

## Large reactivated landslides in weak rock masses: a case study from the Northern Apennines (Italy)

**Abstract** This case study paper is about a large rotational rock and earth slide—earth flow located in the Secchia River Valley, in the Northern Apennines of Italy, that has displayed multiple reactivation phases between 2002 and 2004. The main geological constraints of the mass movement are related to the overlap of flysch rock masses over clayey complexes that allows rock slides to take place in the source area. The disarrangement and weathering of rock masses following slope movements causes large amount of fine-grained debris to be accumulated on the slope and mobilised by earth sliding and flowing. Analysis of rainfall data at the onset of reactivation events has proved that they occurred after periods with cumulated values higher than the averages of the last 30 years. The quantification of the morphological modifications induced by these reactivations has been made possible by comparing pre- and post-event digital elevation models. Depletion and accumulation has been in the range of 30 m in different parts of the slope. In particular, an advancement of the landslide toe of more than 400 m, which caused a 30-m thick landslide tip to deposit, has been clearly seen. Monitoring data regarding subsurface movements and surface tension crack widening (tension cracks so large as to be properly described at trenches) has shown that sliding surfaces as deep as 43 m exist in the upper part of the landslide, while the accumulation lobe has moved by sliding and flowing over surfaces as deep as some 10 m. Velocities of cm/day have been recorded in the deep surfaces and in widening trenches of the source area, while the advancement of the accumulation lobe has been estimated as having velocities of up to 10 m/day. Groundwater in the landslide body has been observed at depths of 5–15 m in the upper areas, while it is estimated as being at the ground level in the toe. On this basis, it is concluded that the landslide still has a high potential for further development, both in the upper landslide zone and in the toe area.

**Keywords** Landslide reactivation · DEM subtraction · Borehole monitoring · Northern Apennines · Italy

### Introduction

Large complex landslides, associating rotational rock slides at the crown with earth slide and earth flows in the main body, are common in mountain areas throughout the world where weak clayey rock masses outcrop extensively. Even if they have a low probability of evolving into fast catastrophic events, their reactivation can induce substantial modification to slope morphology including advancement of the landslide toe. This, together with possible retrogression of the rear scarps, can cause relevant damage to infrastructure and socio-economic activities.

In the Northern Apennines of Italy, this type of landslide covers about 20% of the total hilly and mountain land surface (Garberi et al. 1999). Landslide reactivations that occurred after decades to centuries

of dormancy have caused many civil protection emergencies in recent years.

The Ca' Lita landslide resumed activity in 2002 and underwent major development in winter 2003 and, particularly, in March–April 2004. According to international nomenclature (WP/WLI 1993; Cruden and Varnes 1996), it is a complex and composite roto-translational rock slide—earth flow, retrogressive in the upper part, advancing in the mid-lower part and partially widening on its flanks.

It is located in the lower sectors of the Apennines chain, in the elevation range 250–650 m a.s.l. (Fig. 1). It extends from an elevation of 650 m at the crown to 230 m at the tip. The total track length is approximately 3 km and its maximum width is about 1.4 km in the rear scarp area, with a maximum depth of about 50 m measured in the upper part.

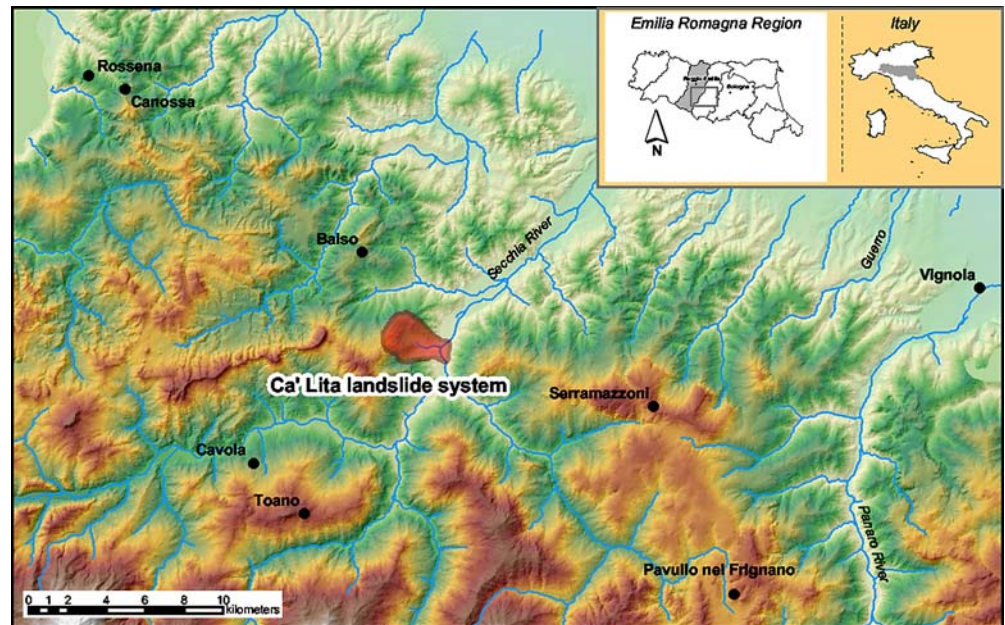
During the recent reactivation events, movements were prevalently taking place at rates of centimetres to metres per day, so they fall within the 'slow' to 'very slow' category in the chart by Cruden and Varnes (1996). However, in 2003, a velocity in the order of 10 m/day was reached in the accumulation lobe, making it a 'moderate' velocity phenomenon in the above-mentioned chart. The advancement of the toe and the retrogression of the scarp caused concern for the possible involvement of an important road running the base of the slope and of some hamlets located both downslope and upslope of the landslide.

The object of this paper is to present the geological and meteorological causes of the reactivation events, to show a quantification of the morphological modifications induced by these reactivations and to produce some considerations regarding the displacement rates and depth that were evidenced by a first monitoring phase during late 2004.

### Geological constraints

The Ca' Lita landslide affects weak clayey rock masses dating from the Upper Cretaceous to the Middle-Lower Eocene (Regione Emilia-Romagna 1982). Flysch rock masses, with a ratio between arenite and pelite components larger than 1, make up the uppermost part of the slope (Monghidoro unit, MOH<sub>3</sub> member). Chaotic complexes of fine bedded clayshales and marls and *mélanges* of clayshales including sandstone and limestone blocks outcrop in the intermediate and lowermost part of the slope (Argille della Val Rossenna, VRO and *Mélange* della Val Rossenna, MVR) (Fig. 2a). An East to West directed fault, buried by landslide deposits, divides the slope into two distinct sectors: one to the North, where rock masses are dipping down slope with an upright way-up, the second to the South, where rock masses are dipping upslope with overturned way-up. In the southern sector of the slope, the overturned bedding attitude causes a more than 100-m thick flysch slab to overlay the basal clayey complexes. The overturning of strata is ascribed to a regional syncline structure with a NW–SE directed axis that, locally, is dissected by the previously

Fig. 1 Location map of the study area



cited fault line (Bettelli and Panini 1992). The degree of tectonisation of the rock masses is high, as a result of the subsequent tectonic phases suffered in this area (Bettelli and Vannucchi 2003).

On a geomechanical basis, all outcropping rock masses can be classified as overconsolidated weak rocks (*sensu* Bieniawski 1989), with a marked lithological and structural complexity. Their basic geomechanical properties are summarised in Table 1. The presented values are derived from the GSI classification for weak rocks (Hoek and Brown 1997; Marinos and Hoek 2001), from data reported in the literature for similar rock masses (Bertolini and Pellegrini 2001; Conti and Tosatti 1996) and from back analysis of failures in the slope. In the back analysis, carried out with the GeoStudio suite, the pre-event slope profile was used and a fully defined shear surface was drawn on the basis of monitoring and refraction seismic data. Limit equilibrium was calculated with the GLE method (Krahn 2004) assuming a groundwater table compatible with the existing piezometric data.

It can be noticed that mobilised cohesions calculated by back analysis are one order magnitude lower than those obtained by the slope failure envelope range correlated to the GSI. This is ascribable to the strong degradation and progressive failure (Bjerrum 1967) affecting such rock masses at low overburden pressures or when slightly disarranged by gravitational movements (Fig. 3). This factor is probably considered poorly in the failure criterion behind the GSI index.

In landslide debris, low values of mobilised and residual friction angles are generally coupled to high values of plasticity index ( $I_p$ , sometimes higher than 80%) and liquid limit ( $w_l$  up to 110%) (Conti and Tosatti 1996).

#### Landslide description

The geologic setting of the slope controls the type of mass movements taking place. In fact, during the reactivation events of 2002–2004, movements were highly differentiated between the source and accumulation areas, both for type and for rate. Consequently, the Ca' Lita landslide can be considered as a composite system subdivided into a number of distinct landslides of different types.

On a first level of approximation, at least two main landslides, which are complex within themselves, can be traced out (Fig. 2b):

- an upper one, involving the sector of the slope where flysch rock masses overlay the clayey chaotic complexes;
- a lower one, involving the sector of the slope where clayey chaotic complexes dominate.

As regards the upper one, it can be specified that in its southern part, rock sliding cuts across the flysch slab dipping upslope, and generates roto-translational movements that cause a series of trenches to develop from 2002 to 2004 in the crest leading to Corciolano. In contrast, in its northernmost part, the flysch rocks dipping down slope favour the formation of rather shallow translational slides over discrete strata, which, however, have not been significantly reactivated. In both parts, the resulting collapsed material is soon weathered and turned into earth masses that are sliding or flowing. This type of dynamic has been reactivated prevalently in the southern part.

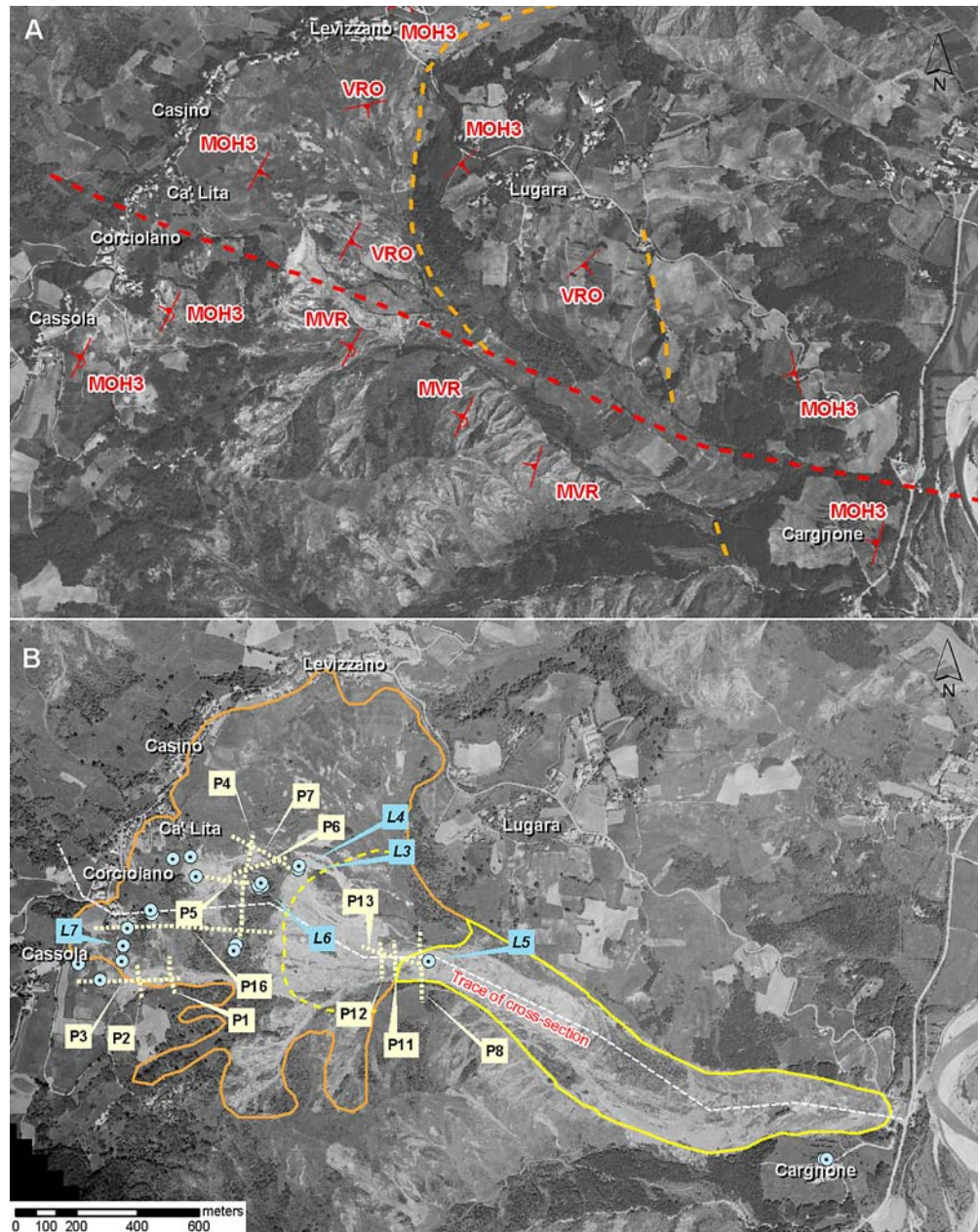
As regards the lower phenomenon, it can be appreciated that its main scarp is extensively buried under the deposits deriving from the uppermost phenomenon, so it is hardly possible to trace it out exactly. In its upper part, the input of debris from the upper phenomenon is a relevant process. This occurs by the retrogression of the marginal portion of the sliding flysch slab, or by mud flows and earth flows. The clayey nature of bedrock causes the earth mass to slide and flow over an almost impermeable layer, and keeps it fully saturated during reactivation events and even months after the suspension of movements. During recent reactivations, debris was accumulated in the upper part during 2002–2003, overloading the lower accumulation lobe that was triggered under undrained conditions in 2004 (Hutchinson and Bhandari 1971; Sassa 1984; Hutchinson 1986).

#### Meteorological conditions at reactivation times

This sector of the Northern Apennines is characterised by an annual average precipitation of about 1000–1200 mm, distributed over 70–100 days. The pluviometric regime shows two peaks, with the main one falling in autumn (October or November) and the secondary precipitation peak in spring (March or May). The lowest precipitation



**Fig. 2** Pre- and post-event aerial photographs of the landslide (courtesy of Regione Emilia-Romagna). **A** orthophoto of year 1996 with geologic sketch. Keys to symbols: MOH3: Monghidoro unit (flysch rock masses, Late Cretaceous to Early Eocene); VRO: Argille della Val Rossenna (chaotic complexes of fine-bedded clayshales and marls, Early to Middle Eocene); MVR: Mngge della Val Rossenna (clayshales including sandstone and limestone blocks, Early to Middle Eocene); dotted red line: fault; dotted orange line: secondary fault and thrust; red arrows: strata attitude. **B** orthophoto of year 2004 with landslide outlines and underground investigations. Keys to symbols: light orange line: rock block sliding area; yellow line: rotational earth slide-earth flow; light blue point: borehole (labelled when instrumented with inclinometer or piezometer); light yellow dotted line: refraction seismic profile; white dotted line: trace of the cross section in Fig. 6



is recorded in summer (usually July), whereas a secondary low is in February.

From a climatic standpoint, in 2002, 2003 and 2004, some episodes of very intense, but short in time precipitations have been observed in this region. In particular, intense rainfall events lasting about 10 min, which on an hourly basis would have potentially produced an input higher than 100 mm, were observed up to three times a year, whereas historical data show that the trend for such peaks is once in a century (Fazlagic et al. 2002).

The analysis of precipitation data recorded at an automatic rain-gauge located 10 km from the landslide area shows that there is a good correspondence between the monthly rainfall and the reactivation phases that occurred in 2002, 2003 and 2004. In Fig. 4 monthly and mean rainfall are shown, together with the four most relevant reactivation events occurred in different sectors of the landslide and

the corresponding displacement histories, with velocities estimated or measured thanks to the available monitoring instruments.

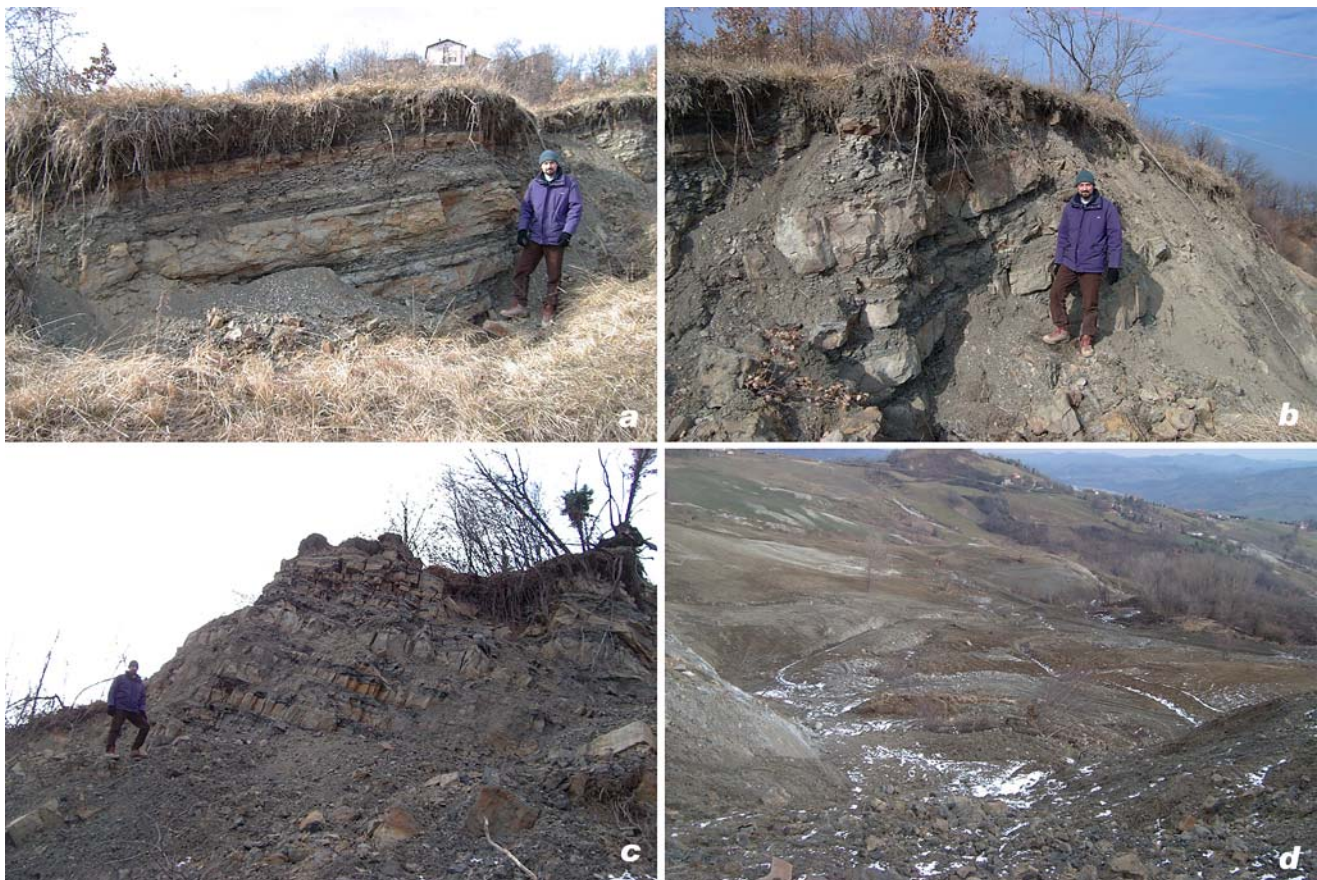
Concerning the single reactivation events, in the year 2002, the total monthly rainfall overcame the average value of the period 1921–1950 between November and December, when the first reactivation occurred. No instrumental data are available, but displacements in the order of millimetres to centimetres per day can be estimated considering the evolution of the phenomenon in the photographs.

In the year 2003, the precipitation followed the average value, except in November, when a monthly value of 192 mm was registered. During this period, the second reactivation of the landslide took place. In this occasion, the displacements of the earth flow were measured using some benchmarks and the velocity of the movement was in the order of metres per day.



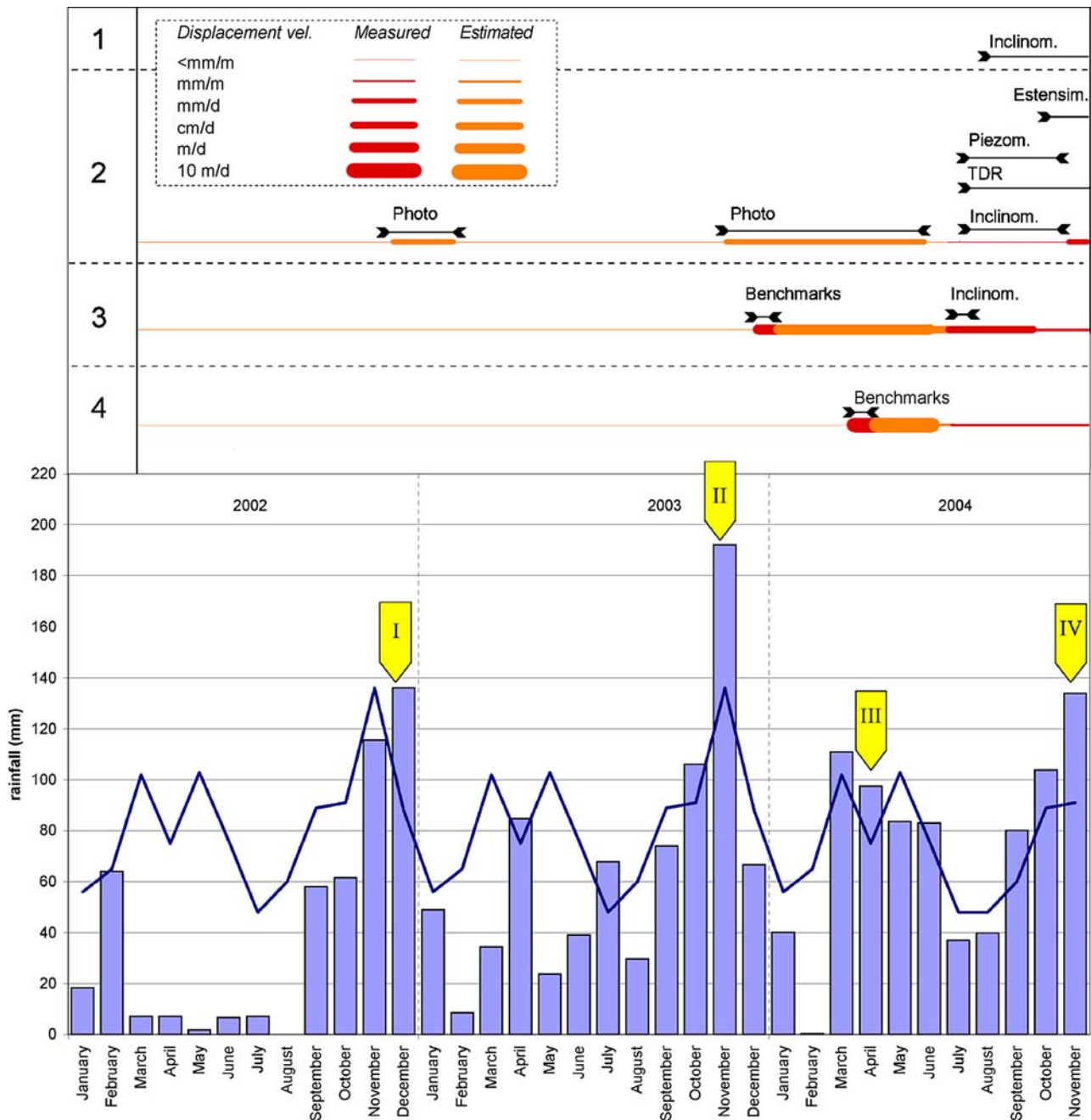
**Table 1** Geomechanical properties of rock masses involved in the Ca' Lita landslide

Parameter	Rock unit code		
	MOH3	MVR-VRO	Landslide deposits
GSI (geological strength index)	19	10	–
Mi (material constant)	17	7	–
UCS (uniaxial compressive strength) of intact material (MPa)	60–20	10	–
Unit weight (MN/m <sup>3</sup> )	0.03	0.02	0.02
Peak cohesion (fit from M-H criterion, general failure envelope range) (MPa)	1.9	0.16	–
Peak friction angle (fit from M-H criterion, general failure envelope range) (deg)	25.5	15.5	–
Slope height assumed for fit from M-H criterion, slope failure envelope range (m)	100	300	–
Peak cohesion (fit from M-H criterion, slope failure envelope range) (MPa)	0.8	0.20	–
Peak friction angle (fit from M-H criterion, slope failure envelope range) (deg)	47	13.9	–
Mobilised cohesion (from back analysis in Ca' Lita landslide) (MPa)	0.015	0.01	0
Mobilised friction angle (from back analysis in Ca' Lita landslide) (deg)	22	18	14
Residual cohesion (from literature) (MPa)	0.015	0–0.015	0
Residual friction angle (from literature) (deg)	22	11–22	8–24

**Fig. 3** MOH3 flysch rock masses dipping upslope with overturned way-up, outcropping in the upper sector of the slope, near Corciolano hamlet. **a** undisturbed; **b** slightly disarranged; **c** highly disarranged; **d** completely degraded

The climatic conditions that preceded the movements occurred during April 2004 were substantially different. In fact, the reactivation event followed a period of high snowfall, under circumstances that are quite rare, at least in the last 50 years. No snow level data have been recorded at the local altitude, which is in the order of 700 m a.s.l. In any case, in Modena, about 30 km away (35 m a.s.l.), 7.6 cm of snow cover in January, 61.6 in February and 23.1 in March were recorded. When compared to the annual average of 41.8 cm,

calculated on the whole historical record spanning from 1830 to 1998 (Fazlagic et al. 2004), the relevance of the event becomes evident. If one considers the reactivation of spring 2004, besides the high values of rainfall during the winter, it is clear that the snow that fell in the period just before the reactivation has had a great importance in determining recharge of deep groundwater and thus in triggering the most significant movements, in terms of both velocities and displaced volumes. In particular, because of the very high degree of



**Fig. 4** Monthly precipitations of the years 2002, 2003 and 2004 (histograms) and mean precipitation for the period 1920–1951 (solid line) recorded at Cavola raingauge (487 m a.s.l.). I-IV: the four relevant reactivation events. Displacement histories in the different sectors: 1. crown; 2. source area; 3. accumulation area; 4. toe

saturation, the earth flow reached velocities of 10 m/day for more than a month.

Finally, on 14 November 2004 a new reactivation of the landslide occurred, just after a rainy period of 6 days that yielded 76.8 mm of rainfall, over an average value of 136 mm, for the whole November.

From these observations, it appears quite clearly that the failure mechanism can be attributed to rises in pore-water pressure that occur in periods from weeks to 1 or 2 months after the rainfall events. This is mainly due to the circuit of groundwater from the uppermost slab of fractured flysch to the lowermost clayey rock masses.

#### Induced morphological changes

The overall effects on slope morphology of the reactivation events between 2002 and 2004 can be fully appreciated by a comparison of pre- and post-event digital elevation models (DEMs).

The post-event DEM has been obtained with an analysis of 2004 aerial photos performed with the digital photogrammetry software SOCET SET. Both in the relative and absolute orientation phases of the different photos, the resulting errors are very small (Table 2).

The DEM was then produced with the same software in a GRID format, with a sampling step of  $3 \times 3$  m. This procedure has yielded



**Table 2** Mean quadratic errors in the orientation phase

Parallax error (pixel)	0.507533
X error (m)	0.372519
Y error (m)	0.442804
Z error (m)	0.676309

a linear error in the order of 1.9 m and a circular error in the order of 0.9 m.

The pre-event DEM has been obtained by digitisation of the contour lines of an official 1:5000 technical topographic map, dating back to 1973, and subsequent linear interpolation using the Borgfors method (Borgfors 1996), implemented in the ILWIS software package. The raster DEM has been produced with a cell size of  $3 \times 3$  m.

Spatial analysis tools embedded into ARCGIS software have been then used to compare the two raster models. The bias between the two DEMs in stable areas has been estimated to be  $<5$  m, so this is the confidence interval of modifications evidenced by the subtraction between the two. This confidence decreases in wooded areas that are not filtered in the 2004 DEM.

Despite these limitations, the results of subtracting one DEM from the other (Fig. 5) show clearly the following:

- the events between 2002 and 2004 have been retrogressive in the crown zones and advancing in the accumulation zone, and have involved about 60% of the whole landslide area.
- the depletion in source area is coupled with an advancement of the rock and earth slide front over the scarp of the lowermost earth slide. Depletion can be estimated in the order of  $-30$  m, and was mainly due to the collapse of some portions of the slope. The advancement of the rock and earth slide front can be estimated in the order of  $50$ – $130$  m, and has caused an apparent uplift of more than  $30$  m.
- the accumulation lobe has been depleted of about  $20$  m in its upper sector. This depletion has been compensated by an advancement

of about  $400$  m of the landslide tip that caused a new accumulation about  $35$  m thick.

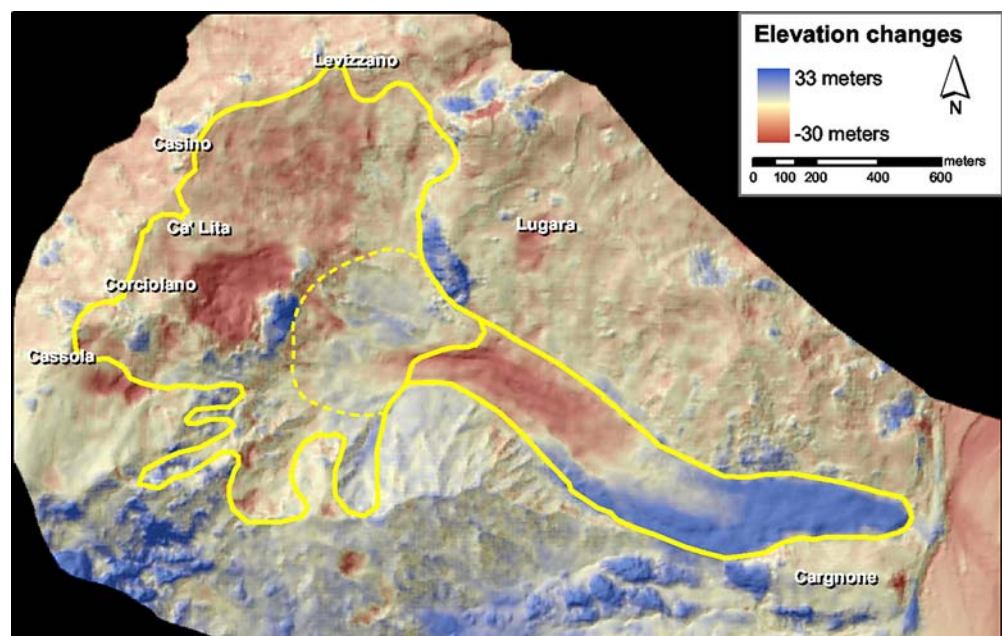
#### Recorded subsurface displacements

Subsurface structures and displacement rates have been interpreted on the basis of 16 boreholes  $40$ – $90$  m deep, from which cores of landslide masses and bedrock have been retrieved and analysed; refraction seismic on various cross and longitudinal sections elaborated with tomography techniques; 9 inclinometer casings  $88$  mm in diameter, measured approximately two to three times a month; 2 time domain reflectometer cables (TDR)  $1 + 5/8$  in. in diameter, measured approximately one time a month; 2 wire extensometers  $10$  m long, placed across a trench; 6 piezometers, some of which equipped with electric pressure transducers and data-loggers for continuous acquisition.

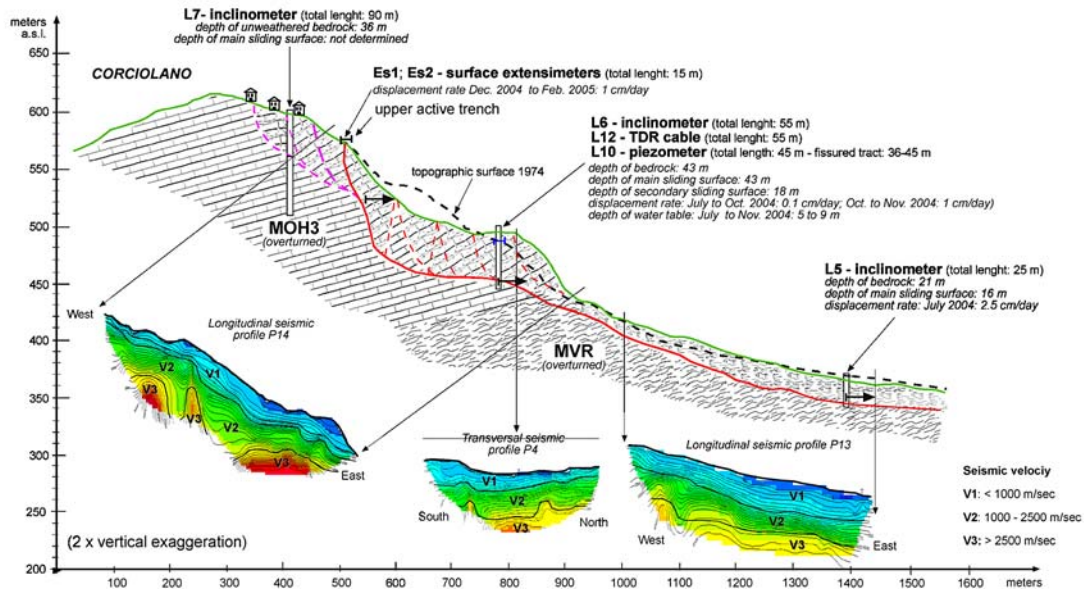
Among all the data collected, those commented in this paper are represented in Fig. 2b. One of the resulting interpretations of these data is presented in the cross section of Fig. 6. The monitoring data, in particular, have shown the following:

- At the very top of the slope, inclinometer L7 gave an  $18$  mm deformation at about  $36$  m depth from August to November 2004. These data are still difficult to interpret and could be related to imperfect coating of the inclinometer case.
- Some  $150$  m down slope, the extensometers Es1 and Es2 crossing an upper active trench have measured a widening of about  $20$  cm in little more than a month (25 November 2004–14 January 2005) (Fig. 7).
- In the lower part of the rock sliding phenomenon, inclinometer L6 and TDR cable L12, installed in August 2004, were cut off at  $43$  m depth by the end of November 2004.
- Previous measurements of L6 in early November showed a marked shear surface at the same depth, with a cumulated displacement of about  $100$  mm, and an overall displacement of the case at the surface of  $450$  mm (Fig. 8). At that time, TDR cable L12 showed no sign of crimping. On this basis, a presumable peak displacement rate of some  $30$  cm in 2 weeks can be estimated (Fig. 7).

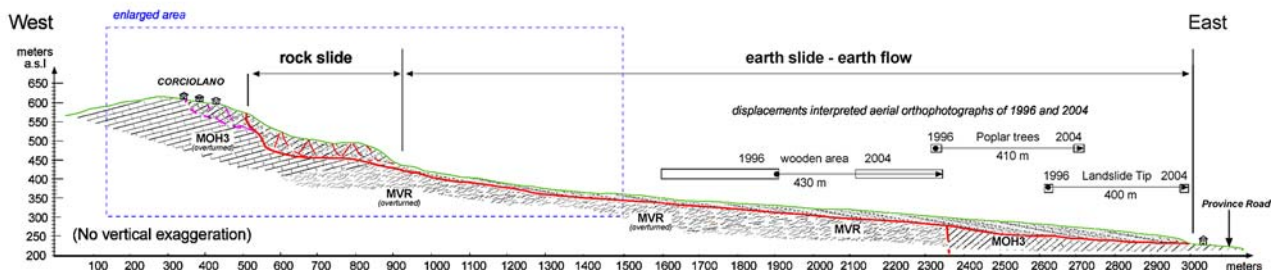
**Fig. 5** Elevation changes computed by subtraction of DEM 2004 and DEM 1973



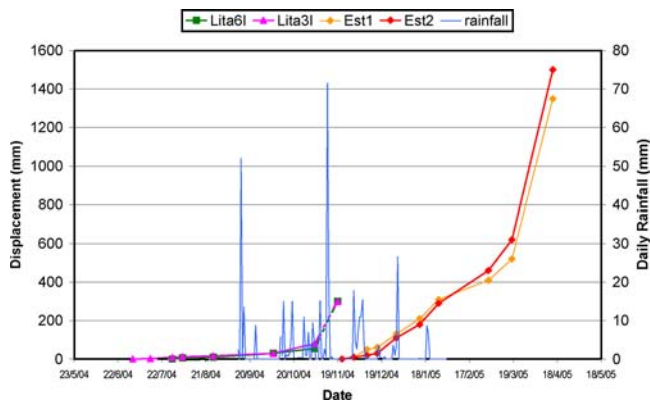
**B**



**A**



**Fig. 6** Cross section of Ca' Lita landslide system along the trace depicted in Fig. 2b



**Fig. 7** Displacement data from inclinometers L6 and L3 (see also Fig. 9) and extensimeters Es1 and Es2, compared with daily rainfall between landslide events III and IV as defined in Fig. 9

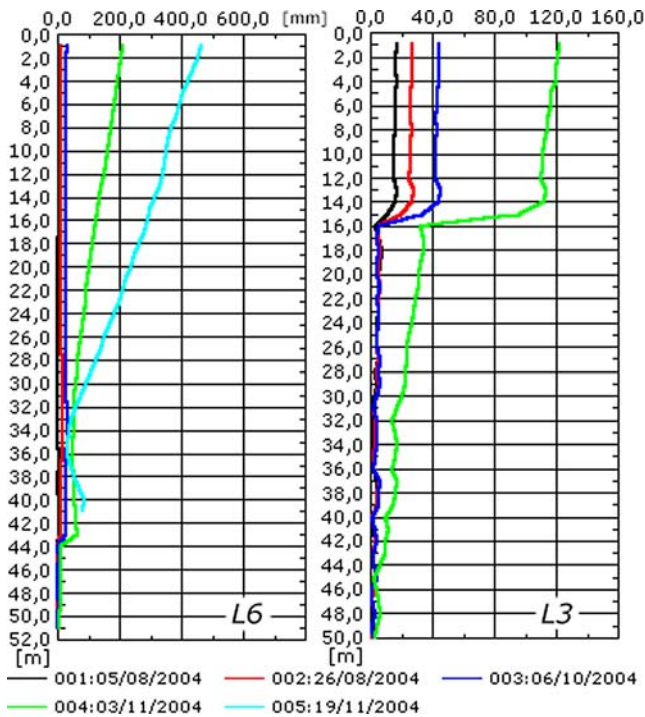
- After being cut at 43 m by the November 2004 event, the TDR cable L12 also showed clear signs of crimping at 18 m depth, to be interpreted as a secondary slide surface in the moving rock mass.
- Water table in piezometer L10, located next to L6 and L12, has fluctuated between -9 and -5 m depth for the whole period of measurements. Unfortunately, only manual measurements were carried out, so that no data about a possible in-

crease of water level just before November reactivation were collected.

- Inclinometer L3 showed a clear shear surface at 16 m until early November 2004, and it was then cut off within the month at the same depth (Fig. 8), which corresponds to the contact between debris and disarranged rock masses.
- Electric piezometer L4 installed nearby inclinometer L3 showed a quite constant level at -5 m that slightly increased due to the cumulated precipitation of November. Just before rupture, the level had a sharp fall, probably due to the opening of cracks in the debris, and then quickly resumed the same level before being cut off (Fig. 9).
- Inclinometer L5, in the upper part of the accumulation lobe, was cut off at -13 m and then at -9 m within 2 weeks in July 2004, proving that even 3 months after the end of the major April 2004 event, in a period of little precipitation, quite dry soil and apparently suspended movements, the accumulation lobe was still undergoing significant residual displacements.

### Discussion

The mechanism of reactivation and development of rock sliding phenomena in the uppermost part of the slopes is believed to be connected to two main factors: on the one hand, to the underground water circulation in the rock masses and the progressive loss of peak mechanical properties of rock masses at low overburden pressures and,



**Fig. 8** Inclinometric data: total displacements (mm) in inclinometer L6 and L3

on the other hand, as a consequence of disarrangement induced deep-seated slope deformations, driven by the sinking of the flysch slabs into the lowermost clayey chaotic complexes (Cancelli and Pellegrini 1987).

The slopes involved in this type of mass movements can in fact be considered complex hydrogeological systems, in which highly tectonised flysch rocks behave as fractured aquifers, and underlying clayey chaotic complexes form base aquitards. The progressive recharge of these low permeability aquifers, which can take months of effective infiltration consequent to prolonged, anomalous but not necessarily extreme cumulated precipitations, distinctive of the fall-winter to spring period (Lollino et al. 2001), can cause the development of high levels of water pressure into fractures of the clayshales strata. As a consequence of degradation, the loss of peak mechanical properties in these strata is very relevant. This, in conjunction with

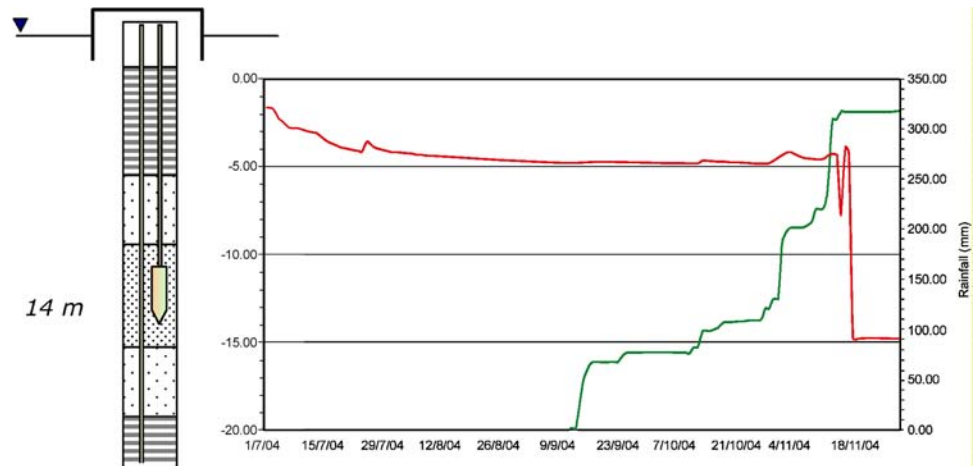
high water pressures, determines mobilised shear strength values one order magnitude lower than the expected peak ones and similar to the residual ones.

Other potential triggering factors, such as earthquakes, have played a clear role in triggering these phenomena only in a few known cases (Mazzini 1995; Castaldini et al. 1998; Genevois et al. 2000), albeit seismic amplification at landslide locations has been observed (Larini et al. 1997).

As regards the mechanism of reactivation and development of earth slides affecting clayey soils deriving from the complete degradation of the rock materials, this is believed to be primarily connected with undrained loading phenomena into the saturated clayey materials (Bertolini and Pellegrini 2001). In the case of the Ca' Lita landslide this is caused by new deposition, in the upper part of the accumulation lobe, of new debris material deriving from either the retrogression and collapse of the main or secondary scarps or by mud or earth flow phenomena reaching the lobe from the upper part of the slope. Water transfer from the bedrock to the basal shear surfaces of the earth mass might also be a factor determining the long run out of certain earth flow lobes, especially when multiple permeability thresholds are found along the slope. Once triggered, movements proceed with the earth mass under conditions of full saturation and residual strength, which means that the earth flow lobes can move over slopes as low as the residual friction angle of material that is generally in the order of  $10^\circ$ . Another factor can be related to the obliteration of lateral channels and the consequent loss of draining capacity that can cause an increase of water table in the earth slide mass.

On the basis of the surveys and monitoring data collected so far, it is believed that the described mechanisms fit to the Ca' Lita landslide. As a matter of fact, a significant circuit of groundwater into the uppermost sliding flysch rock masses exists. This is evidenced by numerous ephemeral springs located in correspondence with the permeability boundary existing with the lowermost clayey chaotic complexes, by the piezometric data showing groundwater tables close to the topographic surface and, also, from the pumping tests carried out in exploratory pits, which have indicated a yield of the most disarranged sliding flysch masses in the order of 6 l/s. Also, undrained loading of the earth flow lobe by the debris conveyed in its upper part by mudflows and by collapses of the frontal part of the sliding flysch slab, is highly likely taking place. This justifies the fact that the accumulation lobe in 2004 was totally remobilised over a  $10^\circ$  slope and advanced for 400 m and more.

**Fig. 9** Data from electric piezometer L4. On the left side: sketch of the installation. On the right side piezometric data from July 2004 till November 2004. In red: groundwater table level; in green: cumulated rainfall





## Conclusions

Looking at the possible further evolution of the phenomenon, and recalling its subdivision into two main complex landslides, one in the upper part of the slope, and one in the intermediate-lower part of the slope, different considerations can be made.

As regards the upper landslide, and its southernmost part in particular, characterised by extensive rock sliding, one cannot overlook to the possibility that further retrogression of movements towards the top of the slope could occur in the future, endangering the Corciolano hamlet. Although the deformation of inclinometer L7 near the top of the slope is not yet indicative of incipient reactivation, this hypothesis is made plausible and worth of attention by the rate at which the lowermost active trench is spreading, by the seismic data indicating a low velocity layers extending upslope and, finally, by the geomorphological evidence indicating that ancient trenches and scarp zones are located all the way up to the top of slope. Quite certain is, on the other hand, that the frontal part of the sliding flysch slab is going to keep collapsing, even retrogressively, while it is undergoing the generalised advancement movements detected by the instrumentation installed. The earth slides and subsequent earth flows developing on both sides of the rock sliding zone are likely to be subjected to further retrogression in the rear scarp area and to give origin to other mud flow events. In the northernmost part of the upper landslide, only partly involved in the 2002–2004 reactivations, there is the possibility for some earth flow phenomena to resume activity. However, considering that the morphology of this sector indicates that the geomorphological evolution has led the slope to a more mature stage, a generalised reactivation of mass movements does not seem to be likely in the near future.

As regards the lower landslide, which is the large earth flow accumulation lobe, it is quite certain that further input of material will occur in the upper zone, when mudflows from upslope will reach it, and while the frontal part of the sliding flysch will keep collapsing. What consequences this input of materials will have on the overall stability of the accumulation lobe, and in particular, if this will promote a new generalised reactivation and further advancement of the tip of the landslide, cannot be assessed, but it is a possibility that cannot be excluded.

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geognostic investigation and monitoring. Claudio Puglisi has carried out restitution of contour lines from 2004 aerial photographs.

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