

## CONTRIBUTION TO THE PLIO-PLEISTOCENE PALEOLIMNOLOGY OF THE BAZA BASIN (SE SPAIN) USING DIATOMS

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### ABSTRACT

Several outcrops with diatoms have been identified in the Neogene-Quaternary Baza basin. The most relevant two are located in the NE margin, in different lithostratigraphic units. Their diatom flora is dominated by *Epithemia adnata* and *Epithemia turgida*, a littoral epiphytic aquatic plants. These diatom assemblages are typical of fresh to slightly brackish waters in shallow and alkaline lakes. Those two diatomitic deposits are interstratified between alluvial sediments and represent permanent shallow lakes developed during two wet periods of time. Barranco de las Lumbres is the oldest of these lake events and is dated by fauna and paleomagnetism as late Miocene (Turolian). The upper beds of the younger lake episode (Rincon de la Losa) is dated by paleomagnetism and mammals at 1.9 Ma. In addition to these marginal diatomitic deposits, other outcrops with diatoms have been identified in more central areas of the Basin in Galera village, the lower part of Barranco del Agua section is composed of gypsum, carbonates and dark-brown clays and marls. Here epiphytic shallow-water diatoms *Epithemia adnata*, *Epithemia turgida* and some planktonic littoral forms (*Fragilaria* sp.) suggest a shallow fresh to oligosaline water environment. Additional diatomaceous deposits were located in a more evaporitic zone of the basin near the town of Castillejar. This outcrop presents species (*Navicula digitoradiata* and *Surirella ovalis*), which indicate distinctive more saline waters and environment. The distribution of the diatom flora in the Baza basin is consistent with stratigraphic data, which indicates an increase of evaporitic facies towards the center of the basin and the occurrence of different kinds of waters within the lake system. The isotopic composition ( $\delta^{34}\text{S}$ ,  $\delta^{18}\text{O}$ ) of the gypsum samples of Baza basin (Gibert *et al.*, 2007a) is consistent with a Triassic origin of the sulphate as a result of chemical recycling. These data also suggest that a similar recycling mechanism operated in the saline lake system, where the gypsum sediments from the margins were coevally recycled towards the inner part.

**Keywords:** Baza basin, SE Spain, diatoms, *Epithemia*, Neogene, Quaternary, lacustrine environments

### RÉSUMÉ

#### CONTRIBUTION À LA PALÉOLIMNOLOGIE DU PLIO-PLÉISTOCÈNE DU BASSIN DE BAZA (SE ESPAGNE) À PARTIR DE L'ÉTUDE DES DIATOMÉES

Les diatomées de quatre coupes lacustres prélevées dans le bassin de Baza d'âge plio-pléistocène sont analysées. Dans la partie marginale du bassin de Baza, les coupes de Barranco de las Lumbres et Rincón de la Losa révèlent une accumulation de calcaires laminés riches en diatomées. Les diatomées de ces deux dépôts, dominées par *Epithemia adnata* et *Epithemia turgida*, espèces littorales épiphytes et oligohalobes indifférentes, et *Navicula halophila* benthique mésahalobe, représentent des lacs peu profonds riches en hydrophytes, d'eau douce à saumâtre et alcaline, développés au cours de deux périodes humides. Barranco de las Lumbres, rattaché au Miocène supérieur (Turolien), est le plus ancien lac, l'autre Rincon de la Losa est daté par le paléomagnétisme à 1,9 Ma. A proximité du centre du bassin de Baza, la section de Barranco Agua Galera se compose d'évaporites et de calcaires stratifiés. Les niveaux palustres carbonatés présentent des taxons épiphytes et oligohalobes indifférents : *Epithemia adnata*, *Epithemia turgida* et des formes littorales planctoniques : *Fragilaria* sp. Dans la partie la plus centrale du bassin de Baza, la section de Castillejar, d'âge Pliocène à Pléistocène inférieur, correspond à une alternance de gypse stratifié et de carbonates riches en diatomées. Les associations de diatomées à *Navicula digitoradiata*, *Navicula radiosa* et *Surirella ovalis* indiquent des eaux plus salines. La distribution de la flore de diatomées fossiles dans le bassin de Baza témoigne d'une augmentation de la salinité de l'eau du lac depuis la partie marginale vers le centre de la dépression et permet de reconstruire différents paléoenvironnements et paléolacs du Néogène et du Quaternaire. La composition isotopique ( $\delta^{34}\text{S}$ ,  $\delta^{18}\text{O}$ ) du gypse du bassin de Baza (Gibert *et al.*, 2007a) est compatible avec une origine triasique du sulfate suite à son recyclage chimique. Ces données suggèrent également le fonctionnement d'un mécanisme de recyclage semblable dans le système de lac salé, où les sédiments gypseux des marges ont été recyclés vers la partie intérieure.

**Mots-clés:** SE de l'Espagne, bassin de Baza, paléolac, diatomées, *Epithemia*, paléoenvironnement, Pliocène supérieur, Pléistocène inférieur, Néogène, Quaternaire

### 1 - INTRODUCTION

Water level and chemistry of lakes are directly related to the hydrologic budget. In a lake system, changes in balance between water inputs and outputs will modify

both level and water chemistry. These changes can affect the composition of the lake's biota.

Common fossils that record these climatically induced lake water conditions are ostracods and diatoms. Ostracods have been studied in the Baza basin recording

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water salinity oscillations (Anadón *et al.*, 1994; Anadón & Gabàs, 2009) but diatoms have never been described before in these lake beds.

Diatoms are unicellular algae, and as biological indicators provide information on habitat types, water depth and on the total and specific salinity. The interpretation of their paleo-assemblages is based on the distribution of modern species and communities from the investigated area, and/or from other basins.

Four sections located in different areas and facies of the basin produced diatoms, supplying new information for the understanding of paleoenvironments in this basin. The sections studied are Barranco de las Lumbres (Late Miocene), Rincón de la Losa, Barranco del Agua and Castillejar (Late Pliocene and Early Pleistocene). This study describes diatom assemblages, which reflect ecological variations and salinity of the aquatic environments of the complex Baza paleolake system.

## 2 - GEOLOGICAL SETTING

The Guadix-Baza basin (37°N, 3°W, SE Spain), is the largest (> 4000 km<sup>2</sup>) of the intramontane basins of the eastern Betic chain. The basin is located at the boundary between the external (sedimentary rocks) and the internal zones (metamorphic rocks) of the Betic chain (fig. 1). The basin has been uplifted until 950 m asl and present climate is of Mediterranean type with a strong continental influence: cold and dry winters, while the summers are hot, with daily maximum temperatures reaching 40 °C. The annual pluviometric average (300 to 350 mm/yr) is less than the evapotranspiration (700-900 mm/yr).

During the Late Miocene, this basin was isolated from the sea, becoming an area of non-marine sedimentation. The basin accumulated sediments until the Middle Pleistocene (Sanz de Galdeano *et al.*, 1992; Vera *et al.*, 1994; Gibert *et al.*, 2007b).

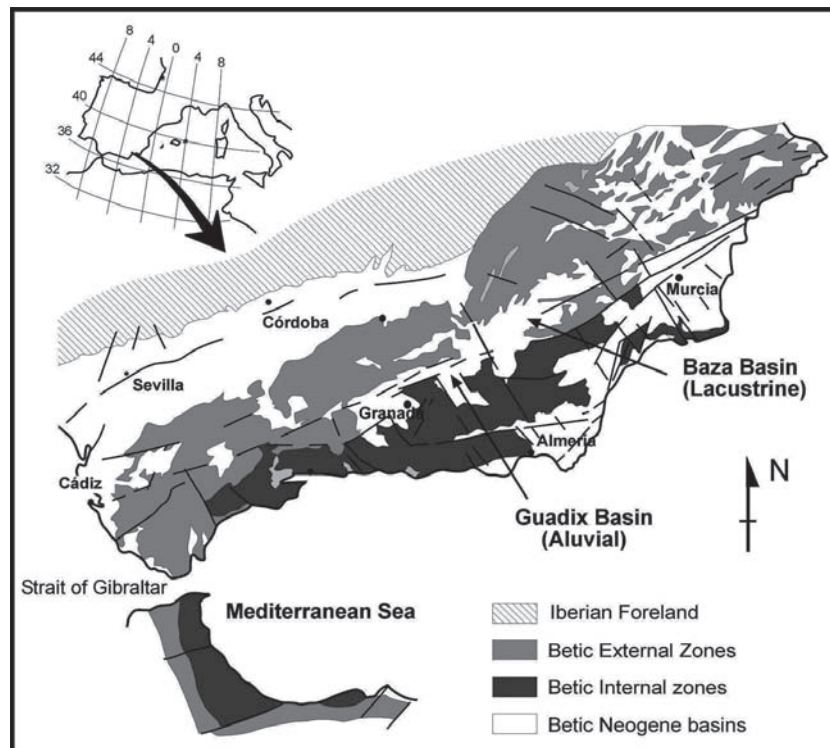
This basin can be divided in two large domains, the Guadix basin, located to the SW, where the deposits are basically alluvial with minor influence of palustrine (Viseras, 1991; Vera *et al.*, 1994). The Baza basin, studied here, is located to the NE of the region and accumulated lacustrine sediments in the central area, and fluvial and shallow lacustrine deposits in the margins.

In the NE sector of the Baza basin, two main areas are separated by a fault (fig. 1). The area located north of this fault shows a long succession of non-marine Miocene and Pliocene deposits, whereas the area to the south exposes Late Pliocene to Middle Pleistocene lacustrine and fluvial sediments.

## 3 - STUDIED SECTIONS

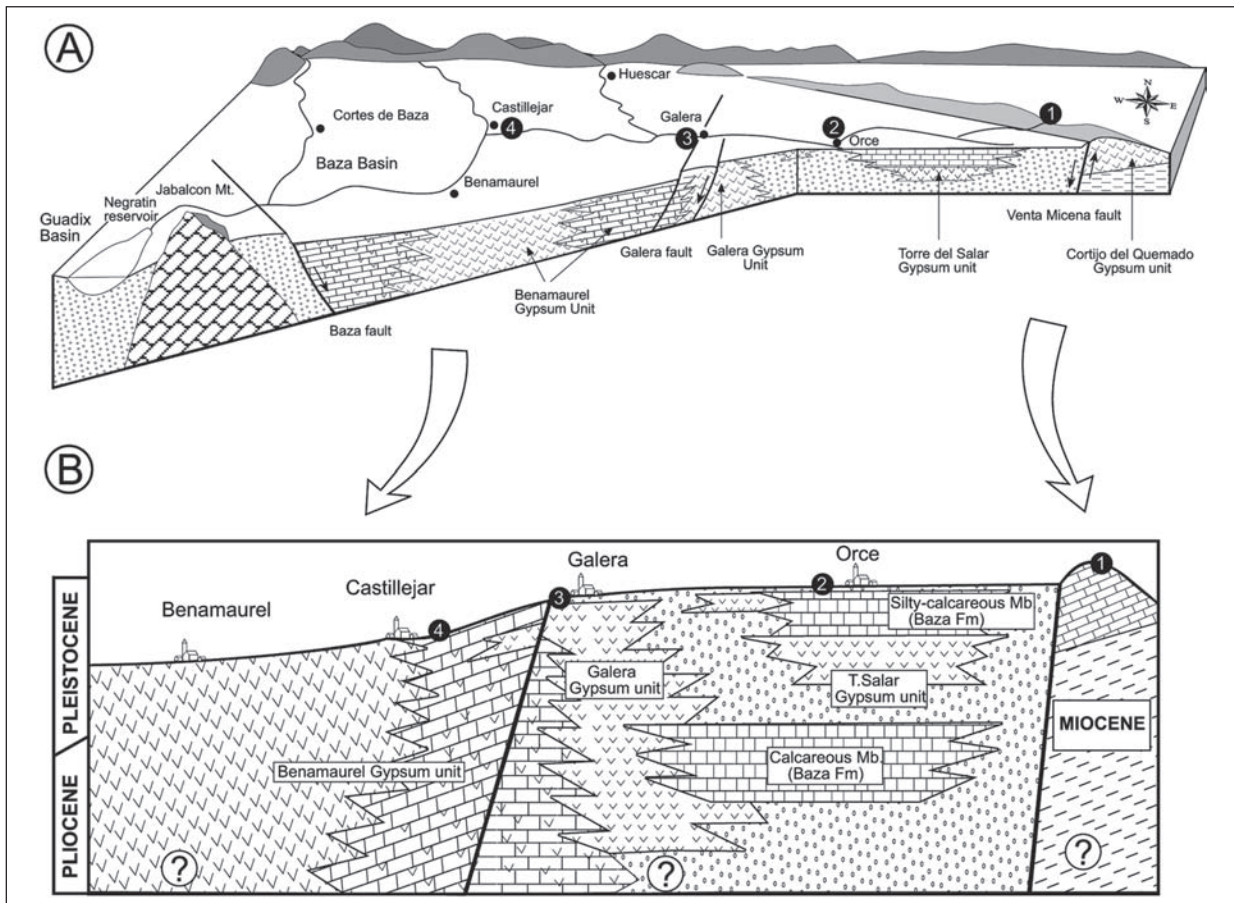
Four major outcrops rich in diatoms have been identified and sampled in the Baza basin (fig. 2). Two of these sections that are situated in the NE margin of the Baza basin, show carbonates and chert (Rincón de la Losa and Barranco Lumbres) and represent lake events interstratified between alluvial deposits. The other two outcrops are situated in more central areas and expose lacustrine evaporitic facies, near the towns of Galera (Barranco del Agua) and Castillejar.

The age of the stratigraphic units have been established using paleomagnetic techniques and were calibrated



**Fig. 1: Location of the Baza Basin in SE Iberia.**

*Fig. 1 : Situation du bassin Baza dans le sud-est de la péninsule ibérique.*



**Fig. 2: Location of the studied outcrops in the Baza basin.**

1/ B. Lumbres, 2/ R. Losa, 3/ B. del Agua, 4/ Castillejar. Note the different facies and the presence of a fault at B. Lumbres, which uplifts the Miocene.  
 Fig. 2: Localisation des affleurements étudiés dans le bassin de Baza. 1/ B. Lumbres, 2/ R. Losa, 3/ B. del Agua, 4/ Castillejar. Noter les différents faciès et la présence d'une faille de soulèvement du Miocène localisée à B. Lumbres.

using fossil information. In general, the lower and upper parts of these marginal sections have a Late Pliocene and Pleistocene age. However, a precise chronology for the lacustrine deposits occurring in the central areas, from which mammals are absent, is not yet available. The oldest of the marginal lake events (Barranco las Lumbres) is dated from the Late Miocene (Turolian) (Gibert, 2006). The top of the youngest lake event (Barranco de la Losa) is dated by magnetostratigraphy and mammals around 1.9 Ma (Scott *et al.*, 2007).

## 4 - MATERIALS AND METHODS

### 4.1 - PREPARATION OF DIATOMS

For each sample, a quantity of approximately 10 g of sediment was attacked with hot hydrochloric acid to remove calcium carbonate and later with hydrogen peroxide to eliminate organic matter. The argillaceous fraction in suspension was eliminated by successive decantation phases. The residue was diluted in distilled water and one drop suspension was spread out over coverslips and stuck to the Nafrax resin.

The observation of the coverslips was carried out under the optical microscope (x 1000). The relative frequency of a species was calculated after counting of 500 valves,

distributed on four blades. All samples were treated and the residual product observed under optical microscope and a selection of samples was studied also under the scanning electronic microscope.

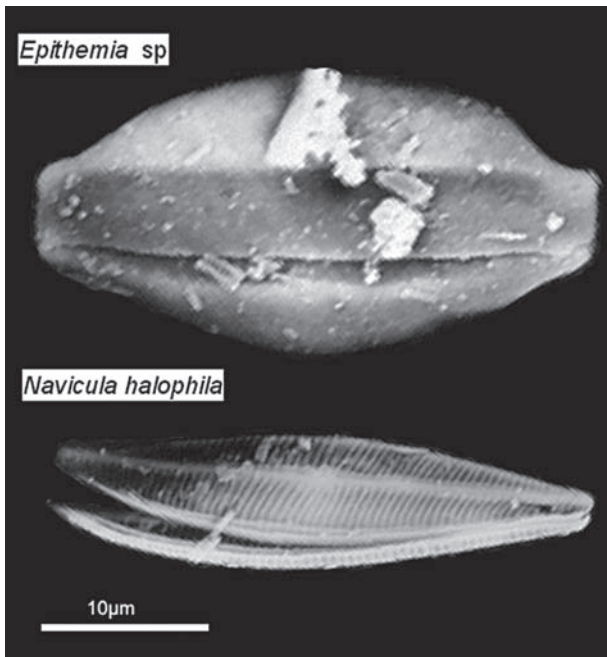
### 4.2 - IDENTIFIED DIATOMS

Diatoms are good indicators of water quality and can provide valuable information about aquatic palaeo-environments. The studied four sections in Baza basin showed characteristic assemblages revealing ecological variations. Analyses of these diatoms provided information on the water-level and on changes in water chemistry. High frequencies ( $\geq 50\%$ ) of the following species were identified in this study:

– *Epithemia* sp. (fig. 3), a littoral epiphyte of aquatic plants species (Hustedt, 1930, p. 383), is considered as an indicator of shallow conditions (El Hamouti, 2003).

– *Navicula halophila* Grunow Cleve (fig. 3) is a benthic littoral species living in low depth water with high total dissolved solids (TDS) conductivity of about 5000  $\mu\text{Scm}^{-1}$  (Gasse, 1986, p. 99) and a pH optimum of 8.25 (Gasse *et al.*, 1995).

– *Navicula radiosa* Kütz grows in various types of environments (lakes, swamps, rivers). It is most abundant on the littoral or in bottom mud of shallow lakes. This species is oligohalobous indifferent and lives in



**Fig. 3: Individuals of *Epithemia* sp. (above) and *Navicula halophila* (below) from Rincón de la Losa section.**

*Fig. 3 : Individus de Epithemia sp. (haut) et Navicula halophila (bas) du site Rincón de la Losa.*

low depth water with conductivity optimum of about  $3200 \mu\text{Scm}^{-1}$  and pH optimum of 7.87 (Gasse *et al.*, 1995).

– *Navicula digitoradiata* Gregory Ralfs is regarded as being a brackish water form (Hustedt, 1957; Cholnoky, 1968) preferring a pH optimum of 8.18 (Gasse *et al.*, 1995). It is commonly found in sea-shore environments (Hendey, 1964, p. 202) but occasionally in continental environments (Germain, 1981).

– *Fragilaria* sp. is well developed in the plankton or littoral shallow lakes, in rivers and swamps of diversified ecological conditions. This taxon prefers fresh waters but tolerates a wide range of chemical conditions (El Hamouti, 2003).

– *Surirella ovalis* Brébisson is a saline algae living in fresh and also brackish water, with a pH optimum of 7.69 (Gasse *et al.*, 1995).

## 5 - HYDROLOGICAL EVENTS

The salinity of the Baza paleolake system can be approximately deduced from the diatom study of these four sites.

### 5.1 - RINCÓN DE LA LOSA SECTION

The Rincón de la Losa section is located 1 km NE from Orce, between the Salar and Vélez canyons (fig. 2, 4 and 5). The complete section is > 60 m and includes five lithostratigraphic units, two lacustrine, two alluvial and



**Fig. 4: Outcrop view of Rincón de la Losa diatomites (up left), Barranco de las Lumbres (lower left), and Barranco del Agua section, in the Galera Gypsum unit (right).**

Diatoms are indicated with an arrow. The Barranco del Agua diatoms occur in a bed of dark-brown clays (10-20 cm) rich in chert nodules above a 7.4 m thick massive bioturbated gypsum that was mined in the area.

*Fig. 4 : Vue des diatomites des affleurements de Rincón de la Losa (en haut à gauche), Barranco de las Lumbres (en bas à gauche), et Barranco del Agua, dans l'Unité du Gypse de Galera (à droite). Les diatomées sont indiquées avec une flèche. Les diatomées de Barranco del Agua sont présentes dans une unité argileuse de couleur brun foncé (10-20 cm) riche en nodules de silex surmontant 7,4 m de gypse bioturbé massif qui a été exploité dans la région.*

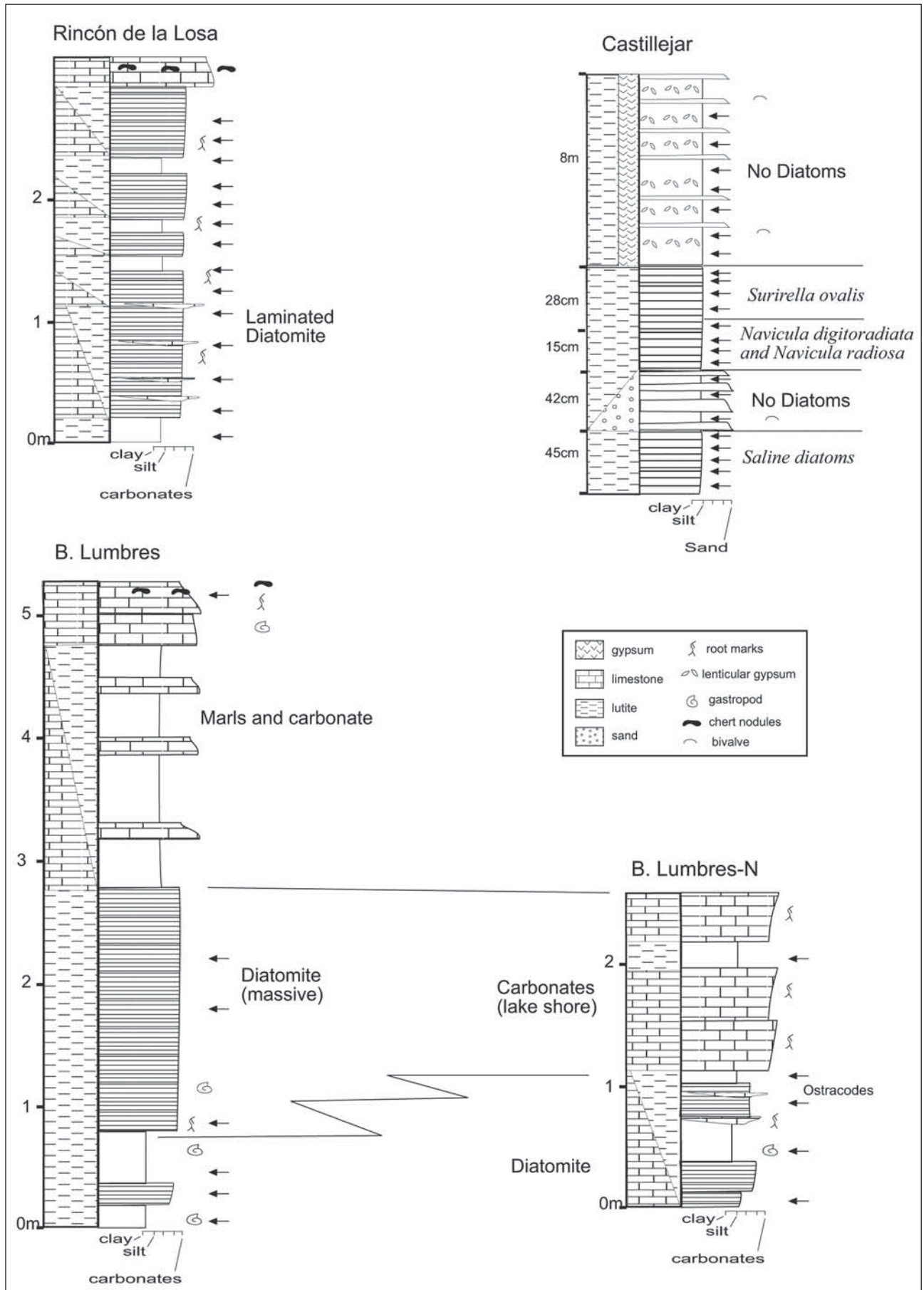


Fig. 5: Stratigraphy of sampled levels at Rincón de la Rosa, Castillejar and in two subsections, about 50 m from each other, and located near the top of Barranco de las Lumbres.

Fig. 5 : Stratigraphie des niveaux échantonnés à Rincón de la Rosa, Castillejar et à deux sous-sections espacées d'environ 50 m et situées près du sommet de Barranco de las Lumbres.

one fluvio-lacustrine (Gibert *et al.*, 2007a). From those, only the lowest lacustrine unit has supplied diatoms. This unit includes an interval of 2.6 m of sediments that consist of laminated calcareous beds (40-70 cm) rich in diatoms (*Epithemia*, *Navicula*), alternating with calcareous sandy claystones (20-40 cm) poor in biological remains. This interval at the base of Rincón de la Losa section is dated by magnetostratigraphy and mammals around 1.9 Ma (Scott *et al.*, 2007). A total of 26 samples were taken at approximately 10-20 cm intervals along this first section.

High frequencies ( $\geq 50\%$ ) in all levels from Rincón de la Losa section of the littoral epiphyte species *Epithemia adnata*, *Epithemia turgida* and the abundant benthic littoral species *Navicula halophila* living in saline water clearly indicate a shallow and alkaline lake. This group reflects fresh to slightly brackish water conditions. These lacustrine deposits and diatom palaeoassemblage indicate wetter conditions.

## 5.2 - BARRANCO DE LAS LUMBRES

The Barranco de las Lumbres section (80 m) is located in the NE margin of the Baza Basin. The section exposes distal alluvial deposits near the base followed with mudstones that represents a transitional environment (mudflats) and lacustrine carbonates deposits at the top.

These lacustrine deposits are substituted by silica especially near the fault and are rich in diatoms and silicified plant remains. This diatomaceous lacustrine unit outcrop extensively and can be followed for kilometers towards the North and East. It has been correlated with the lacustrine unit outcropping in Botardo (Gibert *et al.*, 2006), which have Turolian mammal sites with suggested ages between 6 Ma and 5 Ma (Martín Suárez, 1987; Ruiz Bustos, 2007).

Diatoms assemblage identified at this section is similar to those from the much younger Rincón de la Losa section including *Epithemia adnata* and *Epithemia turgida*, littoral epiphytic taxa, and *Navicula halophila* representing a similar environment with fresh to slightly brackish water in shallow and alkaline lake.

## 5.3 - BARRANCO DEL AGUA SECTION

West of the village of Galera is the the Barranco del Agua (fig. 2, 4 and 5), the outcropping section here is more than 100 m thick; these deposits are dated from Middle Pliocene to Early Pleistocene. Their deduced age is based on available paleomagnetic and paleontological data in the nearby Galera section (Garcés *et al.*, 1997; Scott *et al.*, 2007).

From this long section only the basal portion has supplied diatoms. This small diatomitic unit consists of dark-brown clays and marls (10-20 cm) rich in chert nodules and diatoms placed on top of a 7.4-m-thick formation of white massive bioturbated gypsum beds that were mined in the area. The gypsum unit represents a gypsiferous lake placed in the marginal zone of the basin, in an area dominated by saline mud flats; the claystones

probably represent a period of dilution with more water income.

In Barranco del Agua occurs a different diatomaceous assemblage than the one identified in the most marginal outcrops of Rincón de la Losa and Barranco de las Lumbres. Here, just above the gypsum, in the dark-brown claystones, epiphytic shallow-water diatoms *Epithemia adnata*, *Epithemia turgida* and some planktonic littoral forms (*Fragilaria* sp.) suggest a shallow fresh to oligo-saline water environment. A number of features such as root traces indicate shallow and often exposed conditions only in underlying evaporitic levels. We interpret these diatomaceous beds free of gypsum as an episode of dilution and rising water level in the basin.

## 5.4 - CASTILLEJAR SECTION

The Castillejar section is situated towards the center of the Basin and consists of mudstones covered by and alternation of gypsum, siltstones rich in carbonate and fine sandstones (fig. 2 and 5). Evaporitic lithofacies are present as fine-grained laminated gypsum layers and beds rich in lenticular crystals of gypsum (1-12 cm). Occasionally gypsum nodules are found.

As a difference with Galera section, layers in Castillejar have a large lateral continuity and minor lateral changes in facies suggesting a more extensive depositional system.

Beds rich in the eurytopic bivalve *Cerastoderma* have been identified in this outcrop, but the tolerance of this taxa to a broad range of salinities makes it a poor indicator of prevailing salinity.

A total of 26 samples were taken from the Castillejar section. From bottom to the top of this sequence one distinguishes:

- unit 1 (0-45 cm): grey marls rich in saline diatoms followed by oxidized sand (45-87 cm) without diatoms,

- unit 2 (87-130 cm): yellowish and dark brown marls with predominant saline forms. Successively in the vertical section, *Navicula digitoradiata* dominates (87-102 cm) followed by high frequencies ( $\geq 50\%$ ) of *Surirella ovalis* (102-130 cm). The top of this section are 8 m of rhythmically intercalated gypsiferous-lutites (clays, sands and crystals of gypsum), where diatoms are absent.

*Navicula digitoradiata* Gregory Ralfs is regarded as being a brackish water form and it is commonly found in sea-shore environments. *Surirella ovalis* Brébisson is a saline algae living in fresh and also brackish water. Lacustrine environments are supported by diatoms flora suggesting a more saline lake with a seasonally varying regime. The present species suggest a new different lacustrine environment than the previous described in this more central area of the basin, here the diatom assemblage indicates an increase in salinity in respect to more marginal environments. From the sedimentological perspective, this is a more evaporitic environment, where intense evaporation occurred during the formation of gypsum beds suggesting dominant  $\text{SO}_4$  waters.

## 6 - DISCUSSION

Salinity changes are also recorded in the marginal lacustrine deposits by changes in the geochemistry of biogenic carbonates, mainly from ostracods (Anadón & Gabàs, 2009).

These marginal lakes experienced fluctuations in salinity through time due to mixtures of three water types: inner and saline lake waters, meteoric diluted and saline ground water inputs (Anadón & Gabàs, 2009).

A previous study using ostracods and shell composition through 10 m of a nearby Early Pleistocene section indicates alternating phases of two fossil assemblages, which differ in their salinity requirements (Anadón *et al.*, 1994). These faunal assemblages record phases of slightly saline, Ca<sup>2+</sup> bicarbonate-rich water, and saline, NaCl-dominant water (Anadón *et al.*, 1994).

From a stratigraphical perspective, three different facies zones have been described reflecting environments, where salinity increases towards the center of the basin. In this study, the identified diatom assemblages indicate paleoenvironments consistent with paleoenvironments interpreted on the basis of lithofacies (Gibert *et al.*, 2007a).

Sections Rincón de la Losa and Barranco de las Lumbres are free of evaporitic deposits in a marginal area near water inlets. Fresh to slightly saline shallow lakes can be deduced from the sedimentological and diatomaceous information.

In a less marginal area, in which is described as the Galera Gypsum Unit, more evaporitic facies are found in a long sedimentary succession, which includes a variety of deposits and environments. On top of a massive bioturbated gypsum unit, in a claystone bed, diatoms are found.

These claystones, free of gypsum, indicate a period of dissolution in a gypsiferous lake, the diatoms included in these clays represent fresh water that correspond with a pluvial period characterised by a positive hydrological balance.

Finally the last studied outcrops is located near Castillejar, towards the center of the Basin. Here, continuous gypsum and siltstones beds alternate and are rich in saline diatoms indicating periods of severe evaporitic conditions in a permanent lake. The diatom assemblage reveals more saline conditions as expected by these evaporitic sedimentary facies (fig. 6).

## 7 - CONCLUSION

Two of the outcrops studied (Barranco de las Lumbres and Rincón de la Losa) present a diatom flora dominated by *Epithemia adnata* - *Epithemia turgida* a littoral epiphytic living on aquatic plants, and *Navicula halophila*. These diatom assemblages are typical in fresh to slightly brackish water of shallow and alkaline lakes. These lake deposits are interstratified with alluvial deposits and represent permanent paleo-lakes with a low bathymetric coefficient developed during two periods of positive hydrologic balance. The sedimentary laminations in Rincón de la Losa reflect a climate of seasonal contrast. The oldest of these lake episodes, the Las Lumbres is dated by fauna as Late Miocene (Turolian); the younger wet episode, identified at Rincón de la Losa site is dated by magnetostratigraphy at 2.2 to 1.9 Ma.

The Barranco del Agua diatoms, identified in a marginal setting to the paleo-Lake Baza developed in a saline mud flat environment during the mid-late Pliocene. These

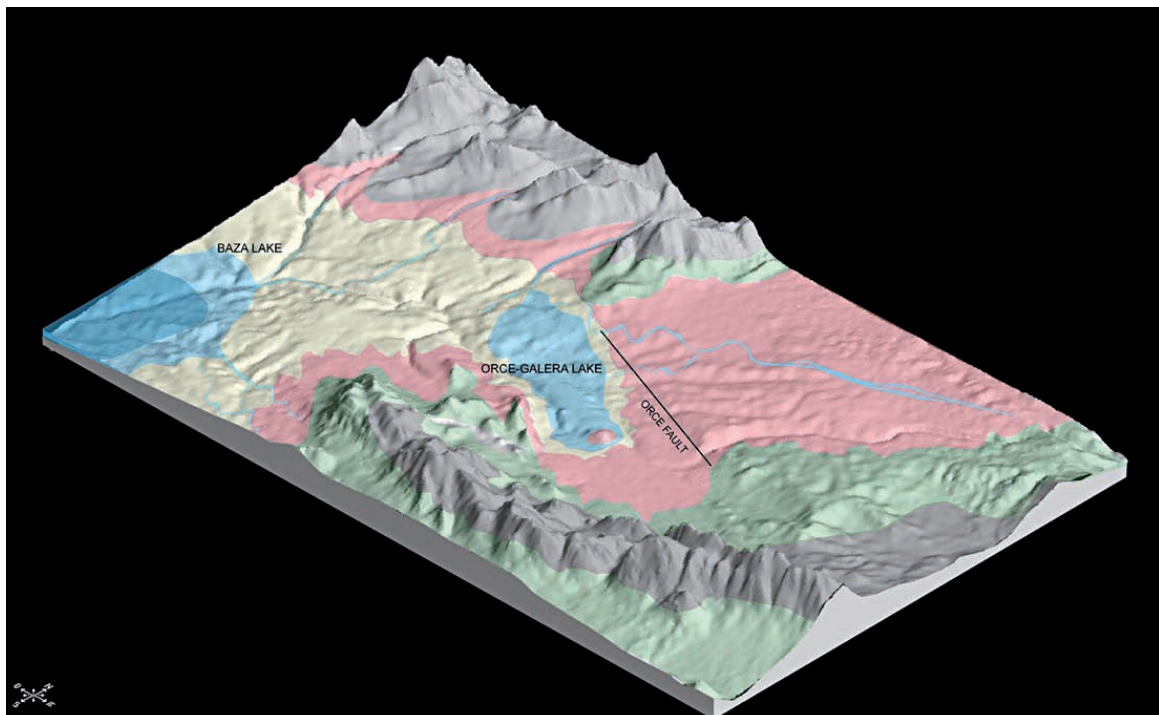


Fig. 6: Paleogeographical interpretation of the Baza lake system, with a central saline lake surrounded by other lakes of minor salinity.  
Fig. 6: Interprétation paléogéographique du système du lac Baza, avec un lac salé central entouré par d'autres lacs de salinité moindre.

diatoms present a fresh to slightly saline association (*Epithemia adnata*, *Epithemia turgida* and *Fragilaria* sp.) that occurred associated to claystones deposited immediately after a unit of massive gypsum. These diatoms are suggested to be formed during a wet period when salinity was diluted during the Middle Pliocene.

Late Pliocene outcrops in a more central lacustrine setting (Castillejar) and present species indicating more saline waters. Intense evaporation is indicated by continuous beds of gypsum. A brackish paleo-Lake Baza is deduced from a first association dominated by *Navicula digitoradiata*, and then from a second association with *Surirella ovalis*.

The distribution of diatom flora in the Baza basin parallels the lithostratigraphic data (Gibert *et al.*, 2007a) indicating increasing evaporitic lacustrine environments toward the centre of the paleo-Lake Baza with the occurrence of episodes of dilution in a dominant evaporitic environment.

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