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Landscape human shaping and spatial mobility of agropastoral practices in the Chaîne des Puys during historical times (Massif Central, France)

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ABSTRACT

The Chaîne des Puys is a great collection of extinct volcanoes that cover the Hercynian basement and belongs to the Auvergne Volcanoes Natural Regional Park. Both the sedimentary record and the historical archives of this area are numerous. However, the cores studied hitherto do not offer a good knowledge of the historical dynamics because most of the wetlands have dried out during historical times, causing gaps in the sedimentary record and pollen oxidization. Moreover, all the studied cores are located on the crystalline basement or on an old volcanic one predating the Chaîne des Puys. Thus they do not directly provide information about the volcanoes.

This article presents the only core obtained from a site, a small maar, located on a volcano. The sequence is short but does not have the same sedimentary gaps as the others. Owing to physical (grain size), chemical (C, N, P, K, Ca, Mg, N–NO_3, N–NH_4), palaeoecological (pollen and non-pollen palynomorphs) and historical analyses, this study gives a more precise recording of the landscape changes during the last 500 years in the volcanic area and contributes to the knowledge of the Chaîne des Puys landscape. It illustrates the mobility of the historical landscape, in particular the progression and regression of the forest and the erosive crises related to more intensive grazing activity. The observations are linked with the social and economical changes, especially with the consequences of the French Revolution and the rural depopulation.

This landscape history gives data about the direction of changes to the landscape preservationists. They demonstrate that even if the Chaîne des Puys landscape looks natural, it has been shaped by a very specific socio-economical system inherited from the Middle Ages. These aspects could be integrated in a management plan.

1. Introduction

In Europe, lower mountains are very sensitive to climatic and land use changes. Their landscape history is studied to provide knowledge about the past dynamics and their impact on the environment, in particular the advance and retreat of forestry and agricultural development (Galop, 1998; Gauthier, 2004; Court-Picon, 2007; Jouffroy-Bapicot et al., 2007; Miras et al., 2007; Ejarque et al., 2009; Mazier et al., 2009; Surmely et al., 2009). This history is also studied to evaluate the landscape heritage in terms of changing vegetation, eroded soils, field patterns, etc (Michelin, 1995; Novák et al., 2010).

The article deals with the reconstruction of the cultural landscapes of an emblematic French lower mountain: the Chaîne des Puys. It is an impressive collection of extinct volcanoes that cover the Hercynian basement. The volcanic activity has created characteristic landforms and led to human activities that gave this landscape its own identity. From a national point of view, it is considered as a major heritage site, which explains the opening of the Auvergne Volcanoes Natural Regional Park in 1977. Sometimes, some nature preservationists consider that the landscape must be protected against the human influence in order to come back to a natural and unchanging state. However, the human influence partly explains the present aspect, and it is not possible to preserve or restore a landscape without knowing its history. Thus, the aim of this study is to offer a better knowledge of the landscape history in order to show that the landscape as it is

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perceived today is not really how the landscape looked like many centuries ago.

In this area, the specific geological history has set good conditions for producing natural archives (Boivin et al., 2004). Since the 1980s, a few cores from this area have been studied (using pollen and/or physical-chemical analyses). They were obtained from lava flow meadows, maars or ponds: the Narse d'Ampoix (Beaulieu and Goeury, 1987); the ponds of Fung, Palou (Michelin, 1992) and Vezolle (Michelin et al., 1991; Michelin et al., 2001); the Narse d'Espinasse (Miras et al., 2004) and the maar of Montchâtre (Ballut et al., 2008). All are located on the crystalline basement or between the volcanic and the crystalline basements, except the Narses d'Ampoix and d'Espinasse, which are located on an old volcanic basement predating the Chaîne des Puys. These cores show human occupation of the land since the Neolithic (Beaulieu and Goeury, 1987; Miras et al., 2004) with an important and growing human pressure on the landscape from the end of the Iron Age to the middle of the nineteenth century, characterized by pasture and cereal cultivation and a low level of forest (Miras et al., 2004; Prat, 2006). These cores present clear clues of a reforestation at the end of the Roman period and around the thirteenth and fourteenth centuries that can be explained by the political context of each era (Michelin, 1995; Prat, 2006). However, the more attractive areas could have been occupied intensively and continuously, as observed in the catchment area of Montchatre, which is located on a crystalline substratum, with water resources, good exposure and shelter from westerly winds (Ballut et al., 2008). In these works, two main examples of the human pressure on the landscape have been recorded. Significant erosion is observed in particular on the crystalline basement (Ballut et al., 2008) and most of the wetlands do not exactly record historical times due to sedimentary gaps and pollen oxidization as a result of human management of this resource (Michelin, 1992).

Archaeological data is scarce because of the poor conservation of the remains and a lack of research. Moreover, it concerns principally the Roman period, with an important Roman temple dedicated to Mercury and an associated town, which are located on the highest volcano of the region, the Puy de Dôme (Paillet and Tardy, 2003; Trément et al., 2003). Fortunately, from the fifteenth century onwards, this region is rich in historical archives (court records, contracts, tenancy agreements, old cadastres, old maps - Fournier, 1962; Charbonnier, 1980). During the *ancien régime*, the crystalline plateau and most of the lava flows were cultivated with a rotation of cultivation, pasture and fallow. Due to the increase of manorial, religious and royal taxes, which were paid in grain, farmers were obliged to cultivate more and more fields, even on the steepest slopes. As a consequence, they pastured their animals in the common forests that covered the slopes of the volcanoes, and this practice contributed greatly to the reduction of the forest areas (Michelin, 1995). The grazing increased and became mainly located on the volcanoes, as confirmed by a number of contracts from the sixteenth to the nineteenth century. They give many details concerning the number of animals involved, the grazing management system, and the practices that were forbidden or allowed. In the second half of the eighteenth century, descriptions of erosion events and their economic and social consequences are also recurrent in the archives of the regional government, the "Intendant d'Auvergne" (AD63-4C570, 1781). Some information about the management of several ponds and lakes, which were the property of rich lords, has also been obtained. These were active for some time, used for fish production, regularly emptied and the fish being sold on Clermont-Ferrand market (Aussy, ans II et III). Whilst dry, the ponds were cleaned by the farmers, and the mud they extracted was donated to them in order to manure their gardens (AD63-1H293, 1760). During the nineteenth century, the Napoleonic cadastral maps,1831 and some old postcards present a very open landscape, cultivated around the villages, with grassland and meadows in the wetter areas and heather or poor pastures on the volcanoes and their associated lava flows. Nevertheless, since the middle of the nineteenth century, the forest has extended everywhere, both by plantation and by natural colonization. Initially, the aim was to reduce erosion, and after the Second World War reforestation continued because of rural depopulation. The management of the wetlands has also been abandoned (Michelin, 1988, 1995).

Despite numerous research studies, two main questions related to the landscape history remain. The first concerns the history of the volcanic landscapes which are not directly documented by the sedimentary archives. The second deals with the lack of precise knowledge about the impact of the historical land use on the landscape both on crystalline and volcanic basements. This lack is due to poorer recording of the dynamics in the sedimentary archives, while the present landscape (soil erosion, parcelling up, management of wetlands) is largely a legacy of this period.

Continuing the previous research, this article presents the most recent sedimentary data obtained from the maar of the Puy des Gouttes (Saint-Ours-Les-Roches). This is the only core localized on a volcano. It documents both the volcanic zone and the historic period, and it demonstrates with precision the social and economic evolutions and their environmental impacts on the Chaîne des Puys landscape.

2. Study area

The Chaîne des Puys is a volcanic region of the French Massif Central (Fig. 1) composed of eighty volcanoes that have been extinct since the beginning of the Holocene (the last eruption took place 7788–7419 cal BP, Boivin et al., 2004). The key feature of this area is its large variety of volcanic landforms; strombolian vent craters, domes, belonites and maars associated with basaltic, trachytic and trachyandesintic lava flows that most often present a scoriaceous and chaotic aspect (block lava flows). Several are also covered with a pyroclastic mantle. The volcanoes and their deposits cover the Hercynian basement which is composed of crystalline rocks (metamorphic or plutonic rocks) (Boivin et al., 2004). The main difference between the two basements is the quality of soils: the brown loamy to loamy-sand soils on the crystalline substratum are slightly acid but often more productive than the stony, eroded and thin soils overlying the volcanoes or their lava flows. Today the landscape consists of pastures (grasslands, meadows, heather) and forest (oak, beech, spruce, pine), in particular on the volcanic substratum. The cultivation of cereals has nearly disappeared.

Recently, a core has been obtained from the Puy des Gouttes (1134 m a.s.l). The studied core is not exceptional for quality and length (190 cm long), but it is the only useful sediment core from the top of a volcano obtained for palaeoecological analyses. It has been extracted from a maar (0.15 ha) located inside a strombolian vent crater composed of scoria. More precisely, the maar is in a small depression (0.5 ha) inside the crater surrounded by steep slopes (10–30%). In depth, volcanic material is included in solifluction deposits between scoria and soil (Boivin et al., 2004). Around the volcano (950 m on average), the slopes reach 4–16%, except to the south–east where a relatively level area is called "la plaine". Some basaltic lava flows (west and east) and multiple or undifferentiated basic ash-fall deposits (south-south–east) compose the basement. They are covered by a trachytic mantle.

3. Method

As a first step, investigations focused on the analysis of the natural archives. The core from the Puy des Gouttes (PG1) was extracted in

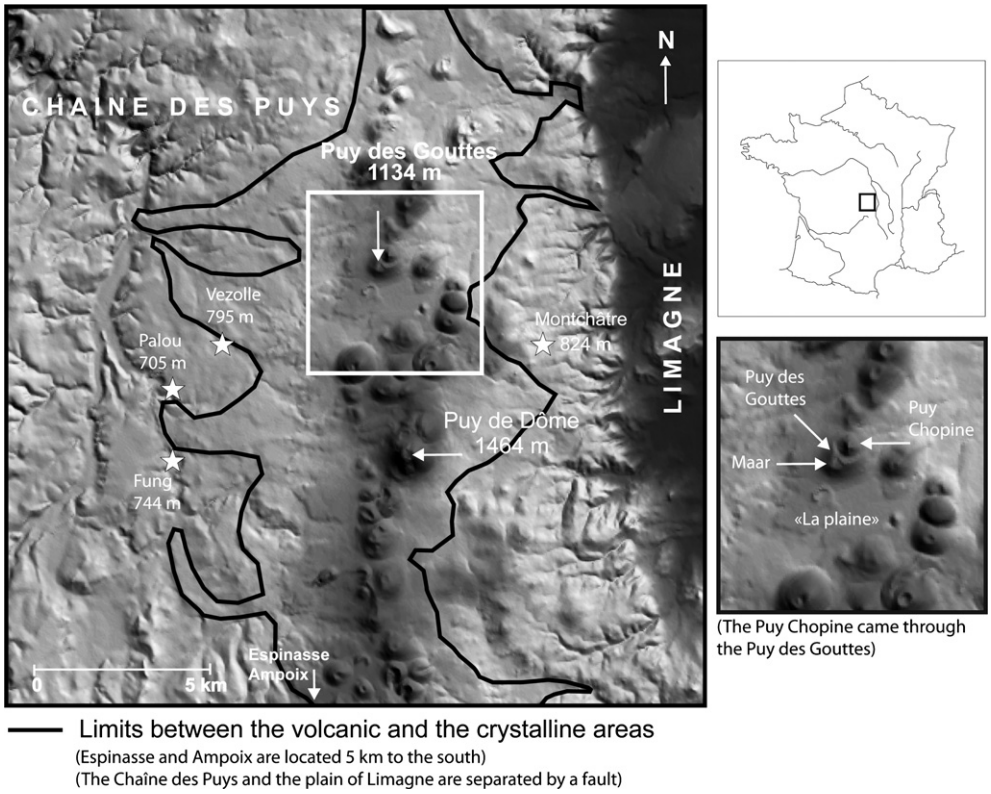

Fig. 1. Geographical context of the study area.

2005 using a 50 × 5 cm "Russian" corer. Radiocarbon dating was attempted at the bottom and at each sedimentary change in the core. Three samples were analysed using radiocarbon chronology, based on AMS ^{14}C ages on organic sediment (VERA Laboratorium, Vienna, Austria). Calibrated dates (2 σ) were calculated using OxCal3.10 program with the INTCAL04 curve (Stuiver et al., 2005).

The samples for physical and chemical analyses were taken at 5 or 10 cm intervals on average. Particle size analyses have been determined with a laser granulometer (LS 350, Beckman Coulter), after organic matter destruction and a prior sodium pyrophosphate dispersion of the clay particles. They reveal water and matter transfers in the small catchment area, even if we consider the possibility of the mineralization of the organic matter. The chemical analyses concerned C, N, P, K, Ca, Mg, $N{-}NO_3$ and $N{-}NH_4$. The carbon and nitrogen contents were determined after dry combustion (NF ISO 10694 and ISO 13878). The ratio of carbon to nitrogen makes it possible to evaluate the evolution of the organic matter. The potassium, calcium and magnesium contents were analysed by spectrophotometry and the phosphorus content by hydrolysis (INRA, 1983). The phosphorus is both an indication of human impact (Michelin et al., 2001; Miras, 2004; Miras et al., 2004) and of humidity, because the lack of oxygen, the acidity (pH) and the presence of oxyhydroxides allow a better fixation of the phosphorus (Duchaufour, 1997; Charman, 2002). The potassium, calcium and magnesium contents have been interpreted with difficulty in the regional literature, but are usually connected with the mineral elements observed in the substratum (Michelin et al., 2001; Miras, 2004; Miras et al., 2004). Ammonium and nitrate contents were obtained by extraction with potassium chloride solution (ISO 14256-2). $N{-}NO_3$ and $N{-}NO_4$ indicate the human impact. Moreover, $N{-}NO_4$ is fixed by humidity and could be oxidized in dry conditions, as for phosphorus.

Samples for palaeoecological analysis were taken at 4 cm intervals on average. They were prepared using standard procedures for pollen analysis (Faegri and Iversen, 1989). This included treatment with KOH, HCl, sieving (200 μ) and treatment with hot HF, acetolysis and mounting in glycerine jelly. Counting of pollen and non-pollen palynomorphs (NPP) was performed using a Leica microscope at 500× magnification. Identification of pollen, spores and NPP followed published illustrations and keys (Van Geel, 1978; Faegri and Iversen, 1989; Reille, 1995, 1999; Van Geel and Aptroot, 2006). Minimum pollen counts of 350 dry land pollen grains per sample were made. Pollen and NPP values were calculated as a percentage of total land pollen, excluding Cyperaceae, fern spores and aquatic plants. The pollen and NPP diagrams were constructed using the program Gpalwin (Goeury, 1997).

The second step included a specific study of historical archives as indirect and complementary clues of human activities, in order to understand how the land was used and with which techniques. Most of the documents studied came from the archives of the "Département du Puy de Dôme" which are classified in series with a code number.

Apart from the settlement of the countess of Montferrand in 1195, the historical sources start in the fifteenth century. The property regime, which has a great influence on the way the land was managed, was very complex. In the surroundings of the volcano where the core was collected, the land was divided between three religious communities, several seignories and common lands belonging to different villages – with never-ending conflicts about property and rights of use. This complex situation explains the richness of the archives and the large number of old maps and sketches. For the *ancien régime*, the main sources have been the religious archives containing old cadastral maps, trials, management books (G and H series), the regional government archives with some petitions related to erosion and new roads projects (C series, during the eighteenth century) and the forest archives after the Colbert law of 1669 rich in maps and statements for illegal coppicing (B series). They are not always exactly located

in the studied area but they give a good indication of the type and intensity of human activities. For the nineteenth century, the Napoleonic cadastral map started in 1831 (P series) and some private archives related to the common land right of use were used. These documents give information about the level of forestation and give information on the grazing system. Many old postcards and photographs from the end of the nineteenth century were examined. Due to the proximity to Clermont-Ferrand, the first aerial photos are from as early as 1910, and some present tangential views, with many marks of erosion cadastral map. Since the Second World War, vertical aerial photographs have been taken roughly every five to ten years and give a general view of the vegetation.

4. Results

4.1. Sedimentary archives of the Puy de Gouttes

Three samples from the 190 cm of the core PG1 were tested for AMS ^{14}C ages. The bottom of the core (180-170 cm) was dated at 15 650–14 750 BC (VERA-3813). An attempt at intermediate dating (102-96 cm of depth) failed due to lack of organic matter. The last one, between 32 and 27 cm of depth, indicates 1650–1810 cal AD (205 ± 30 BP, VERA-4288HS). A total of 17 grain sizes and 17 chemical analyses were carried out. Only 10 pollen and 10 NPP analyses contained sufficient material, and these were located in the upper 40 cm of the core.

4.1.1. Grain size and chemical analyses

The grain size record of PG1 follows four main phases (Fig. 2). From 190 to 110 cm (PG1–A), the granulometry is fine (silty clay loam) and consistent. Fine silt dominates (62.6–65.6%). The sand content is very low (1–3.6%). From 110 to 90 cm (PG1–B), there is a minor increase of the grain size. The sand reaches 13.3% and the coarse silt increases from 12 to 20%. From 90 to 70 cm (PG1–C), the granulometry becomes fine (close to PG1–A). From 70 cm to the surface (PG1–D), the change of the grain size is spectacular and is characterized by the occurrence of coarse sands. The sand content is high (17–49%). In detail, there is a significant increase between 70 and 50 cm, a minor decrease between 46 and 36 cm, an increase between 28 and 18 cm, and finally a clear decrease of the grain size near the surface.

Below 60 cm, the carbon content is very low, although it increases regularly between 110 and 60 cm (from 0.32 to 0.50‰ of dry matter). Above 60 cm, there is a significant increase from 0.50 to nearly 11.53‰. The N content is also low and usually not significant below 60 cm, then it increases regularly up to the surface (from 0.024 to 0.858‰). Consequently the C/N ratio is significant only in the upper 60 cm and shows an increase in the upper 50 cm of the core from 11.57 to 13.44. The higher this ratio is, the more difficult is the mineralization of organic matter.

The analyses of the P, K, Ca, Mg contents also show a break at around 60 cm. The K, Ca and Mg contents decrease distinctly (respectively 0.86, 1.31 and 2.18‰ of dry matter), and then show contrasting patterns of evolution. The K and Ca contents decrease to 35 cm (0.25‰ and 1.12‰), show a progress between 35 and 30 cm (1‰ and 1.46‰) and a new decrease between 26 and 20 cm (0.81‰ and 0.95‰). In the upper 20 cm, K keeps on decreasing (0.27‰) and Ca increases up to the surface (1.85‰). After 60 cm, the Mg content decreases slowly around the 2‰ level, but shows a minor increase between 18 and 10 cm. The P content is the only indicator that progresses near 60 cm (1.32‰). Its evolution is the most distinctive. It decreases after 43 cm (0.48‰), increases after 35 cm (1.02‰), decreases again after 26 cm (0.56‰) and finally shows a marked increase up to the surface (1.60‰).

The nitrates and ammonium contents also progress in the upper 60 cm of the core (respectively from 0.62 to 5.65 and from 8.81 to 13.82 mg N/kg of dry matter), and more quickly after the eighteenth century. The ammonium content also shows a peak near 60–50 cm, the same as phosphorus. Its progression slows down near 26–20 cm, when P also shows a decrease.

4.1.2. Pollen and NPP analyses

Four pollen assemblage zones have been distinguished in the pollen diagram (Fig. 3).

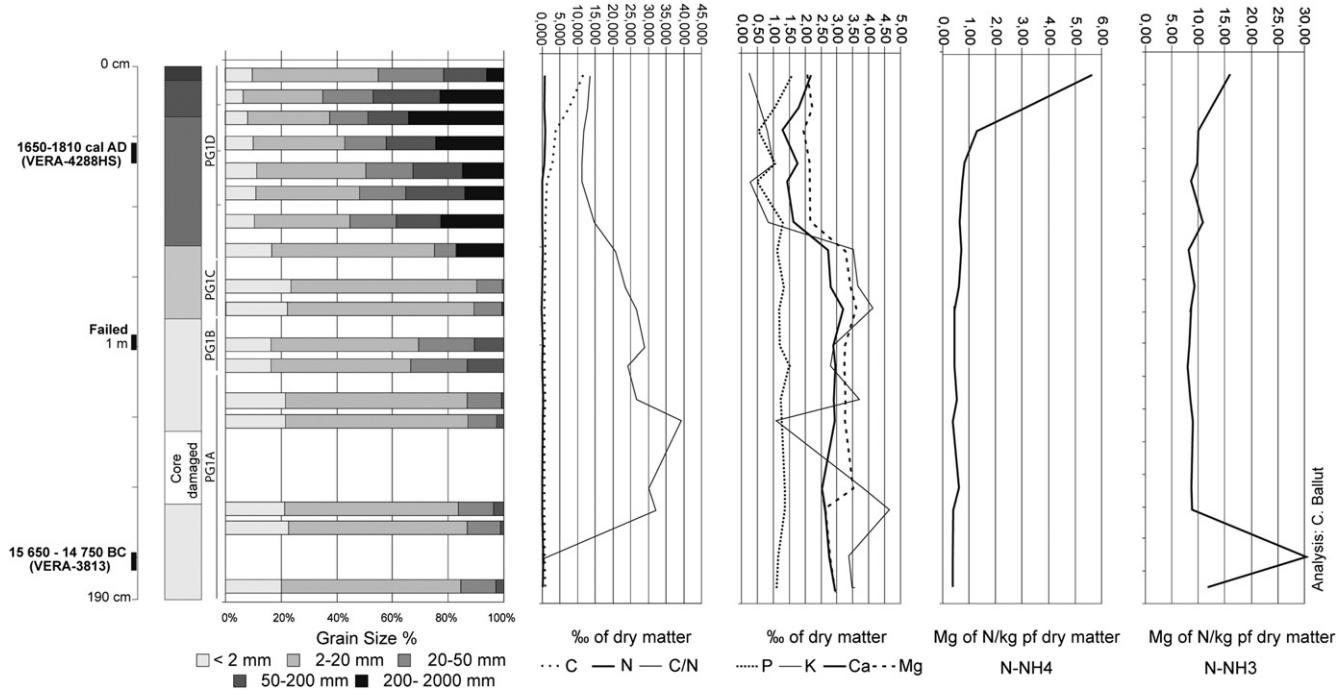

Fig. 2. Physical and chemical analyses of PG1 (Saint-Ours-Les-Roches, 1134 m a.s.l).

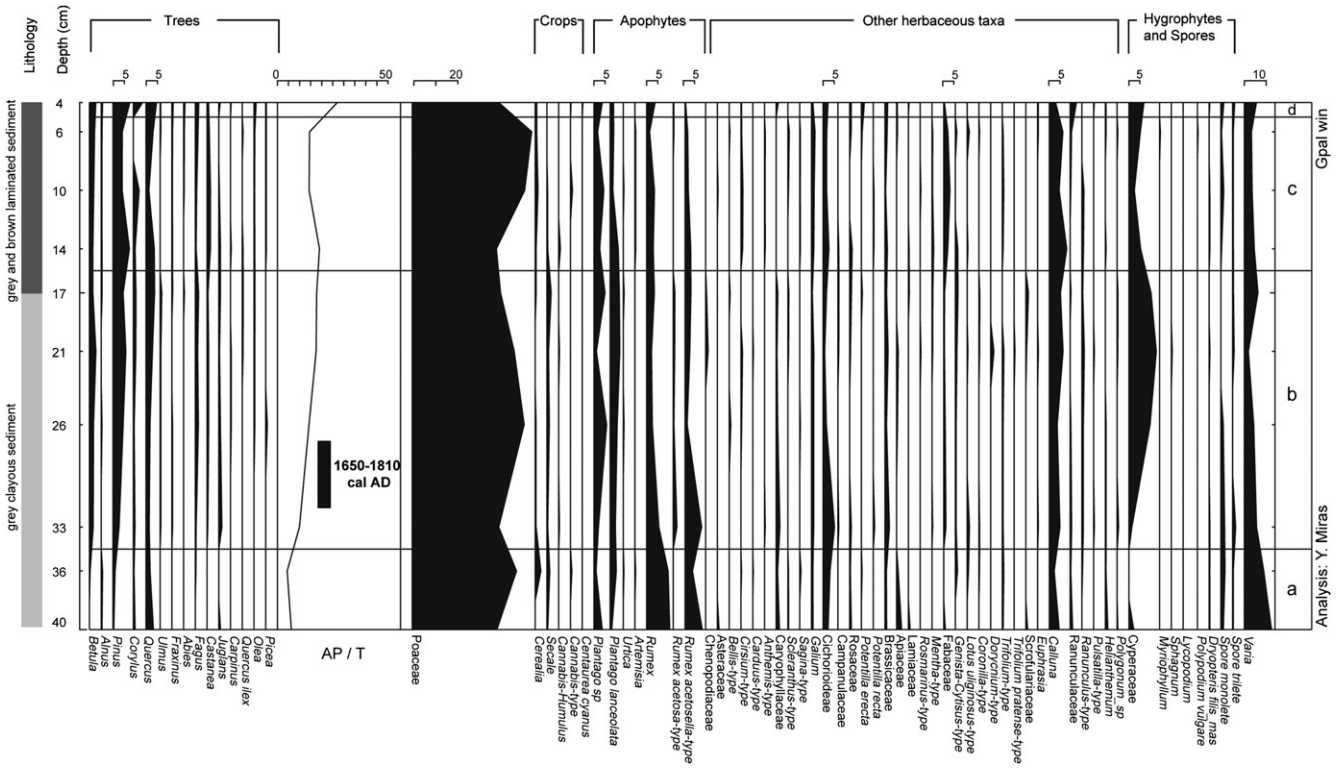

Fig. 3. Pollen analyses of PG1 (Saint-Ours-Les-Roches, 1134 m a.s.l).

PG1–a (40–36 cm). The AP/T (arboreal pollen/total pollen) ratio in this zone has mean values about 5%, which is mainly explained by the frequencies of Quercus (5%). the dominant non-arboreal component is Poaceae (average values about 40%), which is accompanied by anthropogenic pollen indicators such as Rumex (10%), Rumex acetosella-type (5%), Plantago sp and Plantago lanceolata (3%), as well as tall herb communities such as Apiaceae (2%). Cerealia pollen types and Secale appear in the second part of the zone.

PG1–b (33–17 cm). The dominant feature of this zone consists of slight rises in the values of arboreal taxa (AP/T between 10 and 20%). Pinus, Betula and Quercus reach progressively 5%. the first continuous curves of Juglans and Castanea are accompanied by the progression of Calluna heathlands (maximum rates around 10%). In the same period, Poaceae values remain high (rising to 45%) and many apophytes and ruderal plants (i.e. Plantago sp, Plantago lanceolata, Urtica, Rumex acetosa-type, R. acetosella-type, Chenopodiaceae, Bellis-type, Cirsium-type and Galium-type) or heliophilous taxa such as Genista-Cytisus-type either appear or show an overall tendency to increase. Cerealia pollen type percentages decrease while Secale frequencies rise throughout the zone. Regarding the extra-local vegetation, Cyperaceae rates increase to 15%.

PG1–c (14–6 cm). This zone is mainly characterized by a sharp increase in Poaceae values up to 50%, which explains a regress of the AP/T ratio to 15%. Simultaneously, the continuous curve of cerealia-type is recorded together with several indicators of grazing, mainly Plantago lanceolata-type, Plantago sp, cirsium-type, Galium and Rumex and heliophilous herbs such as anthemis-type, trifolium-type and Cichorioideae. Castanea values increase notably.

PG1–d (4 cm). This zone is defined by a renewal of the AP/T ratio (rising to 25%) which is mainly explained by appreciable increases of Pinus, Corylus and Quercus (by about 5%) and the retraction of Poaceae (to 40%). Poaceae nevertheless remain the dominant component in the herbaceous pollen assemblage, which is constituted by a similar group of anthropogenic pollen indicators as the previous zone.

Four non-pollen palynomorph assemblage zones were defined. The limits of NPP zones are consistent with the main environmental changes reported in the pollen record (Fig. 4).

PG1–1 (40–36 cm). The dominant component in the assemblage of NPP 1 consists of fungal spores, mainly coprophilous fungi like Sporormiella sp (HdV-113) and Sordaria sp (HdV-55). type 179 is punctually recorded in the amount of faunal remains.

PG1–2 (33–17 cm). While the rates of undifferentiated fungal spores gradually increase, Sporormiella sp (HdV-113) values register an abrupt decline. Simultaneously, the continuous curves of Spyrogyra sp (HdV-315), of types 127 and 225 also characterize this zone. Gyratrix hermaphroditus (HdV-353) and Canthocamptus sp (HdV-28) are also recorded.

PG1–3 (14–6 cm). The algae remains show an overall tendency to decline until the uppermost part of the zone, where fungal spores dominate, mainly undifferentiated fungal spores (maximum at 20%), Polyadosporites (HdV-367) and Glomus sp (HdV-207). Sporormiella sp (HdV-113) and Sordaria sp (HDV-55) are recorded once again.

PG1-4 (4 cm). fungal forms are more abundant, especially undifferentiated fungal spores and Gaeumannomyces sp (HdV-126). coprophilous fungi are also registered such as Coniochaeta ligniaria (HdV-172), Chaetomium sp (HdV-7A) and Sporormiella sp (HdV-113).

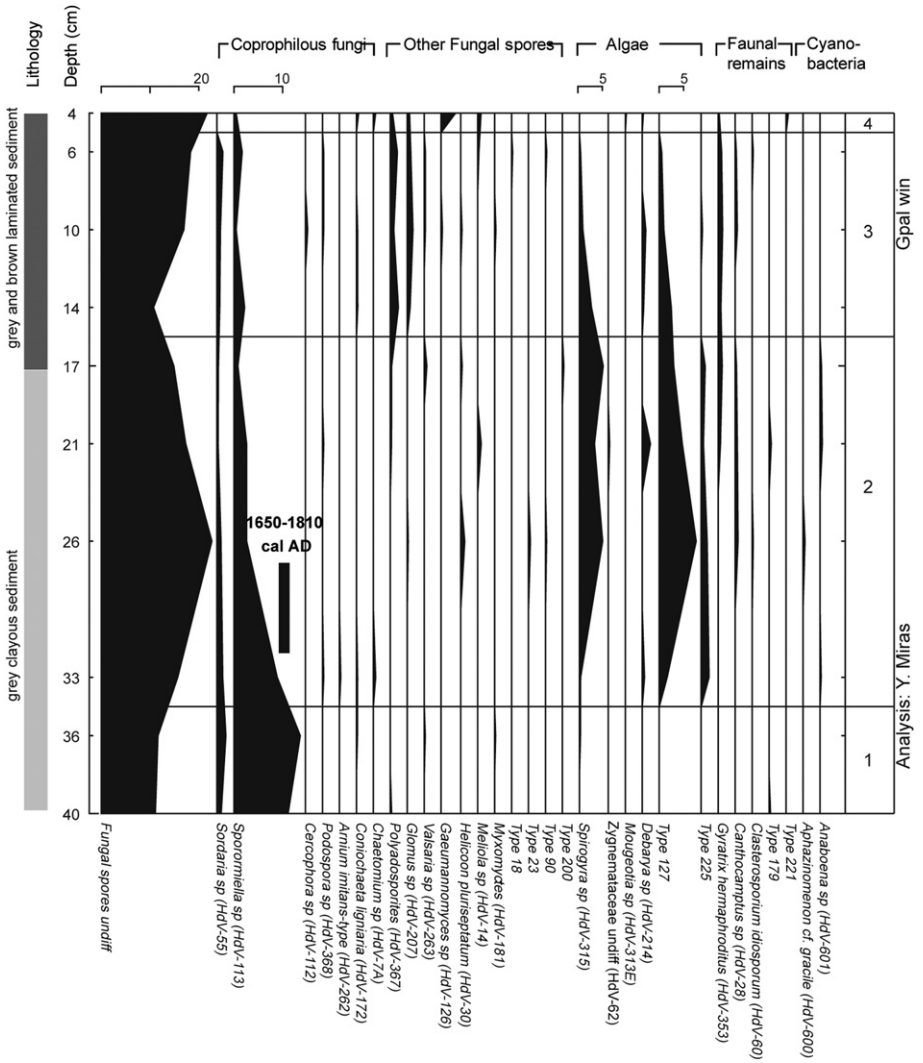

Fig. 4. Non-pollen palynomorph analyses of PG1 (Saint-Ours-Les-Roches, 1134 m a.s.l).

4.2. Historical archives

Manorial documents, trials and old maps do not precisely focus on landscape but contain many precise indications on the way the land was managed, with agronomical and ecological indications (types of trees, quality of the grass, stock rates…) and geographical locations. With an agronomical reading of these historical items, it is possible to transform these data into the landscape appearance of these heathers, fallow lands, woods, fields or grassland.

Charbonnier (1980) indicates that the lower part of the Puy des Gouttes was cultivated before the Hundred Years War (1337–1453 AD). However, information from the fourteenth to the fifteenth centuries is scarce. It was a harsh period for the region, with the Black Death and insecurity which led to a large decrease of the population. Certainly, cultivation was abandoned around the volcano, and forest may have returned, as attested in some contracts from the sixteenth century that allow inhabitants to pasture their livestock and cut trees (Charbonnier, 1980). One map in a contract dating from 1554, from religious archives (AD63-2E931), indicates that the Benedictine monks, who were the lords of this territory, had allowed the inhabitants of the village of Les Fontetes rights of grazing on Puy Chopine, the volcano adjacent to the Puy des Gouttes. From this time to the Revolution, all this territory, including the volcanoes Puy des Gouttes, Puy Chopine and Puy Suchier and the “plaine” in their surroundings, was grazed by common flocks, one belonging to the village of Les Fontetes and one to the village of Chanat. The records of legal proceedings from 1747 (AD63-2E931), arising from a huge conflict between these two communities, give many details about the land use (Fig. 5). The “plaine” had been cleared for cultivation and sometimes the shepherds deliberately let the flocks go out of the pastures for grazing inside the fields. As the limits of the communities were not well defined, the villagers had to describe the borders precisely. They were difficult to find because they were based on the existence of a wood which had disappeared a long time ago, and for which nobody was able to locate the former limits.

During the French Revolution, the religious estates were sold off and the inhabitants gathered to buy them collectively, especially around the Puy des Gouttes (Redon, 1917). The common lands for which it was possible to produce an official proof of property remained in their status of village public good (“sectionnaux”). Except in some specific areas, the farmers ceased cultivation at the base of the volcanoes and concentrated the production of crops around the villages. As each inhabitant had the right to put his ewes in the common flock, the number of grazing animals increased on the slope of the volcanoes. As a consequence, the erosion of the volcanic slopes increased as well (Michelin, 1995). At the end of the nineteenth century, the national forestry administration obliged farmers to replant the eroded lands (Restoration of Mountain Soils

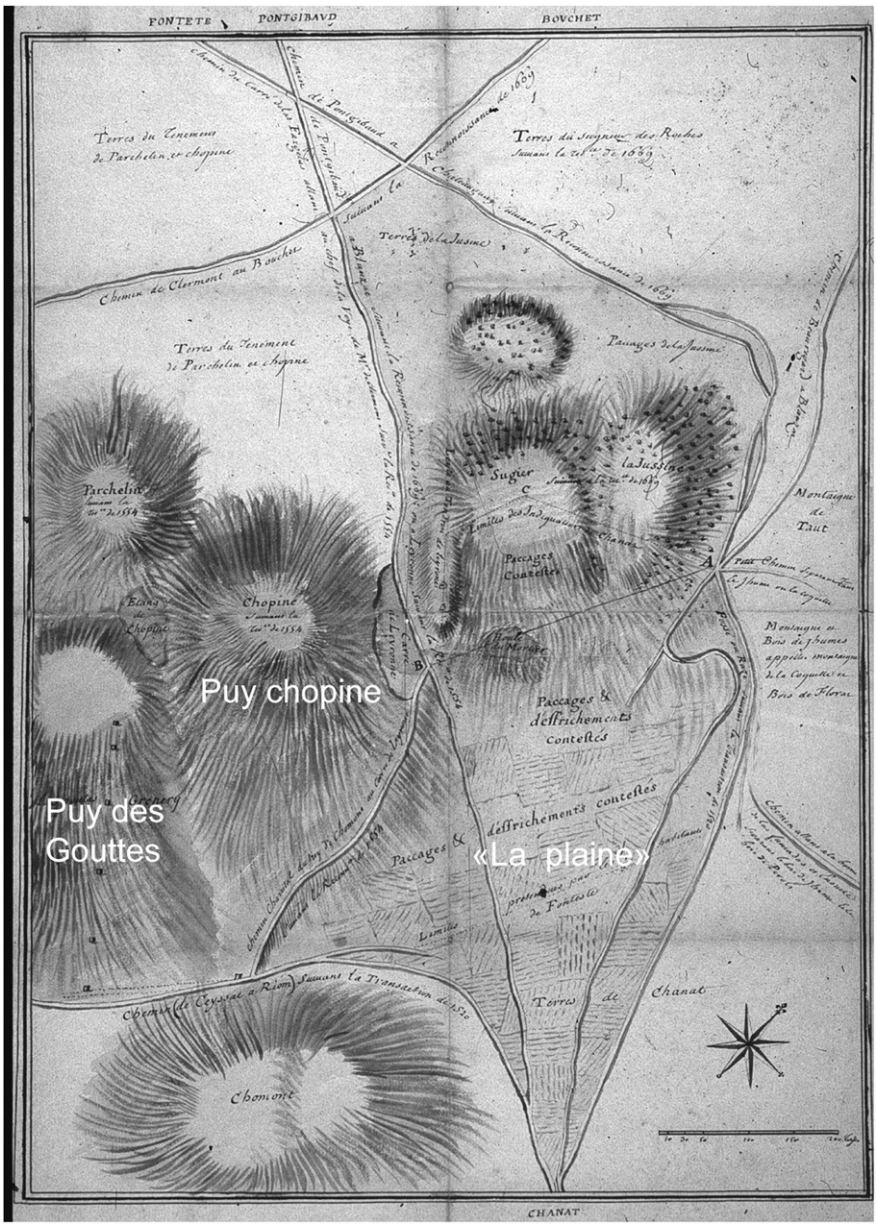

Fig. 5. Old map included in the proceeding of a trial in 1747 (AD63-2E931). The crops are observed in "La plaine" and the slopes are covered with grasses.

law, 10th July 1860). The Puy Chopine was replanted with spruce in the second part of the nineteenth century. After the First World War, many farmers had been killed or injured and the others discovered that the life in the towns was easier. They stopped growing crops on the plateau, abandoned the grazing on the common lands and specialized in cattle breeding. The landscape became more and more forested, with a mix of spruce plantations and natural reforestation, in particular after the Second World War. Still, common flocks continue to graze the Puy des Gouttes and the flat areas present on its foot ("la plaine") even today (Michelin, 1988).

5. Discussion

5.1. Data on the Puy des Gouttes

By combining physical, chemical, pollen and NPP characterizations and historical data, correlations give a precise picture of the landscape changes during the last 500 years in the Chaîne des Puys. The analyses show a change in the sediment between 70 and 50 cm. It is first characterized by an increase of the grain size (70–60 cm) and then a change in chemical indications (60–50 cm). The nitrogen content becomes significant, carbon, phosphorus and ammonium contents increase, and potassium, calcium, magnesium and nitrate contents decrease. The lack of pollen does not allow confirmation of this hypothesis, but it seems that the plant cover changed. The increase of the grain size indicates erosion. Chemical indicators of human presence do not progress in the same way ($N-NO_3$ decreases and P and $N-NO_4$ increase), so it is probable that the increase of P and $N-NO_4$ indicates a higher humidity due to the development of the run-off in the bottom of the depression and not (only) a human impact. Unfortunately, no dating is available for this level.

Until the end of the eighteenth century, two main evolutions were observed in the core (50–30 cm). First (50–35 cm), the sediment continues to record accelerated erosion, even if the grain

size is somewhat smaller than the peak observed previously. The $N-NO_3$ contents increase and indicate a human impact on the landscape. The P and $N-NO_4$ contents decrease. The humidity seems to be not as important as in the previous period. The pollen analyses document only the end of this period (PG1–a and PG1–1). Pollen data show an open landscape (AP/T: 5%), covered with grasslands (Poaceae 40%). All the indicators for grazing and other ruderals present the maximal pollen frequency (*Rumex*, *Plantago* sp, *Plantago laceolata* etc.). The exceptional frequency of the spores of *Sporormiella* sp (>10%), which is strictly coprophilous (Davis and Shafer, 2006), suggests a local presence of cattle (Ejarque, 2010; Ejarque et al., 2010). The grazing activity thus includes the upland area. The pollen of cereals is present, in particular *Secale*. All these facts are validated by the historical archives mentioned above, which show deforestation explained by an increase of farming activity due to the reorganization of the religious estates from the sixteenth to the seventeenth century (Charbonnier, 1980). Grazing on the volcano is always attested during the eighteenth century. The contracts established in this century give an idea of the stocking rates of cattle and sheep, which increased. Cultivation is also attested below the Puy des Gouttes by old maps and contracts. The human pressure has reached such a high level that many conflicts about the right of use the common lands, even the cultivated fields, occurred (AD63-2E931).

Around the radiocarbon date, probably at the end of the eighteenth century, a tendency for decrease in the soil-grain size is shown. The progress of the C/N ratio, P, $N-NH_4$ and algae, in particular *Spyrogyra* (PG1-2), could indicate the increase of humidity (35–30 cm). The grazing activity seems to continue locally, as suggested by the presence of coprophilous fungi (*Coniochaeta ligniaria*; Cugny et al., 2010; Ejarque et al., 2010) and the more eutrophic conditions indicated by a high presence of Turbellarieae (*Gyriatrix hermaphroditus*; Haas, 1996), of other faunal remains (spermatophore of *Canthocamptus*) and of cyanobacteria (*Aphazinomenon gracile*, *Anaboena* sp, Van Geel et al., 1996). These data attest the presence of cattle in the neighbourhood. Nevertheless the drastic decrease of *Sporormiella* sp (<10%) argues in favour of less anthropic pressure (first part of PG1–b and PG1–2). This high area seems to be less affected by grazing. All these observations are completed by a small increase of trees (AP/T: 10–20%). The arboreal taxa probably progress on the abandoned areas (increase of the pioneer taxa and heliophiles like *Betula* and *Pinus*). A decrease of cereals shows a retraction and/or removal of cultivation. Nevertheless, structural or spatial reorganization of the agricultural activities occurs, probably the immediate effect of the French Revolution, as described previously. The religious domain settled on the basis of the volcanoes was abandoned in this period, while the farmers ceased to cultivate the bases of the volcanoes and concentrated on the production of crops around the villages (Michelin, 1995). Initially, the political changes caused a small decrease of the pastoral pressure on the Puy des Gouttes.

During the nineteenth century (30–17 cm), there is an increase of the grain size (highest sand content). $N-NO_3$ continues to increase. The fluctuations of P and $N-NO_4$ are difficult to interpret between the causal factors of humidity and human presence. According to the palaeoecological data and the C/N ratio (decrease of algae and C/N ratio), the humidity seems to be always important but decreases gradually. The pollen and NPP analyses confirm a fully cultural open landscape at a regional scale with a dominating *Secale* culture and the cultivation of *Castanea* (second part of PG1-b and PG1-2). The higher level of grazing is attested by the maximal presence of apophytes (*Plantago* sp, *Plantago lanceolata*), the presence of nitratophilous plants (*Urtica* sp) and other pastoral indicators, as the later consequences of the French Revolution. As each inhabitant had the right to use the common flock, the number of animals increased (Michelin, 1995). The improvement of the standard of living can explain the increase of the population density, which trebled from the end of the eighteenth century to the end of the nineteenth century, and increased the need for cereal production (Bazin et al., 1983).

Around 14 cm, the changes are contemporaneous with the first reforestations with *Picea*, that had been experimented here since the middle of the nineteenth century (Michelin, 1995). A spectacular increase of C, N, C/N, P, Ca, nitrates and ammonium is observed up to the surface. Above 14 cm, there are two phases in the grain size and palaeoecological data.

In the first phase (14–5 cm, PG1–c and PG1–3), the grain size decreases gradually but remains relatively large. An increase of grasses (Poaceae up to 50%) is linked to a minor decrease of the arboreal vegetal cover (*Pinus* and *Corylus*). The progress of coprophilous organisms also attests to the return of cattle to the site (*Sordaria* sp, *Coniochaeta ligniaria* and *Sporormiella* sp). In the wetland, the fungal spores indicate drier and more persistent eutrophic conditions (decrease of *Spyrogyra* sp, *Debarya* sp and increase of *Gyriatrix hermaphroditus* and *Canthocamptus*, presence of *Closterosporum idiosporum*). In the lower part, crops are always well represented, but reorganization is possible because *Secale* is not the dominant cereal. *Juglans* and *Castanea* cultures progressed regionally. These crops do not grow on the slopes of the volcano, which is at too high an altitude, but they were cultivated at most a few kilometres away, close to the village of Chanat and all along the Limagne fault, as visible in the Napoleonic cadastral map.

In the second phase, up to the surface level (5–0 cm), the decrease of the grain size is clearer, the AP/T ratio reaches 40% (increase of *Quercus*/oak, *Corylus* and heliophiles such as *Pinus*, *Betula*) and the human impact is reduced (in particular, the reduction of Cerealia and Poaceae to < 20%). Even if pastures always characterize the landscape of the Puy des Gouttes, the forest areas progressed in the Chaîne des Puys, both by planting and colonization after abandonment (Coquillard and Gueugnot, 1991). This phase corresponds to the effect of rural depopulation mainly observed after the Second World War (Michelin, 1988, 1995).

5.2. Contribution to the knowledge of the Chaîne des Puys

The core of the Puy des Gouttes is the only sedimentary sequence located on a volcano and is the highest yet observed in the Chaîne des Puys. It gives interesting results for the end of the historic period which is usually not well documented by the sedimentary archives. In the Chaîne des Puys, most of the wetlands have been successively transformed into ponds and have dried out. The consequences of the management of the wetlands have been particularly well observed on the site of Montchâtre. For the first time, the creation of a pond has been dated to the beginning of the Middle Ages (AD 600–670, VERA-5034, unpublished data). The sediments then recorded several fluctuations of the water level (fluctuations of the organic matter content, the C/N ratio, the Cyperaceae and other biological indicators) that show an alternation of voluntary drainage to gain more pasturage and inundation to breed fish (Ballut et al., 2008). This management of the wetlands is mainly explained by the human pressure on the landscape and reveals the most intensive land use periods. More generally, and despite this available description, drainage caused the oxidization of pollen, sedimentary gaps and the impossibility of analysing the details of the historical dynamics in many cores. The small maar of the Puy des Gouttes has known a different evolution because of its localization. It could have been managed to create a watering place, but not a pond, and was probably never drained to gain pasturage. Hence it records the historical dynamics without major disturbances, gives new information, and complements both the cores already studied along the historical data. Nevertheless, as in

the other cores, the fluctuations of the humidity are more certainly linked to human hydraulic management than to climatic changes. Today, two watering-places supplied by small springs are still visible.

The study of the Puy des Gouttes confirms the mobility of agro-pastoral practices both at a regional and at a local scale and the importance of the landscape changes during the historical period. This mobility was already visible through the history of the wetlands partly described above. However, because of the sedimentary gaps, for the last 500 years and for the agricultural landscape, most of the studied cores do not offer as much accuracy as PG1 does.

At a local scale, the palaeoecological and sedimentological data combined with the historical data attest a temporal and spatial mobility of both land uses and farming practices:

- a progression and regression of the forest, related to the fluctuations of the grazing activity, mainly explained by the social and economical changes;
- some erosive crises during the more intense farming activity, separated by more stable periods while the management regime was powerful enough to regulate the different types of land use (forest, grazing, cultivation).

At a regional scale, the human pressure on the volcanoes increased at least since the end of the Middle Ages. Grazing was the main activity and the high level of stocking rates drove the landscape towards a severely eroded state in the second part of the nineteenth century. Old postcards from the end of the nineteenth century show that the lava flows and the volcanoes were covered with heather and poor pastures in a totally open landscape (Fig. 6). Nevertheless, the volcanoes and their lava flows seem to have been used for farming at last, probably because they were less attractive, far from the permanent villages and more difficult to manage.

Since the end of the nineteenth century, and particularly since the Second World War, the progressive disappearance of cultivation and the decrease of livestock pressure facilitated the return of the forest

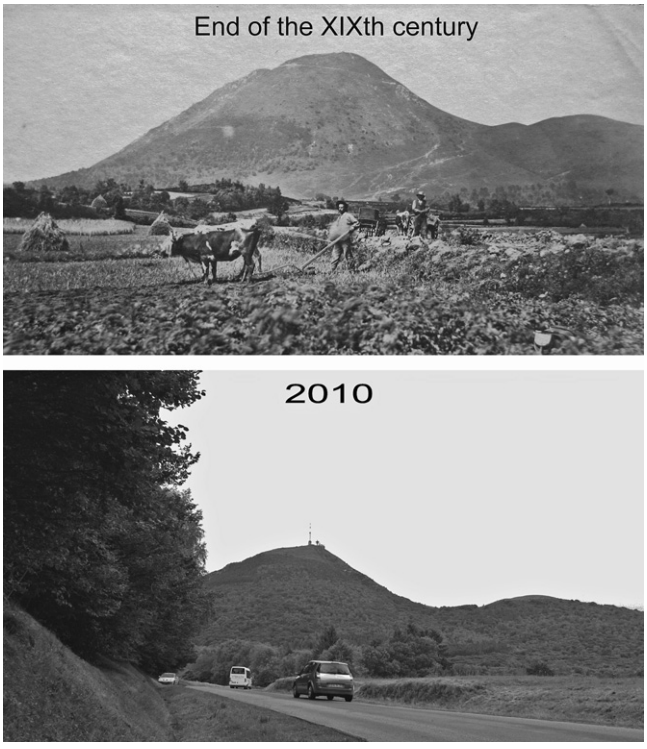

Fig. 6. A comparison between the present landscape and a postcard from the end of the nineteenth century near the Puy de Dôme (photography: Y. Michelin).

on crystalline basement, in particular in the wetlands, and in the volcanic areas that have been abandoned at first. Nowadays, the present landscape of the Chaîne des Puys is composed of pastures (grasslands, meadows, heathers) and forests (oak, beech, spruce, pine) in particular on the volcanic basement (Fig. 6). The volcanic shapes are less visible, except where the common flocks are still at work. As a consequence, the erosion has been reduced on the crystalline plateau and on numerous volcanoes. However, since the 1960s, tourist activity on the volcanoes has created new threats due to the increase of walkers and four-wheel-drive vehicles using new trails on the tops of the volcanoes, while the rest of the plateau, which is being discovered by new inhabitants, offers a suburban aspect with only a few farmers who remain on the land (Michelin, 1997).

6. Conclusion

The core from the Puy des Gouttes is the first one from the volcanic zone to be studied and the only one located on a volcano. It offers a record of the modern and contemporaneous periods rarely recorded elsewhere with a strong correlation with historical archives. The results show a variation of intensity and a diversity of grazing and farming practices, even during historical times, both on a local and a regional scale. In particular, there is a spatial mobility of land use, explained by the adaptation of the human practices to the social and economic context : a high human pressure and a very open landscape at the end of the Ancient Regime, a spatial reorganization of land use and a less pressure on the volcanoes just after the French Revolution, a new increase of land use during the nineteenth century in the whole Chaîne des Puys as a second effect of the French revolution, and the rural depopulation and reforestation observed since the end of the nineteenth century and particularly accelerated after the Second World War. Since the end of the twentieth century, the landscape has agricultural and a touristic functions in a suburban context. This new situation led the stakeholders to decide which landscape they want.

From a methodological point of view, these results illustrate the interest in focusing on the margins of agricultural territories, where a limited change in one factor (climate, farming practices, demography, economic rules) can generate powerful visible changes in the landscape (forest spread or regression, erosion, opening/closure, natural or cultural appearance).

From a theoretical point of view, for many people, landscape changes are often problematic because they consider any change as a degradation of the former landscape. As a consequence, they demand strict protection of the landscape that they want to preserve as it is. The result of this type of policy is often disappointing because landscapes evolve ceaselessly, even if these changes are difficult to perceive from day to day. In fact, this emotional opinion comes from a lack of knowledge of how the landscapes have been constructed. If one wants to manage the landscape of a place in a sustainable way, it is necessary to improve the knowledge of the landscape history through time, as a result of a combination of biophysical and human processes.

From a practical point of view, this information concerning the landscape changes and the impact of human activity on erosion can highlight the stakeholders who have an interest in the planning regulation of this protected area. They can no longer consider the landscape as a fixed image that should be kept in the same state, like wallpaper. They must take into account that this image results from the way this territory has been occupied and managed. If they want to protect the landscape, they have first to define which landscape they want and which conditions are related to this state. That cannot be done with compulsory rules alone, but with the collaboration and the participation of all the stakeholders (foresters, farmers, nature conservators, tourist companies…). Finally, these investigations will

hopefully help them to know better where their surroundings have come from, in order to be more able to define in which direction they want to drive this unique landscape. The recent project of UNESCO World Heritage designation is a good opportunity to put these principles in practice.

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