Geomorphological and Sedimentological Evolution of the *Ramsar*-Listed Wetland Reserve "Laguna de El Conde" (Córdoba, Spain)

J.M. Recio Espejo[*,1], A. Martínez Camero[2] and J. Gil Torres[2]

[1]*Ecology (Physical Geography-Geomorphology). University of Córdoba, Spain*

[2]*Pedology and Agricultural Chemistry. University of Córdoba, Spain*

Abstract: The "laguna de El Conde" wetland Ramsar reserve (Córdoba, Spain) depicts a geomorphological progression with different Pleistocene and Holocene stages and reaching a concluding situation by anthropic manipulation of the local network of tributaries. The nature of the sediments carried into the Triassic-gypsum depression where the reserve is situated. Further, dissolution processes and the formation of an inter-sedimentary layer of water are found to play a critical role in the formation of this protected wetland.

Keywords: Geomorphological evolution, sediments characterization, anthropic modifications, El Conde small-lake, Córdoba, Spain.

INTRODUCTION

The "laguna del Conde" wetland Ramsar reserve (Córdoba, Spain) is a typical shallow (0.70m. depth) and seasonal endorheic ecosystem located in the semi-arid Mediterranean area having a height of 420-410 m, and lying in a depression produced by dissolving keupper gypsum and a quaternary deposits alluvial plain known as "El Salobral" (Fig. **1**) [1].

The water body of the wetland can be found in a heavily-cultivated agricultural area devoted mainly to olive groves, is linked to other wetland reserves and is host to population of white-headed ducks (*Oxyura leucocephla*), flamingos (*Phoenicopterus ruber*) and other key wildfowl species. On such basis, this area has been designated as protected area at an international level.. The vegetation mainly comprises *Salicornia spp*. growing at the bottom of the wetland, and *Tamarix spp* and *Phragmites autralis* on its banks (Fig. **1**).

Moya Mejías [2] previously noted that this was permanent lake overlying Triassic gypsum that was refilled by a powerful sedimentary column afterwards, and Baena y Díaz del Olmo [3] described the evolution of alpine relief piedmont in this ecosystem.

A preliminary study of its hydrology functioning reported that the small-lake is fed by the surface retention of precipitations during rainy season (maximum size of 47 hectares), and in drier season this size reduces and the small-lake is fed by groundwater rising to the surface [4]. Soils of the area and the sediments accumulated in its bottom were analyzed by [5].

This paper commences a novel approach regarding the development of the wetland area based on the geomorphological evolution of the hydrological system feeding this ecosystem and the characterization of its sediments. A special attention about the chronological processes sequence, anthropic participation and on the apparently decisive role of subsurface water in forming the water table in this protected area has been carried out [6].

*Address correspondence to this author at the Ecology (Physical Geography-Geomorphology). University of Córdoba, Spain; Tel: 34 957 218597; Fax: 34 957 218597; E-mails: bv1reesj@uco.es, mame@uco.es

MATERIALS AND METHODS

Geomorphological analysis was carried out by photo interpretation, using 1:30.000-scale aerial photographs taken in 1956; basic geological information was obtained from [1], and a 1:10.000 map was used for topographical analysis (heights and slopes development). Satellite images were obtained and land use was recorded.

A percussion hammer (model HM1800) was used for sampling. Sediment analysis included chroma (wet (w) and dry (d)) by [7], the carbon organic (C) determined by oxidation with $K_2Cr_2O_7$ in a concentrated H_2SO_4 medium and measurement of absorbance at 590 nm [8] and the salinity (electrical conductivity (CE) and dry residue (RS) by [9]. The carbonate content (CO_3=) was determined by $C0_2$ gas volume; soil samples were added with hydrochloric acid in a closed system and the resulting CO_2 gas volume was measured by Bernard calcimeter [11]. The Soil Survey England and Wales method [10] was applied using dispersing solution (sodium hexametaphosphate) which was measured by sieving and through Robinson pipette analyses.

To analyze clay minerals, the clay fraction of the sediments was separated following the method [10]. Clays were saturated in magnesium, introduced in an ethylene glycol atmosphere and analyzed with an X-ray diffractometer (DRX-Siemens D-5000 model). According to Brindley and Brown [12] and Montealegre [13] clay minerals were classified, identified and semi-quantified.

Physical-chemical analysis of subsurface water and groundwater was performed following [14] and [15] using

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atomic absorption technique (Perkin Elmer spectrometer 3100 model). The C_{14} chronology dating was reported by Centro Nacional de Aceleradores of CSIC-University of Sevilla.

RESULTS AND COMMENTS

a) Geomorphological Evolution

The current endorheic basin of the "laguna de El Conde" is fed by two medium-sized streams, the Carrascón and the Quejigal rivers (Fig. **1**). These rise among loamy subbetic outcrops in the southern part of the reserve (alpine reliefs), at heights of 600-700 m.

Both the topography of the area and its hydrological network have evolved in conjunction with the Guadajoz river, the chief waterway which determines base levels over the whole area. The river has two terrace levels situated 60 and 5 m. respectively above the present watercourse, one Pleistocene and other one Holocene. A third level at +20 m.

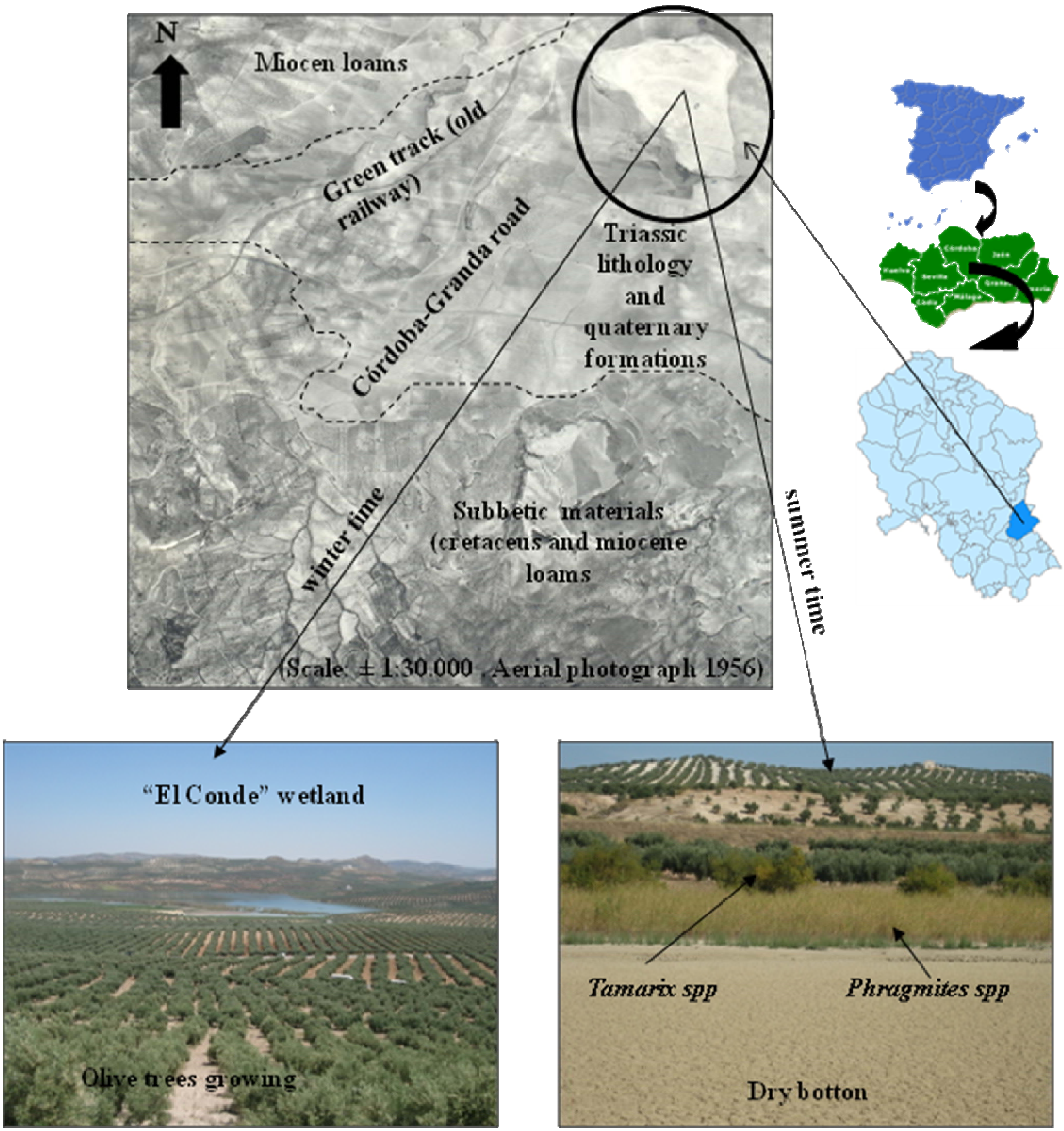

Fig. (1). Geographical location of El Conde small-lake, landscape around and seasonal aspects. Lithologycal domains of the area.

is detectable by [1] in other sections of the middle course, beyond the study area.

The Carrascón stream provides a clear example of stream capture at a height of 500 m., shifting in a north-easterly direction, and an abandoned channel at 470 m. in the north-west direction towards the Cañaveral river, and both are formerly joined (Fig. **2**, stage 1). Around 2.5 km from the wetland, at 470 m., i.e. about 60 m. above the current surface

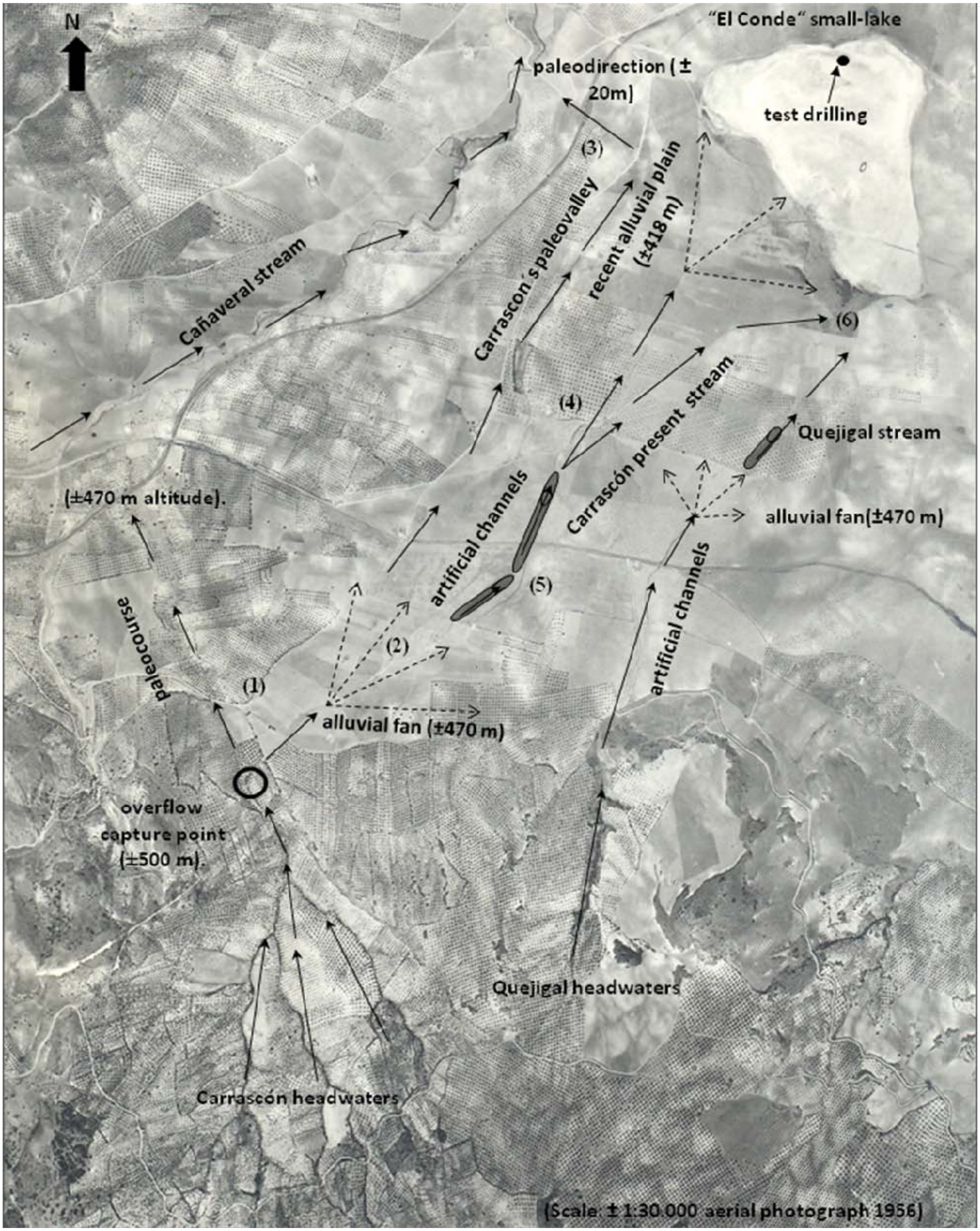

Fig. (2). Geomorphologycal evolution and wetland formation. Sedimentary test drilling situation.

of its water body, an evidence of an old alluvial fan dating from the medium Pleistocene, coinciding with the description of [3] (stage 2), linked to this earlier river current.

Close to the current Triassic depression, there have also been found signs of another old channel 20 m. above the present topography level, linked to the channel indicated earlier and running westwards towards the former main channel of the Cañaveral (Fig. **2**, stage 3).

During the medium Holocene, a final modification of the base level appears to have taken place, reshaping the endorheic hydrological network. The earlier watercourse became fragmented and disconnected, and flowed towards the recently-created gypsum karst depression providing a new local base level with the formation of an alluvial fan (Fig. **2**, stage 4) rich in fine fractions (silt and clay) inside of depression with a chronology about 6.962 yBP.

A very similar pattern has been shown by the evolution of the Quejigal stream, although at all stages it flows from north to south towards the Triassic depression. Variations taking place in the base level are clearly visible in two deep incisions in its channel, and in the formation of an alluvial fan similar to that observed in the other watercourse, also at a height of +470 m. (Fig. **2**).

Table 1. Physicochemical Characteristics of Wetland Sediments and Underlying Gypsum Triassic Rocks

Sample	Depth (cm)	Chroma (d)	Chroma (w)	C (%)	CE (mho s/cm)	$CO3^{-2}$ (%)
1	0 -5,5	2,5Y 7/2	2,5 Y 6/3	0,61	31	46
2	5,5 -9,0	2,5Y 7/2	2,5 Y 6/3	0,55	13	44
3	22,0 -25,0	2,5Y 7/2	2,5 Y 6/3	0,5 5	12	46
4	25,0 -28,5	2,5Y 7/2	2,5 Y 6/3	0,60	15	44
5	37,0 -40,0	5Y 7/2	5 Y 6/3	0,49	21	42
6	40,0 -43,0	5Y 7/2	5 Y 6/3	0,41	19	44
7	50,5 -53,5	10YR 7/2	10YR 7/1	0,28	16	44
8	53, 5 - 56,5	10YR 7/2	10YR 6/2	0,32	18	42
9	56,5 -58,5	2,5Y 7/2	2,5 Y 6/3	0,49	14	46
10	58,5 -61,5	5Y 6/2	2,5Y 6/2	0,27	18	44
11	91,5 -94,5	5Y 6/1	5Y 5/1	0,34	19	46
12	94,5 -97,5	5Y 5/1	5Y 5/2	0,24	35	44
13	**121,5 -124,5**	**5Y 4/1**	**5Y 4/1**	**0,24**	**44**	**26**
14	**124,5 -127,5**	**5Y 4/1**	**5Y 4/1**	**0,28**	**31**	**28**
15	151,5 -154,5	5Y 8/1	2,5Y 7/2	0,10	20	8
16	154,5 -157,5	5Y 8/1	5Y 5/1	0,06	21	2
17	157,5 -162,5	5Y 8/1	2,5Y 7/2	0,00	30	1
18	162,5 -167,5	5Y 8/1	2,5Y 7/2	0,00	37	1
19	187,5 -192,5	5Y 8/3	2,5Y 7/2	0,00	27	1
20	192,5 -197,5	5Y 8/2	2,5Y 7/2	0,00	37	1
21	217,5 -222,5	5Y 8/1	2,5Y 7/2	0,00	25	4
22	222,5 -227,5	2,5Y 8/2	2,5Y 7/2	0,00	28	4
23	247,5 -252,5	5Y 8/2	2,5Y 7/2	0,00	20	5
24	252,5 -257,5	2,5Y 8/2	2,5Y 7/2	0,00	24	10
25	257,5 -264,0	5Y 8/3	2,5Y 7 /2	0,00	34	3
26	264,0 -269,5	5Y 8/1	2,5Y 7/2	0,00	31	9
27	286,0 -291,5	5Y 8/1	2,5Y 7/3	0,00	28	8
28	291,5 -297,0	5Y 7/3	2,5Y 7/3	0,00	26	8
29	319,5 -325,0	5Y 7/2	2,5Y 7/2	0,00	23	9
30	325,0 -330,0	5Y 7/2	2,5Y 7/3	0,00	24	8
31	351,0 -356,0	2,5Y 8/2	5Y 7/2	0,00	27	14
32	356,0 -361,5	2,5Y 7/2	5Y 7/2	0,00	23	17

Parameters	(1)	(2)
CE(mhos/cm)	98,6	5,3
SO_4^{-2}(meq/l)	837	55
Cl^- (“)	1200	21
Ca^{+2} (“)	25	24
Mg^{+2} (“)	879	25
K^+ (“)	2	0,1
Na^+ (“)	1174	16
RS (g/l)	164	4,8

Tab 2.- Subsuperficial (1) underground (2) waters analysis

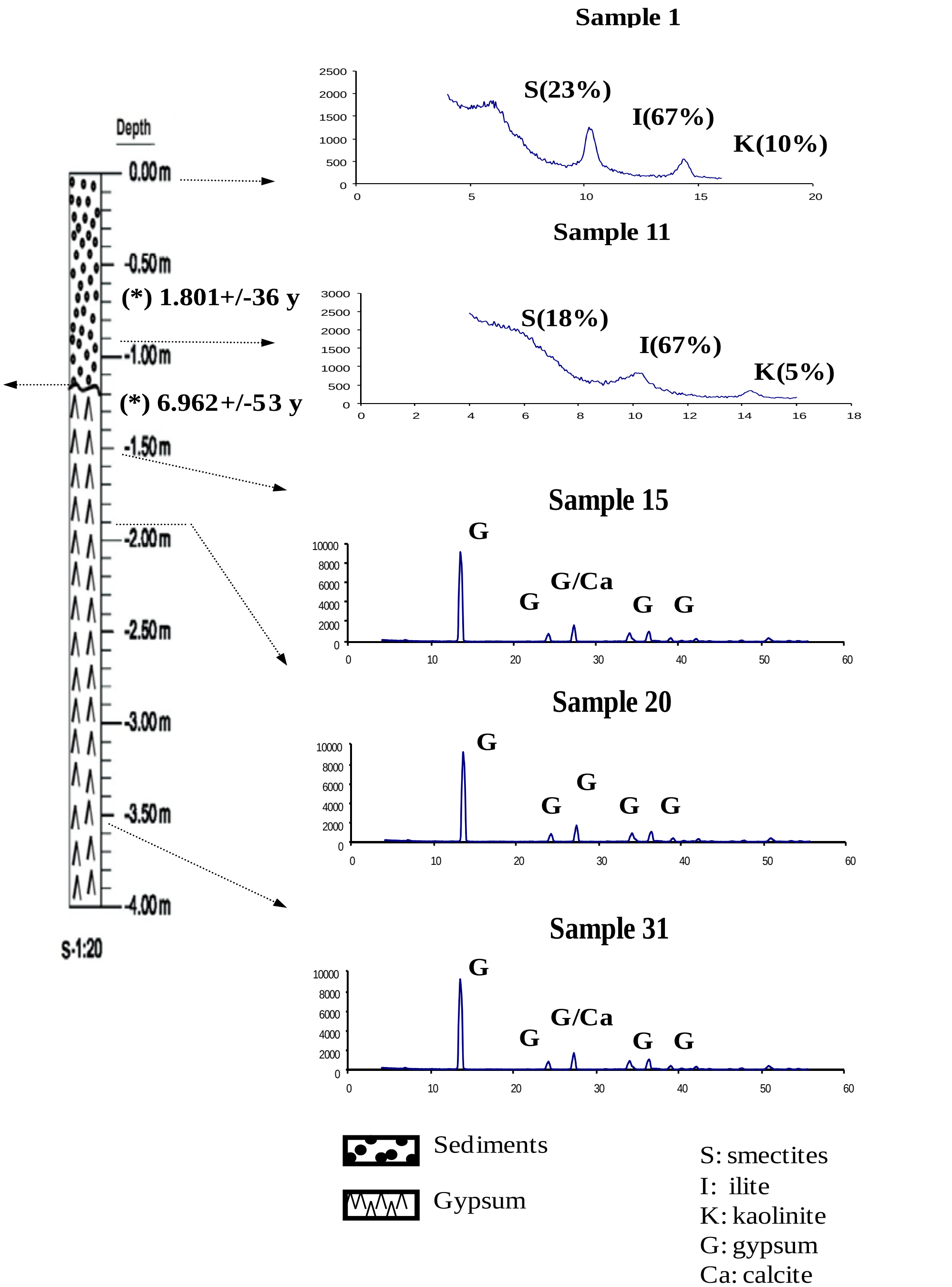

Fig. (3). R-X mineralogical analysis of sediments and lithology.

The occurrence of these alluvial fans, and in order to avoid annual waterlogging prompted by them in overlying cropland, artificial channels were dug out in the nineteenth century to link these two stretches with the headwaters of the streams within the endorheic depression proper. This created news and clearly-anthropic courses, which on current maps appear as natural watercourses (Carrascón and Quejigal streams) (Fig. **2**, stage 5).

b) Sedimentary Characterization

The creation of these new watercourses expedite a considerable augmentation in the volume of water flowing towards the endorheic depression, as well as the arrival of more loamy sediments from the subbetic reliefs around the source. This led to the formation of the contemporary sedimentary plain which predominately covers the underlying gypsum materials, and of the current alluvial fan close to the present small-lake.

There would even appear to have been more anthropic and recent changes within the depression itself, with a final westward shift that would represent a last stage (Fig. **2**, stage 6).

The sediment sampling at the furthest point of this alluvial fan, coinciding with the deepest point of the small-lake basin [4], and revealed an accumulation of 125 cm thick over the gypsum substrate (Table **1**; Fig. **2**). Sediments chroma was 2.5Y6/3 (light yellowish brown), having an elevated salt content (up to 44 mhs/cm) and low organic matter contents. The total carbonates are the 45%, dropping to 28% at the base (Table **1**).

Texture was clayey (65%) and illite composition (67%); the smectites content was 18% at a depth of 90 cm (sample 11), rising to 23% in the most superficial and impermeable layers (Fig. **3**).

At 76 cm in depth, the C14 analysis has revealed a chronology of 1.801 yBP. By this diachronic study the data suppose a very low sedimentation rate (0.4 mm/y) but greater than at the beginning of Holocene sedimentation.

From 1.25 to 4.00 meters in depth the underlying gypsum rock was predominantly white (2.5Y 7/2) (Table **1**), and all the samples examined showed the same mineralogical composition. The texture was not clayey, and electrical conductivity was around 20-37 mhs/cm (Table **I**). Carbonates are found to be in a lesser number and are completely absent in the contact with the upper sediments (154.5-197.5 cm).

The resulting lithological discontinuity prompted a highly-significant change in texture and permeability between the two formations, enabling the formation of suspended water layer at a depth of 125 cm. This water was highly saline in nature (C.E. 98.6 mhs/cm, R.S: 164 g/l), and very different from the groundwater flowing at a greater depth elsewhere in the area (C.E: 5.25 mhs/cm., R.S: 4.6 g/l) [4].

This permanent contact between this subsurface water and gypsum suggests the action of dissolution processes (non carbonated samples 16, 17, 18, 19 y 20) and the intervention of a small subsidence movement sufficient for the formation of the deepest area of the sedimentary plain and the small-lake basin.

CONCLUSIONS

The "laguna de El Conde" wetland Ramsar reserve shows a geomorphological evolution with different stages during Pleistocene, Holocene and historical periods.

The hydrological network linked to the Triassic depression where this wetland is situated, evolved towards an endorheic model in the medium Holocene, characterized by the formation of alluvial plain, fans and disconnection of tributaries watercourses.

Its hydrological dynamics were synthetically modified by means of channels intended to link previously-unconnected watercourses, giving rise to an increase in stream volume and in the amount of sediment brought into the depression where the small-lake is situated.

These sediments retain rainfall at the surface in years of intense rain, giving rise to a relative large column of water. In dry season, the suspended subsurface water layer is formed between gypsum rock and sedimentary deposits are a major contributor to its water body, rising to cut the topographical surface at the furthest and deepest zone of the sedimentary plain.

Due to annual drought-induced desiccation, this subsurface water is extremely saline, and very different from the groundwater flowing at a greater depth.

The data obtained suggest that the conservation and management program implemented at the Ramsar-listed reserve would be modified.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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Declared none.

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