REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEMS AS APPLIED TO MOUNTAIN HAZARD ANALYSIS AND ENVIRONMENTAL MONITORING*

R. Soeters, N. Rengers & C.J. van Westen
ITC
Enschede, The Netherlands.

ABSTRACT

The high resolution and stereoscopic capability of SPOT has widened the fields of application in geomorphological and engineering geological surveying, specially in relation to mountain hazard analysis and environmental monitoring. The integration of satellite remote sensing with data obtained from other sources, such as aerial photographs and maps, has become an essential part of the interpretation process.
The use of Geographical Information Systems has a large potential for this data integration, but it confronts us with specific requirements where the input is concerned. A description is given of the structure of input data for a PC-based GIS, and the techniques used for small scale mountain hazard analysis are explained by an example from Colombia.

INTRODUCTION

The almost exponential growth of the population of our planet and the consequent colonization of virgin and often marginal land, the excessive and uncontrolled exploitation of natural resources and the exaggerated modifications of our landscape in name of, a for sure unsustainable, development, has put the natural environment under unbearable stress. With the consequence of an extremely serious distortion of the geo-ecological equilibrium and an equal serious increase of natural hazards as well in frequency as intensity.

The global annual death toll from natural hazards is estimated on 225.000 and estimates for losses in goods are in the order of 25.000 million dollars per year (Hansen, 1984).

Although slope instability hazards, with a few exceptions, are not primarily characterized by an extreme catastrophic character with high losses of human lives, the frequency of their occurrence places them among the most important natural hazards in respect to economic damages, also due to the fact that they are the most important induced hazards in seismic events, and to a lesser degree in volcanic events. The firm conviction and evidences that landslide prone conditions can adequately be recognised, makes slope instability hazard zoning a major research topic of which mankind in the industrial world as well as in developing countries may expect a large benefit.

The research in the field is directed towards the unravelling of the complex relationships of slope instability and ground conditions and in the extrapolation of the findings over larger areas.

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Geographical Information Systems are playing an increasingly important role in this research, given the large amount of variables involved in instability hazards, whereby the geological, geomorphological and hydrogeological conditions are the most important.

Considering the importance of the geological and geomorphological conditioning factors in slope instability it is primarily the task of the earth scientist to analyze the causative parameters of discrete cases of slope failures and to determine the spatial distribution of the critical factors in order to establish the areas susceptible for slope instability.

A particular difficulty in the process is the complexity of the multivariate system of partly interrelated causative factors. An objective analysis of the problem and the extrapolation of critical variables can only be assured by detailed statistical analysis of measured ground conditions (Neuland, 1976; Carrara et al, 1977), a slope modelling and evaluation through a GIS (Newman et al, 1978; Kienholz, 1988; Wadge, 1988) or by a combination of both.

THE SCALE PROBLEM

The first step in any hazard zoning is to establish the causative terrain conditions which are leading to a particular damaging phenomenon, as only through the understanding of the processes and factors involved a prediction can be made on the susceptibility of the terrain for that hazard. This first phase in the analysis of slope instability is generally based on the combined evaluation of a landslide incidence map obtained from an aerial survey or from a database with landslide records with topographical data and various thematic maps (geology, geomorphology, landuse, climate, etc). Examples of these types of analysis are shown by the scientists active in this field (Meneroud and Calvino, 1976; Carrara and Merenda, 1974; Canuti et al, 1982 ; Brabb et al, 1972) or in the comprehensive texts on this subject by Varnes (1984) and Hansen(1984).

A particular difficulty observed in the analytical phase of the work is related with the fact that an adequate survey of slope instability features and the analysis of the process asks necessarily for a detailed large scale study considering the most frequent size of landslides, while this is not in accordance with the small scale reconnaissance maps required in the initial stages of large engineering or development projects. The use of information of landslides data banks seem to give a solution for the problem, but the crossing of these data only with slope angle and lithology doesn't give a causal analysis of the slope instability.

Other approaches are more pragmatic oriented and try to increase the detail of the analysis according to the pressure for human activity in the area (Vidal, 1984).

In the present article a solution to this problem is given by the simultaneous use of remote sensing images of different scales in the analytical phase.

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REMOTE SENSING IN SMALL SCALE GEOMORPHOLOGICAL MAPPING

In geomorphological interpretation for landslide hazard analysis a number of remote sensing tools are available. The most widely used are given in table 1.

Table 1: Summary Of Remote Sensing Tools

	LANDSAT MSS	LANDSAT TM	SPOT XS	SPOT Pan	Aerial photos scale 1:1000*		
					50	20	5
Size of area on image (km^2)	185^2	185^2	60^2	60^2	11^2	5^2	1^2
Spectral bands	4	7	3	pan	pan	pan	pan
Ground resol.	70^2	30^2	20^2	10^2	1.5^2	0.5^2	0.1^2
<< object with >> contrast	200^2	100^2	60^2	30^2	5^2	1.5^2	0.3^2
<< object with form & contrast	300^2	120^2	80^2	40^2	6^2	2^2	0.5^2
<< object with landform only	stereo	stereo	200^2	100^2	15^2	5^2	1^2

The use of stereoscopic imagery in slope stability studies is very important in view of the clear and diagnostic scars in the morphology, left behind by slope movements. These are generally more characteristic than the smaller and less clear tonal features related with denudated scarps, disrupted vegetation cover or soil moisture and drainage conditions. All these aspects are generally used in conjunction to morphological features as converging evidences. Considering the size of most of the landslides, which is in the order of magnitude of several tens till a few hundreds of metres, the most adequate photoscale is around 1:20.000. At this scale the phenomenon is not only identified as a slope instability feature,but an first analysis of the feature is also possible as the elements of the landslide can be recognised and studied.

The satellite imagery is not suitable for identifying mass movement phenomena, unless they are very large. However they perform an important role in small scale analysis, where the first objective is to divide the terrain in homogeneous zones, i.e. make a terrain classification. Especially SPOT (pan or XS) is very suitable for this purpose due to its stereo capabilities, and the relatively good spatial resolution.

The use of LANDSAT MSS or TM in geomorphological terrain classification is limited due to the lacks of stereo-viewing capabilities and the lower ground resolution. Their higher spectral resolution is generally not so important in terrain classification. However, there are possibilities to overcome the lack of stereo, as will be explained further on.

INTEGRATING REMOTE SENSING DATA WITH GEOGRAPHICAL DATA ON A PC

For a good interpretation a high quality image should be used. Nowadays the processing of the raw images data can be done on relative inexpensive PC-based systems.

An example of such a system is the Integrated Land and Watershed Information System (ILWIS), developed at the International Institute for Aerospace Survey and Earth Sciences, I.T.C.

(Enschede, The Netherlands). This system is particularly suitable for merging and processing data acquired by aerial photo interpretation or other remote sensing techniques and existing data, including station data (rainfall, run-off, geotechnical characteristics)(Meijerink, 1988).

It combines conventional GIS procedures with image processing capabilities and a relational database. All operations can be performed on a 80286-based computer (IBM-AT), with a mathematical co-processor, a digitizer, a Matrox or VGA graphics card, high resolution monitor and output devices (colour printer, plotters). The system was developed for a PC, taking into consideration the situation of most developing countries, where mainframes or minicomputers are still very rare. (Valenzuela, 1988).

For geomorphological applications a system like ILWIS can be helpful in the following operations with remote sensing data:

* Data entry

Remote sensing data from CCT's is read on a system connected to a tape drive and the raster files are converted in the ILWIS format.

* Data display

The display of individual bands or colour composites is facilitated with the standard image processing tools, such as linear stretching, histogram equalisation, transfer functions and filtering.

* Data combination

Geometrical correction can be performed by resampling a raster map to the geometry of another map or to a topographic reference in UTM or geographic coordinates. Individual bands or colour composites can be combined with a Digital Elevation Model to produce a 3-dimensional image, or a stereopair (anaglyph). This combination now gives the possibility to see LANDSAT and TM data stereoscopically, enhancing considerably their interpretability. Also with this technique one SPOT image in principle is sufficient to obtain a stereo image.

* Data interpretation

A new program allows the user to interpret an image on the screen, using screen-digitizing over a displayed raster image. Using a series of control points, the digitized interpretation is geometrically corrected. However in most cases a hard copy is made from the optimally processed image, by means of photographs, colour printing or film writers and interpreted behind a stereoscope.

* Data classification

A sample program creates the facilities to create interactively sample sets for supervised classification. Multispectral classification is done using class statistics obtained in the sample program on a maximum of four bands. Three methods for classification can be chosen: K-Nearest Neighbour Classifier, Box Classifier or Maximum Likelihood Classifier.

TERRAIN MAPPING UNIT APPROACH

In many large engineering or development projects thematic maps of large areas with sufficient quality are not assumed to be available in the initial stage. Instead of creating these maps one by one, followed by their combination, a more suitable approach to a small scale framework (1:100.000 or less) for the storage of different kinds of geo-data, will be terrain classification based on the interpretation of stereo SPOT imagery or small scale photography.

There are many different classification systems developed over the years, which can be grouped in geomorphological analytic, morphometric, physiographic, bio-geographic or lithologic-geologic classifications. A comparison between the most important systems is made by van Zuidam (1986).

However, most of these classifications have a tight hierarchical structure, which may hinder a flexible use, or are based on a single parameter, or a limited set of parameters. To overcome these problems the terrain classification based on the delineation of Terrain Mapping Units (Meijerink,1988) was developed. A Terrain Mapping Units is defined as a unit which groups interrelationships of landform, lithology and soil. It is a natural division of the terrain that can be distinguished on stereo SPOT imagery or small scale aerial photographs, and can be verified on the ground. The units are differentiated on the basis of photomorphic properties in the stereo model. The system doesn't have a strict hierarchical structure. The user can build up his legend according to the important parameters encountered in the study area and the purpose of his study.

A TMU is differentiated in the stereo image on the basis of one or more of the following criteria (Meijerink, 1988):

* Geomorphic origin

This relates to the dominant exogenous or endogenous process responsible for the creation of the terrain (i.e. denudational, denudational structural, volcanic, fluvio-volcanic, etc)

* Specific origin

Within units of the main origin, it may be desirable to subdivide the terrain in smaller units, using other criteria. For example: an area which is almost completely consisting of denudational landforms may by subdivided with respect to altitude or climate.

* Lithology

The boundaries of TMU's coincide with lithological boundaries. Therefore, if small scale geological maps are available, they can be an aid in delineating the TMU's.

* Morphometry

Morphometrical characteristics, such as internal relief, drainage density, slope forms and slope lengths can be used to characterize a TMU.

Quantitative, parametric or statistical descriptions of relief, drainage , slope, geomorphological processes, geology, soils etc. sampled by the interpretation of large scale photographs or during a fieldwork can be attached to the TMU map as an attribute database.

A CASE STUDY: REGIONAL SCALE MOUNTAIN HAZARD ANALYSIS IN THE ANDEAN REGION

For the EEC and UNESCO supported project on the "Development of Mountain Hazard Analysis Methodologies using GIS", in which the Dutch ITC, The French BRGM and the Colombian IGAC are participating, a sample area in the Central Cordillera in Colombia was chosen. The area of 722 km^2 consist of the watershed of the Rio Chinchina, bordering the town of Manizales with about 400.000 inhabitants. See figure 1. The area is representative for the Andean environment: an active mountain chain in the wet equatorial zone, characterized by deep weathering, strong Plio-Pleistocene uplift and associated deep incision and mass movement problems, and active volcanism in the higher part, interfering with Pleistocene glaciation (Florez, 1986).

Figure 1: Location of the study area in Central Colombia.

The area can be generally divided in 4 geomorphological zones.

1. The eastern part of the area belongs to the highest parts of the Central Cordillera, where the active Nevado del Ruiz volcano is the northern most of the string of volcanos located along the cordilleran axis. The Paleozoic metamorphic nucleus is covered with Tertiary and Quaternary andesitic lavas, with evidence of glaciations down to 3200 m.a.s.l. (Herd, 1974). During the last eruption of the Ruiz on 13/11/1985, some 2000 persons were killed by a lahar, in the Rio Chinchina catchment.
2. The area between the Romeral fault zone and the zone 1 consists of a Eocene-Oligocene planation surface in Paleozoic and Cretaceous metamorphic and metasedimentary rocks, covered with lahar and pyroclastic flow deposits of Miocene and Pliocene age (Naranjo 1989). This has been dissected deeply caused by the major uplift in Pliocene times.
3. The Romeral fault zone consists of a N-S oriented stepped fault zone, with mainly reverse faults in Cretaceous metasedimentary and intrusive rocks, which are highly susceptible to mass movements. Although the major seismic events originate at greater depths, with recurrence intervals of 25 years, less intense and shallower earthquakes occur related to the Romeral fault, with a recurrence interval of 7 years.
4. The western part of the area consists of rounded hills composed of sedimentary rocks (partly turbidites) with intercalated basalt flows and metamorphic rocks of Cretaceous age, and wide valleys filled with Quaternary lahar deposits.

AN EXAMPLE OF A TMU CLASSIFICATION

For the study area we have used the following criteria for subdividing the terrain:

1. Terrain Mapping Complexes (TMC)
    - Main origin
    - Climate and altitude
2. Terrain Mapping Units (TMU)
    - Lithology
3. Terrain Mapping Subunits (TMS)
    - Drainage density
    - Internal relief.

Using these classification parameters we come to a total of 9 TMC's, 37 TMU's and 117 TMS's. In table 2 the TMC's and TMU's are given. Figure 2 displays the TMC's in greytones. For TMU's and TMS's only the boundaries are displayed.

As can be seen from the legend we have chosen not to apply the classification criteria too rigidly, as this would result in a number of subdivisions which don't have any meaning. In the TMU classification system the hierarchy is not an end in itself, but a means of facilitating the delineation and selection of the TMU's.

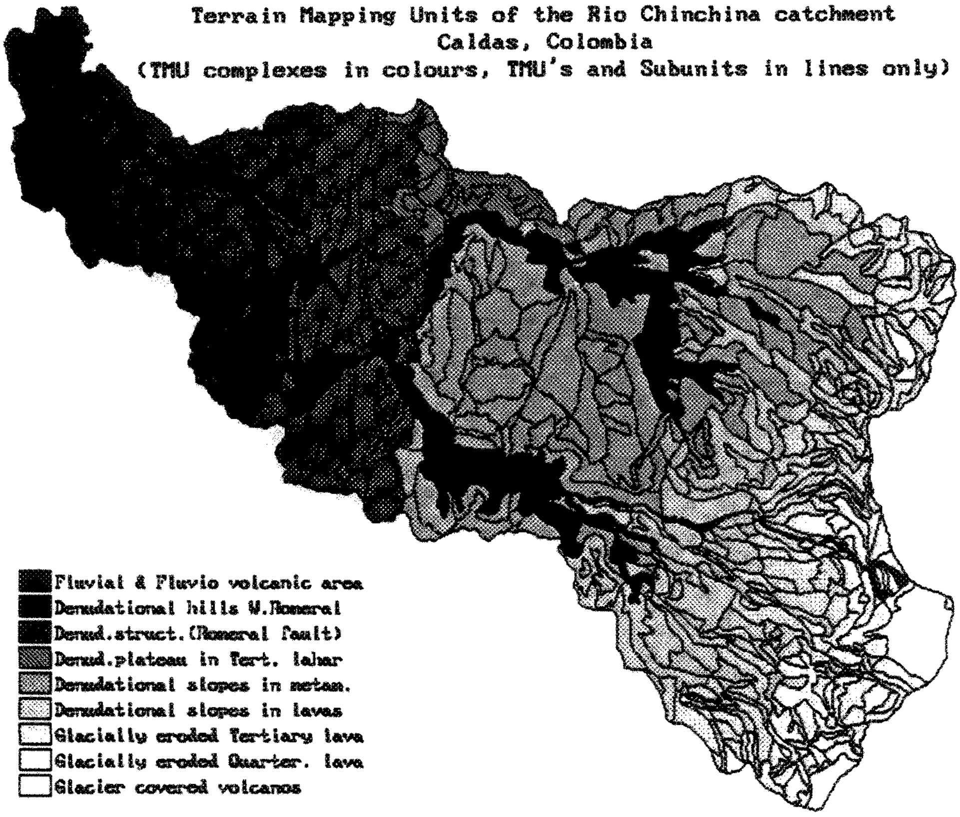

Figure 2: Terrain Mapping Complexes of the study are.

Table 2: Legend Table For TMC's and TMU's

tmu#	Tmucomp#	Origin$	Location$	Lithology$	Tmudesc$	Formation$	polygons#	tmuarea&
11	1	fluvio-volcanic	&_fluvio-glacial	terraces	Floodplain_&_Low_T.	No_formation_name	12	2.385311E+07
12	1	fluvio-volcanic	&_fluvio-glacial	terraces	Terrace_level_1	Licoria_Caldas	11	1.105302E+07
13	1	fluvio-volcanic	&_fluvio-glacial	terraces	Terrace_level_2	Enea-Esperanza	30	2.457771E+07
14	1	fluvio-volcanic	&_fluvio-glacial	terraces	Terrace_level_3	Chinchina-Santagueda	19	3.204350E+07
15	1	fluvio-volcanic	&_fluvio-glacial	terraces	Pyroclastic_flow_T.	Rio_Claro	29	2.101127E+07
21	2	denudational_hills	w._of_romeral_fault	deeply_weathered	Sedimentary_rocks	No_formation_name	5	1.078264E+07
22	2	denudational_hills	w._of_romeral_fault	deeply_weathered	Porphyr._intrusive	Porfidos_Chinchina	4	2.062119E+06
23	2	denudational_hills	w._of_romeral_fault	deeply_weathered	Chloritic_schist	Esq.Lisboa/Palestina	20	3.370497E+07
24	2	denudational_hills	w._of_romeral_fault	deeply_weathered	Amphibolitic_schist	Esq.Lisboa/Palestina	4	5.215076E+06
25	2	denudational_hills	w._of_romeral_fault	deeply_weathered	Metasedimentary_rock	Quebradagrande	4	1.017110E+07
26	2	denudational_hills	w._of_romeral_fault	deeply_weathered	Subaquatic_lava	Quebradagrande	12	2.420131E+07
31	3	den.-struct_slopes	in_romeral_fault_zon	pred_in_metamorphics	Dioritic_gabbro	Stock_dior.Chinchina	9	2.095668E+07
32	3	den.-struct_slopes	in_romeral_fault_zon	pred_in_metamorphics	Metamorph._intrusive	Intr.neis.Chinchina	5	1.032700E+07
33	3	den.-struct_slopes	in_romeral_fault_zon	pred_in_metamorphics	Metasedimentary_rock	Quebradagrande	13	3.926987E+07
34	3	den.-struct_slopes	in_romeral_fault_zon	pred_in_metamorphics	Subaquatic_lava	Quebradagrande	7	1.232981E+07
41	4	denudational_plateau	around_manizales	in_Late_Tertiary_F.	Plateau_in_lahar_dep	Manizales/Casabianca	1	3.921002E+06
42	4	denudational_plateau	around_manizales	in_Late_Tertiary_F.	Slopes_in_lahar_dep	Manizales/Casabianca	12	1.588343E+07
51	5	denudational_slopes	e._of_romeral_fault	pred_in_metamorphics	Volcanic_domes	No_formation_name	4	2.138966E+06
52	5	denudational_slopes	e._of_romeral_fault	pred_in_metamorphics	Metasedimentary_rock	Quebradagrande	23	4.275758E+07
53	5	denudational_slopes	e._of_romeral_fault	pred_in_metamorphics	Subaquatic_lava	Quebradagrande	5	1.376967E+07
54	5	denudational_slopes	e._of_romeral_fault	pred_in_metamorphics	Granitic_intrusive	Stock_de_Manizales	11	3.383890E+07
55	5	denudational_slopes	e._of_romeral_fault	pred_in_metamorphics	Various_metamorphics	Cajamarca	48	8.322442E+07
61	6	denudational_slopes	in_upper_zone	in_Tertiary_lavas	Den._forms_in_lavas	No_formation_name	41	7.082360E+07
62	6	denudational_slopes	in_upper_zone	in_Tertiary_lavas	Acc._forms_in_lavas	No_formation_name	16	1.681101E+07
71	7	glacially_eroded	&_denudational_slope	in_Tertiary_lava	Gl.er._lava_plateau	No_formation_name	25	1.822700E+07
72	7	glacially_eroded	&_denudational_slope	in_Tertiary_lava	Gl.er._lava_flow	No_formation_name	6	8.527891E+06
73	7	glacially_eroded	&_denudational_slope	in_Tertiary_lava	Glacial_valley_floor	No_formation_name	19	1.244850E+07
74	7	glacially_eroded	&_denudational_slope	in_Tertiary_lava	Glacial_valley_slope	No_formation_name	54	5.496873E+07
81	8	glacially_eroded	recently_deglaciated	in_Quarternary_lava	Gl.er._lava_flows	No_formation_name	52	4.089214E+07
82	8	glacially_eroded	recently_deglaciated	in_Quarternary_lava	Glacial_er._valleys	No_formation_name	11	4.106579E+06
83	8	glacially_eroded	recently_deglaciated	in_Quarternary_lava	Volcanic_dome	No_formation_name	5	2.895093E+06
84	8	glacially_eroded	recently_deglaciated	in_Quarternary_lava	Volcanic_crater	No_formation_name	4	1.680429E+06
85	8	glacially_eroded	recently_deglaciated	in_Quarternary_lava	Volcanic_cone	No_formation_name	2	1.792274E+06
91	9	glacial_areas	on_volcanos	of_Ruiz_&_St._Isabel	Glacier	-	1	2.458254E+06
92	9	glacial_areas	on_volcanos	of_Ruiz_&_St._Isabel	Glacier_partly_degl.	-	1	9.735727E+06
93	9	glacial_areas	on_volcanos	of_Ruiz_&_St._Isabel	Glacier_comp._degl.	-	1	6.277565E+05

DATABASE CONSTRUCTION

With the Terrain Mapping Unit approach the construction of a whole series of thematic maps in the spatial database, and the subsequential overlaying and crossing is not necessary. Often most of the thematic maps (such as soilmaps or geological maps) may have boundaries which have been derived from image interpretation as well. Especially when they were created by various persons, the discrepancies in boundaries between the maps may not reflect actual differences in the terrain, but are caused by subjective interpretation differences. Overlaying these maps would result in a large number of less logical combinations. Therefore in the TMU approach these variables are connected to the TMU and are stored in an attribute database.

After digitizing the subunits the basic database table, containing the descriptions of the units, can be created. Two basic tables are made first: TMUDESC (a descriptive table) and TMUCALC (containing numerical parameters).

It is possible now to rearrange the order of the table by changing the key column in such a way that only the values for the TMU complexes or for the TMU's are displayed. In this way the further analysis can always be done on three levels of detail (TMC, TMU, TMS).

Also in this way it is easy to renumber the TMS map to another type, such as TMC, TMU, geology, age, internal relief and drainage density, since these parameters already appear in the table.

Besides of the basic data which is gathered as a result of the TMU classification, a number of other parameters have to be obtained. Table 3 gives an overview of these parameters:

Table 3: Additional Parameters To Be Sampled for TMU's

Type	Parameter	Method of sampling
Morphometry	Slope angle	- Photogrammetrical methods - Sampling in contour map - Calculate from DEM
	Slope length	- Neighbourhood anal. on DEM - Sampling in contour map
	Slope orientation	- Calculate from DEM
	Slope form	- Sampling from airphotos
Drainage	Drainage density	- Calculate from drainage
	Drainage patterns	- Photointerpretation
Soil	Dominant soiltype	- Photointerpretation - Existing data - Fieldcheck
Geology	Dominant lithology	- Existing data - Fieldcheck
	Distance to fault	- Calculate from faults
	Distance to earthq.	- Calculate from earthquakes
Processes	Erosion type	- Photointerpretation
	Mass movement type	- Photointerpretation
Landuse	Dominant landuse	- SPOT classification - Photointerpretation
Climate	Climatic parameters	- Calculate from station data

As can be concluded from the table a considerable number of parameters will have to be sampled from aerial photographs. The description of parameters such as processes using photos is gene-

rally done in a qualitative manner, without actual counting of phenomena, as this would be a very time-consuming job.
With respect to the morphological parameters, they can be obtained by various methods:

- Photogrammetrical sampling, either using parallax bars or using expensive photogrammetrical equipment
- Sampling from existing 1:25.000 or larger contourmaps,or
- Automatic sampling on Digital Terrain Models obtained by interpolating digitized contourlines.

The last method seems most profitable, as one has all the data stored in the computer, and can use it for various purposes. The calculations can be repeated easily. The disadvantage is that the contourmaps should be digitized, which is a tedious work.
The scale of the contourmaps from which the morphometrical data is obtained should be in the order of 1:25.000 or larger, with contour intervals of at least 40 m. The use of less detailed maps will result in large errors for slope angle distribution.
As an example the slope angle distributions derived from 1:25.000 scale maps for 5 TMS's belonging to the same TMU (nr 330) are displayed in figure 3. The corresponding statistics are given in table 4.

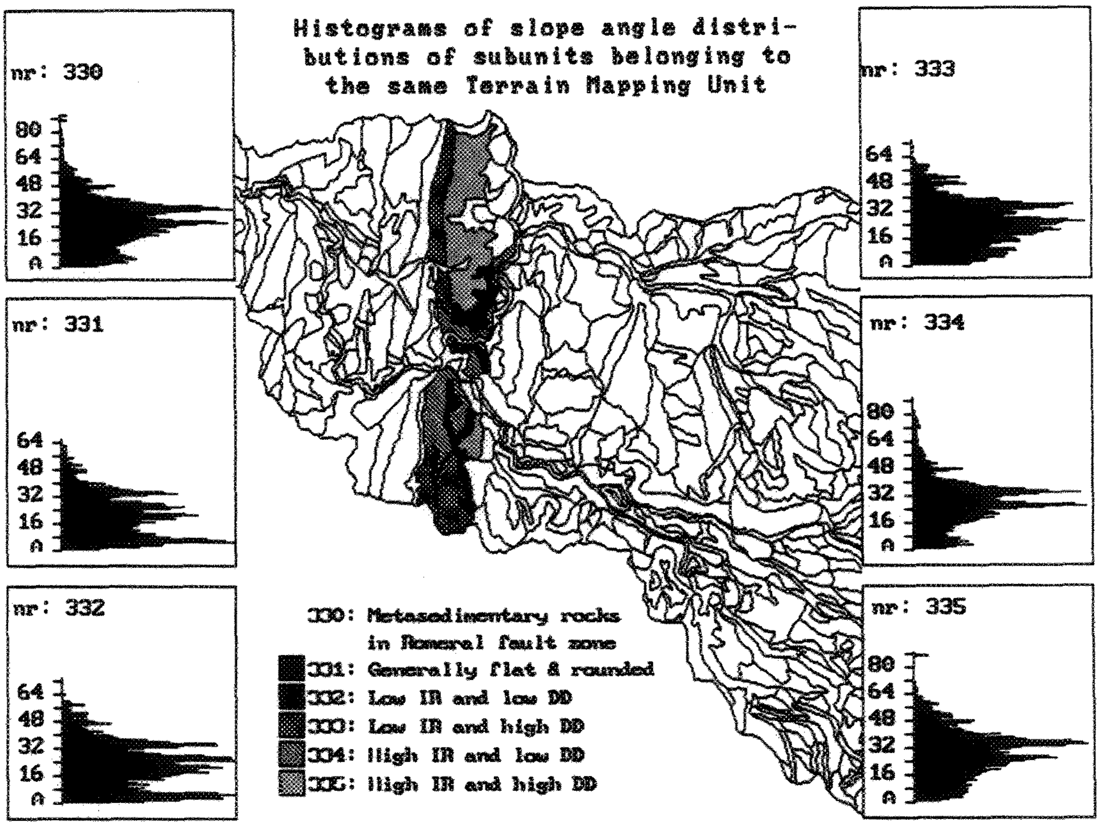

Figure 3: Histograms of the slope angle distributions for the TMU 330 and its subunits.

Table 4: Some Preliminary Results Of Morphometrical Parameters.

	Slope angle Distribution				Heights Internal relief			
	AVG	MED	ST	PRED	MAX	MIN	AVG	IR
TMS: 331	20.5	20	12.6	5	2000	1533	1800	467
TMS: 332	22.1	21	13.2	5	1900	1583	1768	317
TMS: 333	24.7	24	13.1	26	1700	1300	1458	400
TMS: 334	27.5	27	13.3	26	2000	1392	1632	608
TMS: 335	28.8	29	14.0	34	1953	1400	1657	553
TMU: 330	26.8	26	13.7	34	2000	1300	1550	700

From this table it can be concluded that the morphological classification as obtained from the stereo model is not always supported completely by the sampled morphometrical parameters. However, this is more a limitation of the sampling procedures than of the interpretation. The TMS 331 for example, which stands for more or less flat hilltops in metasedimentary rocks within the Romeral fault zone, does seem to have a high % of steeper slopes. This is because in the interpretation an arbitrary line is drawn were the hilltops are changing in sideslopes. Also the internal relief within the unit may be relatively high because we are dealing with an elongated crest which slowly rises from 1533 to 2000 meters.

ANALYSIS

In the qualitative hazard analysis the experience of the geomorphologist and or engineering geologist who has made the input maps is used to manipulate these maps in such a way that they result in hazard maps. This type of analysis can be done basically as a desk study when the TMU map is available with the database as discussed above.
The flow diagram for the analysis is presented in figure 4.
Based on the attributes from the database a hazard zonation can be made in the following ways:
1. Hazard index method
The hazard index method (Yan Tongzhen, 1987; Yin and Yan, 1988) could be used to make a weighting of all the variables in the database with respect to the occurrence of specific types of landslides, by calculating for each parameter the relation between the number of TMU's in which the parameter is present and the number of TMU's with landslides.
2. A qualitative method.
The database is consulted in order to find those ranges of parameters that are critical with respect to the occurrence of mass movements. Based on this, rules are developed and applied to the TMU map and database. For example:
"If the unit is located in an altitude range of 1000-2000, AND the landuse is predominantly coffee, AND the internal relief is more than 150, AND the dominant rocktype is schists, THEN classify such units as high hazard class".

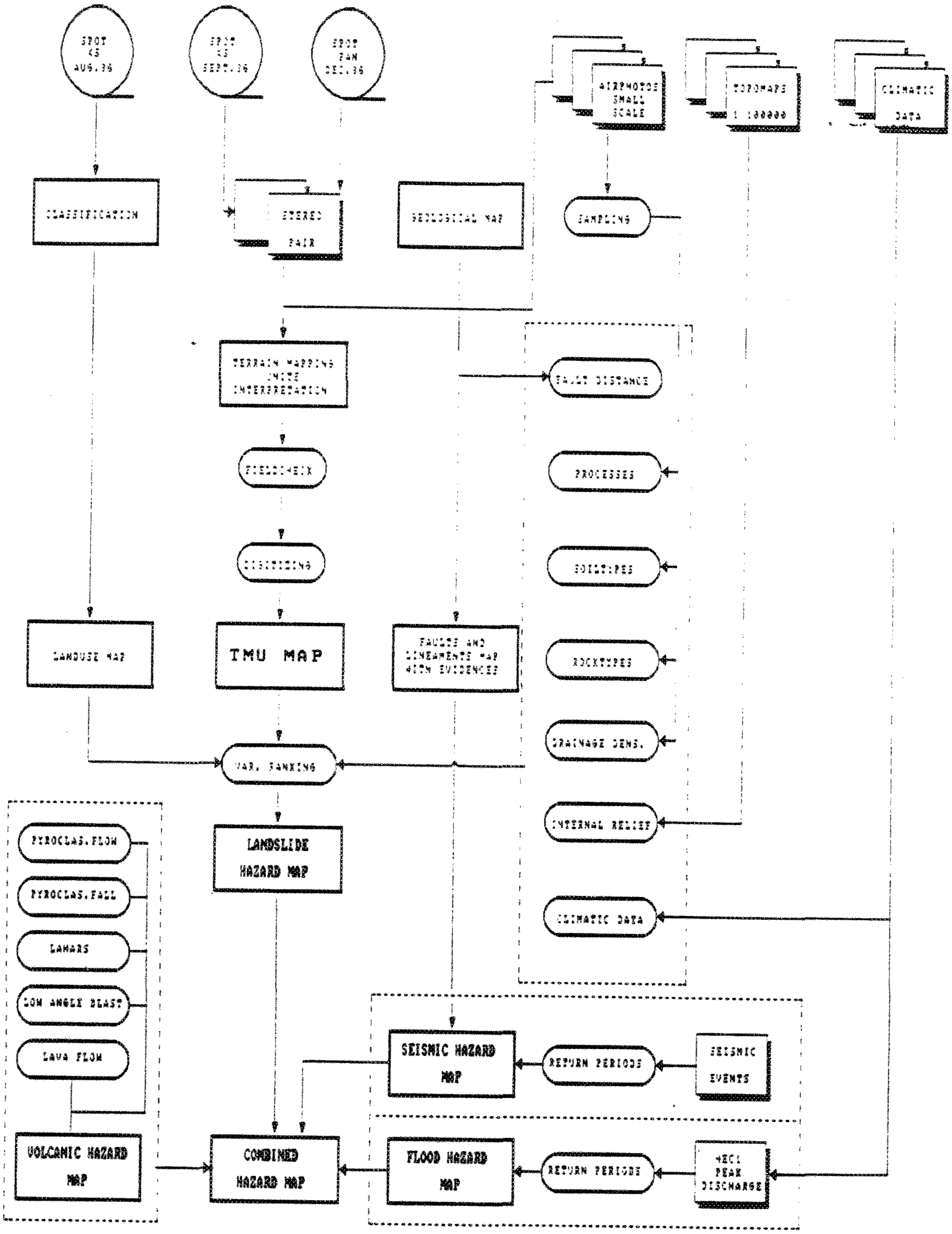

Figure 4:General scheme of regional scale mountain hazard analysis

CONCLUSIONS

The demand for regional scale slope instability hazard maps is high due to the increased awareness that a sustainable development asks for an adequate environmental planning of human activity.

The hierarchical problem of small scale regional studies and the necessary detailed analysis of slope instability features in determining causative parameters is successfully solved by terrain classification, differentiating Terrain Mapping Units on stereo SPOT, while the specific parameters belonging to the TMU's are sampled from large scale aerial photographs, gathered in the field or sampled automatically within the Geographical Information System from digitized existing maps. The methodology of this ongoing research will be developed further in the near future, tested out in a study area in Colombia, and transferred to Earth scientists from the Andean region.

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