STABILITY OF SLOPES NEAR BARCELONNETTE (ALPES DE HAUTE PROVENCE, FRANCE): A CASE STUDY IN SLOPE STABILITY MAPPING[1]

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ABSTRACT

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A systematic inventory of geomorphological phenomena combined with general information about lithology, climate, and the hydrological situation of a region can be used to draw a slope stability map at intermediate scales (1:10000 to 1:25000). As a case study the realization of such a map for a small area in the French Alps is described.

The map not only shows stability classes, but also summarizes important features with regard to slope stability, such as slope angle, lithology, and signs of present-day geomorphological processes. Applications are the identification of unstable areas early in a planning procedure and of areas where site investigation will be necessary prior to construction. It appeared that in the area around Barcelonnette town enlargement plans include many unfavourable places.

INTRODUCTION

This article presents a method to evaluate the slope stability, based on a systematic inventory of geomorphological features, and on additional information that concerns the material of the slopes, hydrological conditions, vegetation, and present-day land use. In this way a slope stability map on an intermediate scale (1:10000) was made.

The method is applied to the area north of Barcelonnette, a town of about 6400 inhabitants in the French Alps (Fig. 1). The future development of Barcelonnette is described in an official document, called the 'Plan d'Occupation des Sols' (POS). Every French municipality has to indicate its intended development by means of such a plan. Because the bottom of the valley in which Barcelonnette is situated does not offer much room for further expansion, enlargement is planned and

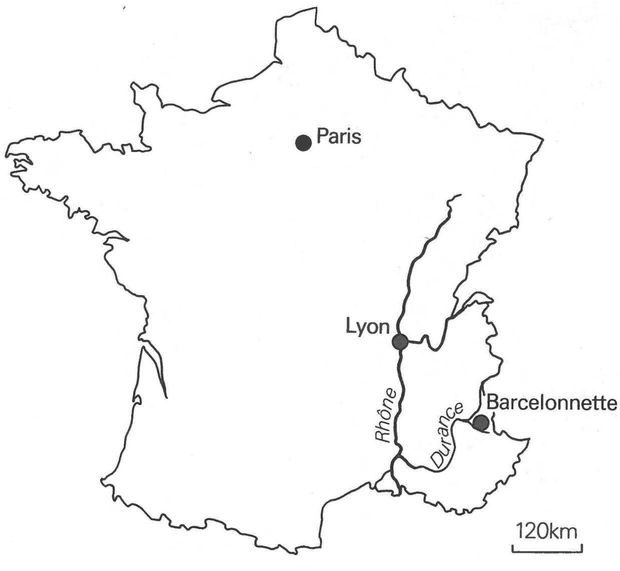

Fig. 1
Locality map.

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already partially realized on the lower parts of the unstable slopes to the north of the town (cf. Fig. 5). Construction of buildings and roads caused many stability problems and indeed much damage resulted.

The fieldwork for this study was executed in 1981, after a preparative phase in which the accent was on the analysis of aerial photographs. The slope stability map, a part of which is included in the article, gives more detail than the so-called ZERMOS-map for this region (ZERMOS: Zones Exposées aux Risques liés aux Mouvements du Sol et du Sous-sol; C.E.T.E., 1974). The research of LEGIER (1977) which was also carried out in the surroundings of Barcelonnette was focused on a number of case histories of land slides in this region. His study was not intended to give an evaluation of the mass movement risk for the whole region.

THE AREA AROUND BARCELONNETTE

The area around Barcelonnette is part of the drainage basin of the Ubaye, a major tributary of the river Durance (Fig. 1). The altitude of the valley floor near Barcelonnette is ca 1100 m; the surrounding summits reach nearly 3000 m.

Geologically the region is characterized by the occurrence of Upper-Jurassic marls (known in the French Alps as 'terres noires') which are exposed in a large window in one of the most important overthrusts in the French Alps, that of the 'Flysch à helminthoïdes' (DEBELMAS, 1974). The geologic setting is indicated in Fig. 2.

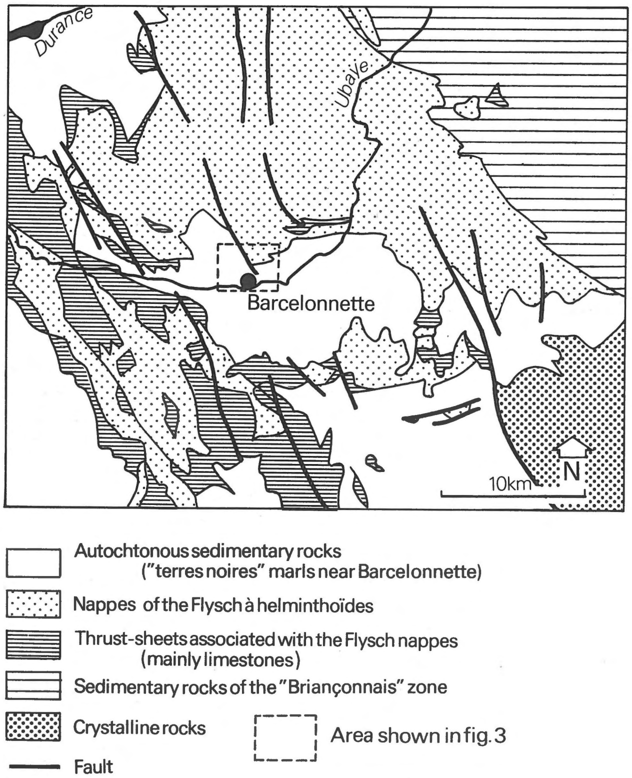


Fig. 2
Geological structure of a part of the French Alps. After Debelmas (1974).

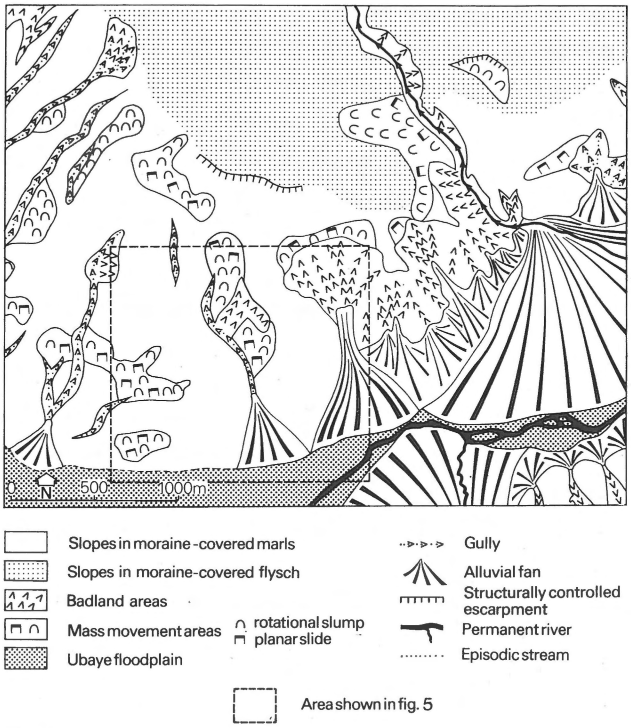


Fig. 3
Geomorphology of the area north of Barcelonnette.

This geologic situation has important geomorphological consequences. Above ca 2000 m the flysch is the main constituent of the mountains including the summits. Relatively steep slopes prevail in this zone. Around Barcelonnette a wide basin with generally spoken gentle slopes is formed in the 'terres noires'. Pleistocene glacial events resulted in a partial oversteepening of the lower valley sides and in the deposition of a cover of morainic material. Holocene development comprised large, deep-seated mass movement that took place shortly after deglaciation (C.E.T.E., 1974; LEGIER, 1977), and strong erosion by running water, often in combination with land sliding of more restricted extent. The latter processes are mainly the result of human impact, especially deforestation and overgrazing. Recent erosional landforms are deep gullies and extensive badlands. Alluvial fans of various dimensions are found in relation with this erosion. The glacially oversteepened lower parts of the valley sides are particularly vulnerable to damage by erosion or land sliding. The major geomorphological features are shown in Fig. 3.

In this region Mediterranean trends are still recognizable in the distribution of the precipitation over the year and in the rainfall intensity during summer and autumn storms (DOUGUEDROIT, 1976; LEGIER, 1977). Characteristics of the climate are given in Fig. 4. Precipitation increases with altitude, and because most winter precipitation is in the form of snow, much water is available in spring on the higher parts of the slopes.

Because the flysch has a large water storage capacity (cf. C.E.T.E., 1974), the spring melting water generally does not cause important problems for the lower parts of the valleys. The combination of snow melt and heavy precipitation that occurs sometimes at the end of the spring, occasionally creates very dangerous situations, as in June 1957, and to a lesser degree in 1973. During these events enormous quantities of material may be displaced, especially as a result of the increased number of mass movements, but also because of their increased volumes (TRICART, 1974).

The original vegetation in this region is a coniferous forest the upper limit of which is at ca 2400 m. Since the second half of the twelfth century deforestation increased. At the beginning of the sixteenth century the slopes north of Barcelonnette had lost almost all of their forest cover. As a consequence, erosion and mass movement became more and more important, and many catastrophic events were recorded (cf. AVOCAT, 1979). At present protection against flooding and against the erosional activity of the large gullies is fairly effective, but mass movement and small-scale erosion are far from mastered.

THE METHOD: SLOPE STABILITY AS REFLECTED IN GEOMORPHOLOGY

A systematic recording of geomorphic phenomena can be used as a base for an evaluation of regional differences in slope stability (cf. C.E.T.E., 1974; BRUNSDEN ET AL., 1975; LEGIER, 1977; DOORNKAMP ET AL., 1979; MARGOT & MAHR, 1979).

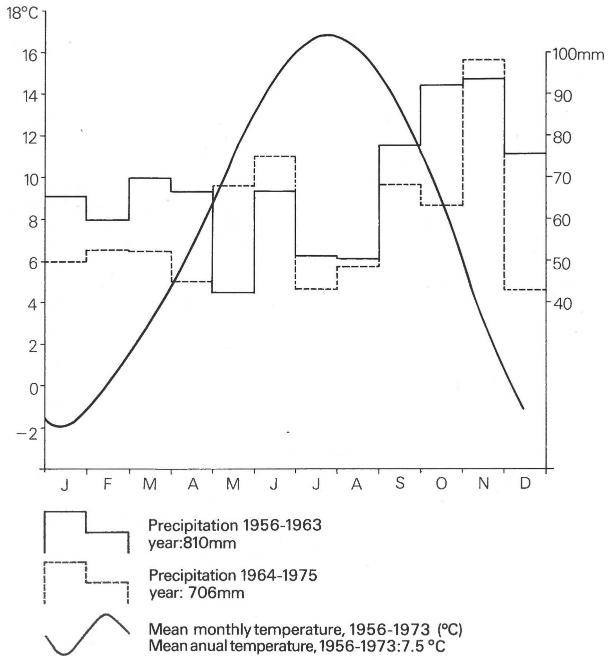


Fig. 4
Temperature and precipitation, Barcelonnette-St. Pons (ca 1130 m above sea level). After Legier (1977).

The stability analysis is based on the following assumptions. First, each type of bedrock is sufficiently uniform in soil mechanical properties, and surficial materials are also thought to be uniform. Second, land units that have similar physical properties are comparable with regard to the risk of damage by mass movement or erosion processes. Both assumptions are supported by field observations in the case of the area near Barcelonnette. However, they are only valid as rough estimates, acceptable for surveys on relatively small scales. Important deviations will be present in many places.

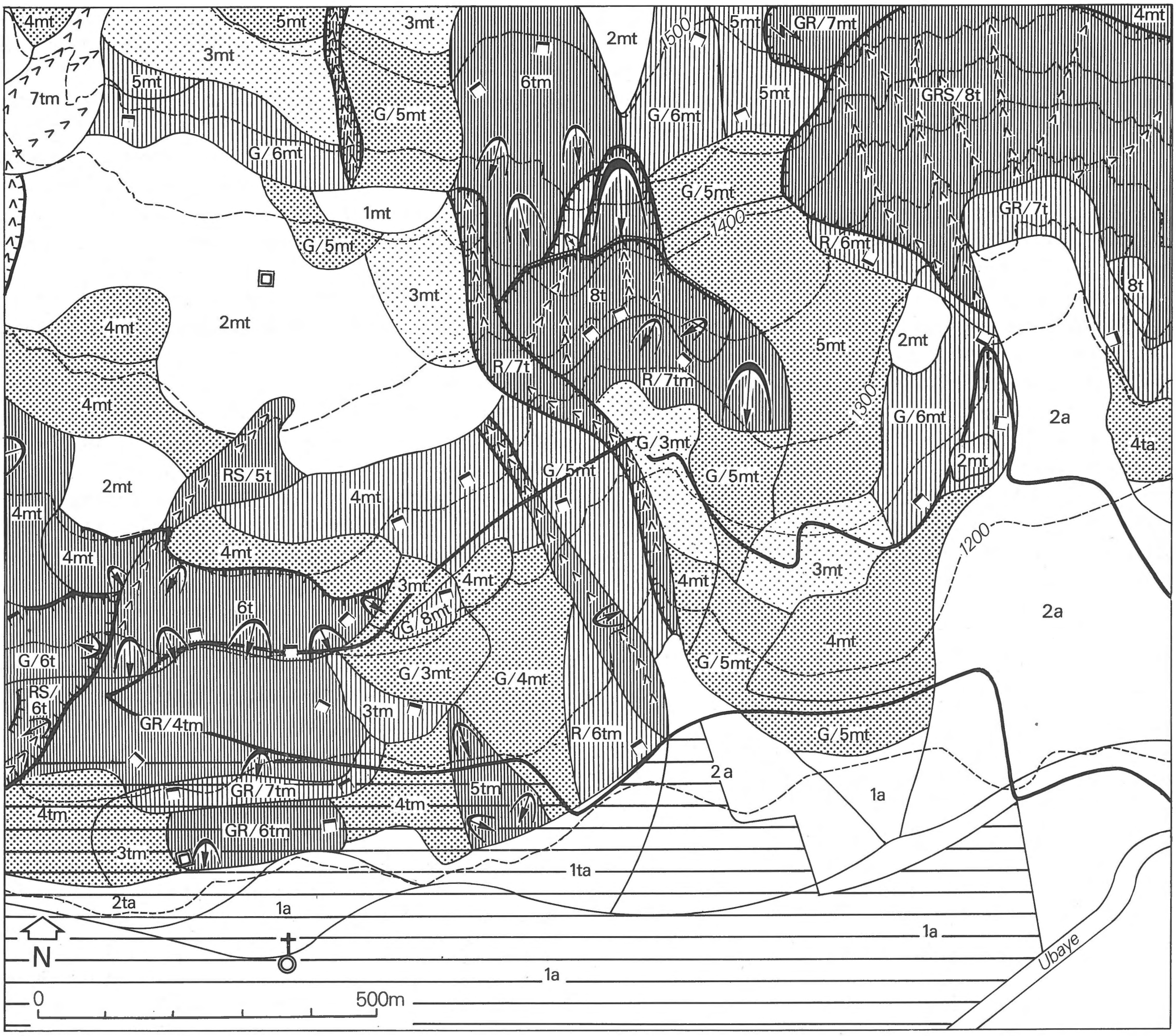
With these assumptions in mind, the observed intensity of mass movement and erosion features in well-defined land units can be used to evaluate the potential danger of slope instability for parts of the area that are not (yet) affected by some kind of instability. This means that the evaluation is essentially based on comparison. The land units mentioned above have to be defined in terms of slope angle and slope form, overall material properties, and hydrogeomorphological characteristics. Intensity of the processes concerns both the spatial density of the features and the process rates, as far as these can be inferred from simple field observation. Hydrogeomorphological aspects are the presence of concavities on the slopes (in plan and in profile, as visible from contour patterns), which concentrate run-off or subsurface flow, signs of stagnant water or other traces of insufficient drainage, presence of springs, and deteriorated small irrigation channels which are locally found in the region of Barcelonnette.

The basic land units, depicted on the stability map, were determined by the analysis of aerial photographs and subsequent field work. Each unit is homogeneous with regard to the factors mentioned before, as well as to vegetation structure and present-day land use. These factors all played a part in the assessment of the stability class for each land unit.

The main division of stability resulted in the definition of three classes: stable – potentially unstable – unstable. However, it appeared possible to describe the risk of slope instability in more detail. Therefore, the last two classes are divided into two sub-classes each, which finally gives five degrees of (in)stability. For convenience these are indicated as five classes:

class 1: stable
class 2: potentially unstable, stage 1
class 3: potentially unstable, stage 2
class 4: unstable
class 5: very unstable.

These classes are used on the stability map, scale 1:10000, a part of which is reproduced in Fig. 5. A detailed description of the classes is given in the following section.



Stability classes

class 1	–	stable
class 2	–	potentially unstable, stage 1
class 3	–	potentially unstable, stage 2
class 4	–	unstable
class 5	–	very unstable

Reservoir

-1200- Contours (50m interval)

Outline of planned town development according to the P.O.S. Barcelonnette

Built-up area of Barcelonnette situation 1982

Example of code arrangement: GR/4mt

Processes: grass cover displacement (G) and rillwash (R)

Slope angle class: 15-19° (4)

Lithology: moraine cover on marl (mt)

Slope angle classes

1 : 0-4°
2 : 5-9°
3 : 10-14°
4 : 15-19°
5 : 20-24°
6 : 25-29°
7 : 30-34°
8 : ⩾35°

Surface material and lithology

a	Alluvial material
l	Limestone
t	"Terres noires" marl
mt	Moraine cover (⩽3m thickness) on "terres noires" marl
ta	Composite material ("terres noires" marl and alluvia; footslopes)
tm	Composite material ("terres noires" marl and moraine; old land slide accumulations)

Geomorphological processes

A Processes attributed to land units as a whole

- G Small-scale grass cover sliding
- R Rill wash
- S Sheet wash

B Processes locally active

- Planar slide
- Rotational slump
- <<< Gullying
- Rock-fall
- Backward erosion of scarps

Fig. 5
A part of the slope stability map.

THE SLOPE STABILITY MAP OF THE VALLEY SIDE NORTH OF BARCELONNETTE

The properties of the stability classes that were mentioned in the previous section can be summarized in the following way:

– Class 1 – stable; slope angles are between 0 and 9°, in exceptional cases between 10 and 14°. Mass movement (present or past) or traces of erosion by running water are nowhere found within land units belonging to class 1. Natural drainage is good, and the vegetation cover is undamaged. The areas that belong to this class are mainly restricted to the alluvial fans and the Ubaye flood plain. Some parts of the moraine-covered slopes are also stable, generally when they have slope angles below 15° and when the bedrock is limestone. It must be stressed that the risk of flooding is out of the scope of this analysis. Flooding hazard exists on the Ubaye flood plain, and to a lesser extent on parts of the alluvial fans.

– Class 2 – potentially unstable, stage 1; slope angles are between ca 10 and 20°. The slope form is rectilinear to slightly convex. Under a morainic cover of up to 3 m thickness the bedrock is either marl ('terres noires'), in which case the slope angle in this class is only 10-15°, or limestone. The only observable active geomorphological process is the movement of small parts of the grass cover. There are no drainage problems. Class 2 land units are found on the moraine-covered slopes in the neighbourhood of class 1 units.

– Class 3 – potentially unstable, stage 2; slope angles are between 15 and 30° on 'terres noires' or between 20 and 30° on more resistant bedrock. Mass movement and erosion phenomena are virtually absent, with the exception of small grass cover displacements and small-scale slides of very limited extent. The other terrain properties are the same as those described for class 2. A second group of land units in class 3 are the accumulation areas of old large-scale slides, if their surface slope is below ca 20°. Steeper slopes in this relatively weak material are unstable.

– Class 4 – unstable; the slope angle is at least 20°. The class is essentially characterized by shallow, planar slides of limited length (generally less than 30-40 m). Often they are accompanied by surficial slides restricted to the vegetation cover, or by rill and gully erosion. Areas belonging to this class are mainly found on the steeper parts of the moraine-covered 'terres noires' slopes directly above Barcelonnette. They are also present on the accumulation areas of old large-scale land slides that have surface slope angles of more than 20°, and near the larger badland areas.

– Class 5 – very unstable; areas affected by deep-seated mass movements as well as shallow slides or areas that show important erosion by running water are classified as very unstable. Often mass movement and erosion by running water are found in combination in such an area. The mass movements comprise rotational slumps, large planar slides, smaller surficial slides, flows, and rock falls. These very unstable areas are not restricted to the steepest slopes, for they are frequently found on slopes of 15 to 25°. This is for instance the case on the valley side close to Barcelonnette, where mass movement and erosion accelerated by human influence has a long history.

For the application of the slope stability map in a planning procedure its content has to be translated into recommendations for building or road construction. It is not possible to give such recommendations without considering other aspects like technology, economy, or the availability of alternative building sites. For the area around Barcelonnette one can state from a geomorphologists' view point that construction activities are undesirable in land units belonging to stability classes 4 and 5. It will be clear that in many class 5 areas construction is virtually impossible. In the potentially unstable areas (classes 2 and 3) site investigation is necessary and construction has to be carried out very carefully.

In the stability map (Fig. 5) the emphasis is put on the visualization of the regional differences in slope stability. For each land unit additional information is given about slope angle class, material in which the slopes are formed, and phenomena of mass movement and erosion. For this purpose codes and conventional signs are used. In this way the stability classification is documented by the features that in each land unit contributed to its assessment. The map was prepared by the second author (VAN DEN HOF, 1982).

CONCLUSIONS

As can be seen from Fig. 5, much of the extension area of Barcelonnette is situated in zones were slope stability problems may occur. In the present-day situation there are no directions concerning slope stability assessment previous to town planning. It is, however, evident from the stability map presented here that stability investigations are highly desirable already in the planning stage.

Maps like the one given in this article can only be the first step in controlling stability problems. The meaning of such a map is that it identifies areas that are (potentially) unstable, with some detail about the seriousness of the problems to be expected. Detailed site investigation remains the necessary next step wherever building activities are planned in potentially unstable areas.

The advantages of the geomorphology-based stability map can be summarized in the following way (cf. BRUNSDEN ET AL., 1975; DOORNKAMP ET AL., 1979; DRAMIS ET AL., 1979):

The map gives an impression of the areal extent and the degree of instability of a region that may be useful early in a planning procedure. Subsequently, it may direct the research in the site investigation phase. An additional advantage, that was also emphasized by DOORNKAMP ET AL. (1979), is that the production of the medium-scale slope stability map is relatively inexpensive, provided that a professional geomorphologist is available. Much information can be derived from conventional aerial photographs, which means that the expensive field work phase can be short.

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