Landuse and soil degradation in the southern Maya lowlands, from Pre-Classic to Post-Classic times : The case of La Joyanca (Petén, Guatemala)

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Abstract

This work focuses on the impact of Maya agriculture on soil degradation. *In site* and *out site* studies in the area of the city of La Joyanca (NW Petén) show that "Maya clays" do not constitute a homogeneous unit, but represent a complex sedimentary record. A high resolution analysis leads us to document changes in rates and practices evolving in time in relation with major socio-political and economic changes. It is possible to highlight extensive agricultural practices between Early Pre-classical to Late Pre-classical times. Intensification occurs in relation with reduction of the fallow duration during Pre-classic to Classic periods. The consequences of these changes on soil erosion are discussed. However, it does not seem that the agronomic potential of the soils was significantly degraded before the end of the Classic period.

Keywords: Maya clay, soil erosion, slash and burn cultivation, Petén, Maya lowlands.

1. Introduction

Since the beginning of the 20th century, the thin soil cover of the Yucatan was interpreted as a consequence of the ancient Maya erosion. Some authors attributed the Maya collapse to the decay of agriculture outcrop associated with drastic soil erosion in overpopulation context [1]. In a region of tropical monsoon climate, with alternate dry and rainy season, slash and burn cultivation is supposed to be a factor of increasing erosion. During the seventies, the discovery of the "Maya clays" into the lake infill of the Yucatan, led to the assumption of a significant and rapid soil erosion phase associated with forest clearance related to the Maya colonization [2]. "Maya clays" were first identified in the lake of the northern part of the Yucatan and « (…) consist mainly of re-deposited soil, input into the lake[s] as the result of Maya occupation» [3]. In fact, they correspond to the accumulation of terrigenous materials, mainly argillaceous to organic, produced by top soil erosion in the lake catchments, and inserted between authigenic sediments, deposited since the Late-Glacial to

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Early Holocene (11.1 Ka to 10.2 Ka, [4]) and post Terminal classic layers (i.e. post *collapse* deposits, ≈ 900 AD [5]). Instead, the term "Maya clays" has no real chronological significance - it is not related to a unique archaeological period. It refers to a whole of diachronic detritic deposits associated with the transformations of the environment by the Mayas over more than 3000 years [6][7][8][9]. As pointed out by Beach et al., during the second Holocene, the anthropogenic erosion seems to be the most efficient geomorphic agent in the Yucatan [10]. The synchronism between the introduction of corn (*Zea mays*) cultivation, deforestation and the deposit of "Maya clays" led the authors to interpret them as a consequence of soil erosion induced by slash and burn agriculture. Scholars have also highlighted the role of urbanisation in the erosion [2]. However, according to some authors, the "Maya clays" deposition might have been triggered by changes in the regional climate around 1000 BC [11][9] and shift in related geomorphic processes. This opinion is supported by major changes in sedimentation rate recorded in a large set of lakes and swamp zone in the Yucatan and Pacific maya coastal zone [13].

In this work, we first review evidence of large-scale erosional crisis associated with Maya colonization in the Yucatan and adjacent areas. We show the results of a detailed study in the southern Yucatan (Petén) and the possible links at a regional scale between erosion and socio-cultural development of a small city, La Joyanca according to geoarcheological and paleoecological evidences.

2. The records of the Maya erosion: an overview

Many studies in the Maya Yucatan have pointed out evidence for land degradation and soil erosion from 1000 BC to 900 AD. The "Maya clays" were identified in a large broad of environments: lakes, swamps, karstic depressions and mangrove as well in the north of Yucatan, in the Pacific Coast, in Petén and Belize (see [14] for a review in Yucatan before 2002). In the Petén district, paleo-ecological and/or sedimentological data were collected in the lakes Quexil [11], Salpetén [9][15], Sacnab [2][11], Macanche [11] and Petén-Itza [16][17].

The infill of the lake Salpetén shows an increase in the terrigenous input towards 1700 BC, in relation with a reduction of high forest taxa pollen [16]. This situation was still going on until the local Terminal classic *collapse* about 850 A.D. The palynological and geochemical data from lake Petén-Itza show early disturbances, around 4690-4590 BC that could be interpreted as the results of the oldest anthropic impact. However, the increase in the terrigenous fraction, documented as well by magnetic susceptibility and geochemistry occurs around 1000-910 BC [17]. In this case, the "Maya clays" do not constitute a well-identified stratigraphic unit. The end of the "Maya clays" deposits is recorded by the decrease of magnetic susceptibility around 895-985 AD and matches with the end of the Classic period.

In the Petexbatun region, the Tamarindito lake core, near the major sites of Dos Pilas and Aguateca, shows a change of sedimentation from organic to detrital at around 1770-1490 BC. Detritic inputs still go on until 610-380 BC [8]. However, datations were carried out on total organic matter of the sediments, that may have induced age errors. Age results seem out-of-date from 300 to 500 years regarding the regional data. Stratigraphic studies of wetlands (bajos) also suggest changes in the deposition process during Early Pre-Classic (around 1500 BC) reflecting a major erosive crisis in the Lowlands [6][18].

In continental environments, it is possible to recognize palaeosoils overlaid by natural and/or anthropic colluvial deposits as evidence for one or few erosional phases. Two major phases of soil erosion are documented by Dunning and Beach for the Maya period in the Bleu Creek, Three River and Petexbatun regions [10]. The first one is associated with the pioneer phase of agrarian Maya colonization, during the 10th century BC and goes on during the whole Pre-classic. A second one is identified during Late Classic (550-900 BC). This study points out that there does not exist a direct link between demographic charge and the magnitude of soil erosion. Recently, lithologic and sedimentation rate changes were also documented in the mangrove of the Pacific coastal zone and related to the transformation of the environment by Maya farming [13].

There is a major contradiction between the idea of an early and drastic soil erosion phase related to the *milpa* cultivation since the Pre-Classic and the duration of the Maya agriculture system which extends over more than 2600 years. It is the more contradictory because in most cases, high cultivation potential soils are thick, calcic rendzinas type, (< 30 cm) [19][20]. In order to solve this contradiction, it appears necessary i) to establish a precise chronology of the Maya "erosive crisis" and its real impact on soils ii) to seek either breaks or gradual evolutions in this depositional episode and iii) to search for possible explanations in the social, economic and/or climatic transformations.

This work is a multidisciplinary study carried out by archaeologists, geomorphologists and paleo-ecologists, in a small urban maya center (La Joyanca) and surroundings. The site was chosen because it is a small size town (area : 1,7 km^2), belonging to an intermediate class level in the regional hierarchy. The chronology of the occupation is well established, as well by the archaeological data and ^{14}C radiocarbons datations [21][22]. The main phases of building of the city and socio-political changes are thus well-documented. First, we present the geomorphological background of the study as well as the archaeological context. Then, the method of study and the principal results are presented and discussed.

3. Study area

The Yucatan peninsula, which was the centre of the development of Maya Classic civilization (Fig. 1a), is a Mesozoïc to Eocene carbonate platform [23]. The thickness of its mainly

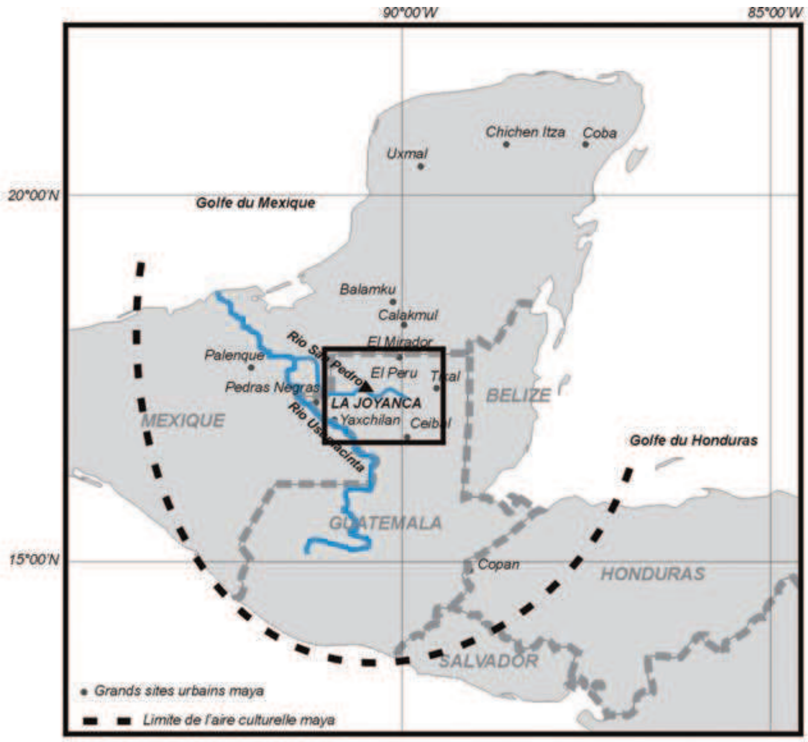
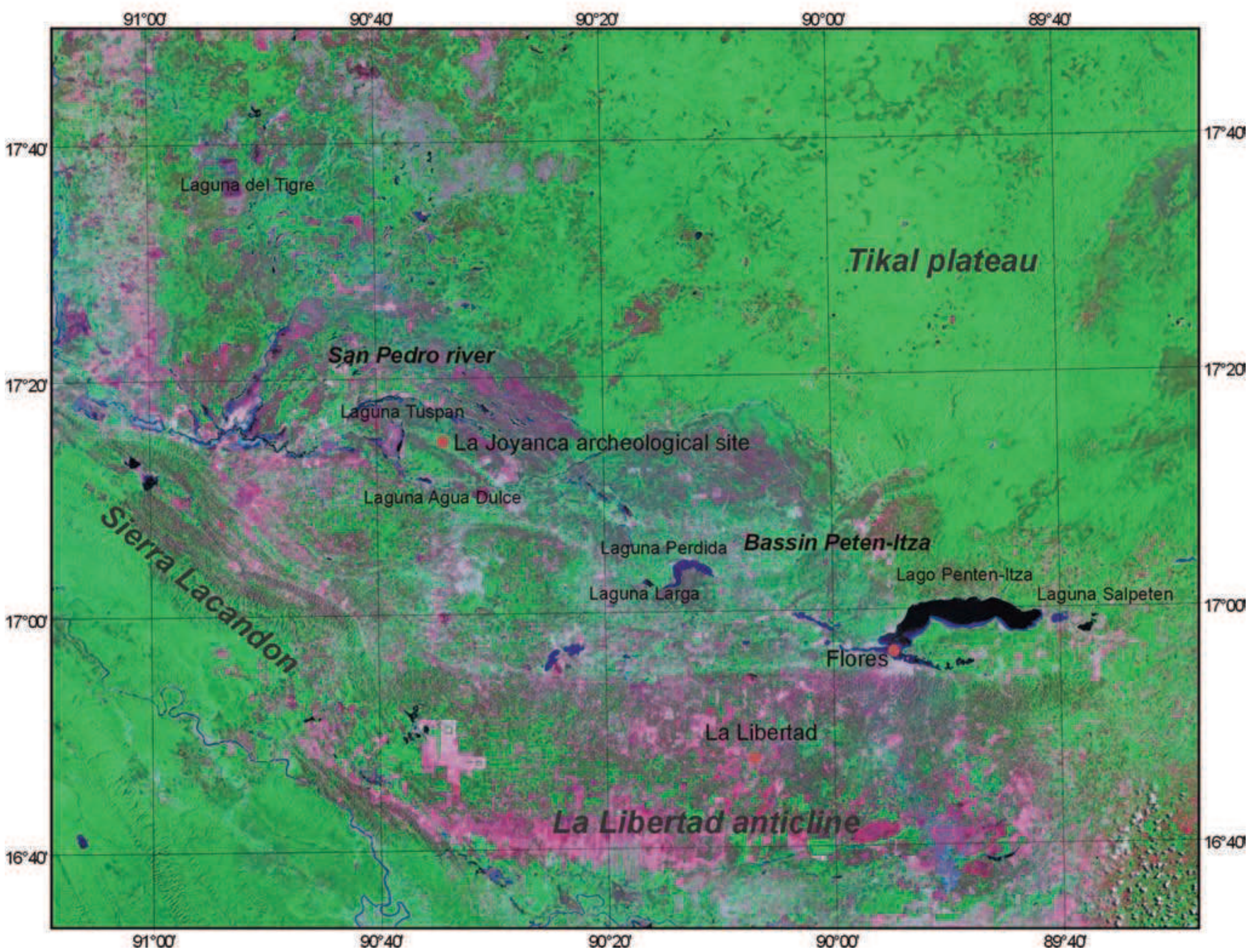


Fig. 1 : Localization of the study area.
a- The Yucatan peninsula. Dash line corresponds to the Maya area.
b- Main morphologic units (Landsat ETM+).



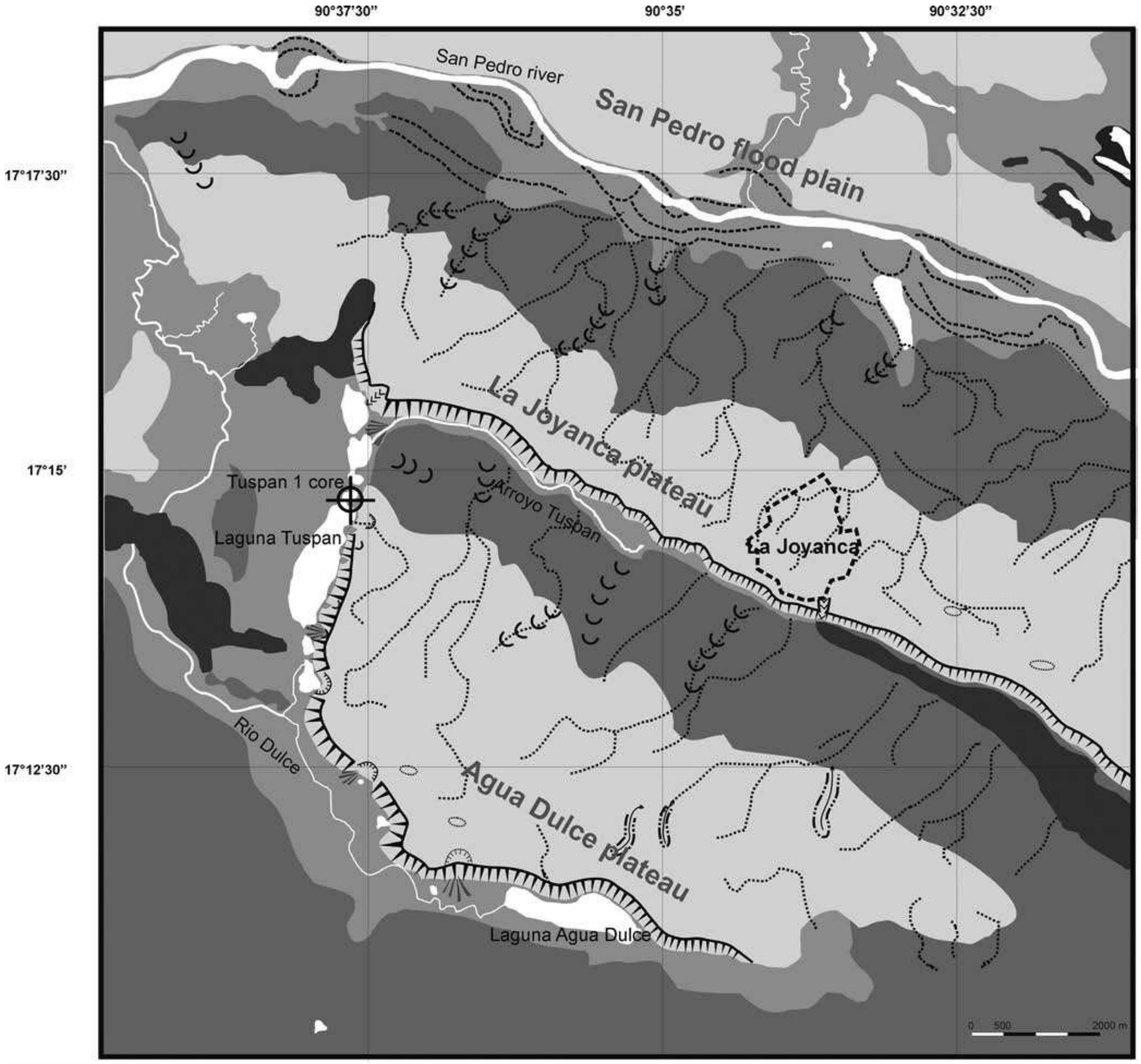
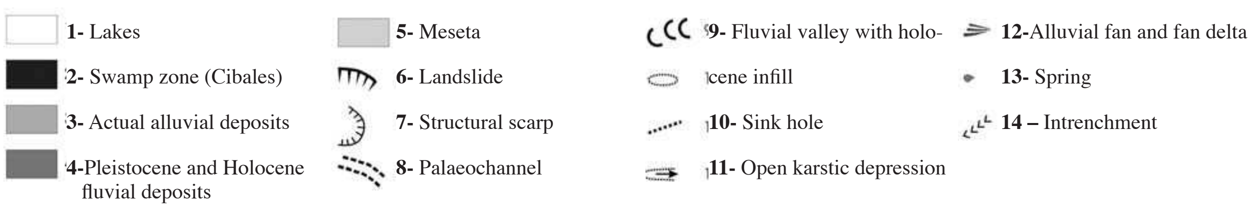


Fig. 2 : Morphological map of La Joyanca area.



marine deposits, can reach more than 3000 meters in the north of Guatemala. Early Cretaceous deposits are mainly shallow carbonate deposits (*Ixcoy* et *Cobàn* formation), as Eocene deposits (*Petén* formation) are massive dolomitic strata, with karstic forms in the south and centre of Yucatan. The Eocene limestones of Petén are eroded and covered by a white calcitic rock, locally named *sascab*, which overlays the whole topography [24]. Geomorphological landforms of the Petén district are varied and allow to distinguish morphological units (Fig. 1b) [25].

The Yucatan peninsula *sensu stricto* is limited to the southwest by the Sierras Lacandones, which constitute a series of narrow SE trending orogenic hills of moderate altitudes. Shaped into Cretaceous carbonates, they are strongly karstified. The main drainage directions are under structural control and guide the flow of the Usumacinta river down to the Gulf of Mexico. Towards S-E, the peninsula ends against the Maya Mountains of Belize, more than 1200 m a.s.l. It includes granitic blocks formations and surrounding carboniferous formations. Directed SW-NE, these reliefs reach the fault system of Motagua transform. The southernmost (?) part of the peninsula, which corresponds to the southern part of the Petén district, south of Flores, is a zone of low limestone meseta developed on the backlimb of La Libertad anticline. The higher zones, whose altitude reaches to more than 300 m, show typical karstic dissolution hills of conical forms (Kuppenkarst and fluvio-karst [26]). The northern backlimb of the anticlinal marks the beginning of the "lakes district" with alternated low altitude meseta and lowlands wet zones [27]. The lake depressions (*lagos* and *lagunas*) and the large swamp zones (*bajos* and *cibales*) are generally endoreic. Some of them are exoreique and flow into the San Pedro Martir river. Surprisingly, the water constitutes an omnipresent element in this low karstic plateau landscape. This type of landscape is extended towards the north to the Laguna del Tigre region. The southern limit between this wet depression and the plateau of Tikal, corresponds to the lithological transition between Paleocene and Eocene formations, in the north of the San Pedro river. The western limit corresponds to Pleistocene wetlands and river sediments.

The study area is located immediately to the south of a large loop of the San Pedro River, where its flow direction changes from SE-NW to NE-SW (Fig. 1b and 2). It consists in a series of tilted plateaus the altitude of which is decreasing from south to north. To the S-W, the highest plateau (alt. 230 m) is strongly karstified ; it dominates the Arroyo Jicotea wetland zone and continues towards the Tuspan Lake. This lake receives water from the Tuspan and Rio Dulce rivers and flows to San Pedro-Martir River. The Tuspan lake basin and La Joyanca plateau are separated by a stepped linear slope, trending N010 in orientation, 120 m at most, corresponding to a fault scarp. The plateaus of Aguacate and La Joyanca are gently tilted northward where they are covered by Pleistocene deposits of the Tuspan and San Pedro rivers. The La Joyanca plateau, where the archaeological site is established, exhibit calcareous highs, covered by thick clay soils (black calcareous lithosols, rendzina-like [19]) and low wetlands. The airborne photographs (Feb. 1987) make it possible to interpret these lowlands as part of a fluvio-karstic network. Topographic data collected during fieldwork confirms this interpretation.

The city of La Joyanca is established at the edge of the plateau and dominates the wetlands of the Tuspan river (*Cibal*). This type of wetland is characterized by important annual variability of the water level. During the rainy season, the water level progressively reaches its maximum, and then decreases as the dry period goes on, so far as to disappear. It is thus disconnected from the regional water table. On the contrary, the Tuspan lake shows apparent stability on annual and inter-annual time scale. It seems to be largely dependent on karstic and regional groundwater supply. This difference in the hydrological regime induces high water quality differences : saturated with carbonate in the lake Tuspan case and poorer in the case of the *cibal*. This hydrological regime of the Tuspan lake is different from those of other lake systems in the nearby region (Laguna Perdida, Laguna San Diego,…). It is probably responsible for the quality of the sedimentary records (regularity of sedimentation, high sedimentation rate, lack of hiatus).

4. Methodology and results

4.1. Protocol study

The absence of accessible sedimentary complexes in the valleys led us to develop an approach combining *in site* investigations (i.e. on the archaeological site itself) and *out site* works (i.e. in karst, lake and wetlands), in order to evaluate the transformations of the environment and the modifications of the geomorphologic system. On the plateau, the fluvio-karstic network presents a 0,60 to 1,40 m thickness infill with high potential of environmental change record. The trenches carried out in various sites show homogeneous filling of clay deposits. The presence of ceramic fragments down to the base of the section suggests that these layers are contemporary of the Maya occupation. However, the strong vertic activity of the *bajos* soils and the vertical movements that it induces can also be responsible for the migration of the artefacts. Thus, on the plateau, the only zones of potential interest for the documentation of environment transformation are the man made zones as result of maya agriculture. In fact, Maya buildings are built on an artificial platform used as a basis for the habitat itself. They use *sascab* and blocks of Miocene lacustrine limestone in the case of La Joyanca. These artificial mounts, ganging from 0,60 to 1,00 m height in the case of modest habitats were built quickly and leading to the burying of the former natural soil, which ceased evolving [28]. In addition, public spaces like the patios, are covered by a large stucco level which protects and also fossilizes paleosoils. Buried paleosoils are frequently found under archaeological structures. In Belize, Turner and Harrison described dark, massive argilo-organic levels intercalated between the archaeological floor and the substratum [29]. But they did not interpret them as paleosoils. On selected area we entrench the whole archaeological (build and collapse level) and natural levels in order to identify and to characterize the soil at construction time. These soils can be directly dated by ^{14}C method or indirectly by archaeological dating of the building phase. ^{14}C datations on palaeosoil were obtained on macrocharcoals at the top of the paleosoil-anthroposoil interface. In Guacamaya and Gavilan group (see Fig. 3 for location), top soil charcoal level is identified. We interpret them as the signature of forest clearing immediately before the first level of occupation. Other operations like in Plaza

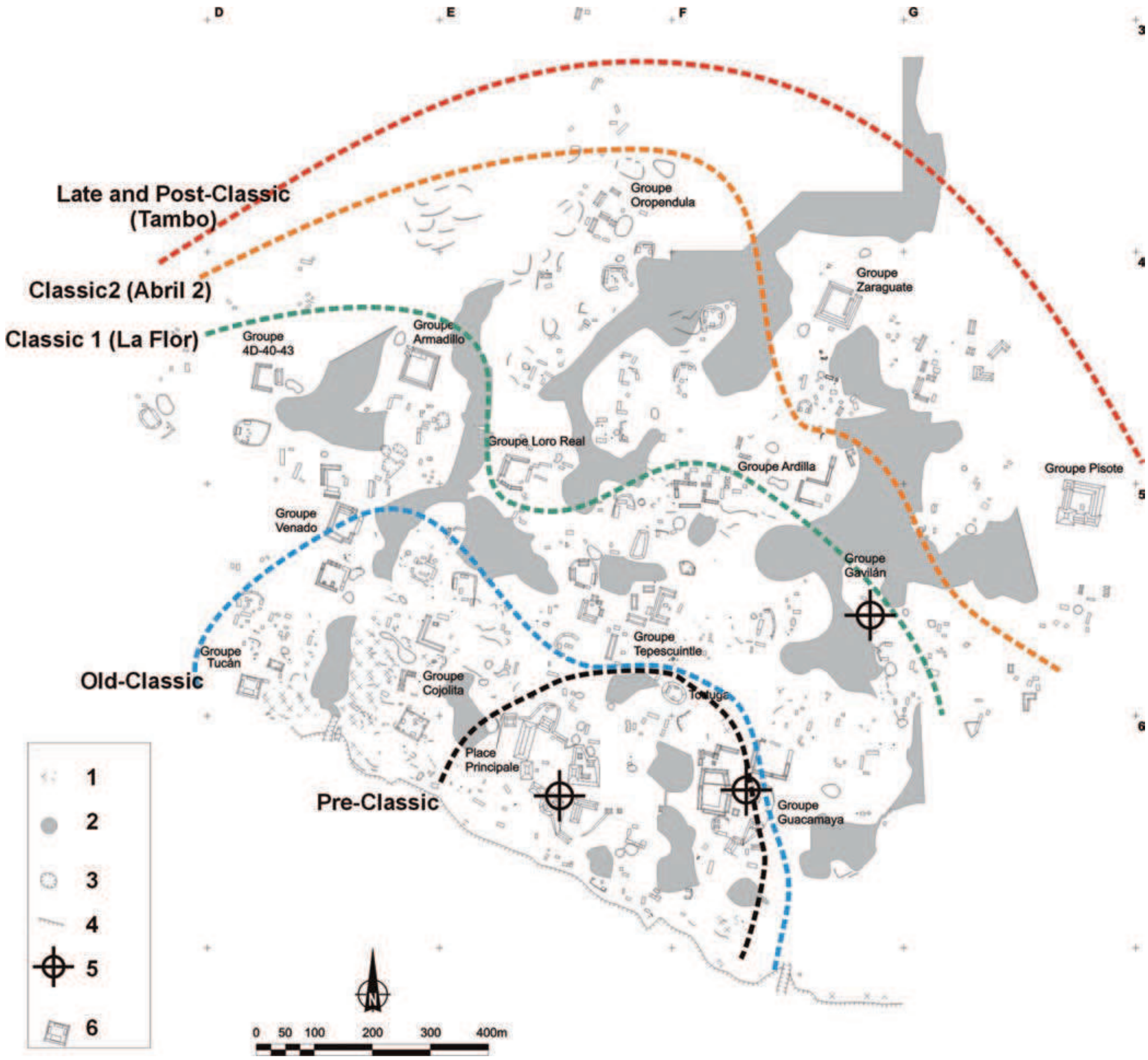


Fig. 3 : Map of La Joyanca city and location of the in site trenches location.
1- Surfacial limestone zone **2-** Swamp zone (bajo de alto) **3-** Water tank (Chultun) **4-** Scarp **5-** Trench location **6-** House building

Principal or Tortuga group (see Fig. 3 for location) show similar stratigraphy, but no ^{14}C radiocarbon datation was carried out. Typically, paleosoils are thick, ranging from 0,24 to 0,32 m, and represent the lowest part of calcitic rendzina soils. Textural and geochemical analyses of these soils were conducted in the INRA laboratory of Arras (France).

The survey planning is copied on the La Joyanca growth model, developed by archaeologists as radial [21]. These works showed that the agglomeration developed around an initial Pre-Classic centre (Plaza Principal and of the Guacamaya and Tortuga groups), located at the edge of the meseta [28]. Then, the city experimented a concentric development during Late Pre-Classic and Classic periods, and the structures and soil covers are younger away from the monumental centre of the city. In addition, we search for soil erosion products in the sedimentary filling of the Tuspan lake. Because of its geographic position at the outlet of the Tuspan river and Rio Dulce, this lake records terrigenous inputs from both La Joyanca and Tuspan mesetas. Furthermore, the inter-annual stability of water level in the lake minimizes risks of disturbances of the sedimentary recording. Three cores were extracted using a Russian coring (El Tambo, Tuspan 1 and Tuspan 2). Only the results of Tuspan 1 will be presented in this work. The samples (the whole core) were analysed in France and Spain. Pollen content was analysed at the Chrono-Ecology Laboratory of Besançon. Non-Pollinic Micro-Fossils were analysed at the Archaeo-botany Laboratory of Madrid. Magnetic surface susceptibility was conducted using MS2E1 surface Magnetic Scanning at the Chrono-Ecology

Site location	Context	$_{14}$C BP	AD/BC calibrated age (+/- 2σ)	Lab number
Plaza Principal	Paleosoil	2780 +/- 70	**1119 (917) 808 BC**	GifA 100621
Guacamaya	Paleosoil	2470 +/- 70	**770(757,695,541) 409**	GifA 100626
Gavilan	Paleosoil	1460 +/- 50	**530 (620) 670**	Beta 155685

Table 1 : Paleosoil AMS radiocarbon determinations. Calibred age using OxCal [30]

Laboratory of Besançon. AMS ^{14}C datations were performed on unique charcoal and organic terrestrial wood fragment (See table 1 and 2) in two different laboratories. The OxCal 3.10 program was used for ^{14}C date calibration [30].

4.2. Results

4.2.1. In site *trenches*

The monumental centre (political or religious monuments) is established on the top of a large interfluve near the edge of the plateau. In these areas, present day pedological observations show clay-organic rendo-soils with an average thickness from 0,25 to 0,35 m. They were developed on limestone and archaeological remains. Trenches observation shows systematic preservation of a clay-organic dark massive layer below the archaeological levels identified as palaeosoils. Three were dated using ^{14}C in Plaza Principal, Guacamaya and Gavilan group (Table 1).

On the patio of the Guacamaya group, trench allows to identify the following stratigraphy : Weathered Miocene limestone bedrock ; a 0,45 cm clay-organic layer interpreted as palaeosoil, undegraded calcitic rendolls type ; 0,10 cm white stucco level ; 0,40 cm of heterogeneous material, reflecting mixing of natural and anthropic components and interpreted as collapse and colluvial deposits. A detailed stratigraphy of the palaeosoil level shows the presence of macro-charcoals (ranging from 0,5 to 3 cm) at the top of the soil. ^{14}C datation was performed on a single macro-charcoal pick up at the interface between soil and stucco level to minimize reworking problems. The age obtained is 2470 +/- 70 BP (520 BC). It is consistent with archaeological data (Pre-classic period, Tambo 1 cultural phase). On the Plaza Principal, similar observations allow us to date another paleosoil. The date obtained is 2780 +/- 70 BP (830 BC) and corresponds to the oldest stage of the city development.

On the Gavilan group, more complex investigations were carried out. They allowed us to establish a precise chronology of the occupation. The archaeological data show a first occupation initiated between 600 and 750 AD (Abril 1 cultural phase). It was followed by a development of the occupation between 750 and 850 AD and a growth of the group (Abril 2 cultural phase). This occupation still went on towards 850-900 AD. A final abandon occurred during the Terminal classic (Tuspan 1 cultural phase, [23][24]). The trench stratigraphy of the house mound shows the following succession (Fig.

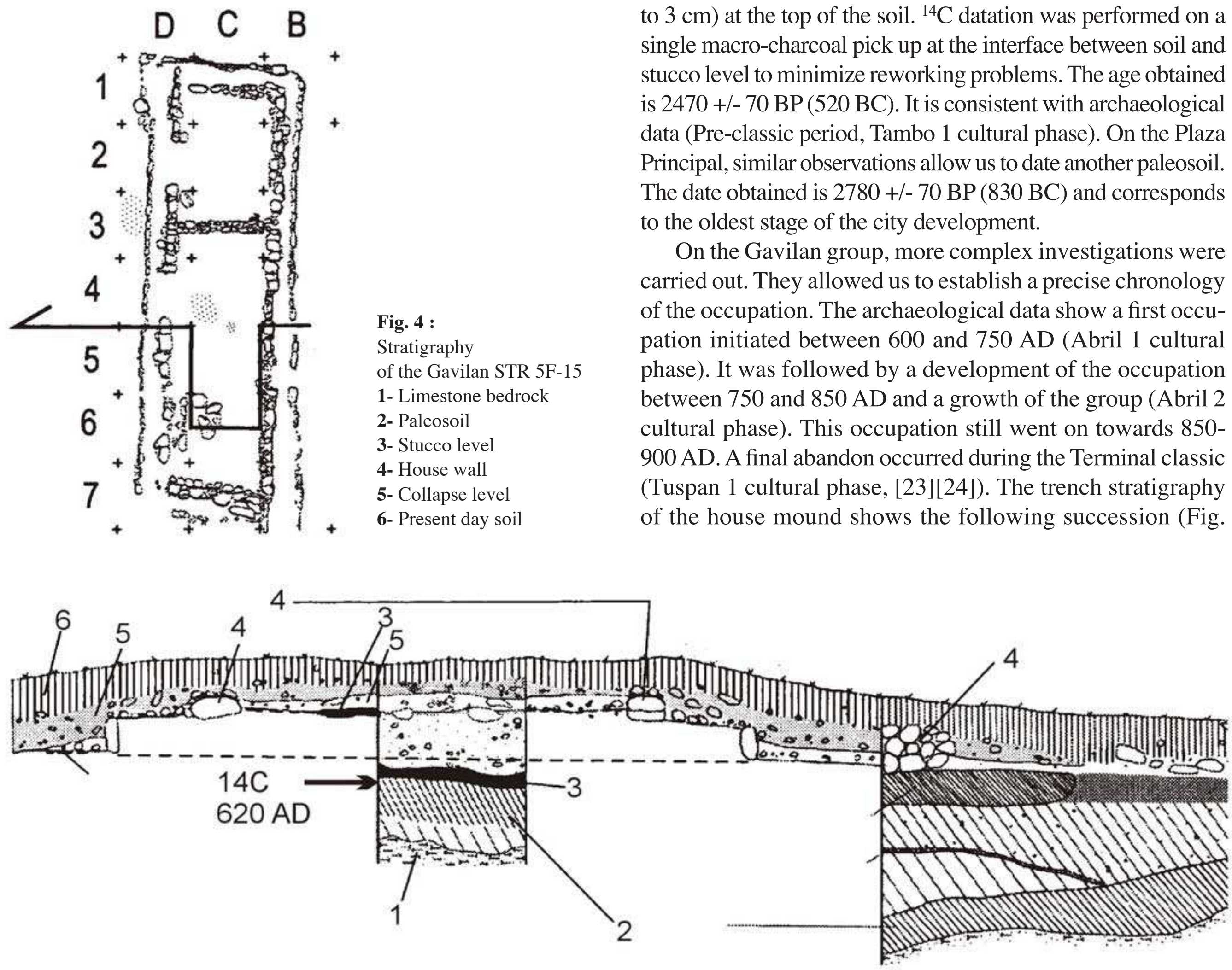


Fig. 4 :
Stratigraphy
of the Gavilan STR 5F-15
1- Limestone bedrock
2- Paleosoil
3- Stucco level
4- House wall
5- Collapse level
6- Present day soil

Lab. number	Deep (cm)	Material dated	$_{14}$C BP	AD/BC calibrated age (+/- 2σ)	Observation
Vera 2833	170	Charcoal	1205 +/- 40	239 (265,375) 423	
Vera 2557	175	Leaf fragment	1635 +/- 30	343 (419) 531	Rejected
Vera 2551	215	Leaf fragment	1650 +/- 35	262 (412) 528	
Vera 2832	232-242	Leaf fragment	1800 +/- 40	94 (238) 340	
Vera 2549	335-340	Leaf fragment	3340 +/- 35	1736 (1677,1673) 1521	Rejected
Vera 2548	452-458	Seed	2995 +/- 35	1375 (1258,1218) 1126	
Vera 2550	537	Leaf fragment	3540 +/- 35	2006 (1882,1834) 1745	Rejected
Beta 166918	635	Wood fragment	3520 +/- 40	1945 (1879,1785) 1703	

Table 2 : AMS radiocarbon determinations from Tuspán core. Calibred age using OxCal [30]

4): Weathered limestone bedrock overlaid by a dark brown argillic level, 0,24 cm high. The superficial soil level shows low carbonate content increasing with depth. The unit is covered by a stucco level reported to the second occupation of the site. As observed in the Guacamaya group, surfacial top soil exhibit macro-charcoals level. ^{14}C dating obtained on one of them gave 1450 +/- 50 BP (620 AD). This age agrees with the archaeological data, which report a first occupation at the Classic (Abril 1 cultural phase). The planimetric excavation lets us show important soil degradation in the outside soil (*patio*). Thus, part of the soil erosion could be directly related to construction and domestic activities.

These data imply i) Initial pre-Maya soils on the meseta were similar to present day soils, calcitic rendzina to mollisol with high clay content. Their thickness is related to the very low insoluble content of the Eocene chalk ii) Soil erosion on the plateau was limited, at least until the end of the Classic period iii) The domestic activities and house building is a possible cause of rapid soil erosion in the city environment iv) The fluvio-karstic network infill could represent a part of the soil erosion products associated with this episode.

4.2.2. Off site *investigation : Tuspán 1 core results*

The Tuspan core was taken in the central part of the Tuspan laguna. It is a 6.50 m long made up of precipitated carbonates ($CaCO_3$) which represents 92,81 to 98,34 %, except for the levels -190/-220, -330/-360 et -390/-410 that correspond to « Maya clays» *sensu stricto*. These levels present a significant reduction in the carbonate content and an increase in clay minerals (mainly kaolinite, smectite and montmorillonite). In opposition with logs data from the north of the Yucatan peninsula and central Petén (Salpeten, Peten-Itza,…), in the Tuspan core "Maya clays" do not constitute a homogeneous unit but a complex sequence showing alternate argillaceous terrigenous inputs and carbonate sedimentation episodes.

The chronology of this sequence is based on 8 radiocarbon dates obtained on terrestrial vegetable remains and charcoals (Table 2). The depth-age relation on these eight dates must be carefully analysed (Fig. 5). Two of these dates, respectively obtained at -3,40 and -5,40 m deep, are not in chronological position. A third one, at -1,70 m deep, shows a significant shift compared to neighbouring dates. These three abnormal dates correspond to organic materials taken into clay levels, corresponding to peaks of magnetic susceptibility and major changes of lithology (Fig. 6). This phenomenon is common in the Yucatan core. We interpret these chronostratigraphic anomalies as a consequence of material reworking phases from superficial storage (soil or karst). These three dates were rejected from the depth-age model. The final depth-age model shows a change in sedimentation rate around 3,60 m deep, corresponding to 800 BC. This shift in sedimentation rate is documented in several lakes and wetlands of the Yucatan peninsula [31][32][33] and in mangroves of the Pacific coast [13]. It could be a consequence of the major climatic change recorded in the Cariaco core [34]. The datations given in this text refer to this depth-age bilinear model.

The recognition of the detritic events is based upon : i) the identification of major lithological and colorimetric changes. This description was used for description of the main events. It shows a very good correlation with the quantitative indicators of lithology. ii) The analysis of magnetic susceptibility. In this case, the changes of lithology associated with the transition between terrigenous clay levels with high ferrous minerals content and the limestones levels are well described by this method. iii) The analysis of the $CaCO_3$ content allows a quantitative approach of the lithological changes variation. It gives a good indicator of the autigene fraction of the sediments. iv) The total organic matter content. This parameter is influenced by two factors. On the one hand, the terrigenous organic matter contribution, resulting from top soil erosion process and on the other hand, organic matter produced *in situ* by the biological activity, especially during eutrophization phases. Taking into account the strong correlation between the total organic content and detrital clay contents, we suppose that the main source of organic matter variation is due to the terrigenous input. On the basis of these indicators, the chronology of the detrital events in the core is established as follows : 1) The lowest part of the core (650-420 cm) shows a succession of terrigenous input events of low frequency and low intensity. They are mainly documented by changes in sediment colour, enrichment in organic matter and minor fluctuations of clay content. The thickness of these levels lies between 0,8 and 2 cm. According to mean sedimentation rate inferred from depth-age model, the average duration between two detrital episodes is about 25 years. During this period, variations in high forest pollen taxa and the variability of *Zea mays* pollen suggest anthropogenic environmental disturbance (Fig. 7). These data suggest rapid displacements of the cultivated zones in a forest landscape. No archaeological data are available to document this period (1600-950 BC). 2) The second period (420-160 cm) corresponds to a change in nature and intensity of the phenomenon and corresponds to high frequency and high intensity cycles. The detrital inputs are massive (mean thickness 22 cm) and separated by phases of carbonate, coinciding with reafforestation, absence or low level of *Zea mays* pollen. It involves the period ranging between 950 BC and 750 AD. The level 210, which marks at the same time the maximum of magnetic susceptibility and the most drastic fall of CO_3Ca content, is located around 450 AD. From an archaeological point of view, this date corresponds to the raising of the royal dynasty of the city according to the discovery of the stele in the Guacamaya group (9.2.10.0.0. in the maya calendar, i.e. 485 AD). 3) The third phase (160-110 cm) corresponds to a return to a situation with low frequency and low intensity events, with three events centred around 1150 AD. In later time, no anthropic disturbance is perceptible, although significant fluctuations of pollens of high forest and sporadic occurrences of heliophyllous plants.

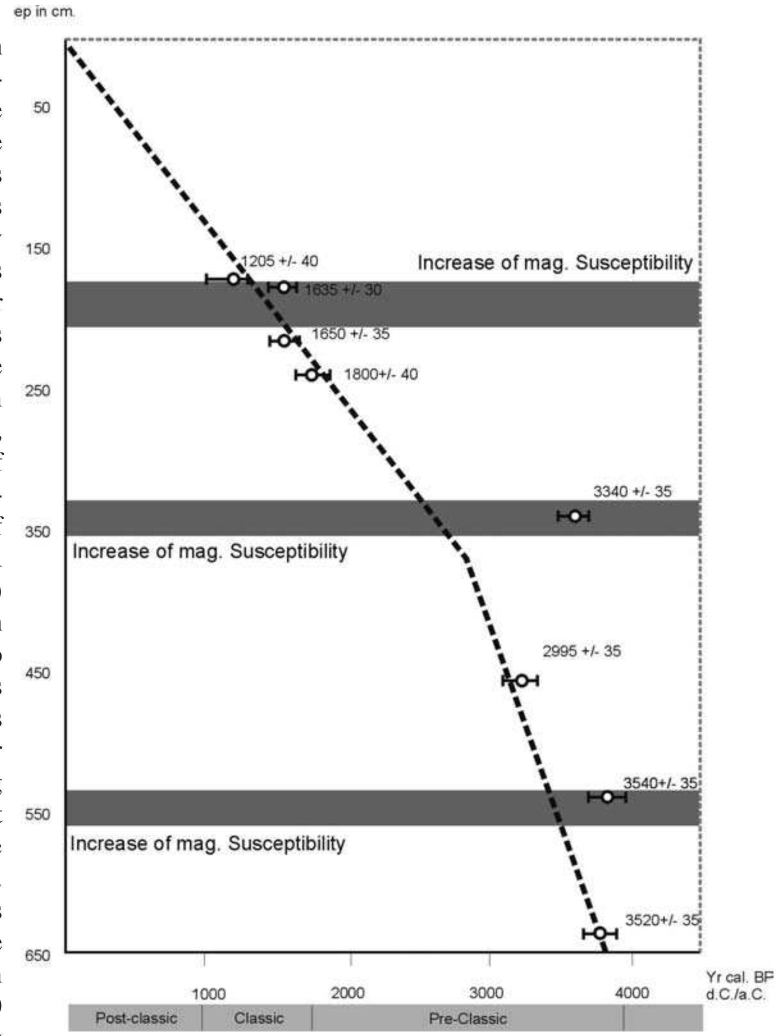


Fig. 5 : Age deep model of Tuspan core. Dash line corresponds to the bi-linear model use for date interpolation. Dark zone are the main detrictic events.

5. Discussion

The coupled study of burring palaeosoils as a consequence of the development of La Joyanca city and correlative detritical sedimentation in lake Tuspan allows to highlight and discuss the signification of the "maya clays". The high sedimentation rate in the lake Tuspan provides a sedimentary record of great quality. The "maya clays" do not represent a homogeneous formation. Major changes recorded in the Tuspan core can be related to socio-economic events documented in the nearby Maya site of La Joyanca (Fig. 6).

The lower part of the sequence, approximately 1700 BC to 950 BC, is probably associated with very low population density. This study shows the oldest evidence of slash and burn cultivation in the Maya lowlands. Moreover, it documents the practice of a long fallow, ranging from approximately 25 to 30 years according to mean sedimentation rate. The landscapes remain marked by a significant high forest cover and the presence of *guamil* pioneer plants such as *Cecropia* (Fig. 7). This management practice minimizes the impact on soil in a monsoon tropical zone. Thus, the impact on soil erosion seems to be weak during this period. The well-preserved paleosoil of Plaza Principal (820 BC) attests the absence of significant erosion until the beginning of the first millennium BC, whereas the cultivation has been attested for at least 900 years ago. In the absence of archaeological information associated with this period, probably because of the use of perishable materials, it is not possible to specify the type of occupation.

Between 950 BC and 450 AD, the decrease of tree pollens and the sporadic argillaceous sediments input in the Tuspan lake results of more severe soil erosion phases. This major change can be interpreted in different ways. As it coincides with the first construction in the monumental centre of La Joyanca, attested in Plaza Principal (820 BC), this transformation can attest that a significant amount of soil erosion could be the result of the urban growth, associated with soil proofing (stucco). Moreover this state could document a first increase in the demography of the city implying land management

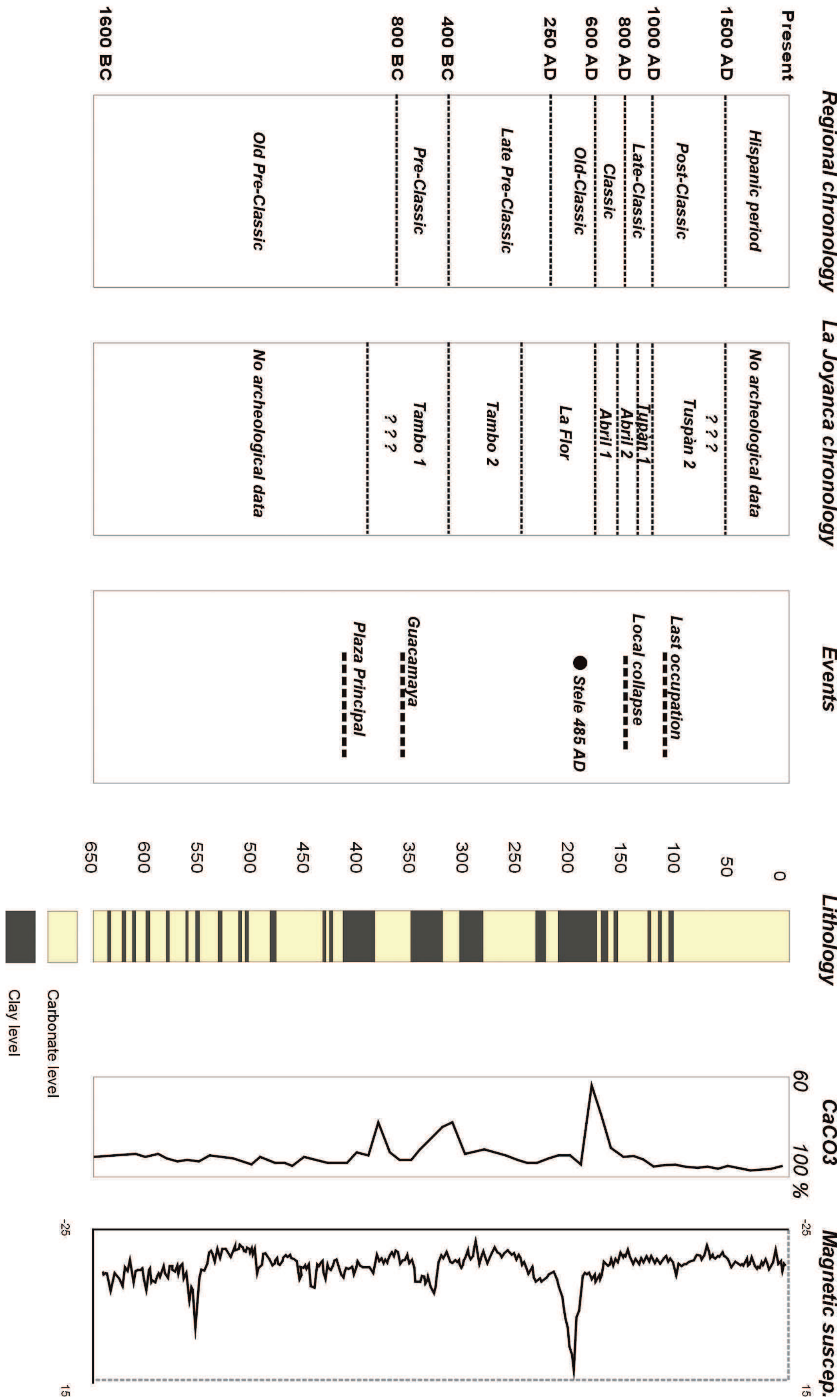


Fig. 6 : Stratigraphic analysis of the Tuspan core.

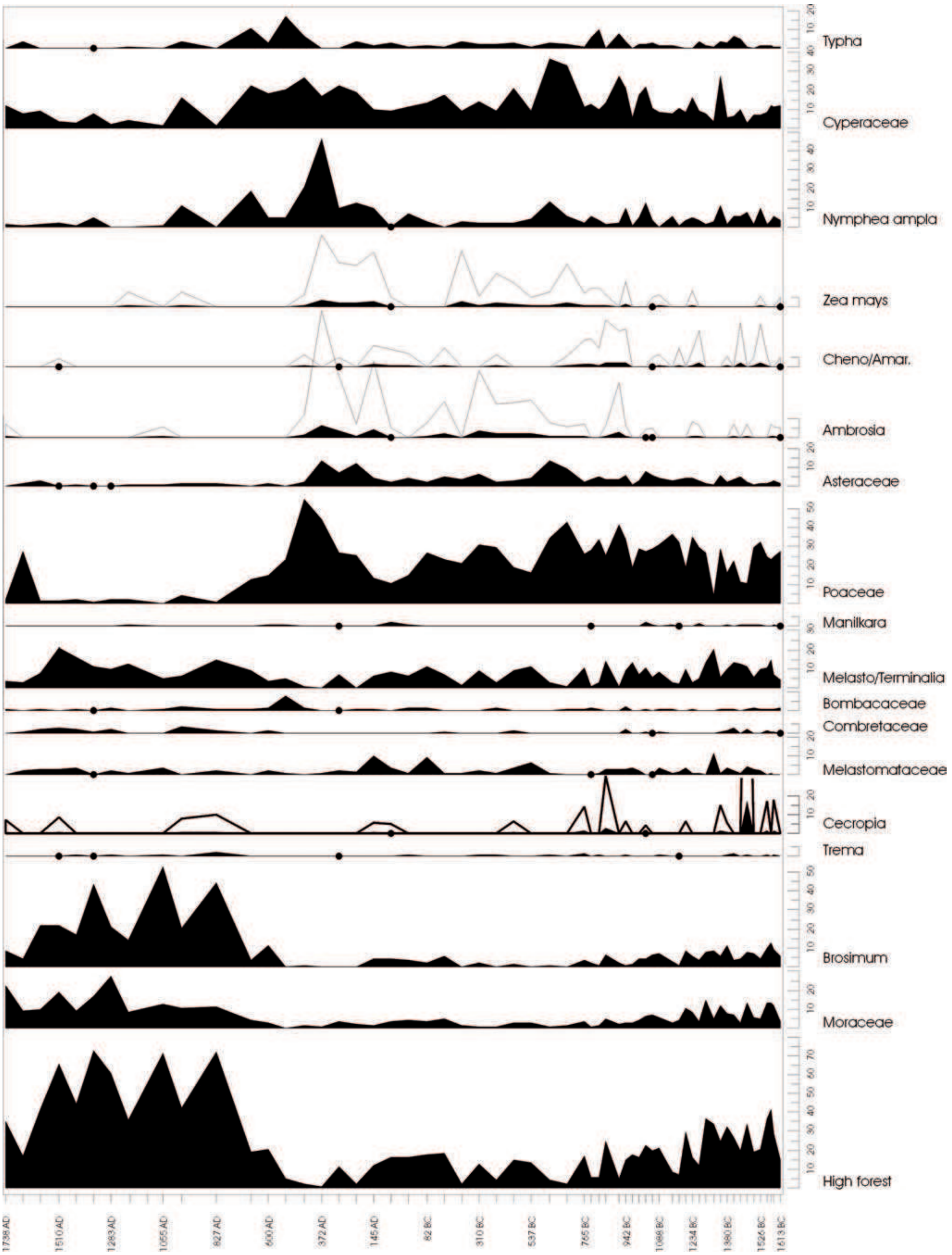


Fig. 7 : Simplified pollen diagram from Tuspan core.

transformation. Cultivation extensiveness [35], i.e. a significant increase of the *milpa* surface within Tuspan lake catchment, could be a response to the demographic growth. This idea is supported by the continuation of tree pollen decrease and by isotopic ^{13}C analysis of the Tuspan core (Carozza *et al.*, in progress). The increase of cultivate surface within the Tuspan lake catchment has as a consequence an increase in detrictic inputs into the lake without change in erosion rate. However as pointed out by Beach and Dunning, this period appears as a major stage in the Maya territories structuring and land management innovation. The low detritic input during a large period of the Old-classic and Late Pre-classic (fig. 6) implies the adaptation of cultivation practices to minimize soil erosion. Recent geoarchaeological data make it possible to consider an agrarian system more diversified and adapted to the variety of the environments [18][36][37]. Practices of *house gardening, infield gardening* and *outfield gardening* are known in the Maya area. The *outfield milpa* based on slash and burn cultivation is only a part of the food resources, strongly dependent on the distribution of well-drained soils [19].

Between 220 AD to 290 AD, the signs of reafforestation suggest a decrease of the *milpa* surface and a correlative decrease of population (Proto-Classic crisis ?). Archaeological evidences of abandonment are very few and do only occur in the Plaza Principal. Between 380 and 450 AD the most significant erosive crisis of the sequence occurs. It is associated with a total high forest clearing attesting a new phase of *milpa* surface extension and coincides with the major social transformation of the city (royal dynastic statute at 485 AD) and significant growing phase of the city. However, the information collected on the site of Gavilan must temperate the signification of this erosion phase. Indeed, since towards 650 AD, soils had been, at least locally, preserved and no structural degradation is noticed.

From 760 AD, the stop of the detritical inputs and rapid reafforestation constitute the local evidence of the regional *collapse*. This interpretation is partially confirmed by the archaeological data. The stop of monumental building and the end of occupation of some groups like *Cojolita*, *Tortuga* y T*ucan*, let us to consider political and/or demographic transformation. Post-classic reoccupations are well documented in some groups of the site. These occupations are also attested by the geoarchaeologic data. At the bottom of La Joyanca meseta a major colluvial deposition phase is documented around 1150. This sequence was dated by ^{14}C. This latest anthropic impact is also recorded in the Tuspan core by three small detrital events from 1060 to 1200 AD. In a context of demographic decay, it could suggest a return to conditions of low environmental and social constraints.

The data collected in the area of La Joyanca site lead to temperate the idea of a drastic erosional crisis associated with the demographic increase from Late Pre-classic to Terminal Classic period. Locally, the geomorphological context of the site, in particular the absence of weak slope, constitutes a factor of explanation. This result is also coherent with the data collected in others geomorphological contexts in Petén , as in Piedras Negras, where δC13 analyses suggest old soils. They would have preserved part of the organic matter inherited from the forestal phase former to the corn culture (profile of the group "Planada" [38]). On this assumption, the soil erosion consecutive of the Maya colonization would have had a limited impact. It is compatible with the maintenance of agriculture over one long period of more than two millennium such as it is observed in La Joyanca.

The changes of rate of soil erosion seem narrowly correlated with the agricultural practices and socio-political and economic evolution of La Joyanca, which thus constitute a key of the interpretation of "Maya clays". Other factors, most of them climatic, seem of secondary importance.

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