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Palaeoenvironmental reconstruction based on charophytes and sedimentology: Can the mid-Holocene Optimum be recognised in western Argentina?

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ABSTRACT

We sought to recognise to which extent the mid-Holocene Optimum can be identified in the Río Jarilla region of western Argentina, situated at the boundaries of the South American Arid Diagonal. The palaeoenvironmental conditions of the Arco del Desaguadero Formation, formed by a sedimentary sequence of late Pleistocene to middle Holocene age, were reconstructed based on charophyte assemblages and sedimentology. Three fluvio-lacustrine cycles were recognised with evaporitic layers at the top of each, reflecting the high temperatures that characterise the Holocene. For the second cycle, three ^{14}C dates were obtained, ranging from ca. 11 to 7 ka BP which, together with sedimentology and the palaeontological record allowed us to infer a warm and semiarid period assigned to the mid-Holocene Climatic Optimum. The gyrogonites found in the sediments belong to *Chara* cf. *contraria*, *Chara* cf. *papillosa*, *Chara halina* and *Chara hornemannii*, species related to extant species from Argentina. The presence of *C. hornemannii* imbedded in sedimentary rocks (evaporites) reflects higher temperatures in the past, although further research is needed to establish the significance of this species for reconstructing Quaternary climate.

1. Introduction

The reconstruction of Late Pleistocene and Holocene environmental variability across the key climatic boundary of the Arid Diagonal in South America is poorly understood (Fig. 1A). Although the last decade has seen an increase in palaeoclimatic studies in South America, continuing palaeoenvironmental research clearly shows the necessity to analyse past climate variability from a more regional perspective (Piovano et al., 2009). Climatic changes during Late Pleistocene and early Holocene affected the characteristics of sedimentary deposits of the fluvial basins directly connected with the Andes, and therefore related to deglaciation of central west Argentina.

In southern South America, climatic archives show a complex pattern of timing and even antiphase climate responses. For example, arid conditions have been proposed for western Argentina, during the middle Holocene. By contrast, for the Pampean region, Iriondo and García (1993) suggested warm and moist conditions from 8 to 3.5 ka with the development of a mid-Holocene Optimum soil. The Desaguadero-Curacó-Salado basin (our study area) is situated in central western Argentina, where the palaeontological record is poor compared to that of the Pampean region and mostly confined to fluvio-lacustrine systems. Accordingly, multiproxy data are necessary for a more accurate understanding of the region's past climates. This study investigates the sedimentology and charophyte associations from the Río Jarilla section in order to reconstruct the palaeoenvironmental history of central western Argentina.

Charophytes inhabit most types of non-marine habitats, from fresh to hypersaline waters, between the coast to inland lakes and they are sensitive to environmental change. Each genus and species can indicate different ecological conditions, such as ephemeral or permanent waterbodies, pH, depth, temperature, substrate types, and principally salinity (García, 1994). The aim of this work is to

Abbreviations: AD, Arid Diagonal; AMS, accelerator mass spectrometry; OM, organic matter; RJ, Río Jarilla.

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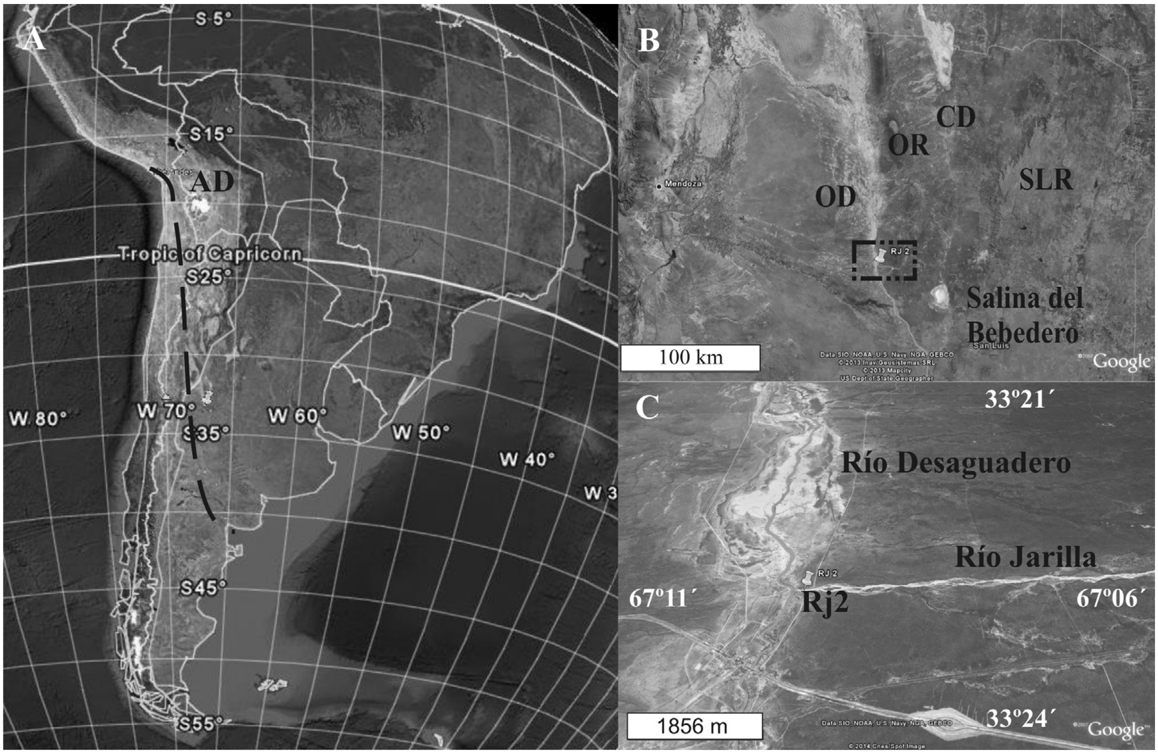

Fig. 1. (A) Position of the South American Arid Diagonal (AD). (B) Geomorphological units. Occidental depression (OD), Occidental range (OR), Central depression (CD), San Luis range (SLR) and study area (within the square). (C) Detail of the study area, with latitude and longitude coordinates.

recognise whether the mid-Holocene Optimum from this area of central-west Argentina can be characterised by reconstructing the palaeoenvironmental conditions inferred from charophytes and sedimentological evidence.

2. Materials and methods

2.1. Study site

The study area forms part of the arid-semiarid region of central west Argentina (Fig. 1A and B), which according to its vegetation communities is considered an ecotone between the Chaco and Monte-Espinal provinces, in the Chaco domain (Cabrera, 1976) assigned to the Occidental Plains by Costa et al. (2001). The terrain is flat, only interrupted by the channel and aggradational plains of the Río Desaguadero, which flows from north to south. The outcrop studied is located at the Junction of the Río Desaguadero and the Río Jarilla which originates in the western Sierras Pampeanas and flows westerly (Fig. 1C). The Río Desaguadero has been the major fluvial system of the Central Andes throughout the Quaternary (last 2.6 Ma) and constitutes the main sediment-transport system from that region to the Atlantic Ocean. Currently, the climatic conditions are arid to very arid, with the volume of water transported by the river being small, with insignificant flow and, at times, the river is completely dry. However, sedimentological, stratigraphical and geomorphological data indicate that were periods, particularly in the Pleistocene, when the volume of water was similar to that of the current Río Paraná, which rises in Brazil and flows along the eastern margin of Argentina to join the Río de La Plata, which has an average flow of 17,100 m^3/s (Bello et al., 2009). The Río Desaguadero, fed by snowmelt precipitated in the Andes by direct influence of the Pacific Anticyclone, is at present 1518 km long, and occupies a basin area of 248,000 km^2 extending from ~27°35″ S to ~38°50″ S.

The study site is located within the Arid Diagonal (AD) (Fig. 1A), a narrow band in South America with precipitation less than 250 mm/year which extends from Ecuador (west coast) to the Patagonian Atlantic coast (Argentina, east coast). The AD is at the boundary or transition between two different atmospheric circulation systems driven by the Atlantic and Pacific dominant moisture sources. Numerous palaeohydrological reconstructions suggest dominantly wet conditions during cold phases in regions located west and south of the AD, like Patagonia or the Central Andes, with a dominant Pacific source of moisture. During the same climate phase, dry conditions have been proposed across the subtropical lowlands east of the AD, under the influence of an Atlantic summer precipitation regime. Conversely, extensive dryness across Patagonia and wet conditions in the Pampas can be inferred during warm climate phases (Piovano et al., 2009).

2.2. Methods

A stratigraphic survey of the basin was performed during several fieldtrips, with the analyses of an outcrop from Río Jarilla. Palaeontological sampling was performed each 10 cm through the profile and 200 g of sediment were washed with tap water through 500 μm, 250 μm and 125 μm sieves and dried at ambient air exposure. All gyrogonites that were complete or almost complete (lack of apex) were isolated by picking, analysed by stereoscopic microscope and a few specimens separated for scanning electron microscopy (SEM) undertaken at the Laboratorio de Microscopía y Microanálisis (LABMEM), Facultad de Química, Bioquímica y Farmacia, Universidad Nacional de San Luis (UNSL). The systematic recognition of gyrogonites was made using the contributions of Soulié-Märche (1989) and García (1990, 1993a, b, 1996, 1999).

All charophyte species recognised had extant representatives, so reference information about some of the ecological factors affecting their distribution was available. The salinity classification of waters proposed by Hammer et al. (1983) was used, who considered fresh as 0–0.5 g L^{-1}, subsaline as 0.5–3 g L^{-1}, hyposaline as 3–20 g L^{-1}, mesosaline as 20–50 g L^{-1}, and hypersaline as >50 g L^{-1}. Gyrogonite

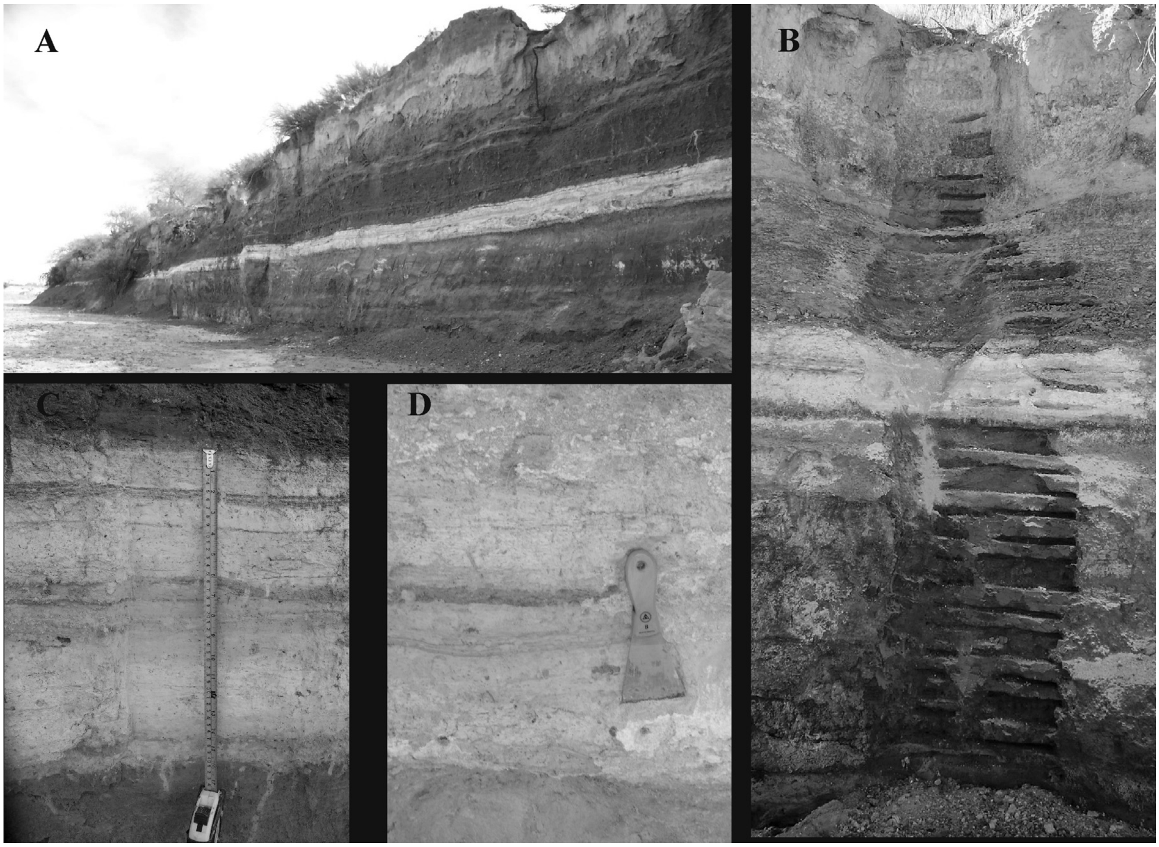

Fig. 2. (A) Stratigraphic setting of the Río Jarilla section. (B) The sampled Río Jarilla section. (C) Detail of the limestone with organic matter layers from the second cycle, unit 5 RJ2-9. (D) The dark grey organic-rich layer at the centre of the limestone, dated by AMS.

length, width and number of spirals were measured in complete specimens.

For the determination of the proportion of sand, silt and clay, the Bouyoucos (1962) densimetric method was performed. This method is applicable to soils and sediments with a predominantly fine-grained component. Particle size is determined using Stokes' law which predicts the velocity of free falling spherical particles in water based on particle size. The larger the particle size, the faster the settling velocity. The viscosity of water affects particle settling velocity and is itself affected by temperature. Therefore, a correction is necessary for temperatures deviating from a standard temperature of 20 °C. Particle size analysis is accomplished first by the addition of a chemical dispersant, sodium metaphosphate, with subsequent mechanical agitation (Huluka and Miller, 2014). With the hydrometer method, the density of the sediment suspension is determined using a Bouyoucos hydrometer at specific times depending on the particle size being measured (Gee and Bauder, 1986). Also, another portion from each sample was sieved through 2000 μm, 1000 μm, 500 μm, 250 μm, 125 μm, 63 μm and 53 μm meshes, and the values obtained were integrated with the data from the Bouyoucos method to produce a complete textural analysis.

For colour determination the Munsell Soil Colour Chart was employed, evaluating and comparing both moist and dry colours for sediment descriptions.

Three radiocarbon ages were obtained from the calcareous unit 5 of the second cycle. One ^{14}C date (bulk organic matter) was obtained by AMS at NSF-Arizona AMS Laboratory, and the other two (on $CaCO_3$) by the conventional radiocarbon method at the LATYR (Laboratorio de Tritio y Radiocarbono), Universidad Nacional de La Plata, Argentina. The ages are reported with 1 sigma error and calibrated through the "shcal13.14c" calibration data set from Hogg et al., 2013, using the Radiocarbon Calibration Program CALIB REV7.0.1 (Stuiver and Reimer, 1993).

3. Results

3.1. Stratigraphic sequence

Río Jarilla section (33°23′17.88″ S, 67°08′43″ W) (Fig. 2).

We recognised three laterally extensive river-lacustrine cycles in the basin and described as the Arco del Desaguadero Formation (Rodríguez and Barton, 1993). The sedimentary succession is dominated by sand and silt, both laminated and massive, deposited in a fluvial environment of moderate to low energy, with connected shallow lake basins and extended floodplains.

The abundance of chemical precipitates is a response to the water balance in the arid to semiarid environment and is noted as a moderate consolidation in the sediment and the presence of nodules, films and rossettes of carbonate, sulfate and chloride of crystalline aspect. Also, some minerals are of volcanic origin present as vitreous particles and round clasts up to 5 cm diameter. This succession has developed over a cut-and-fill sedimentological structure carved into Early to Middle Pleistocene sediments; while the surface is covered by a soil horizon of younger age, that we assigned to Late Holocene (Medieval Climatic Anomaly), and aeolian deposits of Late late Holocene (Little Ice Age), considering the evidence proposed by González and Maidana (1998) and Ojeda et al. (2014). The contacts between the layers are horizontal and clear but with granulometric continuity that suggest gradual variations in the hydrologic regime (Fig. 3). The base of the sequence was described by Chiesa et al. (2010), and is exposed ~3 km south of the junction of Río Desaguadero-Río Jarilla at La Guasquita. Here,

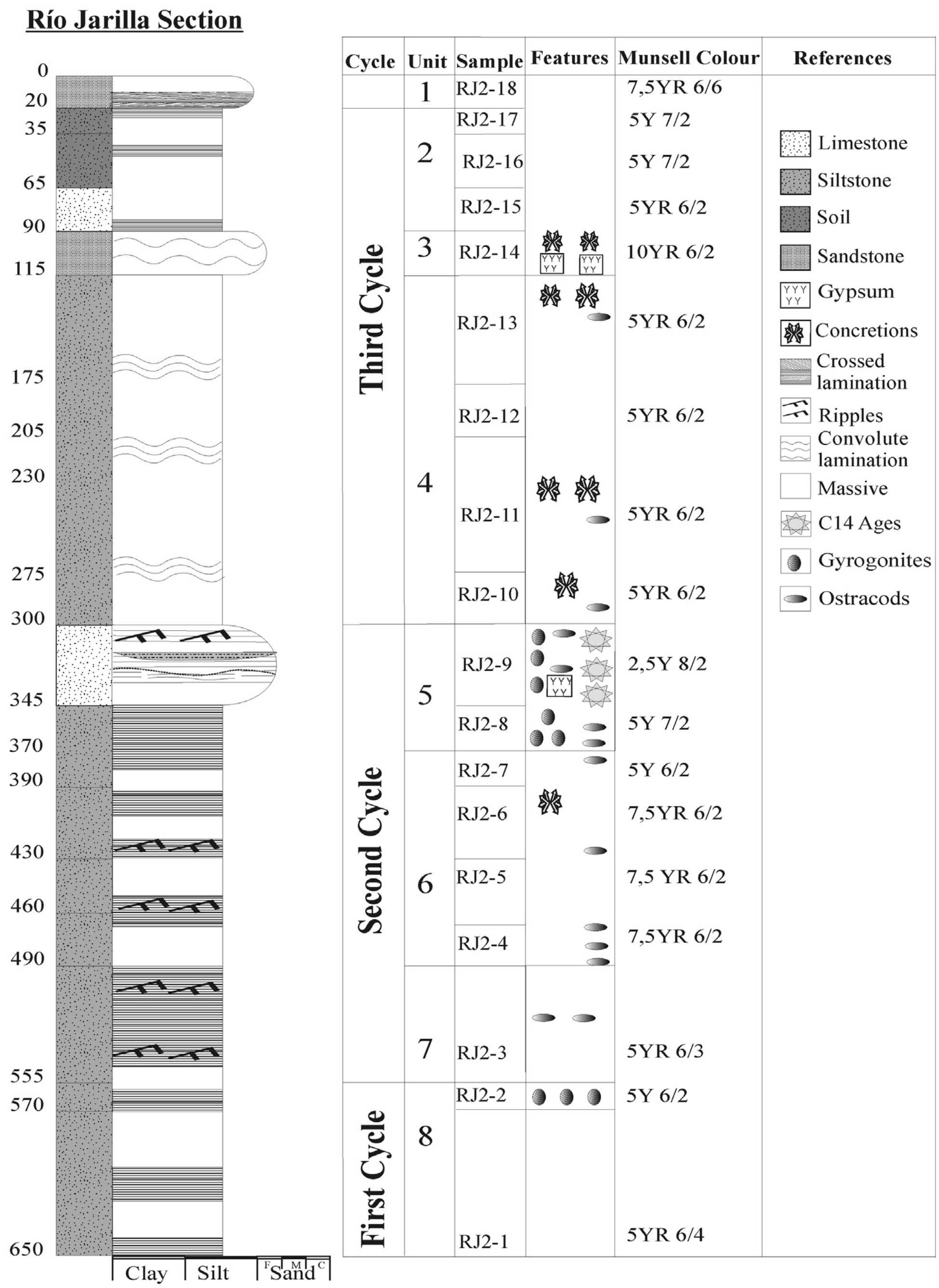

Fig. 3. Stratigraphic column of the Río Jarilla section. Depths, at left, are in centimetres.

the succession is dominated by sand, suggesting a high-energy fluvial regime related to Last Glacial Maximum (LGM, ~20 ka ago), as inferred by González and Maidana (1998) for the Salina del Bebedero basin, which is also connected to the Río Desaguadero. In this study stratigraphical and sedimentological characteristics were used to propose the evolution of three depositional cycles (Figs. 2 and 3).

The first cycle contains only one exposed unit (unit 8) which is characterised by sandy clayey silt, light reddish brown in colour at the base and light olive grey colour at the top of the unit, characterised by a massive structure with minor laminations and moderate consolidation. The unit is dominated by clear and sub-angular quartz (54%), sub-angular to rounded rock fragments (28%), sub-angular gypsum (16%) and rounded pink feldspars (2%).

The second cycle includes three units. Unit 7 is formed by silt, light reddish brown in colour, with a laminar structure and moderately consolidated, with Fe-oxide nodules. This unit is dominated by clear angular to sub-angular quartz (65%), angular to sub-rounded rock fragments (29%), gypsum (5%), and pink sub-angular to rounded feldspars with cleavage (1%). Unit 6 is formed by sandy silt, pinkish grey at the base and light olive grey at the top, with a poorly defined laminar to massive structure, moderately consolidated, with gypsum rosettes and films. Unit 6 is dominated by clear and angular to sub-angular quartz (35%), light red feldspar with cleavage (9%), sub-angular rock fragments (7%), carbonates and/or gypsum fragments (5%). Unit 5 is formed by limestone (60–80% $CaCO_3$), of light olive grey to pale yellow colour, moderately consolidated, with massive to minor laminated structure, and micritic texture showing concretions from rootlets and bioturbation. In this unit, two brownish horizons are separated by a middle layer of fine silty-clayey sand, with a laminar structure, moderately consolidated and containing organic matter (OM). The sand is dominated by clear and angular to sub-angular quartz (63%), sub-angular rock fragments (17%), carbonates (5%), angular gypsum (6%), and pink sub-angular feldspars with cleavage (3%).

The third cycle contains 3 units. Unit 4 is formed by sandy and clayey silt of pinkish grey colour, showing a massive and markedly convoluted structure, moderately consolidated with oxide nodules. This unit is dominated by clear and sub-angular quartz (54%), sub-angular to rounded rock fragments (28%), subangular gypsum (16%), and pink and rounded feldspars (2%). Unit 3 is formed by sand, of light to brownish grey colour, with a massive and gently convoluted structure, moderately consolidated, and with gypsum rosettes and films. The unit is dominated by shiny clear and angular quartz (43%), angular to sub-angular gypsum crystals, (33%), white and black mica (13%), green and clear-angular volcanic glass (7%), and light red coloured feldspars with cleavage, sub-angular to subrounded (4%). Unit 2 is composed of sandy and clayey silt, of pinkish grey to light grey colour at the top, with laminated and massive structure, from low consolidation to moderately friable with root concretions and bioturbation, containing clear and sub-angular quartz (54%) and pink subrounded feldspars (2%). Towards the top, an edafic horizon of 10 cm is distinguished by its dark brownish-grey colour and laminar structure. Superimposed is unit 1, formed by friable reddish to yellowish aeolian sands, showing massive structure crossed by low angle poorly defined stratification.

3.2. Radiocarbon dating

Three ^{14}C ages were obtained from unit 5 (sample RJ2-9; Fig. 3) of the second cycle. One AMS ^{14}C age of 6519 ± 54 yr BP (7433–7324 cal BP) was obtained from a layer of fine-grained organic matter (Fig. 2C). Two conventional ages were obtained, from calcareous sediments (8950 ± 80 yr BP; 10,181–9912 cal BP) and from gastropod shells (9580 ± 120 yr BP; 11,091–10,697 cal BP). The shells of *Chilina mendozana* were used for dating; they were taken at 30 m in front of the Río Jarilla section, from a level that was correlated with unit 5 based on the stratigraphical continuity of the horizon in the basin. The preservation of *Chilina mendozana* is poor and indicative of high-energy water flow, as shown by the fragmentation and abrasion of the shells (this evidence led us to consider this age with caution as transport of the material is possible).

Such differences among ages from the same stratigraphic level can be explained by the nature of the samples. We considered as a minimum age the date on OM by AMS compared to the dating of calcareous sediment and shells that give maximum ages for RJ2-9. Not every organism metabolises carbon from the same environment or carbon reservoir, some will not be in equilibrium with atmospheric ^{14}C (Harkness, 1983). Accordingly, the *apparent ages* of shells are commonly *older* than conventional ^{14}C ages (Stuiver and Polach, 1977), due to the *reservoir effect*. Thus, the true age of our shells should be considered younger than 11,091–9912 cal BP and older than 7433–7324 cal BP. The resulting range of 8–6.5 ka is within the interval commonly known as the mid-Holocene Climatic Optimum.

3.3. Microfossils

Charophyte and ostracod remains were found only in sediments from the first and second cycles (Fig. 3). Sample RJ2-2 from unit 8 (first cycle), had few well preserved gyrogonites of *Chara* cf. *contraria* and *C.* cf. *papillosa*. Above these levels, there are no signs of charophyte remains until near the top of unit 5 of the second cycle, wherein samples RJ2-8 and RJ2-9 contain gyrogonites of *C.* cf.

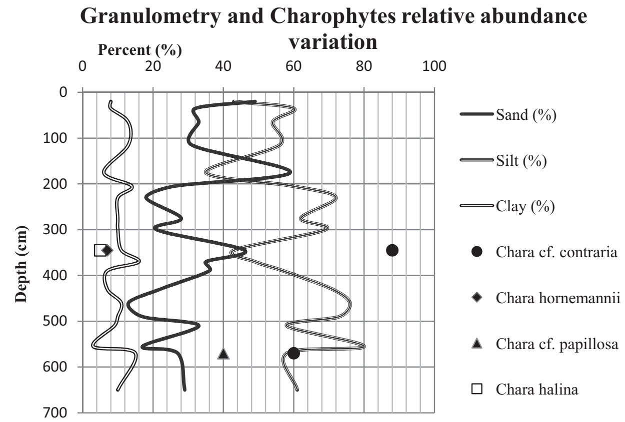

Fig. 4. Plot (percentage vs depth) showing the variation of sediment grain-size and charophyte species relative abundance for the Río Jarilla section.

contraria, *C. hornemannii*, and *C. halina* with very poor preservation and showing signs of dissolution especially at RJ2-9. In contrast, ostracods are present almost without interruption through the whole second cycle. Fig. 4 shows the relative abundance of charophyte species (0–100%) in relation to sediment grain-size. There is a clear relationship between the presence of charophytes in sections where sediments are very fine grained (27–46% sand, 58–43% silt and 11–15% clay).

The charophyte species that were recognised by their gyrogonites have been found living in several regions of Argentina with the exception of *Chara hornemannii*. We compare the description of the species by García (1990, 1993a, b, 1996, 1999) with our findings. The number of specimens found did not allow us to make statistics, so further collection and analyses are required for a better understanding and comparison.

Division: Charophyta Migula 1897
Family: Characeae Richard 1815
Genus: *Chara* Linnaeus 1753

Chara cf. *contraria* A. Braun ex Kützing 1845 (Fig. 5A)

Description. Gyrogonites prolate, apical outline pointed to sub-truncate and basal outline rounded, 700–800 μm long and 500–600 μm wide. Spiral cells 10.5–13, in lateral view, well calcified; some specimens have a middle line of low calcification. In the apical periphery, the spiral cells diminish in width and thickness, showing a periapical depression that appears as a real groove. In the base, the spiral cells increase slightly in width and thickness, delimiting thin edges which surround the basal plug.

Observations. These gyrogonites are very similar to other gyrogonites identified as *C. hispida* var. *major* by Soulié-Märche (1989, Pl. XVIII and XXIII). They can be compared also to Pleistocene-Holocene gyrogonites from Salina del Bebedero assigned to *Chara* cf. *hispida* var. *major* by García (1999), although this author previously described them as *Chara contraria* and *Chara contraria* s.l., based on extant material from drainage channels near Pedro Luro, Province of Buenos Aires (García, 1999). We will consider the gyrogonites from Río Desaguadero as *Chara* cf. *contraria* until further research enables clear taxonomic delimitation.

Habitat and distribution (taken from García, 1994). This taxon grows in subsaline to mesosaline environments, pH 7 or slightly higher, over silt or silty clay substrate. It is very incrusted in $CaCO_3$. *Chara contraria sensu lato* is a cosmopolitan species which lives in fresh to slightly saline, alkaline waters; from about 15 cm to 10 m depth; in most climates. It can form extensive populations in calm water and is frequently covered by $CaCO_3$.

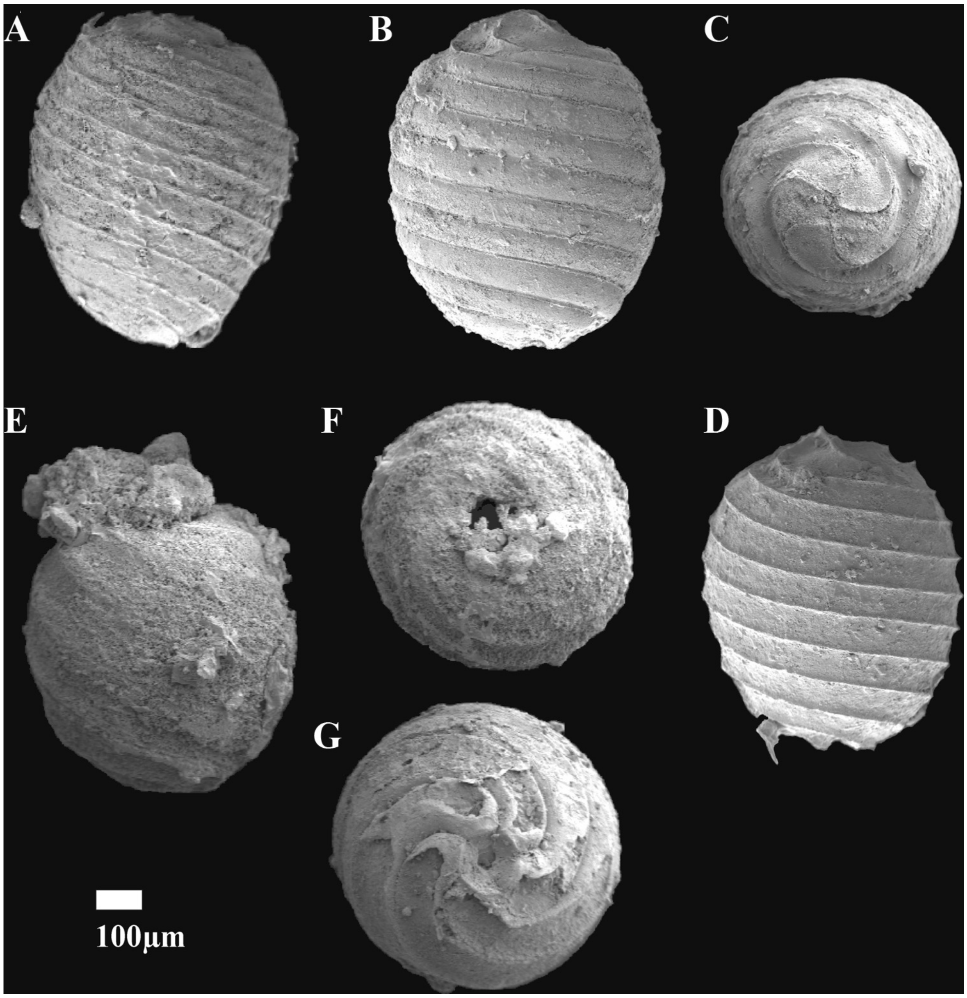

Fig. 5. Gyrogonites from the Río Jarilla profile. A. Chara cf. contraria from RJ2-2 and RJ2-9, lateral view. B-D. Chara cf. papillosa from RJ2-2. B. Lateral view. C. Apical view. D. Lateral view. E-G. Chara hornemannii from RJ2-9. E. Lateral view. F. Apical view. G. Basal view.

Material. 37 gyrogonites, found mostly in the second cycle.

Chara cf. *papillosa* Kützing 1834 (Fig. 5B–D).

Description. Gyrogonites sub-prolate rarely prolate, spheroidal. Apical and basal outline truncated to sub-truncated; 700–745 μm long and 525–600 μm wide. Spiral cells 9–11 well calcified. In the apical periphery spiral cells diminish in width and markedly in thickness. In the base, the spiral cells diminish in width and maintain thickness, surrounding the basal plug that is in surface or slightly sunken.

Habitat and distribution. García (1996) explains in detail the problem related to the taxonomy of this species sometimes treated as a variety of *C. vulgaris*, or as *C. intermedia* Braun. *C. papillosa*, following Kützing, has been cited from Lake Titicaca, Bolivia where Guerlesquin (1991) indicated that the species was found growing at depths from 1.30 to 9 m, and can have the vegetative parts strongly encrusted.

Material. 3 complete gyrogonites.

Chara hornemannii Wallmann 1853 (Fig. 5E–G).

Description. Gyrogonites prolate to sub-prolate, with apical and basal outline truncate to sub-truncate, 640–700 μm in length, and 580–630 μm in width, with maximum diameter in the middle part of the gyrogonite. Spiral cells 6 in lateral view, with pronounced calcification.

Habitat and distribution. García (1999) indicates that *Chara hornemannii* lives in littoral zones in subsaline to mesosaline waters, having an American distribution from USA to Brazil. Although not found living in Argentina, gyrogonites of this species are found in Quaternary sediments from several localities. García (1999) recorded this taxon in a 264 m lacustrine sequence, obtained during drilling for water near La Paz, Province of Mendoza and in shoreline sediments from Salina del Bebedero.

Material. 4 complete gyrogonites.

Chara halina García 1993

Description. Gyrogonites subprolate to prolate, rarely prolate spheroidal, with apical outline truncate to sub-truncate and basal outline truncate but pointed from the equatorial line; 700–750 μm long and 500–600 μm wide, with maximum diameter at or near the equatorial line. Spiral cells 6–8 in lateral view, plane to convex in outline, with thick calcified walls. The spiral cells diminish in thickness towards the apical zone. In the basal zone, spiral cells diminish slightly in width but the thickness remains constant, delimiting a funnel, wider in outer view.

Habitat and distribution. García (1993a) described extant *Chara halina* from Arroyo del Bebedero, San Luis, Argentina. The species lives in sodium-chloride rich, hyposaline to mesosaline (18–36 g L^{-1}) waters, in environments with changing salinity due to high evaporation and low precipitation rates associated with a semiarid climate. *C. halina* has an endemic distribution in Argentina, cited by García (1993a) from Laguna La Salada, Buenos Aires; Laguna La Amarga, La Pampa; and Arroyo Bebedero, San Luis. The species has been found in Quaternary sediments from Salina del Bebedero, San Luis, Argentina (García, 1999).

Material. Only 2 gyrogonites were found that fit the description.

4. Discussion and conclusions

The stratigraphic and sedimentological characteristics of the Arco del Desaguadero Formation described by Rodríguez and Barton (1993) have been augmented with microfossil analysis and the identification of three drying-upwards depositional cycles; the first assigned to late Pleistocene-early Holocene; the second from early to middle Holocene and the third developed from middle to late Holocene. The pale yellow limestone (sample: RJ2-9), from unit 5 has two OM-rich layers with charophyte remains, suggesting the development of large waterbodies followed by increasing evaporation related to higher temperature, causing the precipitation of carbonates from increasingly saline waters.

Rodríguez and Barton (1993) suggested that the Arco del Desaguadero Formation displayed lacustrine sedimentation and could be assigned to the "Platense" mammal age (Holocene), occupying the top of "Lujanense" (Late Pleistocene). However, our radiocarbon ages suggest the second cycle ranges from early to middle Holocene. Furthermore, the mid-Holocene Climatic Optimum was identified and chronologically constrained to a fine layer of OM from the limnic level (7433–7324 cal BP). The period between 9 and 8 ka ago is characterised in the region as warm and semiarid, which affected existing waterbodies formed during deglaciation (~17–14 ka ago) by snowmelt water transported by the Río Desaguadero from the central Andes.

Mehl and Zárate (2013) describe the presence of palaeosols and limnic levels for the same period in the nearby area of Arroyo La Estacada basin (Andean piedmont of Mendoza between 33° and 34° S), reporting a major concentration of carbonates that would likely indicate more evaporation in the alluvial basin. Also, they describe limnic levels as dark-coloured levels, with a homogeneous appearance without gradual colour variation downwards and restricted lateral extension compared with palaeosols. The morphology of the limnic levels is characterised by the occurrence of lenses formed by OM within a fine-grained clastic matrix. Its configuration is similar to that described for *gyttyas* or sedimentary peats. Limnic levels form due to the precipitation of OM suspended in water or by direct action of aquatic organisms (Fox 1985, in Mehl and Zárate, 2013). The Holocene limnic levels are fair indicators of an increment in vegetation productivity in the floodplain, especially in waterlogged environments. Also, they likely record an increase in the amount of OM carried by water along the fluvial valley (Mehl and Zárate, 2013).

According to the stratigraphic characteristics, other regional evidence, and data from the microfossils, we consider that the depositional palaeoenvironment of the sedimentary succession corresponds to a meandering river (with high proportion of fine-grained sediments, including suspended load) associated with the development of lacustrine basins. This situation has a current analogue about 30–70 km further north in the upstream course of the Desaguadero's fluvial system, where a lacustrine complex (Huanacache) occurs. It is postulated that during the mid-Holocene Climatic Optimum charophyte communities developed in a lacustrine environment, but evaporation increased as snowmelt water inflow from the Andes diminished, generating the precipitation of evaporites from oversaturated waters, causing charophyte death and the development OM layers in a context of higher temperatures than today and in a semiarid regional climate.

The charophyte *Chara* cf. *contraria* dominated the entire sequence (Fig. 4). The assemblage of *C.* cf. *contraria* and *C.* cf. *papillosa* found at the top of the first cycle (Fig. 3; unit 8, sample RJ2-2), recovered from the light olive grey sediments of this unit indicates subsaline to mesosaline waters. The upper section of the second cycle (unit 5, RJ2-9) has a calcareous composition, particularly micrite, with two layers of OM intercalated with abundant gyrogonites, although showing signs of dissolution. *C.* cf. *contraria* dominated this association with only a few gyrogonites of *C. hornemannii* and *C. halina* indicating a proximity to the shoreline in a variable but mostly saline environment with changing water levels and salinities due to high evaporation associated with a semiarid climate and higher temperatures. It is particularly interesting that *C. hornemannii* currently has a tropical to subtropical distribution, with a southern boundary limited to Brazil, and it has not been found living in Argentina, although Quaternary remains are prolific for this species. It is possible that the distribution of *C. hornemannii* in the past was limited by the same ecological requirements as today, including temperature. Accordingly, we may infer a shift in the Quaternary distribution due to temperature changes, indicative of higher temperatures in the region at the time of its burial in unit 5.

The dissolution of the gyrogonites is probably related to the organic-rich layers (when the waterbody had shallow fluctuating water). As the charophytes died, they mixed with the sediments, OM increased and the pH decreased. Then when the waterbody dried completely, evaporites (carbonates, gypsum) were precipitated. The poor preservation of gyrogonites especially in unit 5, sample RJ2-9, together with the micritic composition of the stratum, suggests the importance of charophytes in the bioconstruction of limestones. Thin sections are being studied in order to better describe the micromorphology of unit 5. This is particularly important for supporting or rejecting the idea that the environment evolved in response to a reduction of water volume inflow. Consequently, the lacustrine body was isolated from the river, with subsequent evaporation and increasing salinity, death of organisms, and accumulation of charophytes in the already reductive OM-rich sediments, until the waterbody dried completely. The coexistence of limestone and OM suggests the evaporation of a carbonate-rich waterbody in a regional context of warmer and drier climate.

Future work should include analysis of the limnic micromorphology (mineralogical and crystalline structure of unit 5) that will improve the palaeoenvironmental interpretation of this marker horizon within the Desaguadero basin. Further study of microfossil taphonomy would assist the interpretation of fossil preservation in semiarid regions with evaporitic environments. Finally, the presence of *Chara hornemannii* with evaporites appears related to higher temperatures in the past, although further ecological research is needed to improve the significance of this species for the Quaternary.

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