

DEVELOPMENTS IN APPLIED GEOMORPHOLOGICAL SURVEY AND MAPPING¹

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ABSTRACT

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Considerable progress has been made in the standardization of concepts and legends of geomorphological maps. Diversity inevitably persists where applied maps are concerned. Three types can be distinguished: *analytical geomorphological maps* emphasizing morphogenetic and chronological aspects, *synthetic (holistic) geomorphological maps* encompassing also terrain parameters related to soils, hydrology, etc., and *pragmatic maps*, tailor-made for specific purposes, such as natural hazard zoning.

The contents of applied geomorphological maps can either be derived from analytical and/or synthetic data or be decided upon prior to the survey. Storage of all data gathered in a geobased information system and the subsequent retrieval of the data relevant for specific purposes only, holds a promise for the future.

INTRODUCTION

The present day concepts of geomorphological survey and mapping gradually emerged in the last few decades from two rather different sources.

First, systematic in-depth geomorphological studies resulted in analytical geomorphological maps. These are predominantly monodisciplinary and apart from giving information on landforms and exogenous processes, they emphasize matters of morphogenesis and morphochronology and they also may include morphostructural aspects.

Secondly, the relationships are investigated between the geomorphology of the land on the one hand and diversified elements of the natural environment on the other. These relationships are placed in the context of landscape ecological surveys of 'terrain' or environment and result in synthetic (holistic) maps. Such surveys are characteristically multidisciplinary and integrate geomorphological data particularly on landforms with data on lithology, soils and sediments, vegetation, surface and groundwater conditions. Increasingly also exogenous processes are included.

Therefore, the two approaches, analytical and synthetic, are obviously complementary: the analytical survey providing

mapping units and the in-depth geomorphological information; the synthetic survey contributing the environmental context and landscape ecological interrelationships. Applied geomorphological maps in some cases can be derived from analytical geomorphological maps whereas in other cases synthetic maps may lead to terrain classification for specific purposes.

Usually, however, a third, pragmatic approach is nowadays opted for the purpose during which the data gathering concentrates on those types of information which are considered relevant for the specifications set for the survey. A variety of applied maps exists that comes under this third category of pragmatic geomorphological maps. Fig. 1 illustrates this.

ANALYTICAL GEOMORPHOLOGICAL SURVEY AND MAPPING

Essential aspects in analytical geomorphological mapping are (1) morphology (i.e. morphology and morphometry), (2) morphogenesis (morphostructure and morphodynamics), (3) morphochronology and (4) morpho-arrangement.

The mapping incorporates both static and dynamic aspects and the latter give an unique position to the geomorphological mapping in the domain of earth sciences.

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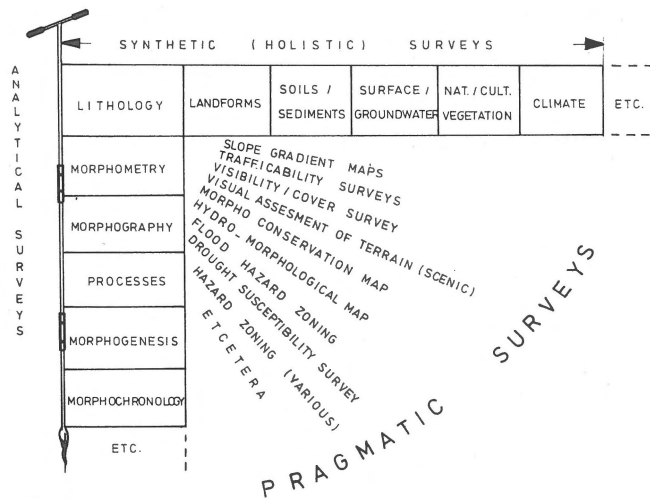


Fig. 1
Three main approaches to Geomorphological surveying: Analytical, synthetic and pragmatic.

Leaving apart a few earlier attempts, analytical geomorphological mapping has taken shape since the nineteen fifties. HELBING (1952) produced a 1:25 000 geomorphological map of the Sern Valley in Switzerland where ANNAHEIM (1956) was also among the early advocates. In France, CHOLLEY ET AL. (1956) published a geomorphological map of the Paris Basin and TRICART (1959) and his group of the CGA at Strasbourg surveyed the Senegal Delta for purposes of development. A particular important impetus came from Poland where KLIMASZEWSKI (1956, 1958) and his school in Krakow and GALON (1962) in Toruń launched a countrywide systematic geomorphological survey resulting in a map series at the scale of 1:50 000.

The Commission on Geomorphological Survey and Mapping of the International Geographical Union has aided the standardization of the concepts and the legends of geomorphological mapping in various countries. These are not mentioned here, with the exception of the 1:50 000 map series of The Netherlands devised by MAARLEVELD ET AL. (1974) and the widely used system of geomorphological mapping developed at the International Institute for Aerial Survey and Earth Sciences (ITC) (VERSTAPPEN, 1970; VERSTAPPEN & VAN ZUIDAM, 1975).

SYNTHETIC GEOMORPHOLOGICAL SURVEYS

Geomorphology has a leading role in synthetic surveys for delineating the mapping units, mainly because landforms are more readily recognisable in the field and on aerospace imagery than most other environmental parameters. All of these parameters are, of course, on an equal footing for determining the inherent characteristics and assessing the potential of every terrain unit distinguished.

Early synthetic landsurveys date back to the nineteen-thirties but the method got well established when the Land

Research and Regional Survey Division of the CSIRO (Commonwealth Scientific and Industrial Research Organisation) launched landsystem surveys in Australia and in Papua/New Guinea (CHRISTIAN & STEWART, 1953, 1968). Aerial photograph interpretation has always been an essential part of the survey work. Field surveying consists of quick observations by a team of experts along transects and in detailed observations on landform, soil, vegetation and hydrology at characteristic sites. Comparable methods have also been developed in other countries, such as by the Land Resource Division of the Directorate of Overseas Surveys (DOS) in the U.K. (BRUNT, 1967), in the USSR (VINOGRADOV, 1968; ISACHENKO, 1973). At the ITC, The Netherlands, a System for (synthetic) Terrain Classification has been developed by VAN ZUIDAM & VAN ZUIDAM-CANCELADO (1979) which leans heavily on geomorphology and is interlinked with the already mentioned ITC System of (analytical) Geomorphological Survey. Four hierarchical classification levels are recognized, i.e.:

1. Terrain components. On this level there are no generalizations in areal classes and no or minor generalizations in detail. They form the smallest terrain classes in which relief is most important as a classification criterion. The units are basically uniform in landform, lithology, soil, vegetation and processes, but one terrain form or characteristic may be predominant. The map scale, in which such terrain components are represented, is generally 1:10 000 or larger.
2. Terrain units refer to one landform or a homogeneous landform complex related to a particular terrain characteristic or pattern of terrain components. The terrain units reflect external and internal characteristics distinct from those of surrounding landforms (to which they are genetically related) within the same terrain system. Relief, lithology and genesis are the main classification criteria. The map scale in which only landforms/terrain units are represented may vary from 1:10 000 to 1:50 000.
3. Terrain systems refer to a landscape unit of characteristic relief development in a certain ecologic environment, frequently determined by genesis, lithology and climate. The map scale, suitable for depicting the terrain systems, is, in principle, larger than 1:250 000.
4. Terrain provinces are the largest units into which associations and complexes of terrain systems and units are combined. A province is basically uniform in broad genetic, climatic or lithologic characteristics. The suitable map scale is frequently smaller than 1:250 000.

Basically, the terrain classification map may be simply made up of black unit boundaries and letter and number symbols. Geomorphologic properties but also other terrain characteristics related to e.g. soils, hydrology and vegetation/land use may be incorporated in the description of the mapping units.

PRAGMATIC GEOMORPHOLOGICAL SURVEYS

Applied geomorphological maps for specific purposes can be derived from the analytical and/or synthetic data gathered. In the case of the ITC System of Geomorphological Survey this has been attempted for erosion/conservation studies (morphoconservation maps) and for hydrological purposes (hydromorphological maps). It gradually became evident, however, that since for most applied studies not the complete range of analytical/synthetic information is required, it is often more efficient to concentrate from the onset only on those parameters which are relevant for the purpose at hand. In fact a variety of types of pragmatic geomorphological surveying has already developed.

They range from straightforward slope gradient maps e.g. for agricultural uses, through trafficability (foot- and vehicle movement) surveys, and visibility/cover surveys serving military purposes, maps for visual (scenic) assessment of terrain made in connection with nature conservancy or recreation and morphoconservation, and hydrogeomorphological maps already mentioned, to natural hazard surveys of various kinds.

Fig. 1 shows the three major types of geomorphological survey: the in-depth analytical surveys, the broadscoped synthetic surveys and the numerous types of pragmatic surveys.

NATURAL HAZARD SURVEYS

Natural hazard surveys carried out in the framework of disaster mitigation programmes are becoming increasingly important because of the great losses in life and property, particularly in densely populated areas. The subject has been dealt with at some length by one of us (VERSTAPPEN, 1983); it is

essentially a multidisciplinary issue. It is evident that in order to mitigate the damage if and when disaster strikes, the hazard situation should be studied and assessed in advance. A hazard or risk zoning should be established and the state of preparedness for disaster should be optimised. The methodology involved includes matters such as: monitoring the hazard (gauging of rivers; surveillance of volcanoes), surveying spatial patterns of hazard susceptibility, hazard/risk zoning, setting up an early-warning system, formulating building codes, land use planning, planning of emergency/relief operations and post-disaster planning.

The geomorphological map in such cases will usually be complemented by a hazard zoning map for use by the authorities. A potential damage or vulnerability map may be prepared in connection with it. Furthermore the geomorphologist may be involved in monitoring the hazard or advise on several of the issues just mentioned. His main contribution is the hazard zoning, for which co-operation with other earth scientists may be required. His main counterparts are engineers who will have to devise an appropriate design for engineering structures, government authorities and other decision makers who have to legalize the hazard zoning, create and/or increase the hazard-awareness of the public, organize an early-warning system and prepare a scenario for use when a disaster occurs.

Natural hazards can be divided into those of endogenous origin (mainly earthquake and volcanic hazards), those of exogenous origin (floods, drought, accelerated erosion, mass movements, avalanches, etc.) and those of anthropogenous origin (man-made structures, earthquakes induced by reservoir lakes, subsidence resulting from the extraction of natural gas/oil or water or from the compaction of peat). Fig. 2 gives an overview of the diversity of hazard types. It also shows the interrelationships that exist between the three main groups of hazard types.

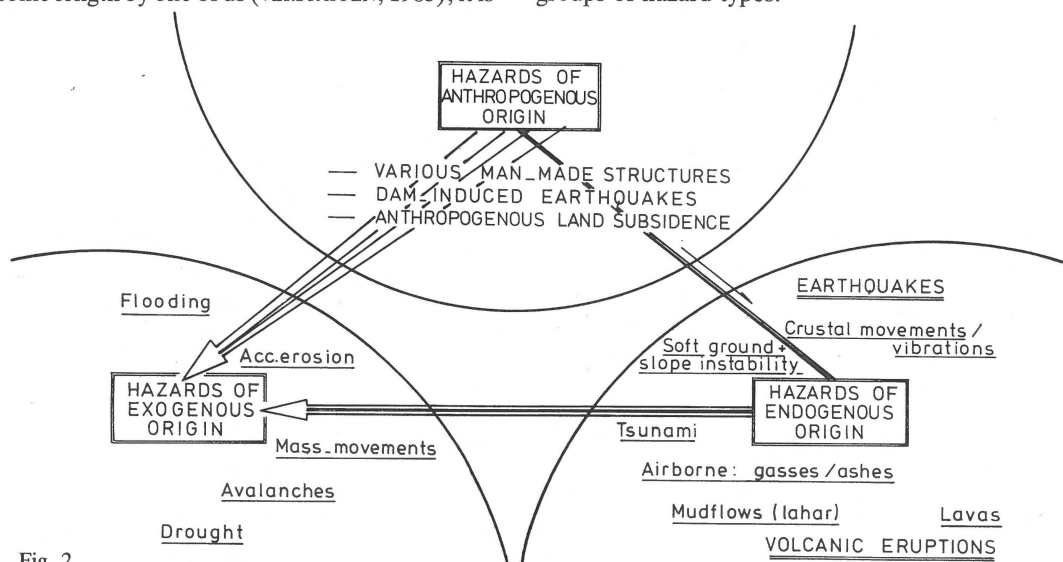


Fig. 2
Main natural hazards and their three interrelated types of origin: Exogenous, Endogenous and Anthropogenous. Arrows show interrelationships.

Anthropogenous factors are important catalysers of exogenous processes and thus aggravate the situation with respect to hazards of exogenous origin. The anthropogenous effect on hazards of endogenous origin is slight but endogenous factors in their turn may give rise to exogenous processes such as volcanic mudflows, thus increasing the exogenous hazards. The thickness of the arrows of Fig. 2 illustrates the situation.

For each of these types of natural hazard surveys a specific set of geomorphological criteria has to be selected and tailor-made legends are now gradually evolving. Flood susceptibility surveys and flood hazard zoning have been developed particularly in the deltaic lowlands of East and Southeast Asia where flooding is a major problem (OYA, 1973; 1977). Drought susceptibility is an important issue in the Sahel zone. A pilot survey has been carried out by ITC in co-operation with the University College of Botswana in the Makgadikgadi Pans Area (VERSTAPPEN & COOKE, 1982).

Avalanche surveying, logically, is a speciality of Alpine and Nordic countries. In fact, recent developments of pragmatic applied geomorphological surveying have occurred in those areas where the problems are most manifest.

AUTOMATION AND INPUT IN GEOBASED INFORMATION SYSTEMS

A chief aim of a geobased information system is to utilize computer stored maps of a varied nature in order to rapidly make new maps for specific purposes. These new maps are based on re-combinations of the attributes stored, or by rating of selected mapping units. A practical barrier is the filling up of the data base with the required relevant terrain attributes or 'land' attributes in the wider sense of the word. A geomorphological map or a terrain classification map based on the geomorphology is a rich source of information to fill up a data base with many attributes.

Generally the raster mode is used for storage of spatial data. All attributes are stored per cell and each mapping unit is a polygon consisting of cells. This mode allows easy manipulation of the attributes. The other mode of storage, the vector mode allows high quality output in the form of line maps, but manipulation requires sophisticated equipment. In the vector mode the lines of the polygons are defined by position vectors. Conversion from one to another creates an ideal situation.

Filling up the data base

Three approaches are in use:

1. A cell by cell input of attributes (single or in combination). We do not advocate this method for geomorphological input data, as this method negates the efficient use of mapping units (KUNA RAJ, 1974; ROWE & SHEARD, 1981).

2. Interpolation of point data. The nature of certain data, such as borehole data or meteorological data, may require such an operation.

3. Preparation of maps consisting of mapping units of a complex nature; geomorphological maps, soil maps and the like, followed by digitizing and conversion of the polygons to cells.

Maps showing single attributes, such as slope steepness values, soil texture and soil depth, hydrological properties of surface materials and so on, may be derived from the complex input map by software operations. This is by far the most efficient way to fill up a data base and use is made of the fact that a geomorphological map contains information on lithology, slope forms, process and surface materials.

DERIVATION OF THE MAPS

The state of the art in obtaining a geomorphological or terrain classification map may be described as follows:

– Digital processing of Landsat data of various dates, using image enhancement techniques, to obtain the best interpretable image. The large difference in information on scenes of different dates is shown in Fig. 3, which pertains to the area south of Zaragoza (Spain). This area is used in the discussion further on.

After geometric corrections, Landsat imagery is very suitable as a base map (DONKER & MEIJERINK, 1977). Certain geomorphological units can be delineated straightaway, others have to be transferred onto it from other sources. This method is particularly suitable in areas with poor topographic maps or for small scale surveys.

– Completion of the map by aerial photo-interpretation. The aerial photograph of Fig. 4 shows certain geomorphological units which could not be identified and delineated on the Landsat images.

– Collection of field data and checking of the interpreted units. For many purposes it is necessary to collect data on superficial materials and soils. Since the various attributes in the mapping units may vary, it is useful to consider the sample size within each unit. The number of samples per mapping unit depends on the accuracy wanted as is given by the equation $n = 4(\sigma/L)^2$, where n is the sample size, σ the standard deviation, and L the desired level of accuracy in percents (SNEDECOR & COCHRAN, 1967).

– The last step is the finalisation of the results and storage in the data base.

MAPPING UNITS AND ATTRIBUTES

It should be understood that the mapping procedure described is based on identified units, as they are found in the areas of interest. The ITC system of surveying and mapping is

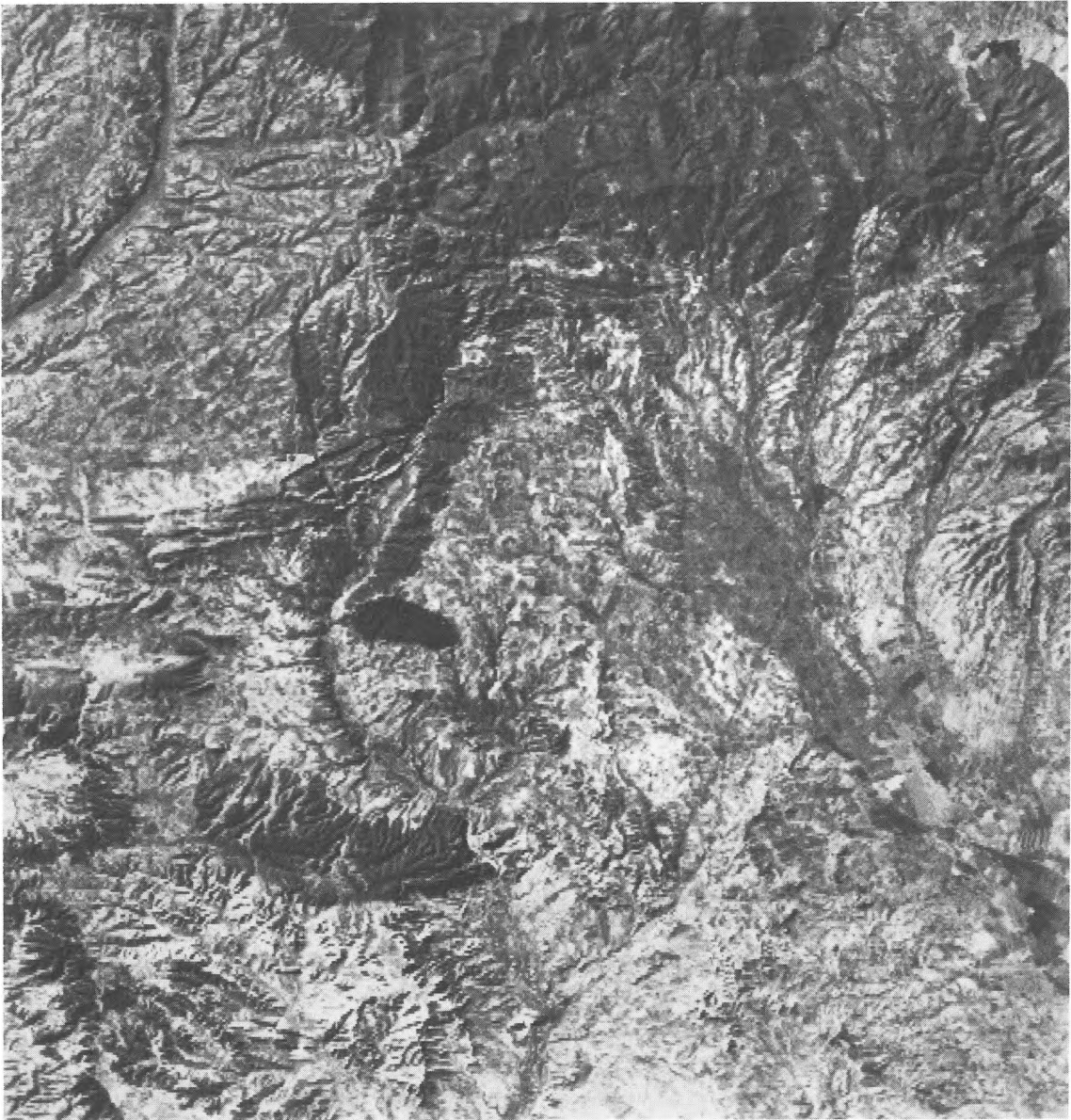


Fig. 3

Example of a geometrically corrected Landsat image, which may serve as a base map. Deconvolution has been applied to enhance relief features. Area: Spain, Cariñena, S. of Zaragoza.

quite suitable for the acquisition of input attributes, because it is flexible and may incorporate synthetic elements at a lower hierarchical level. The units often consist of associations of more homogeneous sub-units, particularly at reconnaissance scales. The scale of mapping is dictated by considerations of time and money. This implies that an analysis of variance may easily lead to the conclusion that for certain attributes, the units do not differ from each other.

However, this forms no objection to retain the units. Statistical analysis is a useful tool to obtain an insight in the variation of the attributes within units and between units. Statistics or algorithms do not result in superior maps, but do influence the decision procedures for transformation. For a

thorough discussion of this subject, we refer to ROWE & SHEARD (1981).

Insight in the nature of the units is required for a selection of the decision rules to transform the contents of the data base into thematic maps. This point is illustrated by discussing a single, but important, geomorphological attribute 'slope steepness'.

Attribute: slope steepness

In the currently used land classification procedures, slopes are grouped in classes with increasing ranges of intervals. The use of such classifications assumes in fact, that the slopes within a

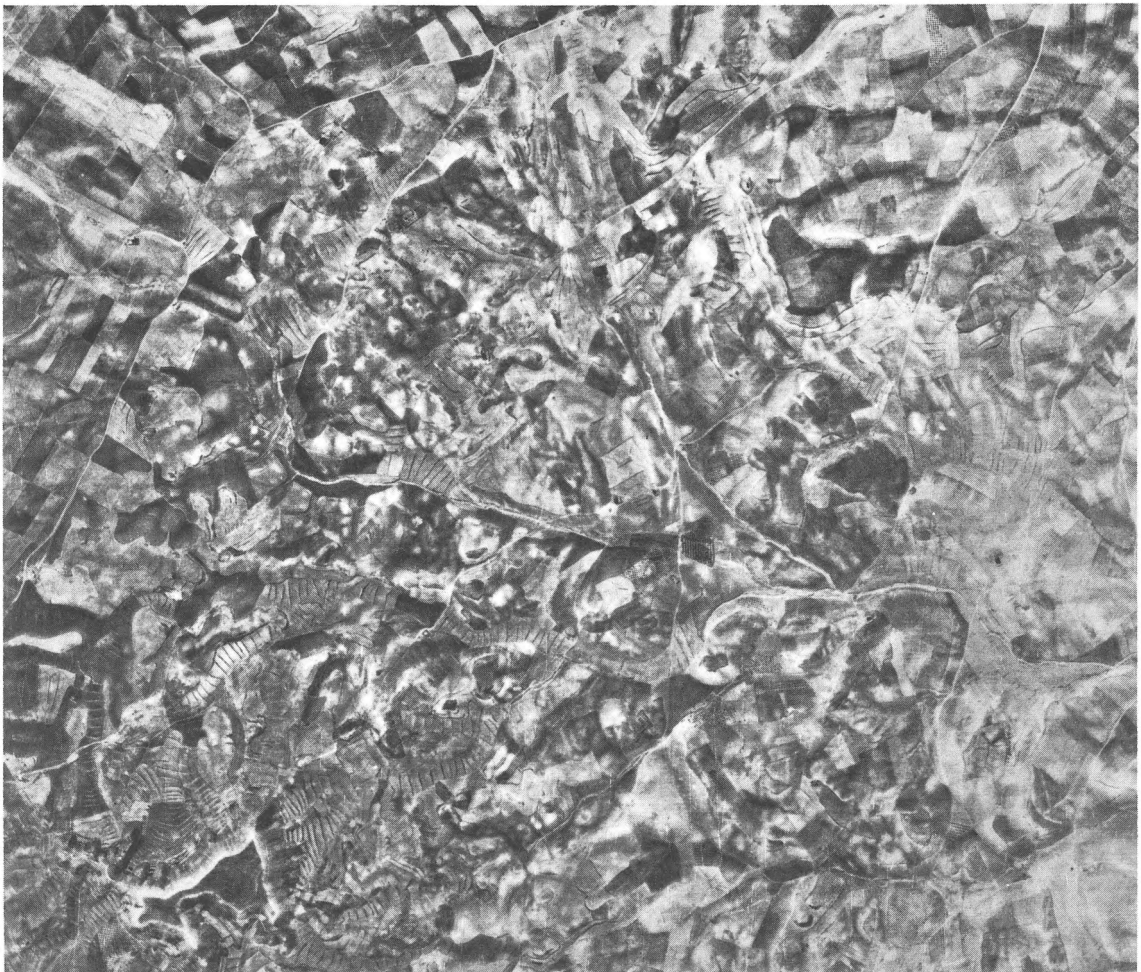


Fig. 4
Aerial photograph showing a part of the lower right corner of the Landsat image of Fig. 3. Mapping units on reconnaissance scale will consist of associations of structural, denudational and fluvial landforms.

mapping unit are more or less normally distributed and that the mean coincides with the mid-values of a class interval. This assumption is not true for most units. For example, Table I shows the slope distributions of mapping units of an area in Spain (shown on the Landsat image of Fig. 3). The units nos. 1, 7 and 11, being of the same hierarchical level, have similar slope distributions, but they represent (1) bare hillocks on limestone, (2) denudational hills on Pliocene fanglomerates and (3) an association of fertile infilled valleys and accumulation glacis, erosional glacis and small structural hills on Miocene lacustrine deposits.

The large standard deviation of the slope distributions of the three units and the fact that they differ fundamentally in nature, poses problems in a straightforward application of simple decision rules as how to transform the data into new thematic maps.

Besides slope statistics, there are other attributes to be incorporated in the transformation. However, many characteristics cannot be properly described by a single numerical value. A mechanical application of rules will lead easily to

unrealistic results. Pixels or even units may obtain scores for the new map, which they do not deserve. This is particularly so when the mapping units which serve as input, describe associations of attributes.

TRANSFORMATIONS

The above example may illustrate that the transformation of geomorphic and other data stored in a geobased information system requires careful consideration. The following options for transformation are briefly mentioned.

Empirical, qualitative methods

The terrain attributes together with data of another nature (meteorological, hydrological) may be used to give qualitative ratings of new units for specific purposes, by means of a re-grouping of selected attributes or mapping units as such. Semi-quantitative approximations may be possible, depend-

Table I
Student-Newman-Keuls test and Tukey's HSD applied to slope distributions of 12 mapping units. The distributions of the units (3,8,4,6,5,2) do not differ from each other. The same applies to the units (1,11,7), which are described in the text.

Statistical comparison of slope distributions of 12 mapping units
A: Student-Newman-Keuls test, B: Tukey's HSD

A+B : error mean square = 8.962

degrees of freedom = 320

alpha level = .05

B : HSD value = 3.213

mapping unit	mean, multiple	comparisons on sample size	SLOPE separation	
			A	B
3	1.140	6	a	a
8	1.835	21	a	a
4	2.080	30	a	a
6	2.583	43	a	a
5	3.754	16	a	a
2	4.189	33	a	ab
12	4.318	23	a	ab
1	7.337	63	b	bc
11	8.117	29	b	c
7	9.325	23	b	cd
9	11.977	27	c	de
10	14.840	8	d	e

ing on the availability and analysis of measured data of the specified theme.

MEIJERINK (1977) discussed such a rating for peak runoff and sediment yield. Simple as it may seem, this procedure is often fraught with difficulties because of often insufficient knowledge of the behaviour of the terrain elements.

Models derived by statistics

The effect of selected individual attributes, e.g. variables, is assessed by statistical analysis. A promising method is to determine the magnitude of the variable of interest (erosion intensity, crop yield, etc.) in a number of locations. Factor analysis may be used to determine the important variables and by multiple regression the numerical values of the independent variables can be assessed. With these values the data base can be transformed. This approach is demanding a careful consideration of the mapping units in terms of an analysis of variance of the attributes of the mapping units. Applicability is limited to the area of study.

Simple models

Quite an efficient use of a data base can be made if well-tested simple models are available to create thematic data out of the stored attributes. Examples of such models are for instance the agrohydrological estimates as developed by DOORENBOS & PRUITT (1977) and DOORENBOS & KASSAM (1979) or the runoff estimation methods of the U.S. Soil Conservation Service. Reconnaissance or semi-detailed scales of survey match the approximate results yielded by the above methods.

Dynamic models

The ultimate aim in modelling complex processes, such as slope development and rainfall-runoff-sediment yield relationships, is to develop distributed deterministic models. The spatial base of such models has generally a cell or grid structure to store the physical parameters (see for example the models described by FREEZE (1980) and by BEASLEY ET AL. (1982)). Apart from performing calculations, the cell structure is of course suitable for storing environmental changes and soil moisture changes, for which satellite remote sensing platforms offer opportunities (PRICE, 1980; BELL ET AL., 1980).

CONCLUSIONS

Geomorphological mapping started some three decades ago with analytical mapping. Land resource studies gave impetus for the development of synthetic geomorphological surveys. The scope for geomorphologically based surveys is recently further widened by the natural hazard surveys.

It is expected that geobased information systems will be increasingly used to produce thematic maps, if only to save on time consuming cartography. The various geomorphological surveys, both the synthetic and the analytical ones, are valuable source documents to provide much input for the data bases. Decision rules and models to transform the stored data in a relevant way into the new thematic maps will require much attention in the near future.

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