Morphological and sedimentological characterization of Honda temporary lake (southern Spain)

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ABSTRACT

A bathymetric map, a morphometrical study based on bathymetry, and a sedimentological analysis of Honda Lake are carried out. Some relationships between morphometrical parameters and lake characteristics are presented. Results of the bathymetric map show that Honda Lake presents an ovoid outline form, with only one slightly convex basin. Phyllosilicates are the most abundant phases in the characterisation of the sediments, followed by gypsum and, in smaller proportions, by calcite, quartz, halite, and dolomite. Results obtained from the sediment texture shown that the most important texture in deep samples is silty-clay, while surface samples present higher proportions of silty-clay-loan. Finally we emphasise the importance of this study, in relation to possible future changes in morphometrical parameters as a consequence of human impact.

Keywords: Bathymetry, lake morphometry, sedimentology, saline lake, Andalusian endorheism, Spain.

RESUMEN

Se realiza un mapa batimétrico, un estudio morfométrico y un análisis sedimentológico de la laguna Honda, mostrándose algunas relaciones entre los parámetros morfométricos y las características de la laguna. El mapa batimétrico muestra que la laguna Honda presenta una forma elipsoide, con un único vaso ligeramente convexo. Los filosilicatos son la fase más abundante en la caracterización del sedimento, seguido por yesos y en menor proporción por calcita, cuarzo, halita y dolomita. Los resultados obtenidos del análisis de la textura del sedimento muestran que la textura predominante en profundidad es la limo-arcillosa, mientras que las muestras de superficie presentan valores más altos de arcilla. Finalmente se remarca la importancia de este estudio en orden a posibles futuros cambios en la morfometría de la laguna a consecuencia de los impactos de origen humano.

Palabras clave: *Batimetría, morfometría, sedimentología, lagos salados, endorreísmo andaluz, España.*

INTRODUCTION

A limnological description of a lake is a necessary step in the research of an aquatic ecosystem and it includes the study of lake forms, their genesis and their role in a physical limnological perspective (Håkanson, 1981). In this sense, the morphology of a lake basin reflects processes closely related to its origin, which is a useful descriptor towards the classification of wetlands (Florín *et al.*, 1993). In addition, morphometrical parameters exert a major control over a wide range of processes and features of a lacustrine ecosystem, and are fundamental in most limnological and hydrological projects.

One of the oldest limnological principles is that basin morphometry influences lake metabolism (Thienemann, 1925; Naumann, 1932). As a consequence, many studies have demonstrated how lake morphometry affects the rates of certain processes and the distribution of certain physical, chemical and biological parameters,

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such as lake trophic state (Pinel-Alloul *et al.*, 1990), phytoplankton and submerged macrophyte abundance, structure and production (Schindler, 1971; Duarte & Kalff, 1986, 1988; Pinel-Alloul *et al.*, 1990), loading, dilution and recycling of nutrients (Pick and Lean, 1987), ratio of nitrogen to phosphorous (Smith, 1982), light climate (Sterner, 1990), sediment focusing (Blais & Kalff, 1995), thermal structure (Robertson & Ragotzkie, 1990), and dissolved humic matter (Eloranta, 1986), among others. In this sense, Guiral & Pérez (1980) pointed out the importance of the cartography and morphometry of lake ecosystems as a first step in any kind of aquatic research.

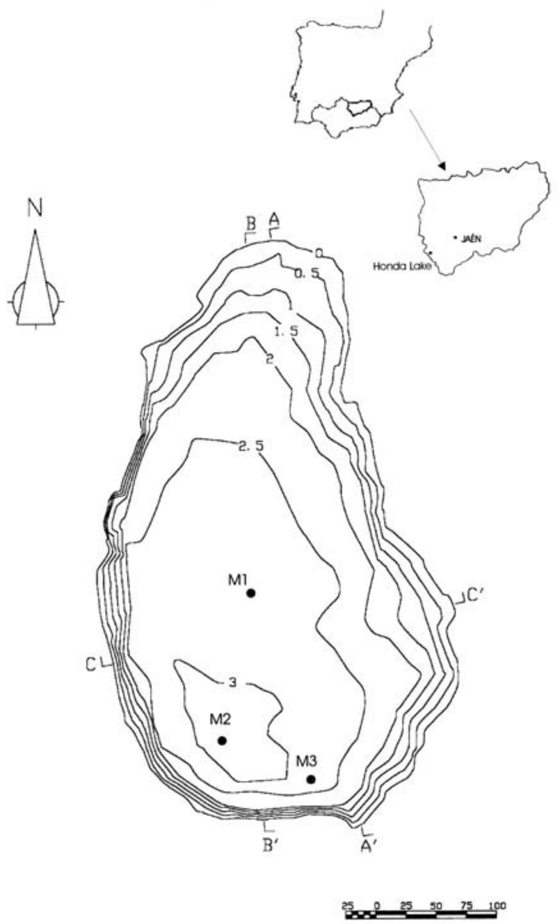

Figure 1. Geographic location of the Honda Lake, bathymetric map, and location of the sampling points (M1; M2 and M3). *Localización geográfica de la laguna Honda, mapa batimétrico y situación de los puntos de muestreo (M1; M2 y M3).*

However, most of the morphometric analyses carried out nowadays are based on measures of surface dimensions, but this type of study is insufficient to establish a good relationship with the physico-chemical and biological parameters of an aquatic ecosystem. That is why it would be necessary to include a more detailed analysis of morphometrical parameters of both, surface and subsurface dimensions.

In Spanish lakes there are few studies on morphometric lake parameters (see for example Rico *et al.*, 1995). This study is intended to contribute to this type of knowledge by means of the morphometrical and sedimentological analysis and bathymetrical characteristics in Honda hypersaline lake (south-eastern Spain). This analysis complements some previous works (Guerrero & Castro, 1997; López González *et al.*, 1998), and can be used as a basis for future limnological studies.

STUDY AREA

Honda hypersaline lake is situated in southwestern Jaén (Fig. 1), close to the marshes of the Guadalquivir River (UTM-geographic coordinates: 30SVG992619), at 460 meters above sea level in an endorheic area. It is included in the Andalusian endorheism, with arid and semiarid climates. The Andalusian endorheism was characterised by Dantín (1940) and Pardo (1948), and is located on Triassic materials, that are mainly marls and clays. Deposits of evaporite (fundamentally gypsum and halits) are responsible for the hypersaline character of the lake (Castro, 1995). From a hydrological point of view, Honda Lake receives direct supply from rainfall, ground-water flow, and surface runoff from sporadic streams (Ingemisa, 1993).

MATERIAL AND METHODS

The construction of a bathymetric or contour map was performed in May 1999 by depth soundings made along transects by using a prism coupled with a Leica 805/L total station to a ranged pole. Depth measures were obtained from 17 diagonal transects. With the coordinates of all points, a computational digital terrain model was built, and a map at a scale 1:5000 was plotted. Contour intervals were 0.5 m. We used SDR-VARIN 6.0 and AutoCAD R-14 software. The morphometric analysis followed Håkanson (1981).

In order to carry out a sedimentological characterisation, six sediment samples were collected in the dry season of the 1994-95 hydrological cycle, when the lake underwent complete desiccation and the maximum depth was less than 0.5 m. Samples were taken at three different points (M1; M2 and M3), which are representative of the lake basin (Fig. 1) and at two depths [5 cm (S) and 30 cm (D)]. Granulometric analysis was carried out by sieving the sediment sample and subsequent sedimentation in a Robinson pipette, with the following fractions: clay (<2 µm), silt (2-50 µm) and sand (50-2000 µm) (Soil Conservation Service, 1972). Gravel fractions (>2 mm) were not detected. Other analyses were carried out on the fine fractions of the sediment (<2 mm): (i) organic carbon content by the dichromate oxidation method; (ii) $CaCO_3$ equivalent by volume to Bernard's calcimeter; (iii) pH in a 1:1 fine fraction: water suspension (w/w), and (iv) electrical conductivity by the saturation extract method (Wolt, 1994). Organic matter content was estimated by multiplying organic carbon percentage by a correction factor of 1.724 (Soil Survey Staff, 1999).

The mineralogical composition of the fine sediment was determined by X-ray diffraction (XRD) in samples of un-oriented powder by using a holder filled from the side. A Siemens D-5000 diffractometer was used under the following operating conditions: radiation (Cu Kα) at 35 kV and 15 mA, time constant 2 s.; step size 0.02 °2θ. Semi-quantitative analysis was determined by the intensity factors method (Klug & Alexander, 1976), using the data published by De la Torre (1995).

Table 1. Morphometrical parameters of Honda lake (according to Håkanson, 1981). *Parámetros morfométricos de la laguna Honda (según Håkanson, 1981).*

Area		a	99 433 m^2
Shoreline length		I_o	1322.12 m
Shore development	$F = I_0/2\sqrt{\pi a}$	F	1.18
Maximum length		L_{MAX}	497.78 m
Maximum width		B_{MAX}	284.50 m
Mean width	$\bar{B} = a/L_{MAX}$	$\bar{B}$	199.76 m
Maximum depth		D_{MAX}	3.16 m
Volume		V_p	204 726.39 m^3
Mean depth	$\bar{D} = 1000V_p/a$	$\bar{D}$	2.06 m
Relative depth	$D_r = D_{MAX}\sqrt{\pi}/20\sqrt{a}$	D_r	0.88 %
First quartile depth		D_{25}	2 m
Median depth		D_{50}	1.25 m
Third quartile depth		D_{75}	0.55 m
Mean slope		α	1.78 %
Volume development	$V_d = 3\bar{D}/D_{MAX}$	V_d	1.96
Dynamic ratio	$DR = \sqrt{(a10^{-6})}/\bar{D}$	DR	0.15
Direction of major axis			S-N
Lake form			SCx-Lma

RESULTS AND DISCUSSION

A bathymetric map is the standard way of recording the morphometry of lakes. The Honda bathymetric map (Fig. 1) shows an ovoid outline form, with one single basin. Table 1 shows the morphometrical parameters of Honda Lake. Among these parameters, mean depth ($\bar{D}$) is probably the most useful morphometric feature available, because it could be related to the productivity and trophic status of lakes (Håkanson, 1981). It serves as a surrogate for most morphometric attributes and a host of biological processes, but no correlate can provide unambiguous information on underlying causes (Kalff, 2002). However, a high value of mean depth both in freshwater and in saline lakes, normally tends to show low levels of nutrients in water and consequently of productivity indicators such as chlorophyll-*a* (Chow-Fraser, 1991; Sakamoto, 1966). Even though this parameter was developed to compare different lakes, we used it to evaluate changes in the same lake (Honda Lake) across two different hydrological cycles. Therefore we can see a very different ecosystem performance. In this way, during the 1994-95 hydrological cycle Honda Lake underwent complete desiccation. It shows a $\bar{D}$ < 0.3, and chlorophyll-*a* values, a common estimator of productivity or lake trophic status, were always higher than 225 µg l^{-1} (Guerrero & Castro, 1997). On the other hand, in the 1998-99 hydrological cycle the lake did not become dry in the summer period and thus, mean depth value was higher ($\bar{D}$ = 1.4) and chlorophyll-*a* values did not exceed 2 µg l^{-1}.

Mean depth is greater than median depth (D_{50}), as it is characteristic of a slightly convex basin (see below). The median depth may be used to determine the lake bottom roughness, which is a useful parameter in sedimentological contexts and in the optimization models for lake hydrographical surveys (Håkanson 1981). Neumann (1959) concluded that the depth ratio ($\bar{D}/D_{max}$) provides a useful approximation to lake form. Honda Lake showed a value of 0.65, similar to an ellipsoid form and it is characteristic of shallow lakes with flat bottoms (Carpenter, 1983). Honda Lake shows also a relative depth (D_r), a parameter that may be used to describe stability of stratification of lakes, typical of small

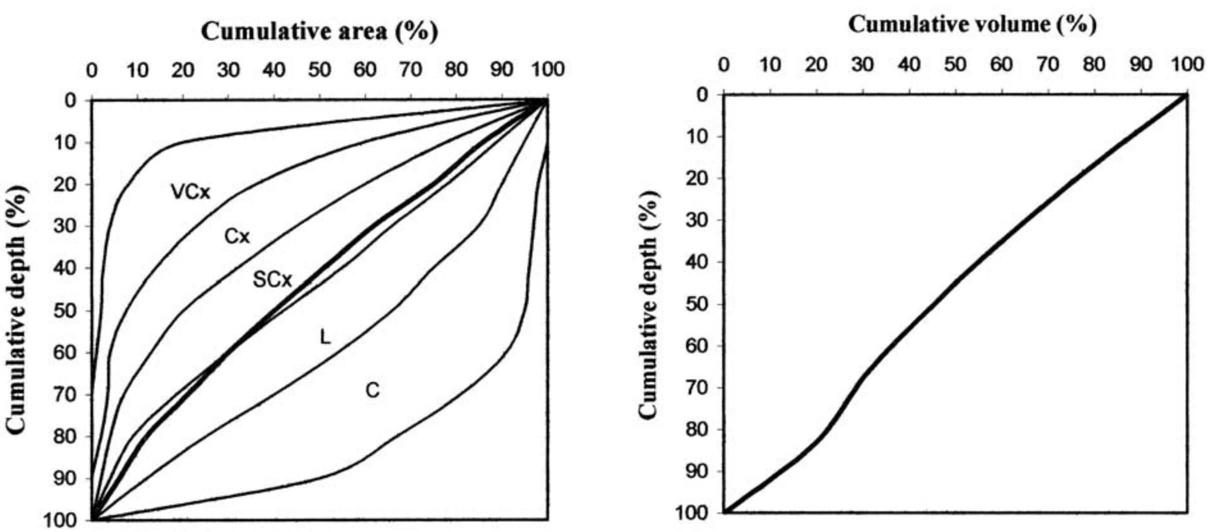

Figure 2. Relative hypsographic (A) and volume curves (B) for Honda lake (symbols and the class limit of lake morphologic classification system according to Håkanson, 1981). *Curvas hipsográficas relativas (A) y de volumen (B) de la laguna Honda (simbología y límites de clases del sistema de clasificación morfológica de la laguna según Håkanson, 1981).*

Table 2. Mineralogical analysis (X-ray diffraction) of fine earth fraction (<2 mm); all values are %. (tr: traces; x: <5%; xx: 5-15%; xxx: 15-30%; xxxx: 30-45%; xxxxx: 45-60%). *Análisis mineralógico (difracción de rayos-X) de la fracción de tierra fina (<2 mm); todos los valores están en %. (tr: trazas; x: <5%; xx: 5-15%; xxx: 15-30%; xxxx: 30-45%; xxxxx: 45-60%).*

	M1S	M1D	M2S	M2D	M3S	M3D
Gypsum	xxx	xxxx	xx	xxx	xxxx	xxxxx
Phyllosilicates	xxxxx	xxxxx	xxxxx	xxxxx	xxxxx	xxx
Quartz	x	x	xx	x	x	xx
Calcite	x	x	xx	xx	x	xx
Dolomite	x	x	x	x	x	x
Halite	xx	x	x	xx	xx	xx

and shallow basins. Shore development (F) is near 1 and it represents a measure of the irregularity of the shoreline (Håkanson 1981), which is one of the morphological parameters that reflects processes related with lake origin. Salobral Lake, another shallow and temporary lake situated near Honda Lake, has an F value of 1.3 (Recio *et al.*, 1985), as is normal for two basins which are originated by dissolution (Rico *et al.*, 1995). Accordingly, the origin of Honda Lake could be connected with the karstic phenomena in gypsum and saline materials of the Trias.

Dynamic ratio (DR) is a morphometrical parameter designed to represent bottom dynamic conditions (Lindström *et al.*, 1999). The influence of this parameter over processes such as lake desiccation and other processes related to the water-sediment interface denoted its importance. The dynamic ratio value (DR = 0.15) indicates that has lower bottom areas exposed to wind/wave energy. In the same way, distribution coefficient ($V_d/3$) is a useful tool to know the amount of sediment available for re-suspension on the erosion and transport areas (ET-areas), the fraction that goes to deep waters, and the fraction ($1-V_d/3$) that goes to surface waters (Håkanson *et al.*, 2000). The values obtained mean that 65.3% of the matter available can be assumed to be transported to deep waters and 34.7% to surface waters.

Honda Lake has slight shore slopes, although there is some dissimilarity between the two shorelines. The slight slope allows for colonisation of the sediment by submerged macrophytes and helophytes (Ortega & Guerrero, 2003).

The hypsographic curve, that represents certain elements of the basin's form and provides a means whereby the area of any depth level may be determined (Håkanson 1981), indicates that the form of Honda Lake is slightly convex in the upper 3/4 of its cumulative area, and linear in the lower 1/4 (Fig. 2). This curve may also be used in graphic determinations of the lake volume. In this sense, sixty per cent of the total volume is located in the first upper meter.

In relation to sedimentological characterisation, the minerals that were determined in the sediment are: phyllosilicates (mainly mica and chlorite); quartz; gypsum; calcite; halite and dolomite (Table 2). Semi-quantitative analysis shows mainly that phyllosilicates are the most abundant phases, followed by gypsum and, in smaller and decreasing proportions, by calcite, quartz, halite, and dolomite. Gypsum was the only analysed mineral that showed a consistent pattern of increased proportions with depth. All other minerals showed either no changes with depth or no consistent pattern of change with depth among sample locations. This mineralogical composition is very similar to that of Salobral Lake (Recio *et al.*, 1995), due to the Triassic materials of Keuper that crop out in both basins (Ingemisa, 1993).

Results obtained from the sediment show that silty-clay is the most important texture in deep

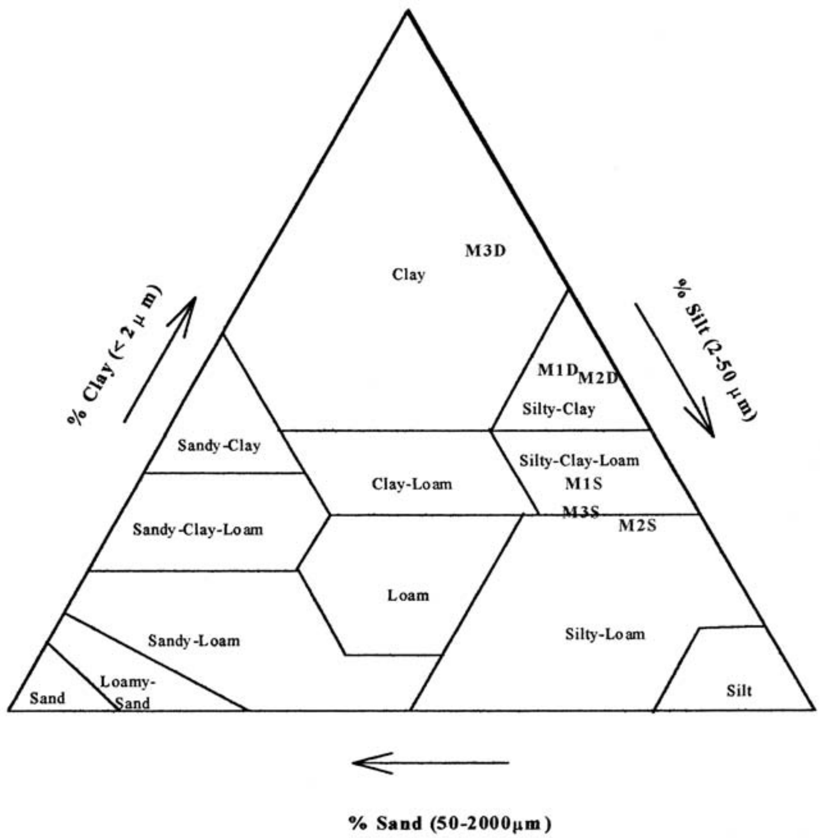

Figure 3. Textural classification of the sediments according to USDA (1972). *Clasificación de la textura de los sedimentos de acuerdo con USDA (1972).*

samples (Fig. 3), while surface samples present mainly a silty-clay-loam texture. Table 3 shows the values of pH, conductivity, percentage of equivalent calcium carbonate, and organic matter content from sediment samples from 5 and 30-cm. of depth. Honda presents an irregular distribution with depth in these parameters, with higher values always at 30-cm. of depth, except in conductivity. The comparison with the results obtained by Vargas et al. (1983) in Fuente de Piedra saline Lake allows us to appreciate the differences between both lakes, with lower values of calcium carbonate in Honda Lake and higher values in organic matter content, with maximum values over 2 and 16% respectively.

The organic matter distribution with depth, with maximum values at 30-cm. and minimum at 5-cm. depth, allows us to think about

Table 3. Some characteristics of the sediment of Honda lake (O.M.= organic matter). *Algunas características del sedimento de laguna Honda (O.M.= materia orgánica).*

	M1S	M1D	M2S	M2D	M3S	M3D
Conductivity (S cm^{-1})	11.7	7.5	11.0	6.0	8.8	7.7
pH	7.6	7.9	7.6	7.7	7.3	7.8
$CaCO_3$ equiv (%)	10.1	13.3	12.2	17.7	8.2	18.5
O.M. (%)	2.3	14.1	5.7	15.8	3.6	11.9

the influence of basin silting, the most important human impact affecting this ecosystem, mainly due to an inadequate olive tree tillage on its shorelines (Montes & Martino, 1987; García Fuentes *et al.*, 1996; Ortega *et al.*, 2003). This implies changes in morphometry parameters and destruction and substitution of littoral plant communities around the lake. Thus, we want to emphasise the importance of this study in terms of possible future changes in morphometrical parameters as a consequence of human impact.

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