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The time dimension in the study of mass movements

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Abstract

This paper comprises two parts. The first gives the results of a study of the temporal dimensions of mass movements which was carried out by the European Centre for Geomorphological Risks in 1993. We observed that the time terminology was often inaccurate or incomplete, so we have tried to clarify concepts such as the state and mode of activity, dormancy, the return time and the age of a movement.

The second part sets out a few principles which may be helpful in applying these cartographic concepts in maps of various scales and types. Its object is to give greater consideration to temporal aspects which are just as important as intensity for this type of hazard, but which are often harder to recognise and thus often ignored or overlooked, particularly in maps.

1. Introduction

We know that hazards are defined in terms of intensity and the probability that a phenomenon will occur or recur. However, the incorporation of time into the mapping of mass movements is still very limited. In most small-scale inventory maps we try to mention the phenomenon's recent or former character and to indicate if the movement is still in progress or if it has stopped, temporarily or permanently. Terms such as active or dormant have a different meaning, depending on the author (Flageollet, 1989). In large-scale geomorphological or geotechnical maps recorded speeds are sometimes used in drawing a zonation of slides. On maps which establish a hazard degree the probability of occurrence is based on activity or dormancy and on the presence of favourable site factors, such as the slope or the rock type. We still have a great deal to learn about the past in terms of frequency or return period, type, activity mode etc.

A study of terminology relating to the time factor has been carried out within the European Centre on Geomorphological Hazards (CERG). The essential results of this study are presented in the first part of this paper. Operating within a European framework, the group's teams have used this terminology to present the results of their research into the history of mass movements in the zones selected and the lessons which can be drawn for temporal forecasting. These results have been partly translated in the form of maps. The second part of this paper lays the groundwork for a collective reference list for the time factor.

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2. Presentation and discussion on time terminology

2.1. Activity

Terms such as active and dormant have a different meaning for different authors, and are interpreted as wide or narrow, depending on the duration of activity or inactivity. In English terminology the adjective "dormant" is applied to old landslides which are still unstable, and according to Varnes (1978, 1984) a slope is active if there has been at least one movement during a seasonal cycle. Some authors base their distinction between dormant and active on the respective ages of the movements. According to Yanai and Usui (1987) in Japan, they are active if they have occurred several times at the same place in the last 300 years, and they are dormant if there has been no activity for a thousand years.

Furthermore, some works on geomorphological mapping try to differentiate the inherited processes, which are "extinct", from active processes in current morphoclimatic conditions. Gelifraction and gelifluxion, for example, which caused accumulated patterned ground of periglacial origin in temperate oceanic zones during the cold Pleistocene periods, are inherited and no longer functioning, therefore inactive. Thus mass movements appearing in the key to the maps, as active, are or could be functioning if the conditions which provoked and maintained them are still present or if movement is still possible.

There have therefore been two proposals. The first is to limit the notion of activity to real movement during the time period considered, and the second is to use a short time-scale, based on danger and prevention. If movement occurs during the period of observation it is regarded as active. Any land which has not moved during this period is regarded as inactive.

2.2. Type of activity and return time

Like many authors, we could take maximum safety precautions and maintain that a slide which occurs intermittently is active if the *return period is less than a year* (Fig. 1). This raises the problem of how the movement is recorded. Obviously there may be considerable differences in this observation. If it is visual, the only movements recorded will be those of a certain breadth or speed. This leads some practitioners (D.U.T.I., 1985) to use the "recency" of the characteristic shape of the land and the changes in covering vegetation to distinguish between movements which are very active, strongly active, moderately active and seldom active. If we rely solely on direct visual observation, a landslide may appear dormant or even intermittently active (Bisci and Dramis, 1991, 1993); however, if observation is based on relatively sophisticated instrument readings (C.F.G.I., 1991), accurate measurements of movement may show that this is not the case, and that in fact there is continuous activity consisting of phases of seasonal acceleration, usually in winter in Europe, followed by deceleration. It is highly desirable, therefore, that the map key should specify how movements have been assessed, and whether they were simply estimated or actually measured.

To some extent the type and scale of the map gives us some idea of how movement was recorded in the absence of an explicit note. For example, a medium-scale survey map showing a fairly large number of landslides can only give accurate movement measurements in one or two cases. It must therefore reduce them to the lowest common denominator, i.e. it must rely solely on observation and leave aside the results or partial or occasional measurements, however interesting they may be. However, we can easily determine the inactivity period from a large-scale map of one or two instrument-monitored landslides for which there have been continual and accurate readings. Generally, these inactivity periods are no more than a few weeks or even a few days, and activity may even be continuous at some points. The landslide will therefore be regarded as active overall and mapping will consist in showing the zones of activity. This can therefore be specified and quantified, as it is on some maps, by the use of movement speeds (D.U.T.I., 1985; Maquaire, 1990, etc.).

2.3. Commencement or reactivation

A movement may occur once, for the first time, on a site which has previously been stable. Thenceforward it is an *active first time failure* if it continues, or an *inactive first time failure* if it stops, permanently or temporarily. If one or more movements have already occurred on the same site, this *removement* can be called *reactivation* if it is an active intermittent movement, such as a seasonal reactivation, for example, or it may be termed *renewal* if it relates to a dormant movement.

2.4. Mode of activity

It is important to know how rapidly a movement is about to commence or reactivate, or to terminate, temporarily or permanently, with a view to prevention. The answer is obvious for the fall of a block,

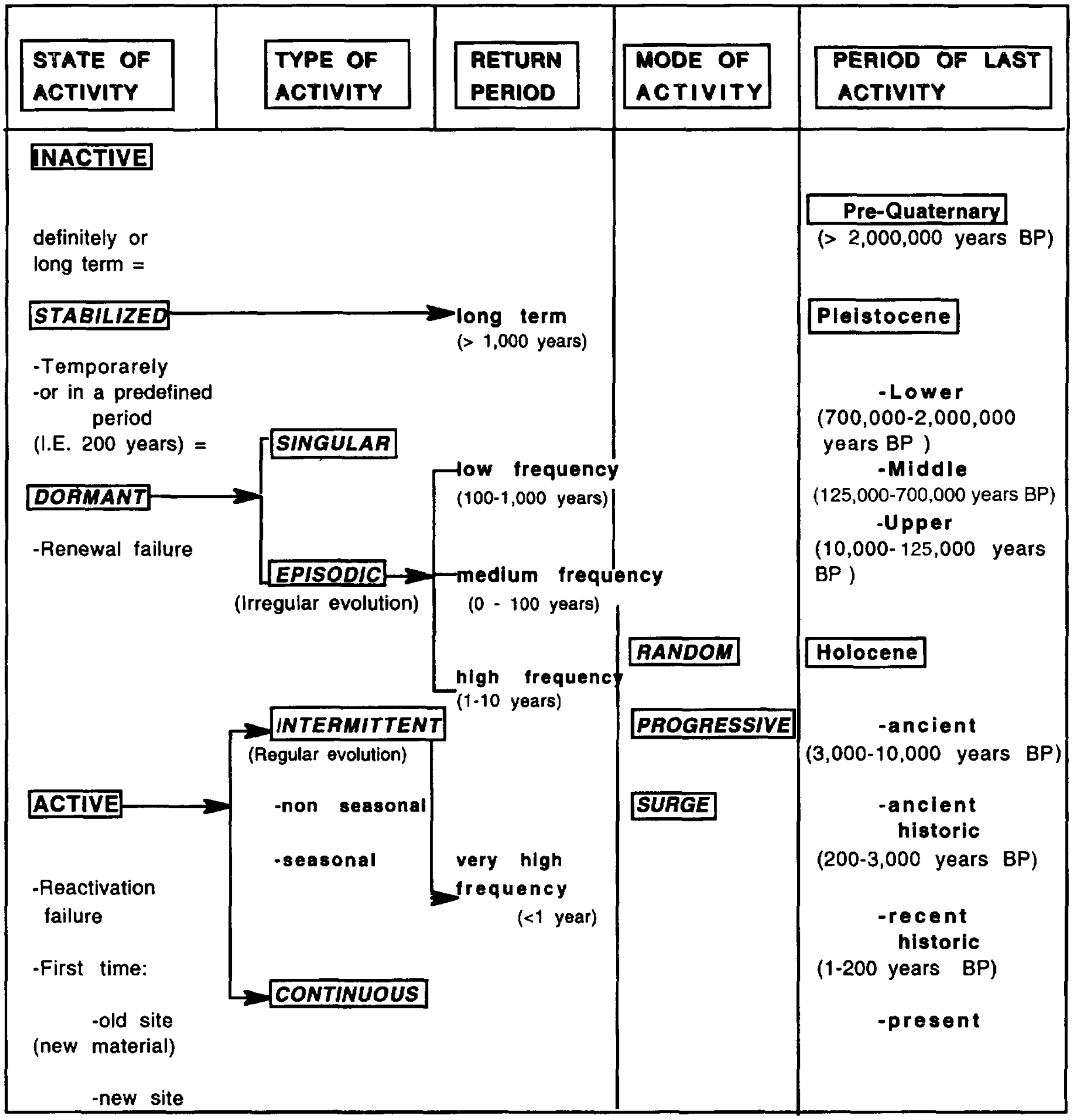

Fig. 1. The temporal occurrence of landslides: time terminology.

for example; when it is suddenly detached from a wall, it falls instantaneously and its immobilisation is sudden rather than progressive. It is less evident in the case of slides, flows and rockfall avalanches. The latter are complicated by the fact that the type of movement changes during development. We know that the generalised rupture phase and the sudden instantaneous slide is preceded, over a longer or shorter period, by deformations of the slope, packing and possible subsidence, recorded and measured during the surveillance phase. The activity of some slides increases *progressively*, while others start and finish *irregularly*, with after-shocks following structural rearrangements, for example. The flows often occur in successive *surges*.

The question should also be considered over a wider spatial scale and over a longer time scale. It is a question of designating the *onset mode* of an *active period* of mass movement, either or *sudden*, over a more or less extensive region. Slides or block falls have perhaps been more active and more frequent at certain periods, for example, just after the last glaciation or in the little ice age, and decrease, either progressively or suddenly, depending on the progressiveness or suddenness of changes in climatic conditions, or, again, with the changes in land use and human activity.

2.5. Most recent period of activity

It would be misleading to give the age of an earth movement without specifying the methods or techniques by which it was obtained. Relative dating obtained in geomorphology by observing the succession of forms and formations often relate to a very long period of time. C-14 dating of fossil wood in the material of a slide may indicate when the movement started, but not necessarily when it ended.

The time scale used here takes account of the Pleistocene period because the sliding or subsiding masses, more or less well-preserved or fossilised, whose last or only activity goes back that far into the past, are better and better known and localised because of progress in relative or absolute dating.

It is legitimate to sub-divide the Holocene into an earlier period and a later, more recent or historic period, since ca. 3000 BP, for which we have more information. It is also desirable to distinguish between an older and a more recent historic period, the demarcation being set at less than 200 years. There are several good reasons for this. The climatic worsening which was a feature of the Little Ice Age ended some two centuries ago and the natural conditions governing mass movements have changed. It is also the commencement of contemporary history and the duration of a period which is rich in archive data. Those of the 19th century are sometimes richer than those of the 20th century; we verified this in newspapers, for mass movements in Normandy.

3. Cartographic interpretation of time data

3.1. Analytic translation

In the rare cases in which research has enabled us to obtain all the temporal data on all, or the majority, of mapped movements, the first method consists in choosing a representation mode for each of the headings above, and working by superimposing colours, signs or symbols. This is conceivable, if need be, for large-scale cartography of a single or a few types of movement only. In a medium- or small-scale map containing several types of movement at once, the space available for time data is necessarily limited. Taking a simple map showing the types of landslide in the Cortina d'Ampezzo basin (Gasparetto et al., 1994) as an example we have tried to show the temporal data specified above (see also Flageollet, 1994).

It has been arranged in order of importance, placing stratigraphic or palaeogeomorphological data (the incidence period) below other data, in this case relating to activity, which are more important for short-term forecasting.

In a manual cartographic test activity is obviously represented in colour in order to contrast active and non-active, with the type of activity expressed in colour gradations. The other information is overwritten, playing on the size and density of the patterns for the period frequency.

The advantages of a computer are incontrovertible (Flageollet, 1994) in particular for the ease in superimposing signs and coloured frames, but there are disadvantages in reading the five superimposed data levels. There are also one or two problems with regard to mapping logic, for example the use of a single sign, based on the size, in this case a square-based frame which cannot represent different types of movement logically.

3.2. Synthesis of data

Because temporal data are introduced along with other information, for example that related to hazard intensity, we must look for a more synthesised representation.

Fig. 2 shows how the state and type of new activity, defined by the return period, synthesises the whole of the temporal data except the activity mode. This is implicit in certain movements, such as block falls, for example, which occur suddenly and which stop almost equally quickly. Cartographic translation in this case is therefore superfluous or an accessory.

In the temporal sense, the "active continuous" and "active intermittent" types are synonymous with the expressions "active" or "infrequently active" which are met with on some maps.

In small-scale maps, or if the return period is poorly defined or uncertain, we may be obliged to simplify it considerably, keeping only the state of activity or inactivity.

4. Conclusions

The scientific community has taken a great deal of trouble to diversify the mapping of mass movements and, in particular, to make maps with a professional finish. Nevertheless we must make further efforts to take account of the temporal factors which are a vital aspect of forecasting. The concepts and the terminology presented above need to be discussed and refined, but above all it is desirable to develop their cartographic aspects. The difficulties of combining or reconciling temporal and spatial data in classical cartography have faded or disappeared with the advent of new computerised tools.

Acknowledgements

Colour figures have not been included here, these can be found in earlier work (Flageollet, 1994).

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Return period	=	*Activity*		*Age*
<1 day	=	**Active continuous**		
< 1 year	=	**Active intermittent**	=	Recent history
1-10 years	=	**Dormant episodic frequent**	=	Recent history
10-100 years	=	**Dormant episodic moderately frequent**	=	Recent history
100-1,000 years	=	**Dormant episodic infrequent**	=	Recent or ancient history
> 1,000 years	=	**Stabilized**	=	Holocene or Pleistocene or Pre-Quaternary

Fig. 2. Caption for a synthetic mapping of time in landslides.

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