung

Darstellung eines Verfahrens zur Ermittlung von raumbezogenen Daten aus historischen Fotos. Die Methode wird auf eine vierzigjährige Folge von Schrägluftbildern des Black-Ven-Erdrutsches in Dorset, England angewendet. Einige der Möglichkeiten zur Datenverarbeitung werden diskutiert und an Hand einiger vorläufiger Ergebnisse von dem oben genannten Erdrutsch veranschaulicht.