11 Gallocanta Saline Lake, Iberian Chain

F. Javier Gracia

Abstract

Gallocanta Lake, covering 14.5 km^2, is the greatest ephemeral saline lake in Europe. It is located in the Iberian Chain, NE Spain, in the bottom of a karst polje. The Gallocanta saline lake formed once Jurassic limestones were almost completely corroded, and the floor of the depression was underlain by Triassic clays and evaporites. The late Quaternary evolution of the lake can be reconstructed from the deposits underlying the lake bottom and from different levels of lacustrine terraces located in its downwind side. Different phases of flooding and desiccation can be deduced from both sources of data. The current dynamics of the lake is controlled by water-level fluctuations and wind action. Wind-driven waves and longshore currents transport sediments to the downwind zone and generate barrier islands, spits and submerged bars, with a dynamic behaviour very similar to that of marine coastal environments. Lake segmentation due to cuspate foreland growth has divided the original lake into minor ones. Segmentation is still active at present and tends to isolate a minor lacustrine body. Progressively decreasing rainfall, together with sediment supply to the lake, enhanced by extensive agricultural practices in the basin, have frequently led to lake desiccation over the last decades. Extensive polygonal soils and salt crusts cover the bottom during drying-up periods.

Keywords

Saline lake • Holocene evolution • Coastal dynamics • Iberian Chain

11.1 Introduction

Gallocanta Lake, covering 14.5 km^2, is the greatest ephemeral saline lake in Europe, and probably one of the best preserved (Fig. 11.1). It is 7.7 km long, 2.8 km wide, and has a maximum depth of 2.5 m (reached in 1917; Rodó et al. 2002), although during dry periods, it becomes completely desiccated. Water salinity is between 100 and 1,000 times higher than the salinity of the fresh meteoric water entering the lake (Comín et al. 1990). Salts in the lake waters are entirely supplied by underground flow from underlying evaporites. The sediments in the centre of the lake consist of carbonate and sulphate muds, while during dry periods, the bottom is covered by a thin and discontinuous salt crust.

In 1972, Gallocanta Lake was declared Zone of Controlled Hunting, in 1984 National Hunting Refuge, and in 1995 Wildlife Refuge of International Interest. Since 1988, it is included in the list of wetlands with international interest (Ramsar Convention). It is also Zone of Special Protection by the European Birds Directive. In 2006, the lake and a peripheral zone were declared Nature Reserve by the regional government. The lake constitutes an extraordinary

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Fig. 11.1 Views of Gallocanta Lake. *Left* satellite image of Gallocanta Lake taken in July 2010 (Google Earth). *Right* oblique aerial view taken in winter time (*Photo* B. Leránoz)

important station for European migratory birds. Among the numerous species identified every year, the most significant and representative one is the crane (*Grus grus*), which can be present every winter in an average number of individuals higher than 25,000 (Sampietro 2002). Two visitor centres and a Museum of Wild Birds can be visited in the surroundings of the lake.

11.2 Geographical and Geological Setting

The Gallocanta Depression is located in the central sector of the Iberian Chain (NE Spain, Fig. 11.2). This closed topographic basin has a catchment area of 550 km^2, with an elongated shape parallel to the main structural grain of this Alpine orogen (NW–SE). It is flanked by mountain ranges with summits reaching more than 1,400 m a.s.l. The bottom of the depression is located at an average elevation of 1,000 m a.s.l. The endorheic basin hosts more than 20 lakes of variable size, Gallocanta Lake being the greatest. Their nature is variable (e.g. permanent, ephemeral, filled with sediments) and most of them are freshwater lakes. However, Gallocanta Lake and some other minor ponds located in the centre of the basin have saline waters.

The zone has a typically semiarid climate with a mean annual precipitation of around 450 mm and an average annual temperature of 10–11 °C. The depression is dominated by NW winds channelled along the topographic trough, reaching up to 100 km/h.

Geologically, the ranges bounding the depression are composed of Palaeozoic and Lower Triassic siliceous rocks. The NE range close to the lake (Fig. 11.2) is formed by an isoclinal series of Ordovician quartzites. This mountain range flanks an extensive fault-bounded outcrop of deformed Mesozoic sediments. Upper Triassic clays and evaporites (Keuper facies) form the impervious substratum of the Gallocanta Lake. The rest of the Mesozoic units correspond to Jurassic and Upper Cretaceous carbonate rocks. The Alpine deformation structures show a prevalent NW–SE trend. Locally, the carbonate Mesozoic sediments are unconformably overlain by Tertiary detrital sediments and some of them, of probable Late Pliocene age, form isolated mesas.

Quaternary landforms and deposits are mainly represented by pediments, infilled valleys and lacustrine sediments (Fig. 11.2). Pediments develop at the foot of the important mountain fronts and are mantled by a thin alluvial cover. The erosion of the NE quartzitic range produced a sequence of three pediment levels, inset and stepped towards the depression bottom. Wide flat-bottomed valleys develop inside the mountain ranges and are filled by alluvial sediments supplied by the surrounding slopes, many of them characterized by active frost-shattering processes during winter.

The lacustrine sediments around Gallocanta Lake form a stepped sequence of lacustrine terraces. Under the lake, just a ca. 1 m thick sequence of lacustrine sediments has been identified by drilling (Schütt 1998; Pérez et al. 2002, among others). Several stepped Neogene planation surfaces of regional extent can be recognized in the surroundings of Gallocanta Depression (Gutiérrez and Gracia 1997). The lacustrine depression is inset with respect to these regional planation levels, indicating a post-Pliocene age for its generation.

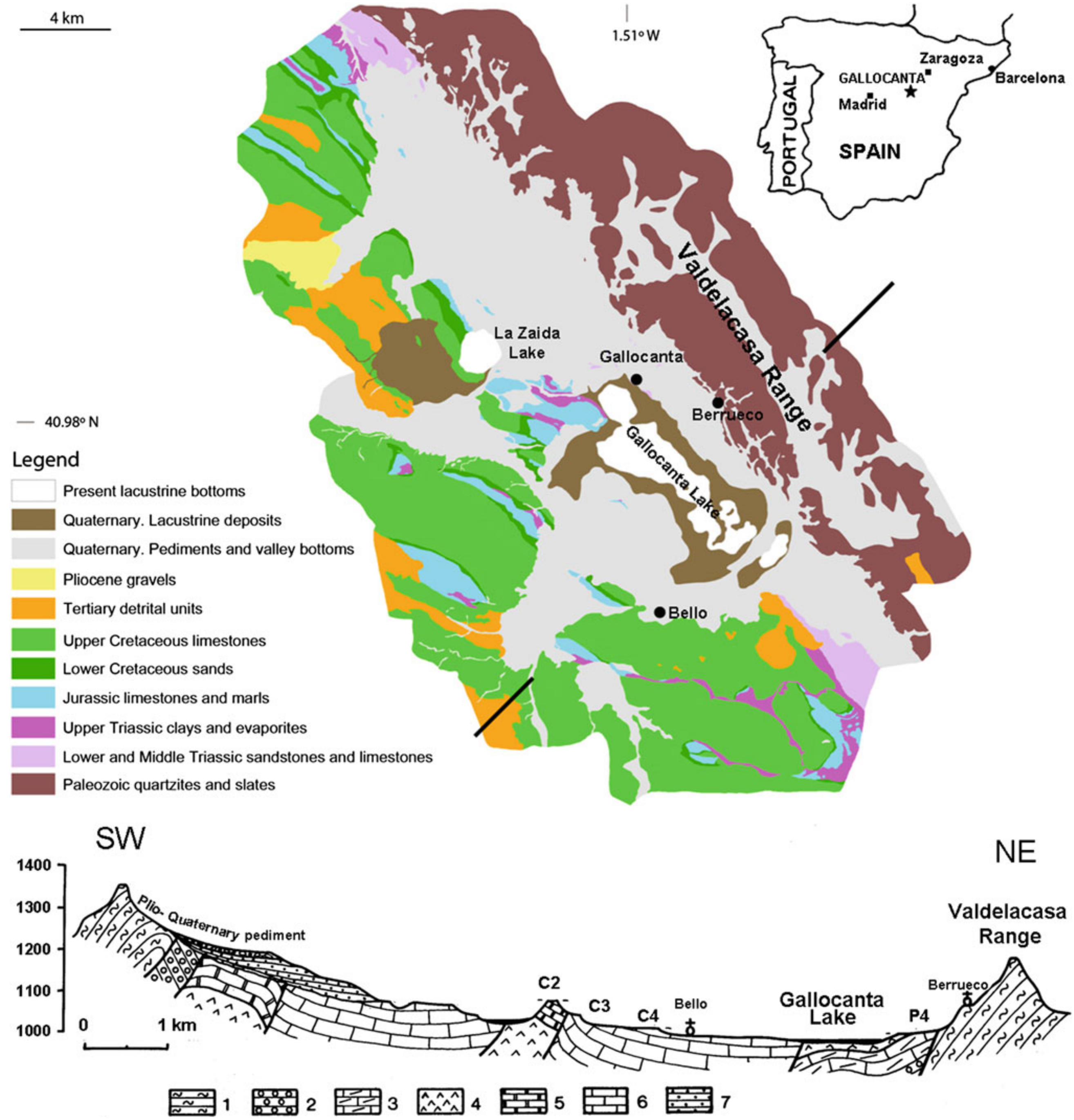

Fig. 11.2 *Top* Location and geological map of Gallocanta lacustrine depression (modified from CHE 2003 by C. Castañeda). *Bottom* Geological cross section of Gallocanta polje (modified from Gracia et al. 2002). Legend: *1* Palaeozoic quartzites and slates, *2* Lower Triassic sandstones, *3* Middle Triassic carbonates, *4* Triassic clays and evaporites (Keuper), *5* Jurassic limestones, *6* Cretaceous limestones, *7* Neogene sands and conglomerates, *C* Karstic corrosion surfaces, *P* pediment

11.3 The Origin and Evolution of the Lacustrine Depression

The origin of the depression was interpreted by Gracia et al. (2002) as a polje developed during the Quaternary. Four corrosion surfaces can be recognized in the basin, the two lowest ones surrounding the main lake (Fig. 11.3), with dolines and abundant karren locally covered by residual clays. The corrosion surfaces show a concentric distribution and are stepped towards the Gallocanta Lake. They develop upon Jurassic limestones, being constrained by the outcrops of Pliocene detrital deposits.

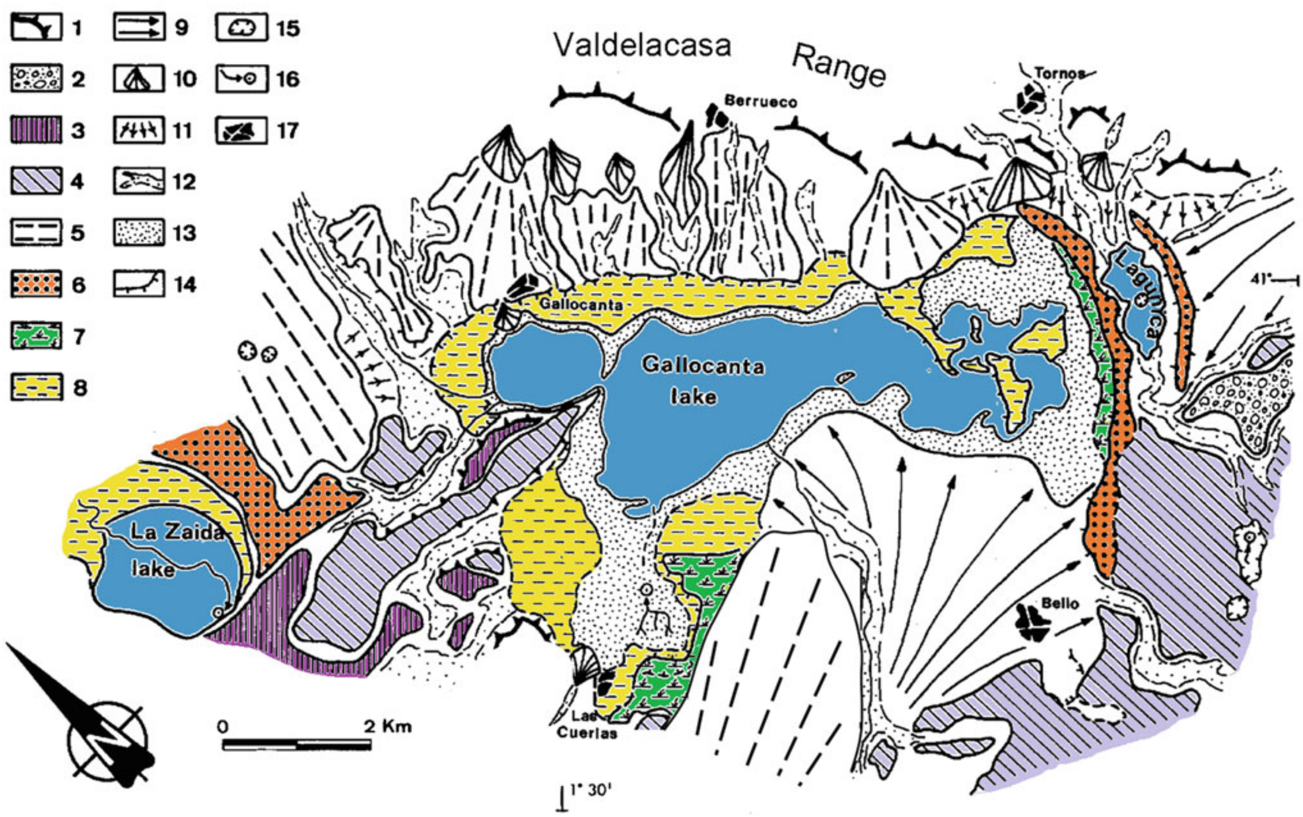

Fig. 11.3 Geomorphological map of Gallocanta Lake and surrounding areas (modified from Gracia et al. 2002). *1* structural scarp, *2* Neogene clastic deposits, *3* corrosion surface C3. *4* corrosion surface C4. *5* pediment P4. *6* lacustrine terrace T4, *7* lacustrine terrace T5. *8* lacustrine terrace T6. *9* mantled pediment P7. *10* alluvial fan, *11* covered slope, *12* flat-bottomed valley, *13* lacustrine floodplain, *14* scarp in Quaternary deposits, *15* Doline, *16* Swallow hole (ponor), *17* village

The formation of the depression and the corrosion surfaces probably occurred after a regional extensional tectonic phase in the Late Pliocene (Gutiérrez et al. 2008). This episode produced differential vertical movements along the range. Very likely, tectonic subsidence generated a shallow basin with internal drainage. The deepening of the polje bottom and the development of stepped corrosion surfaces were controlled by the relative lowering of the local water table, which would favour vertical dissolution and the deepening of the polje bottom until reaching the epiphreatic zone. The alternation of periods dominated by bottom deepening and periods of planation of the polje bottom, both controlled by the position of the water table, resulted in the four stepped corrosion surfaces found in the Gallocanta Polje. The deepening stages of the polje bottom also involved the generation of three stepped levels of mantled pediments around the lake. The deepening of the polje bottom is restricted by the thickness of the soluble materials, about 150 m in this case. Once the polje floor approached the impervious Triassic substratum, a stable lacustrine system developed in its bottom. Consequently, the generation of Gallocanta Lake is linked to the interruption of the polje deepening in the Late Pleistocene (about 12,200 year BP), according to the numerical dates presented by Burjachs et al. (1996).

During its evolution, the Gallocanta Lake has undergone a progressive segmentation due to the growth of paired and cuspate littoral spit bars (Fig. 11.3), a common process in elongated lakes oriented parallel to the dominant wind direction. Wind-generated waves produce shoreline erosion and sediment transport along the lake margins. The dissipation of the wave energy takes place roughly at similar places on both margins of the lake and leads to sediment deposition and the growth of paired spits or cuspate forelands (Lees 1989). The sedimentological and palynological analysis of lake sediments from boreholes shows different stages of lake evolution (Schütt 1998; Luzón et al. 2007a). After an initial development of the lake in the Last Glacial Maximum, during which marginal alluvial fans developed, a second stage began around 10,100 year BP with the establishment of a perennial brackish lake. The maximum lake level was probably reached around 8,010 year BP, with about 10 m water depth. The top surface of the oldest lacustrine terrace (T4), 8 m above the present-day high

Fig. 11.4 Oblique aerial view of the channel between paired spit bars connecting the two main lake portions (*Photo* F. Gutiérrez)

Fig. 11.5 Oblique aerial view of the coastal barrier islands and spits along the southwestern shore of the lake (*Photo* F. Gutiérrez)

water level, connects to the lowest corrosion surface C4 and pediment level P4, and hence, all these surfaces can be considered as roughly coeval. This terrace level constitutes the depositional closure of the original downwind lake embayment and produced the first segmentation episode with the generation of the Lagunica Lake (Fig. 11.3). The sedimentological characteristics of the lacustrine deposit of this terrace level suggest a succession of changing conditions related to lake-level fluctuations (Gracia 1995).

An intermediate episode of water level fall (between 3,405 and 1,510 year BP) could be related to a regional reduction in the hydrological balance (Luzón et al. 2007a). Increasing aridity in historical times (post-Middle Age) produced an ephemeral carbonate-saline lake with frequent oscillations. During this period, new lake segmentation episodes occurred, tending to subdivide the main lacustrine body into minor ones. Although this process is still incomplete, a palustrine zone has formed in the SE border

Fig. 11.6 Lake *bottom* during desiccation episodes. **a** Non-orthogonal desiccation cracks on muds (August 2012), **b** Small pedestals and patterned ground revealing an underlying salt layer, **c** Desiccation of algal mats in a palustrine shore

of the lake and new paired cuspate forelands have grown, which divide the lake into two main portions, connected by a channel with intermittent activity (Figs. 11.3 and 11.4). About 750 years ago, a change is recorded in the lake sediments, from a shallow carbonate lacustrine system with oscillating water level to a saline lake rich in carbonates and organic matter associated with a significant drop in the water level. This change could be related to karst processes developed in the underlying Triassic evaporites (Gracia 1990) or to changes in the underground watershed (Luzón et al. 2007b).

11.4 The Lake

At the present time, the Gallocanta Lake undergoes frequent water-level fluctuations, ranging between 2.5 m of maximum water depth and complete desiccation. Long-term patterns of lake-level variations have been inferred from mineralogical analyses, dating of lacustrine sediments, aerial photogrammetry, historical satellite imagery and in situ continuous measurement of water depth on the deepest sector of the lake. All these records reveal a positive response to the El Niño Southern Oscillation (ENSO), while the lake seems insensitive to the North Atlantic Oscillation (Rodó et al. 1997). Apart from their influence on geochemical and biological processes (Comín et al. 1992), lake-level fluctuations also have important geomorphological effects.

During flooding periods, wind-generated waves and longshore currents travel towards the downwind side of the lake (SE). Clastic sediment supplied by rivers, mainly along the SW lake shore, is transported and deposited throughout the southern coastline. As a consequence, a set of barrier islands and spits develops which enclose small lagoons, in a similar way as those characteristic of marine coasts (Fig. 11.5). When the water level is at its highest stage, some of these depositional landforms are almost completely flooded and become islands (Fig. 11.1).

The progressive sedimentary infill of the SW coastal lagoons is accompanied by an increase in water depth in the northern shore, where waves become higher and more erosive. Different indicators of coastal erosion and shoreline retreat can be observed along the NE lake shore. A retreat of

Fig. 11.7 Salts in the lake bottom during drying-up periods. **a** Salt accumulation on desiccation cracks, **b** Polygons on a gypsum and organic matter-rich ground, **c** Aeolian deposition of salts in the downwind side of the lake (*Photo* P. Vicente), **d** Salt trapping by halophyte plants

about 400 m can be deduced for the eastern border of the central lacustrine body (Gracia 1995), where a 2-m-high microcliff has developed, probably over the last millennium.

During drought periods, the lake becomes completely desiccated and its bottom shows a patterned ground related to the development of different types of desiccation cracks, mainly non-orthogonal systems (Fig. 11.6a). In some cases, stone micro-pedestals and sorted polygons can be observed near the shores, where small stones fill the cracks (Fig. 11.6b). These may be attributed to salt expansion and contraction processes because of thermal changes (Hunt and Washburn 1966). In palustrine areas, algal mats desiccate and discontinuously cover the muddy shores (Fig. 11.6c).

Gallocanta Lake is a hypersaline lake of the Na–Mg–Cl–(SO_4) type (Comín et al. 1990). Intense evaporation and strong winds induce the precipitation of salts. Desiccation cracks are often covered by a thin layer of salt crystals (Fig. 11.7a). The presence of organic matter and gypsum favours the development of deeper cracks and greater polygons (Fig. 11.7b). Prevailing winds transport salts, which accumulate in the downwind margin of the lake (Fig. 11.7c). Most commonly halophyte plants, such as *Salicornia*, act as aeolian salt traps (Fig. 11.7d). Renewed flooding episodes cause mud accumulation in the bottom and silts and fine sands in the shores.

11.5 Conclusions

The evolution, morphology and present dynamics of Gallocanta Lake are strongly controlled by the nature of its substratum and the frequent water-level fluctuations. Karstic corrosion of Jurassic carbonates and the consequent deepening of the Gallocanta polje ended once the underlying Triassic evaporites became the substratum of the lake, causing its salination. Structural control on the distribution of Mesozoic formations led the lacustrine depression to acquire an elongated morphology parallel to the regional structural grain, which coincides with the direction of the prevailing winds channelized along the depression. Climatic oscillations governed the hydrological evolution of the lake during the Holocene, giving rise to a set of stepped lacustrine terraces. Throughout its evolution, prevailing winds generated waves and currents which transported sediments and formed coastal sandy barriers. Wave action also induced the generation and growth of cuspate forelands which segmented the lake in several phases, a process still active. In recent times, climate aridification and hydrogeological processes have changed the lake water geochemistry, leading to the concentration of salts and transforming the originally carbonate lake into a saline lake. Dry periods often lead to the complete desiccation of the lake, with extensive salt precipitation. Climatic trends suggest that this may become a progressively more frequent situation in the near future.

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