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Risk assessment strategies for the reactivation of earth flows in the Northern Apennines (Italy)

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ABSTRACT

The aim of this paper is to analyze the reactivation mechanism of ancient earth flows, with a view to gleaning information that can subsequently be utilized to formulate a risk-reduction strategy. All considerations made herein are the result of direct experience and observation of actual events which have occurred over the past few decades in the Northern Apennines. Particular attention has been paid to the analysis of the evolution of landslides during actual reactivation, acknowledging a typical, recurring succession of events that precede the failure of the slope. The hazard assessment of these large landslide bodies, which are of slope scale, constitutes a thorny problem, especially in view of the inapplicability of traditional deterministic models such as limit equilibrium stability analysis. Nevertheless, a site-specific assessment of probability of reactivation of these large and ancient earth flows is fundamental to effective land-use planning.

1. Introduction

Earth flows are a natural component of landscape evolution in several regions of the world, in particular where shaly or weak formations are present. Ancient earth flows, whose origin often dates back several thousand years, are among the most tangible evidence of past active geological dynamics and/or climatic changes. In short, they are a source of risk but they also present an opportunity to investigate the past. They represent an extraordinary case study both for scientific and applied research. The outcomes of several studies performed by the Emilia-Romagna Regional Authority, that represent a large portion of this territory, are here presented.

2. Landslide susceptibility in Northern Apennines

In a large portion of Northern Apennines (Fig. 1), the so-called "Argille Scagliose" (mainly Cretaceous in age) prevail. They represent the main source of landslides, with a high susceptibility value (LDI from 20 to 40%).[1] This type of rocks consists of blocks of different dimensions and lithologies (mainly arenites and limestones) included within a *scaly clay* matrix. They are chaotic formations, tectonic or sedimentary melanges (i.e. "olistostromes"), supporting or including less disturbed sets of flysch strata ("bimrocks" or *block-in-matrix rocks*, according to Medley, 1994). As regards the relationship between morphology and susceptibility, the majority of landslides are concentrated in areas where the slope gradient ranges from 8 to 11° (Bertolini and Pizziolo, 2006), which is the usual slope angle of "Argille Scagliose" and similar formations, whereas in slopes whose gradients exceed 25° they are very rare, thanks to the presence of a stronger bedrock.

3. Features of ancient earth flows

Large ancient earth flows are quite common in Emilia-Romagna Apennines. From plan view, these landslides show a large crown, a relatively narrower middle "channel" –corresponding to the area of flow– and a wide basal fan reaching the valley floor, with a modest or null slope inclination. The 2.6 km long Morsiano landslide, with sharp hourglass shape, is a typical example (Fig. 2).

Their thickness is usually no more than a few tens of metres. The majority of them (52%) reaches a depth ranging from 10 to 30 m. About 10% of them show a depth exceeding 40 m. The depth has seldom reached a magnitude of 80–100 m, as in the Corniglio case (Larini et al., 2001a).

Following sedimentological laws, their internal structure shows several superimposed "strata" originating at different periods in the past and from different parts of the slope. Consequently, their lithology is extremely variable and usually characterised by a block-in-matrix structure, with a prevalence of clay matrix produced by the softening of shaly units.

In terms of shear strength properties, these materials show a high degree of variability, both spatially and temporally, which is difficult to quantify.

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[1] According to the regional 1:25,000 *Landslide Susceptibility Map* (Bertolini et al., 2002), geological units show a predisposition to instability that may be quantified on the basis of the "Landslide Density Index". LDI represents the ratio between the sum of landslide areas affecting a given geological unit and its total mapped surface.

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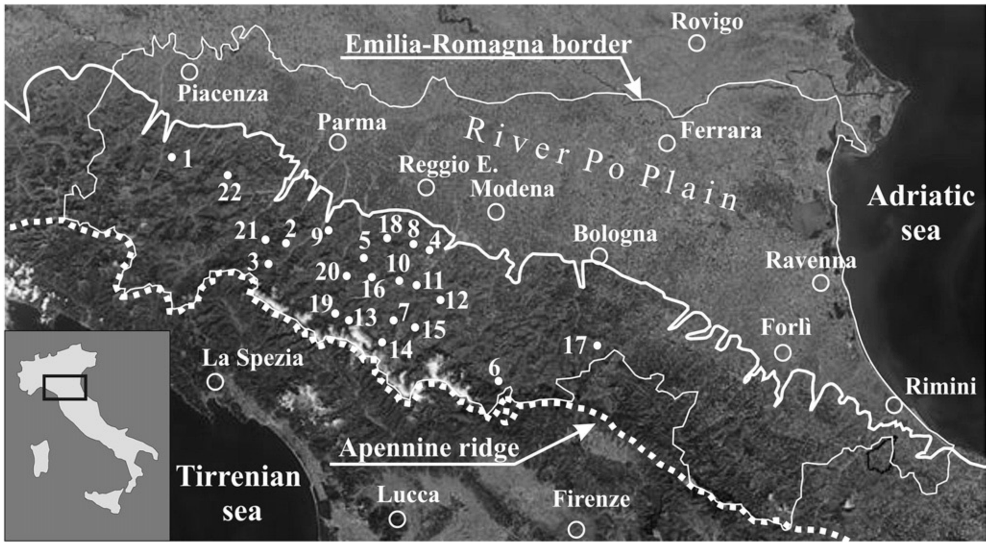

Fig. 1. Location map of the study area. Landslides cited in the text: 1— Velleia; 2— Signatico; 3— Corniglio; 4— S. Romano; 5— Lavina di Roncovetro; 6— Gaggio Montano; 7— Morsiano; 8— Casoletta; 9— Provazzano; 10— Magliatica; 11— Cà Lita; 12— Morano; 13— Cerrè Sologno; 14— Febbio; 15— Boschi di Valoria; 16— Cavola; 17— Cà di Sotto; 18— La Vecchia; 19— Cervarezza; 20— Groppo; 21— Costa di Casaselvatica; 22— Casa Ravera.

The minimum shear strength values are found in argillaceous materials with montmorillonite minerals (for example, *Argille di Viano Formation*; Bertolini, 2001b).

4. The origin

The Emilia-Romagna Regional Authority (Bertolini, 2003, 2007; Bertolini et al., 2003, 2004) has applied radiocarbon dating techniques to wood remnants collected by core boring inside the earth flow landslide bodies (e.g. the landslides of Cavola and Sologno, Figs. 3 and 4). These studies, carried out on dozens of cases, demonstrate that these landslides are the result of multi-phase events occurring over a period of thousands of years through the superimposition of new earth flows. Consequently, inside the landslide body, the age of wood remnants usually increases with the increasing depth (Fig. 5).

Data show that these landslides evolved through phases of rapid growth and others of minor activity, like that which we are experiencing today. In fact, as shown in Fig. 5, some past accumulation rates describe a landscape dynamism that is unequalled today (e.g.: 4.5 cm/year for a time period of 1000 years in the case of Cavola and ~1 cm/year for 2800 years in the case of Sologno).

The majority of these landslides originated after the last glacial maximum and grew during the wettest periods of the Holocene (on this subject also see Bertolini and Tellini, 2001 and Tellini, 2004).

Fig. 6 shows the radiocarbon dating of wood remnants (buried by landslides) collected in 21 different landslide bodies, often sampled by core borings at different depth (after Bertolini, 2007). As paleo-climatic indicator, this data suggest the existence of a wetter period within the Holocene (Sub-boreal, early Sub-Atlantic). However, the number samples is insufficient to draw conclusions about the Early-Holocene and pre-Holocene periods of time.

5. Large earth flows as risk factors

We can consider these landslide bodies as the legacy of former, more conducive climatic periods, but, in spite of their ancient origin, they are still dangerous.

Few earth flows are perpetually active (e.g. the *Lavina di Roncovetro*, Bertolini and Gorgoni, 2001), while the majority of them alternate periods of activity with periods of dormancy lasting from a year to a century. Longer periods of dormancy cannot be ruled out *a priori*, because of the lack of historical records.

A comparison of these different behaviours (e.g. the landslides of Roncovetro and Talada, Figs. 7 and 8) indicates the main problem caused by anthropogenic factors and urban management: the longer the dormancy period, the more people have erected buildings and structures upon the landslide body. If the landslide reactivation occurred more frequently, the more people were aware of the danger and avoided building.

Consequently, permanently active landslides are usually less problematic with regard to risk-management than dormant ones. In other words, just because of the history of their evolution, the risk related to a great number of ancient landslides may be inversely proportional to the hazard, as exemplified by the following examples (Figs. 7 and 8).

The 2 km long "Lavina di Roncovetro" (Fig. 7) is permanently and evidently active. In the archive documents it is cited ten times in a 100-year period, corresponding to a mean annual probability $P=0.1$. It is because of its evident dangerousness that it does not represent (and it did not represent) a serious menace to settlements and human life.

Differently from the Roncovetro landslide, the large Cervarezza landslide (Fig. 8), now dormant and less evident, reactivated in 1472, 1560, 1697, 1714 and 1936, that is 5 times over a 500-year period, corresponding to a mean annual probability $P=0.01$. Because of its non-evident dangerousness, it damaged and destroyed several times the three villages lying on it.

In terms of urban management the consequences are evident, as the example of Corniglio teaches (Fig. 12). This large landslide was deceptively safe until complete reactivation in 1994 after nearly a century of dormancy. In the seventies the medieval village –which stood in a relatively safe position, out of the main landslide body– expanded toward the dangerous part of landslide: in 1902 only ten edifices were exposed to risk, in 1994 this number had increased to 70.

6. The reactivation mechanism

A recurring behaviour can be seen in the majority of reactivations of ancient earth flows that have occurred during the last decade.

In many documented or observed events, when a *reactivation* occurs, the first movements are rotational slides in the source area that cause a regression of the main scarp, which is the most unstable part of the slope. The displaced material reaches a liquid state of consistency, thus producing earth/mud-flows moving downward as far as the landslide body's mid-section (phase 1 in Fig. 9). The

Fig. 2. The Large Morsiano Landslide. Despite its age (a wood sample found inside it dates back to 13,500 Cal. years B.P) the landslide is still active in several portions, threatening and damaging the village. According to historical records, reactivations occurred in 1631 (partial), 1651 (total), 1880 and 1959 (partial). Photo by G. Bertolini (2007).

undrained surcharge induces a sudden increase in pore water pressures, thus triggering a series of imbricate thrust surfaces connected to the basal slip surface (usually the original and thus oldest one) of the entire landslide body (phase 2 in Fig. 9). This pattern migrates valleyward, propagating progressive failure along the base of the ancient landslide, which may entirely reactivate by sliding (phase 3 in Fig. 9). The activation of new thrusts downhill triggers the relative deactivation of those uphill (see also Figs. 10 and 11). The multiplication of slip

Fig. 3. The Cavola (right) and Oca (left) landslides. The 4.2 km long Cavola landslide is considered inactive since 1960, but it still shows movements at instrumental scale. See also Fig. 5. Photo by G. Bertolini (2005).

surfaces may sometimes lead to a complete disorder of the mass. Complete reactivation by flowing is a rare eventuality, limited to shallow landslides (usually <5 m, with the exception of Cà Lita, see Table 1) and to the superficial layer of larger ones.

This sequence of events, with many variations and sometimes only partially achieved, was observed in many recent cases: Corniglio (both in 1902 and in 1994 events, Larini et al., 2001a, Fig. 12), Costa di Casaselvatica (Larini et al., 2001b), Casa Ravera (Danini et al., 2001), S. Romano (Fig. 11), Magliatica, Lavina di Roncovetro (Bertolini and Gorgoni, 2001, Fig. 7), Casoletta (Bertolini, 2001b), Morano (Fig. 10), Sologno (Bertolini and Sartini, 2001, Fig. 4) and Cà Lita (Borgatti et al., 2005; Corsini et al., 2005, Fig. 13).

In a few cases, the movement led to a significant advancement of the toe (e.g., 28, 56 and 400 m respectively in the Corniglio, Cerrè Sologno and Cà Lita cases— Larini et al., 2001a; Bertolini and Sartini, 2001; Borgatti et al., 2005).

In the great majority of cases, the movement comes to a stop in few months.

The Corniglio and Cà Lita cases are an exception: they returned to dormancy, respectively, after about 6 and 4 years of activity.

This mechanism of reactivation has few documented exceptions; notably the Groppo ancient earth flow whose activity started from the tip (Bertolini, 2001a).

During the reactivation of the main landslide body other recurring features and behaviours may be observed:

- despite the *block-in-matrix* internal structure of the landslide (usually also visible at the microscopic scale), a layer evidently enriched in highly plastic clay appears on the main shear surfaces; this almost impermeable layer, some 1–2 cm thick, helps to retain water inside the landslide ("bathtub" effect in Baum et al., 2003). The layer is evident during the movement, while, if exposed to external elements, it is rapidly weathered after a few days;
- according to Skempton (1964) and Calabresi and Scarpelli (1985), this layer shows an "anomalous" natural water content (*Wn*): in the Casoletta case, laboratory tests measured a *Wn* higher than 30% with respect to landslide material (Bertolini, 2001b);
- accordingly to Baum et al. (2003), the reduced shear strength of this clay layer "helps to perpetuate movements" on surprisingly gentle slopes (for this reason the French term "couche savon" –soap layer– could be appropriate);
- again in accordance with the afore-mentioned authors, observations of active events demonstrate that even where (and when) landslide material reaches a sufficiently degraded state of consistency as to produce an actual earth flow, the prevailing type of movement nonetheless remains a sliding advancement along the basal surface, which appears notably striated; the significant internal deformation, on the other hand, is produced by a multiplicity of less persistent but pervasive slip surfaces; in this case, elongated ridges (or "levees", Baum et al., 2003) tend to form along both flanks of the earth flow, ascribable to alternating rates of movement, with slowing, dilation and relevant accumulation of material, followed by an intensification of movement within a narrower "channel".

We have learned from experience gained over the past few decades that reactivation of large earth flows can achieve different levels of intensity. The scale of deformations and displacement

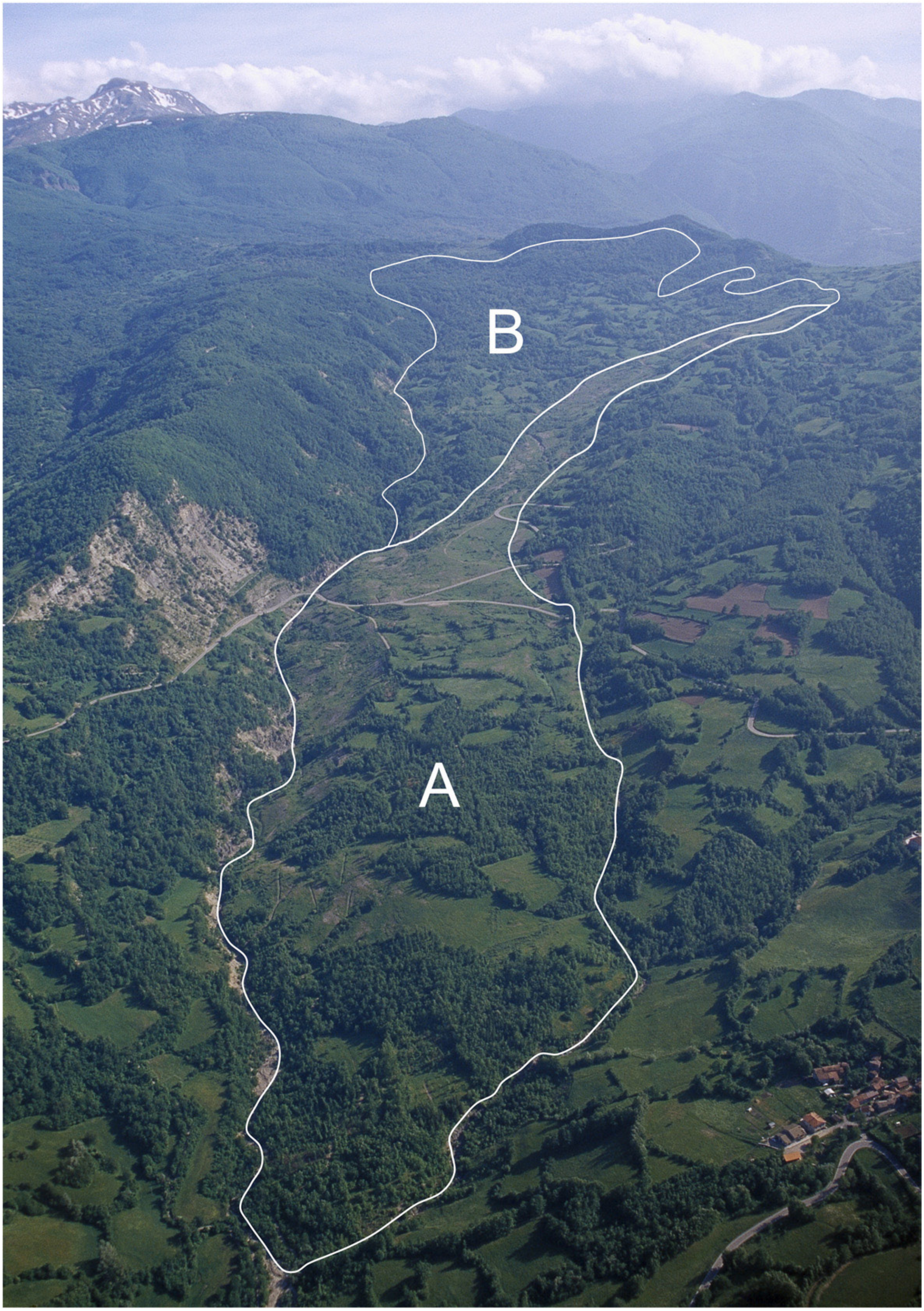

Fig. 4. The 4 km long Sologno landslide. The "A" sector reactivated in February 1996; its activity lasted for two months, while "B" remained dormant. The absence of human settlements is probably the reason of the lack of historical records about previous reactivation. See also Fig. 5. Photo by G. Bertolini (2007).

velocities decreases moving from the source sector in the direction of the toe, which is generally the last section of the landslide to reactivate. In the majority of cases, deformation of the ancient landslide is limited to sliding over several or tens of metres towards the valley floor. Only rarely does the landslide body reach the proportions of an actual earth flow. This occurs when the thickness of the landslide body is limited, but the displacement of the landslide reaches hundreds of metres.

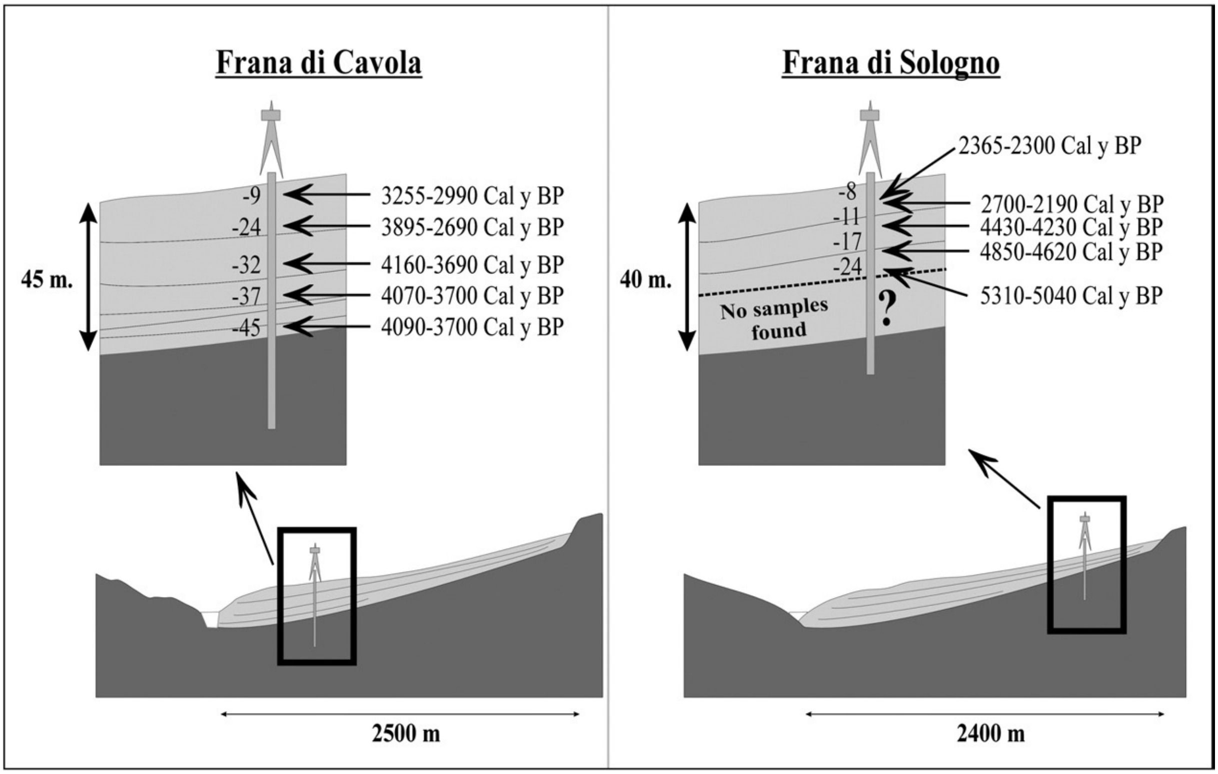

Fig. 5. The age of the ^{14}C samples found inside the landslide bodies usually grows accordingly with the sedimentation rules: the greater the depth, the greater the age. After Bertolini (2007).

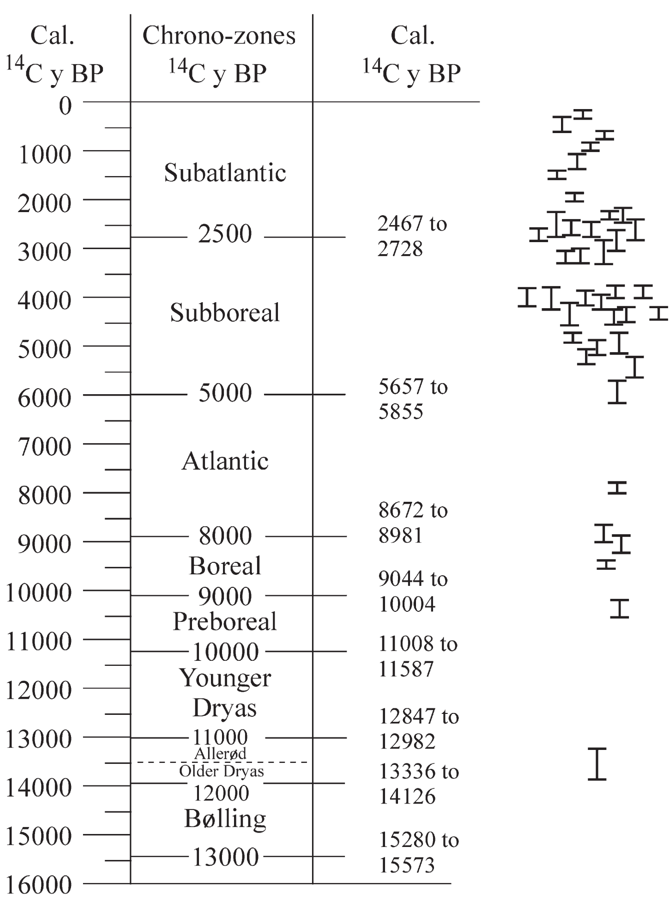

Fig. 6. Radiocarbon dating of landslide events from the Late-Glacial to the present in the Emilia-Romagna Apennines.

Total reactivations are rare but usually catastrophic for people's properties while partial ones, more common, are less dangerous.

In very few cases, the velocity is “very or extremely slow”: infrastructures and villages lying on the moving part of the landslide can survive with slight damage.

In the majority of cases the usual displacement rate is “slow” (accordingly to Cruden and Varnes scale 1996), but in limited sectors of the landslide and for a limited period of time this rate may be classified as “moderate” or “rapid”.

The threat to human life produced by reactivation of ancient landslides can usually be managed thanks to the many precursory signs that become evident years, months or weeks before the triggering.

7. Causes of reactivation

A large number of well-documented cases demonstrate that intense and/or prolonged precipitation plays a major role as triggering factors in reactivating landslide bodies.

In addition, the time-series analysis usually suggests a clear correlation between the number of landslide events in a given period (and in a given area) and the local, respective cumulated precipitations.

Long-lasting rainfalls are the more frequent triggering factors throughout the year, while melting snow cover has particularly effect in the months of March and April (Basenghi and Bertolini, 2001).

In one case (the *Lavina di Roncovetro*) Bertolini and Gorgoni (2001) stated that the evident perennial activity that characterises that landslide (Fig. 7) is caused by high pore water pressures maintained by the inflow of highly mineralised groundwater mixed with methane, coming from the subsurface.

Seismic triggers have seldom been incontrovertibly identified by means of historical investigation on the relationship between landslides and earthquakes. The definite cases are few and confined to limited areas (Romagna, Reggio Emilia ridge sectors) were strong

Fig. 7. The permanently active "Lavina di Roncovetro". Photo by G. Bertolini (2006).

earthquakes historically occurred (e.g. the Febbio earth flow landslide triggered in September 1920 by an earthquake of 8° MCS intensity). However, from a statistical point of view, precipitation is a much more important triggering factor than earthquakes.

8. The Corniglio and Cà Lita case histories

To illustrate different landslide behaviour, we will turn our attention to two major reactivation events of recent decades: they

Fig. 8. The large, dormant Cervarezza landslide. Photo by G. Bertolini (2005).

are cases which may be considered “borderline” in terms of the volumes involved and the levels of displacement recorded. The cases in question are the landslides of Corniglio (Parma Province, Fig. 12) and of Cà Lita (Reggio Emilia Province, Fig. 13), both well documented in scientific literature thanks to studies carried out by a number of researchers, from which the data in Table 1 is partly derived (Larini et al., 2001a, Lollino et al., 2001; Corsini et al., 2005, Borgatti et al., 2005): this table presents a brief comparison of the two events.

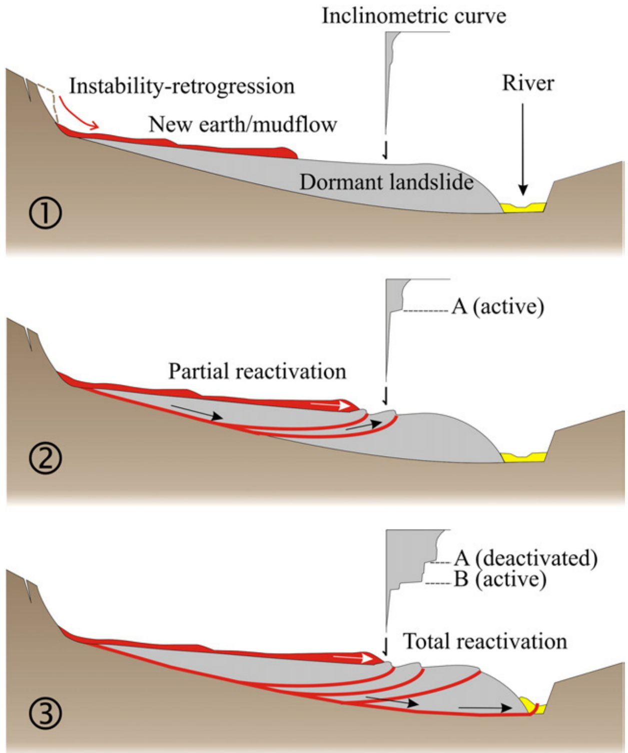

Fig. 9. Reactivation often occurs through recurring behaviour (see text, Section 6). The inclinometer curve exemplified in the figure shows a "single slip surface" in the phase 2 and a "multiple slip surface" in phase 3. "A" deactivates (relatively) after the trigger of "B".

In the Corniglio landslide, despite far higher levels of precipitation, the landslide body did not reach a plastic-fluid consistency, thus restricting total displacement. The landslide nonetheless destroyed over 70 buildings which had been recklessly constructed in the Seventies and Eighties on top of the ancient landslide. At Cà Lita, on the other hand, an earth flow up to 18 m thick in places formed, the toe advancing 400 m during the winter of 2003–2004.

Table 1 also shows that the triggering precipitations between the two events were deeply different, especially in terms of percentage of annual average precipitation.

As the Cà Lita earth flow demonstrates, exceptional levels of precipitation are not always necessary to trigger reactivation; what is decisive, on the other hand, is that such precipitation occurs with a certain regularity over a period of time and that it is sufficient to bring about the progressive failure which unfolds over the weeks or months that follow.

Precipitation levels during the progressive failure stage are certainly the main factor "governing" the physical behaviour of the moving mass.

In the Cà Lita landslide the intensity of deformation of the landslide body was so much greater than that of Corniglio as a result of the very heavy snowfall of the winter of 2003–2004, unprecedented in the past 50 years (cfr. Borgatti et al., 2005).

9. Consequences

Ancient dormant earth flows have been areas wrongly judged as suitable for human settlement since ancient times, thanks to the low slope of their frontal and mid-accumulation zones: a real trap for many hamlets and villages. As a result, in the Emilia-Romagna Region

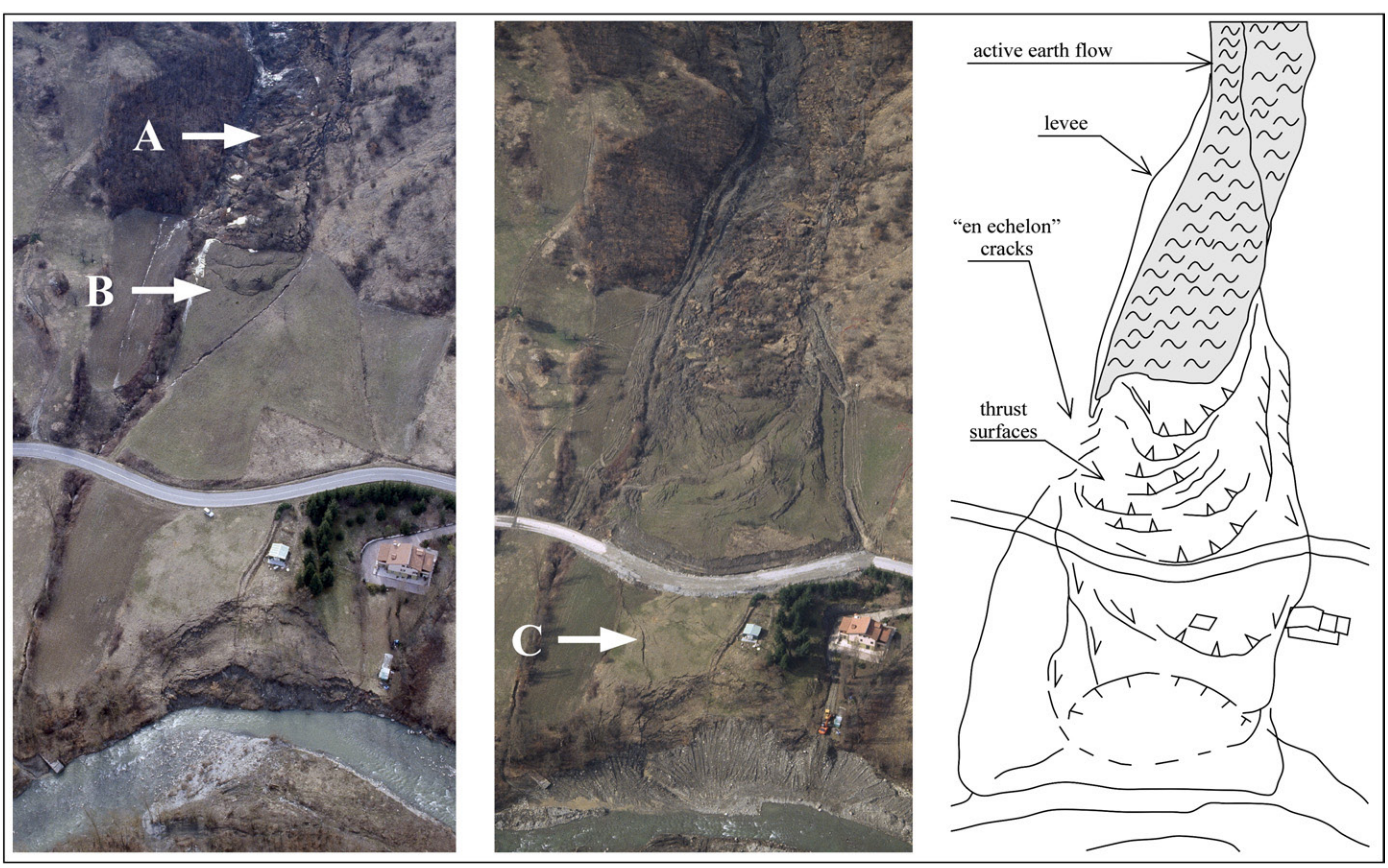

Fig. 10. The Morano landslide reactivation. These photos show two different moments of the progressive failure. Left (5 March 2006): the new earth flow (A), coming from the main scarp (not visible in these photos), reaches the mid-section of the dormant landslide and triggers a series of imbricate and arcuate thrusts (B). After 15 days the net of shear surfaces reaches the toe of the landslide (C), whose sliding displacements are now of about 1 m/day (right). After further 5 days the movement suddenly stopped. Photos by G. Bertolini (2006).

Table 1
The Corniglio and Cà Lita events in comparison

	Corniglio event (1994) Fig. 12	Cà Lita event (2002) Fig. 13
Elevation range	550–1150 m asl	230–640 m asl
Slope angle	10°	8–10°
Length	3100 m	2700 m
Maximum width	1120 m	1500 m
Max thickness	80 m	43 m[a]; 18 m[b]
Total volume	110×10^6 m^3	42×10^6 m^3
Date of reactivation	15 November 1994	December 2002 (?)
Activity period	Nov. 1994–1999	Dec 2002–2006
Classification (prevailing mechanism, from the crown to the toe)[c]	Earth flow/roto-translational earth slide	Roto-translational rock side/earth flow
Total displacement occurred during the activity period (mid-sector/toe)	185 m/28 m	430 m/400 m
Measured maximum movement rate	2 m/h (rapid[c])	0.5 m/h (rapid[c])
Reactivation cause	Pore pressure–rainfall	Pore pressure–rainfall
Previous complete reactivations (as documented in historical literature)	16th century, 1612, 1740, 1770, 1902	1928
Time elapsed between the beginning of the reactivation (first movement in the crown) and total reactivation (toe)	15 months	16 months
Annual average precipitation (aap)	1500 mm	1100 mm
Precipitation prior to the initial reactivation		
30-days cumulated rainfall	450 mm (30%)[d]	120 mm (11%)[d]
60-days cumulated rainfall	750 mm (50%)	180 mm (16%)
90-days cumulated rainfall	1450 mm (96%)	240 mm (21%)
120-days cumulated rainfall	1500 mm (100%)	240 mm (21%)

For further details see also Figs. 12 and 13.
[a] Source area.
[b] Mid-lower sector (earth flow).
[c] Cruden and Varnes (1996).
[d] Percentage of annual average precipitation (aap).

territory, 281 inhabited centres (defined as four or more buildings, excluding "scattered houses") lie upon or are directly affected by active landslides and 1608 by dormant landslides. Dozens of municipal centres are among them.

The constant threat looming over settlements and infrastructures penalises the human population and is a contributing factor in migration from these rural areas and subsequent concentration of the population in a few towns. At least 16% of the total road network is on top of existing landslide bodies, and so is threatened and periodically affected by slope movements.

The cost of this situation is staggering: in Emilia-Romagna, over the last 5 years 390 million Euros has been invested in reconstruction, relocation of villages, consolidation work and monitoring of unstable slopes. These costs were entirely covered by the national and regional governments.

Luckily, the number of human casualties caused by reactivation of earth flows is almost negligible, thanks to the generally slow displacement velocity of this type of landslides.

10. Risk-reduction strategies: territorial forecasting

10.1. A new consciousness deriving from recent events

After the reactivation of the Corniglio landslide (1994), archive research demonstrated that this landslide completely reactivated with similar behaviour on the following previous occasions: XVI Century, 1612, 1740, 1770 and 1902. It is important to underline that the last reactivation occurred after almost a whole century of dormancy.

This event brought a new consciousness, causing a revolution in the legislation that as a result became more restrictive and prudent.

In the subsequent 10 years, further complete reactivations of ancient earth flows occurred (landslides of Casoletta, Cerrè Sologno, Magliatica, Boschi di Valoria, Cà di Sotto, Cà Lita, Morano). As a result, many other villages were damaged, relocated or required expensive consolidation work.

These events led the regional authorities to acknowledge that a detailed inventory of these large landslide bodies was the first step in order to reduce the risk. In fact, most of them are still recognisable by their geological or morphological features.

As a consequence of these studies and inventories, the Emilia-Romagna Authority became more and more aware that these already existing landslide bodies –and in particular ancient earth flows– represent almost the whole source of risk: it has been demonstrated that *about the 90% of damage caused by landslide activity derives from their reactivation*.

10.2. The role of cartography and territorial planning

Since almost all damage deriving from landslides occurs on already existing –and known– ancient earth flows, appropriate mapping is a powerful tool for minimising risk. For this reason in 1996 the Emilia-Romagna Regional Geological Survey carried out a complete Landslide Inventory Map (LIM) of his territory (Pizziolo, 1996).

LIM became a powerful means of performing *territorial forecasting* and a reference for urban management plans. LIM is systematically updated on a yearly basis.

Emilia-Romagna was the first Italian regional authority that applied geo-thematic maps in territorial planning and, based on these, enforced rules and obligations addressing landslide hazard reduction.

On the basis of LIM, restrictions have been placed on activities on landslides: only existing hamlets and villages can extend on dormant landslides, but only after detailed geological study and monitoring demonstrates that the risk is acceptable; on active ones, all new construction are forbidden.

The use of this terminology (active, dormant), which is purely descriptive, restricts the usability of the map. The description of the state-of-activity was written as the survey was being carried out, using terminology introduced by Cruden and Varnes (1996), but could now be "obsolete" because of the changes subsequently occurred. Moreover, this terminology has no "legal" or "officially recognised" support and is therefore a frequent bone of contention.

11. Risk-reduction strategies: temporal forecasting

Uncertainty about geological and hydro-geological parameters minimises the reliability of deterministic methods (such as stability analyses) for forecasting purposes.

The main obstacle is the variability in space and time of geomechanical parameters (on this subject also see Urciuoli et al., 2007 and Chowdhury and Flentje, 2003) and the continuous changes in pore water pressures brought about by external (precipitation, snow melting) or internal factors (overload, local stresses, nourishment from subsoil waters).

11.1. Time-series analysis

During recent years, several studies have attempted to obtain triggering thresholds from real events (e.g. Bertolini and Pellegrini, 2001; Galliani et al., 2001; Lollino et al., 2001). Many of these are based on the usual empirical relationship between rainfalls and landslide behaviour (on this subject also see Sorriso Valvo and Ibsen, 1994).

Lollino et al. (2001) in the case of the recent Corniglio reactivation event (1994), emphasises the role of the pattern of precipitation (in time and space), which can bear a greater influence than the simple amount of precipitation. In this case, the same Author underlines the inadequacy of statistical or empirical methods based on commonly used precipitation parameters.

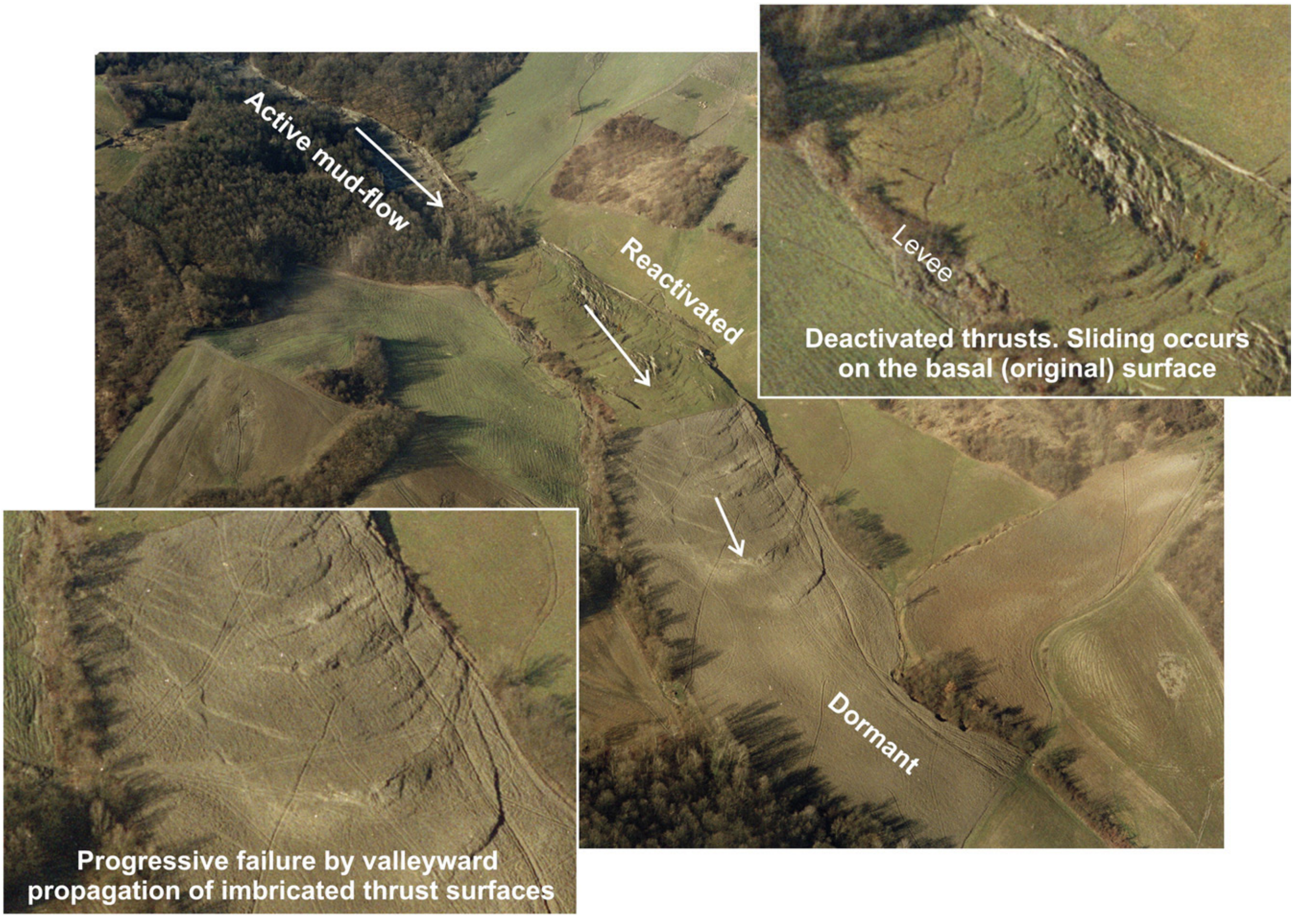

Fig. 11. The reactivation of the S. Romano landslide in 1996. As described in the text, the valleyward propagation of the progressive failure is here evident. Photo by G. Bertolini (1992).

Basenghi and Bertolini (2001) draw attention to the role of the melting of snow cover in reactivating a large number of landslides and underline the inadequacy of the simple rainfall time-series analysis in order to identify and quantify the triggering causes of a landslide.

So far, because of the uncertainty of results, for the landslides under study, these findings remain of scientific interest but, at the moment, do not find any real application.

The problem is that the relationship between causes and effects is anything but simple. Experience teaches us (see also Table 1) that a certain ancient earth flows can reactivate under different triggering conditions as a consequence of the real distribution and magnitude of stresses inside the slope. Hidden progressive failures can be in progress for years. Internal stresses are continuously changing over time and consequently the same amount of rain (or snowmelt) can produce different effects from time to time.

11.2. Site-specific hazard assessment

In principle, if a detailed knowledge of past events exists, the site-specific hazard *P* (related to a given landslide) may be calculated as the inverse of the "recurrence interval" *T*, defined as the period of time between consecutive reactivations (see also Ko Ko et al., 2004a,b). This can be performed on the basis of many direct methods: multiple-date aerial photos, previous ground surveys, earth observation techniques (e.g. InSAR), absolute dating (e.g. ^{14}C methods) or review of historical data (on this subject also see AGS, 2000).

In the regions and countries where old, long-standing administrations (governmental or/and religious) exist, historical records represent the most promising source of data.

This is particularly true in Italy where the public administration usually offers compensation for damage caused by unstable slopes and provides funds for the consolidation of the latter. As a result of the many claims, the national and local archives contain a great number of administrative files.

A historical data-base of Emilia-Romagna Region has been compiled for about two thirds of its territory and in the near future the regional administration will complete the research covering the remaining territory. Presently, the data-base contains about 6600 landslide events pertaining to 4700 landslide bodies.

However, in practice, even with such an exhaustive data-base, calculating the reactivation frequency for a given landslide can be a frustrating task. Fig. 14 shows the recurrence of reactivation in a few large earth flows, randomly selected in the data-base of historical landslide events of Emilia-Romagna. As suggested by this figure, it seems that historical records only partly reflects reality: the XX century higher frequency is probably due to anthropogenic factors (e.g.: increased exposure) and loss of ancient records.

These records are influenced by different factors, not always related to the evolution of the landslide activity.

For example, changes in legislation and availability of funds can lead to a proliferation of administrative files and maybe to a degree of exaggeration about the effects of the landslide.

On the contrary, dramatic events in human history such as the 1st and 2nd world wars, led to an underestimation of reality for these periods of time.

Another problem is related to a natural factor: the extreme variability in time of the length of the dormancy periods for each individual landslide, which is difficult to express with a simple average value.

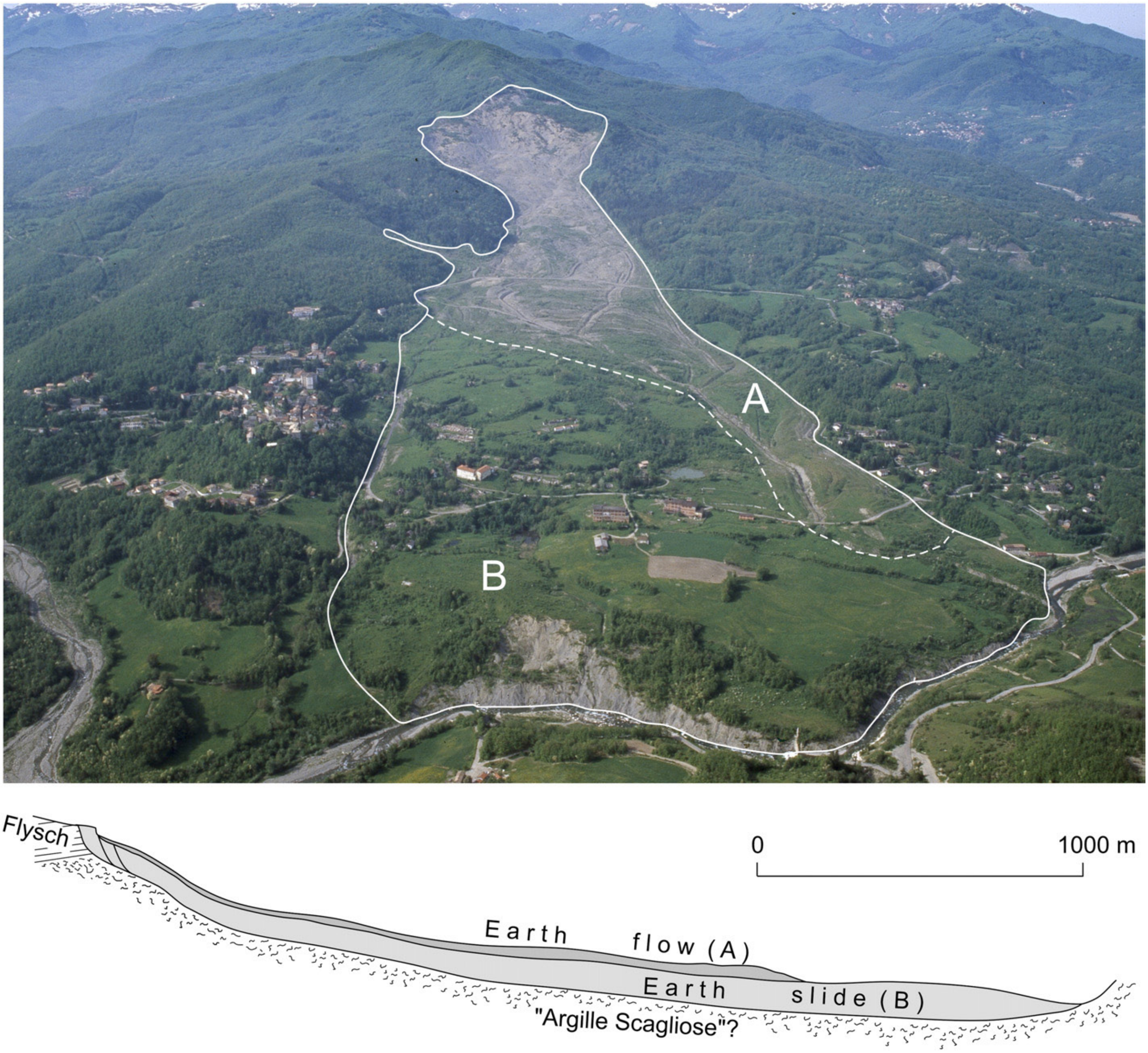

Fig. 12. Aerial photo and schematic cross-section of the Corniglio landslide. The sector A reactivated by flowing in 1994, after almost one century of dormancy. The sector B reactivated by sliding after 15 months, destroying 70 edifices. Both sectors remained active until 2000 (Larini et al., 2001a). Cross-section with no vertical exaggeration. Photo by G. Bertolini (2006).

11.3. About radiocarbon dating

The radiocarbon method gives us the age of earth flows that buried trees or bushes living on the previous surface of the landslide body. The magnitude (in terms of thickness and volume) of these events cannot be confused with those described by historical records, which are usually related to events considered relatively "minor" albeit a threat to human life and property. In the great majority of cases, these events occur due to sliding (usually of few metres) of the landslide body and the burial of vegetation occurs only in a limited area near to the head of the landslide.

Consequently, in synthesis, the lack of organic remnants inside the landslide body does not necessarily indicate absence of activity.

Besides, radiocarbon dating is usually applied to events that occurred centuries and thousand of year ago, in poorly known climatic contexts, probably different from today. In general, given our concerns with establishing the hazard, they cannot be considered exhaustive in the assessment of the present frequency of reactivations.

12. Final remarks

12.1. Recent progress

During the last decade, great progress has been made:

- thanks to geological survey recently carried out at the scale of 1:10,000 by regional authorities, the position, shape, dimension and type of almost all the large landslide bodies of Northern Apennines are now identified;
- the great majority of these landslides are ancient earth flows built by superimposition of minor events which occurred during previous periods of deteriorated climate. They are a result of multi-phase events occurring over a thousands years period;

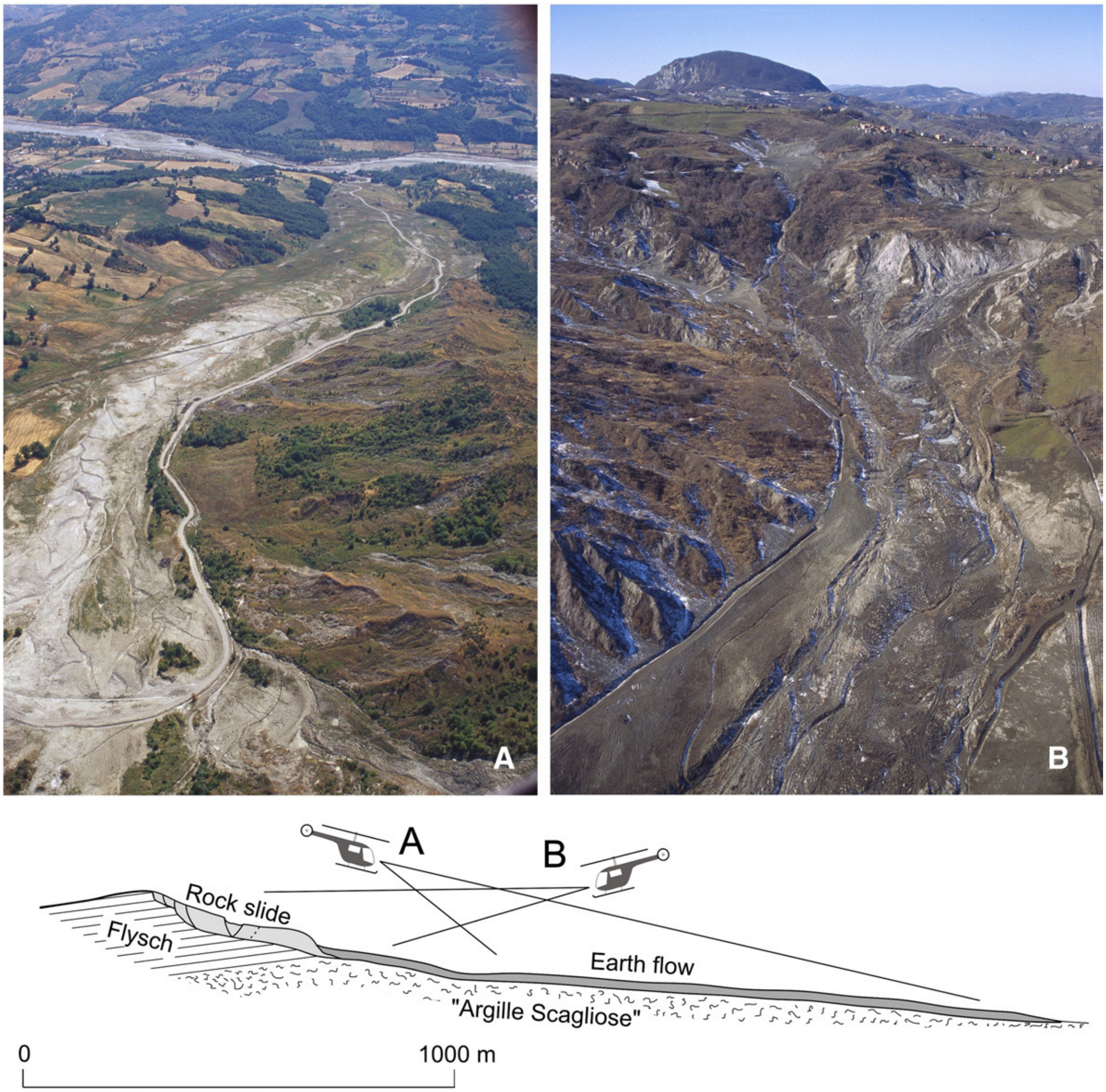

Fig. 13. Aerial photos and schematic cross-section of the Cà Lita landslide, reactivated in 2002. On the left (year 2004): the earth flow's mid- and lower sectors seen from "A". On the right (year 2003): the source area, formed by several main scarps carved in the sliding rock mass, seen from "B". Cross-section with no vertical exaggeration. Photos by G. Bertolini (2003, 2004).

- we know that present-day landslide activity is nearly always related to the intrinsic instability of these ancient earth flows and that their period of inactivity –between two consecutive reactivations– may last from months to centuries;
- above all, we have increasingly come to realize that the geological and recent history of large and ancient earth flows is important in order to understand their present-day behaviour.

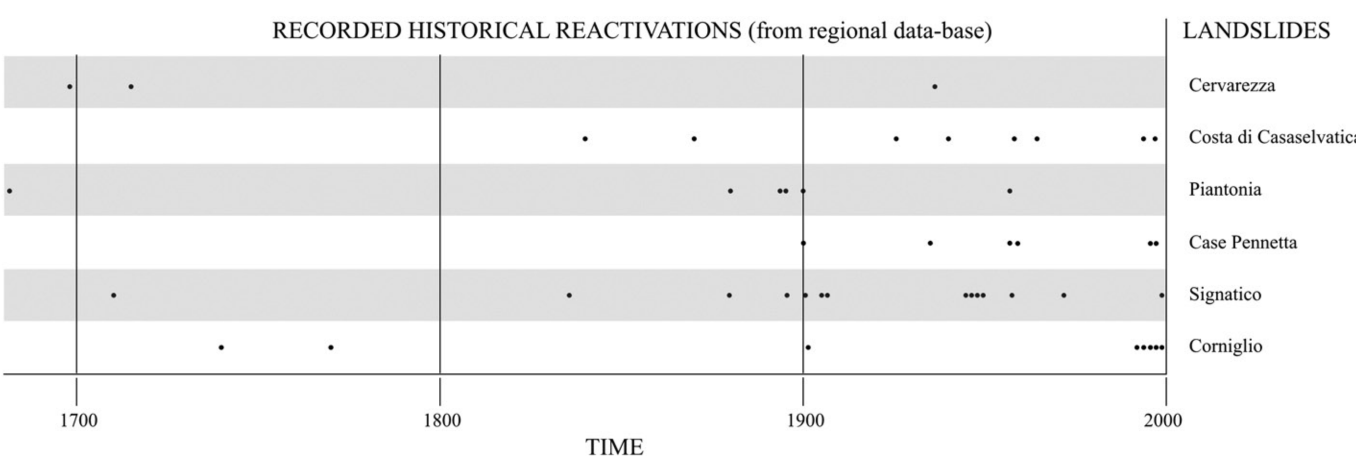

Fig. 14. Recurrence of reactivation in a few large earth flows, randomly selected in the data-base of historical landslide events of Emilia-Romagna.

Fig. 15. The Provazzano landslide in Province of Parma symbolises the problem of risk assessment and management in ancient, dormant earth flows. Five villages and several factories lie "undisturbed" on it. Villages have grown, during the last centuries and decades, almost only on the landslide that is the smoother area and *seems* the most reliable site of the slope. Photo by G. Bertolini (2006).

12.2. The perception of hazard

In general, continuously active landslides are not problematic with regard to risk-management: if displacements are continuous or the landslide frequently resumes movement (for example every year or every few years) the population is aware of them. This is particularly true in the case of earth flows which are very evident when active. In these cases, people easily accept rules and restrictions because they know that the hazard evidently exists. On the other hand, defining and explaining the hazard related to more inactive earth flows deposits, those that have not moved for many years, decades or even centuries, is more difficult (e.g. the Velleia landslide, inactive since Roman times, and the Provazzano landslide, Fig. 15).

For this reason, among other risk-reduction strategies, the sharing of knowledge should not be overlooked. People accept restrictions and rules only if they are aware that the problem exists. Many initiatives aimed at the dissemination of maps and inventories are underway in Emilia-Romagna and, more generally, in Italy. Users can find information about the territorial distribution of landslides on various Internet sites, without restrictions (e.g.:www.regione.emilia-romagna.it/geologia/frane.htm and ww3.atlanteitaliano.it/atlante.htm).

12.3. Large dormant earth flows: problems, methods and future goals

A deterministic approach including stability analyses and numerical modelling is useful in assessing triggering mechanisms (causes) but it has a limited forecast function in large, ancient earth flows situated in a complex geological context, as in many Apenninic slopes.

Historical research has proved to be a very effective instrument for the assessment of the hazard based on previous events, but, because of the non-periodical behaviour of ancient earth flows, its use for a quantitative assessment of failure rate is by no means simple.

Manual monitoring techniques –and in particular traditional inclinometers– are very useful for measuring the dimensions and the state-of-activity of these landslides. On the other hand, this knowledge is useless for other purposes, such as the time-series analysis, because of the low frequency of the manual readings. In particular, several field experiences teach us that manual piezometers may be misleading in the description of real water-table fluctuations.

Indeed, only continuous measures capture the way the behaviour of the moving landslide is evolving (e.g.: acceleration or deceleration, pore pressure increasing or decreasing); in many cases they can also define the short-term risk (Bertolini et al., 2005).

In conclusion, prudent land-use planning for these ancient earth flows has to be based on a site-specific assessment of hazard. In order to minimise the effect of the above cited uncertainties, this assessment should be reached by a multiple approach, pooling together several elements of evaluation:

- the analysis of the landslide's recurrence interval of reactivations (or "historical failure rate", according to Wu et al., 1996);
- the analysis of recurrence interval of triggering conditions that could lead to the reactivation of the landslide: precipitation (i.e.: rainfall and snowmelt waters) or seismic triggering thresholds measured by monitoring of real events or estimated by means of time-series analysis;

- in the absence of recent or historical data, an “interpreted” recurrence interval could be assessed on the basis of similar cases in analogous conditions (e.g.: from geological, morphological, climatic and seismic viewpoint);
- detailed observation of field evidence (through ground survey, earth observation methods; preferably surface and sub-surface investigations and monitoring) must define with accuracy the landslide perimeter and recognise possible indicators of present movements or situations that could lead to future movements (e.g.: local instabilities in the source area or riverbank erosion at the toe);
- the landslide spatial impact has to be defined, considering the expected scenario in case of reactivation (e.g. estimation of retrogression, widening and travel distance on the basis of local conditions and previous or analogous events).

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