Sedimentary and diagenetic features in saline lake deposits of the Monegros region, northern Spain

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Abstract

The Monegros region in northern Spain is marked by the occurrence of a large number of ephemeral to dry lake basins, occupying small karstic depressions. The lacustrine sediment fill of these basins contain various carbonate and silicate minerals whose origin and palaeoenvironmental significance is poorly understood. For the present study, 14 lake basins were sampled in order to establish vertical, lateral and regional variations in mineralogical and textural characteristics, aimed at determining the mode of formation of the various mineral phases present. In nearly all basins, the same sequence of three lithological units is recognized, including a basal clayey unit, a middle magnesite-bearing and gypsum-rich unit, and a calcite- and dolomite-dominated surface unit. Distribution patterns of carbonate minerals indicate that magnesite is a synsedimentary precipitate, dolomite formed as a diagenetic authigenic phase, and calcite is partly authigenic and partly allogenic. All clay minerals, including sepiolite and smectite, appear to be allogenic. Regional variations are marked by similarities between groups of neighbouring basins, but no overall trend related to regional drainage patterns is recognized. The middle lithological unit records a lake stage with predominantly chemical sedimentation (Unit II), overlying a less well documented interval corresponding to a perennial lake stage with lower salinity (Unit III), whereas the surface unit formed during a period with predominantly clastic sedimentation. Based on a comparison with other regional records, the middle unit is attributed to an Early Holocene humid stage, separated from the overlying Late Holocene deposits by a hiatus that corresponds to a Mid Holocene arid stage.

Keywords : Monegros, lake deposits, magnesite, dolomite, gypsum

1. Introduction

The Monegros region in Aragon, northern Spain, is marked by an abundance of dry salt lake basins that occupy small karstic depressions (Fig. 1, Fig. 2). Several studies have documented the nature of sedimentary and diagenetic processes of mineral formation in these lakes, ranging from seasonal precipitation of highly soluble salts to possible silicate mineral formation (Pueyo-Mur, 1978/1979; Pueyo-Mur, 1980; Mingarro et al., 1981; Pueyo-Mur and Inglés-Urpinell, 1987a, 1987b). A number of lakes have also been the subject of palaeolimnological research projects, whereby mineralogical composition has been an important criterion for palaeoenvironmental reconstruction (e.g. Schütt, 2000; Valero-Garcés et al., 2004; González-Sampériz et al., 2008). The results of these studies of present-day and

Late Quaternary sediments indicate a need for a better understanding of mineral distribution patterns and of the underlying sedimentary and diagenetic processes.

The present study is part of an investigation of mineral formation in atmospheric conditions, based on an analysis of vertical and lateral variations within lake basins and of differences between lakes within a region. The paper deals with carbonate and clay minerals, in combination with textural sediment properties and petrographical features. The nature of gypsum occurrences is discussed elsewhere (Mees et al., subm.).

2. Setting and earlier studies

The study area in the Monegros region is situated on a plateau along the northern edge of the Ebro valley (ca. 350 m elevation). The geological substrate is composed of Miocene continental deposits, comprising limestone and gypsum beds (Salvany et al., 1996). The sequence includes an upper and lower red claystone unit, which appears in outcrops to the north and south of the study area (Fig. 1). Karstic depressions formed as a result of dissolution of the bedrock, at locations that are partly controlled by structural factors (Arlegui and Soriano, 1998).

Mineralogical data are available for the uppermost part of the deposits of several basins, of which Pito has been the most intensively investigated (Pueyo-Mur, 1978/1979; Pueyo-Mur, 1980; Pueyo-Mur and Inglés-Urpinell, 1987a, 1987b). Palaeolimnological studies have been published for Pito (Schütt, 1998, 2000) and La Playa (Moreno et al., 2004; Valero-Garcés et al., 2005; González-Sampériz et al., 2008). Palaeolimnological data for Salineta (Valero-Garcés et al., 2001, 2004, 2005; González-Sampériz et al., 2008), north of the study area, are not directly relevant for the present study, because of its different geological setting (see Fig. 1) and hydrological context (Samper-Calvete & García-Vera, 1998), resulting in much longer persistence of surface brines and more active evaporite sedimentation. For other basins in the study area, only pollen data are available, specifically for Camarón and Rebollón (Pérez-Obiol and Roure, 1990) and for Guallar (Davis and Stevenson, 2007).

3. Materials and methods

A total of 14 lake basins were sampled, comprising nine without vegetation and five with a halophytic vegetation cover (Fig. 1, Table 1). In the basins without vegetation, with high salinity (10-30 mS cm^{-1} for 1:5 soil:water extracts) and well-documented in terms of surface hydrology (e.g. Castañeda and Herrero, 2005), three sampling sites were selected along an east-west transect. This orientation, parallel to the dominant wind direction, has been demonstrated to be the most significant for basins in the study area, in terms of recording lateral variations in the nature of surface deposits, basin floor level and the occurrence of surface brines (Pueyo-Mur, 1978/1979). In basins with a vegetation cover, two sampling sites were used, with the exception of one basin with a single sampling site (Gramenosa). The sediments were sampled in profile pits, down to the groundwater table, which was generally about 1 m below the surface. At most sites, lower parts of the deposits were observed and sampled, in much less detail, by hand augering, down to the bedrock where possible. The limestone and claystone bedrock was sampled for mineralogical analysis around basins where they are exposed *in situ*.

Mineralogical analysis of the sediment samples included X-ray diffraction (XRD) analysis of the total fraction after removal of gypsum by repeated washing with a sodium chloride solution. Separation of the clay fraction (< 2 µm) was done after decalcification with a sodium acetate buffer (pH 4.9), and XRD analysis of that fraction involved the use of five standard treatments (K saturation followed by heating at 350 and 550°C, Mg saturation followed by glycolation). For auger samples, bulk XRD analyses were done without removal of gypsum, and clay analysis was limited to the < 50 µm fraction, untreated and glycol-treated. Textural analyses were done for the residue remaining after decalcification with a 1 N HCl solution.

A total of 167 thin sections, generally 6 by 9 cm large, were prepared after impregnation of undisturbed oriented samples with a polyester resin.

4. Results

4.1. Vertical variations

Data for selected representative profiles are compiled in Table 2, and examples of sampled profiles are illustrated in Figure 3. In the upper part of the deposits, two distinct lithological units are recognized (Unit I, Unit II). The nature of the deposits is less well documented for the underlying sediments by the present study, provisionally grouped in a single heterogeneous unit (Unit III). The maximum observed depth of the bedrock, reached at the base of Unit III, ranges from 155 to 300 cm between the studied basins (see Table 1). Fragments recovered from the base of the borehole are composed of micritic limestone or white fine-grained gypsum rock, the main lithologies in exposure around the basins.

4.1.1. Unit I

The upper unit (Unit I) has a carbonate fraction composed of calcite and dolomite. The relative abundance of these minerals shows no systematic variations within the unit. Minor amounts of magnesite occur in the basal part of the unit in some profiles and throughout the unit at Guallar and Muerte.

The clay fraction consists of mica, kaolinite and variable amounts of smectite. Chlorite generally occurs in small quantities, often confined to the upper part of the unit, predominantly in the lake-marginal sites. At some sites, chlorite occurs throughout the unit in greater amounts (Piñol, Rollico). Sepiolite occurs throughout Unit I at one site (Guallar). Elsewhere it is only detected at the top (Amarga Alta, Valdecarretas) or the base (Vinagrero I) of the unit, corresponding to levels with a high smectite content.

The deposits contain an admixture of silt- to fine sand-sized detrital mineral grains and larger limestone fragments, as observed in thin sections. Some intervals with a high silt/fine sand content show layering or grading (Piñol). In the same basin, the upper part of the deposits is partly characterized by horizontal alignment of the clay particles. XRD analysis shows a higher quartz content in the upper part of the unit in several profiles (Pez, Piñol, Vinagrero II). Charophyte remains occur in Unit I deposits at Amarga Alta, Vinagrero I, Vinagrero II and Rebollón.

At several sites, the unit comprises two distinct intervals, rather than showing a gradual vertical change. The lower of these intervals (Unit Ib) has a high dolomite content and low calcite content at some sites (Amarga Alta, Gramenosa). Elsewhere, it has a higher clay/silt ratio and a higher fine silt content (Rebollón).

4.1.2. Unit II

Unit II is mainly characterized by high magnesite and gypsum contents. Magnesite is only absent in two southern basins (Pez, Rebollón). The deposits are highly gypsiferous in all basins. Pronounced layering due to variations in gypsum content characterizes the deposits at Amarga Alta and Amarga Baja. At Muerte and in the western part of Camarón, Unit II includes a clay intercalation with a lower amount of gypsum, occurring in the form of relatively large crystals.

The magnesite content is generally high throughout the unit. At Piñol, it is only high in the upper part of the unit, and magnesite is absent in the lower part of a heterogeneous Unit II interval in the nearby Muerte basin. In one of the two basins where magnesite is absent (Rebollón), the profiles show clear differences in gypsum content, clay/silt ratio, silt grain size and carbonate content between Units I and II. In the other basin with magnesite-free deposits (Pez), recognition of Unit II boundaries is uncertain.

The calcite content is lower in Unit II than in Unit I at Camarón and Guallar, except in some samples with a higher quartz content. In other basins, there is no difference between both units, as in the southern lakes, or the calcite content varies within and between the profiles. The dolomite content is either similar to that of Unit I, or somewhat higher.

The mica and kaolinite content is similar to that of Unit I. The smectite content is higher in several profiles (Gramenosa, Guallar, Vinagrero I, Vinagrero II, Valdecarretas), whereas other profiles show no major differences in smectite abundance between both units. Sepiolite occurs in the Unit II deposits of the basin where it also occurs throughout Unit I (Guallar). The mineral is also present at both sites in the Valdecarretas basin.

In thin sections, limestone fragments and an important silt/fine sand admixture are generally absent. Charophyte remains are present in the highly gypsiferous layered Unit II deposits of the Amarga Alta and Amarga Baja basins.

4.1.3. Unit III

In profile pits, Unit III was only reached in two basins (Piñol, Camarón), where it is generally different from the overlying Unit II deposits by an absence or lower abundance of magnesite, a different grain size (either coarser or finer), a low gypsum content, and a clayey field appearance. Auger observations in these and other basins show a clay interval that extends down to the bedrock, below the highly gypsiferous Unit II interval.

Analysis of a small number of auger samples indicates the presence of magnesite in at least part of Unit III in several basins (Amarga Alta, Amarga Baja, Guallar, Rollico, Vinagrero I), generally in small amounts. The clay mineral association is comparable to that of Units I and II. The smectite content is generally similar to that in Unit II in the same profile, with the exception of Amarga Alta and Amarga Baja, where smectite is absent in the available Unit III samples.

4.2. Lateral variations

The boundary between Units I and II is generally at a similar depth throughout the basin (see Table 1). The amount of limestone fragments and silt to fine sand grains observed in thin sections is commonly higher in one or both lake-marginal sites in comparison with the central profile (Camarón, Guallar). The lake-marginal sites can also be characterized by a higher sand content, a coarser silt fraction and/or lower clay/silt ratios (Guallar, Rebollón, Rollico). In several basins, the dolomite content is higher in the western sampling site (Muerte, Pez, Piñol, Rollico). A less pronounced trend is a somewhat lower magnesite content in the western sampling site relative to both other profiles in the same basin (Camarón, Guallar, Piñol).

4.3. Regional variations

Based on similarities in the nature of their deposits, four groups of lakes are recognized, each comprising neighbouring basins in a specific part of the study area.

Camarón, Guallar, Muerte and Piñol form a first group of basins with similar characteristics, located in the northwestern part of the study area. Several features are shared between two neighbouring basins, such as the occurrence of magnesite throughout Unit I (Guallar, Muerte), high magnesite concentrations in the upper part of Unit II (Muerte, Piñol) and the occurrence of a clay intercalation within Unit II (Camarón, Muerte). Two basins near the upper claystone outcrop have deposits with a high smectite content (Camarón, Piñol). They also have a high dolomite content relative to both other basins that are part of the same group. Guallar is an aberrant site, with a low total dolomite content, sepiolite in all Unit I and II samples, and magnesite throughout Unit I.

Pez, Rebollón and Rollico form a southwestern group. The most northern of these basins (Rollico) has a distinct magnesite-bearing Unit II interval, as in the northwestern group but with a much lower magnesite content. Pez and Rebollón are the only basins without vegetation where magnesite is absent.

The three central basins with vegetation (Vinagrero I, Vinagrero II, Valdecarretas) show an identical vertical sequence in the field, which includes a nearly non-gypsiferous Unit I interval and highly gypsiferous Unit II deposits. Vinagrero II, located to the east, is aberrant within this group because of a complete absence of magnesite and sepiolite. Valdecarretas is similar to Guallar to some extent, by having sepiolite-bearing deposits with a low dolomite content.

In the southeastern part of the study area, two basins are similar in having layered Unit II deposits (Amarga Alta, Amarga Baja). The neighbouring Gramenosa basin shows vertical variations in carbonate mineralogy within Unit I that are similar to those in the central Amarga Alta profile.

4.4. Bedrock composition

The carbonate fraction of the available limestone and claystone samples is generally composed exclusively of calcite. Subordinate dolomite occurs at one site (Muerte), as well as in reference samples of the red claystone unit south of the study area and green claystone sampled to the north (Salineta). The presence of minor dolomite in the local limestone has also been documented by earlier studies (e.g. Quirantes Puertas, 1978; Arenas et al., 1998).

The clay fraction is generally dominated by mica, with smaller amounts of kaolinite and often with minor chlorite. The smectite content is high around basins in the northwestern part of the study area (Camarón, Guallar, Muerte, Piñol), but it is absent in the south (Rebollón, Rollico) as well as to the east of the first group (Vinagrero I).

5. Discussion

5.1. Depositional environment during the main lake stages

5.1.1. Unit I

Unit I represents a period with predominantly clastic sedimentation. Limestone fragments and other materials were washed in from the sides of the basins. The presence of relatively coarse rock fragments, as well as the existence of lateral variations in abundance of those fragments and in silt/sand content, excludes a predominantly aeolian origin of the coarse detrital fraction. This is in disagreement with González-Sampériz et al. (2008), who relate high quartz (and clay) contents to strong aeolian inputs during arid periods. Also, the horizontal alignment of clay particles in the upper part of the deposits at one site records sedimentation from suspension.

Magnesite occurring in the basal part of the unit at several sites is probably derived from reworking of the underlying magnesite-rich formations, rather than having formed as an authigenic precipitate during a transitional early stage of the Unit I period. The scarcity of dolomite in the local Tertiary bedrock implies that it represents an authigenic precipitate in the lake deposits, which is quite common in lacustrine environments (e.g. Last, 1990). The higher dolomite content in the western part of several basins suggests a partly diagenetic origin, which does not necessarily involve transformation of calcite. A higher dolomite content in lake-marginal areas in general was observed by Pueyo-Mur and Inglés-Urpinell (1987a), who refer to mixing of saline and dilute solutions. Calcite can be largely authigenic, based on the absence of co-variations for the amounts of calcite and siliciclastic material (e.g. González-Sampériz et al., 2008).

The clay fraction is largely detrital, being mainly composed of minerals that are typically allogenic (mica, kaolinite, smectite, chlorite) and whose presence in the local bedrock was confirmed. The occurrence of chlorite in the upper part of the unit at several sites is most likely related to a relatively coarse grain size of this phyllosilicate mineral in the source rocks. Variations between basins must be largely determined by bedrock composition.

The change from Unit II to Unit I sedimentation was abrupt, yielding sediments with a different carbonate mineralogy and a high clay/silt ratio, recording a freshening of the lake relative to the end of the Unit II stage. The contact between both units most likely represents a major hiatus. This implies that the basal part of Unit I should not be discussed in terms of transitional conditions. The contact between both units can be partly erosive, formed by aeolian deflation that may have resulted in the development of the gypsum dunes along the eastern margin of some basins.

In a number of basins, all with a low gypsum content of Unit I, a charophyte vegetation was present during an early part of this lake stage, which can develop in ephemeral saline lake environments (e.g. Burne et al., 1980; Davis and Stevenson, 2007). Several basins record a change to sedimentation with a greater supply of coarse material to the sampling sites during later parts of the Unit I stage. The resulting occurrence of two distinct intervals within Unit I at several sites records an event of at least regional significance.

5.1.2. Unit II

Unit II corresponds to a stage when the basins were occupied by a saline lake with abundant synsedimentary gypsum formation. These lakes, which can have been ephemeral or perennial, supported the existence of charophyte populations in some basins. In two southeastern basins, layered deposits record periodic variations in salinity, and elsewhere a clay intercalation was formed during a single period with lower salinity.

Magnesite formed as a synsedimentary precipitate during Unit II sedimentation, in a few basins characterizing mainly the final stage of this period. Magnesite is relatively rare in lake environments, generally occurring in settings with seasonal variations in water composition (see Deelman, 2008). The occurrence of magnesite within a unit whose upper boundary also marks an important change in the nature of the siliciclastic fraction, as well as in synsedimentary gypsum content, is not compatible with a present-day diagenetic origin, suggested by Pueyo-Mur and Inglés-Urpinell (1987b). The latter will generally yield distribution patterns that are unrelated to lithological boundaries. Minor lateral variations in relative magnesite abundance are more compatible with a diagenetic origin, but these can also be related to dilution by other components. No magnesite is reported in palaeolimnological studies of the Salineta, La Playa and Pito basins (e.g. Schütt, 2000; González-Sampériz et al., 2008), where it could in principle be absent, as in the southwestern basins considered for the present study. However, the occurrence of magnesite is explicitly mentioned for all three basins in an earlier sedimentological study (Pueyo-Mur and Inglés-Urpinell, 1987a).

Dolomite has been used as a palaeosalinity indicator in most palaeolimnological studies of the Monegros basins, for which magnesite is in fact better suited. As in Unit I, major lateral variations in dolomite content observed for several basins indicate a diagenetic origin of the mineral. Within the northwestern group, proximity to the dolomite-bearing claystone unit of the Miocene bedrock seems to be a factor, whereby this formation may have acted as a source of magnesium rather than as a source of detrital dolomite. The higher calcite content at some levels with higher quartz concentrations suggests a partly detrital origin.

As in Unit I, the clay fraction is at least largely detrital. The higher smectite content in Unit II relative to Unit I is attributed to an expected relatively fine grain size of smectite in the source rocks. Sepiolite, which commonly forms as an authigenic phase in saline lake environments (e.g. Jones and Galán, 1988), is the only clay mineral for which a non-detrital origin can be considered. One argument for authigenic sepiolite formation is its occurrence in Unit II at Valdecarretas. In the nearby Vinagrero I basin, sepiolite in the lower part of Unit I may be derived from reworked Unit II deposits. An authigenic origin could also be considered for the common occurrence of sepiolite at Guallar, where an aberrant carbonate mineralogy indicates hydrochemical conditions that are unusual for the region. The nature of the deposits is in fact somewhat similar at Valdecarretas, where the dolomite content is equally low. Mineral authigenesis is also in agreement with SEM observations for fibrous clays by Pueyo-Mur and Inglés-Urpinell (1987a). They report the presence of fibres on surfaces of authigenic minerals (cf. Eswaran and Barzanji, 1974) and fibrous textures along the edge of plate-shaped clay particles (cf. Bachman and Machette, 1977), which both record diagenetic sepiolite formation within the lake deposits, albeit by different processes. However, an allogenic origin of sepiolite is also possible and apparently more likely. The mineral was not detected for bedrock samples analyzed for the present study, but its presence has been reported for Tertiary limestone of the region in other studies (e.g. Quirantes Puertas, 1978). An allogenic origin is also suggested by the high smectite content of sepiolite-bearing intervals at Valdecarretas and Vinagrero I. Another argument is the occurrence of sepiolite throughout successive intervals recording different environmental conditions at Guallar, which should not all be equally conductive to authigenic sepiolite formation.

5.1.3. Unit III

The deposits of Unit III formed in a perennial lake with lower salinity than during the Unit II period. Studies of lower parts of the lake deposits in continuous cores indicate that several distinct intervals can be identified (e.g. González-Sampériz et al., 2008), but this cannot be confirmed based on the auger observations and limited analytical data for Unit III that were obtained for the present study. The study does show that conditions favouring magnesite formation were already met during this stage in several basins.

5.2. Comparison with other basins of the Monegros region

Palaeolimnological studies within the study area are available for La Playa, Guallar and Pito (see Fig. 1). Although no magnesite occurrences are reported in these studies, tentative correlations with the sediment sequence documented by the present report do appear to be possible. The proposed correlations require confirmation by radiocarbon dating, which was outside the scope of the present study, dealing with conditions of mineral formation.

At La Playa (González-Sampériz et al., 2008), an upper calcite-dominated unit (0-30 cm) is probably the equivalent of Unit I, and a more dolomite-rich underlying interval with coarse-crystalline gypsum seems to correspond to Unit II (30-80 cm; 9795 ± 119 cal YBP at 80 cm), overlying an interval in which the deposits generally have a low gypsum content (80-160 cm), correlated with Unit III. This record is interpreted to comprise a Late Glacial period with alternating humid and arid stages (Unit III), an Early Holocene humid period with a late-stage transition to more arid conditions (Unit II), an arid Middle Holocene period corresponding to a major hiatus, and a Late Holocene ephemeral saline lake stage (Unit I).

At Guallar (Davis and Stevenson, 2007), pollen data and colour changes are interpreted to record an Early Holocene period with generally high lake levels, corresponding to Unit III, followed by a stage with shallower lake conditions whose onset is dated at 8285 ± 135 cal YBP (Unit II). An important hiatus is inferred for the boundary between these Early Holocene deposits and the overlying Late Holocene sediments (Unit I; 0-48 cm).

At Pito, Schütt (1998, 2000) recognizes a similar sequence, with a different chronology, unsupported by radiometric age determinations. The non-gypsiferous lower unit (133-200 cm) probably corresponds to Unit III, and the gypsiferous upper unit (0-133 cm) seems to include Units II and I, whereby deposits of an inferred humid stage near the top of the sequence (5-25 cm) might be the equivalent of Unit I. Unit III is considered to have formed during the Early Holocene (late Boreal and early Atlantic), Unit II is assumed to reflect more arid conditions during the Middle Holocene (Subboreal and younger), and the lower part of Unit I is considered to have been deposited during historical times (Little Ice Age) (Schütt and Baumhauer, 1996; Schütt, 2000).

5.3. Regional variations

Regional variations are marked by the presence of several groups of neighbouring basins with similar characteristics, related to differences in hydrological and geological conditions between parts of the study area rather than between individual lake basins. No overall regional trend is recognized for the authigenic minerals. For instance, there is no increase in relative abundance of magnesium carbonates from north to south, which could be expected for a series of flow-through basins in a system draining towards the Ebro valley. The reverse trend is in fact recognized, whereby Rollico has an intermediate position between Rebollón and Camarón in terms of magnesite content.

Variations in smectite and chlorite content between basins are partly determined by bedrock composition. Proximity to the claystone formations is another factor, for instance resulting in high smectite contents at Camarón and Piñol, where the claystone outcrop is near the low northwestern edge of the basin.

6. Conclusions

The present study mainly concerns the origin of carbonate and silicate minerals in salt lake deposits of basins that are part of a large group of karstic depressions. Vertical, lateral and interbasinal variations in mineralogical and textural characteristics of the deposits allow the recognition of different genetic types of mineral occurrences, including synsedimentary authigenic magnesite, diagenetic authigenic dolomite, and most likely allogenic sepiolite. Some of these minerals have been used for the identification of depositional environments in palaeolimnological investigations for the study area, in part with a different interpretation of their occurrence, based largely on single-core studies. The present study demonstrates that the study of lateral variations is needed for a correct assessment of several parameters, considered in combination.

A similar sequence of lithological units is recognized for nearly all basins in the Monegros region, marked by a correlatable subsurface unit of typically magnesite-bearing gypsiferous deposits. The correlatable sequence as a whole records regional to global events, with differences in response related to local conditions. The same factors have acted at various stages, for instance resulting both in an absence of magnesite in one main unit and in a low gypsum content of the overlying deposits, in the southwestern group of basins.

In addition to the three basins that have been the subject of earlier palaeolimnological studies (Salineta, La Playa, Guallar), various other basins in the Monegros region are suitable for this type of research. Promising sites include basins with a thick sediment fill (e.g. Amarga Alta) and those where several distinct lithological subunits are recognized for the upper part of the deposits (e.g. Piñol).

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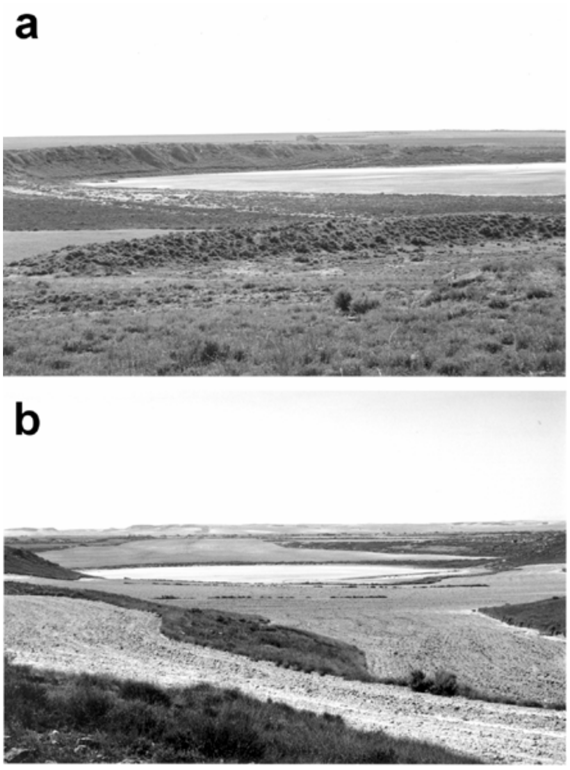
Figure captions

Fig. 1. Location of the study area within Spain (inset), and location of lake basins (base map with indication of main roads and nearest towns) – studied basins without vegetation (normal font), studied basins with vegetation (italics), and other lakes mentioned in the text (between brackets). Geological setting is illustrated by indication of surface occurrence of the upper claystone formation (light grey) and lower claystone formation (dark grey) (after Salvany et al., 1996).

Fig. 2. View of two basins of the Monegros region. (a) Guallar; (b) Pez.

Fig. 3. Field appearance of selected profiles. (a) Muerte, Site 3. (b) Amarga Alta, Site 1. (c) Vinagrero I, Site 1. Arrows indicate the boundaries between Units I and II in all profiles, and also between Units II and III in the Muerte profile.

Figures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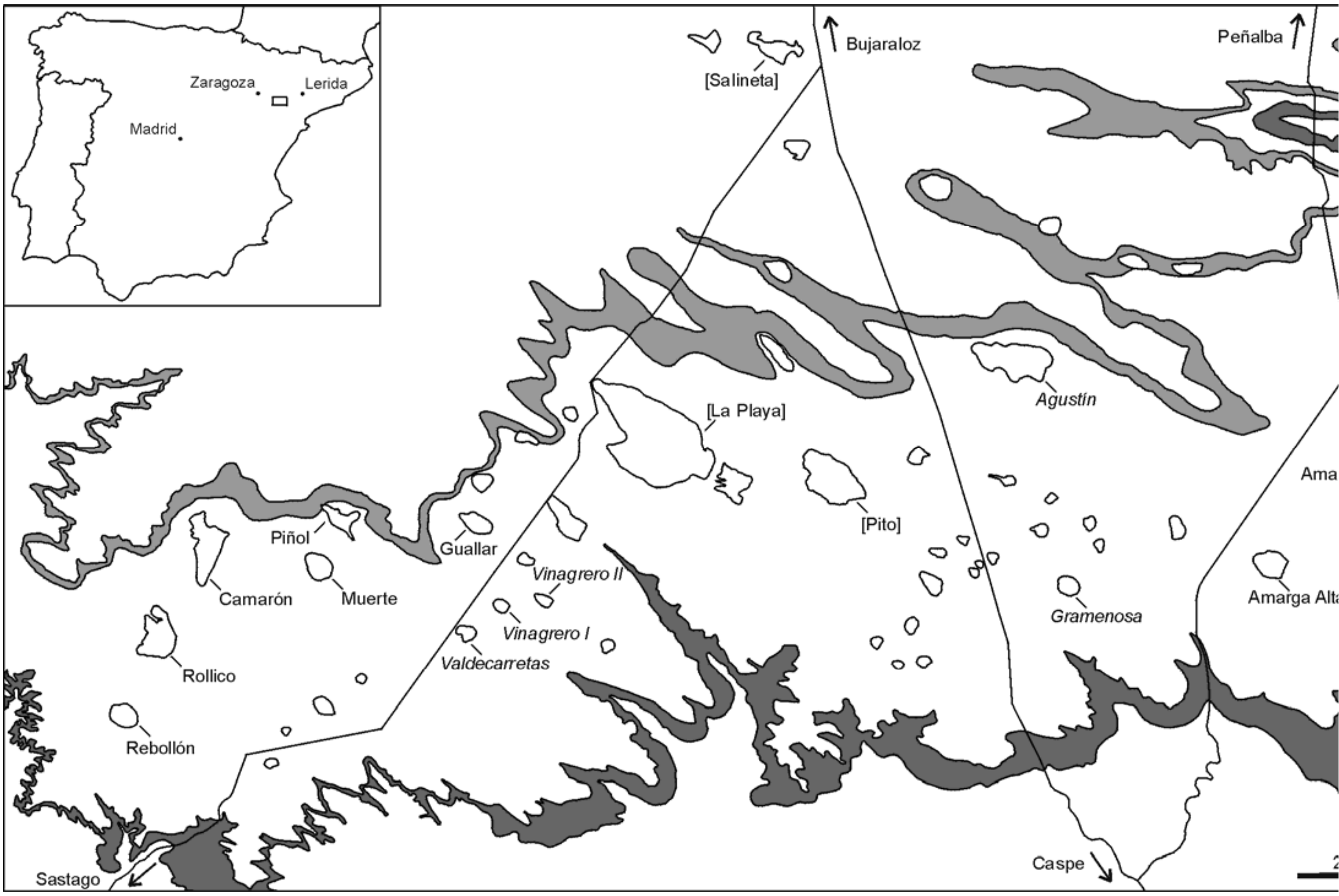
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Vinagrero I
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Gramenosa
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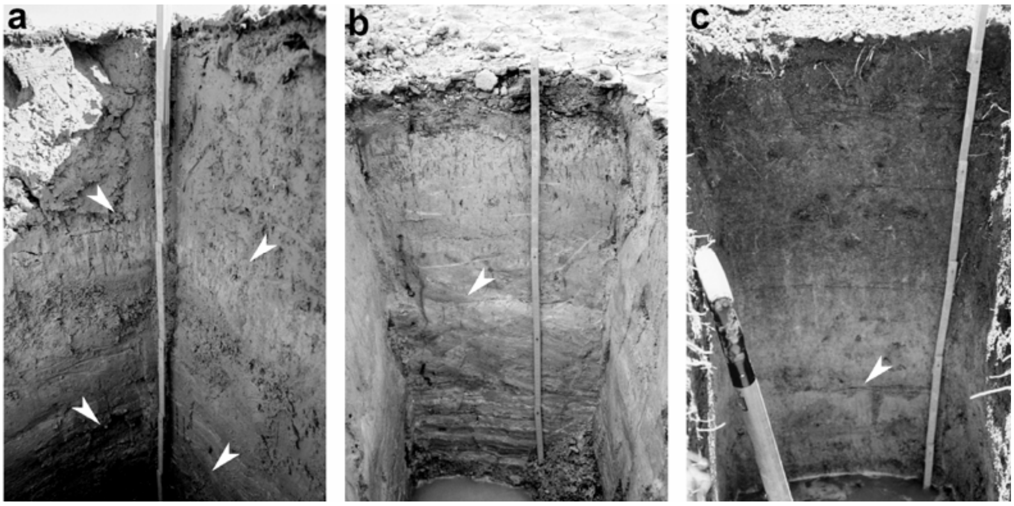
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