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# PERIGLACIAL DEPOSITS AND CORRELATED PROCESSES IN THE NINGLINSPO VALLEY (ARDENNE MASSIF, BELGIUM)

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(7 figures, 1 table)

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**ABSTRACT**. Located in the northern part of the Ardenne massif, the Ninglinspo catchment shows morphologic features (valley floor benches, slope dissymmetry, river superimposition, etc) which constitute the likely heritage of periglacial processes. Here, we consider chiefly the geomorphic meaning of the valley floor benches. Assuming that bench deposits resulted at least partially from periglacial processes during the last glacial means that, during the Holocene warming, the river was unable to evacuate them totally. Reasoning in the same way for previous glacial and interglacial episodes (e.g. with a river unable to transport during warm periods the entirety of the materials provided by periglacial slope processes), implies that a polygenic genesis of these benches should be considered. In this study, we try to bring to the fore this polygenic origin using different various techniques, including geophysical surveying and tephrochronology. Finally, catchment denudation rates by periglacial slope processes ranging from 0.45 to 2 mm/ka have been inferred since the last glacial.

**Keywords** : geomorphology, valley floor bench, mud flow, resistivity tomography, tephrochronology.

## 1. Introduction

It is admitted that, during the Quaternary glaciations, the Ardenne Massif underwent periglacial climatic conditions (Pissart, 1976; Pissart, 1987; Pissart, 1995) and therefore present nowadays numerous inherited periglacial features in its morphology. While paleo-ice wedges and stratified debris (periglacial breccia) have been observed in some deposits (Pissart, 1995), many studies focused on block accumulations in the valley floors (Bastin et al., 1972; Pissart *et al.*, 1975) and on remnants of cryogenic mounds on the Hautes Fagnes Plateau and the Malchamps ridge (southward of Spa). Concerning the latter, they were first interpreted as pingo remnants (Pissart, 1956 ; Bastin *et al.*, 1974), then palsas (Pissart, 1974; Pissart & Juvigné, 1980) or mineral palsas (Pissart, 1987 ; Pissart, 1995), before being considered nowadays as remnants of lithalsas. As these closed depressions are filled with peat, palynologic analyses (Florschutz, 1937; Bastin *et al.*, 1974) were realized, showing that the filling started at the beginning of the Holocene. Moreover, $^{14}C$ dating carried out in peat layers underlying the wall encircling these depressions combined with the presence of the Laacher See Tephra within this wall proved that these cryogenic mounds (lithalsas) formed during the Younger Dryas (Pissart & Juvigné, 1980 ; Pissart, 1995).

Though some authors also studied the general geomorphology of the northern part of the Ardenne massif (Beckers, 1979; Demoulin, 1980; Girolimetto, 1990), no specific geomorphical study was yet carried out in the Ninglinspo valley (Amblève catchment). Therefore, we essentially focused on the periglacial bench deposits of the Ninglinspo valley. Using geophysical surveying and topographic measurements, we described their morphology as well as their structure and we attempted to determine which kind of processes created them. Finally, tephrochronology was used to date the deposits and to refine the understanding of their evolution.

## 2. Study area

### *2.1. Localization*

The Ninglinspo creek is a right-side tributary of the lower Amblève River, in the northern part of the Ardenne massif. Its catchment (~10 km²) is situated at the western margin of the Vecquée ridge (Fig. 1) which is itself an extension of the Hautes Fagnes plateau in the WSW direction. Formed by the confluence of the Blanches Pierres and the Hornay streams (Fig. 1), which have their source at elevations of respectively 513 and 494 m, the Ninglinspo flows into the Ambleve at an elevation of 153 m near Nonceveux. The total length of the Ninglinspo is about 6 km. Considering the elevation difference between the source and the confluence with the Ambleve (~350 m), the average longitudinal slope of the Ninglinspo is very steep, about 60 $^{0}/_{00}$. In the lower section, it receives

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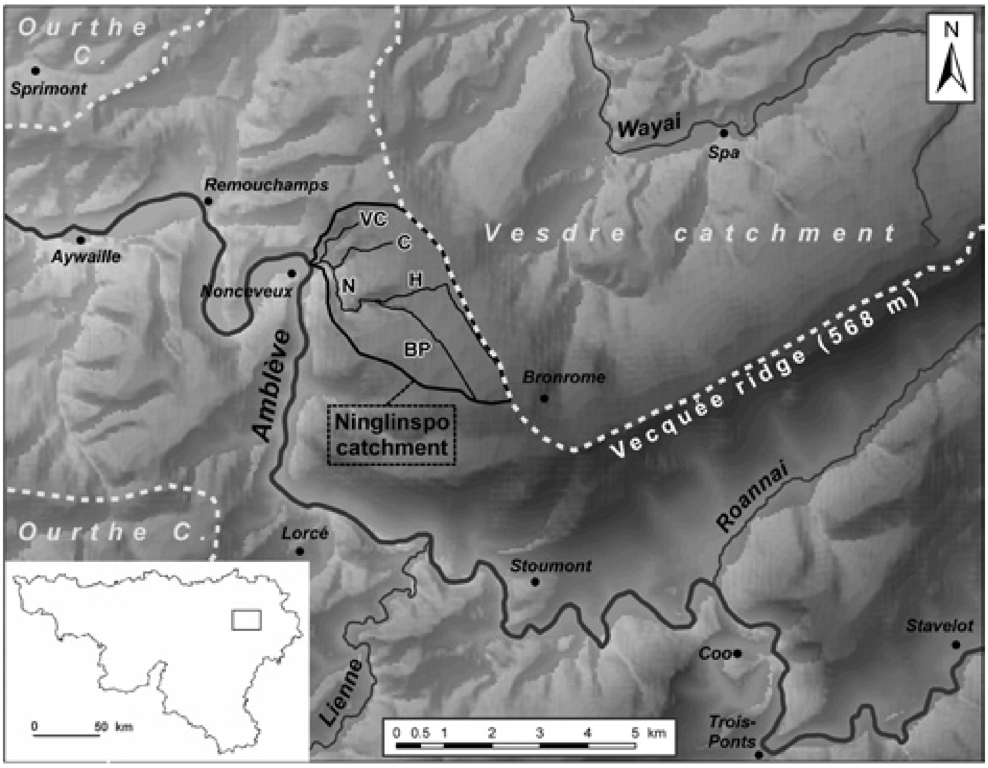


**Figure 1**. Location of the Ninglinspo catchment in the lower Amblève valley. BP : Blanches Pierres stream ; C : La Chaudière stream ; H : Hornay stream ; N : Ninglinspo stream & VC : Vieux Chera stream. Dashed grey lines delimit the Amblève catchment.

its two main tributaries, the La Chaudière and the Vieux Chera streams (Fig. 1).

### *2.2. Geological setting*

The Ninglinspo catchment is located at the contact between two regional structural units: the Cambro-Ordovician Stavelot Massif at the East and the Lower Devonian of the Dinant Synclinorium at the West (Fig. 2). The Stavelot Massif is represented in the catchment by the Cambrian Formations of La Venne-Coo and La Gleize which belong respectively to the middle (Rv3-4) and upper Revinian (Rv5). The first one is characterized by a predominance of dark-colored quartzites, often strongly veined, whereas the second formation is mainly composed of black slates. Within the catchment, the Dinant Synclinorium is represented by the rocks of the lower and upper Lochkovian, with the Marteau and Bois d'Ausse Formations respectively. The Marteau Formation can be divided in two distinct units: the lower member corresponds to the basal Quarreux Conglomerate, constituted itself of quartzitic elements stemming from the La Venne-Coo Formation, while the upper member is characterized by reddish shales and siltstones, with subsidiary micaceous sandstones. The youngest rocks of the catchment, the Bois d'Ausse Formation, mainly consist of grey-brown sandstones. Because of its discontinuous appearance and its strong facies and thickness variation, the Quarreux Conglomerate attracted numerous Belgian geologists since the beginning of the 20th century, either at a regional level (Graulich, 1951), or at the scale of the Ninglinspo catchment (Asselberghs, 1922 ; Fourmarier, 1928 & 1938 ; Geukens, 1959 ; Graulich, 1959 ; Sintubin & Matthijs, 1998).

Being at the contact between these two structural units, the Ninglinspo catchment is strongly disrupted by tectonics (Fig. 2). The Eupen fault, which corresponds to the southern boundary of the Theux window, steps over southwards in the La Chaudière thrust fault that affects the whole Amblève section located between Lorcé and Nonceveux (Sintubin & Matthijs, 1998). Within the Ninglinspo catchment (Fig. 2), this fault constitutes the lithologic limit between the middle Revinian formation (La Venne-Coo, Rv3-4) on the one hand and the Lochkovian formations (Marteau and Bois d'Ausse) as well as the upper Revinian formation (La Gleize, Rv5) on the other hand. Moreover, this section of the Amblève River is classically interpreted as a broad anticlinal structure. In this area, the Lower Devonian formations are in contact with Cambrian rocks while, both northwards and southwards, the Lochkovian formations lay on Ordovician rocks (Salmian). At its western margin, the broad folded structure of the Vecquée ridge plunges very steeply westwards with secondary folds. Two of them are located in the Ninglinspo catchment: the syncline of the Ninglinspo valley with a slate core (Rv5) and the anticline of the La Chaudière valley with a quartzitic core (Rv3-4).

## 3. Methodology

A detailed study of the deposits forming the valley floor benches was carried out using various techniques.

(a) The bench elevations with respect to the present-day river channel were measured by means of an Abney level. As we needed only a rough determination of the main height variations of the benches, the elevation uncertainty (better than 0,5 m) is quite acceptable.

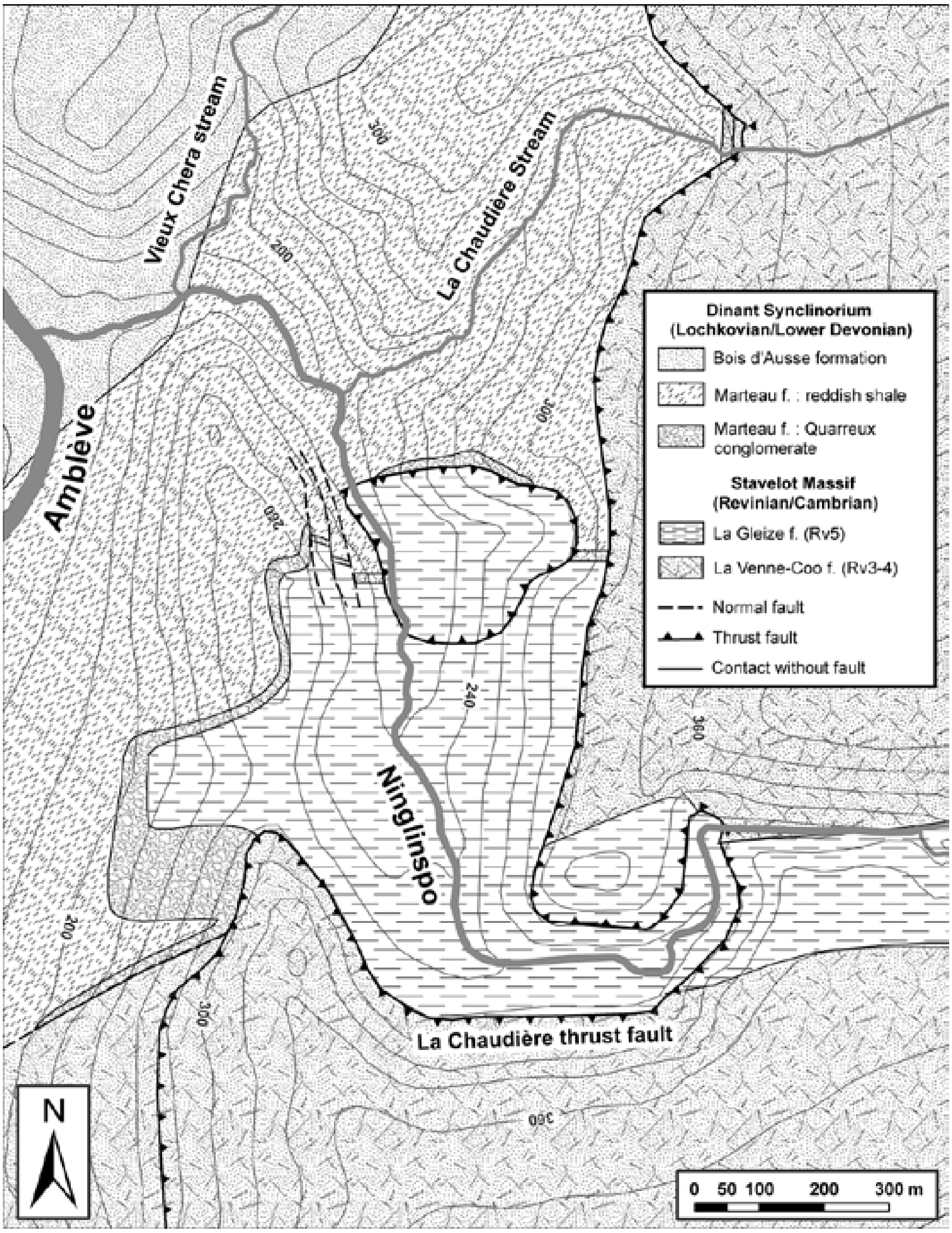


**Figure 2.** Geological map of the lower Ninglinspo valley (modified from Sintubin & Matthijs, 1998).

(b) Two 2D electrical tomography (IRIS, Syscal Junior model) were carried out across the benches in the lower section of the Ninglinspo valley with the aim of determining the contact between the bedrock and the bench deposits and, consequently, their thickness. The first one (RT1) was entirely realized in the bench LB1 (110 m in length) while the second one (RT2) was located both in the bench RB2 and on the hillslope (80 m in length) (Figs 3 & 5). An electrode spacing of 1 m was used in both cases in order to have a good resolution over a depth profile of 8 to 10 m.

(c) Six trenches were carried out in the periglacial deposits of the lower Ninglinspo valley to take samples for the search of volcanic heavy minerals (tephra). In the Ninglinspo area, two distinct volcanic fallouts are potentially present.

The Rocourt tephra is characterized by the presence of megacryst fragments of magnesian orthopyroxenes (enstatite). The origin volcano of this tephra still remains unknown but belongs to the western Eifel volcanic field; its age is comprised between 74 and 90 ka (Pouclet *et al.*, 2008).

The eruption of the Laacher See volcano, located in the eastern Eifel volcanic field, produced the tephra of the same name. It is characterized mostly by the presence of sphene (and apatite) in its mafic mineral association; its age is ~12.9 ka (Bogaard, 1995) or ~13,2 ka (Walter-Simonet *et al.*, 2008).

In each section the colluvium and the material hosting the present soil have been removed in order to take samples from uncontaminated periglacial layers. After laboratory

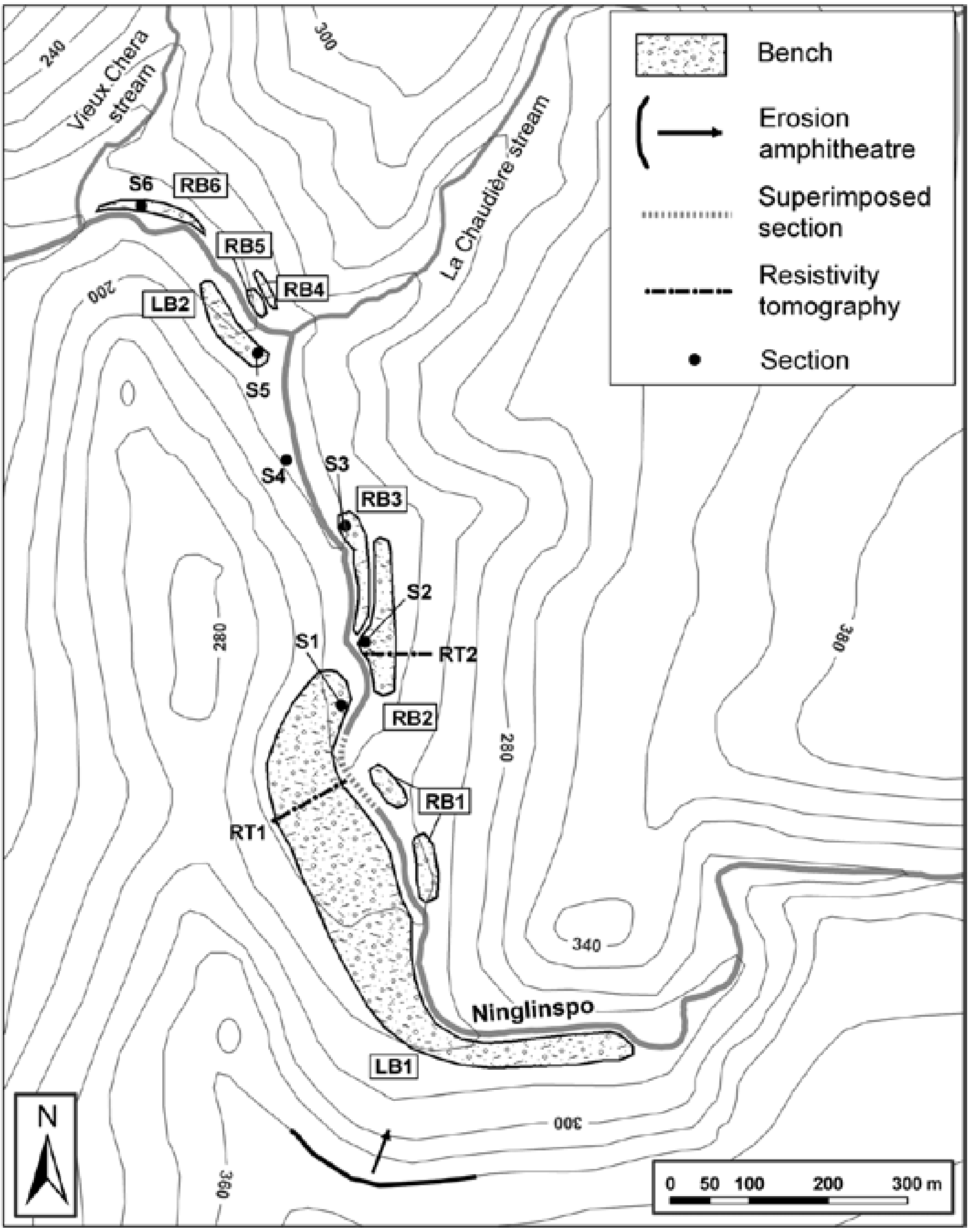


**Figure 3.** Geomorphological map of the lower Ninglinspo valley.

treatments, the granulometric fraction corresponding to fine sands (from 63 to 420 μm) was used to count 100 transparent heavy mineral grains per sample. A distinction was made between the volcanic minerals representative of the tephras (enstatite, clinopyroxene, brown amphibole and sphene) and the ubiquitous minerals (tourmaline, zircon, rutile).

## 4. Results

During our field investigations, we identified four closed depressions filled with peat and encircled by a wall of small elevation (<1m) at the limit between the Ninglinspo and the Vesdre catchments (about 600 m westwards of the Bronrome Farm) at elevations comprised between 530 and 540 m. In his geomorphological map, Beckers (1979) already mentioned two similar features in the upper part of the Ninglinspo catchment and interpreted them as remnants of cryogenic mounds (pingos). However, considering more recent studies (Pissart & Juvigné, 1980 ; Pissart, 1987; Pissart, 1995), the forms identified by Beckers and ours are more likely remnants of lithalsas. Beside these inherited periglacial features which certainly deserve a specific study, we essentially focused on the valley floor benches. These benches are particularly well-developed in the lower section of the Ninglinspo (Fig. 3). Six of them are located on the right bank of the river (respectively named RB1, RB2, RB3, RB4, RB5 and RB6 in a downstream order) and two on the left bank (LB1 and LB2). All of these benches display a gentle transversal slope in the direction of the current river channel though their extensions are quite variable (Fig. 3). In this respect, LB1 constitutes the best preserved bench in the Ninglinspo valley. Its length reaches almost 800 m while its width is greater than 100 m, despite the considerable entrenchment of the valley (Fig. 3).

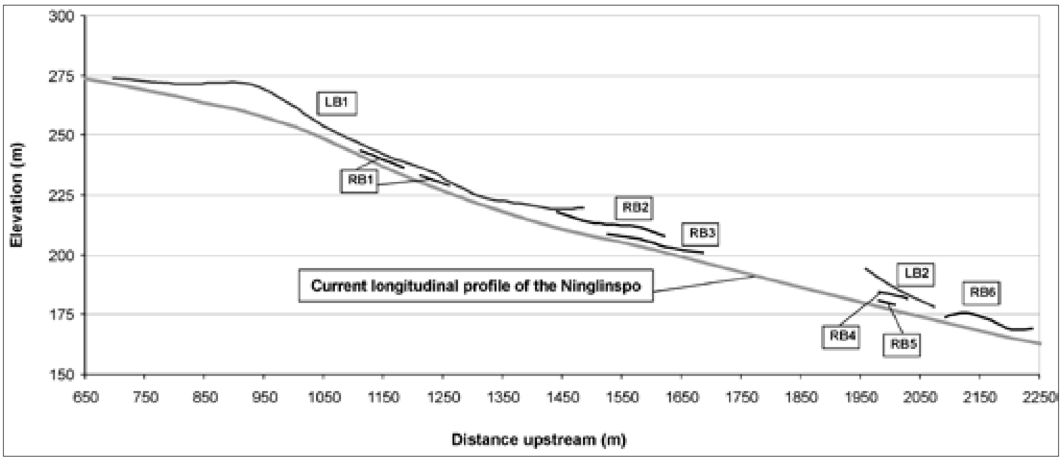


**Figure 4.** Longitudinal profiles of the lower Ninglinspo benches and the present-day channel.

### *4.1. Elevation measurements*

*4.1.1. Left bank benches*

The relative elevation of the bench LB1 in relation to the present-day river channel shows important variations (Fig. 4). Its relative height grows first downstream to reach a peak of 12-13 m after about 200 m. From this place, it decreases then gradually and stabilizes in values between four and six meters. Finally, its height increases again up to ten meters just before the bench disappears from the topography. The elevation of the bench LB2 decreases quickly from its upstream extremity (13,5 m) to its downstream end (3 m). With a length of 120 m (Fig. 4), it is characterized by a steep longitudinal slope (~ 9 %).

*4.1.2. Right bank benches*

The bench RB1 is divided in two distinct parts by a slate

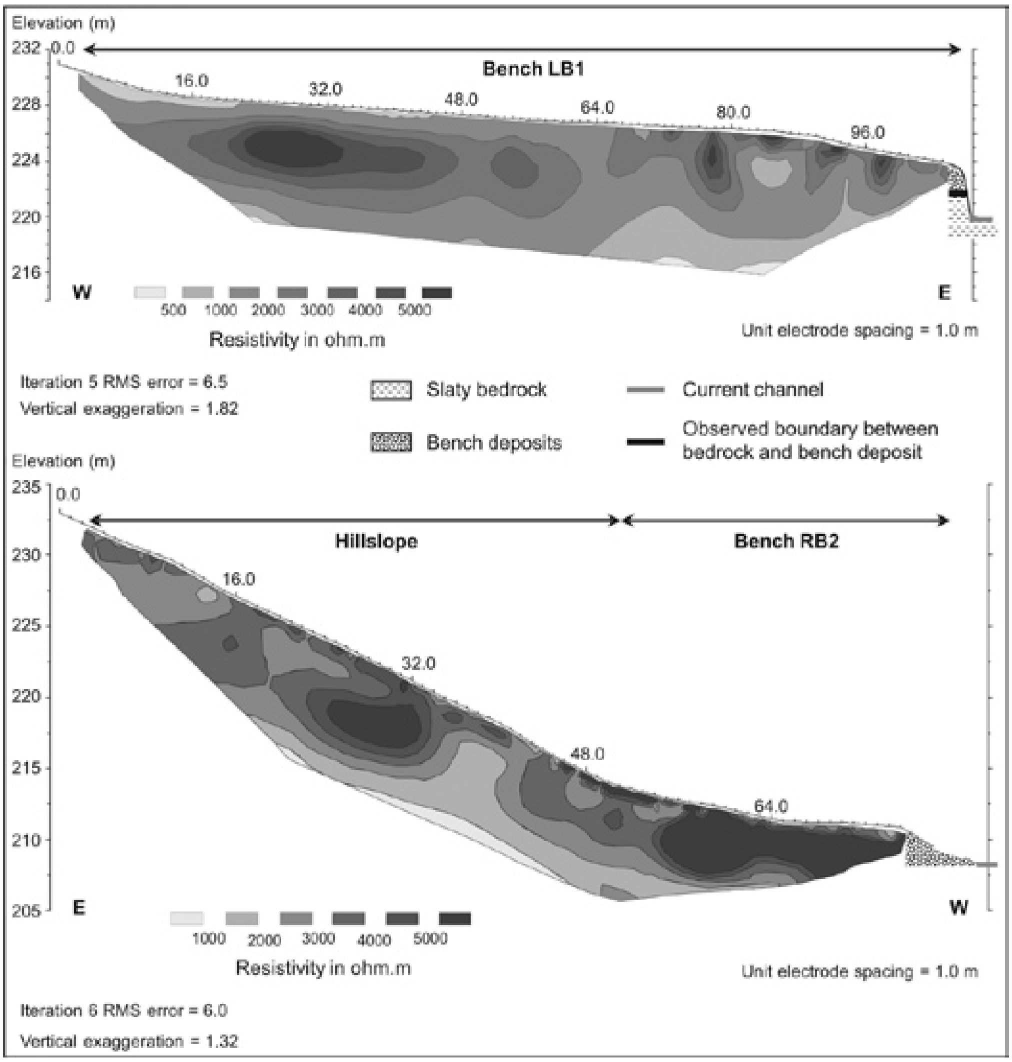


**Figure5**.Tomographies resulting from RT1 (bench LB1) and RT2 (bench RB2).

outcrop (Rv5). The average height above the present channel of the upstream part is about 2,5 m while the elevation of the downstream part reaches 4 m (Fig. 4). The main characteristic of the bench pairs RB2/RB3 and RB4/RB5 is that their elements appear simultaneously but at different elevations in relation to the riverbed (Figs 3 & 4). The benches closer to the present channel, RB3 and RB5, have lower relative elevations (respectively ~1,5 m and 2 m) than RB2 (~5,5 m) and RB4 (~6,5 m). Moreover, it is interesting to notice that the appearance of the bench RB3 fits precisely to the height increase of the bench RB2 (downstream part). Finally, the elevation of the bench RB6 shows important variations, from 2 m above the riverbed up to 6 m (Fig. 4).

### *4.2. 2D resistivity tomography*

Generally, the detection of the contact between two distinct units, namely the slate bedrock (Rv5) and the bench deposit, relies on the identification of a sharp resistivity gradient. Though not well defined, such a gradient can be observed in the western part of RT1 (Fig. 5). A place of very high resistivity values (>5000 Ωm) actually appears at a depth comprised between two and four meters whereas the resistivity below this spot decrease constantly to reach values smaller than 1000 Ωm at a depth of seven meters. In the second tomography (RT2), the resistivity gradient is observable at two distinct places (Fig. 5). It appears clearly in the bench RB2 which shows very high resistivity values from the surface to a depth of 4-5 m before decreasing quickly deeper, and on the hillslope, though it is not so well defined as the latter.

Moreover, a morphologic feature helped us to determine the contact between the slate bedrock and the bench deposits. RT1 was realized where the width of the bench LB1 is maximal and was ended up on the left bank, just above the channel. At this place, the elevation of the riverbed which flows directly on the slate bedrock (Rv5) is 219.5 m (Figs 5 & 6A). On the left bank, the slate bedrock, observed up to two meters above the present-day channel (221.5 m), is overlain by two metres of loose deposits (Fig. 5). Therefore, the combination of the observed resistivity gradient with this morphological feature suggests that high resistivity values could represent the bench deposits whereas the lower values could be attributed to the slate bedrock. Although the limit between both units remains relatively unclear, an approximate thickness of deposits of

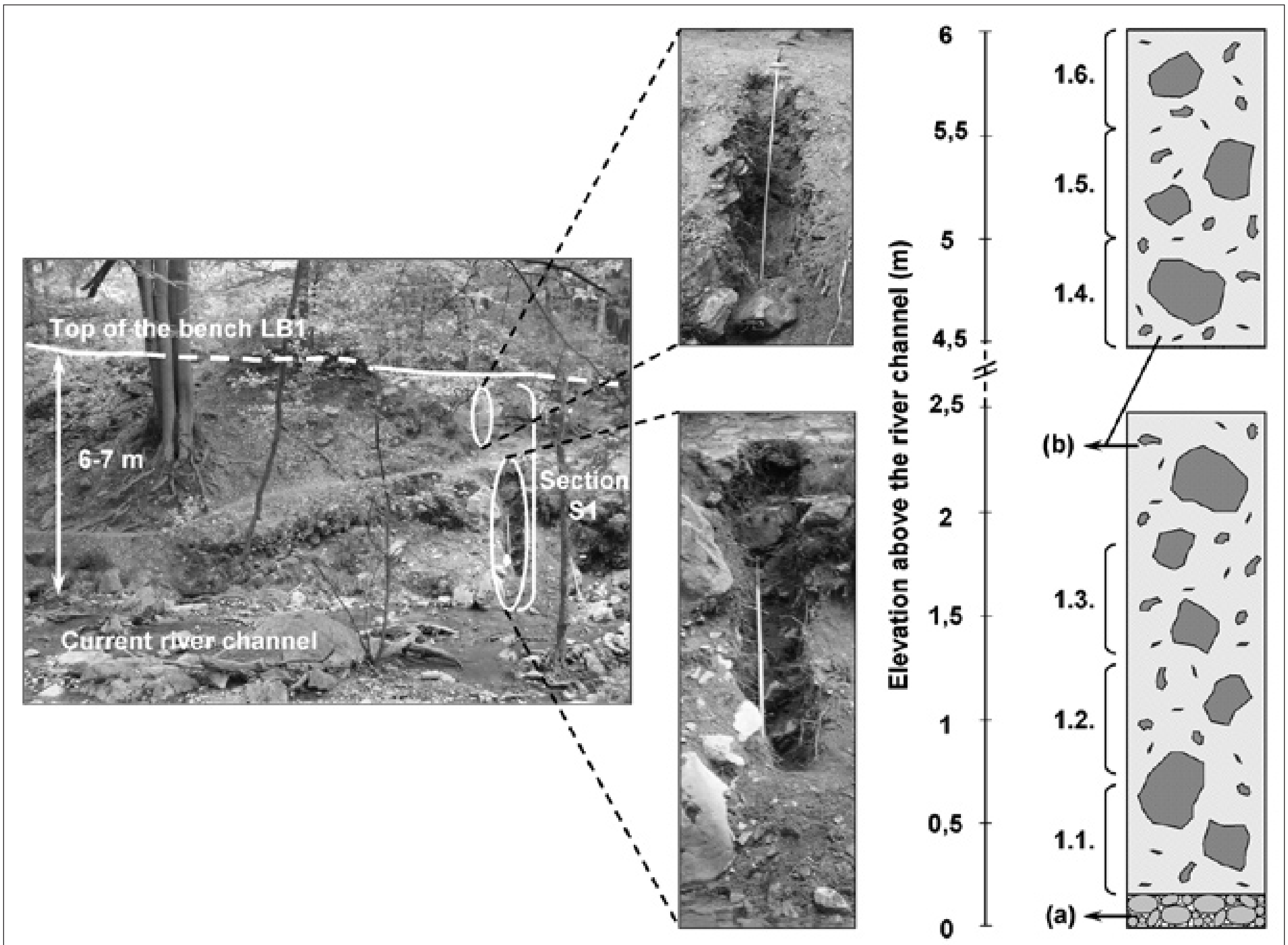


**Figure 6.** General and detailed view of the section S1 in the bench LB1. Granulometric description of the LB1 bench deposit. (a) : current river bedload ; (b) : pluridecimetric quartzitic blocks and clasts (< 10 cm) embedded in a fine matrix (clay, silt & sand) with subsidiary slate clasts (<3-4 cm). The approximate proportion of fine matrix/blocks and clasts is 35-40%/60-65%. 1.1. to 1.6. : samples locations for the search of heavy volcanic minerals (tephras).

several metres (from 2-3 m up to 6-7 m) can be assessed in these benches.

### *4.3. Volcanic heavy minerals (tephras)*

Five sections (S1, S2, S3, S5 and S6) are respectively located in the following benches: LB1 (Fig. 6), RB2, RB3, LB2 and RB6 while the last one (S4) was realized in another local deposit situated between 1 and 2 m above the current river channel (Fig. 3). Most of the bench deposits observed in the lower Ninglinspo, except those from S5 (LB2) and S6 (RB6) which are essentially composed of slaty fine gravel, have a very heterogeneous granulometric composition. They are indeed characterized by quartzitic blocks of decimetric and metric size included within a fine matrix composed of sand, silt and clay elements with subsidiary slate clasts of small dimensions (Fig. 6).

Brown amphiboles were found in samples from all sections, except in S5 where no volcanic mineral was found (Table 1). The sections S1, S2, S4 and S6 showed the presence of clinopyroxenes. Since brown amphiboles and clinopyroxenes are present both in the early Weichselian Rocourt Tephra and in the Allerød Laacher See Tephra, it is not possible to allocate those minerals to a precise tephra. Nevertheless, enstatites characteristic of the Rocourt Tephra were found in the basal deposits of the benches LB1 and RB2 (Table 1) and also in two samples from S6 (bench RB6). Finally, both samples of S4 and three samples from S6 showed the presence of titanite (sphenes) characteristic of the Laacher See tephra.

## 5. Discussion

### *5.1. Geomorphological processes*

The heterogeneous granulometric composition (quartzitic block embedded in a fine matrix) observed in most of the benches is insufficient to determine exactly which kind of slope processes installed them. Nevertheless, three particular morphologic features suggest that most phenomena which have affected this part of the catchment correspond most probably to mud flows. Firstly, the existence of a continuous bench whose length is up to 800 m (LB1) strongly points to this kind of process. When a mud flow reached the valley floor, it actually continued moving in the general flow direction and could fill the thalweg on a considerable distance (Pissart, 1975). Secondly, the presence of quartzitic blocks randomly abandoned on both banks of the lower section of the Ninglinspo where only Lochkovian rocks (conglomerate, shale and sandstone) crop out, indicates that these blocks have been transported longitudinally. As

| | | Identified volcanic minerals | | | |
|---|---|---|---|---|---|
| | **Sample** | **Enstatite** (Rocourt Tephra) | **Clinopyroxene** (Rocourt & Laacher See tephras) | **Brown amphibole** (Rocourt & Laacher See tephras) | **Sphene** (Laacher See tephra) |
| Section 1 (Bench LB1) | 1.1. | - | - | - | - |
| | 1.2. | - | - | - | - |
| | 1.3. | 2 | 1 | 5 | - |
| | 1.4. | - | 3 | - | - |
| | 1.5. | - | 2 | 2 | - |
| | 1.6. | - | 1 | 4 | - |
| Section 2 (Bench RB2) | 2.1. | 2 | 2 | - | - |
| | 2.2. | - | 2 | 1 | - |
| Section 3 (Bench RB3) | 3.1. | - | - | 1 | - |
| | 3.2. | - | - | 3 | - |
| Section 4 | 4.1. | - | - | 21 | 6 |
| | 4.2. | - | 2 | 48 | 6 |
| Section 5 (Bench LB2) | 5.1. | - | - | - | - |
| | 5.2. | - | - | - | - |
| Section 6 (Bench RB6) | 6.1. | - | - | 1 | - |
| | 6.2. | - | 1 | 3 | 1 |
| | 6.3. | 1 | 1 | 5 | 1 |
| | 6.4. | - | - | 1 | - |
| | 6.5. | - | 1 | 8 | - |
| | 6.6. | - | 1 | 3 | - |
| | 6.7. | - | 2 | 4 | - |
| | 6.8. | 1 | 2 | 6 | 1 |

**Table 1.** Volcanic minerals (tephra) spectra in the sampled sections.

the blocks are located above the present-day river channel, fluvial mobilization can be excluded and the most likely explanation of their presence at this place is their transport within mud flows. Thirdly, the local superimposition of the Ninglinspo which directly flows on the slate bedrock and cuts it in several places constitutes the last argument in favor of this kind of processes (Fig. 7A-B). Concerning the deposits analysed in S4, S5 (LB2) and S6 (RB6), their composition are each characterized by a predominance of slaty fine gravel. Given that hillslopes are constituted at this place by lochkovian shales of the Marteau Formation (Fig. 2), these deposits could be the product of solifluction processes which locally affected the hillslope.

### *5.2. Bench morphology and structure*

The bench elevation measurements permitted to localize the possible source area of an important mud flow on the hillslope. At the place of the bench LB1, the left valley side describes a broad concavity at the level of the bench peak elevation. This amphitheatre could have been the starting point of one or several mud flows. This assumption is confirmed by the numerous quartzitic blocks accumulated just down slope of the amphitheatre (Fig. 7C). Moreover, once the mud flow reached the valley floor, it probably divided in two separate branches. One of them moved counterslope while the other followed the channel slope. The upstream branch was logically less important than the other one but both contributed to the filling of the thalweg and, consequently, to the formation of the bench LB1. Finally, the height increase observed in the downstream part of the bench LB1 could be explained by a lithological change. At this place, the Revinian slates (Rv5) are replaced by the Marteau Formation (Fig. 2) and the more resistant Quarreux conglomerate could have determined a narrowing of the valley hindering further development of the bench LB1.

To explain the superposed disposition of benches RB2 and RB3 (Figs 3 & 4), two distinct mud flows are at least required. After a first flow had created the bench RB2, the river evacuated the fine fraction (clay, silt and sand) of the materials left by the mud flow. Moreover, while incising the deposits, the Ninglinspo could also erode laterally the deposits in such a way that its channel width increased progressively at the expense of the width of the bench RB2. Afterwards, a second flow, less important, could fill the riverbed and formed the bench RB3. If we can consider that the first mud flow which left the deposits of the bench RB2 came from upstream, either from the erosion amphitheatre previously identified (Figs 3 & 7C) or from an undetermined place, the second flow which constituted the bench RB3 could have a local origin. The appearance of the latter in the topography corresponds precisely to the height increase in the downstream part of the bench RB2 (Fig. 4). Thus, admitting that the second flow came locally from the right valley side, it probably superimposed some materials upon the preexisting deposits of the bench RB2 but also created the bench RB3. This assumption tends to be confirmed by the resistivity tomography RT2. The superficial materials covering the right valley side and those constituting the bench RB2 actually show extremely high resistivity values which are almost similar, suggesting that they might be mud flow deposits in both cases (Fig. 5).

### *5.3. Age of the deposits and periglacial denudation rate during the Last Glacial*

The presence of volcanic heavy minerals allowed us to date some parts of the host material located in the lower Ninglinspo valley. The enstatites from the Rocourt tephra found in the basal parts of the benches LB1 and RB2 indicate that these deposits were accumulated sometime during the last glaciation (Weichsel). Despite the presence of these minerals in the lower part of both benches, it is however impossible to decide whether the deposits were left by a single mud flow. The brown amphiboles identified in S3 (bench RD3) are unfortunately insufficient

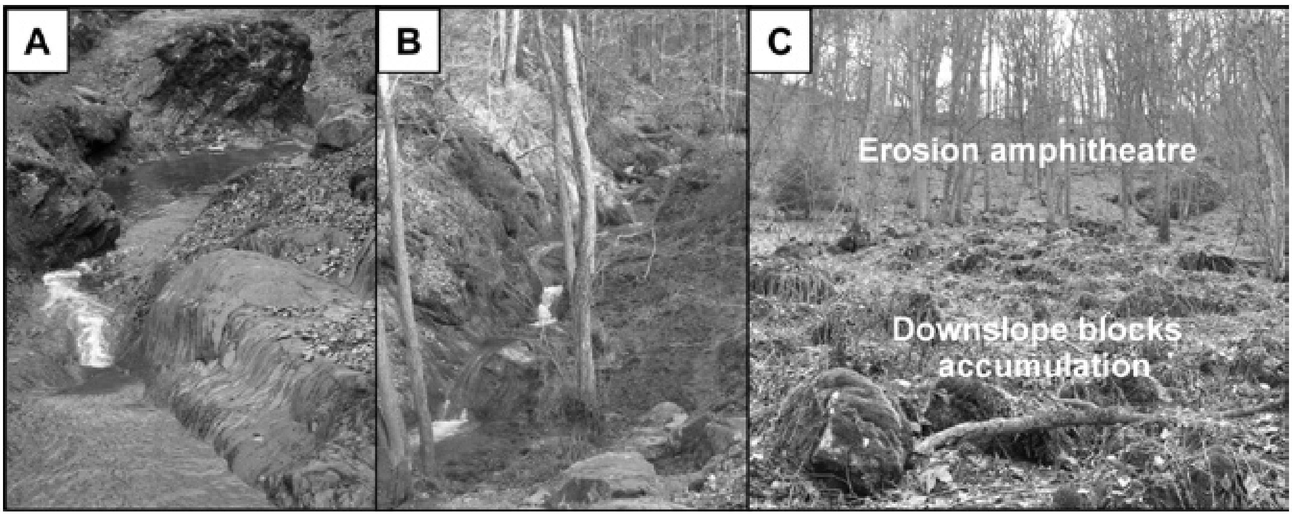


**Figure 7**. A : Revinian slates outcrop in the present-day channel (superimposition) at the place of the resistivity tomography RT1 (downstream view). B : General sight of the superimposed reach. C : Erosion amphitheatre and downslope block accumulation.

to determine from which volcanic fallout they come from. On the other hand, titanites of the Laacher See Tephra that are present in samples from S4 and S6 (bench RB6) allow us to allocate the emplacement of the relevant host sediments very likely to the Younger Dryas, maybe to the Holocene.

Periglacial processes which affected the Ninglinspo valley can also be correlated, in a broader context, with the Pleistocene evolution of the lower Amblève. Thanks to fauna remains and paleomagnetism dating in the Belle-Roche site (Cordy *et al.*, 1993; Juvigné *et al.*, 2005), it has been proved that the post-Main Terrace incision in the lower Amblève occurred clearly before the last glaciation (middle or even lower Pleistocene). Moreover, Bustamante Santa Cruz (1974) and Juvigné (1979) found minerals of the Rocourt tephra in a very low terrace situated ~1 m above the present-day floodplain in the Coo meander, near Trois-Ponts (Fig. 1). However, this tephra was absent in a terrace of ~6 m relative elevation located near Remouchamps (Fig. 1). Consequently, Juvigné (1979) considered this terrace older than the Rocourt tephra and concluded that the recent incision of the Amblève in the reach between Coo and Aywaille was in the range 1-6 m since 74-90 ka. Taking thus into account the timing of the incision in the lower Amblève, it is very likely that the main incision phases in the Ninglinspo valley also occurred before the last glaciation. Since the start of mud flows took place on steep hillslopes (at least for two of them) inherited from pre-weichselian incision, mud flows could have occurred during former cold periods as well (e.g. Saalian glaciation). During the Weichselian itself, it is however very complicated to allocate the start of a mud flow to a specific cold stage (i.e. MIS 4 or 2) due to the lack of resolution of tephrochronology.

Thanks to the bench elevation measurements and the resistivity tomographies, the thickness of the bench deposits can be assessed and we compute a corresponding volume of ~ $4*10^5$ $m^3$. Considering that most of these deposits were accumulated during the last glaciation (as proved by the presence of the Rocourt tephra in the basal part of LB1 and RB2), and referring to a ~10 $km^2$ for the Ninglinspo catchment, they represent hillslope denudation rates ranging from 0,45 to 2 mm/ka, depending on the assumption that they were accumulated either over the whole last glacial or mainly since the LGM (~25 ka) . By contrast, Schaller *et al.* (2001, 2004) calculated average denudation rates of 10-40 mm/kyr from $^{10}$Be concentration measurements in the bedload of middle European modern rivers (catchments from $10^2$ to $10^5$ $km^2$) and mean rates between 25 and 80 mm/kyr for the Meuse basin upstream of Maastricht at different times during the last 1 Ma . Though the modern $^{10}$Be-derived rates are 1,5 to 4 times greater than the corresponding rates derived from measurements of river load (gauging record), the latter are still strongly higher than those estimated from the periglacial deposits of the Ninglinspo. These local rates, which actually represent the rate at which periglacial material accumulated downslope, obviously underestimate the actual denudation rates in the Ninglinspo catchment. In fact, the comparison of the values given above shows that the river removed more than 90% of the material provided by hillslope erosion, whether through mudflows or other processes. Moreover, quartzitic blocks located above the present-day channel in the lower section attest that some mud flows themselves reached the Amblève confluence and directly evacuated the sediments from the Ninglinspo valley.

## 6. Conclusion

The combination of various investigation methods was needed to understand the polygenic origin of the valley floor benches in the lower Ninglinspo valley. The geomorphological analysis localized the starting place of a mud flow on the hillslope and also showed that several events occurred during the Weichsel glaciation. The superposition of the benches RB2 and RB3 as well as RB4 and RB5 constitutes the best evidence thereof while electric tomography was useful to study the internal structure of the bench deposits. Finally, though the search for tephra was not able to definitively highlight the polygenic origin of the bench deposits, it however allowed the dating of some parts of the bench deposits. Moreover, it also contributed to distinguish mud flows which occurred during the Pleniglacial (and probably also during former glaciations) and solifluction processes which seem to be more characteristic of the Younger Dryas in the Ninglinspo catchment. Hillslope denudations rates of 0,45-2 mm/ka were calculated for all or part of the last glacial on the basis of the volume of the present-day bench deposits. These low values demonstrate the minor role played by the storage of periglacial deposits in the valley floor, the present-day benches representing only a few percents of the total volume eroded from the hillslopes. Finally, further investigations (e.g. more accurate geophysical surveying in the bench LB1) are needed to ascertain definitively the polygenic origin of the periglacial deposits of the lower Ninglinspo.

## 7. Acknowledgments

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