HOLOCENE ECOLOGICAL TRAJECTORIES IN LAKE AND WETLAND SYSTEMS (AUVERGNE, FRANCE): A PALAEOENVIRONMENTAL CONTRIBUTION FOR A BETTER ASSESSMENT OF ECOSYSTEM AND LAND USE 'S VIABILITY IN MANAGEMENT STRATEGIES

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NOTES

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ABSTRACT – Multi-proxy palaeoenvironmental studies are very important for the development of sustainable management strategies for ecosystems and modern landscapes. Analysing the relationship between societies, climate and environments through time, these studies contribute to define adequate policies and strategies for socio-environmental management, protection and legacy. Two complementary case studies– Aydat lake and Espinasse fen - from the south of the Chaîne des Puys (Auvergne, Massif Central, France) are presented. The analysis of these sedimentological records (both lacustrine and peat) follows a multi-proxy approach combining abiotic and biotic palaeoindicators (density, magnetic susceptibility, X-Ray Fluorescence spectrometry, Rock-Eval, pollen, non-pollen palynomorphs, molecular biomarkers). Aydat lake and Espinasse fen analyses were performed following a high spatio-temporal resolution. Results underline that long-term models of detrital input and eutrophication correspond to complex patterns with early and recurrent phases of human-induced ecological disturbances. They also evidence the existence of diversified long-term land use systems (deforestation, grazing, agriculture, hemp culture and retting) that provide fresh insights into the understanding of present-day mountain environments. This history between diversified human activities and hydrosystems responses must be taken into account for the construction of accurate retrospective and prospective model simulations of hydrosystem functioning.

KEYWORDS: HUMAN IMPACT, SOCIO-ENVIRONMENTAL VIABILITIES, EUTROPHICATION, DETRITAL INPUT, HYDROSYSTEMS, HOLOCENE, AUVERGNE

INTRODUCTION

Nowadays, a consensus exists within the global scientific community for underlining the importance of palaeoenvironmental studies in the development of strategies for the sustainable management of ecosystems and modern landscapes (Dearing et al., 2011). Palaeoenvironmental studies allow the understanding of the genesis and evolution

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of ecosystems as well as the long-term shaping of landscape (e.g. temporal trajectories, thresholds). Through the analysis of the relationship between societies, climate and environments along time, they also contribute to define adequate policies and strategies for socio-environmental management, protection and legacy. Taking into account diachronic socio-environmental dynamics appears crucial in areas presenting a high sensitivity to global change such as the Mediterranean basin (e.g. Curras et al., 2012; Mercuri & Sadori, 2011) or European mountains (e.g. Ejarque et al., 2009; Galop et al., 2011). The mid-altitude mountainous configuration of the volcanic Chaîne des Puys (Auvergne, Massif Central, France), at the boundary of oceanic and continental climatic influences, makes this area particularly sensitive to climatic change. Besides, its vicinity with the regional capital city of Clermont-Ferrand explains a more remarkable anthropisation than in other parts of the Auvergne region. Finally, the socio-economic development of this region needs to be consistent with environmental legacy objectives such as the future registration of the Chaîne des Puys at the UNESCO's World heritage list (http://www.chainedespuys-failledelimagne.com/). Scientific stakes are thus important, particularly for recent ecological investigations at the Chaîne des Puys which aim at developing and testing new methods to design models that could guarantee the viability of both ecosystem quality (e.g. lake eutrophication) and land-use development in the area (e.g. touristic and agro-pastoral activities, residential areas) (Deffuant & Gilbert, 2011). Viability can be here defined as the persistence of multi-constrained system dynamics (Aubin, 1991), such as hydrosystems (e.g. lakes and wetlands). In this sense, diachronic palaecological studies are excellent tools since they allow (1) to describe a "pre-impact" state; (2) to draw the diachronic ecological processes; (3) to characterize forcing of disturbances and (4) to define a "post-impact" state and the mechanisms that drive resilience and human adaptability.

Two complementary case studies located at the south of the Chaîne des Puys –the Aydat lake (N 45°39.809' / E 2°59.106' / 837 m a.s.l.) and the Espinasse fen (N 45°38' / E 2°53' /

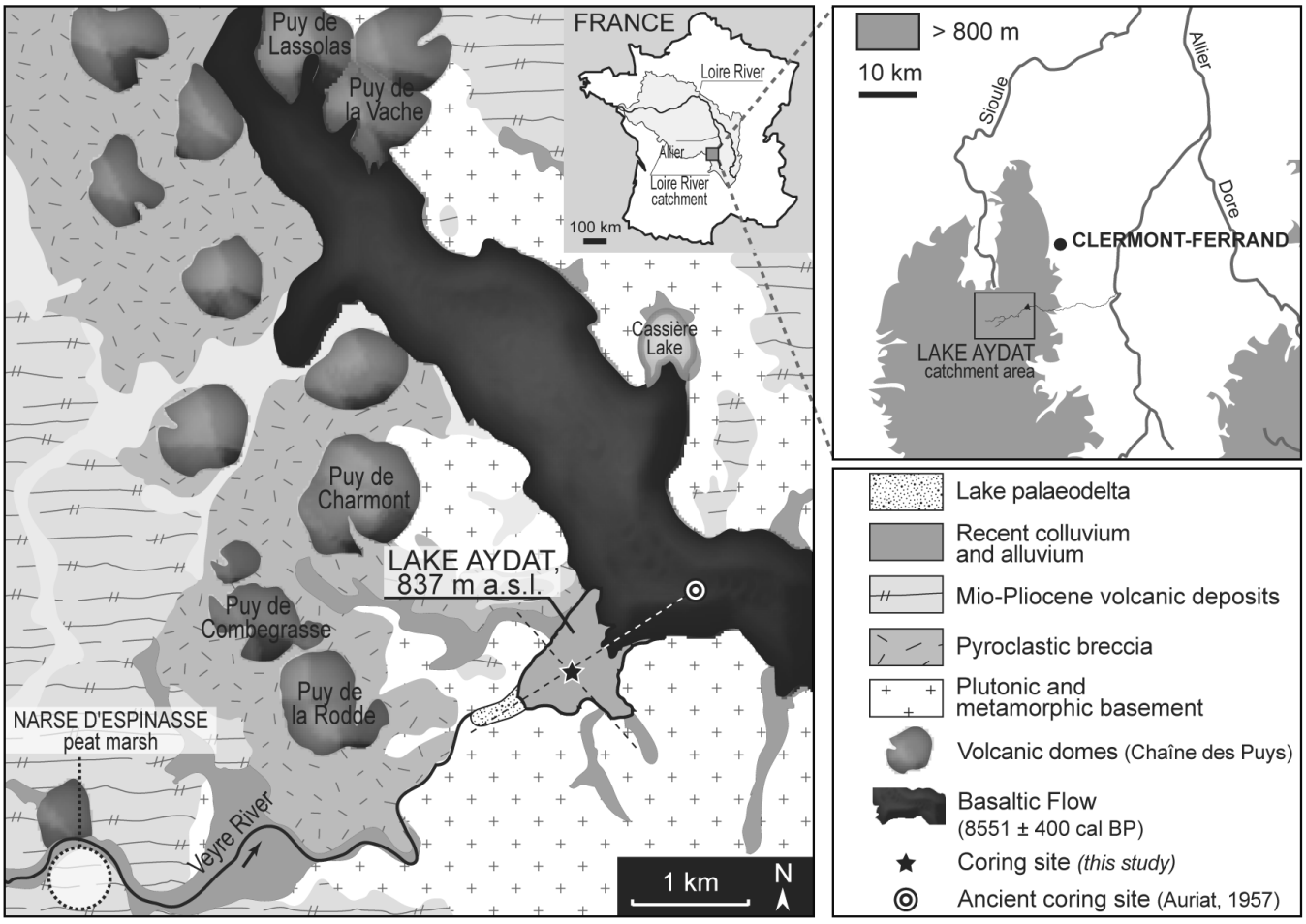

Figure 1. Location of Aydat lake and Espinasse fen (after Lavrieux et al., in press).

1160 m a.s.l.) - will be presented here to illustrate how palaeoecological data can be helpful in the proposed objectives and approach (Figure 1). They have been selected among the available palaeoenvironmental studies- including palynological analysis- which have been performed in this area because they have been carried out using a multi-proxy approach combining abiotic and biotic indicators and they propose the overall goal of analyzing hydrosystem's evolution along time with a particular interest on human impact (Lavrieux, 2011; Lavrieux et al., accepted; Lavrieux et al., in press; Miras et al., 2004). Indeed, previous studies were either mainly focused on vegetation history and tephrostratigraphy (Beaulieu & Goeury, 1987; Juvigné et al., 1988) or not carried out at a sufficient high temporal resolution (Michelin et al., 2001). In addition, recent investigations were not performed on long-term lake or fen records (Ballut et al., 2008; Ballut et al., 2012). Conversely, the 19 and 5-meter-long sedimentary records retrieved in the Aydat lake and the Espinasse fen respectively cover the last 6700 and 5000 yrs. Analyses were performed at a very high resolution and reliable age-depth models were constructed (Lavrieux et al., accepted; Lavrieux et al., in press; Miras et al., 2004). Besides, the close vicinity of these two sites, which are located in the same drainage basin, allows a comparison of environmental changes at a micro-local scale. Micro-local studies are indeed the most suitable approach to analyse human-environments interactions (Dearing et al., 2006), particularly in upland environments (Ejarque et al., 2010).

The Aydat lake and the Espinasse fen are currently two anthropogenic hotspots in the Auvergne region. Both sites are highly frequented by tourists and account for agro-pastoral activities (Figure 2), and as a result of that, they are deeply impacted by human activities. For instance, the eutrophication level of Lake Aydat can be so high that summer swimming is sometimes forbidden. In consequence, local authorities, organizations of environmental management (e.g. Parc Naturel Régional des Volcans d'Auvergne) and the scientific community have begun to pay attention to the restoration of the ecosystem services, combined with a sustainable socio-economic development. This paper aims to demonstrate that palaeocological investigations have to be taken into account as they furnish essential data concerning the long-term anthropogenic forcing on hydrosystem evolution. This paper is focused in: (1) model of sedimentation and (2) eutrophication phases.

Materials and Methods

Multi-proxy approach is based on the integration of abiotic (density, magnetic susceptibility, X-Ray Fluorescence spectrometry, Rock-Eval) and biotic indicators (pollen, non-pollen palynomorphs, and molecular biomarkers). Employed methods follow standard procedures (see complete methodology in Lavrieux et al., accepted; Lavrieux et al., in press; Miras et al., 2004). Age-depth models are based on AMS radiocarbon dates: 17 for the Aydat lake and 5 for the Espinasse fen. In the Aydat lake, the top of the sequence has been dated using ^{137}Cs, ^{241}Am, ^{210}Pb and ^{7}Be measurements and the correlation with historical flood events (Lavrieux et al., accepted).

Figure 2. Current situation of Aydat lake (a. photo M. Lefeuvre) and Espinasse (b. photo Y. Miras).

RESULTS

Sedimentation and erosive mass wasting

Sediment analysis of Aydat lake's reveals two units on the basis on sedimentological and bulk geochemical indicators (Lavrieux et al., accepted). Multi-proxy palaeoenvironmental analyses were performed on the lower (1076-1974 cm depth) and the upper unit (0-829 cm depth). The intermediate unit (829-1076 cm depth) corresponds to a mass wasting deposit (Lavrieux et al., accepted). Between 6730 and 3200 cal BP, 6 phases of relatively higher background detrital input have been underlined, the first one starting at ca 6000 cal BP with a major flood event reported at ca 3800 cal BP. In the Espinasse fen, detrital phases are also observed between ca 4850 and 3900 cal BP (Miras et al., 2004). This first Aydat unit ends with an erosive mass wasting deposit dated to ca 1770±60 cal BP. From 1770 cal BP to the present day, 6 phases of higher background detrital input are distinguished in the Aydat lake's sediments and dated at ca 1510-1210, 1130-1000, 950-670, 620-500, 430-150 and 90-50 cal BP (Lavrieux et al., accepted).

Eutrophication phases

Different trophic states have been evidenced in the Aydat lake on the basis of pollen and non-pollen palynomorph data and sediment geochemical data. Earlier phases of trophic variation and/or nutrient enrichment occurred between 6000-5750 and 4900-4600 cal BP. Eutrophication phases have also been highlighted during the lapses 3900-3500 and 1470-888 cal BP, reaching a maximum level between 1200 and 1130 cal BP (Lavrieux et al., accepted) and 515 and 200 cal BP (work in progress). The recent period– between 150 cal BP/present day- also corresponds to a high nutrient level.

DISCUSSION

Both the Aydat lake and the Espinasse fen sequences reveal long-term processes of detrital input and changes in eutrophic conditions (Figures 3 and 4). Pollen and non-pollen palynomorph data indicate that this variability in lake status correspond to early and recurrent phases of human-induced ecological disturbances. Together with a climate driver– lower solar activity could favour enhanced soil erosion on catchments (Debret et al., 2010), the anthropogenic forcing is also evidenced for the phases at ca 6000-5700 and 4800-4600 cal BP (Lavrieux et al., accepted). Moreover, ecological changes dated to 3800 cal BP are not correlated with a climatic event but with a more intense landscape management (3900-3500 cal BP). This period corresponds to the major flood event in the Aydat sequence and to an erosive mass wasting in Espinasse fen (Lavrieux et al., accepted; Miras et al., 2004). Pollen and charcoal data suggest a clear fire-induced woodland opening associated with the extension of grasslands and heliophilous taxa. The significant rise of anthropogenic pollen indicators and dung-related fungi attest the expansion of local grazing activity which provokes the first nutrient enrichment of the lake. If climatic conditions and human impact worked together until the Mid-Holocene, sedimentation and eutrophication were principally controlled by anthropogenic forcing during the Late Holocene, especially since 1500 cal BP. During historical times, background sedimentation increases and over-enrichment phases of the Aydat lake are always synchronous with more intensive and persistent human pressure on environment. All this indicates that lake and fen systems in the Chaîne des Puys have intensively and continuously been impacted by human activities since the Neolithic and the Early Bronze age and these mountains must not been considered as pristine and marginal areas. These ancient anthropogenic impacts also underline the high vulnerability of these ecosystems. Such a long-term history of human activities and hydrosystem interactions must thus be taken into account for the construction of accurate retrospective and prospective simulations models of hydrosystem functioning.

Multi-proxy palaeoecological investigations performed in the Southern part of the Chaîne des Puys also evidence complex and diversified land use systems along time. This contrasts with a common view of European mountain areas which tends to focus on ecological disturbances uniquely caused by grazing activity. Even if this practice had an important impact on upland hydrosystems since millennia, this is only one of the multiple activities which were developed in mountain areas (Ejarque et al., 2011). In the South of the Chaîne des Puys, pollen data evidence that agriculture reaches at the altitudinal of the Aydat lake in determinate phases. This is the case for the period from the 12th to the 18th centuries (work in progress). Moreover, pollen and the cannabinol molecular tracer indicate that hemp culture and retting activity were also very important, particularly between the 13th and the 19th centuries (Lavrieux et al., in press). However, a hemp culture is also suggested during Gallo-roman times. Hemp retting caused a degradation of the water quality of the Aydat lake during the Modern period, as suggested by recurrent blooms of *Anabaena* akinetes (work in progress). This concept of a diversified exploitation of natural resources in mountain environments undoubtedly provides fresh insights into the understanding of mountain present-day environments.

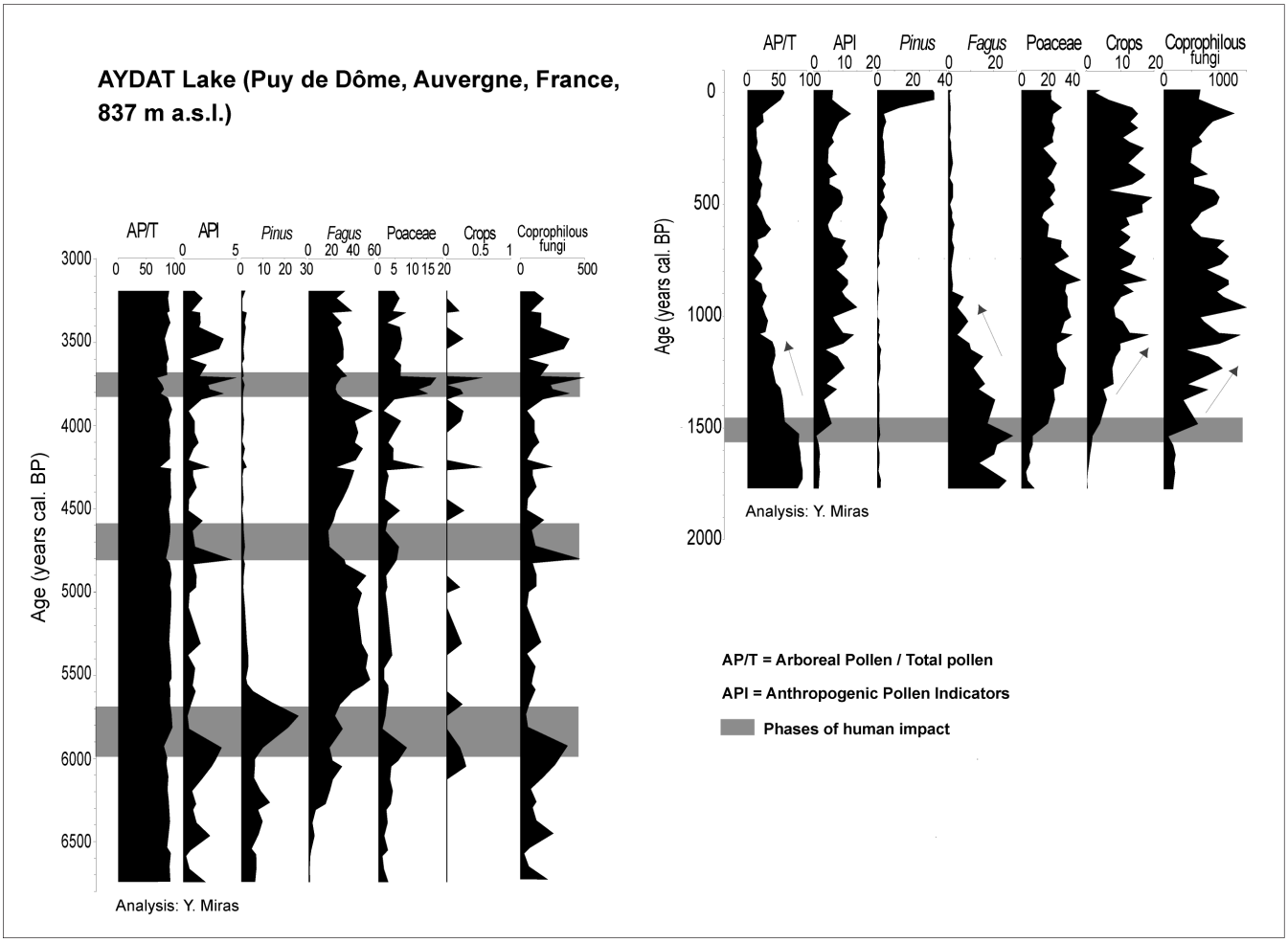

Figure 3. Pollen and non-pollen palynomophs percentage diagram of selected taxa from Aydat Lake (after Lavrieux et al., in press).

Conclusions

The overall objective of this paper was demonstrating that lessons can be learned from multi-proxy palaeoenvironmental investigations. Results obtained can be of benefit for the long-term sustainability and the management of ecosystems and services. The design of mitigation strategies to both current and future socio-environmental stresses requires a good understanding of the long-term response of ecosystems to cumulative changes caused by climate variations and human activities. This integrated and transdisciplinary approach also addresses the adaptability of past societies to environmental (e.g. climatic) changes and furnishes valuable tools to manage consequences of global change. This research is still in progress and a better quantitative and spatial assessment of past human impact is required. For this, two research strategies can here be quoted. Firstly, new palaeoecological methods need to be tested to obtain valuable and innovative biotic indicators, mainly within the non-pollen palynomorphs assemblages, for exploring new questions such as the nature of grazing, eg. type of animal, grazing system, or different land-use systems. Secondly, this integrated palaeo- and ecological approach should be – if possible! - supplemented with archaeological, historical and ethnographical data-sets in order to properly evaluate, characterize and spatialize human occupation and land use. This work is actually in progress in the Chaîne des Puys.

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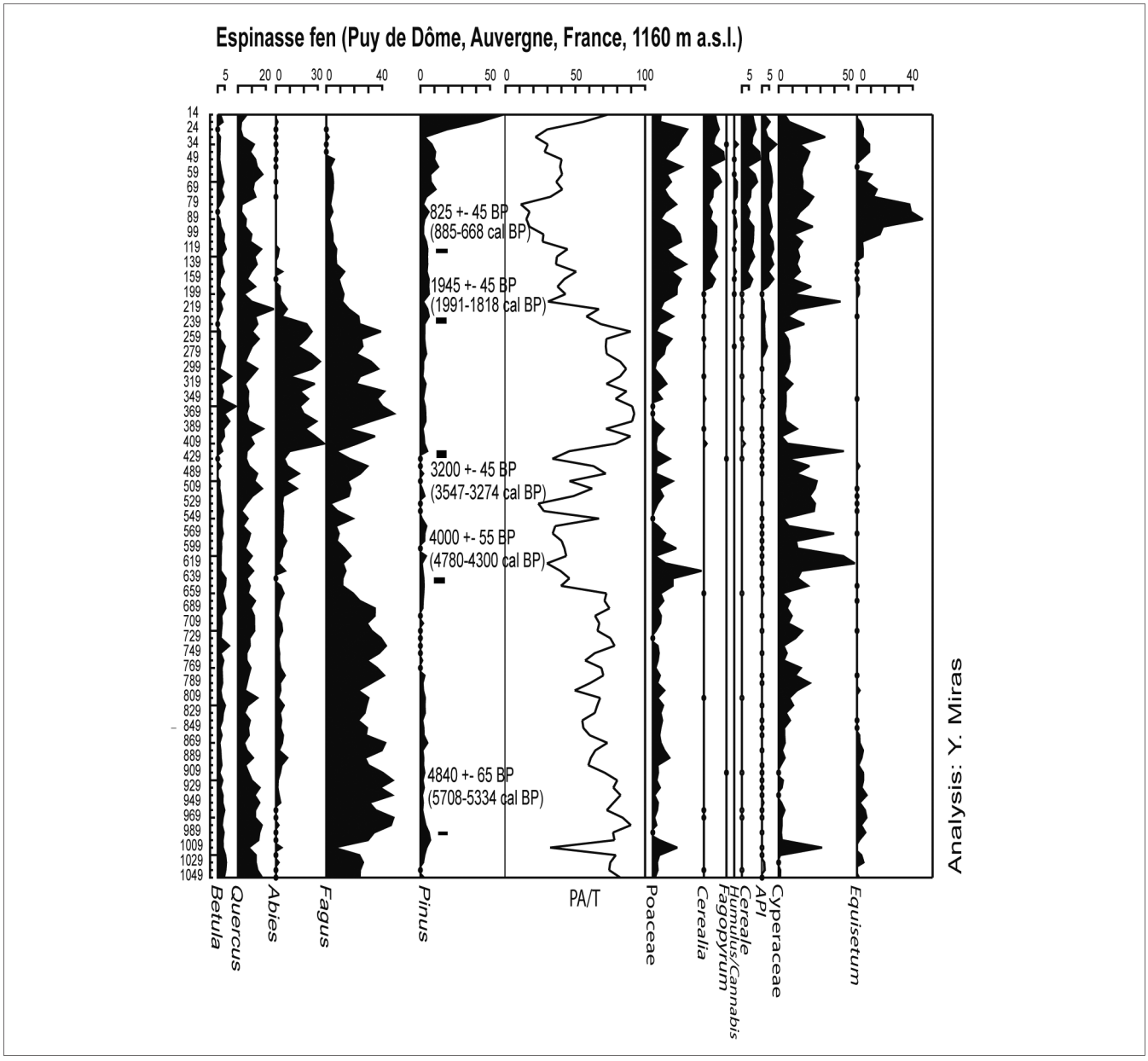

Figure 4. Pollen percentage diagram of selected taxa from Espinasse fen (after Miras et al., 2004).

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