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The use of the soil map of Belgium in the assessment of landslide risk

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This paper shows how the use of the soil map of Belgium provides useful information in the assessment of landslide risks. The analysis is based on a report from the Laboratory of Geomorphology and Remote sensing of the University of Liège concerning Mont-de-l'Enclus hill (Province of Hainaut, 20 kilometers north of the city of Tournai). After a landslide in a street of the hill, the regional administration ordered, in 1998, a detailed study of the hillside (7 square kilometres). The report is in three parts. The first one analyses the influence of human settlement on the landslide hazards. The second one studies all the environmental components in relation to the landslides. Finally, a synthesis map gathers the most important conclusions drawn from the first two parts. The Belgian soil map is very useful when combined with geological and geomorphological data. This is called geo-morpho-pedologic approach. Analysis and comparison have been made with the geographical information system Arc/Info-Arcview. The landslide of the "rue du Renard" is located at the interface between discontinuous layers of clay (5 to 15 meters) and sand. Geology gives us a global evaluation of the layer of clay responsible for the landslide. Geomorphology increases the accuracy of location for the clay layer through several elements of the landscape such as superficial landslides, water seepage, concavities and convexities. Pedology matches up previous information through different kinds of data such as texture, "natural soil drainage", soil profile and derived series. The geo-morpho-pedological approach is not always effective in foreseeing a landslide phenomenon such as in the case studied. The report from the Laboratoire de Géomorphologie et Télédétection (remote sensing) indicates, however, that the methodology gave better results than the geotechnical approach in this particular case, and it was also less expensive. The geotechnical approach had either not worked, or was too difficult to use because of the geological conditions (lateral variation of clay facies, absence of outcrops).
Keywords. Landslide, pedology, Geographical Information System, natural hazards, soil map, Mont-de-l'Enclus, Belgium.

Utilisation de la carte des sols de Belgique dans l'évaluation du risque de glissement de terrain. Cet article montre que la carte des sols de Belgique apporte des informations pertinentes dans la problématique d'une cartographie des risques de glissement de terrain. L'analyse est basée sur un rapport, réalisé en 1998 par le Laboratoire de Géomorphologie et Télédétection de l'Université de Liège, concernant la colline du Mont-de-l'Enclus (Province du Hainaut, à 20 kilomètres au nord de Tournai). Suite à un glissement de terrain, l'administration régionale a commandé une étude détaillée de l'ensemble du massif afin de pouvoir continuer à délivrer des permis de bâtir en connaissance de cause. La zone étudiée couvre une surface d'environ sept kilomètres carrés. L'étude du Laboratoire de Géomorphologie et Télédétection comporte trois parties : l'influence de l'Homme sur le milieu et les conséquences possibles sur les glissements ; les éléments naturels à la source des dangers de glissement et, finalement, la synthèse des données, sous la forme d'une carte, basée sur les conclusions des deux premiers points. Il ressort de l'étude du milieu naturel du massif enclusien que la carte des sols de Belgique gagne en intérêt lorsqu'elle est combinée avec des informations géologiques et géomorphologiques. C'est ce que nous appelons l'approche géo-morpho-pédologique. L'analyse et la comparaison ont été effectuées à l'aide du système d'information géographique Arc/Info-Arcview. Le glissement de terrain étudié s'est produit à l'interface entre une couche d'argile d'épaisseur variable (5 à 15 mètres) et des sables. La géologie offre une vision d'ensemble du système mais localise de manière imprécise la position de la couche d'argile responsable du glissement. La géomorphologie affine la localisation au travers de divers éléments traduisant la présence de cette roche meuble (glissements superficiels, suintements d'eau, concavités et convexités). La pédologie recoupe les informations précédentes au travers des données relatives à la texture,

au “drainage naturel des sols”, au profil et aux séries dérivées. L’approche géo-morpho-pédologique n’est pas, à priori, conçue pour prévenir des phénomènes de glissements de terrain tel que celui étudié. Le rapport du Laboratoire de Géomorphologie et Télédétection montre cependant que cette manière d’aborder un problème très complexe est la plus adaptée et la moins chère lorsque l’approche géotechnique est inopérante ou trop onéreuse pour devenir opérante du fait de conditions géologiques difficiles (variations latérales de faciès des argiles, absence d’affleurements).
Mots-clés. Glissement de terrain, pédologie, Système d’Informatique Géographique, risques naturels, carte des sols, Mont-de-l’Enclus, Belgique.

1. INTRODUCTION

During the winter of 1993–1994, following exceptional rains with a return period of slightly less than 50 years, a landslide damaged many houses placed on a hill in the district of “Mont-de-l'Enclus” (“rue du Renard”). This event happened on a slope of about eight degrees, at the interface of impermeable clay and sands deposits. The “Institut National Interuniversitaire des Silicates et Matériaux” (INISMa) studied and stabilised one part of the landslide by pumping. By taking many drilling samples it was possible to understand some of the geological complexities and the dynamic flow of the underground water. However, many samples and the stability studies carried out in laboratory did not explain the precise mechanism of the phenomenon. Indeed, according to the models, the slope would not have moved and this is obviously not the case. Due to this result and in order to continue to deliver authorisation to build houses on the hill safely, the Walloon Region ordered the “Laboratoire de Géomorphologie et Télédétection” (LGT) of the “Université de Liège” to report on the physical and geotechnical constraints of the “Mont-de-l'Enclus” hill (LGT, 1998). In this paper, we present the more significant results obtained in the use of the soil map of Belgium for this particular application.

Photo 1. Rue du Renard. Fractured house — *Rue du Renard. Maison lézardée.*

2. MATERIALAND METHODOLOGY

The Geographical Information System Arc/Info 7.1.3. (Unix) utilises a cartographic database which is useful to produce customised documents for the field study. The analysis has been performed with Arcview 3.0a. Field work consists of the collection of information from the inhabitants, in detailing systematically the likely causes of ground movements or evidence of movements which have already occurred such as fractured houses (**Photo 1**), landslides, changes in the landscape as a response to the surface movements of the soil (**Photo 2**), water logging, the sharp rise of the ground due to local geology …

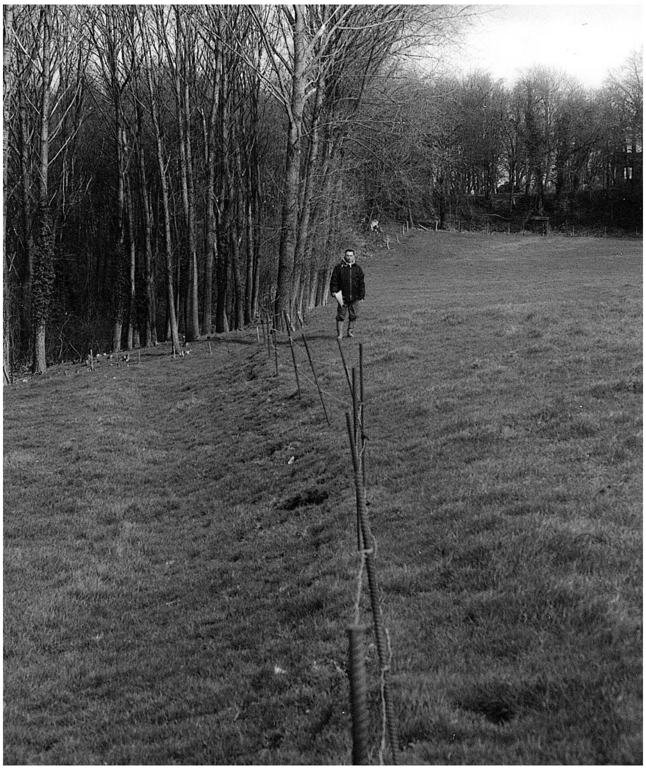

Photo 2. Environmental behaviour to the superficial movement of the soil — *Réponse de la végétation au fluage des couches superficielles du sol.*

3. ANALYSIS OF THE STUDYAREA

3.1. Topography

The "Mont-de-l'Enclus" hill (**Figure 1**) is located in the "Collines flamandes" country, on the right bank of the Scheldt river, which is a few kilometers away and flows at an altitude of about 20 m above sea level. The top of the hill is also approximately 140 meters above sea level. The erosion factors give an undulating look to the hillside. The steep slopes (greater than 20 degrees) near the top diminish progressively to become only several degrees at the base of the massif.

3.2. Geological formation

Sequence of deposits. Two lithological sets of subhorizontal deposits make up the hill. The Kortrijk Formation is situated from the base to the middle. It is constituted of clay of Mont-Héribu (10 m), Saint-Maur (27 m), Saint-Moen (45 m) and of Aalbeke (5 to 15 m). The Aalbeke clay was responsible for the landslide. The top of this deposits is found approximately between 60 m to 80 m. The Formations of Tielt (20 to 30 m), Gent (30 m), Lede (5 m) and Maldegem (2 to 3 m) occupy the top. The mica and clay sands that make up the Tielt Formation alternating with layers of clay, also contain many sandstone outcrops. At the top of the massif, the layers are essentially sand, but the clay layers are never totally absent. There exist many hard layers of sandstone particularly in the Formation of Lede.

Cartography of the Aalbeke clay. The solution to the problem posed by the Walloon regional authorities is exclusively connected to the precise identification of the upper limit of the Aalbeke clay. It is the place where water can be trapped and destabilises the side of the hill. The geological map called "Kortrijk 29", at the scale of 1/50 000, gives the geological limits to a generalised topographic background from contour data of the basic map at the 1/25 000 scale. Due to over-simplification however, the top of the Aalbeke clay layer does not appear at the correct altitude. Among the documents furnished with the geological map, a transparency gives the contours for the base of the Aalbeke clay. The contours at 60 m and 70 m make it easy to draw, on a 1/10 000 scale map, the intersection between the base of the Aalbeke deposits and the topography (**Figure 2**). An arbitrary thickness of ten meters is given to the layer and a buffer of five meters defines an area of imprecision on either side. The limit of the top of the layer of Albeeke clay is located with a very high probability within these three areas although the exact position is not precisely known. The analysis of the data obtained from the drilling carried out by INISMa indicates that the contact between layers is complex. This complexity is not the result of landslides but of irregularities of the formations themselves. The variation of the thickness is probably the result of a complex sedimentation. Another important element is that the top of the layer of Aalbeke clay lies at 73 m in the N-E of "Orroir" and at 76 m in "Horlitin". These altitudes show the inclination towards the north and the west. This fact can be useful to explain the high wet areas of the natural drainage map derived from the soil map of Belgium. In order to validate and/or increase the accuracy in drawing the top of the clay, we compared the geological data with the information from the geomorphology and pedology of the area.

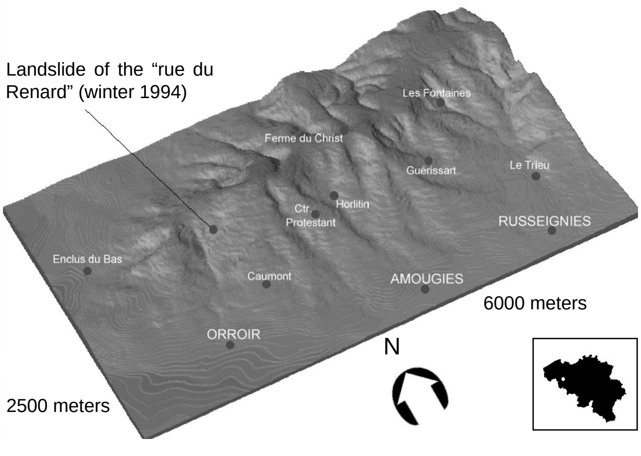

Figure 1. Tridimensional model of the Mont-de-l'Enclus hill — *Modèle tridimensionnel de la colline de Mont-de-L'Enclus*.

4. COMPARISON WITH GEOMORPHOLOGY

4.1. Seepage and springs in relation to the Aalbeke clay

Seepage and springs are revealed on the ground as well as in the old and more recent maps. The research done by INISMa shows that the clay levels (Formation of Tielt) above the Aalbeke clay might also contain reservoirs of water. The comparisons show that the large majority of springs can be found near the top of the clay. It is more often only seepage which appears inside or below it. In some places and notably close to "Guérissart", it appears there are two levels of springs. Unfortunately, with the absence of any indication as to the flow from the springs during the year, it is not possible to estimate their importance and to draw conclusions.

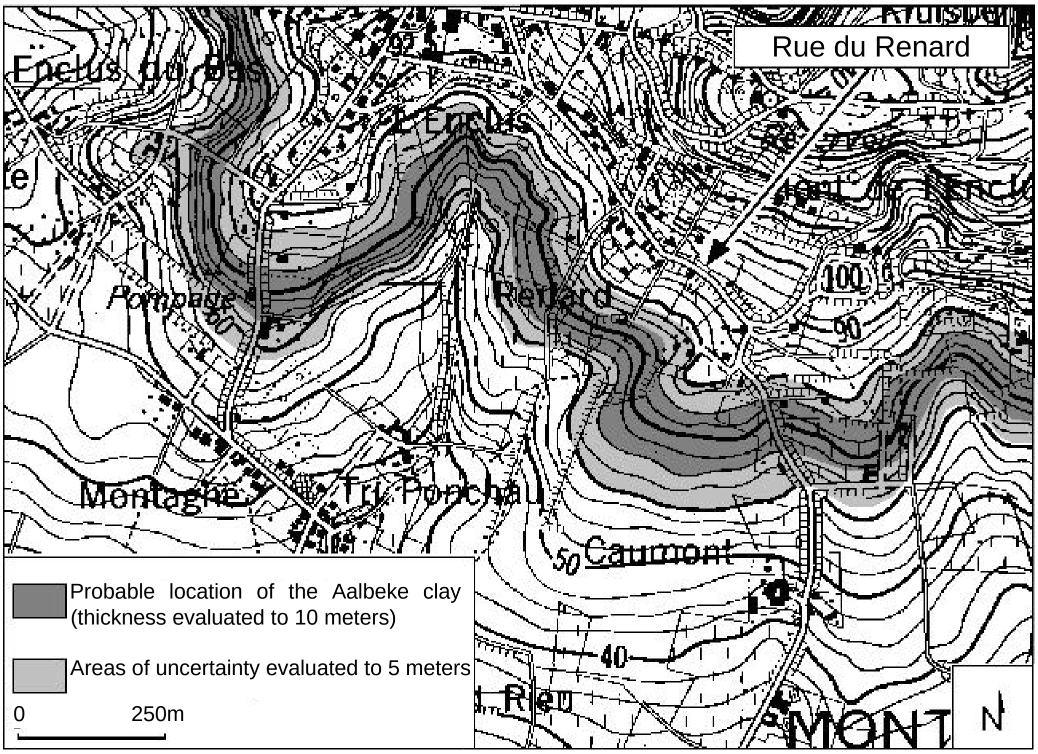

Figure 2. Theoretical location of the Aalbeke clay from geology — *Localisation théorique de l'argile d'Aalbeke par la géologie*.

4.2. Relief variations in relation to the Aalbeke clay

Indications of stability or instability were collected on the ground by analysing the local landscape such as traces of old landslides, steep slopes and flat areas due to the geological structure and morphological evidence of the stability of the slopes. The geomorphological mapping has shown the existence of two types of superficial landslide but does not explain the landslide. The Aalbeke clay can be observed in the landscape as a steep slope. The signs of the geomorphological evidence are located inside the limits of the Aalbeke clay defined by the geological map.

5. COMPARISON WITH THE PEDOLOGICAL DATA

The mapping of the soils of Belgium began in 1947. Its objective was to survey the many different types of soil. The local planning maps (1/5000) were used to report the information of two drillings to a depth of 125 cm per hectare. In order to cover the whole country, it was necessary to produce 450 different sheets of which 370 were published. The area of “Mont-de-l'Enclus” is located in the part that has not been published. Photocopies of the local planning maps were acquired from the Ghent Geology Institute. They have been scanned, grid referenced and then digitalized before being superimposed on other data.

In the legend adopted, the soil series are the fundamental units. There are major series and derived series. The major series are distinguished by three or four characteristics. We worked with the relevant information of the bed rock, the state of the natural drainage and the profile development. The derived series occur when a different lithological substratum appears within 40 to 80 cm depth of the surface layer.

5.1. Soil texture

The “Mont-de-l'Enclus” massif is covered by a sandy material. The summit is covered by light sandy and sandy silty soils. These last deposits correspond relatively well with the distribution of Diest and Maldegem Formations on the geological map. The same sequence of clay deposits occurs in the west and the east of the study area. In those places, where steep slopes are specifically associated with the Aalbeke clay (**Figure 3**), it is possible to observe the larger extent of superficial landslides. The silts lie in the flat areas of the central and eastern part of the hill.

5.2. The natural drainage of the soil

The natural drainage of the soil can be defined in different classes based upon gleyification and the depth at which it occurs. The degree of intensity depends on the absence or presence of reduced horizons which make it possible to distinguish many different categories. The sheet for “Mont-de-l'Enclus”

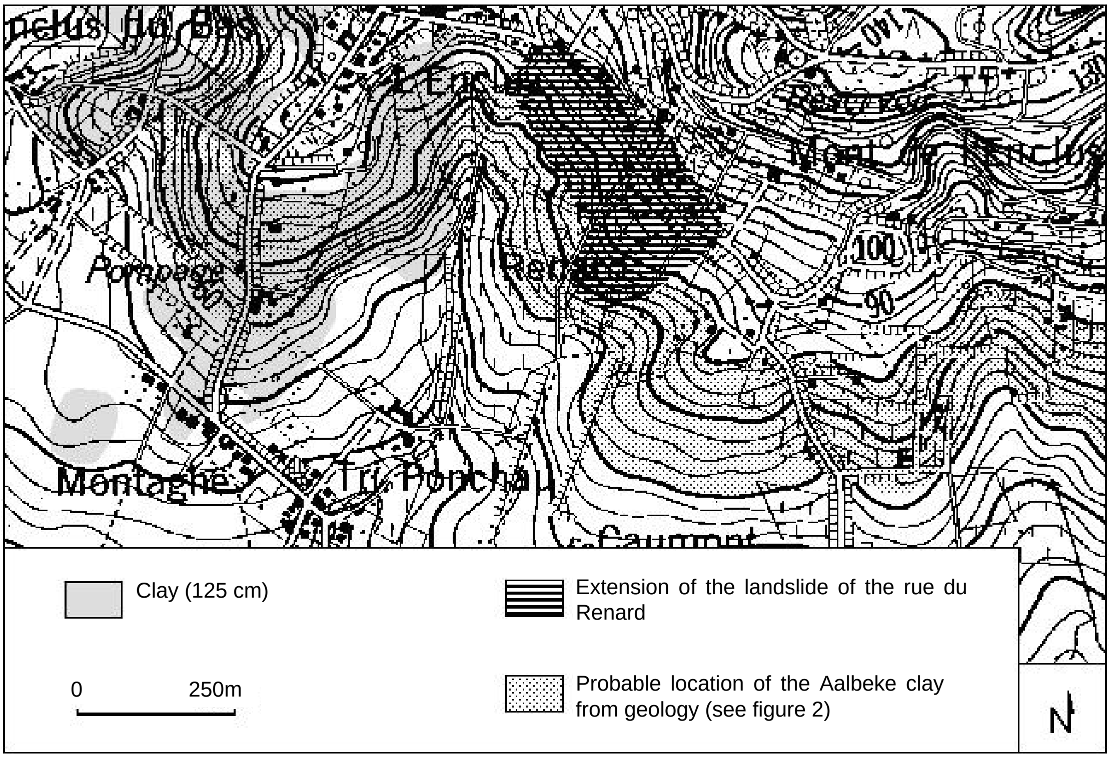

Figure 3. Location of clay from the texture data of the pedologic map at the scale 1/5000 according to the soil map of Belgium —*Essai de localisation de l'argile superficielle à partir des données de la texture d'après la carte des sols de Belgique levée au 1/5000*.

presents classes B ("excessive" to "favourable"), b ("favourable"), c ("moderated"), D ("moderated" to "imperfect"), d ("imperfect"), h ("temporary water table") and e ("permanent water table"). Most of the areas of types "D" to "e" appear between 60 and 80 m. This confirms the geological data concerning the location of the Aalbeke clay. It also shows the places where lenticular clay deposits exist above the Aalbeke clay layer. The greater number of "d" and "h" surfaces occur more in the west than in other parts (**Figure 4**). This is related to the preponderance of clay materials and the gentle westward slope of the Aalbeke clay deposits. In a lower part of the "rue du Renard", there exists a large surface of "h". It is quite interesting to note that the inhabitants of the old neighbouring houses say that the wells never dry up. Furthermore, a person who has been living there for the last 63 years did not connect to the local water supply because of the abundance of underground water. The permanent water table "e" appears twice below the 60 m level. The temporary water table "h" figures in three areas. One, in the extreme west, corresponds to a valley situated below a very unstable area. A house, during the last century, has been known to have shifted over a hundred meters! The second is situated below the "rue du Renard". The third is in the eastern part of the study area, below the 60 m level. The zones with slight or moderate gleyification "c", "d" and "D" are found mainly in the west and east. The natural drainage moderate "c", favourable "b" or excessive "B" take up the center part and the summit of the hill. This factor is indirect evidence for the relative stability. The difference between the centers and the east and west parts could be explained by the lateral variation of the facies.

5.3. Soil profile

The top layer is influenced by climatic, biological and topographical conditions that have changed through the course of time. They have given rise to the soils which comprise more or less the different distinct horizons, recognised by texture, structure and colour and by other morphological characteristics. The soils have been classified into two categories: those with or without profile development (**Figure 5**). The presence of a profile development might be considered as an evidence of a relative stability to a depth of 125 cm. The elements within the soil have moved over time and have constituted the different horizons. From the landslide point of view, it means that there are no superficial movements. These are found on the pediments and on the flat parts of the top. The soils without profile are alluvium, slope deposits or soils with unidentified profile or superficial landslides. The two first ones are easy to detect due to the position in the landscape. The two last ones imply field study. There is a spatial correlation between the movements observed, the areas of seepage and springs, and the areas without profile development. These data are particularly adapted for identifying where an anchorage is necessary using special engineering

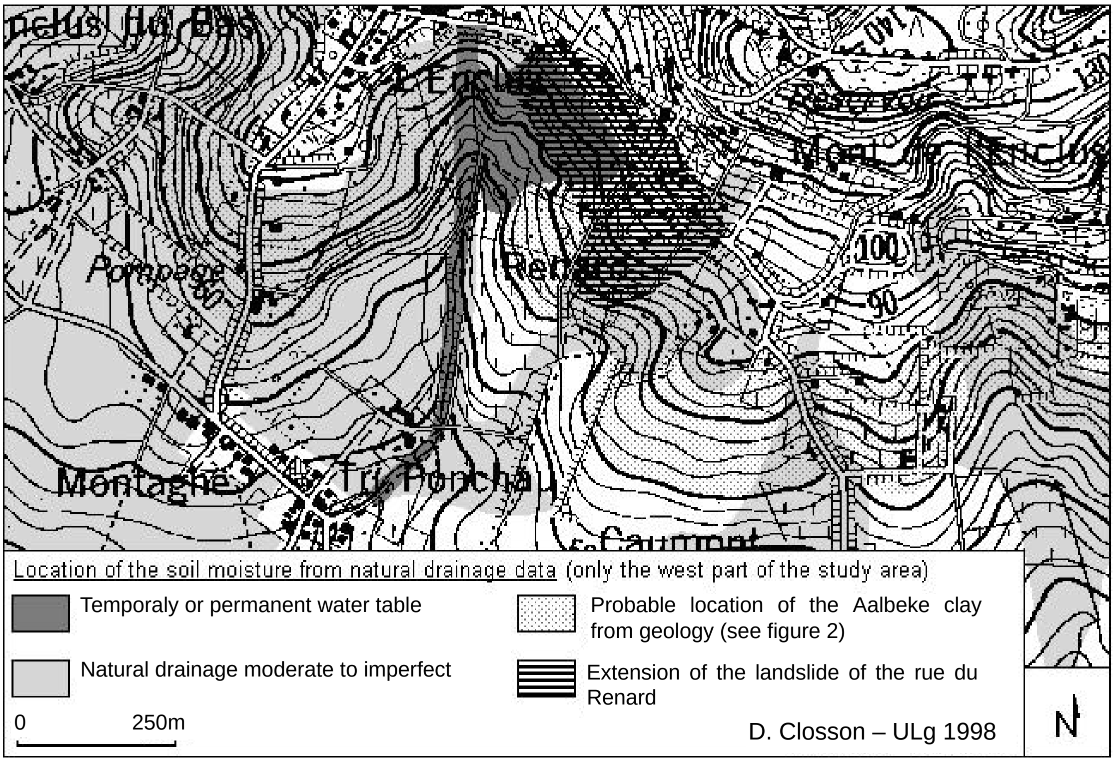

Figure 4. Location of humid areas of a given “natural drainage” data according to the soil map of Belgium at the scale 1/5000 — *Localisation des zones humides à partir des données du “drainage naturel”, d’après la carte des sols de Belgique levée au 1/5000*.

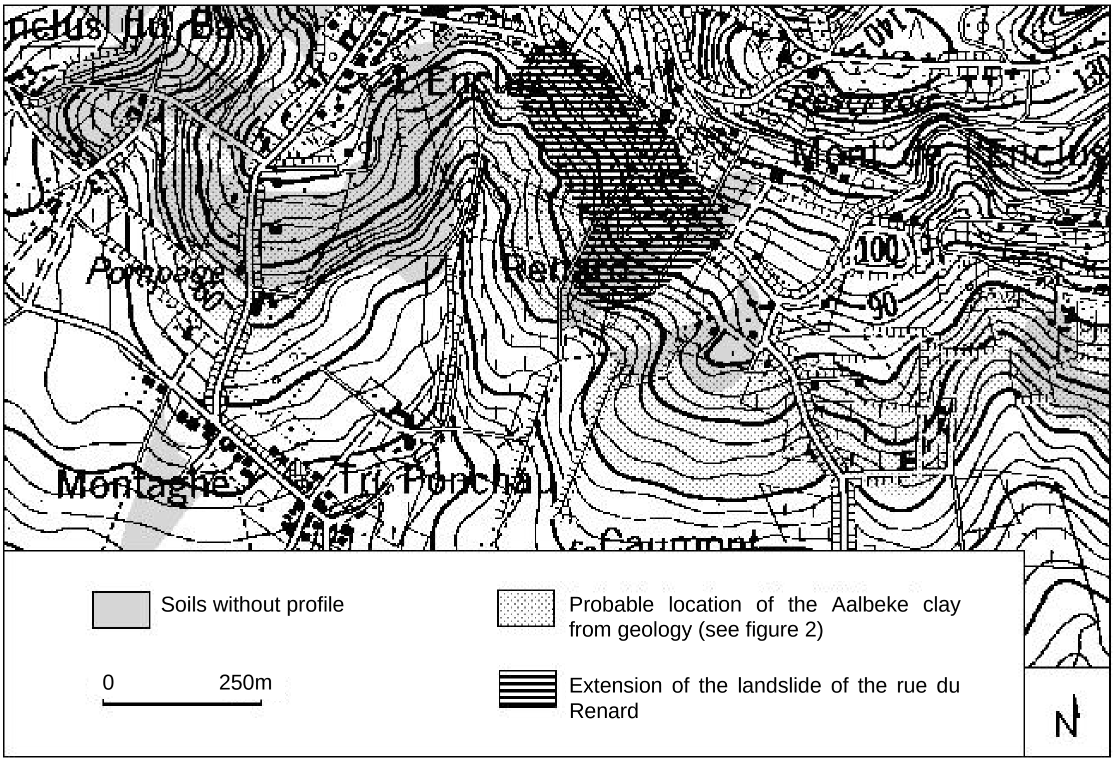

Figure 5. Location of soils without profile development according to the soil map of Belgium at the scale 1/5000 — *Localisation des zones sans développement de profil, d’après la carte des sols de Belgique levée au 1/5000*.

techniques in the soil. It is notable that the landslide of the “rue du Renard” does not fit the correlation observed everywhere else. In this case it is a unique phenomenon.

5.4. The derived series

The derived series are related to the major series but with the difference that another substratum appears between 40 to 80 cm. This information may help to clarify the exact distribution of clay through the first 125 cm of the soil. Indeed, the texture map shows discontinuous patches of clay and if combined with derived series, the clay layer appears continuous in the east and west parts (**figure 6**), except in the valley floor. The presence of a variation of material at a depth of 80 cm on the slopes can be explained by the slow movement of the topsoil. This barely visible phenomenon due to the extreme slowness is however confirmed by several inhabitants, notably the farmers who cultivate these parts of “Mont-de-l'Enclus” hill.

5.5. Synthesis of evidence from soil maps

Taking into account the detailed information of the soil map, the means whereby this work was carried out and the subjectivity of its authors, great care is needed to interpret the information. However, the spatial correlation between the soil movements and the pedological data is remarkable. **Table 1** is an attempt to extract the most significant factors in the problems of landslides .

6. CONCLUSION

The cause of a landslide is the result of an interaction between a degree of slope, lithographic and hydrogeologic factors. The geophysical approach is aware of the danger of giving a degree of security for the ratio between the forces which cause the slide and forces of stability. The geo-morpho-pedological approach combines three disciplines which throw a different light on the same subject. It allows for the definition of potentially dangerous marginal areas in most cases. In the current state of knowledge, geo-morpho-pedological and geophysical sciences could not identify beforehand the landslide of the “rue du Renard”. Only the pedological data in this case, notably the data concerning the natural drainage, would have warned of the potential danger in the west of the studied zone. The geo-morpho-pedological approach would not have been useful to delineate the areas exposed to landslide risk such as the “rue du Renard” because the main elements and interactions at the origin of the phenomenon are located deep inside the hill. The information is essentially indicating the probable location of the Aalbeke clay as well as likely areas suitable for classical geophysical prospecting. Practically, the Walloon regional administration has adopted the conclusions of the study asked to the

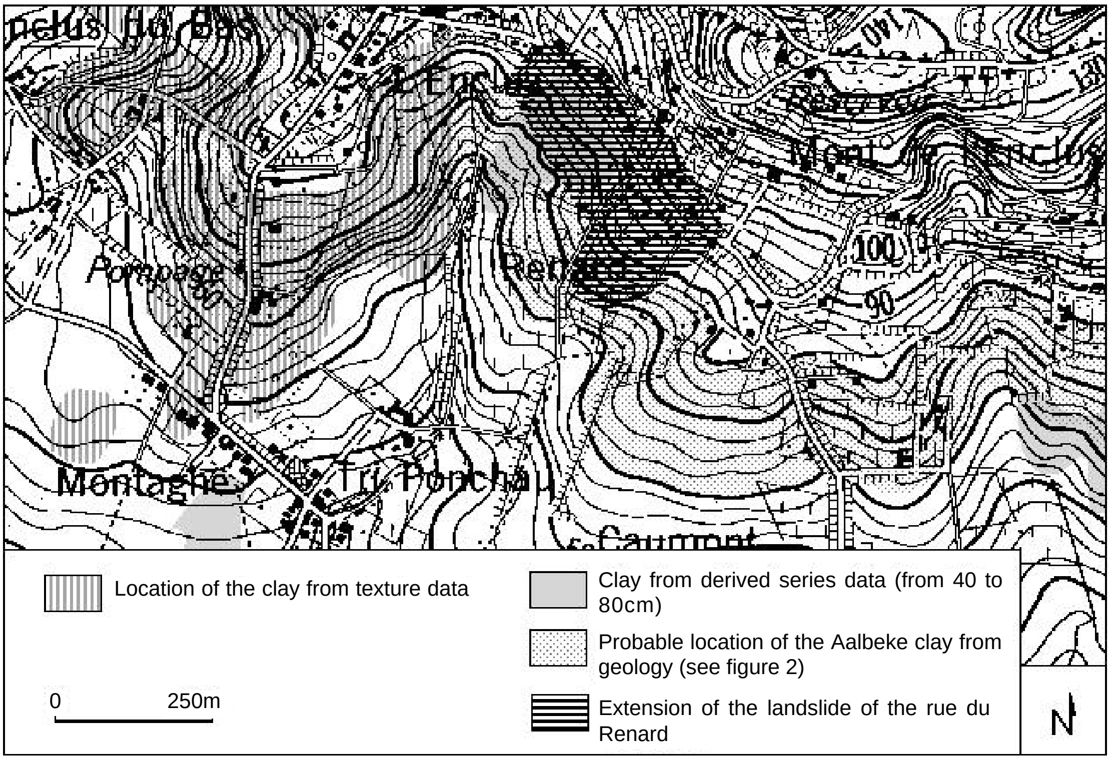

Figure 6. Location of the underlying clay in the pedological profile from derived series data according to the soil map of Belgium at the scale 1/5000 — *Localisation de l’argile sous-jacente dans le profil pédologique à partir des données des séries dérivées, d’après la carte des sols de Belgique levée au 1/5000*.

Table 1. Contribution of the soil map data to the study of landslide hazards — *Apport des informations pertinentes de la carte des sols dans le cadre de l'étude des glissements de terrain*.

Pedological data	Main information	Interest in landslide risks
Texture soil	Clay	Potential top movement, outcrop of impermeable rocks
Natural drainage	Permanent and temporary water tables	Potential top soil movement, high danger areas if combined with steep slopes
Profile	Developed and non developed such as alluvium, colluvium	Permanent or discontinuous flows
	Areas with no profile	Potential unstable areas
Derived series	Clay below 80 cm depth	top soil movements

"Laboratoire de Géomorphologie et Télédétection". The synthesis map concluding the report delineates red areas where it will be impossible to build new houses. Areas with a potential danger, where a geophysical study must be realised are given in orange. Finally, areas without landslide danger are indicated in green colour.

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Institut National Interuniversitaire des Silicates et Matériaux – INISMa. Orroir - rue du Renard. Étude géotechnique du glissement de terrain de 1994. Study ordered by the Land Administration of Mont-de-l'Enclus. Three copies : text (53 pages), appendix and documents.

Laboratoire de géomorphologie et télédétection - LGT (1998). Étude des contraintes physiques et géotechniques du Mont-de-l'Enclus. Study ordered by the Direction Générale de l'Aménagement du Territoire, du Logement et du Patrimoine - DGATLP. One copy : text (87 pages) and two appendices.

Complementary reading

CarraraA. , Cardinali M., Guzzetti F., Reichenbach P. (1996). GIS based techniques for mapping landslide hazard. The content of this document was largely derived from the chapter "GIS technology in mapping landslide hazard" of the volume "Geographical Information Systems in Assessing Natural Hazards", published in 1995 by Academic Publishing, Dordrecht, The Netherlands. http://deis158.deis.unibo.it/gis/chapt0.htm.