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GEOMORPHOLOGICAL HAZARD ASSESSMENT OF THE AREA OF THE MEDIEVAL VILLAGE OF RIOLA (BOLOGNA APENNINES, NORTHERN ITALY)

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ABSTRACT. – Geomorphological hazard assessment of the area of the medieval village of Riola (Bologna Apennines, Northern Italy). The medieval village of Riola has recently been gaining increasing interest for possible future tourist exploitation. This study is aimed to assess the geomorphological hazards of that area, through detailed geomorphological mapping (cross-verified by applied-geology investigations). Particularly, the area's instability has been analysed, also with the aim of verifying the official maps of the Bologna Province' territorial plan, where the greatest part of the area has been defined at elevated hydrological risk, strongly limiting future development. This study has demonstrated how a detailed geomorphological mapping, coupled with an hazard classification method adopted, with modifications, from the Swiss hazard-mapping guidelines, can give a more realistic picture of the slope instability framework of a municipality than that given by the provincial maps. The latter are based on geological maps and on interpretation of aerial photographs: the primary aim of geological maps is not to identify landslides, while aerial photographs can only give a first glimpse of a landslide's body, not having much to say on its state of activity.

Keywords: *landslide, geomorphological mapping, hazard, risk, territorial planning, Bologna Apennines.*

1. INTRODUCTION

Situated in the municipality of Castel d'Aiano (Bolognese Apennines), the medieval village of Riola is of historic, architectural and landscape importance and recently it has been gaining increasing interest for possible future tourist exploitation (fig. 1). This study is aimed to assess the geomorphological hazards of that area, through detailed geomorphological and applied-geology investigations. Particularly, the area's instability

Fig. 1. Panoramic Wiew from North-East of the Medieval Village of Riola (Bolognese Apennines).

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has been analysed, also with the aim of verifying the documents of the Province-Coordinated Territorial Plan (from now on named as PTCP) of the Bologna Province (Provincia di Bologna, 2004), where the greatest part of the area has been defined at elevated hydrological risk, strongly limiting possible territorial plans.

2. GEOGRAPHIC AND GEOLOGICAL SETTING

The village of Riola is located in the southern sector of the municipality of Castel d'Aiano, middle Bolognese Apennines. Its hydrographical basin is the Aneva Torrent's, left affluent of the Reno River (fig. 2). One hectare of area, the village spans from 710 to 723 metres above sea level. Despite this, the entire study are covers some 3 square kilometres, with elevations spanning from 435 m, at the Aneva Torrent, to some 850 m on the peaks above the village.

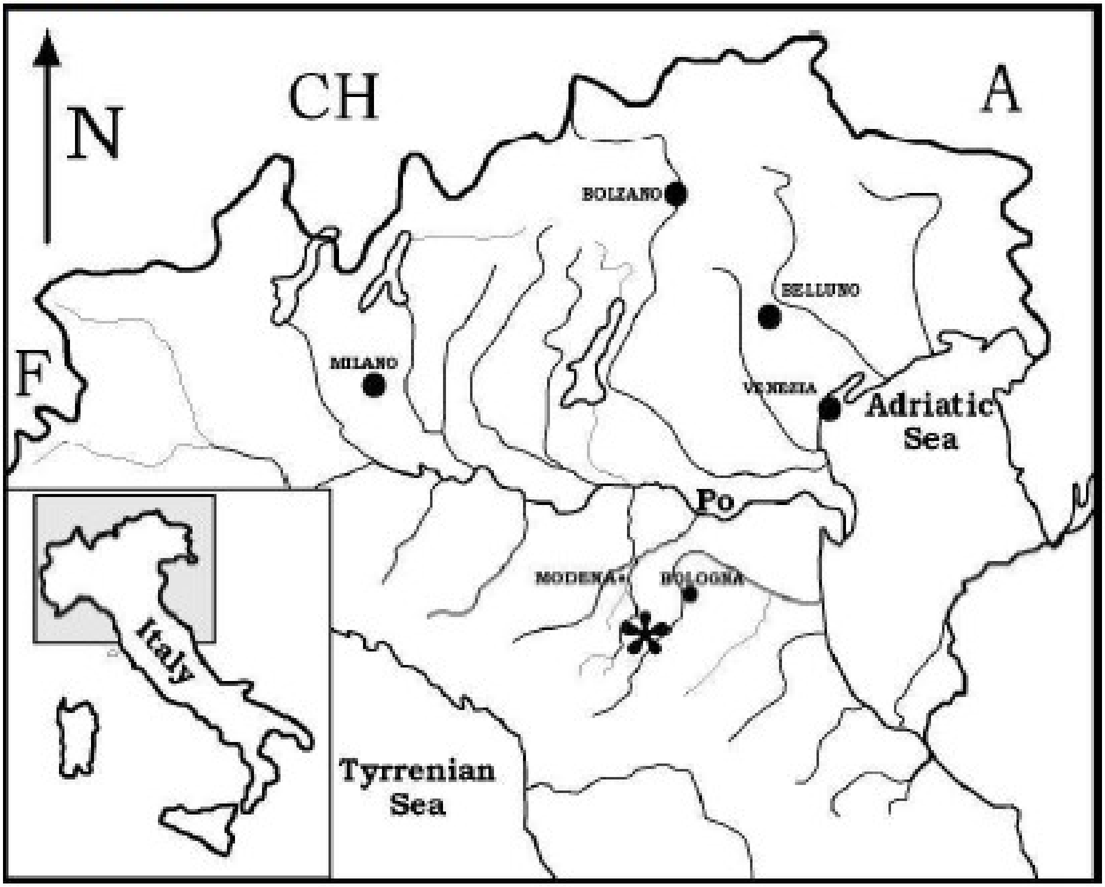


Fig. 2. The location of the study area, within the Bologna Apennines, is represented by the star.

The Bologna Apenninse belong to the Northern Apennines which are a fold-and-thrust belt resulting from a complex and multi-staged evolution. The geological features of the chain are quite complicated (e.g. see Boccaletti & alii, 1981; Cerrina Feroni & alii , 2002). In short, the main geological units forming this sector of the Apennines are as follows (Bettelli & De Nardo, 2001):

- Tuscan Units, made up of Tertiary siliciclastic deep-water turbidites, continuously cropping out along the Apennine chain's axis; they result prevalently from the infilling of distinct migrating Tertiary foredeep basin;

- Ligurian Units made up of deep-sea sediments including Jurassic ophiolites followed by thick sequences of Cretaceous to Eocene calcareous or terrigenous turbidites;

- Mainly terrigenous epi-Ligurian sequences of the Middle Eocene to the Late Messinian, unconformably resting on the previously deformed Ligurian Units. The epi-Ligurian sequences and the Ligurian Units are exposed in the mid-Apennines;

- the belt of Plio-Quaternary marine terrigenous deposits unconformably overlying the Ligurian Units and the epi-Ligurian sequence cropping out at the Apennine margin and dipping under the alluvial deposits of the Po Plain.

The study area has been object of various studies, at different scales, among which Annovi (1975 and 1980), Colombetti (1975) and Panini et al., (2002). On the basis of the most recent cartography (Regione Emilia-Romagna – Servizio Geologico, Sismico e dei Suoli, 2008), all lithologies croppig out in the area belong to the Epi-Ligurian sequences. In stratigraphic order they are as follows:

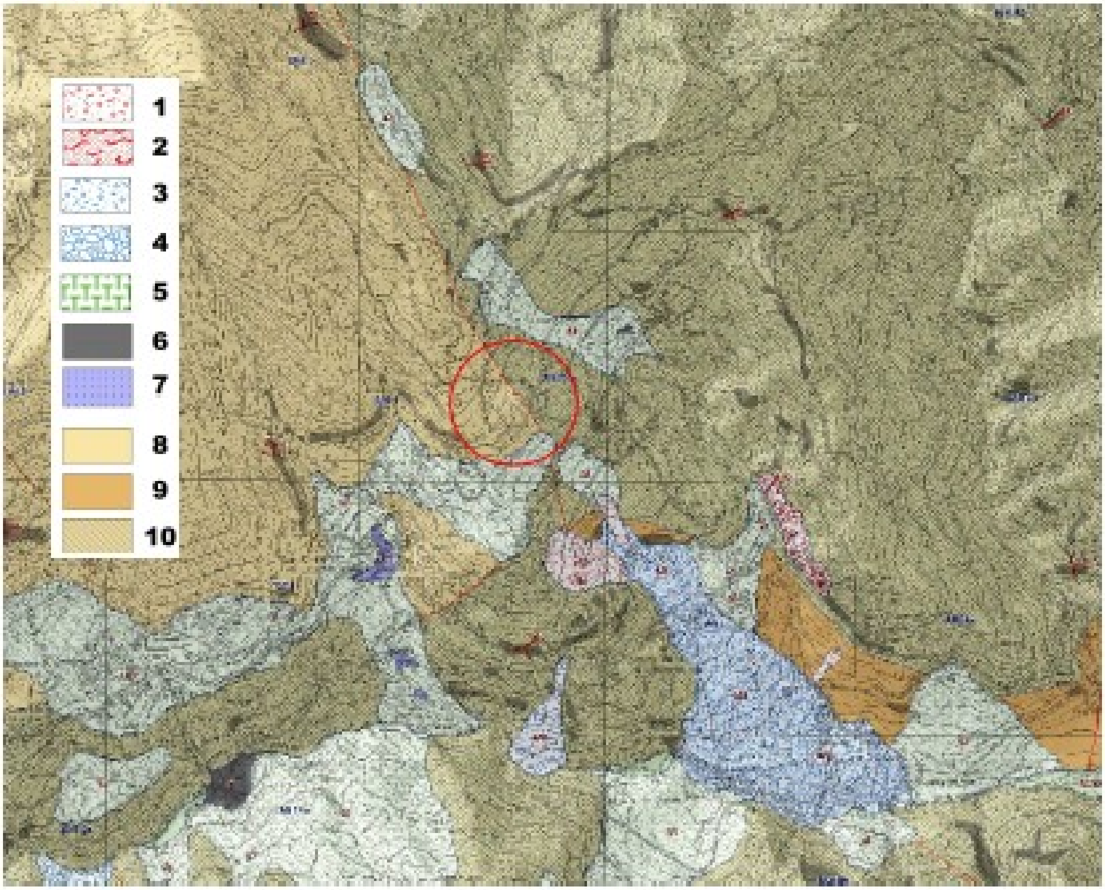


Fig. 3. Geological map of the study area (Extract from Servizio Geologico, Sismico e dei Suoli (Regione Emilia-Romagna – web site). Legend: red circle: location of Riola.1) Deposit of active slide; 2) deposit of active slow flow; 3) deposit of dormant slide; 4) deposit of dormant complex landslide; 5) talus heap; 6) inactive alluvial fan; 7) travertine; 8) Formazione di Pantano (Membro di Sassoguidano), PAT1; 9) Marne di Antognola, ANT; 10) Marne di Antognola – Membro di Anconella – silty-arenaceous litho-facies, ANT4a.

- pelitic sandstones of the Membro di Anconella (Formazione di Antognola), *Upper Rupelian - Burdigalian* (ANT4a in fig. 3). This lithotype has the highest occurence in the area, except for the north-western sector;
- marls and clayey marls of the Formazione di Antognola, *Upper Rupelian - Burdigalian* (ANT); they crop out, in some limited sites, in the sowth-eastern sector;
- arenites of the Membro di Sassoguidano (Formazione di Pantano), *Upper Burdigalian – Lower Langhian* (PAT1); they crop out just in the north-western sector.

Regarding tectonics, the village of Riola is located in the southern reaches of a direct, high-angle fault with a NW-SE direction. The fault has caused the lowering of the Membro di Sassoguidano (PAT1), on its west side, relatively to the Membro di Anconella (ANT4a), on its eastern side.

3. GEOMORPHOLOGICAL STUDY

The geomorphological study is an essential phase towards the geomorphological hazard assessment. The geomorphological characters of an area are shown on a geomorphological map (fig. 4), obtained, with some appropriate variations, according to the legend and guide proposed by the Italian Gruppo di Lavoro per la Cartografia Geomorfologica (1994).

In order to realize fig. 5, besides field survey, fundamental was the interpretation of aerial photographs and high-definition satellite images, both multi-scale and multi-temporal, analogical and digital.

The concept of “state of activity” has been of crucial importance when applied, in general, to define the dynamics of geomorphic processes (and their relative forms and processes) and, in particular, of hydrological-instability phenomena.

It is known that many definitions of “state of activity” exist for geomorphological processes (and consequently for active, dormant and inactive landslides) and for their deriving forms and deposits. This is because it has an extremely interesting applicative matter. Moreover, the term is frequently used without specifying its meaning.

Without listing all the existing bibliography about this matter, for this study the definition given by the PROVINCIA DI BOLOGNA (2004) has been used. For instable areas, it defines:

- “Areas affected by active landslides”: landslides which are currently active or that have been reactivated since the last 30 years (rock-falls are also included);
- “Areas affected by dormant landslides”: landslides that have not showed signs of activity since the last 30 years and that could be reactivated by their original causes, compresi gli scivolamenti di blocchi, le espansioni laterali e le Deformazioni Gravitative Profonde di Versante (DGPV);
- “Potentially instable areas”: quaternary deposits affected by evident superficial morphogenetic processes such as creep, solifluction etc.; alluvial fans; areas affected by relevant erosional processes; naturally stabilized or relict landslides.

The reason is that the Provincia di Bologna (2004) is a reference document for the territorial planning of the Bologna Province and that the methodology to be applied for the hazard assessment (see paragraph 6) considers two return-period classes: < 30 years, and from 30 to 100 years.

The geomorphological characteristics of the area, represented in the geomorphological map of fig. 4, will be described now on.

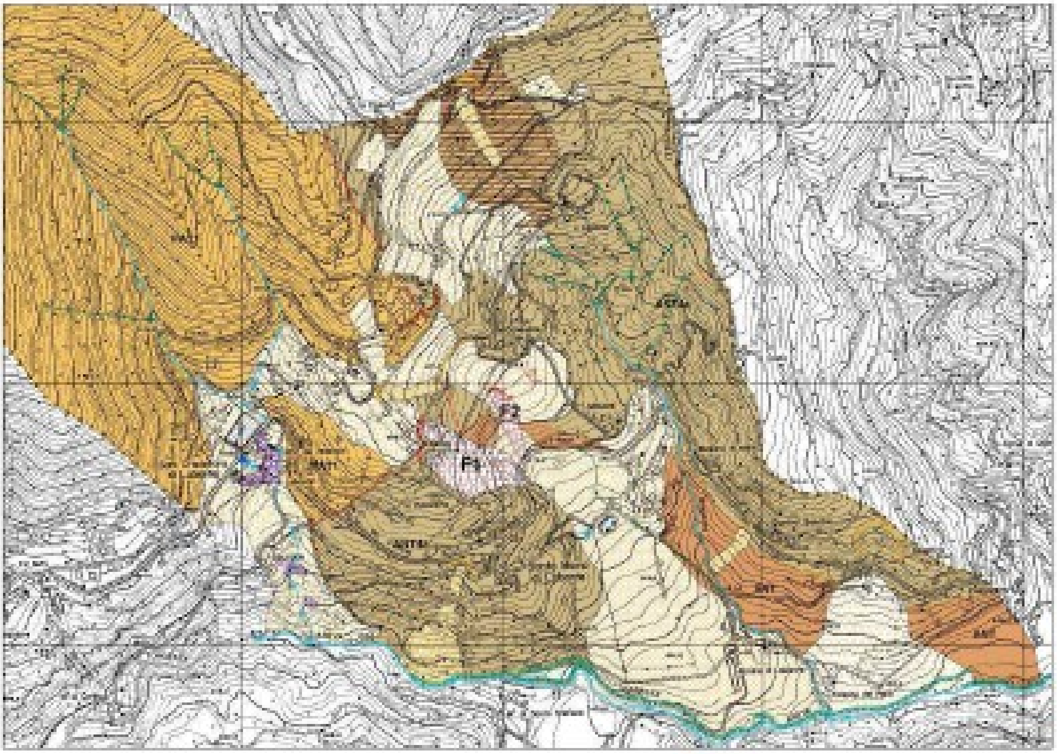
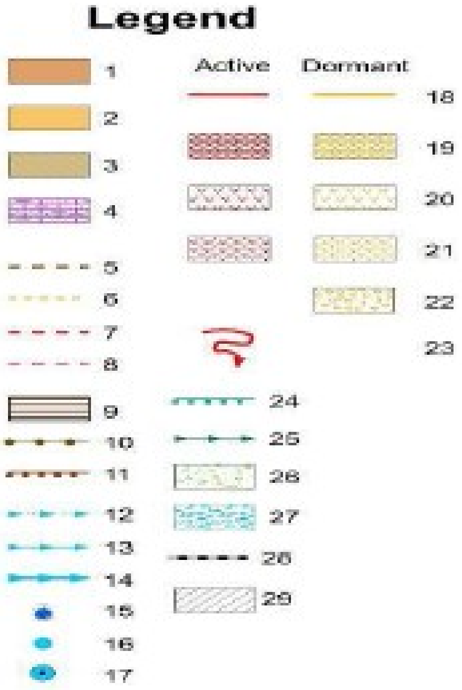


Fig. 4. Detailed geomorphological map of the study area. Legend: 1) Marne di Antognola, ANT; 2) Formazione di Pantano (Membro di Sassoguidano), PAT1; 3) Marne di Antognola – Membro di Anconella – silty-arenaceous litho-facies, ANT4a; 4) travertibe; 5) uncertain lithologic boundary; 6) uncertain stratigraphic/lithologic boundary; 7) assumed fault; 8) fracture; 9) structural surface; 10) ridge; 11) structure controlled scarp edge; 12) canalised stream; 13) secondary stream; 14) torrent; 15) tapped spring; 16) spring; 17) water well; 18) edge of degradation and/or landslide scarp; 19) landslide body due to flow; 20) body of rotational slide; 21) body of complex landslide; 22) talus heap; 23) slope affected by solifluction; 24) edge of torrential erosion scarp; 25) gully; 26) alluvial deposit; 27) water retention basin undergoing rapid sedimentation; 28) artificial embankment; 29) abandoned quarry; F1) Ribecco's landslide; F2) Canevare's landslide.



The area is drained by a dense network of gullies that convey their waters into two main water courses, the Rio Riva and the Rio Bragoara. These two are feed from the left side the Aneva Torrent that, with a W-E flow within small fluvial scarps, borders the area to the south (fig. 5). The infiltration of superficial waters occurs where topography shows counter-slope or concave shapes; the underground flux is sensibly reduced where waters encounter clay-rich lithologies.

Near San Cristoforo di Labante, the abundance of water flowing out from a spring and the peculiar chemical composition of rocks have determined favourable conditions to calcium-carbonate precipitation and the formation of travertine.

The waters of the S. Cristoforo di Labante's spring feed the homonymous waterfall that, together with the close by "cave of the Germans" represents the main tourist attraction of the area (fig. 6). Nearby, an abandoned mining pit has been converted to a resting place for tourists.

Fig. 5. Panoramic view of the Abbazia di Labante's landslide at whose foot the Aneva Torrent flows.

Fig. 6. The travertine waterfall near S. Cristoforo di Labante.

Regarding the structural-tectonic characters, the orographic setting is conditioned by a system of faults and fractures with a NW-SE direction at which various water courses have developed, divided by watersheds and structural scarps. The fault of the Riola village, that represents the most important element of that system, separates the outcrops of arenaceous lithologies into two sectors: the western one is characterised by counter-slope strata dipping towards N and NE; the eastern one characterised by along-slope strata dipping towards SE.

The buildings of the medieval village lie on top of arenaceous lithologies having a general counter-slope attitude of the strata. The western sector shows a higher relief energy and steeper slopes; the eastern one shows a relatively more gentle relief where, at some places, the slopes is a structural surface (fig. 7). Less steep slopes occur in the south-eastern sector where marls crop out.

The most abundant superficial deposits around Riola are scree deposits produced by physical weathering of outcropping sandstones and mobilised along slopes. Less abundant, although particularly important for instability, are landslide deposits, occurring mainly where pelitic sandstones of the Formazione di Antognola crop out. Landslide types are: rotational rock-slides, earth flows and complex landslides. In detail, a rotational rock-slide, clearly active, affect the south-eastern slope of Ribecco (from now on called "Ribecco landslide", identified by F1 in fig. 4). In the upper part of the slope, a few metres from the buildings, rock prisms can be observed, partially detached by their outcrop along sub-vertical surfaces from which other rock-falls and rock-slides might take place (fig. 8). Rock-fall deposits can be observed along the slope whose shape is characterised by many counterslopes. Somewhere trees are inclined. Moreover, witnesses and bibliographies refer about frequent remaking of the tract of the Provincial Road "Val d'Aneva" that borders the landslide foot. The causes of that landslide are probably related to tectonic-structural factors because, according to what Regione Emilia-Romagna – Servizio Geologico, Sismico e dei Suoli (2008) says, the area lies over the continuation of the Riola's fault and at the boundary between arenaceous and marly lithologies. On the basis of these data it is possible to assume the presence of a mechanical weakness that not only may have fractured the rock mass, but that may have also favoured preferential infiltration of superficial waters along sub-vertical fractures until the contact with underlying marls. Once saturated, marls could trigger slides that may destabilise also the overlying sandstones.

Fig. 7. Along –slope attitude of strata, given by a structural surface, NE of the medieval village of Riola (far left in the photograph). The bedrock is composed by pelitic sandstones of the Membro di Anconella.

Fig. 8. Panoramic view of the upper part of the Ribecco landslide. Note the detached rock prisms near the landslide scarp, very close to the buildings of Ribecco.

Probably a complex landslide (rotational slide and flow) has been identified east of Ribecco's landslide, south of Canevare: it affects the screes and it will be called, from now on, "Canevare's landslide", identified by F2 in fig. 4). The process, of limited extent, has been considered active due to the evident soil scars and to the slid earth lobes, not yet revegetated. The presence of water on the planar slope above could be the main cause of the landslide.

Two other relevant landslides can be observed on the slope between the Provincial Road Val d'Aneva and the Aneva Torrent. Particularly, the most extensive mass movement (13 hectares) is represented by the complex landslide east of Santa Maria di Labante at whose foot the locality of Abbazia di Labante lies ("Abbazia di Labante's landslide", fig. 5). Clues of activity can not be derived neither from interpretation of aerial photographs, nor from witnesses, nor from field survey. Moreover, bibliography data do not exist. It is a dormant landslide whose activation causes might be quite similar to those assumed for the Ribecco's landslide. The toe seems to have diverted the course of the Aneva Torrent.

A dormant rotational earth-slide can be observed at the eastern boundary of the area, at Casone del Papa ("Casone del Papa's landslide"). The source area is at the boundary between pelitic sandstones and clayey marls. Therefore, the cause of the movement could be the availability of water at the contact between the two lithotypes. Water seepage is favoured to reach the permeability threshold by the counterslope attitude of arenaceous strata.

Completing the framework of instability processes, four dormant landslides, of limited extent, occur north of Abbazia di Labante ("Abbazia's landslide"), south-west of Santa Maria di

Labante ("landslide SO of Santa Maria"), north of Ribecco ("landslide N of Ribecco") and at the northern boundary of the study area, east of La Casella ("La Casella's landslide").

4. GEOPHYSICAL INVESTIGATIONS

In order to characterise the area under the geological, seismic and geotecnical point of view, a specific gephysical campaign has been set up in the place where the buildings of the medieval village lie (and where refurbishment works are planned). The investigations were: 13 heavy penetrometries and 4 seismic refraction lines.

Penetrometries have shown the widespread presence of a superficial terrain with good geotechnical parameters, having different thikness and overlying the bedrock. Generally, the superficial terrain is composed by scree deposits made of fine silt and sandy silt, showing the lowest resistance values. Right below them, the terrain is more compact and with good resistance. The bedrock lies deeper down, where penetrometries stpped, showing high resistance values.

From a geotechnical point of view, the investigations have shown good resistance values for superficial deposits, rapidly increasing untill reaching the bedrock. The presence of water has never been detected.

The seismic refraction investigation has been undertaken in order to determine the stratigraphy of the upper ground, searching for the bedrock depth under the superficial detritical cover. The analysis of seismic data has identified 3 seismostratigraphic units. The most superficial one, associated to the scree deposits, is 1 to 4 metres thick. The second one, 2 to 5 metres thick, is partly related to scree deposits and partly to the weathering of the bedrock. The shape of the refraction surface is more or less similar to that of the ground. The third unit, from -3 to -9 metres below ground, can be related to the bedrock whose weathering and/or fracturing decreasing with depth.

Also during seismic investigations the presence of water has never been detected.

5. ANALYSIS OF GEOMORPHOLOGICAL HAZARD

According to PANIZZA (1987), geomorphological hazard can be defined as the "probability that a certain phenomenon of geomorphological instability and of a given magnitude may occur in a certain territory in a given period of time".

Therefore, a hazard analysis assumes the knowledge of the spatial distribution of instability phenomena (in this specifi case, ladslides) that occurred in the past in a certain area. Also their intensity and their reactivation frequency ("return period") should be known. It also implies another assumption: that insyability phenomena (landslides), already active in the past, reactivate in the same place, with similar intensity and with similar frequency. Although the assumption is not ideal, so far it is the only possible starting point to set up an hazard analysis, since the complex cause-effect mechanisms that rule the spatial and temporal evolution of landslides are not yet known.

Frequency and Intensity classes used for the matricial hazard assessment (from Panizza et al., 2004). Legend: Rp: return period; V: velocity; GS: geometric severity

Table 1

Frequency (F)	Return Period	Class
Very high (active)	< 1 year	Rp 5
High (frequent)	1 – 30 years	Rp 4

Medium (medium frequncy)	31 – 100 years		Rp 3
Low (less frequent)	101 – 300 yeras		Rp 2
Very low (rare)	> 300 years		Rp 1
Intensity (I)	*Velocity* (with reference to the velocity classes by Cruden & Varnes, 1995)		Class
Strong	> 3 m/minute (class 7 and class 6)		V 3
Medium	> 13 m/month and < 3 m/minute (class 5 and class 4)		V 2
Weak	< 13 m/month (class 3, class 2 and class 1)		V 1
Intensity (I)	*Thickness involved*	*Diameter of blocks*	Class
Strong	> 10 m	> 2 m	GS 3
Medium	> 2 – 10 m	> 0.5 – 2 m	GS 2
Weak	< 2 m	< 0.5 m	GS 1
Intensity (I)	*Combined intensity* *(Velocity x Thickness or Diameter of blocks)*		Class
Strong	V3xGS 3 / V3xGS2 / V2xGS3		I 6-9
Medium	V2xGS2 / V3xGS1 / V1xGS3		I 3-4
Weak	V2xGS1 / V1xGS2 / V1xGS1		I 1-2

Operatively, from the geomorphological map a thematic map has been derived where landslides and their hazard class have been highlighted. The derived map is called Geomorphological hazard map, (fig. 10). The implementation of this map made reference to the method applied by Panizza et al. (2004) and by Corsini et al. (2005) in South Tyrol (Italy) and by Castaldini D. & Ghinoi A. (2007) (in print) in the Modena Apennines. This method, derived from Heinimann et al. (1998), is based on a classification of the intensity and frequency of landslides (table 1). This is achieved by means of univocal matrix combinations which allow the definition of various levels of geomorphological hazard (fig. 9). The Heinimann et al. (1998) method is still used in Switzerland for landslide mapping and risk assessment (Loup & Raetzo, 2009).

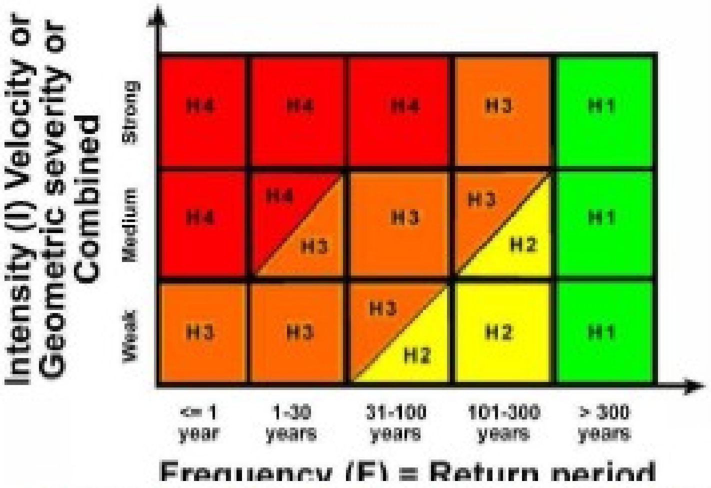


Fig. 9. Evaluation matrix for landslide hazard (from Panizza et al., 2004). H4 = very high; H3 = high; H2 = medium; H1 = residual.

The definition of hazard classes has been possible when quali-quantitative data were available for intensity and frequency of landslides. Moreover, where mitigation works have been done, a distinctive symbol has been used over the hazard color in order to point out that the hazard class assigned by the matrix can be reasonably lowered. When no data of intensity and frequency was available, the same symbol used in the geomorphological map has been assigned to the landslide.

The hazard characters of the area, shown in the Geomorphological Hazard Map (fig. 10), are described below, only for those phenomena whose activity clues were surely available.

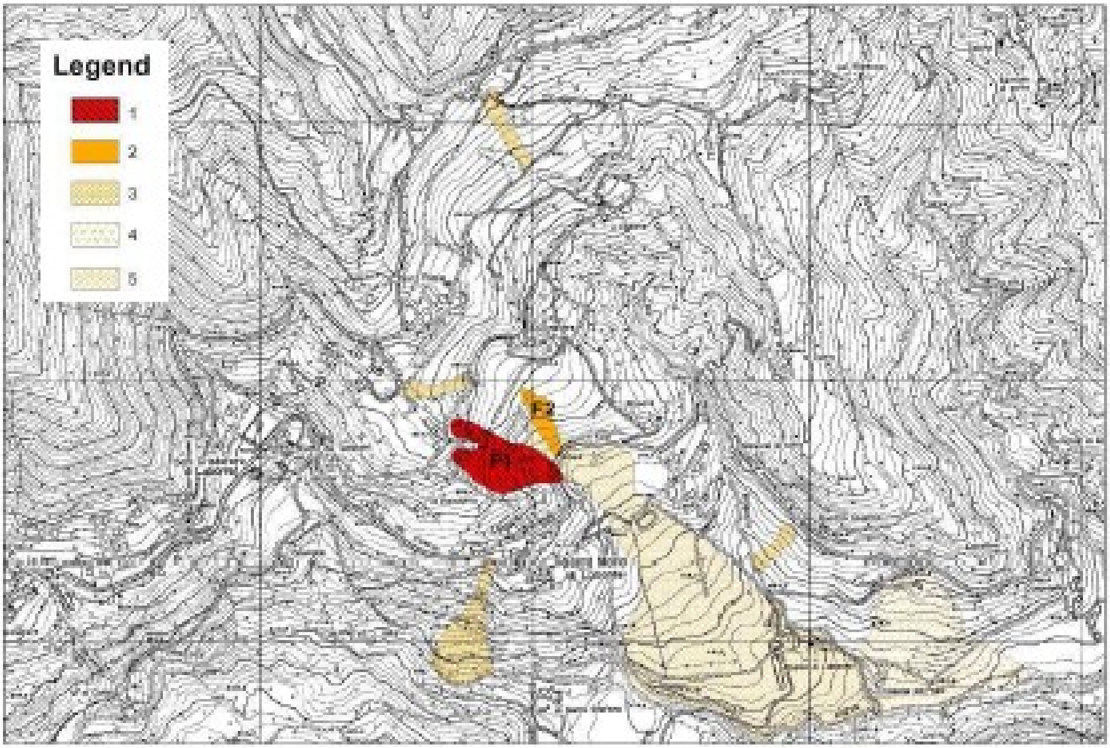


Fig. 10. Geomorphological Hazard Map of the study area. Legend: 1) Hazard class H4, very high, with mitigation works; 2) Hazard class H3, high; 3) dormant landslide body due to flow; 4) body of dormant rotational earth-slide; 5) dormant body of complex landslide; F1) Ribecco's landslide; F2) Canevare's landlside.

5. 1. Ribecco's landslide (F1)

Regarding the rotational slide of Ribecco, the return period was deduced by articles from newspapers where evidences of reactivation have been witnessed in 1996 and 1997. Therefore, the landslide has been assigned the class Rp4 (from 1 to 30 years). Moreover, witness and bibliography sources (Cardinali et al., 1998) refer to frequent remakes (also during the last years) of the tract of the Provincial Road "Val d'Aneva" that borders the landslide's foot. The landslide thickness has been assumed by the observation of the dimension of unstable blocks at the source area (from 2 to 10 m): therefore, the intensity class relative to just the geometric severity is GS2 (medium).

Velocity is that of quick rotational slides, similar to that of rock-falls, assumed from the same newspaper articles according to which the 1996 movement was heard by a big sound, typical of a sudden collapse. The intensity class relative to velocity is V3 (high). The combined intensity class is therefore I6 (high). The hazard class is H4 (very high).

From CARDINALI ET AL. (1998) it can be known that drainage works and other mitigation works were done after the second reactivation of January 1997: therefore, it has been chosen to put the mitigation symbol on top of the hazard colour, in order to reduce the matrix hazard degree.

From the field survey it is evident how the source area shows signs of potential reactivations, characterised by a retrogressive incipient movement.

5. 2. Canevare's landslide (F2)

For this phenomenon, evidence were found only from field survey. Particularly, the fresh soil fractures and the accumulation lobes not yet vegetated lead to assume the landslide active, in the short period. Therefore, the return period Rp4 (from 1 to 30 years) has been assigned to it. The thickness seems not to be greater than 2 metres, which lead to assign to it the intensity class GS1 relative to just the thickness of the slid mass. The velocity, assumed to be similar to that of earth-flows with medium-to-low fluidity, considering the short length of slope affected, should not be higher than 13 m/month, from which an intensity class V1 (low), related just to velocity, can be assigned. The combined intensity class is therefore I1 (low). The hazard calss is H3 (high). The extent of the phenomenon is anyhow quite small. To be noted is the presence of a counterslope upword from the landslide, with water ponds, which could favour the retrogressive evolution of the landslide. For this reason it should be useful to realize a proper water drainage in order to avoid infiltration that could lower the mechanical resistence of the terrain leading to possible slides.

6. REMARKS AND CONCLUSIONS

The data obtained during this study, represented in the Geomorphological map (fig. 4) and in the Geomorphological hazard map (fig. 10), are sometimes different from those recently published in "official" geological documents. Particularly, substantial differences between the geological maps of REGIONE EMILIA-ROMAGNA – SERVIZIO GEOLOGICO, SISMICO E DEI SUOLI, (WEB SITE) (fig. 3) and the Geomorphological map (fig. 4) attain to landslides. In detail, in this study the Ribecco (F1) and Canevare's (F2) landslides have been mapped and classified in a different way. Moreover, the La Casella's landslide and the N-of-Ribecco's landslide have been newly mapped, since they were not identified by the regional geological map. The same thing applies to the Casone del Papa's landslide, previously identified as scree deposit. The landslide SO of Santa Maria, previously identified as slide, has been reinterpreted as complex.

Examining the Carta del Dissesto di Provincia di Bologna, i.e., the Instability Inventory Map of the Bologna Province (2004) (fig. 11), the area between Ribecco and Santa Maria di Labante is partly identified as instable (zone 1 in red) and partly as evolving towards instability (zone 2 in yellow). Practically, that area corresponds to the sector occupied by the Ribecco's landslide (F1), by the Canevare's landslide (F2) and by the upper part of the Abbazia di Labante's landslide within the Geomorphological map (fig. 4) and within the Geomorphological hazard map (fig. 10).

Moreover, the Instability Inventory Map of the Bologna Province (2004) identifies the whole sector between La Casella and the Aneva Torrent, therefore also the medieval village of Riola, as an area with a very high landslide risk (R1). Differently, the detailed geomorphological survey and the geophysical investigations undertaken for this study have pointed out that: i) the north-eastern portion of the study area is characterised by a superficial bedrock and it might be affected just by very superficial soil-slips/flows; ii) the area with very high or high landslide hazard is limited to the Ribecco (F1) and Canevare's (F2) landslides, therefore the relative risk can be circumscribed to Ribecco, due to the retrogression of the landslide scarp.

Therefore, following the results of this study, the area classified as of very high hazard (R1) by the Instability Inventory Map of the Bologna Province (2004) should be re-examined and its extent very much limited.

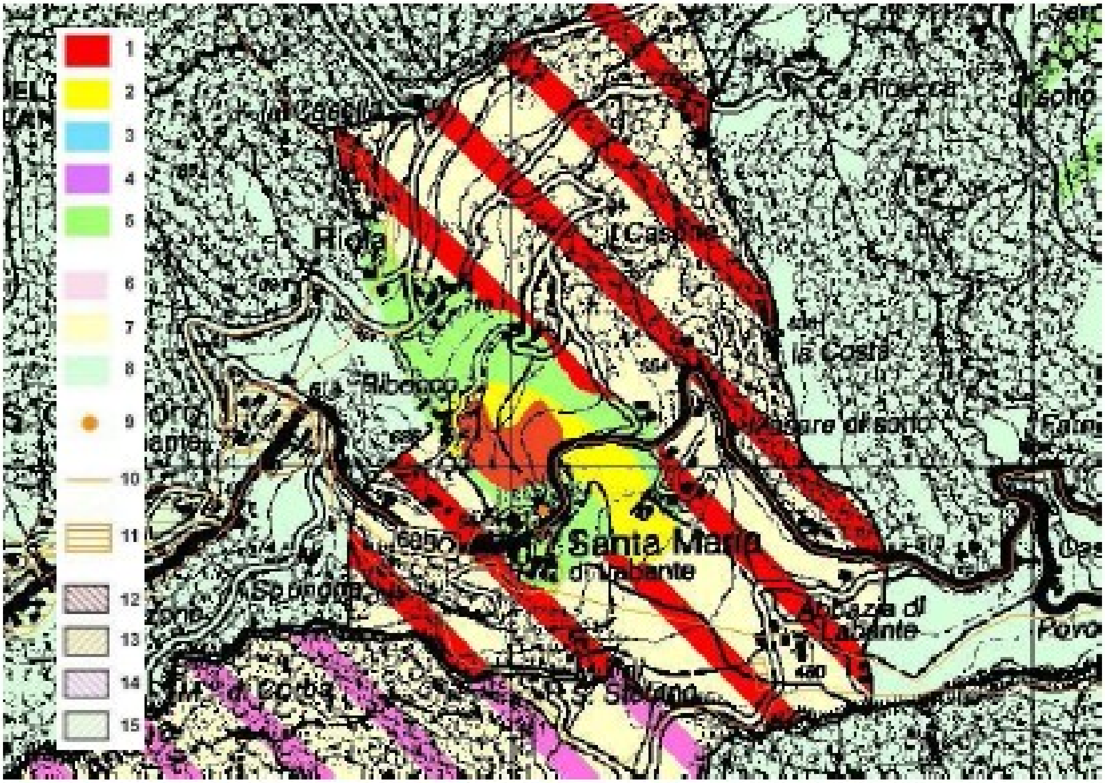


Fig. 11. Instability Inventory Map of the study area (Extract from Provincia di Bologna, 2004). Legend: 1) Zone 1: instable area; 2) area where the instability phenomenon might evolve to; 3) area on which the instability phenomenon might have an influence; 4) area to be subject to controls; 5) area where the evolution of the phenomenon might have an influence; 6) Elementary Hydrogeological Unit (EHU) not suitable for urbanistic use; 7) EHU to be verified; 8) EHU suitable, or with few limitations, to urbanistic use; 9) dwellings, manifacture and industrial sites; 10) cattles and transformation of agricultural products, urbanistic planns; 11) graveyards, architectural assets, highways, state amd strategic roads, railways, aqueducts, sewer network, depurators, dumpings; 12) EHU at very high risk; 13) EHU at high risk; 14) EHU at medium risk; 15) EHU at moderate risk.

In conclusion, the differences between the detailed geomorphological survey undertaken for this study and the geological map published by the REGIONE EMILIA-ROMAGNA – SERVIZIO GEOLOGICO, SISMICO E DEI SUOLI (WEB SITE), basis for the Instability Inventory Map of the Bologna Province (2004), reveal how the geological maps often give more importance to the spatial distribution of landslides than to their state of activity. The latter often varies within the same landslide body, affecting the definition of risk and, therefore, the validity of cartographic documents officially used in territorial planning.

The main limit of the official instability cartography is that it generates planning constraints at municipality scale starting from a base cartography that has a lower degree of detail (lower scales) and that most of the times is not conceived to analyse hydrogeological hazards. Often, detailed investigations at municipality scale are missing, although they would be necessary in order to verify what is mapped in higher-rank territorial planning.

A detailed geomorphological analysis undertaken using the methodology here proposed should be adopted and encouraged in order to improve the official planning maps. Besides the geophysical investigations, that here have had the only aim of improving the survey's results, the easy and replicable hazard analysis based on the Heinimann's matrix (Heinimann et al., 1998) would be more than sufficient to better define the hydrogeological (and, in particular, landslide) hazard and risk framework. If adopted at municipality scale, this methodology could lead to a reduction of areas to verify, as it has been shown in this study. In this specific case, the study has allowed to punctually define landslides and landslide hazard in the area surrounding the medieval village of Riola, pointing out that no landslide hazard affects the village whose exploitation may therefore undergo transformation works.

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