

HERMAN TH. VERSTAPPEN (\*)

## SATELLITE REMOTE SENSING, GEOMORPHOLOGICAL SURVEY AND NATURAL HAZARD ZONING SOME NEW DEVELOPMENTS AT ITC, THE NETHERLANDS (\*\*)

**Abstract:** VERSTAPPEN H. TH., *Satellite remote sensing, geomorphological survey and natural hazard zoning. Some new developments at ITC, the Netherlands.*

Diversified developments in aerospace technology during the last few decades have led to digital terrain data and high-resolution imagery becoming readily available also for surveying and mapping of natural hazards. Multi-spectral data increase the survey efficiency while multi-temporal data facilitate monitoring and thus contribute to the establishment of early warning systems. The SPOT satellite, launched in February 1986, is the most perfected second-generation operational resource satellite. It has a spatial resolution of 10 m in the panchromatic mode and of 20 m in the multi-spectral mode. Its temporal resolution is in the order of a few days while, crucially important for geomorphological applications, also stereoscopy is provided.

The methodology of natural hazard surveying and mapping likewise is rapidly developing. Both analytical geomorphological data and synthetic data of terrain are required for the purpose of hazard zoning, but usually only a part of the information obtained by these two survey technologies is in fact of direct relevance. In order to increase the survey efficiency therefore a pragmatic type of survey is opted for, using a tailor-made legend for the purpose of the survey at hand.

Digital data handling leading up to a geographical information system with a data base and a rule base geared to hazard-related environmental (and other) factors is of growing importance to cope with the problem of the cascade of data provided and required.

Examples are given of an attempt at earthquake hazard zoning in Southern Italy and of mountain hazards in the Nepalese Himalayas.

**KEY WORDS:** Remote sensing, Geomorphological survey, Natural hazard, Italy, Nepal.

**Riassunto:** VERSTAPPEN H. TH., *Telerilevamento da satellite, rilevamento geomorfologico e zonizzazione dei rischi naturali. Alcuni nuovi sviluppi all'ITC in Olanda.*

Negli ultimi decenni gli sviluppi diversificati della tecnologia aerospaziale hanno reso prontamente disponibili dati digitali del paesaggio ed immagini ad alta risoluzione anche per il rilevamento e la cartografia dei rischi naturali. I dati multispettrali fanno aumentare l'efficacia del rilevamento, mentre i dati multitemporali facilitano il monitoraggio e quindi contribuiscono alla costituzione di sistemi d'allarme. Il satellite SPOT, lanciato nel

Febbraio 1986, è il satellite della seconda generazione più avanzato per il rilevamento delle risorse; ha una risoluzione spaziale di 10 m nel panchromatico e di 20 m nel multispettrale. La sua risoluzione temporale è dell'ordine di pochi giorni ed è anche possibile la visione stereoscopica, fatto importante per le applicazioni in geomorfologia. Come conseguenza, la metodologia per il rilevamento e la cartografia dei rischi sta evolvendo rapidamente. Per la zonizzazione della pericolosità sono richiesti sia dati analitici della morfologia che sintetici del paesaggio, ma generalmente solo una parte dell'informazione ottenuta da queste due tecniche di rilevamento risulta in effetti di una certa rilevanza. Allo scopo di aumentare l'efficacia del rilevamento, pertanto, è stato preferito un tipo di rilevamento basato su una legenda appositamente predisposta. L'elaborazione dei dati digitali, che prelude ad un sistema informativo geografico con banca dati sui fattori di rischio, è di grande importanza per affrontare i problemi derivanti della quantità di dati forniti e richiesti. Sono qui illustrati esempi di un tentativo di zonizzazione del rischio sismico nell'Italia meridionale, e della pericolosità geomorfologica nell'ambiente montano dell'Himalaya nepalese.

**TERMINI CHIAVE:** Telerilevamento, Rilevamento geomorfologico, Rischio naturale, Italia, Nepal.

### GEOMORPHOLOGICAL SURVEYING FOR NATURAL HAZARD STUDIES

The last few decades have witnessed a rapid growth in geomorphological mapping. Three main reasons can be given for this development:

- the methodology of geomorphological studies and related mapping techniques have evolved.
- consequently a large number of applied geomorphological surveys has emerged.
- new types of aerospace techniques and images/data have become available.

Since the terrain configuration is a key factor in the spatial distribution of natural hazards, geomorphological survey is a logical starting point for hazard assessment. However the traditional morphogenetic, analytical approach does not cover all applied requirements. Also the synthetic methods of mapping terrain do not cover the whole field: usually a combination of both approaches is required which has led to the gradual introduction of pragmatic legends each of which serves a specific purpose (VERSTAPPEN, 1982, 1983,

(\*) *International Institute for Aerospace Survey and Earth Sciences (ITC), P.O. Box 6, 7500 AA Enschede, the Netherlands.*

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1985). At the International Institute for Aerospace Survey and Earth Sciences (ITC) this has led to an adaptation of the ITC System of geomorphological survey, the first approximation of which appeared in 1968. A second approximation, rooted in analytical concepts but also including synthetic methods and pragmatic types of survey, particularly for hazard surveying has been developed and will appear in print soon (VERSTAPPEN & V. ZUIDAM, 1968).

Aerospace technology has facilitated geomorphological mapping to a great extent. Stereoscopic aerial photographs of appropriate scales have been used since many years in detailed and semi-detailed geomorphological surveys. Satellite imagery has provided the general overview for direct medium and small scale geomorphological mapping without the conventional methods of generalization and scale reduction. The limited spatial resolution and the lack of stereoscopy inherent of the first generation of high-resolution satellites (Landsat, etc.) have been a drawback particularly for applications in the field of earth sciences. A multiphase approach, including the use of satellite imagery and aerial photographs thus has been developed. These limitations have recently been overcome by the introduction of the second generation of high-resolution satellites, notably SPOT. The SPOT satellite, launched in February 1986, has introduced stereoscopy (with a vertical precision of 5 m) and has at the same time raised the spatial resolution to 10 m (panchromatic) or 20 m (color). Geomorphological maps in scales of 1:50,000 now can be made using satellite imagery alone, without the use of aerial photographs. Research in this area has been carried out at ITC in recent years and is reported about in this paper. Further details, particularly about pragmatic surveying for hazard zoning are given by VERSTAPPEN (1988). Some case studies are discussed elsewhere in heading this paper. Another important field of development is the introduction of geoinformation systems, made possible by computer technology. The methods of data storage, data handling and data retrieval, now being developed, hold a great promise for geomorphology. This is reflected in the ILWIS system now in use at ITC for mapping and describing terrain mapping units (TMU). It has been invented by MEYERINK & VALENZUELA (1987).

#### FIRST CASE STUDY: EARTHQUAKE HAZARD SURVEY IN SOUTHERN ITALY

The geology and geomorphology of the area in Campania, Southern Italy, severely hit by an earthquake (RICHTER 6.8) in November 1980, has been studied using SPOT stereo images at scales 1:100,000 and 1:200,000. The area is drained by the Sele and Ofanto Rivers and the epicentre was located in the area, near the town of Laviano along a WNW-ESE fault.

The main objective of the project was to explore the potential use of SPOT stereo images for geomorphological survey and terrain assessment geared to earthquake hazard zoning and subsequent disaster mitigation. The results of

the survey were compared with the results obtained earlier using aerial photographs and Landsat imagery. The possibility of extrapolating the hazard zoning to other, nearby, areas of comparable geomorphology, lithology and structure also was investigated. The Agri River Valley, further to the SE was used for this purpose, since earlier surveys based on airphotos and Landsat there also existed.

The Landsat images used in 1986 and earlier had proved useful in the first place for placing the study area in the regional morphotectonic framework and for identifying major geomorphological units. The geomorphological details could not be distinguished, however, and also for mapping settlements, roads, etc. aerial photographs were indispensable. This multi-phase approach could be abandoned when in 1987 SPOT images became available. The material used was panchromatic, with a pixel resolution of 10 metres and enlarged to scales of 1:200,000 and 1:100,000. The interpretation was carried out using the ITC stereo-scan stereoscope which accommodates enlargements  $50 \times 50$  cm. The images show sufficient detail for geomorphological mapping in scales of 1:100,000 or even 1:50,000. Since only very few geomorphological boundaries can be defined with a precision of less than 10 metres (0.1 or 0.2 mm in the map) the use of aerial photographs becomes rather superfluous. SPOT thus is competitive with aerial photographs in mapping lithomorphological units, slope forms and major landslides. The images provide at the same time an excellent general overview. Although the area covered by one frame is considerably smaller than a Landsat frame, this is more than compensated for by the stereoscopy.

The stereoscopic study of the images is adversely affected by the interval between the acquisition dates of the stereomates: seasonal variations in spectral reflectance of the terrain, notably its vegetation cover, result in differences in density patterns between the stereomates. Intensive use was made of the SPOT images also in the field: most of the road-system shows up clearly and this provides better orientation in the field than when using the 30 years old aerial photographs and the topographic maps. The geometric qualities of the images proved invaluable during the mapping phase of the work.

Apart from geomorphological mapping also slope estimates were made, using the ITC-Mekel slope meter. Good results were obtained for steep and medium slopes. Some measurements of gentle slopes were, however, seriously in error, which is thought to result from spectral discrepancies between the multi-temporal stereo mates. The results are given in tab. 1.

The pattern of the great amount of lineaments visible on the SPOT images was analysed and compared with those traceable on aerial photographs, Landsat images and indicated on the geological map. This was done for the various lithological types separately. Their numbers and total lengths were expressed in  $\text{km}/100 \text{ km}^2$  to compensate for differences in surface area and their average length in km was calculated in km. It follows from the measurements that (see tab. 2):

TABLE 1 - SLOPE ESTIMATIONS

Slope number	1	2	3	4	5	6	7	8	9	10	11	12
True slope (°)	10	9	8	8	38	10	37	36	6	8	35	48
SPOT results	4 <sub>e</sub>	7	8	7	37	5 <sub>e</sub>	34	35	4	18 <sub>e</sub>	36	50

e = erroneus

TABLE 2 - LINEAMENTS IN THE SELE RIVER VALLEY, CAMPANIA, ITALY  
in limestone (L) Castel Vetere flysch (F) and varicoloured clays (VC)

	SPOT	Geol Map	Airphotos	Landsat	
L	48.3	78.3	56.6	33.3	(number per 100 km <sup>2</sup> ) (total length in km/100 km <sup>2</sup> ) (average length in km)
	66.0	75.8	56.1	60.0	
	1.37	0.97	0.99	1.80	
L	52.6	36.8	105.2	31.6	
	63.2	26.8	66.3	46.3	
	1.20	0.73	0.63	1.47	
VC	57.1	14.3	42.9	16.1	
	71.3	9.3	37.9	28.0	
	1.25	0.65	0.88	1.74	

LINEAMENTS IN THE UPPER OFANTO BASIN, CAMPANIA, ITALY  
in Plio-Pleistocene deposits (Q/Pl)

	SPOT	Geol Map	Airphotos	Landsat	
Q/Pl	34.9	1.2	12.0	1.2	(number per 100 km <sup>2</sup> ) (total length in km/100 km <sup>2</sup> ) (average length in km)
	101.9	3.0	19.8	11.4	
	2.92	2.5	1.64	9.5	
statistically insignificant					

LINEAMENTS IN THE UPPER SELE RIVER BASIN

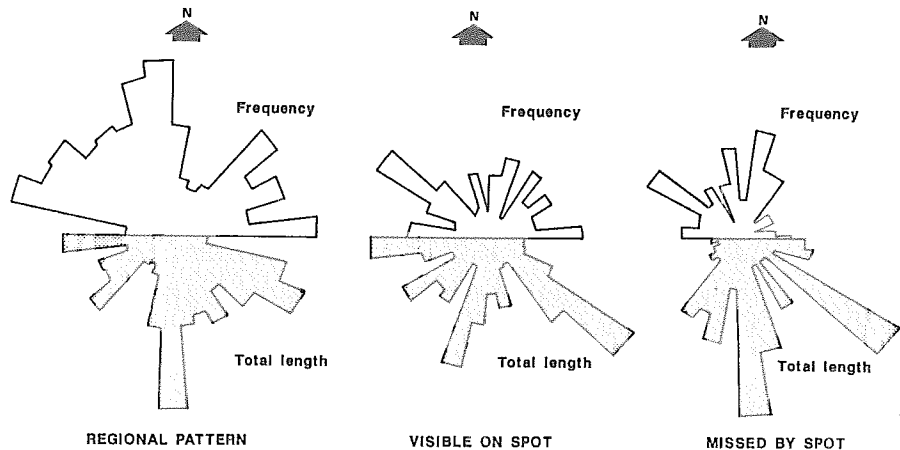


FIG. 1 - Rose diagrams of the lineaments in the Upper Sele river basin.

Left: the regional pattern based on existing data. Centre: the lineaments in the upper Sele river basin traced on SPOT stereoscopic imagery. Right: the part of the lineaments in the Upper Sele river basin traced on airphotos, Landsat imagery and/or the geological map, that was not observed on SPOT imagery.

N.B. The number of lineaments used for the construction of the diagrams decreases sharply from left to right (from: ELSINGA & VERSTAPPEN, 1988).

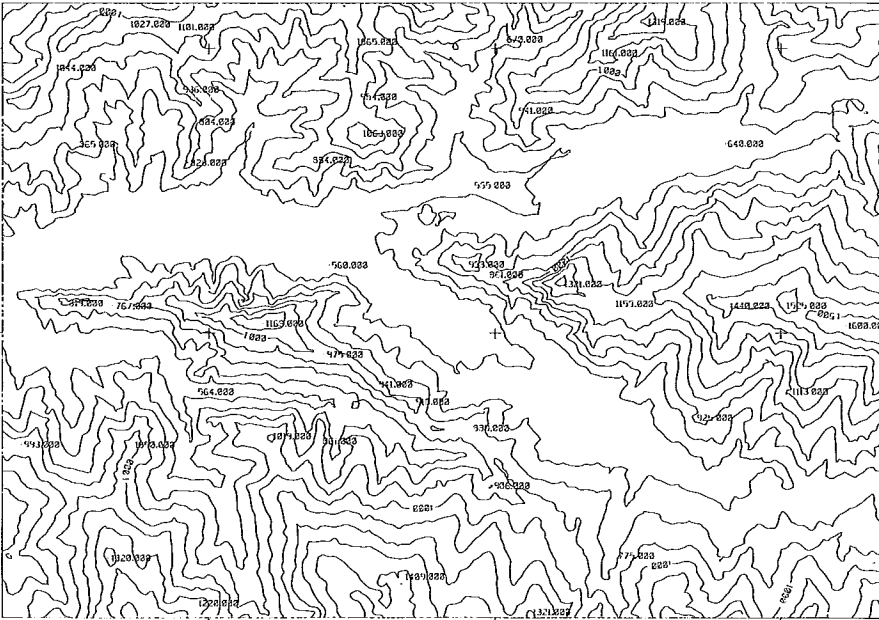


FIG. 2 - Contour lines of the test area in NW Nepal as derived from SPOT stereoscopic data. Contour interval 100 m. Note the greater detailness as compared with the map contours. Scale 1:100,000 (from: GRABMAIER & alii, 1988).

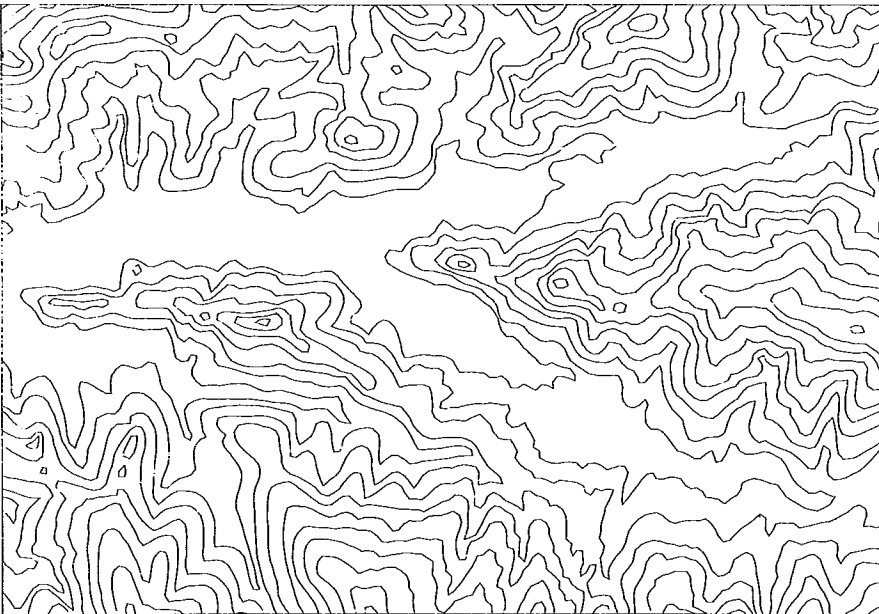


FIG. 3 - Contour lines occurring on the 1:100,000 topographic map of the SPOT test area NW of Kathmandu, Nepal. Contour interval 100 m.

- the geological map performs well in the limestones but gives an incomplete picture in softer materials.
- aerial photographs and SPOT are compatible in limestones and Castel Vetere flysch; the greater number of lineaments on aerial photographs being compensated by greater length on the SPOT image.
- Landsat images show only a limited number of lineaments, probably because of lack of stereoscopy, but score high in average length.
- SPOT performs better than any other data source specifically in areas of soft rocks. This is important in earthquake hazard zoning because lineaments on instable slopes are high risk zones.

The lineaments were subsequently analysed for all lithological types combined and pictured in rose diagrams (fig. 1). The left diagram gives the regional pattern and is based on all available sources. The central diagram gives the pattern of SPOT lineaments in the area of detailed analysis. It concurs well with the regional pattern, discrepancies probably resulting from peculiarities of the study area. The right diagram indicates the lineaments missed by SPOT and recorded by one or more of the other sources. It appears that, for reasons not understood, east-west stretching lineaments are more easily detected than north-south directed ones. The left rose diagram is based on the largest number of observations and the right hand one on the fewest.

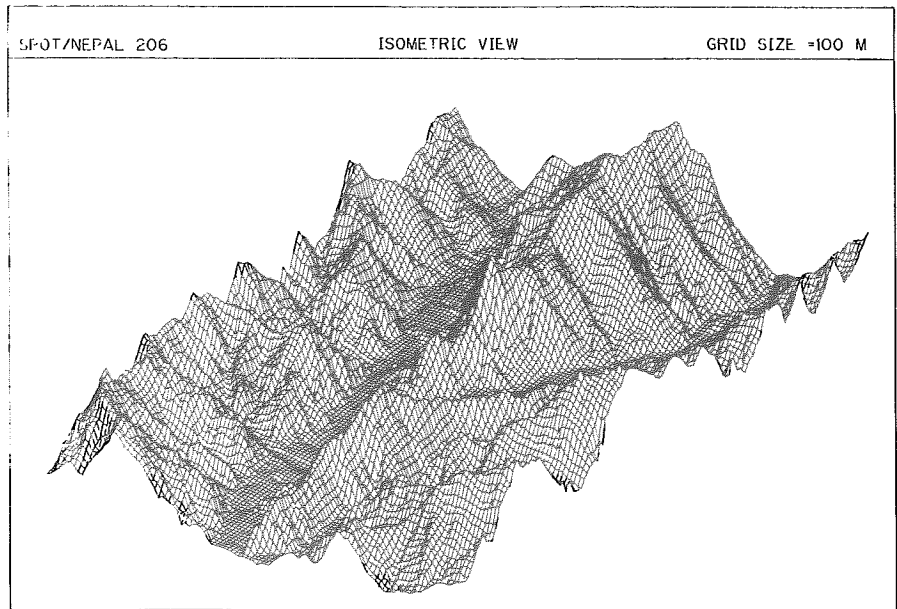


FIG. 4 - Digital elevation model (DEM) of the test area NW of Kathmandu, Nepal, obtained from SPOT stereoscopic data. Distance between N-S and E-W profiles 100 m. (grid size). Greater detailness as compared with map-derived DEM of figure 5 is obvious. Scale 1:100,000 (from: GRABMAIER & *alii*, 1988).

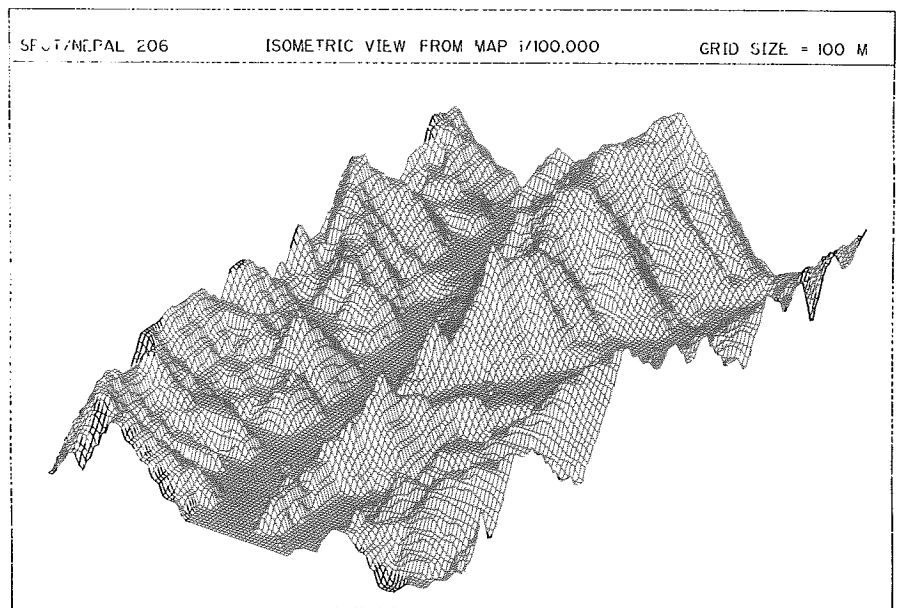


FIG. 5 - Digital elevation model (DEM) of the SPOT test area NW of Kathmandu, Nepal, based on the existing 1:100,000 topographic map.

The study of earthquake hazard concentrated on the main hazard factors such as mass movement, faulting, erosion, etc., established during the geomorphic survey and also included anthropogenic factors. Three hazard classes have been distinguished, namely:

1. low hazard, including plateaus/hills in conglomerates, sandstones or limestones not weakened by recent faults/lineaments and recent alluvial terraces.
2. medium hazard, including potentially instable areas, mainly in clays at present more or less stable but with traces of palaeoslides.
3. high hazard, including clayey areas affected by faults/lineaments where active mass movements occur, major

fault zones in resistant rocks and areas susceptible to liquefaction.

#### SECOND CASE STUDY: SLOPE INSTABILITY SURVEY IN NEPAL

The main objective of this research project was to assess the suitability of SPOT stereo data for relief analysis, morphometric analysis and topographic mapping as applied to slope instability problems in the Nepalese Himalayas. Contrary to the previous case not visual interpretation but digital approaches were emphasized. Two images, processing 1-a, having an inclination of 25° 1 to the right and 29° 3 to the

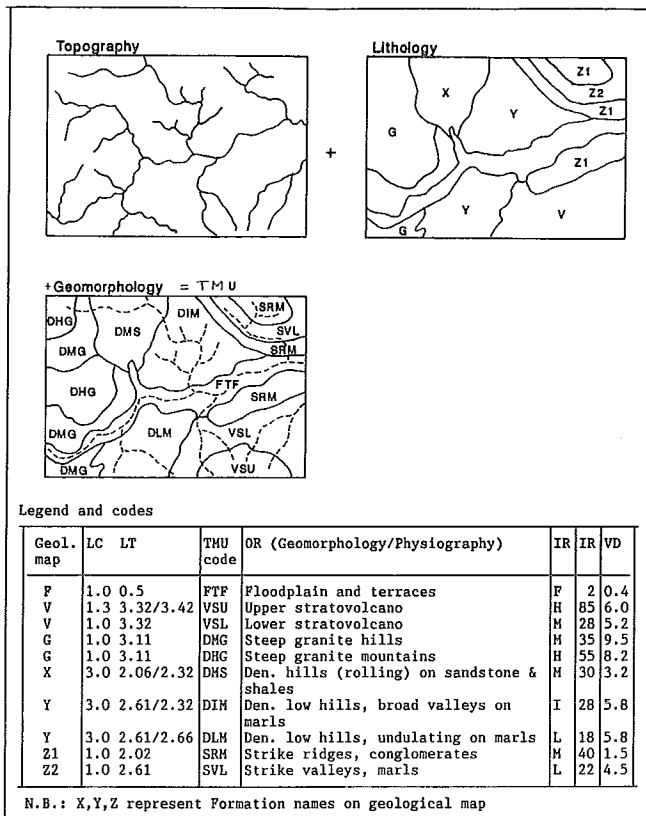


FIG. 6 - Example of coding and mapping of geomorphological terrain units (TMU) based on satellite and map data using the ITC system of geomorphological survey and specifically the ILWIS geoinformation system developed at ITC by MEYERINK & VALENZUELA (1987).

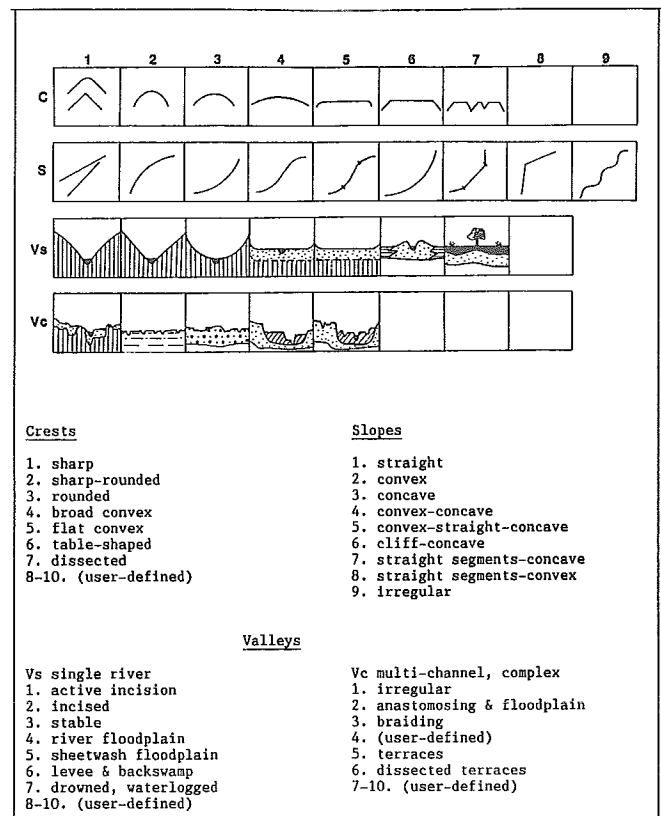


FIG. 7 - Input codes for forms of crests, slopes and valleys used in the ILWIS geoinformation system (MEYERINK & VALENZUELA, 1987).

left, were used for the purpose. As ground truth for the geometry a topographic map 1:100,000 with contour interval of 100 metres was available. The measurements were done in cooperation with the Institute for Image processing and Computer graphics in Graz, using software developed for a KERN A.S.P. More than 11,000 points were measured, partly along break lines and partly in a square grid.

The results are shown in figures 2, 3, 4 and 5. The contourlines with an interval of 100 metres, digitized from the existing map, proved to be considerably more generalized and inaccurate than the digitized contours obtained from SPOT. Also the isometric views (DEM) obtained from the map and SPOT respectively, by interpolation in a regular square grid pattern with an interval of 100 metres (i.e. 1 mm in the original map) show the same picture. Subsequently a slope map with seven slope steepness categories was prepared from the digital data. A map showing slope aspect in several categories also is in preparation.

The geomorphological studies accompanying the morphometric analysis described above, are in progress. Part of the field studies have already been carried out.

## THE USE OF GEOINFORMATION SYSTEMS IN GEOMORPHOLOGICAL MAPPING

A geoinformation system ILWIS (Integrated Land and

Waterresource management Information System) has recently been developed at ITC by MEYERINK & VALENZUELA (1987). Apart from a base module (administrative boundaries, roads, settlements, etc.) it includes three thematic modules related to terrain/soil, vegetation and water respectively. The terrain/soil geography module is of particular interest for geomorphological mapping as it defines and describes the main terrain units and their corresponding soils. It is based on the ITC system of geomorphological mapping, has a geologic-geomorphologic nucleus and also incorporates physiographic and morphometric aspects.

The data required to define and describe the terrain mapping units (TMU) are obtained from various sources. The system uses:

- digitized (vector) map data
- remotely sensed (raster) data
- application models known from literature or available as software packages
- IBM compatible personal computers.

The hardware of the ILWIS system includes an 8086 or 80286 based microcomputer with Random Access Memory (RAM) of 640 Kbytes and a mathematical coprocessor. At least one high density disk drive (1.2 Mbytes) and a minimum of 20 Mbyte hard disks are required and a high resolution display with a color board MATROX 960

## Legend and codes

Geol. map	LC LT	THU code	OR (Geomorphology/Physiography)	IR	IR	VD
F	1.0 0.5	FTF	Floodplain and terraces	F	2	0.4
V	1.3 3.32/3.42	VSU	Upper stratovolcano	H	85	6.0
V	1.0 3.32	VSL	Lower stratovolcano	M	28	5.2
G	1.0 3.11	DMG	Steep granite hills	M	35	9.5
G	1.0 3.11	DHG	Steep granite mountains	H	55	8.2
X	3.0 2.06/2.32	DMS	Den. hills (rolling) on sandstone & shales	M	30	3.2
Y	3.0 2.61/2.32	DIM	Den. low hills, broad valleys on marls	I	28	5.8
Y	3.0 2.61/2.66	DLM	Den. low hills, undulating on marls	L	18	5.8
Z1	1.0 2.02	SRM	Strike ridges, conglomerates	M	40	1.5
Z2	1.0 2.61	SVL	Strike valleys, marls	L	22	4.5

### Crests/Slopes

- |                      |                              |
|----------------------|------------------------------|
| 1. sharp             | 1. straight                  |
| 2. sharp-rounded     | 2. convex                    |
| 3. rounded           | 3. concave                   |
| 4. broad convex      | 4. convex-concave            |
| 5. flat convex       | 5. convex-straight-concave   |
| 6. table-shaped      | 6. cliff-concave             |
| 7. dissected         | 7. straight segments-concave |
| 8-10. (user-defined) | 8. straight segments-convex  |
|                      | 9. irregular                 |

### Valleys

- |                         |                              |
|-------------------------|------------------------------|
| Vs single river         | Vc multi-channel, complex    |
| 1. active incision      | 1. irregular                 |
| 2. incised              | 2. anastomosing & floodplain |
| 3. stable               | 3. braiding                  |
| 4. river floodplain     | 4. (user-defined)            |
| 5. sheetwash floodplain | 5. terraces                  |
| 6. levee & backswamp    | 6. dissected terraces        |
| 7. drowned, waterlogged | 7-10. (user-defined)         |
| 8-10. (user-defined)    |                              |

CP a table digitizer Calcomp 2000 or 9100 series, a line printer and a Tektroniks color plotter or IBM color jet-ink (or compatible) also form part of the system.

Figure 6 shows the coding and mapping of geomorphological (TMU) units and figure 7 gives an example of the input codes for morphometric information.

## CONCLUSIONS

It is evident that important changes in methods of geomorphological mapping are developing and will become increasingly important in the near future. The impetus of first generation satellites (Landsat etc.) was mainly in direct small scale mapping. The second generation of high resolution stereoscopic (SPOT) satellites brings detailed geomorphological mapping using satellite imagery instead of aerial photographs within reach. The methodology changes are further affected by the growing emphasis of applied types of surveys particularly for purposes of natural hazard zoning and using pragmatic legends rather than purely analytical or synthetic ones.

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