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Terrain models -- A tool for natural hazard mapping

RONALD TOPPE
Norwegian Geotechnical Institute, PO Box 40 Taasen, N-0801 Oslo 8, Norway

ABSTRACT Survey mapping of potential snow-avalanche and rock-fall hazard can be done based on information derived from topographical maps alone. A computer based system using digital terrain models will automatically identify potential starting-zones, perform computation of run-out distance, and assist map editing and production. The theoretical basis, practical use and experience gained from such a system used in Norway are described.

MODELES DE TERRAIN - UN INSTRUMENT DE CARTOGRAPHIE DES HAZARDS NATURELS
RESUME La cartographie globale des zones sujettes aux avalanches et ébolements rocheux peut être baseé sur la seule information de castes topographiques. Un système programmé utilisant des modèles de terrain digitalisés peut identifier automatiquement les zones de glissement initial possibles, calculer leur étendue et aider à l'édition et la production de cartes. L'article décrit la base théorique, l'utilization pratiqué et l'expérience acquiese avec ce systéme développé en Norvège.

INTRODUCTION

Hazard mapping using digital methods

Mapping of snow-avalanche and rock-fall hazard implies basically two aspects; identification of the starting zones and determination of the run-out distance. Both these considerations traditionally rely on the skill of the person doing the mapping and on the tedious work of searching maps and aerial photographs for small starting zones.

In **survey mapping** of **potential** snow-avalanche and rock-fall hazard, both identification of starting zones and computation of run-out distance can be done solely from topographical information (Hestnes, Lied 1980):

Field experience has shown that all areas steeper than 30° are potential starting zones.

Run-out distance of snow-avalanches can be determined by use of the Bakkehøi, Domaas, Lied method (Bakkehøi, Domaas, Lied 1983).

This method computes the maximum run-out distance to be expected for the actual avalanche, using topographical parameters from a two-dimensional terrain profile along the path, combined with statistically based constants (fig.1). Run-out distance of rock-fall is computed in a simpler way. A recent study shows that 95% of all rock-falls will stop inside the point on the profile having a horizontal angle of 32° with the rock-fall starting point (fig.2) (Domaas 1985).

These factors implicate that survey mapping of snow-avalanche and rock-fall hazard can be done with a computer based mapping system. All the needed information can be extracted from the map, some of it semi-automatically, and the computer will perform the run-out computations fast enough to make the mapping interactive.

Another argument for using computers is that the availability of **digital maps** - maps where the information is represented as digits inside a computer - is increasing. Keeping maps in digital form make them easy to update, easy to store, they can be combined with other information and they can be presented in different ways. Most new maps are digitized when constructed, and existing maps can be manually or automatically digitized.

An ordinary contour-line map has an obvious drawback when it comes to extraction of topographical information. It does not supply information of the terrain between the contour lines. This problem can be overcome by making the map into a **terrain model**, a three dimensional description of the terrain. Terrain models can be divided into two groups:

Primary models, where information about a point on the surface is derived from the digital map every time the information is wanted during the mapping.

Secondary models, where the original input data is used to interpolate surface information that is stored in a grid. Information about the surface is derived from this grid, and not from the original input data, during the mapping.

A primary model performs quick enough when the digital map is small. But in survey mapping the areas to be covered tend to be very large and a primary model would use too much time to search through the digital map to be of any use. In a secondary model the time-consuming map searching is done once and for all before the interactive mapping starts. During the mapping a secondary model can perform very quickly.

Some kind of **interpolation** is involved in all terrain modelling systems; the way you derive terrain information for a point on the surface based on known elevations other places (e.g. elevation between contour lines). Most systems (both primary and secondary) use linear interpolation. This has obvious limitations, and may lead to inaccurate and even wrong results. It is clearly better to use some kind of higher order function and specially polynomial **spline functions** have proved useful. A polynomial spline function is the "best fitting" smooth curve for a collection of points that actually move through the points. "Best fitting" implies that the second derivative of the function, not the curvature, is minimized. An infinite number of spline functions exist for a given collection of points (fig.3). The "best" spline for use in terrain modelling systems is the one that resembles "natural curvature" the best.

Hazard mapping in Norway

In the 1976 the Norwegian Geotechnical Institute started to look into the possibility of performing survey mapping of potential snow-avalanche and rock-fall hazard for all the inhabited parts of Norway. A total of 100,000 km², nearly 1/3 of the country's land surface would be covered (Statens Naturskadefond 1977).

It was concluded that the hazard maps should be based on the Norwegian Geographical Surveys map series M711; topographical maps in scale 1:50,000 with a contour-line interval of 20 m and covering an area from 500 to 700 square kilometers. The maps are available in digital form and vary in size from 2 to 7 Mb of elevation-carrying information (contour-lines and water contours).

To perform the mapping manually using printed maps, aerial photographs and field survey proved to be both tedious and time consuming. It was decided to carry out the mapping program using computer based methods.

Observing the factors mentioned above we searched for a digital terrain modelling system that would fulfill our needs; interactive mapping of the entire map in one operation, with high precision, and parts of the mapping done automatically (Toppe 1983).

Such a system did not exist, but the basis of an acceptable model had been developed by Leif Erik Stabell at The Norwegian Centre for Industrial Research (SI) (Stabell 1981). From 1982 to 1984 the terrain modelling system TERMOS was developed as a joint venture between SI and NGI (Toppe, Lied 1984).

TERMOS, A DIGITAL TERRAIN MODELLING SYSTEM

With digital map input TERMOS uses a secondary terrain model. A regular grid, with a maximum of 810,000 elements, is placed on the map (fig.4). The intersections between the horizontal and the vertical gridline and the four nearest contour-lines on each side is found. A cubic spline function is computed based on the four points in each direction. The computed elevation in the gridpoint is equal to the mean of the Z value in the grid-point of the two splines. Steepness and exposition is determined from the planes defined by the tangent to the splines in the grid point. This method takes advantage of the fact that a map gives more terrain information than just X,Y and Z values. The contour-line distribution is controlling the cubic splines and the interpolated elevations are double-checked with the contour lines to avoid errors (impossible elevations, exaggerated mountain-tops etc.). In this model the surface is mathematically determined and elevation can be computed quickly anywhere on the grid, also in between the grid-points. This feature makes TERMOS specially suitable for work that implies profiling.

The full system runs on Prime minicomputers, using the Tektronix 4106 - 4129 range of graphical work-stations. These work-stations has built-in zooming and panning features, and all map handling during an interactive work session is performed locally in the workstation. This drastically shortens the time used on displaying sections of the map. A 7 Mb map is updated in seconds, a task that would take a lot of computation, and minutes to do from software.

TERMOS consists of different modules, covering tools for terrain model creation, mapping tools for graphic-line editing, elevation retrieval, terrain-inclination retrieval and three-dimensional viewing, and tools for plotting of the mapping results. The mapping is performed using on-screen hierarchical menus, puck and tablet.

A development project like this has a great spin-off potential and today TERMOS is a family of terrain model-based mapping systems. Beside the application for hazard-mapping (named TERMOS-HAZARD), it is used for power-line planning by the Norwegian Electricity Board, flood-wave simulation by the University of Oslo, planning and construction of built-up areas by NGI and monitoring of sedimentation in water-reservoirs by the Ministry of Water-resources in Zimbabwe.

HAZARD MAPPING USING TERMOS

The first task is to produce a terrain model from the digital map. To assure optimum quality, the maximum grid size of 810,000 elements is used: Elevation and steepness is interpolated for every 30 metres in the terrain. To perform such a detailed computation for a map covering 700 km^2 will take around 36 hours on a Prime 9750, and all model-creations are therefore performed during the week-ends.

The mapping is divided into four parts:

Yellow areas
Areas without habitation or roads are ignored and appear yellow in the finished map. So, first all yellow areas are outlined using the graphical editor.

Starting zones
Next, all the starting zones are found. The area where the terrain inclination is to be computed is indicated and the inclination limit given (we use 30°). The computation takes typically 1 minute for an area of 8 km^2, and the starting zones are outlined on the map (fig.6).

Runout distance
The procedure for computation of snow-avalanche and rock-fall runout distance is the same. The operator draws the avalanche path on to the map, and the system computes the terrain profile along

the path. When snow-avalanche run-out distance is computed, the parameters used in the Bakkehøi, Domaas, Lied method are extracted (fig.1). The best-fitting parabola approximating the profile is computed using a least-square algorithm, and the second derivative of this is used as a curvature parameter (y"). The distance from the avalanche start-point to the parabola minima us used as the height parameter (H). The inclination of the starting zone (θ) (the uppermost 100 meters, or uppermost 20 meters for short paths) is computed using the profile itself. This is also the case when the point on the profile where the inclination becomes less than 10° is found (the β-point). To avoid small level parts higher up in the path, a β-point is accepted only if it is inside the section of the profile limited by the points where the angel between the tangent of the parabola and the horizontal plane is between 5° and 15° (the β-field). Then the α-angle is computed, and the corresponding point on the profile found (the α-point, or stop point). If it is impossible to compute the α-angle (path too level or too steep), or the α-point cannot be found (the path too short), understandable error messages are given.

If successful, the avalanche start- and stop-points are indicated by small crosses, and the operator continues with the next path. This time the start- and stop-points are linked with the first ones, and an upper and lower danger zone starts to form.

When rock-fall runout distance is surveyed, the point on the profile having a horizontal angel of 30° with the rock-fall starting point is found (fig.2). The work then proceeds as for snow-avalanches.

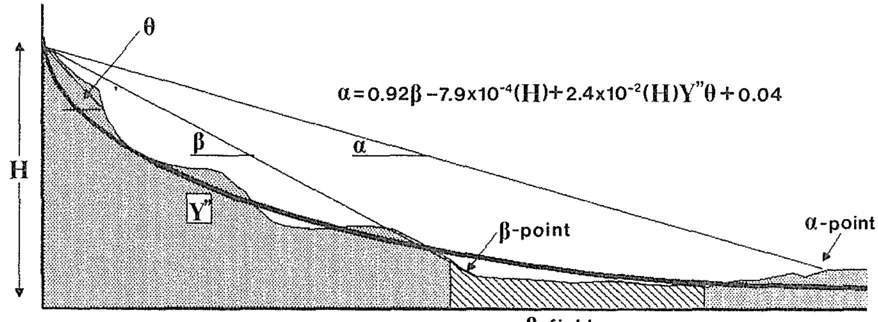

FIG.1 Formula and topographical parameters used in the Bakkehøi, Domaas, Lied method for computation of snow-avalanche run-out distance. The topography in this example is exaggerated to exemplify the possibility of having several potential β-points.

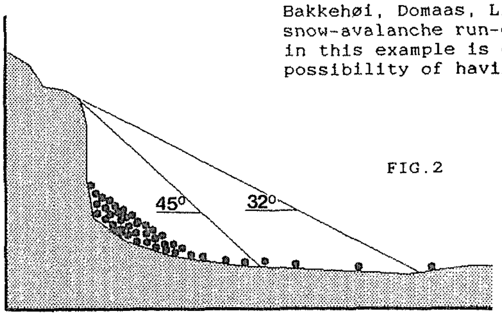

FIG.2 Run-out distance for 50% (45° line) and 95% (32° line) of the rocks falling from the cliff.

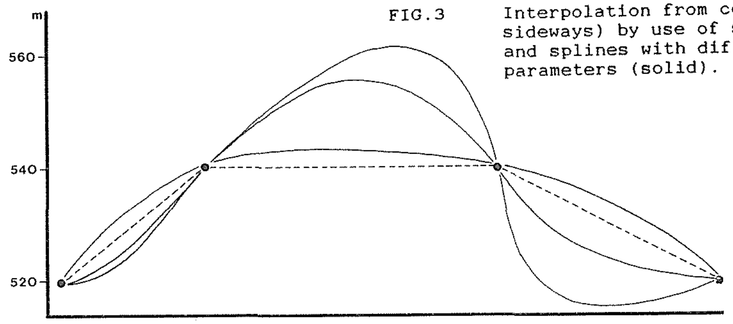

FIG.3 Interpolation from contour lines (viewed sideways) by use of straight lines (dashed) and splines with different tension and end parameters (solid).

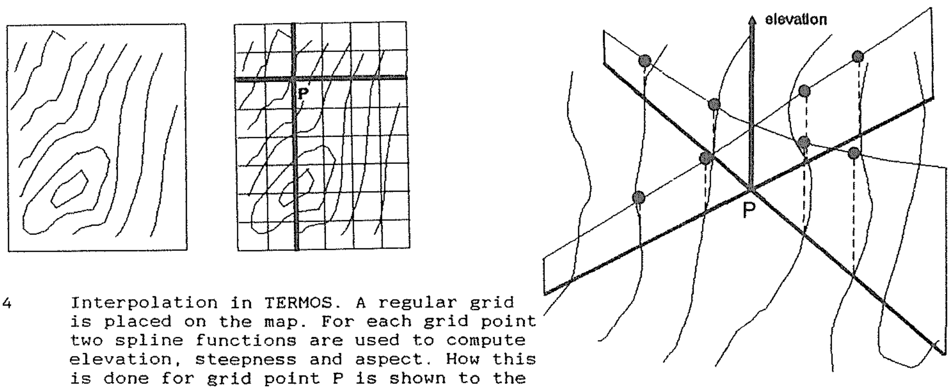

FIG.4 Interpolation in TERMOS. A regular grid is placed on the map. For each grid point two spline functions are used to compute elevation, steepness and aspect. How this is done for grid point P is shown to the right.

During this work three dimensional images of the terrain can be viewed on the screen, as an aid in determining the avalanche or rock-fall paths (fig.5).

When all the actual sections of the map are surveyed, the borders indicating yellow areas, the outline of the starting zones, and the calculated hazard zones are plotted on top of a printed edition of the map and then surveyed in the field (fig.6).

Red areas

After the field survey the calculated hazard zones are edited by using the graphical editor, according to the observations made in the field. New borders can be drawn, deleted (parts or entire borders) and borders can be extended or linked together. The editing results in the concluding potential hazard areas (fig.7), printed in red on the final map.

The film used for printing of the final hazard-map are cut on a digital drawing machine, guided by the yellow and red zone information from TERMOS-HAZARD.

CONCLUSIONS

TERMOS-HAZARD was put to use in January 1985 and so far 32 maps are completed on the computer. The bottle neck of the mapping is the field work. The summer-season is short and hectic, and only 20

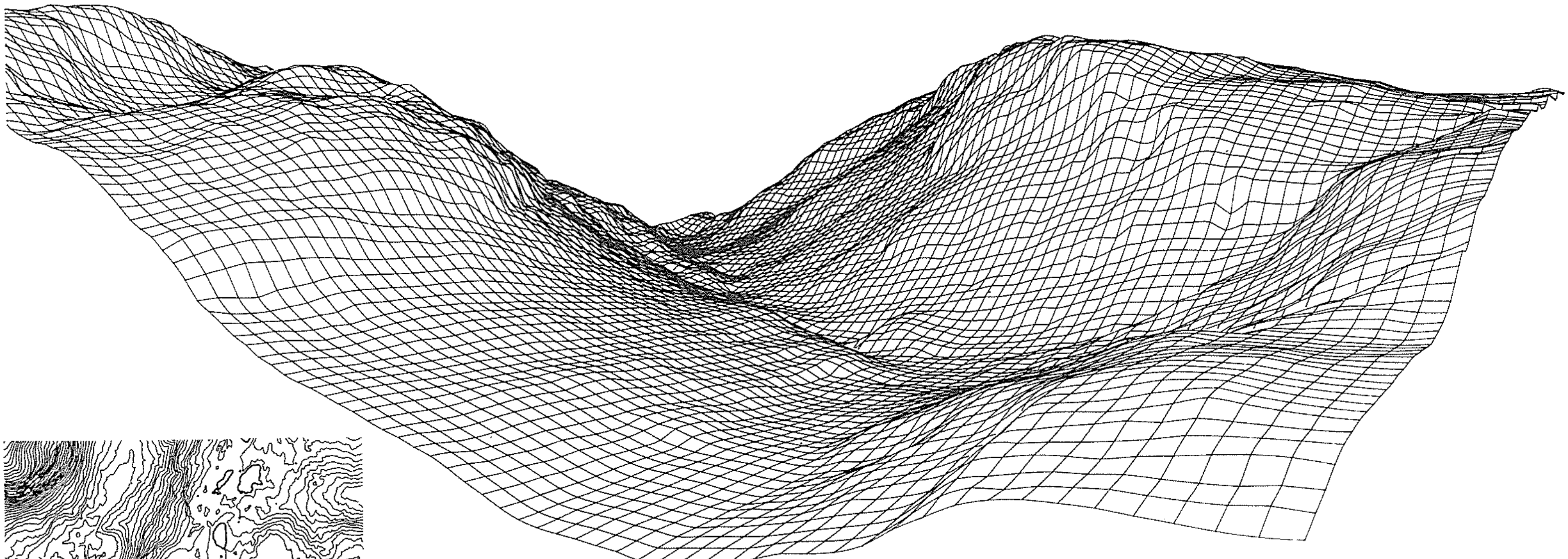

FIG.5 Three dimensional image of the area indicated by the square on the map. The location of the viewpoint is marked by the dot, 200 meters above the valley-floor. The patch size is equal to the grid-size; 30 by 30 meters.

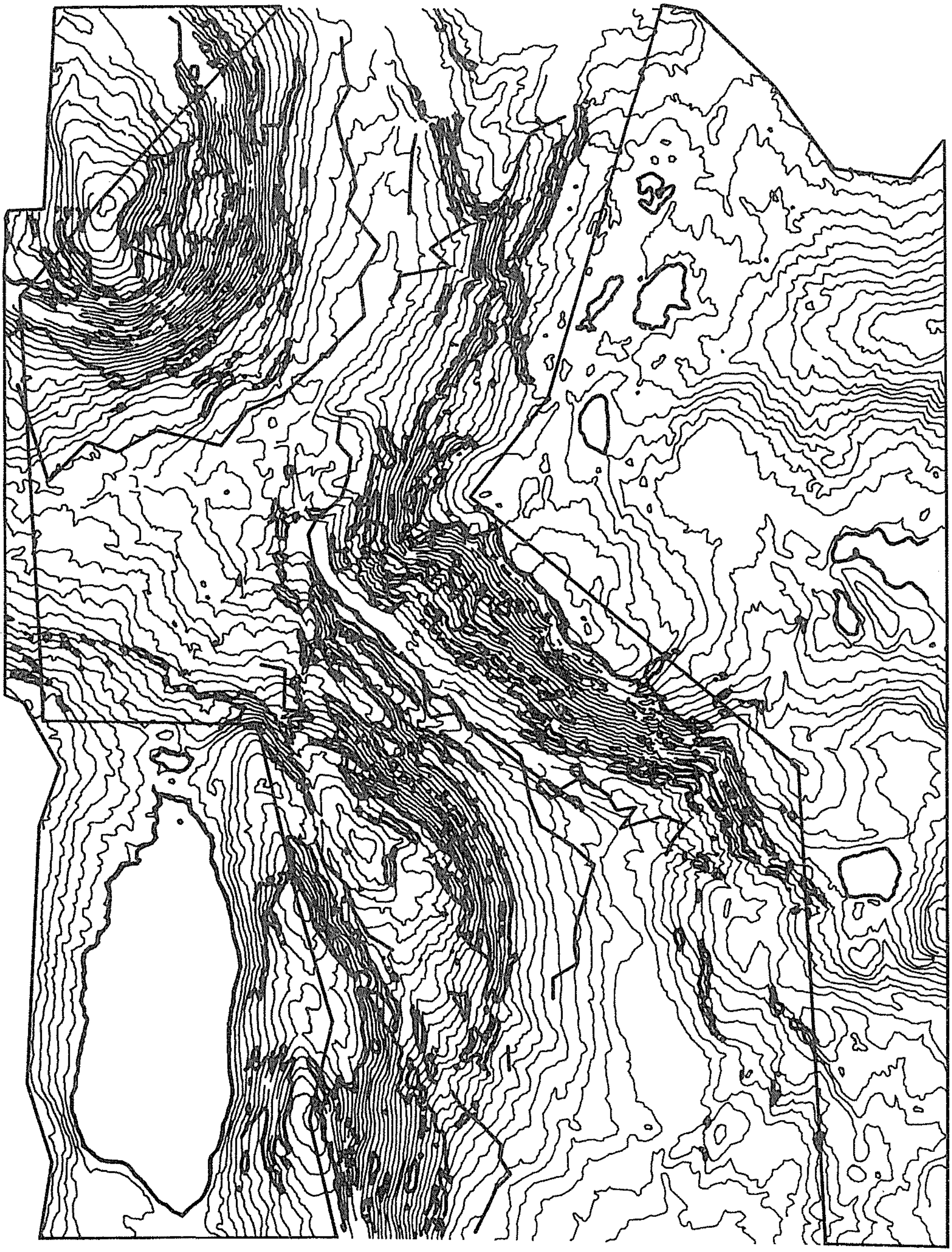

FIG.6 Lines indicating the snow-avalanche and rock-fall run-out distance, the yellow area outline, and starting zones (areas steeper than 30°), is drawn onto the map. The map is now ready for field survey. This information is normally drawn on top of the printed edition of the map, in scale 1:50.000. This example is in scale 1:39.667.

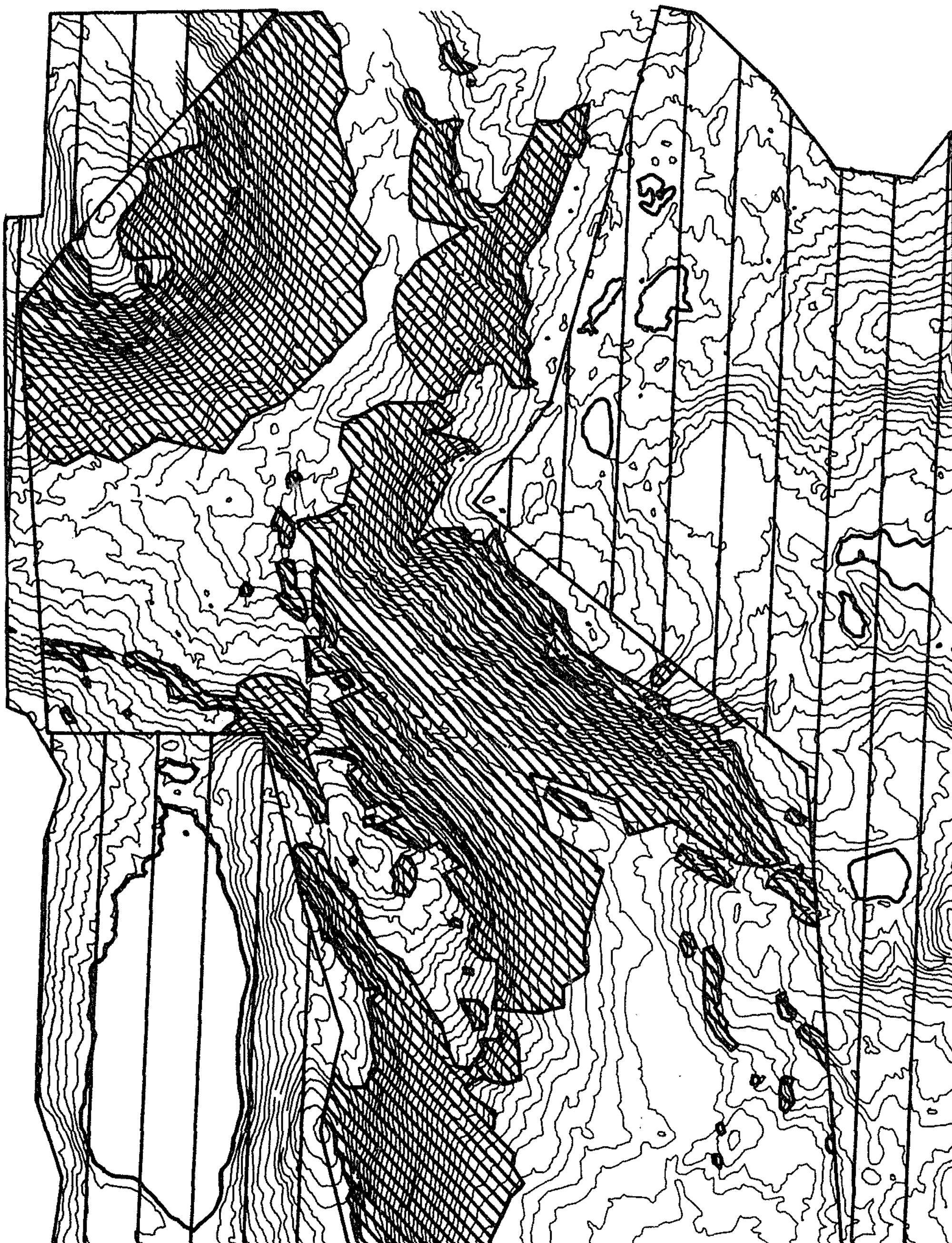

FIG.7 The final map, ready for printing. All the map examples are made using a small section (40 km², scale 1:39.667) from a M711 map. Ordinary survey mapping is performed on the entire map (400 to 600 km², scale 1:50.000). The avalanche zones are filled in with colour on the finished map, and not hatched as in this example.

maps have been surveyed in the field and are ready for printing.

Total time used to produce one map is 40 hours on average. First 16 hours at the work-station, then 16 in the field, and finally 8 hours at the work-station. Administrative work amounts to 8 hours per hazard-map. The production costs are dependent on how the computer usage is priced. With "normal pricing" the cost would be too high to justify use of a computer-based mapping system. But since the bulk of computation (terrain-model creation) is done in otherwise idle time, we can keep the price down to an acceptable level. Another cost-factor is education of the operators and reorganizing and adaption of the new procedures. This involves not only money, but also human factors. An expert aerial-photo interpreter does not always like being placed in front of a computer work-station, facing the novice-role.

There are several reasons for using a system like TERMOS: We are assured high quality maps. The computer will not overlook a potential starting zone and the best tools we have for determination of run-out distance can be used. Manual mapping implies manual transfer of information. Borders are copied from draft maps, to print original, to print film. This may cause errors; a small detail is forgotten or a line inaccurately drawn. With a computer based system all drawing is performed by the computer, and the risk of transfer-errors eliminated. As mentioned before, having maps in digital form is an advantage in itself. Another important reason is that the mapping itself becomes easier, more fun, than manual mapping. Most of the tiresome work is done by the computer and efforts can be spent on more challenging tasks.

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