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Development of the Hautes-Fagnes peat bogs (Belgium): new perspectives using ground-penetrating radar

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A 800 ha area of drained peatlands in the Hautes-Fagnes (Belgium) was surveyed by means of a ground-penetrating radar and a global positioning system. The survey provided very accurate information about the subsurface relief and the thickness and extent of the peat deposit, as well as stratigraphical information and suggestions of possible links between subsurface, hydrology and present vegetation.

Keywords: ground-penetrating radar, Hautes-Fagnes, raised bogs

INTRODUCTION

The Hautes-Fagnes State nature reserve

The Hautes-Fagnes plateau (eastern Belgium: Fig. 1), culminating at 694 m a.s.l., has a relatively cool and humid climate conducive to the development of peatlands. The Cambro-Ordovician bedrock (mainly quartzites and slates) gave rise to an alteration layer rich in clay. During glacial episodes loess accumulated but remains only locally. Peat soils cover 3 750 ha, including about 1 000 ha of raised bogs protected since 1957 in a State nature reserve. A general description of the Belgian peatlands, in particular those of the Hautes-Fagnes plateau, was provided by Frankard et al. (1998). Most of these bogs are now strongly disturbed due to drainage, peat cutting and *stiernage* (mowing of the vascular plants and living *Sphagnum* surface, and gathering of the product). The fagne des Deux-Séries bog complex investigated in this study, which was intensively drained 100 years ago, is now mostly covered by monospecific lawns of *Molinia caerulea* (L.) Moench. Small areas of mesotrophic vegetation occur locally.

Objectives of this study

Despite the great ecological interest of these bogs, very little information was available on their genesis and development. A general subsurface survey was therefore useful. Its objectives were the characterisation of the peat deposits (initial topo-

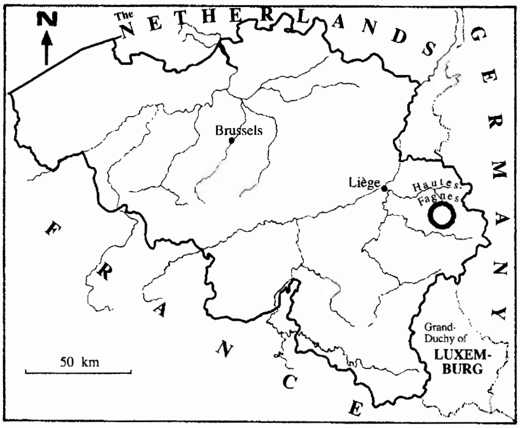

Fig. 1. Location of the study area.

graphical conditions and development stages, extent and thickness, structure of the peat deposits) as well as investigation of subsurface influences on the present vegetation. Preliminary results are explained below.

METHODS

A GPR (ground-penetrating radar) profiling was made along parallel lines 50 m apart, combined with a GPS (global positioning system) survey, covering 120 linear km. Additional borings, water samplings and palynological datings were performed to help interpretation of the data.

Ground-penetrating radar (GPR)

The waves sent by the transmitter antenna are reflected by discontinuities in the soil back to the receiver antenna. The radar waves are sensitive to permittivity contrasts, notably changes in water content related to changes in the hydrophysical properties of the deposit, such as the degree of peat humification, ash content, etc. The clayey silt generally found under the peat acts as a strong reflector, impermeable to the radar signal.

The equipment generates images showing cross-sections of the peat deposit, their main elements being the topographic surface, the subsurface relief (continuously recorded), and local reflectors within the peat.

More information about the GPR technique and its application to peatlands is given by Halleux (1990), Hänninen (1992), Theimer et al. (1994) and Ziekur (1998).

A GPR device (RAMAC GPR, Malå Geoscience, Sweden) with 200 MHz antennas was used. It was carried on a light PVC sledge specially designed to ensure the stability of the antennas over the *Molinia* tussocks.

Global positioning system (GPS)

A GPS with an accuracy of less than 1 dm in x, y and z co-ordinates (4000 SSI, Trimble, USA) was used, not only for the exact topographical positioning of the profiles, but especially in order to add altitude data to the radar profiles.

RESULTS

Initial topographic conditions where peat started to accumulate

The role of lithalsa remnants

Numerous *lithalsa* remnants have been found under the peat. The term lithalsa was proposed by Pissart et al. (1998), following Harris (1993), to designate a permafrost mound lacking a peat cover that forms by segregation ice accumulation in the soil (i.e. by cryosuction without any hydrostatic pressure). The process of its formation is thus the same as for a palsa (permafrost mound with a peat cover). Material eroded from the mound accumulates at its base. Lithalsas formed in the Hautes-Fagnes during the Younger Dryas (ca. 10 100–9 400 BC CAL) (Pissart et al. 1998). Melting of ice at the beginning of the Holocene resulted in circular depressions, about 50 m in diameter, surrounded by a rampart (Fig. 2).

These depressions provided favourable conditions where peat started to accumulate since the Preboreal (ca. 9 400 BC CAL). At the bottom of the deposit, a layer of silt rich in organic matter is sometimes present (solifluxion material from the rampart) and may be easily identified on the ra-

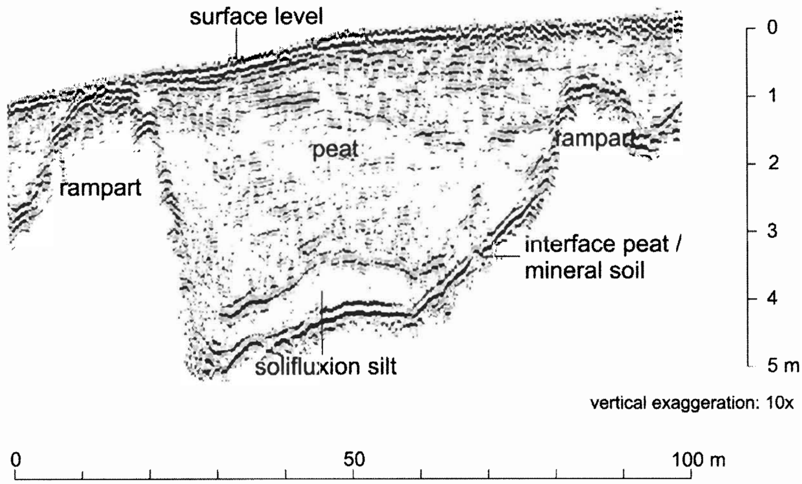

Fig. 2. Vertical section through a lithalsa remnant. The depression was filled in with peat underlain by a solifluxion deposit from the rampart, identified on this radar profile but not present in all instances.

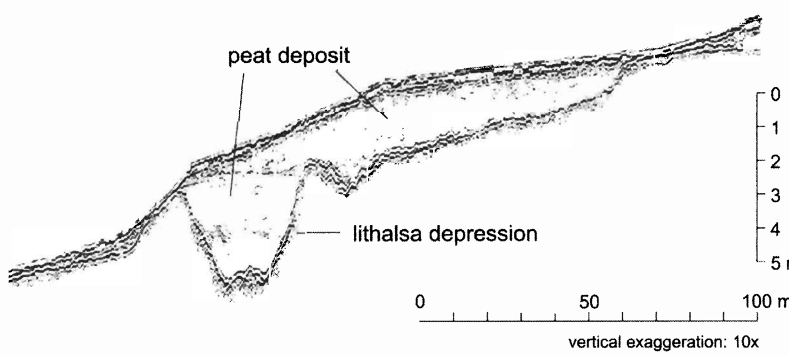

Fig. 3. Filling of a lithalsa depression with a limited lateral extension of the peat beyond it.

dar profiles (Fig. 2).

The importance of the lithalsas in bog formation is illustrated by two cases with different development. In the first case (Fig. 3), peat first filled in the depression, then a small deposit grew out beyond it, but with a limited lateral extent. In the second case (Fig. 4), in an area with densely grouped lithalsa remnants, the peat developed into a raised bog. The deposits outside the depressions did not begin to form before the Atlantic period (ca. 6410 BC CAL).

Distribution of lithalsa remnants

In some places, a limit appears between a subsurface strongly affected by periglacial processes and a flat subsurface relief. Lithalsas need particular hydrological and granulometric conditions to develop; their distribution might thus indicate topographical, lithological and/or hydrological differences in the substratum. These differences may in turn have influenced the processes of bog formation.

Other situations

Peat deposits also occur in areas devoid of lithalsa remnants. Most of them are soligenous or topogenous mires that have evolved into ombrogenous bogs.

Internal structure of the peat deposit

Plane reflectors within the peat deposit indicate an interface between different hydrophysical

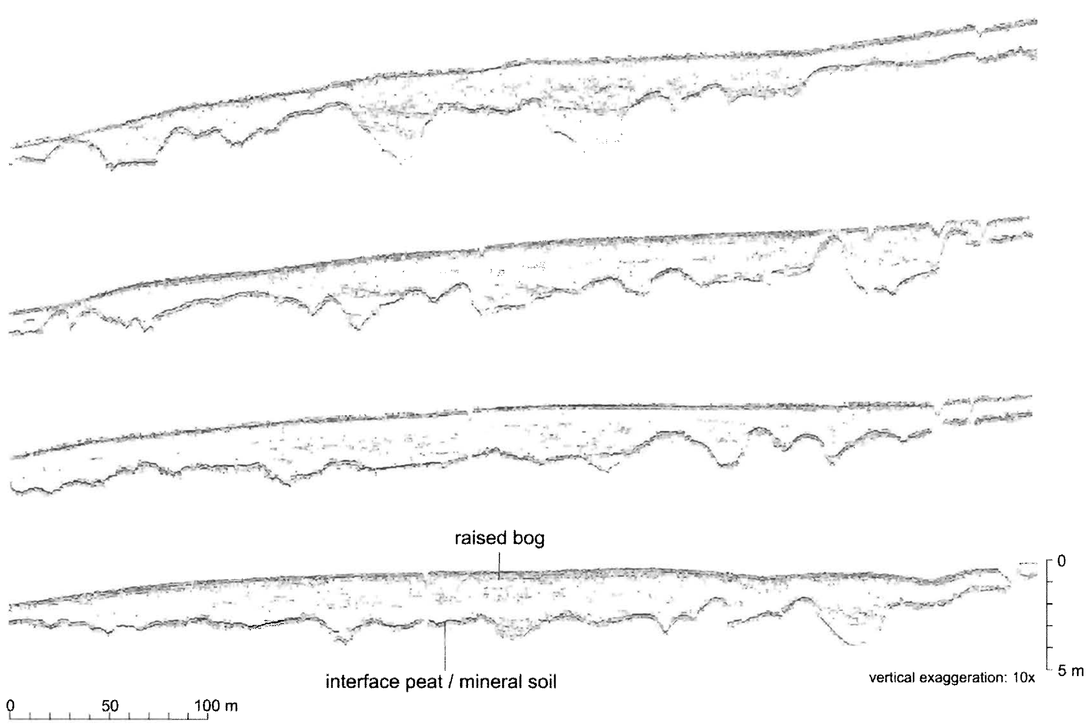

Fig. 4. Subsurface and surface topography in an area of densely grouped lithalsa remnants. The peat formation developed into a raised bog. Successive parallel profiles at 50 m intervals.

properties of the deposit. The most salient features are described below.

Solifluxion material at the bottom of the deposit

As already mentioned, a silty solifluxion layer is sometimes found at the bottom of the lithalsa depressions (Fig. 2). It may also be present at the foot of any slope in the subsurface relief.

Silty layers deposited in lithalsa remnants

In most lithalsa depressions, the peat shows a plane reflector just below the level of the top of the rampart (Fig. 5). This is correlated with an abrupt change in ash content due to silt enrichment. The origin of such events has still to be elucidated. In particular, the dating of these deposits should tell us whether they are all of the same age, which would mean that they result from a climatic event and could thus be considered as a stratigraphical reference.

Alluvial deposit

A plane reflector has also been correlated with an alluvial silt carried in by the ancient flooding of a rivulet (Fig. 6). The GPR allows the mapping of such extended reflectors.

Subsurface influences on present vegetation

Small areas of mesotrophic vegetation also occur in the form of mounds often covered by reed (*Phragmites australis* (Cav.) Steud.). The water there is characterised by a higher pH (up to 7.9) and a higher electrical conductivity (> 150 $\mu S\ cm^{-1}$) than under the oligotrophic vegetation. Most of these mounds are correlated with lithalsas (Fig. 7).

DISCUSSION

The GPR is an appropriate method to measure peat thickness and volume more rapidly and accurately than by manual borings, as already re-

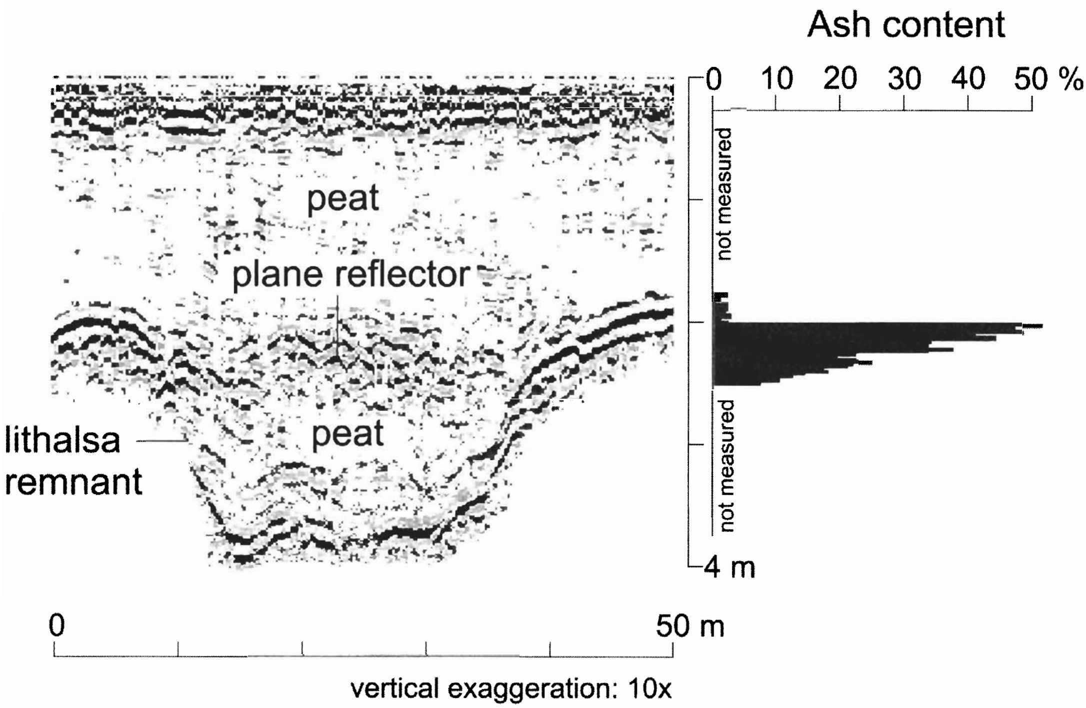

Fig. 5. Plane reflector in the peat deposit in a lithalsa depression. It is correlated with a silty layer of higher ash content.

Fig. 6. Ancient alluvial deposit of a rivulet.

ported by Ulriksen (1980). GPR data are easily processed to draw very accurate maps of the thickness and extent of the deposits. Some peat characteristics may also be assessed aiming at a more effective peat utilization (Tiuri et al. 1983, Hänninen 1992). Our study shows that it can also yield various kinds of information about the genesis, development and structure of the peat deposit, in a mire conservation perspective.

Using accurate topographical data measured with the GPS, a variety of topographic features could be recognized as areas of initial peat formation. Among them, the lithalsa depressions played an important role. Although little direct information may be obtained about the clayey soil, indirect evidence of topographical or lithological differences may be inferred from the uneven distribution of periglacial features.

Different kinds of peat were not identified. The reason is that the peat deposit investigated is rather homogeneous, because the acrotelm has disappeared almost everywhere and the whole profile consists of well decomposed peat (usually H9–10 even in the upper layers). Theoretically it would be possible to distinguish layers with a different degree of humification (Bjelm 1980, Warner et al. 1990), provided that the transition between them is sufficiently sharp (Theimer et al., 1994).

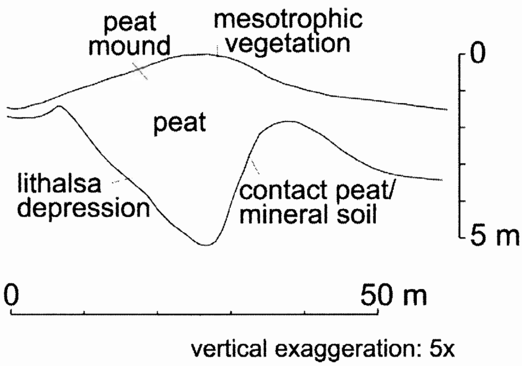

Fig. 7. Sketch of a peat mound covered by mesotrophic vegetation with *Phragmites australis* denoting artesian influence, confirmed by high pH and electrical conductivity of the water. This mound has grown over a lithalsa remnant. The lithalsa might be either the cause or the consequence of this particular hydrological situation.

However in our tests, the reflection of woody peats did not differ from fibrous peats. Most stratigraphical information in our survey is due to abrupt changes in ash content, related either to silty layers or to charcoal levels.

The continuous stratigraphic profiling could not be replaced by data from manual borings with the same level of detail. In that way, this GPR survey provides a very useful base for subsequent research. It greatly helps to identify problems and to locate areas which should then receive more attention by conventional methods. It also reveals stratigraphical features that would not appear from a visual examination of a peat core. It allows valuable correlation between the subsurface and the present vegetation.

The results presented here are preliminary. Further developments will give more attention to the analysis of the reflections and will investigate other types of peat and peatlands.

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