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PALYNOLOGICAL CHARACTERIZATION OF THE PO DELTA SUCCESSION (NORTHERN ITALY): HOLOCENE VEGETATION DYNAMICS, STRATIGRAPHIC PATTERNS AND PALAEOCLIMATE VARIABILITY

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ABSTRACT: The 40 m-long core EM2, recovered in the innermost portion of Po delta plain, was sampled for palynological analysis, in order to link coastal-deltaic facies architecture to vegetation dynamics and Holocene climate variability. Pollen data refine facies characterization of the 25 m-thick Holocene succession: freshwater swamp clays alternating with overbank/channel sands document millennial to centennial-scale water table oscillations that invariably peak in correspondence of peaty layers. Pollen signature allows identification of the landward equivalent of the Maximum Flooding Surface atop the 7.6 ka-dated peaty interval and furnishes new insights on the relationship between coastal facies patterns and climate events.

KEYWORDS: Palynology, Holocene, Po delta plain, climate events, sequence stratigraphy

1. INTRODUCTION

Mediterranean delta plains are considered natural archives of the interactions between Holocene depositional, climate and human dynamics. In these regions, the combined effect of high sea-level conditions, remarkable rates of subsidence and sediment supply led to the deposition of stratigraphically expanded, relatively continuous fine-grained sedimentary successions, useful for high-resolution palaeoenvironmental and stratigraphic reconstructions.

The Po delta plain is one of the most studied Mediterranean deltas. A detailed characterization of sedimentary facies and a high-resolution sequence-stratigraphic framework (with the identification of a set of millennial-scale parasequences) is available for the 10-30 m-thick Holocene succession (Amorosi et al., 2017). However, the relationships between parasequence development and the well-known millennial-scale climate variability (Bond's events *sensu* Bond et al., 1997) are still matter of debate. Furthermore, palynology is a relatively unexplored stratigraphic tool for the identification of flooding surfaces within successions devoid of marine -influenced facies. Through an integrated palynological-stratigraphic approach, this study aims to reconstruct post-glacial stratigraphic patterns at the landward margin of the Po Delta and to unravel their relations with Holocene climate events.

2. MATERIAL AND METHODS

A 40 m-long core, recovered in the innermost portion of the Po delta plain (core EM2), was selected for palynological analysis, being composed of a ~25 m thick, chronologically well constrained (9 radiocarbon ages) paludal succession, framed into a robust stratigraphic context and dated to last ~13 ka (Amorosi et al., 2017; Bruno et al., 2017). Thirty-seven samples were collected, with special focus on organic-rich, fine-grained intervals, where a rich palynological association was expected. About 3-9 g of dry sediment per sample were weighed and then a *Lycopodium* tablet was added to calculate pollen concentration. Samples were mechanically disrupted in a 10% Na-pyrophosphate solution and filtered. Then, each sample underwent the following treatments: 10% HCl solution, acetolysis, enrichment with a heavy liquid, 40% HF solution, ethanol suspension and evaporation at 60 °C. Finally, microscope slides were prepared with glycerine jelly and paraffin. For each sample, at least 300 grains were counted and recognised after Reille (1992). Species ecological characterisation and pollen groups were based on Pignatti (1982, 2017). On the other hand, non-arboreal pollen (NAP) was split into herbaceous plants (H) and shrubs (sh) to better estimate the canopy thickness.

3. POLLEN SEQUENCE

The EM2 pollen spectra reported in Fig. 1 confirm the persistence, at the study site, of freshwater conditions throughout the Holocene (absence of halophytes) and highlight the vertical succession of fifteen Pollen Zones-PZs that correspond to distinct vegetation phases. In particular, a series of Lateglacial-Holocene climatic events were identified by combining high-frequency changes in relative abundance of specific pollen groups (Fig. 1) with the available radiocarbon ages. All these events are marked by relative peak concentrations of montane trees-MT (6-10%) and/or cold steppe taxa-CST (3-8%), indicative of sudden cooling, sharply followed by

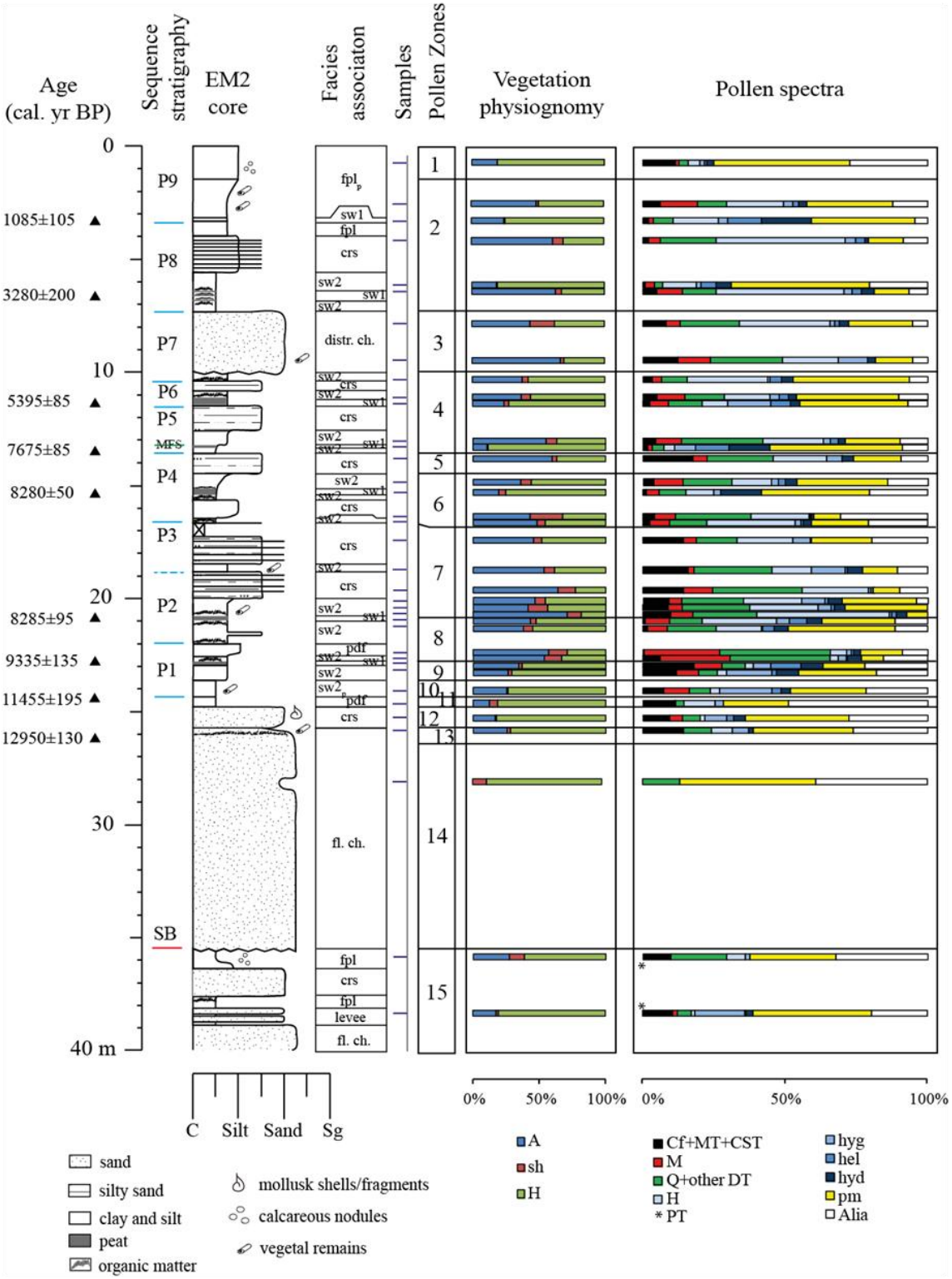

Fig. 1 - Sedimentology and pollen characteristics of core EM2: PT (Pleistocene taxa), Cf (conifers) MT (montane trees), CST (cold steppe taxa), M (Mediterranean trees), Q+other DT (mixed-oak forest and other deciduous trees), H (woody hygrophytes), hyg (herbaceous hygrophytes), hel (helophytes), hyd (hydrophytes), pm (pasture-meadow). Facies: fl. ch. (fluvial channel), distr. ch. (distributary channel), crs (crevasse splay), fpl (floodplain), pdf (poorly-drained floodplain), sw (swamp). The “p” subscript indicates a weakly pedogenised deposit. PS: parasequence (light blue lines are parasequence boundaries; dotted lines indicate minor flooding surfaces). MFS: Maximum Flooding Surface. SB: Sequence boundary from Bruno et al. (2017).

high percentages of climate optimum indicators (i.e., holm oak-mixed-oak forest, M-Q+other DT) within a relatively continuous stratigraphic interval, a few tens of centimetres thick. Along the core, conifers show similar vertical variations relative to MT+CST and, thus, were interpreted as a regional pollen rain, analogous to the cold indicators *sensu stricto*.

The oldest cold spell (PZ 13), chronologically attributed to the Younger Dryas event, occurs within the uppermost portion of the fluvial channel succession deposited under Glacial-Lateglacial conditions (Amorosi et al., 2017; PZs 14-13) and observed between ~35.5-26 m core depth (Fig. 1).

The overlying, 25 m-thick sedimentary succession, composed of alternating swamp clays and overbank/channel sands is assigned to the Holocene period, based on combined radiocarbon ages and pollen data (PZs 12-1), the latter reflecting an overall climate-optimum-like vegetal landscape. However, three distinct phases of rapid cooling are recognised and reasonably ascribed to the Preboreal Oscillation (PZ 11), Boreal Oscillation (PZ 9) and 8.2 ka event (PZ 7), respectively. More uncertain are dating and interpretation of other two cooling events recorded by PZs 5 and 3.

Finally, a relatively high concentration of MT and CST (7% total), paralleled by a sharp decrease in holm oak (from 13% to 1%), is recorded at the top (1 m) of the cored succession, within pedogenized floodplain deposits, possibly documenting the Little Ice Age event.

4. HOLOCENE VEGETATION DYNAMICS AND FACIES STACKING PATTERNS

The palynological analysis also refines facies characterization, especially of fine-grained deposits, allowing the distinction between poorly drained floodplain facies, characterised by the absence or scarcity of helophytes and hydrophytes, and swamp clays. Moreover, two types of swamp deposits were identified within the Holocene succession on the basis of the relative abundances of woody and herbaceous hygrophytes, helophytes and hydrophytes:

- *Peaty swamp* **(sw1)**: herbaceous wetland community with sparse alder carrs tolerating prolonged periods of radical drowning (helophytes) or aquatic plants (hydrophytes); subordinate hygrophytes, Poaceae and alder (mixed or not) bordering the locally flooded depressions. This pollen assemblage, invariably recorded within peaty layers (~10-30 cm thick), indicates relatively high water table conditions.
- *Swamp* **(sw2)**: open to dense alder carr with a mixed oak-holm oak ecological component in subordinate position. This pollen assemblage, found within organic-rich grey to dark grey clays, documents a relatively low water table.

Throughout the Holocene succession, sw1 peats are vertically constrained between sw2 clays, which in turn are commonly overlain by crevasse splays or distributary-channel sandy deposits containing a pollen assemblage indicative of a hygrophilous, open to dense mixed oak-holm oak forest. This repeated stacking pattern of facies tracks short-term (millennial to sub-millennial scale) oscillations in the relative water table, allowing the identification of small-scale, T-R depositional cycles (i.e., parasequences bounded by flooding surfaces-FSs) in a fully freshwater sequence.

Specifically, each cycle is composed of basal sw2 grey-dark grey clays, commonly showing an upward increase in dispersed organic matter, and culminates into a peaty interval (sw1 that reflects the most drowned conditions). Upwards, a shallowing-upward trend is identified by pollen data, marking the progradational part of the parasequence (PS).

Furthermore, an overall increase in water table was recorded from the oldest swamp (dated around 11455±195 cal yrs BP) to the swamp recorded at ~13.35 m core depth and dated to 7675±75 cal yrs BP. This deepening-upward trend is considered as the sedimentary expression of the Maximum Flooding Surface - MFS at proximal locations. Upwards, swamps generally show less developed peat accumulation and a lower water table relative to the underlying transgressive swamps.

5. DISCUSSION AND CONCLUSIONS

Diagnostic changes in vegetation patterns enable the precise documentation of parasequence development at the landward margin of the Po delta plain during the Holocene. Therefore, because of the absence of meiofauna and molluscs in this freshwater paludal succession, the sequence-stratigraphic refinement at a millennial – sub-millennial scale was performed by palynological analysis.

Throughout core EM2, the relative abundances of woody and herbaceous hygrophytes, helophytes and hydrophytes record alternating periods of rising water table (i.e., flooding events), which peak in correspondence of cm to dm-thick peaty swamp intervals (i.e., the most drowned conditions within each PS), and which subsequently decreases. The highest relative water table was reached atop the peaty swamp deposit belonging to PS 4 and dated to ~7600 cal yrs BP (Fig. 1), which separates a set of transgressive parasequences from the highstand ones. Highstand parasequences are characterised by the development of peaty swamp intervals under lower water table conditions, reflecting the general progradation of the Po Delta system during the mid-late Holocene. These data, supported by the chronological and the stratigraphic frameworks available for the entire study area (Amorosi et al., 2017; Bruno et al., 2017; Campo et al., 2017), suggest a strong allogenic control (i.e., glacio-eustatic oscillations at the Milankovitch time-scale) on depositional dynamics ca. 35 km upstream from the modern coastline.

A unique exception is the uppermost peaty layer, recorded at 3 m core depth and dated to ~1000-1100 cal yrs BP, which reflects the local establishment of a high water table possibly related to the historical Po River avulsion in Ficarolo. The northward shift of the Po River system and the subsequent marked reduction in sediment supply reasonably induced the flooding of the southern portion of the subsiding Po delta plain, where EM2 core was recovered.

The comparison between stratigraphic and pollen-derived climatic data documents a complex interaction

between parasequence development and Holocene climate events. Not all peats (sw1-peaty swamps) developed under mild conditions, suggesting the influence of other driving mechanisms, such as early Holocene eustatic jumps (MWP-Melt Water Pulse) and autogenic factors. On the other hand, the thick alluvial successions in the uppermost portions of PSs 2, 3 and 6 saw the development of cool-temperate communities, the eldest of which was chronologically constrained to the 8.2 ka event. As a whole the three PSs suggest a strong sedimentary response to these short-term phases of climatic cooling in terms of increased sedimentary input and partial filling of paludal basins.

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