The record of the latter glacial and interglacial periods in the Guadalquivir marshlands (Mari López drilling, S.W. Spain)

El registro de los últimos períodos glaciares e interglaciares en las marismas del Guadalquivir (sondeo Mari López, S.O. de España).


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RESUMEN

El estudio de un sondeo de 65 m en las marismas del Guadalquivir permite reconocer siete intervalos que reflejan cambios climáticos y eustáticos e intensa neotectónica durante tres periodos interglaciares (IS 7.1, 5 y 1) y dos glaciares (IS 6 y 8-7rs, 8s 4, y 3 y 2-Würm). Se discute el valor de las ‘vetas’ como indicadores geofísicos.

Key words: Glacial, Interglacial, radiocarbon, estuary, Pleistocene, Holocene, Doñana

Geogaceta, 26 (1999), 119-122
ISSN: 0213-3683X

Introduction

The geological history of the Plio-Quaternary sediments of Guadalquivir marshland (marisma) is poorly known partly due to the monotonous lithology and the tectonic complexity of the basin. Salvan y Custodio (1995) correlated hydrological drillings and offered geological sections distinguishing four Units: Deltaic (Middle-Late Pliocene/Early Pleistocene), Alluvial (Late Pleistocene), Aeolian (Pleistocene/Holocene), and Marsh (Holocene).

The present Guadalquivir estuary (Fig. 1) is enclosed by the spits of Doñana and La Algaida (Lario, 1996, Rodríguez Ramírez et al., 1996, Zazo et al., 1996). After the maximum of the Flandrian transgression (ca. 6.500 ¹⁰C yr BP), the estuaries in the Gulf of Cadiz experienced vertical aggradation until, ca. 2.500 ¹⁰C yr BP, when coastal progradation and growth of spits prevailed (Zazo et al., 1996). The estuarine barriers have been repeatedly studied (Goy et al., 1996, Lario, 1996, Rodríguez Ramírez et al., 1996) since Zazo et al. (1994) defined four spit units aged (reservoir effect corrected), ¹⁰H: 6.500-4.400 ¹⁰C yr BP; ¹⁰H: 6.500-4.400 ¹⁰C yr BP; ¹⁰H: 4.200-2.550 ¹⁰C yr BP; ¹⁰H: 2.300-800 ¹⁰C yr BP, and late cali-

Figure 1.- Geological map of the Guadalquivir marshland. Paleogene-Neogene includes olistostromes and allochthonous rocks. Key: (VC) Veta Carrizosa; (LN) Veta Las Nuevas-Tarajales; (LZ) Veta Los Zorros; (VQ) Veta Quemada; (VL) Vetaelguia, (GM) Guadiamar-Matalascañas.

brated by Borja et al. (1999). Dabrio et al. (in press) studied the post-glacial evolution of the Odiel-Tinto and Guadalete estuaries.

We offer the first palaeoenvironmental evolution of the Pleistocene–Holocene Guadalquivir estuary, based on the study of a 65 m-deep drilling, with additional information from other sources.

Geological setting

The semidirunal mesotidal coast of the Gulf of Cadiz is of medium wave-energy, but prevailing south-westerly winds induce longshore drift and growth of spits to the south-east. The continental shelf extends 45 km, down to 130 m water depth, with average slopes of 0.28% (Rodríguez Ramírez, 1996).

The marshland covers 1,800 Km² with topographic elevations below +4 m (Fig. 1). Fluvial outflow in middle 19th Century concentrated in the channels of Brazo del Este and Guadalquivir, whereas the flood tide entered the Brazo de la Torre to Isla Mayor (García Otero, 1847) and flooded the marshland, particularly in spring equinoxial tides. Silting up and public works have confined the tidal influence to the river channel.

Below the marshland, Plio-Quaternary deposits up to 300 m thick overlay unconformably the Late Miocene–Early Pliocene blue marls (Salvany and Custodio, 1995) and the olistostrome. Palaeozoic and Mesozoic rocks form the basement of the basin. Geomorphology and stratigraphic architecture of deposits evidence neotectonic activity at least until the Late Pleistocene along normal faults, promoting a domino tectonics that controls the drainage pattern of rivers and the present coastline. The most relevant faults are: (a) the E-W faults of Torre del Loro (Goy et al., 1994, Zazo et al., 1997, Zazo et al., in press) and Hato Blanco [first deduced by Salvany and Custodio (1995), but named in this paper] located by geomorphological criteria; (b) the NNE-SSW faults of Guadiamar-Matalascañas (vertical offset ca. 150 m, Salvany and Custodio, 1995) and Bajo Guadalquivir (Viguier, 1977, Zazo et al., 1985); and (c) the NW-SE system (Goy et al., 1994, Flores and Rodríguez Vidal, 1994).

Figure 2.- Stratigraphic section of the Mari López drill core.

Figura 2.- Columna estratigráfica del sondeo Mari López.
<table>
<thead>
<tr>
<th>Estuvar de Guadalquivir</th>
<th>Sample code</th>
<th>Locality</th>
<th>Laboratory code</th>
<th>²³⁰⁳⁰e yr (a)</th>
<th>Error yr ±</th>
<th>Cal BP age</th>
<th>³⁶⁰⁸⁰e (% PDB)</th>
<th>Material sampled</th>
<th>Depth (m)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt Marsh</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Drill core ML 97</td>
<td>Mari López</td>
<td>GX-238339*</td>
<td>3915</td>
<td>50</td>
<td>3827</td>
<td>-1.9</td>
<td>Shell</td>
<td>7.3</td>
<td></td>
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<td>GX-23840-A*</td>
<td>5370</td>
<td>50</td>
<td>5680</td>
<td>+0.4</td>
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<td>10.8</td>
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<tr>
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<td>Mari López</td>
<td>GX-23841*</td>
<td>47600</td>
<td>3100</td>
<td>47600</td>
<td>-5.8</td>
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<td>27.49</td>
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<td>Drill core LPI3-1</td>
<td>Lucio El Pescador</td>
<td>UC-4028*</td>
<td>2400</td>
<td>60</td>
<td>2620</td>
<td>-2.9</td>
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<tr>
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<td>Lucio El Pescador</td>
<td>UC-4031*</td>
<td>2400</td>
<td>105</td>
<td>2720</td>
<td>-2.9</td>
<td>Shell</td>
<td>7.3</td>
<td></td>
<td>(1)</td>
</tr>
</tbody>
</table>

| Ridges ('retes')       |            |          |                 |               |            |           |              |                |           |           |
| Trench MD-1**          | Mari López | UC-4024*  | 3240            | 100           | 3570       | -1.87     | Shell       | 0.40           | (2)       |           |
| Trench MD-2**          | Mari López | UC-4177*  | 2750            | 100           | 2930       | -7.3      | Shell       | 1.0            | (2)       |           |
| Trench VL-1            | Vetelengu | GX-21822  | 1625            | 115           | 1170       | -0.4      | Shell       | 0.25           | (2)       |           |
| Surface                | Vetelengu | R-2283    | 1750            | 90            | -          | -         | Shell       | 0             | (3)       |           |
| Surface                | Vetelengu | Beta-88016| 1750            | 105           | -          | -         | Shell       | 0             | (3)       |           |
| Surface                | Las Nuevas (Tarsijas) | GX-21823 | 1960            | 120           | 1510       | 0.2       | Shell       | 0             | (2)       |           |
| Trench                | Las Nuevas (Tarsijas) | GX-21824 | 1955            | 80            | 1500       | -1.3      | Shell       | 0.5            | (2)       |           |
| Surface                | Los Zorros | GX-21825 | 2895            | 75            | 2700       | 0.3       | Shell       | 0             | (2)       |           |
| Surface                | Huerto del Caro | GX-21826 | 2100            | 110           | 1550       | 0.1       | Shell       | 0             | (2)       |           |
| Surface                | Veta Quemada | GX-21828 | 3160            | 130           | 2950       | -0.4      | Shell       | 0             | (2)       |           |
| Trench                | Veta Quemada | GX-21828 | 3180            | 85            | 2950       | 0.2       | Shell       | 0.1            | (2)       |           |
| Surface                | Carrizosa | R-2273    | 4548            | 59            | -          | -         | Shell       | 0             | (3)       |           |

Table 1.- Data base of ¹⁴C results, (1) Dubrio et al. (in press), (2) Dubrio et al. (1996), (3) Rodriguez Ramirez (1996). (m) Depth in meters below MSL (high-tide mark); (a) reservoir effect corrected (-440 ± 85 yr BP); (*M*): AMS; (**): Reworked sample. Laboratories: (GX) Geochron Laboratories, Krueger Enterprises, Inc., Cambridge (USA); (UI) Utrecht Van der Graaf (The Netherlands); (R) Centro di Studio per la Geodinamica Applicata a la Stratigrafia Recent; (CRN) Dipartimento Fisica, Universita “La Sapienza”, Roma (Italy); (Beta) Beta Analytic Inc. Miami, FL (USA).

Methods

The borehole Mari López (ML-97, co-ordinates: 37°01'23"N, 6°19'56"W, elevation +2.5 m AMSL) was drilled using a rotation rig with core diameter 65 mm, to a depth of 65 m with continuous recovering. It is 400 m S.E. of the well ‘Lucio de Mari López, Almonte’ described by Menanteau (1979) and Salvany and Custodio (1995). We gathered information from cores of the neighbouring Lucio del Lobo, Lucio del Pescador (Lario, 1996), and Marismillas (Fig. 1), and trenches in Doñana (Zazo et al., 1994, Borja et al., 1999) and La Algaida (Rodriguez Ramirez, 1996) spits.

This study includes: (1) geological mapping of morpho-sedimentary units, (2) micropaleoecology (foraminifera and ostracods), macropaleoecology (including taphonomy), and palynology, (3) palaeomagnetism, particularly magnetic susceptibility, (4) mineralogical and textural analyses, (5) ²³⁰³⁰e dating with accelerator mass spectrometry (AMS), (Table 1). Ages expressed in ²³⁰³⁰e yr BP are normalised and corrected for marine reservoir effect (Table 1).

Palaeoenvironmental interpretation and chronostatigraphic results

According to our data from the neighbouring Lucio del Lobo drill core (Fig. 1), all the penetrated deposits are inside the Brunes period of positive polarity. The magnetic susceptibility (MS) log shows a high anomaly (39.60 to 42.15 m) related to a notable increase in oxidative magnetic matter (Walkley and Black modified technique), but does not clearly depict the peak at 11.90 m due to increased K and ²³⁰³⁰e Th.

We distinguish eight intervals, with limits at depths ca. 60, 54, 39, 27, 17, 11 and 9 m (Fig. 2).

Interval 65 (bottom) to 60 m is azoic. Predominance of quartz and feldspars upon scarce siltoclastites and carbonates suggest deposition in clean, fluvial waters. This must represent the Isotopic Stage (IS) 7.

Interval 60 to 54 m. Ammonia sp., Cyprides sp. and Leptocythere sp. characterise a fresh-water lake between 60 and 43 m. The pollen assemblage is typical of a glacial period, with Pinsus as a principal arboreal component and dominance of herbaceous steppe-like taxa such Artemisia. We interpret it as IS 6 (Riss).

Interval 54 to 39 m. Increase phylloclades and an oscillating decrease of quartz and feldspars (potassic and plagioclase) suggest more suspended load with frequent phases of settling of micas in a low-energy lake. Hauffenia sp. and Cyprides torosa (43-39 m), dolomite and gypsum indicate brackish waters. The increase of Quercus pollen points to a more temperate climate and ample vegetal rims around the lakes. We interpret the warm event as Last Interglacial (IS 5), but its upper limit is uncertain.

Interval 39 to 27 m. Mineralogy evidences a quiet marsh environment dominated by settling, in fresh to brackish waters witnessed by ostracods (Loxonohnia, Cyprides L. Leptocythere), charophytes in two samples, reduced dolomite contents and absence of gypsum. Abundant macrofauna (Ostrea, Cardium edule) and microfauna (Ammonia-Elphidium-Haynese) between 29 and 26.5 m suggest marine influence. We do not imply that the sea reached this elevation, but it should be close to it, and we interpret the alternations of fresh and brackish waters as eustatic oscillations with highstands below the present. As the age of sample ML 97, GX-23841 (47,400 ±3100, Table 1) is Last Glacial (Würm, probably IS 4), we correlate these oscillations with either one of the rapid glacial retreats at 55-45 Ka (Duplessy et al., 1998) or the highstand cited by Somoza et al. (1997) at ca. 60 Ka.

Interval 27 to 17 m. Detrital minerals (quartz, feldspar) increase at 27 m, followed upward by at least four 'pulses' or sequences marked by small increments of detrital minerals, calcite and dolomite. Fauna and pollen are very scarce. We date this interval as IS 3 and correlate the event of marine influence at 19.75-20 m, indicated by millilioids and bryozoans with a glacial retreat at ca. 33 Ka cited by Duplessy et al. (1998). We place the base of IS 2 (ca. 25 Ka) at 19m during subaerial exposure marked by fauna.

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Interval 17 to 11 m. We interpret the change of colour and fauna, and the increase of sand at <17 m as the Last Glacial Period (ca. 18 Ka) when sea level dropped 125 m in this area (Somoza et al., 1997) and the sea retreated 46.5 km.

Interval 11 to 9 m. An erosional surface at <11 m marks the Flandrian flooding surface overlain by a diversity of marine shells aged 5.370±0.50 C4 BP (Tab. 1).

Interval 9 to 0 m (top). Halite, dolomite, some gypsum, macro and microfossils indicate restricted, brackish conditions in the muddy marsh where clay and mica prevail upon quartz and feldspar. The monotonous AP/NAP (ArboREAL Pollen/Non ArboREAL Pollen) general index and specific taxa curves suggest a stable landscape physiognomy throughout this period until 2.15 m. In contrast, the increase in herbaceous taxa, the disappearance of Ericaceae (heather), and the progressive substitution of evergreen Quercus (Kermes oak) by Juniperus and Pinus (pine) in the topmost 2.15 m reflect unequivocally the impact of recent human populations. The prevalence of the fluvial input upon vertical accretion ca. 3.000-2.500 yr BP (H2H4) caused restriction of marshes and a rapid growth of the estuarine barriers.

Linear ridges (vetas), shell accumulations and recent palaeogeographical evolution

Interpretations of the Late Holocene evolution of the estuary relay on geomorphology, paleontology and radiocarbon dating of recent morpho-sedimentary units, particularly the narrow, linear, elongated sandbar ridges (the so-called vetra, Fig. 1) that barely rise 1.5 m above the muddy marsh (‘matismas’) and remain emergent during winter floods. Well preserved ridges follow former fluvial distributary channels. Geomorphological analysis demonstrates that the ridges generated as levees of channels, as suggested by Menanteau (1979). Accumulations, less than 25 cm thick, of shells pertaining to mixed biotopes (Nassarius reticulatus, Murex brandaris, Trunculariopsis truncula, Bittium reticulatum, Ostrea sp., Cardium cf. glaucum, Glycymeris glycymeris, Dentalium) cover the flanks of the ridges and the closest part of the adjacent marsh that face the prevailing winds from SW (Veta Quemada, Veta del Lucio de Mari López) and E/SE (Veta de los Zorros and Las Nuevas). They are characterized as early invertebrates and microfossils removed from the flat bottom of the marshes and accumulated them on the elevated levees, with gently inclined parallel lamination. This implies that, radiocarbon dating is inadequate. Besides, the shallow-marine Glycymeris shells (that are usually collected for radiometric dating, Table 1) appear to have been carried by people to the inland vetra and used to pave the floor of huts, a cheap insulator still visible near Las Marismillas. Most huts have been demolished recently leaving behind the Glycymeris shells until run-off moved them to the thalassocoenosis at the toe of the ridge.

Conclusions

A multidisciplinary study of Mari López drill core permitted to recognise seven intervals, with limits at depths ca. 60, 54, 39, 27, 17, 11 and 9 m, that represent changing eustasy, climate, and neotectonics during two Glacial (Riss and Wurm) and three Interglacial (77, 5, and 1) Periods. Accordingly, the ‘Marismas’ unit (Salvany and Custodio, 1995) began to form at least in the Middle Pleistocene.

Neotectonic activity of NNE–SSW (Bajo Guadalquivir and Guadalquivir–Matalacñas faults), E–W (TOR del Loro and Hato Blanco faults), and NW–SE fault systems in Middle–Late Pleistocene, together with eustatic oscillations explain the environmental pattern during I5 and I1 and the absence of Last Interglacial marine deposits.

We interpret the linear ridges (vetas) as fluvial levees, where storms and men mixed shells from diverse biotopes radically changes key assumptions concerning the genesis of the Holocene Guadalquivir estuary, namely: (a) The occurrence of Glycymeris does not necessarily indicate palaeocoastlines (as in Rodríguez Ramírez et al., 1996); (b) The radiometric ages of Glycymeris shells collected from the ridges are unreliable palaeoecological indicators.

Acknowledgements


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