Landslide inventory bimodality in volcanised tertiary basin of Puy-en-Velay (France) : a geoindicator of climate change and geomorphologic evolution

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Landslide inventory bimodality in volcanised tertiary basin of Puy-en-Velay (France)
A geoindicator of climate change and geomorphologic evolution

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1. Background & Study area

The study of landslides aims often to understand the mechanisms and processes in order to reduce the hazard and the risk. The investigation of the past relations between climate and landslide is a common way to take account the impact of climate change on the landslide activity. By this way, landslides could also be used as a geoindicator of climate change and regional geomorphic sensitivity (Borgatti & Soldati, 2003; Canuti *et al.*, 2004; Damm & Terhorst, 2010).

The tertiary basin of Puy-en-Velay is located Southeast of French Massif central in an area of 400km². The tertiary sandy-clay material composing the basin is particularly sensitive to landslide and the relief inversion caused by volcanic shape create a complex slope system (**fig.1**).

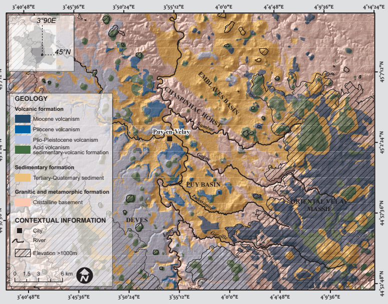


Figure 1 – Geological map of the Tertiary basin of Puy-en-Velay in the regional geologic context

The regional landslide activity is important and cause numerous injuries and damages on the infrastructures. If the present day landslides are essentially thin (<5m), they often correspond to a surficial reactivation of old deep-seated landslide. This justifies the PhD research on the landslide hazard on the tertiary basin of Puy-en-Velay.

The first step of the hazard study is the historical inventory of landslide and its analysis. One interesting analysis approach is the frequency-magnitude for interpreting the structure of the population and proposing theoretical explanations.

This poster presents the frequency-magnitude analysis of the historical landslide inventory of the Puy basin and its geomorphological interpretation.

2. Methodology

The inventory of landslides was based on two classical approaches:

1. A photo interpretation of aerial photographs obtained by Google Earth©
2. A field survey to verify the photo interpretation and to prospect under forest cover

❶ All the landslides were digitalised on a GIS software. The colour aerial photography had a 50cm resolution and the digitalisation was carried off to 1/1000. When it was possible, we allocate a landslide type for each polygon.

❷ Each polygon was verified in the field to determine the type of landslide, the geologic material, the possible causes of rupture, etc.

In addition, more detailed investigations on some representative landslides have been made (**fig.2**):

Figure 2 – Example of field investigation (DGPS monitoring, peat extraction for C14 dation, geophysics, Pressler extraction on a tree, borehole)

1. **Geophysics** – 2 seismic tomography cross-sections and 15 boreholes,
2. **Monitoring** – centimetric DGPS monitoring with a monthly frequency during one year for 4 landslides
3. **Dendrogeomorphology** – 12 trees investigating on 2 landslides
4. **Datation** – C14 dation of 4 palaeolandslides

All these investigations have allowed us to specify for each landslide the type and the processes.

1. Results

More than 200 landslides were inventoried in the study area.
The analysis of the inventory pointed out the existence of two clear populations i) the recent landslide (<100 years) et the ii) the old landslide (>1000 years).

LOCATION OF LANDSLIDES

The landslides are spatially structured in clusters, especially the old landslides (**fig.3**) .

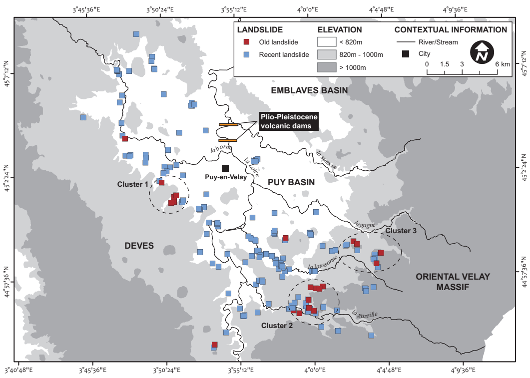


Figure 3 – Location map of inventoried landslide

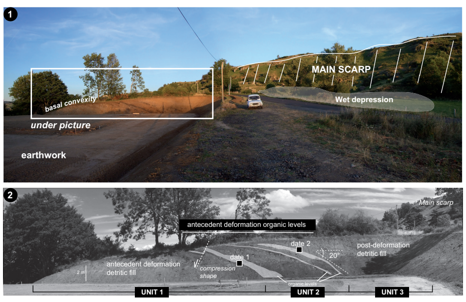
The old landslides are located between 820m height and 1000m, corresponding to the elevation of Plio-Pleistocene volcanic dams located at the north of the Puy-en-Velay. These old landslides are numerous at the rims of the Oriental Velay massif (clusters 2 and 3) and are concentrated in the deep valleys cutting into the Devès plateau (cluster 1). This corresponds to the front of the Pleistocene erosion wave succeeding to the dams erosion.

TYPOLOGY OF LANDSLIDES AND AGE OF OLD LANDSLIDES

The recent landslide are organised in 3 different type of landslide while old landslide can be group in one type (**tab.1**).

Table 1 – Landslide type inventoried in the study area

Recent landslide	*Surficial translational slide*	Planar landslide with less than 2m deep
	Surficial or deep rotational slide	Rotational slide with deep between 2 and 5m
	Flowage	Soil deformation with a viscoplastic comportment
Old landslide	*Like Complex or flow-slide*	Basaltic cornice dismantling and flowage



Four old landslides have been dated by C14, with peat formation in the reverse slope cause by a rotational component of the high part of this kind of landslide (**fig.4**). Three landslides were dated between 4469±43 Cal.BP and 2820±42 Cal.BP, so during the Subboreal period. The last one (**fig.4**) presents two phases of activation, the first one before 25,975±223 Cal.BP (date 1) and the second one after 20,457±115 Cal.BP (date 2). The second phase might have occurred during the Subboreal so.

Figure 4 – Example of a palaeolandslide. 1) generalcontext of the landslide; 2) details of the formations and the mechanic deformation of detritic and organic filling

MORPHOMETRIC ANALYSIS

The landslides present a clear bimodality in their dimensions (**fig.5**) and their frequency-magnitude relation (**fig.6**)

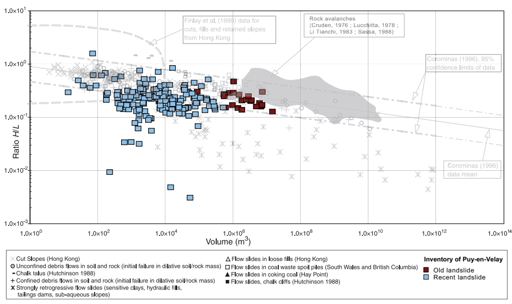
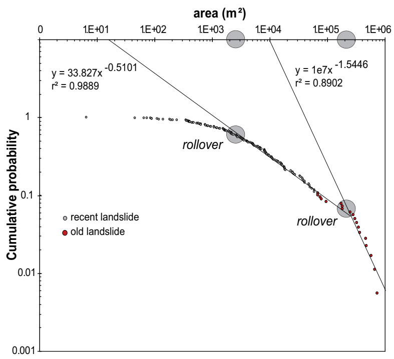


Figure 5 – Tanα/Volume relationship of the landslides inventory compare to other referential inventories

The old landslides form a group of high volume and low Tanα compare to the recent landslides which have higher values of Tanα but lower in volume. Those criteria define a different physical comportment and initiation processes. The recent landslides are defined by soil rupture initiation or like-flowslide mechanical comportment. The old landslides are closed to the flowslide or debris avalanche comportment.

This difference of apparent mechanical comportment , with the same geological material, can be caused by the triggering factors or the physiography. The frequency-magnitude relation gives us some elements.

Figure 6 - Frequency-magnitude distribution of landslides of Puy-en-Velay basin



The first rollover at 20,000m² separates the old landslide (>2e5m²) from the recent landslide (<2e5m²). The old landslides are fit by a power law with β factor equal to -1.54. A second rollover at 2000m² separates the very thin recent landslide (superficial translational landslide < 2e3m²) from the other recent landslide (flowage and rotational slide <2e3m²). This others recent landslides are fitted by a power law with a β factor equal to -0.51.

Interpretations & Conclusions

The landslide population of the tertiary Puy basin is composed of two sub-groups: i) recent landslides, majority surficial and often due to local reactivation of old landslides and ii) old landslides, deep and complex, with real effects on relief (basaltic cornice dismantling) and with a timely convergence on the Subboreal period. This period is also known by other authors in Europe (Dapples, 2002 ;Soldati et al., 2004; Hradecky et al., 2007; Van-den-Eeckhaut et al., 2007; Panek et al.,2008a; Gioia et al., 2010).

Concerning the different power law β factor, we can interpret it as a physiographic limit as Guthrie & Evans (2004) but the time separates the two populations is not so long to obtain a real physiographic difference. We prefer to bring the findings of Van Den Eeckhaut *et al.* (2007) in the Flemish Ardennes and consider that the β factor corresponding to a different sensitivity of the geormorphologic system, which was submitted to triggering factors with the highest magnitude in the past (highest β factor) than the present day (lowest β factor). In our study area, we consider than the Subatlantic conditions correspond to a β factor of 0.51 while the Subboreal period corresponds to a β factor of 1.54. This magnitude difference equals $p^{1.36}$.

All these conclusions are in agreement with literature (Buma & Dehn, 1998; Dehn *et al.*, 2000*;* Soldati et al., 2004) that considers the Subboreal period is marked by a largely positive water balance. This positive water balance is also in agreement with old landslide with low Tanα values and close to flow-slide or debris avalanche mechanical comportment.

Finally, this two landslide populations can be considered as witnesses of climatic conditions evolution and geoindicators.

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