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PALEOTOPOGRAPHICAL VIRTUAL RECONSTRUCTION OF THE HISTORIC CITY OF CARTAGENA (SPAIN)

RECONSTRUCCIÓN VIRTUAL PALEOTOPOGRÁFICA DE LA CIUDAD HISTÓRICA DE CARTAGENA (ESPAÑA)

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Abstract:

The city of Cartagena and its immediate surroundings have experienced significant topographical changes throughout its history. Originally built on five hills which border south and west with the Mediterranean Sea, the city has expanded to the north over the last five decades, occupying a lacustrine system which has now dried up due to the diversion of riverbeds which, from time to time, used to flood the place. These changes have been documented and studied from the lithology present in over 400 geotechnical drillings carried out in the urban renewal of the city for the last two decades. In addition, another 20 new continuous drillings have been conducted within the Project "Surveying and planning a privileged Mediterranean city, Arqueotopos I and II" which is still ongoing. The information obtained is completed with the study of all existing historical maps on it. Digital Terrain Models (DTMs) have been generated with this drilling data, then several lithological layers have been selected for its interest: anthropic fill, mud and underlying bedrock. The thickness of each of the layers has been studied in different areas and viewed through various longitudinal profiles that have been plotted. Finally, a three-dimensional (3D) virtual reconstruction has been undertaken to see graphically the documented changes that have occurred in each of these layers, to serve both research and divulgation knowledge.

Key words: virtual reconstruction, geoarchaeology, Cartagena, documentation, 3D reconstruction, digital terrain model (DTM)

Resumen:

La ciudad de Cartagena y su entorno inmediato ha experimentado significativos cambios topográficos a lo largo de su historia. La ciudad, levantada originariamente sobre cinco cerros que limitan al sur y al oeste con el mar Mediterráneo, se ha extendido en las últimas décadas hacia el norte, ocupando un sector lacustre subsidente, ahora desecado por el desvio de los cauces que recurrentemente lo encharcaban. Estos cambios han sido documentados y estudiados a partir de la litología presente en cerca de 400 sondeos geotécnicos realizados en la renovación urbana de la ciudad durante las dos últimas décadas, así como en otros 20 nuevos sondeos de perforación contínua realizados dentro de los Proyectos "Topografía y urbanismo de una urbe mediterránea privilegiada, Arqueotopos I y II" actualmente en curso. La información obtenida se ha completado con el estudio de toda la cartografía histórica existente sobre la misma. Desde esta información se han elaborado modelos digitales del terreno (MDTs) de distintas capas litológicas seleccionadas por su interés: relleno antrópico, fangos y roca subyacente. Se ha podido estudiar así la potencia de cada una de las capas en diferentes zonas y visualizarlas a través de los distintos perfiles longitudinales que se han trazado. Finalmente, se ha realizado una reconstrucción virtual tridimensional (3D) que permite apreciar gráficamente las variaciones documentadas que se han producido en cada una de dichas capas, con fines tanto investigadores como de divulgación.

Palabras clave: reconstrucción virtual, geoarqueología, Cartagena, documentación histórica, reconstrucción 3D, modelo digital del terreno (MDT)

1. Introduction

The topography of the town of Cartagena has experienced significant changes over the centuries. The available historical cartograhy, carried out to a large extent for different projects of military architecture, allows for the traceability of such changes, both in the old town and in its expansion. An example of this is the map of the beginning of the 19th century illustrated in Fig. 1. This east-facing map reveals the town protected by the 18th century wall, in addition to the military arsenal already built in the port area.

Polibio, in the middle of the 2nd century B.C., affirms that the town stood at the bottom of a bay, on a promontory surrounded by five hills and with borders to the south and

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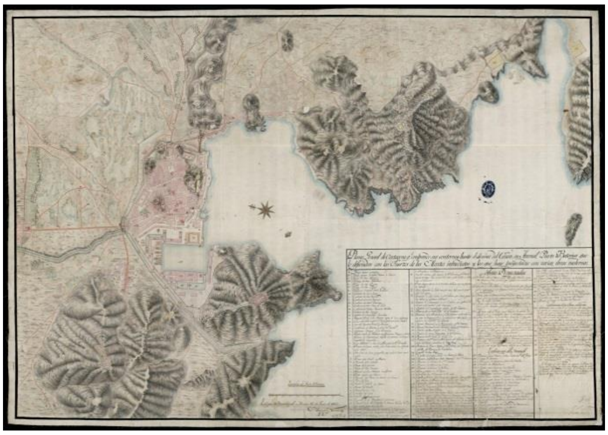


Figure 1: Map of Cartagena in 1812, Ministry of Defence, Spain (Ref.: AGMM-SH-MU-6/11).

west with the sea, while bounded to the north by an estuary of stagnant water linked artificially with the sea (Polibio, X, 10, 5). As has been said, there were five hills conforming the geological sustratum on which the original urban area was erected. However, the Mont of the Concepción is noted for the greatest height and for its extension across a wide surface. On the western and eastern hillsides, respectively, the Theatre and Amphitheatre were erected, which constitute two of the most impressive public buildings in the Roman town (Fig. 2).

The subsident area of the marsh saw a shallow marine influence in the 7th-6th cal. yr. BP milleniums by a Holocene transgressive effect and the fracturing of its most southern area. This can be explained by the dynamics of the faults of Cartagena-La Unión and Benipila (Ramallo Asensio & Ros Sala, 2016; Ramallo et al., 2016). The frequent and torrential nature of the Benipila and the Hondón creeks, which drained to the marsh to the west and on the east respectively, filled the former swamp area throughout the centuries. It then

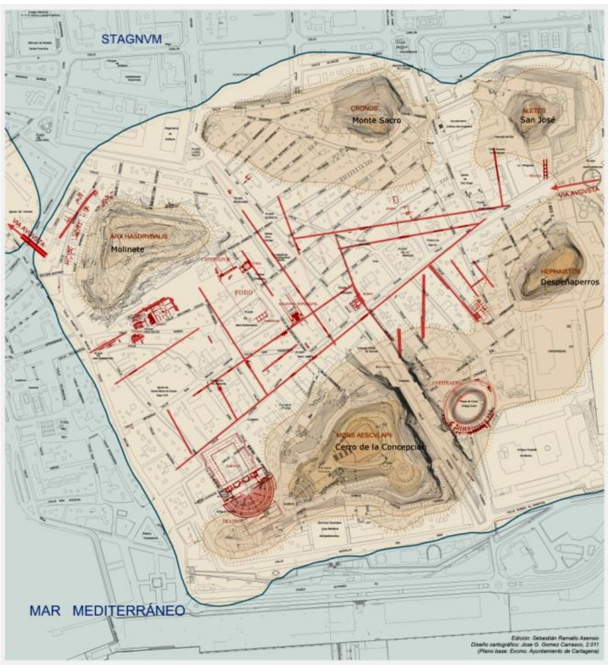


Figure 2: Map of Carthago Nova with the location of the main archaeological findings dating back to Roman times (from Ramallo, 2011).

turned into a salty, swampy environment as can be seen in the Greco-Latin texts referring to the topography of the town (Livio, 26, 45, 7; Polibio, X, 8, 7). The substantial continental contributions of the cited rivers affected the northern marsh area as well as the harbourfront located to the west of the town, known later as the Sea of Mandarache.

This alteration process ended with the construction of the Military arsenal, finished by 1782. As a part of the project, the waters of the Benipila creek, one of the most active of those which flowed into the subsident area, were deviated. In 1900, the Ministry of Interior adopted the Project of Widening, Reform and Sanitation of the town which was drafted in 1896 by Pedro García Faria, Francisco Ramos Bascuñana and Francisco de Paula Oliver Rolandi. The proposed widening was more than ten times the size of the existing town (Ros Mcdonnell & Ródenas López, 2012) and included the initially occupied site by the marshy area, known as Almarjal. Nevertheless, this area was, to a large extent, already drained after the definitive disposal of every artificial linkage with the sea. The map of the project (Fig. 3) shows how the extension of the town to the north was designed, occupying the old marshy area, which nowadays is built up.

Figure 3: Project of Widening, Reform and Sanitation of Cartagena, 1896, Map by F. de P. Ramos, P. García Faria and F. de P. Oliver (Municipal Archive of Cartagena).

Likewise, different projects of the port area reform, such as that of José Almazán (1857), or those subsequent during the early 20th century, ended up fully transforming the spaces in the surroundings of the port and its coastline. They turned a natural environment into a completely anthropised and artificial space (Rubio Paredes, 2005).

The lithology shown in the boreholes by continuous coring carried out during the Arqueotopos Project has allowed us to define the surface which was occupied by the marshy area as well as the nature of the diverse lithological facies identified through different proxies. On a Pleistocene sustratum in some cases and Plio-pleistocene in others, a layer of soft clays is found, to which a significant and, sometimes, strong muddy silt layer is superimposed. On top of this layer silts and clays of alluvial origin and anthropic contributions from different times were deposited. The conducted sedimentary study, supported by granulometric analysis and an identification of bio-indicators, ^{14}C radiocarbon dating and racemization of aminoacids on ostracods has proved to be an entirely scientific work of undoubted importance for the determination of the environment. It has allowed us to define, with better precision than before, the changes experienced by this sector, subject to a wide debate in the historiography studying the town from the 16th century until now. Accordingly, the changes appear in the paleotopography of the sector, definitively characterising the area as a deprived, partially muddy and marshy one in certain points. Therefore, the terms used by Polibio in the description of such area can be endorsed: "very muddy and which could be forded almost everywhere every day in the evening" (Polibio, X, 8, 7).

2. Methodological proposal

To virtually reconstruct the paleotopography of a space, sector or area, it is fundamental to know how and to what extent such space has been affected by each process of sedimentation. These processes modified the space's configuration over time and therefore must be reflected on maps. These maps would be erroneous or misleading if the strong packages of deposits, originated during the natural and anthropic processes, had not been taken into account in the simulations. These processes were registered with the lithology obtained in the process of integral study in the area of interest. Thus, geotechnical studies turn out to be an essential tool in order to obtain such information (Arteaga, Schulz, & Roos, 2008).

On this methodological basis, and taking into account the necessary transparency in the process of data-processing (Vico López, 2011), the current study gives particular importance to: 1) the georeferencing of every borehole drilled in the area: 377 from civil, public and private work and 20 drilled with continuous core within the Arqueotopos Projects I and II; 2) the interpretation of the geological information obtained through its sedimentary columns (Fig. 4); and 3) when the timeliness of other information sources allowed it, its data have also been incorporated into the process of virtual reconstruction of the site, mainly in the inner part of the city. These is the historical and urban-engineering cartography found in different records such as those of Simancas, of the Army, the Port Authority in Cartagena, etc. (Cerezo Andreo, 2014; Ramallo et al., 2016).

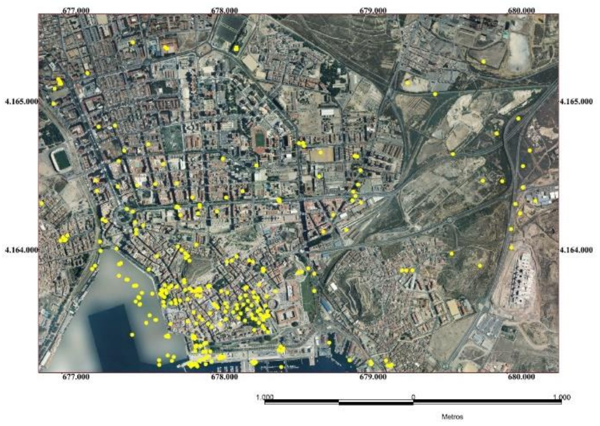


Figure 4: Ortoimage with yellow dots positioning the boreholes available (from Arqueotopos Project archive).

The methodological process which has been followed is comprised of three consecutive phases. The first involved the scanning, compilation and study of all the primary documentary sources. Instances are the historical and archival cartography which exist from the area, together with the lithological information provided by the sedimentary columns and the one contained on a database generated with the information coming from the numerous archaeological sites carried out in the town. With those data, the digital models of the land of the area, surrounded by the five hills and standing on the primitive promontory, were elaborated (García-León, García-Martín & Cánovas Ambit, 2015). A series of points considered to be invariant, that is, with the same level as the current ones, most of them located on the hills, were also included. The geology of the area was also considered by means of the existing faults.

The second phase was focused on the drafting of several virtual topographical models of the area of interest. In order to elaborate the digital models of the land, representing the changes during the geological evolution of the plot, three big layers have been identified. The first and most superficial one is that of anthropic filling, which may imply a thickness in some cases exceeding 4 m in this area. These fillings are, to a large degree, intentional cloggings formed mainly by materials originated from demolitions and removal of the old town and the ones intermittently deposited by the developed hydrological network which pours the water runoff -sometimes energically- into the floodable zone, to the north of the historic centre of the town. The second layer comprises the muds, and its interest lies in the possibility of knowing whether the area was a lacustrine environment or not in the past. Finally, the rock roof layer has also been studied, in order to understand the basement on which the different sediments were placed as regards not only the inner sediments brought by the creeks, but also those of marine origin.

In a third phase, the 3D reconstruction of the town's paleotopography and its surroundings was accomplished. This reconstruction has been done following the different layers of interest, using the mud wall as basement, and texturing it with blue colours for underwater, or with sienna colour for emerged surface. A light shadowing has been undertaken to enhance relief. Afterwards, a rendering of the area has been carried out, setting the altitude of the sealevel in the period which corresponds to the represented sedimentary event to clearly differentiate the submerged areas from those emerged.

2.1. Initial data

377 geotechnical boreholes were available, drilled by different private companies for diverse reasons, such as the construction of new buildings in the area. These were drilled in the last 15 years, being very heterogenous in depth and in their lithological characteristics.

The spatial distribution of these boreholes was not the most suitable for this study, as there were areas where important variations in the topography occurred and without any data. This is why, in the cases where it was possible, a densification of the data was carried out. Gardens or specific lots, for which the necessary authorisations were obtained, were chosen to position the new surveys. Nevertheless, the completion of the new surveys has been conditioned by the availability of these public or private spaces in the current urban design of the town.

2.2. Own data

The distribution of our 20 boreholes can be seen in Figure 5. As indicated, these boreholes drilled have allowed us to densify the information of certain areas, completing it in others and, at the same time, work by means of the extensive sampling conducted. This sampling has aimed to determine the subsequent means with the help of geomorphological studies and those of neotectonic dynamics, granulometric and bio-marker studies, etc., together with their dating through the measurement of the ^{14}C of organic matter in bulk sediments and racemization of amino acids in alkanes.

Figure 5: Location of the boreholes carried out, according to the orthoimage, pointed with a red dot (From: Arqueotopos project archive).

An instance among the 20 surveys recently drilled is the CT-417 (Fig. 6). Its sedimentary column, of quaternary formation, reaches 18 m deep, showing the most significant lithostratigraphic features in the studied region. From the ceiling to the wall, that is, from the top down, the anthropic layer can be observed in said column, with four sub-layers of fillings with ceramic remains and other stone materials. Down below, at 8.10 m and a power of 8.30 m, the layer of muds is located, focusing this analysis at a global level, and comprised in this case of a sediment of silts and sands with bioindicators typical of a lagoon-brackish environment. Its dating between 8090 cal. BP and 2780 cal. BP suggests a continental origin with marine contributions at given times in the Holocene, totally or partially submerged in accordance with the contributions of both origins. Under this layer of muddy silts, Pleistocene sands levels have been identified.

This borehole is therefore a good example of the different layers which make up the lithostratigraphy of the area of study, from which the digital models of the land and the corresponding time sequence have been carried out.

2.3. Data processing

Once all the boreholes were compiled, the first process has been to homogenise their coordinates in the geodetic reference system linked to the stable part of the European continental plate, the ETRS89. This is the official system in our country, since 2007, having substituted the previous ED50. The process has consisted of transforming the planimetric coordinates of the boreholes drilled, which were expressed in different geodesic systems, to ETRS89.

For each layer the data from the surveys have been collected, with its corresponding level. Equally, points

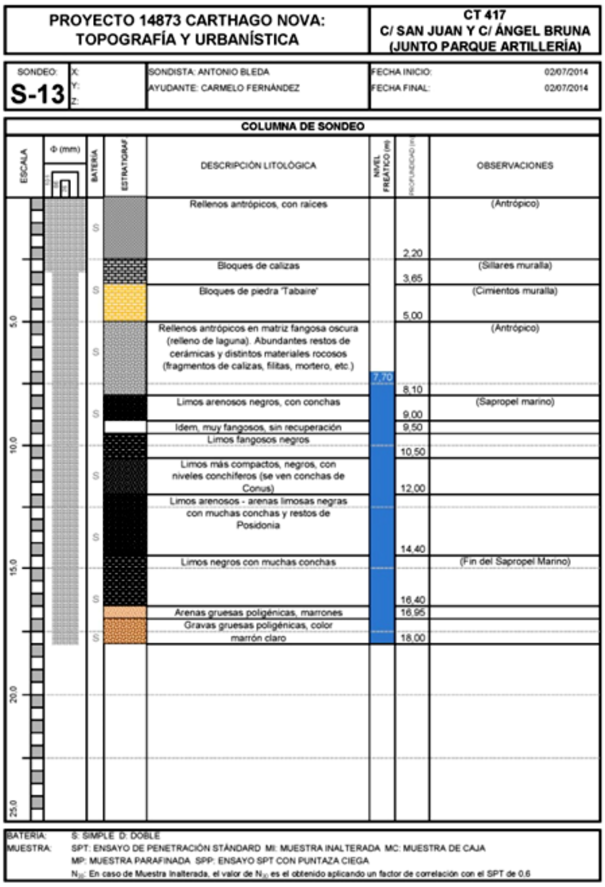


Figure 6: Lithostratigraphic column of the borehole CT-417 (From: Arquetopos project archive).

located on the surface of the hills of the current model have been introduced, considering them invariant. At this point, it is worth mentioning the fact that the erosion which could have affected the layer has not been quantified, since it is not known. Nonetheless, a verification of the quotas in the archaeological remains found in some of these hills was conducted. Significant variations of quota were not found from the Roman high-Imperial period until now.

The knowledge of the geology in the area has allowed the inclusion of the faults which exist there, introducing them in the model as break lines, using the TCP-MDT software. With all this, the TIN (Triangulated Irregular Network) of each layer has been generated, drawing its curve and subsequently transforming it into a raster digital model of the terrain with the free GIS (Geographic Information System) gvSIG. The quality of the information employed to make the triangulation turns out be essential, since it is going to determine the accuracy and veracity of the models generated.

Therefore, a first model of the lower level of the muds layer was obtained, on which similarly, with dark brown tones, the promontory with the five hills rises (Fig. 7). Posteriorly the town would be built on those hills. The lower quota of the muds layer reaches, at a certain point, depths of 19 m below level sea, both in the old Almarjal and in the sector of the Mandarache where the Arsenal was later built. The quota is not uniform in all the marshy area but, in accordance with the paleotopography indicated by the top level of the stones layer, important variations can be seen. It is also relevant that the quota of said layer in the distal section of the inner valley, that

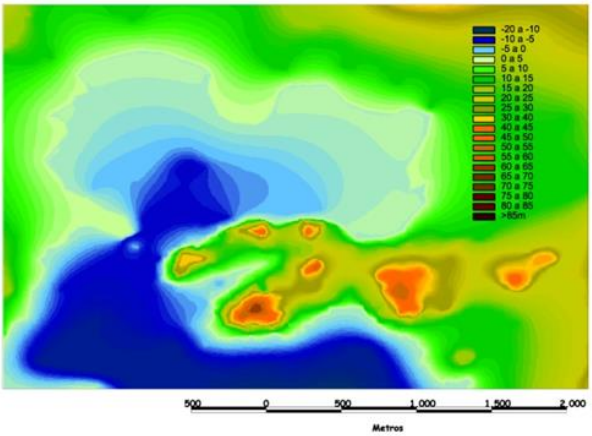


Figure 7: Digital model of the terrain of the lower level of the muds layer, with the contours above and below the current quota of the sea level (from Arquetopos project archive).

structured the relief of the town between the hills of La Concepción and El Molinete, is further studied in detail through the profile of our boreholes.

The Z altitude of each point of a layer, according to its planimetric position, is available with the models created. From these, the profiles can be obtained in every section of each model and the thickness of each layer can be studied simply by comparing consecutive layers and substracting the lower quota from the top quota. The differences between the surfaces delimiting each layer can also be studied, thus calculating the volume of mudswhich exist in the current town or within the anthropic filling in the old marsh. When delimiting the muds layer the floodable area known as the Almarjal can be mapped with precision and at different times.

In an axis that structures the previously mentioned inner valley, an alignment formed by 6 of our boreholes has been carried out. A detailed profile has been traced linking the boreholes, with the aim of determining when the area could have been flooded and, even, whether at a certain time, this sector could have had port functions. As shown by the longitudinal profile obtained with the information supplied by the boreholes drilled along the aforementioned axis (Fig. 8), the thickness of anthropic filling reached 4 m while the power of the muds, represented with a blue colour, is more than 2 m.

It can be observed from the archaeological information that the occupation of this area, previously flooded, had to be completed after its sanitation and urban adaptation in the time of Augustus, when an ambitious urbanisation process of the town was undertaken, with the construction of important emblematic buildings, characteristic of a Roman town such as Carthago Nova.

3. Analysis of results

The different models have been made and refined and a digital model of the land of each layer of interest has been obtained: a) lower level of the anthropic filling; b) top level of the muds layer; c) lower level of the muds layer; d) top level of the rock level or geological sustratum. Regarding the study of the flooded areas, the hypothesis of the sea level located at the same quota as nowadays has been taken, since currently the highest level reached by the

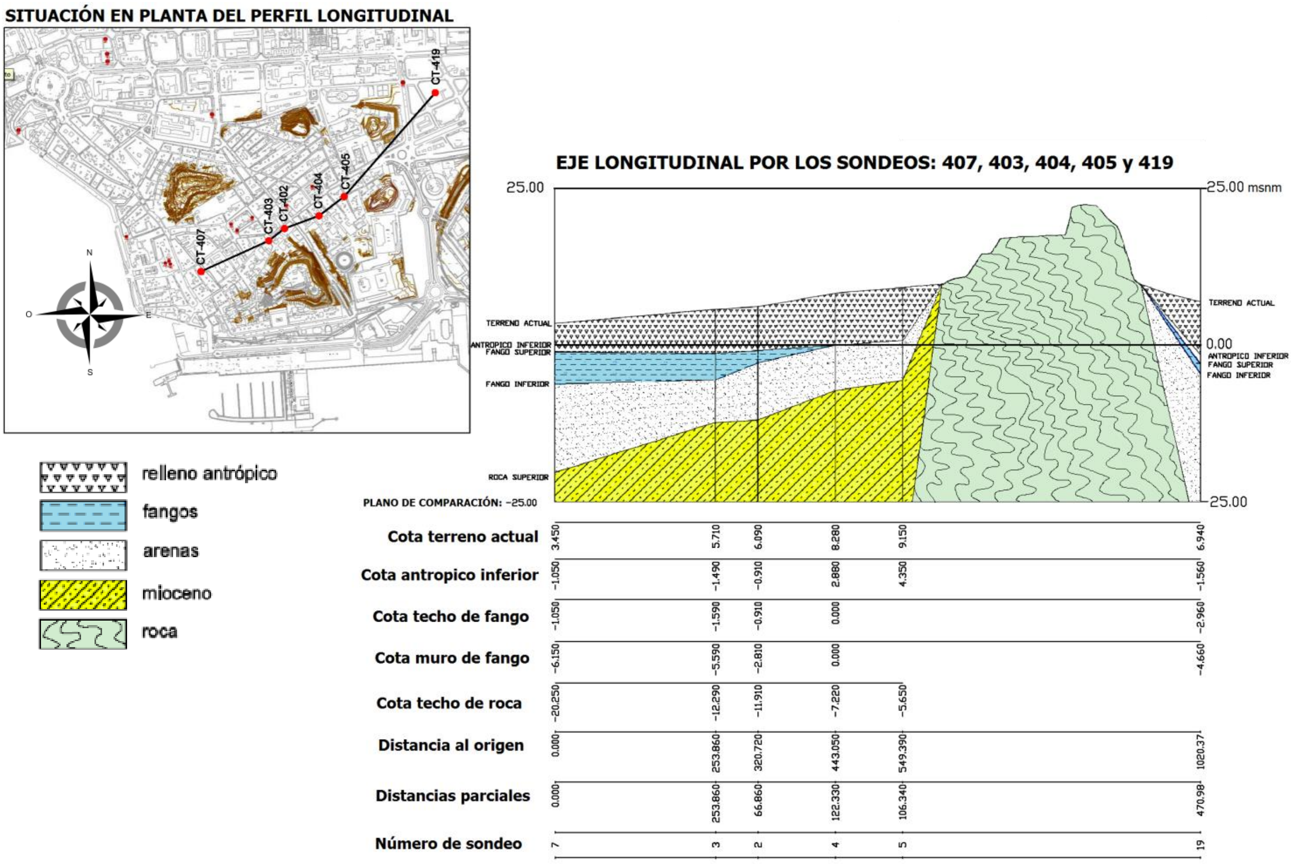
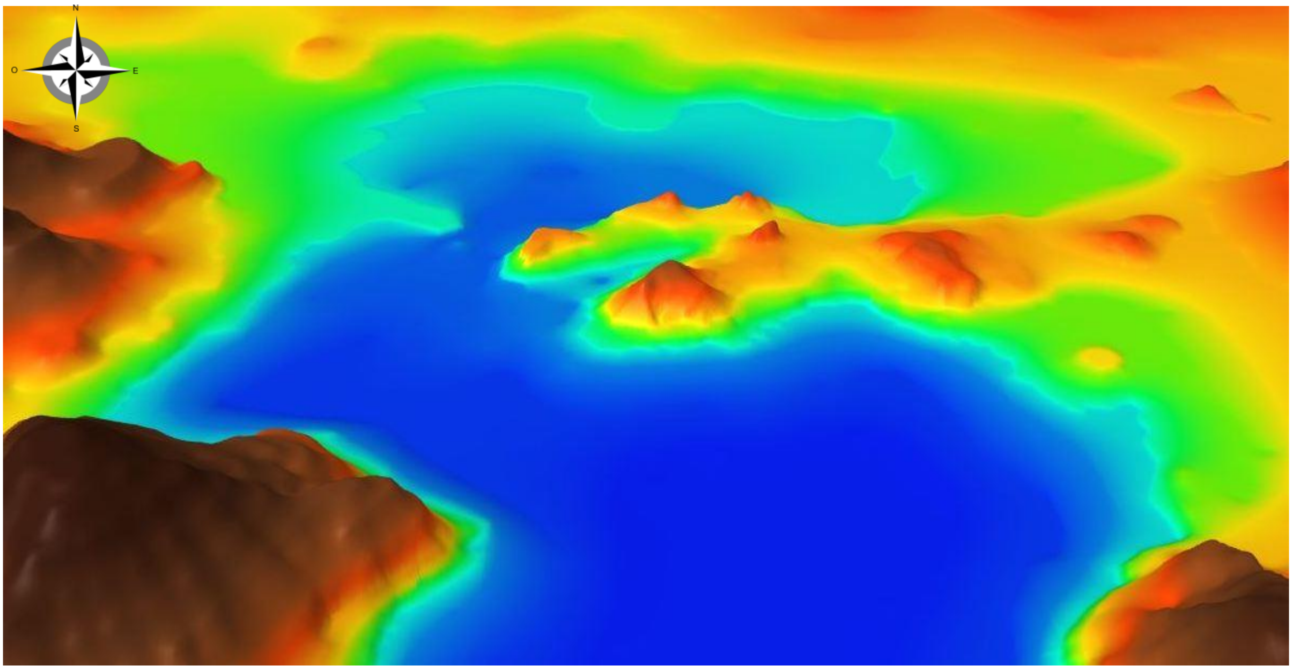


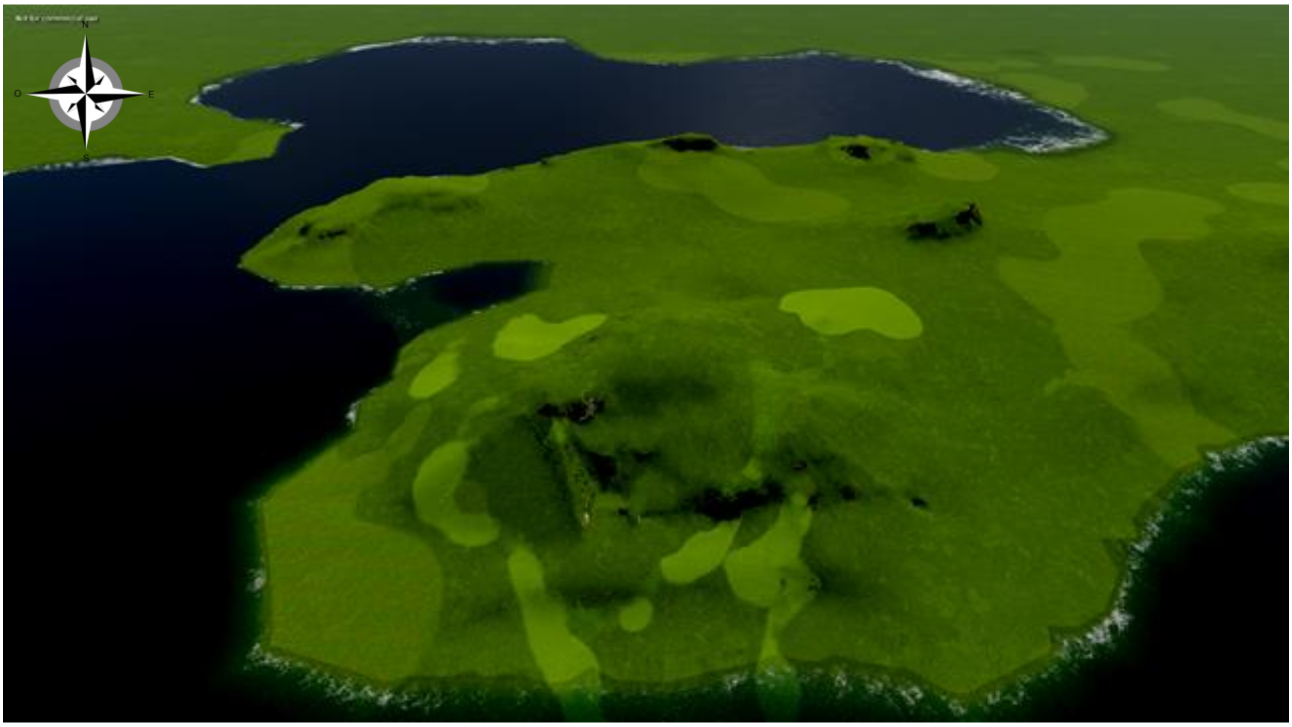
Figure 8: Longitudinal profile in the inner valley between the hills of *La Concepción* and *El Molinete* (from Arquetopos project archive).

Mediterranean Sea is considered to be sensitively the same as the current one (Mörner, 1976; Fairbanks, 1989; Arteaga et al., 2008). Nonetheless, it is accepted that the average level of the Western Mediterranean sea in Roman times was between 120-80 cm below the current level (Lambeck & Purcell, 2005; Morhange et al., 2013).

With the 3D generation, depending on the height of the sea level and the surface occupied by the muds, the zones which would respond to these conditions have been determined. Each layer has been textured in a simplified way with a chromatic legend which enables distinguishing what is above or below the sea level, giving us an idea of which areas could be submerged or flooded, indistinctly, with respect to what it would be solid ground. Accordingly, the model of the lower level of the muds layer would represent the original topography of the primitive environment (approx. 8000 years cal. BP), much earlier than the configuration of the city, with the lacustrine area still communicated with the Mediterranean Sea and the more distal sector of the inner valley of the flooded promontory in the space between the hills of La Concepción and El Molinete (Fig. 2). For the 3D reconstruction of this layer (Fig. 9a), the shades to be



(a)



(b)

Figure 9: a) 3D virtual reconstruction of the wall muds layer; vertical exaggeration of 2 (from Arqueotopos project archive); b) Visualisation with synthetic colours of the wall muds layer.

used must respond to the influence of the light, indicating the appearance that the surfaces will have when filled. Finally, with the illumination, realism in the model is achieved (Flores Gutiérrez, Romero Soria, Martínez García, Ramallo Asensio, & Fernández Díaz, 2013), allowing a better appreciation of some aspects of the scene (Fig. 9b).

4. Discussion

The digital models and the 3D reconstructions have been obtained from the information provided by the geotechnical boreholes made in the town. The spatial positions of the points where these boreholes were made, follow an irregular and heterogeneous distribution, conceived for purposes other than the one at hand. From this information and by applying interpolation methods (TIN), a mesh of triangles has been created, so that each of them allows the calculation of values in their points. However, this initial information came from an external source, possible to use thanks to the generosity of all those involved. Nevertheless, it had not been previously designed taking into account what was intended to be estimated or the level of precision required (Olaya, 2012) and its distribution was not, therefore, optimal for this work. Fortunately, it has been possible for us to conduct several boreholes as well, completing and improving the existing sampling, by placing them in the areas of greatest variability and uncertainty, and hence increasing the accuracy of the models.

It is important to evaluate the quality of the finished work and to compare the generated models with those obtained by other interpolation algorithms, such as the krigging or the reverse distance, since it is possible that, starting from the same set of initial data, the results vary considerably according to the adopted criteria (Sala, Matko, Falk, & Grings, 2014). The quality of the cartographic production, being in this case the one from the final models, must meet the NSSDA (National Standard for Spatial Data Accuracy) requirements, which introduce a statistical methodology to quantify the positional accuracy of maps and geospatial data (Ariza-López, García-Balboa, & Amor Pulido, 2004).

5. Conclusions

The 3D digital models are an effective tool when it comes to performing simulations that allow the validation of work hypotheses of multidisciplinary research. Thesesimulations contribute, thus, to amplify, diversify and reinforce the concept of Heritage. Their diffusion through the Internet and at interpretation centres represent major progress within the heritage and scientific field.

This application for space analysis is also proving its worth in the port and for nautical issues of the old town, now allowing the performance of complex analysis of diffuse visibility or Tobler accessibility.

This aspect turns out to be essential, since having an MDE according to the chronological moment to be analysed is basic for the results to be interpretable from an archaeological and, therefore, heritage point of view. This applies especially in an area as modified and altered as the city and port of Cartagena.

On the other hand, the chance of linking structures known in the field of archaeology to an ancient coastline allows us, in turn, to reinterpret these structures. For instance, this happens now with diverse structures of storage in the western area of the city, fully associated with port functionalities. The same occurs with visibility, visual communication and visual prominence analyses, which are carried out on different anthropic elements located in the natural landscape.

In this study, those digital tools have been used, from the information provided by the Geoarchaeology in its widest sense, within the Arqueotopos Project context. The present study is, thus, part of the Project's working methodology. The results of a series of geotechnical boreholes have been relied upon and some new archaeological surveys have been carried out as well, which has allowed us to complete the initial database in some insufficiently informed areas.

The conclusions obtained from the lithological, sedimentological and hydrographic data, from absolute chronologies and from the characterisation of biomarkers have been transferred to the final digital terrain models. Thus, the extent and characteristics of the northern lacustrine area, the delimitation of the marine and brackish environments, the evolution of the paleotopography in the Punic-Roman town in its initial phases, etc., can be shown thanks to the useful virtual reconstruction as previously mentioned for the research (archaeological and geological), but also with sufficient reliability to pose future applications for dissemination.

The documentation process of a heritage asset requires, first of all, knowing that asset, no matter the aim of that knowledge. Any study allowing the improvement ofthe information about its paleoecological and historical aspects will contribute to a more reliable transmission of the knowledge generated and to expand the heritage asset's value. In short, it is a question of contemplating and enjoying the past through a tool of the future (Almagro et al., 2009), one of the objectives outlined in the Arqueotopos project.

In this regard, this project may contribute to the desired declaration of the town of Cartagena and its environment as a World Heritage site, a project called “Cartagena World Cultural landscape” and launched in 2004 by the town hall of Cartagena, the Polytechnic University of Cartagena and the International Centre for Heritage Conservation.

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