Geomorphic evolution of the ancient site of Los Millares, Andalucia (Spain) –mid-Holocene sedimentation, eustacy, and tectonic activity

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Abstract: The material remains of the Copper-Age (ca. 5200-4200 BP) site of Los Millares (Almeria province), currently 19 km inland from the Mediterranean, suggest marine connections. It is architecturally complex, and its clifftop setting above the aggrading Andarax River suggests defensibility. Its mid-Holocene age suggests the possibility of formerly extensive estuarine environments (net tectonic base-level control being locally minor despite regional tectonic activity), thus giving the site unusual trade potential. In spite of substantial subsurface data, geomorphic reconstruction becomes ambiguous past known medieval estuarine morphology due to the difficulty of acquiring datable material from depth. Certainly Los Millares when occupied had much closer access to marine waters than at present, and protecting cliffs were more formidable. Our conclusions suggest that additional investigations of several types are warranted.

1. INTRODUCTION

The site of Los Millares gives its name to the earliest complex culture of the western Mediterranean (3,200-2,200 BC, referred to as the Copper Age[i].), and is the most prominent site of this Millaran Culture. The site itself is a prominent concentrically-walled ruined settlement, citadel, and accompanying necropolis, atop impressive cliffs above the Andarax River, a major drainage of the Betic Cordillera, 19 km above the river's present mouth (fig. 1A). It was a metal-smelting center for its culture and a trading center both regionally and beyond, and its precocious place in the development of complex societies in western Europe is well established (e.g. Siret 1893, Leisner and Leisner 1943, Almagro and Arribas 1963, Arribas et al. 1979, 1981, Gilman and Thornes 1985, Arribas and Molina 1993, Molina and Camara 2005) and widely recognized (e.g. Castro 1995; Chapman 1991, 2005, 2008; Lillios 2019).

At present one does not readily associate the location of the site with a formerly strategic coastal position. However, its mid-Holocene age is a "sweet spot" time for coastal sites due to maximum estuarine development. In this paper we explore aspects of its geology and geomorphology that clarify its original physiography and thus its prominence and trade potential.

2. THE SITE AND MILLARAN CULTURE

The site of Los Millares is located on a peninsular plateau margined by the Andarax River and the Rambla (Creek) de Huéchar 19 km above the mouth of the river in the Mediterranean (figs. 1, 2). The site consists of a village of 6 ha with concentric fortifications and a necropolis of 80 collective graves, all surrounded by 13 forts, in total circumscribing 150 ha.

An analysis of the surrounding territory confirms the commanding nature of the site. The plateau where the town and the necropolis are installed are excellent for control of the territory, and the margins of this plateau are cliffs and bluffs above the adjacent drainages (e.g. fig. 3). Within the concentric walls of the site are four walled enclosures flanked by towers and bastions and a moat up to 6 m wide and about two meters deep outside one wall. The town is also surrounded by a double line of forts that control access to resources in the nearby Sierra de Gádor for minerals, pasturage and nearby water sources (recently clarified by Jakowski 2019). Thus the defensibility of the site, its population, and economic resources is clear.

The site of Los Millares was discovered and initially excavated by Siret (1893 a,b) and Flores, and the necropolis described by Leisner and Leisner (1943). Further necropolis excavation was by Amagro and Arribas (1963) and on the town/fort system by Arribas and Molina (1991). Much of our information comes from the megalithic collective tombs, which can contain various ceremonial and exotic goods; for the purpose of this paper these include decorated bell-beakers and goods that suggest maritime transport in certain periods (table 1). These are briefly described below, but detailed description is beyond the scope of this paper.

The site gives its name to the Millaran Culture, that spread through the current provinces of Almería, and parts of Granada and Murcia at the time of its occupation (fig. 1C). As in the case of Los Millares, some are walled towns located on flat hills, having complex defensive systems with circular huts between 3.5-6 m in diameter, built with a masonry and mud, wooden posts and organic matrix. These settlements based their economy on rainfed agriculture with different types of barley, olives, peas and beans which suggests the presence of an alternation of cereal and legume crops (Buxó, 1997); and local raising of goats, sheep, cattle and pigs, and their secondary products (Molina et al. 2004).

The chronologic designation of Los Millares as part of the Iberian Copper Age reflects local evidence of smelting. The metallurgical production of arsenical copper first appears (table 1) in some settlements in a domestic setting. In the case of Los Millares there is in addition a specialized metallurgical production with workshops specifically dedicated to such activity, such as those located inside Wall III (Arribas et al. 1983) where a workshop was found with all the expected indications of production (hearth, mineral drops, ceramics with mineral impregnation). Processing areas contain polished hard-stone hammers and boat-shaped metates with manos (Carrion et al 1993). At Los Millares, archaeometallurgical research shows processes of mining, quarrying and/or smelting (Keesman et al. 1991; Moreno, 1993). Especially in the Seville area, coeval intensification of metallurgical production in industrial neighborhoods occurred (Nocete *et al*, 2008).

The research carried out to date on the paleoenvironment of Los Millares shows important changes in environmental conditions compared to today (Molina and Cámara, 2005), a higher rainfall rate and the presence of numerous plant species with *Quercux ilex* forests in nearby areas. and other species such as *Pinus nigra*, *Pinus silvestris, Quercus Faginea* in higher altitude areas as well as *Populus sp*. and *Salix* in the riverbank areas that correspond to a continuous water flow throughout the year (Rodriguez-Ariza, 1992, Rodriguez-Ariza and Vernet, 1991); and animal species such as *Lynx Pardinus*, *Cervus elaphus*, and birds such as *Anas platyrhynchos* and *Tetrao urogallus* (Peters & Von Den Driesch, 1990) from more humid areas that are now missing.

Table 1.—Chronology of the Copper Age of Iberia (fig. 1) as exemplified by its center in Los Millares. Periodization by Molina and Camara (2005). Changes ca. 2600 BC

from review by Lillios (2019). Maritime themes on ceramics figured by Escacena *et al*., (2009), Guerrero, (2009)

Period	Apparent age BC	Introduced features	Ceramics
Recent Neolithic	3800 to 3400/3300	Fortified agricultural villages (moats, palisades), megaliths	
Ancient Copper	3400/3300 to 3000	Towns with necropolis, first well-documented metallurgy	Domestic ware of orange paste some w/ black design
Full Copper	3000 to 2600	Maximum extent and influence of Los Millares center, simple peripheral forts; exotic grave goods	Domestic ware of orange paste some w/ black design
Late Copper	2600 to 2400	Complex system of forts, some walls abandoned	Bell-beakers in some graves; some maritime themes
Final Copper	2400-2200	Fires in forts, decreased population	

Here we describe three geologic aspects of the site as they may have impacted the settlement's environment. These are: local geology, environment relative to active tectonics, and geomorphic environments as they relate to sea-level history and consequent river behavior. We adopt an incremental approach using the post-medieval geomorphology of the site to establish directions of evolution.

3. LOCAL GEOLOGIC ENVIRONMENT

The small peninsular plateau of Los Millares is at an elevation of about 230 to 240 m, bounded by the Andarax River and Rambla Huechar on the north and east respectively, which at their junction is at an elevation of 164 m (fig. 2). On this plateau stands the multi-walled habitation and a necropolis of the site. The steep margins of the bluff are precipitous—even overhanging locally-- in their parts below about 200 m elevation, extending down to the level of both drainages (fig. 3).

Exposed in these cliffs are indurated conglomerates of Pleistocene age (IGME 1983). These are among the youngest strata of a complex Neogene sequence that reflects considerable tectonic uplift and faulting, climate change, and of course eustatic sea-level change in coastal environments (Garcia et al., 2004; Harvey and Mather 2015).

In the cliffs below the site, the conglomerates are dipping a few degrees to the SSW. Clast size ranges from boulder-to-pebble, commonly within a single bed (fig. 3). Bedding is as trough fills, each typically 1 to 3 meters thick. Clasts are mostly sub-rounded, consisting of about 60% schist and gneiss, 30% limestone, and 10% quartz. Their imbrication suggests sedimentary transport toward the east. Matrix is coarse and interstitial, i.e. the array is clast-supported. Induration is partly due to multiple caliche layers, observed also on the plateau above, where such cementation is at the surface or very shallow.

Figure 4 is a cross-section of the Andarax valley at Los Millares. The conglomerate on which the site sits (unit P) is apparently a deposit of an ancestor of the Andarax River, as suggested by its distribution, coarse grain size and eastward sedimentary transport. It currently forms a shallow synform parallel to the modern river (IGME 1983), whether of primary or tectonic origin, whose axis is under Los Millares. Dips as shown in figure 4 are as shown by IGME and measured by ourselves in the conglomerate (corrected for vertical exaggeration). The exact age of the P unit is unclear to us, but apparently pre-OIS8, as travertine deposits of that age (Garcia et al. 2004) overlie it. Recent faults are shown nearby in this sequence (Pulido-Bosch et al. 1992, Pedrera et al. 2012) but none were observed in the immediate substrate of the site.

The high cliffs along the south side of the river bound Holocene gravel fill that forms the Andarax floodplain (fig. 4). The cliffs seem likely to be inherited in part from earlier events in the Holocene, as they seem overly precipitous even for a flashy braided river. Indeed as the following section shows, these cliffs are partially drowned features, so we show a subsurface extension of the cliffs in figure 4. Such bluffs and cliffs extend up- and downstream along the Andarax River for a few kilometers, from about Gador to Santa Fe de Mondujar, but the site of Los Millares is steepest and has the most peninsular plateau above them, giving the site unique defensive advantages.

Detailed geologic maps (IGME 1983) show that Pleistocene conglomerates like those under the Los Millares site overlie Pliocene deltaic deposits cropping out at and just above river level, dipping as shown (Fig. 4). Thus the Holocene channel must be excavated primarily in these pre-conglomeratic Tertiary deposits.

Description of local geology would be incomplete without mention of the Andarax River itself. It is vigorously aggrading from its mouth to well above Los Millares, its bed being a network of braided channels depositing coarse cobbly material. Indeed its channel is fairly straight, with only a broad bend beginning above Pechina/Benehadux at about 11 km above its mouth (figs. 1, 2), to just above Los Millares at 19 km, where braiding continues but sharp beds appear. Braiding continues as far upstream as Instincion, at about 33 km. Its gradient through this stretch is regular, varying from about 15 m/km (0.015) in the upper reaches shown, to about 10 m/km toward the mouth (fig 5), where lesser gradients finally appear.

The steepness of the regional gradient is a consequence of draining the southern flanks of the near-coastal Sierra Nevada (Garcia et al. 2003).

Minor irregularies in grade (fig. 5) occur near major tributary junctions, though the tributaries of the Andarax do meet the river at grade. These are generally aggrading and braided themselves, notably the Rambla Huechar which continues this character over a kilometer upstream from its junction with the Andarax.

4. REGIONAL TECTONICS

The Almeria area is tectonically active as shown by its earthquakes of A.D. 1357, 1487, 1518, and 1522 (Reicherter and Hubscher 2007, Benito et al. 2010, Pedrera et al. 2012), which all resulted in damage in Almeria, and possibly in some shoreline change there in the post-medieval period[ii].

One of the most active faults in the western Mediterranean, the Carboneras fault, is pertinent to the discussion of sea-level base of the Andarax River. This fault trends northeast from where it intersects the shore in the Gulf of Almeria, and separates the volcanic rocks of the Cabo de Gata massif from Neogene deposits of the Nijar plain (fig. 1). Motion is largely strike-slip in a left-lateral sense. GPS data show that a horizontal component of motion is regular at about 1.5 mm/year, probably in addition to periodic offsets due to earthquakes such as those listed above. Seismic hazard/frequency studies (e.g. Benito et al. 2010) suggest Copper-age inhabitants of Los Millares are likely to have experienced several damaging[iii] earthquakes over their 1000 years based on instrumental and historic activity (cf. Silva et al 2003).

The Carboneras fault, vertical as observed at El Barranquete, is composed of a number of strands (Rutter et al. 2012, Pedrera et al. 2012). Some strands are separated by positive flower structures, which suggest compression across the fault. Offshore in the Gulf of Almeria, continuations of various strands of the Carboneras fault have been detected by seismic profiling (Reicherter and Hubscher 2007). Some of these profiles, at depths of over 200 m[iv] are attributed to down-to NW movement, though others suggest the opposite to us. Neogene coastlines onshore to the NW roll down into the Carboneras fault (Goy and Zazo 1986, fig. 1). Thus it is possible--but not certain by any means--that the area of the Andarax delta may have subsided at some times in the Holocene. Given low sedimentation rates, any such subsidence would tend to prolong the existence of the Andarax estuary. It might also produce local sea-level incursions within the delta wedge (cf. Pulido-Bosch et al. 1992, Hoffman 1992).

Vertical offsets of different parts of the Almeria-area shoreline are known to correspond to different tectonic blocks. Evidence of Quaternary emergence in the block NW of Carboneras fault (Harvey and Mather 2015, fig. 4.1 after Braga) includes late Quaternary uplift of a few meters both east and west of the mouth of the Andarax (Goy and Zazo 1986, Harvey and Mather p. 37-38). Greater uplift rates have been noted on the SE block (Bell et al. 1997), though in the NW block uplift rates increased NW-ward (Goy and Zazo 1986, fig. 1). Silva et al. (2003) show Quaternary uplift of each block, but the mouth of the Andarax is indeterminate in their analysis. The record may be jerky in detail, exemplified by the swarm of earthquakes in the 1300-1600 period.

In any case, interpolations of the Quaternary data for the length of time of the Holocene suggest that Holocene uplift probably was negligible. The most pertinent direct data for the Holocene are those from the Dalias shore (fig. 1), which show no Holocene uplift (Goy et al. 2003). We tentatively conclude that Holocene tectonic uplift was not a significant factor in geomorphic development of the Los Millares site.

In summary, despite the considerable tectonic activity of the Almeria region, this activity seems to have produced rather little uplift of the mouth of the Andarax. The response to glacioeustatic events was of greater import to habitation of Los Millares.

5. POST-MEDIEVAL EVOLUTION OF LOS MILLARES

Any reconstruction of Copper-Age geomorphology for Los Millares must pass incrementally through the better-documented medieval and post-medieval periods, remarkable in themselves for their relation of river aggradation to sea level. This later period provides a clue to the Holocene behavior of the Andarax system.

The mouth of the Andarax is currently a delta—actually a fan-delta--that projects about 4 km into the Mediterranean. It has grown since medieval times (Hoffman 1992); prior to 1570 the mouth formed an estuary, a factor in Almeria becoming a port. Between 1570 and 1720 the mouth migrated from roughly 5-6 km inland to 4 km inland (Hoffmann 1992, figs. 2 and 6). The gradient of the river is such that the elevations of these former mouths are now at about 40-50 m and 30 m above MSL respectively. The larger figures imply a volume of about 300 million cubic meters of post-medieval deposition above sea level along the Andarax coast sector; the smaller ones still imply over 100 million cubic meters [v].

Figure 5 includes a hypothetical gradient diagram for the medieval period, based on the following assumptions: 1) the intersection of this gradient with sea level is at the head of mapped estuary position, 2) the gradient is as regularly graded as the modern gradient, and 3) the former and present gradients intersect where the latter is sufficiently narrow that aggradation cannot be assumed, at about 33 km along its valley above the river mouth. With these assumptions, the medieval River Andarax would be about 23 meters below the current river at Los Millares. The current bluffs, precipitous in their lower 35 meters, would have been cliffs more than 55 meters high at that time.

Note that the shape of the hypothetical medieval gradient of figure 5 has a steep stretch to sea level, followed by a segment to seaward that is nearly flat, reflecting the known floor of the estuary. The distribution of Roman and Phoenician sites in Almeria province suggests remarkable similarity of estuary shorelines to that in the medieval period (Lario et al. 1995). This stasis is consistent with tectonic stability during this period. Observed post-medieval progradation is thus probably due to voluminous sediment supply.

Fortunately, subsurface data for the Andarax valley is available, based on boreholes to determine aquifer characteristics (figures 6 and 7 modified from Sanchez-Martos 1997)[vi]. These longitudinal and cross-sections show the depth of Quaternary deposits in the Andarax valley. This depth, as shown especially in longitudinal section I-I', matches the hypothetical medieval gradient of figure 5 fairly closely. The precision of such matching is limited both for control of the medieval gradient and by the distribution of boreholes controlling the subsurface contact. However, the medieval Andarax River probably was entrenched about the entire thickness of Holocene gravels as shown in figure 4, and most coarse sedimentary fill above this contact accumulated in post-medieval times.

6. PROBABLE COPPER AGE SITUATION

Evidence for the exact physiographic situation of Los Millares at the time of occupation lies near the base of the adjacent Holocene gravel unit. The difficulty of acquiring either archaeological or radiometric dates there limits our ability to be specific. Some aspects, however, seem clear.

6.1 Geomorphology

The medieval estuary was a relict feature of post-Pleistocene sea-level rise, which resulted in drowned river mouths worldwide (reviewed by Khan et al. 2015) and locally (Hoffman 1992). Sea level rose at average rates of more than a centimeter a year from about 15 ka to 6 ka (4000 B.C.) but not at all afterward in this area (Hoffman 1992). At 3000 B.C., post-Pleistocene sea-level rise had stabilized quite recently, and estuaries would be at their maximum extents. Assuming coastal uplift was minor as we have seen, the Andarax estuary would be at nearly maximum extent at the time of Los Millares occupation, but would begin retreating due to sedimentary infilling, in the way recorded in the post-medieval period (e.g. Hoffmann 1992, Molina and Camara 2005).

The boreholes of figures 6 and 7 show the contact of overlying deposits mostly of Holocene age with underlying Pliocene deposits. This surface is well above sea level in the Andarax valley at Los Millares and intersects modern sea level in the area of Viator, 6 .3 km at most above the present river mouth. This fact would seem to provide a maximum extent of the Andarax estuary at the time of occupation of Los Millares during the newly-established sea-level highstand. However, there is an alternative possibility:

This apparent estuary extent is surprising in that it is essentially the same as that for the medieval period—and given the distribution of regional Roman and Phoenician sites (Lario et al. 1995) it appears that the estuary remained somewhat static, perhaps for 4500 years. This picture however produces a conundrum--the Andarax would have to flow without delivering significant amounts of sediment for 4500 years, despite the fact that in the next 500 years it filled its estuary and built a delta with such sediment.[vii] We think there are few possibilities for addressing this unusual situation. These include:

1. Stream gradients may have been steeper from the Copper Age until the medieval period, allowing allow voluminous deposits to lodge upstream. However, there is no evidence in Holocene terraces for this scenario.
2. Land use practices or climate had changed, changing sediment supply. This has been suggested by previous authors, notably Hoffmann (1992) and Lario et al. (1995), but should not cut off sediment supply for 4500 years.
3. Base level may have been different due to sea-level change and/or tectonic disturbance, permitting sediment by-passing. We argue against this above, and note that invoking such base-level change in this case requires that the change reverse itself completely and near-exactly before the medieval period.
4. The profiles of figures 6 and 7 may have missed a steep-sided inner gorge or arroyo filled with the sediment that is missing. That is, deep channels cut into soft Pliocene deposits during Quaternary low-stands of sea level may be filled with Holocene sediment (below the base of unit H in figure 4). Some boreholes near the modern river mouth show Holocene (IGME 1987) and other young gravels (Jorreto et al. 2009) extending 100 m below sea level--adjacent to others with marine deposits up to sea level (Hoffmann 1987), difficult to explain without the hypothesized arroyo. Such hidden channels could be over 100 m wide without detection. The hypothetical volume of deposits in such channels varies tremendously with one's assumptions, but can be configured to deal with the magnitude of the missing-sediment problem.

Due to listed problems with other possibilities, we prefer the fourth by default. We admit we have not solved the problem. Seismic profiling should test this fourth possibility, as it not only addresses our central question but also carries interesting practical implications. For example, an inner gorge permits a volume of Almeria's aquifer that is greater than is documented in current literature.

Most pertinent to this paper, a narrow mid-Holocene estuary could have reached nearer to Los Millares than the subsurface profiles suggest. This would increase the trade potential of the site; the subsurface profiles suggest the distance from Los Millares to estuary was about 13 km but the fragmentary data suggesting a former arroyo allow this distance to be 10 km or less. Note from figure 4 however that downcutting sufficient to make Los Millares an estuarine site is highly unlikely. Since this hypothetical former arroyo would have been cut partially on Pliocene deposits, we cannot say how easy transport along it would have been.

6.2 Implications for Los Millares

Detailed reconstruction of the Copper-Age geography of the Los Millares site—especially the distance to tidewater—is unclear. However, there are some aspects on which we're confident. First, the distance to tidewater was considerably shorter than the currently long-drainage of 19 km, suggesting a marine trade potential not apparent in the current physiography of the site. Second, we should envision the Los Millares peninsular plateau as being bounded by cliffs at least 60 m high. During habitation, this would make the site impregnable from the north and formidable from the east and west.

Agricultural potential for the region of Los Millares in the Copper Age is largely unknowable. The formerly greater entrenchment of the Andarax River and its tributaries means that nearby riparian environments are now mostly deeply buried[viii]. We note that base-level evolution needs to be brought into studies of former paleogeography in this and other ancient sites, especially along coasts.

In contrast, the greater ease of maritime trade in Copper-age Los Millares is evident; its geology and geomorphology corresponds with some of its material remains. Some of the extensive evidence of contacts among Copper-age societies of the Iberian Peninsula with North Africa and Asia during IV-III millennium BC comes from material remains at Los Millares. These include "exotic" products such Asian ivory (Schuhmacher et al. 2009, fig. 6; Schuhmacher and Banerjee 2012) and ostrich egg shells, deposited as trousseau in different collective graves there (Siret, 1908; Almagro and Arribas, 1963; Chapman, 1991; Molina and Cámara, 2005). Los MIllares also seems to have been a gathering point of goods from other Copper-age settlements of Iberia including inland sites (Almagro and Arribas 1963, Arribas 1979, Molina and Camara 2005, Lozano et al. 2010)). Investigations at Los Millares have determined the presence of marine fish (Molina and Camara, 2005), and the circulation of other raw materials such as metals, hard rock for tools, and flint from the Cabo de Gata area (Carrión *et al*. 1993; Haro *et al*. 2006), but local, overland and "down-the-line" trade, possibly along the northern shore of the Mediterranean, suffice for these. The involvement of Africa requires truly maritime contact, however. In this connection, it is intriguing that several bell-beaker fragments with "barquiform" decorations occur, most easily interpreted as longboats (Escacena *et al*., 2009, Guerrero, 2009) more elaborate than would be required for fishing. Closely similar longboat depictions elsewhere in the Mediterranean are known for the time period of Los Millares (e.g. Basch 1987, Broodbank 2000, Martinelli 2018). We therefore see a connection between the former trade potential of Los Millares and its exotic material remains. Further exploration of such trade seems promising--but beyond the scope of this paper.

7. CONCLUSIONS

The importance of glacioeustatic sea level change in reconstructing the original environment of Los Millares follows from its mid-Holocene age, which corresponds to maximum estuarine development in the Andarax drainage. Subsurface data and historic records show the former presence of an estuary of some length, and permit an estuary reaching about halfway to Los Millares during its habitation. Los Millares was probably originally sited to take advantage of the combination of defensible cliff-top site location and short transport to a safe estuarine harbor, and its material remains suggest that marine trade did occur.

Tectonic factors that may have influenced the environment of Los Millares prove to be minor at the site itself. Because the Almeria region is tectonically quite active, tectonic factors could potentially have influenced the geologic environment of Los Millares, especially via base level of the Andarax River. We conclude, however, that Holocene tectonic uplift was apparently minor locally, and that response to glacioeustatic sea-level history was more important.

8. RECOMMENDATIONS

Unknowns abound at Los Millares. Geologically most urgent is a seismic reflection study crossing the Andarax valley somewhere in the reach from the Los Millares site down to Benehadux, in order to determine whether a filled inner gorge or arroyo is present. This would not only test our hypotheses about extent of the former estuary, important to fully understand Los Millares, but would also have practical modern applications as noted above. In the longer term, funding to acquire datable material from near the base of Holocene units would permit necessary drilling.

Archaeologically, we applaud current governmental support of further exploration at Los Millares and note the great potential of such studies to better place Los Millares in its western Mediterranean world relative to connections with points east and with Africa—as well as transformations in its temporal world of the IV and III millennium BC. Modern methods of study, utilized at some other Millaran sites (Lillios 2019), should permit better conclusions about Los Millares itself; isotopic, trace-element, genetic, and remote sensing studies should play a part, but so will such basics as provenance studies of the decorated ceramics via petrographic methods.

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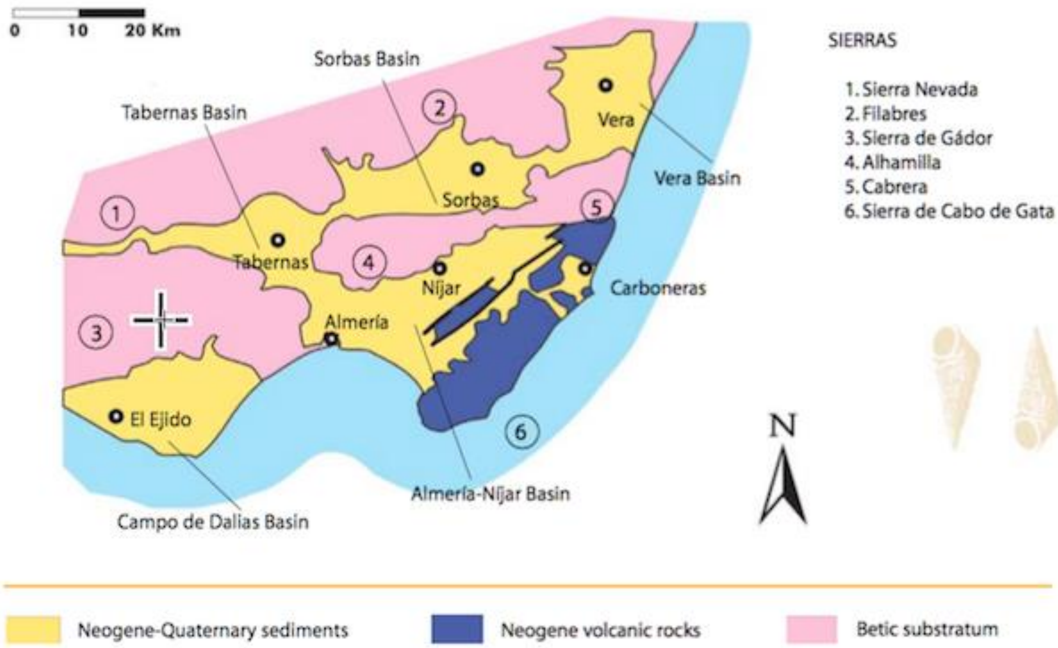
Fig. 1—Location of the Los Millares site relative to the Andarax River, the Carboneras fault, and coeval sites. A. Physiography. The Andarax River connects Los Millares to Almeria. Note locations of Gador, Benehadux, and Cabo de Gata peninsula. B. Geologic context. Note Carboneras fault shown between Carboneras and Cabo de Gata (actually extending into the Gulf of Almeria, map after Braga and Martin, unpublished guidebook “Almeria-Nijar basin”). C. Distribution of Copper-age Millaran Culture sites of the region as described to 2020, compiled by Martin Haro.

A.

B.



C.

Fig. 2—Physiography of the immediate area in shaded relief.

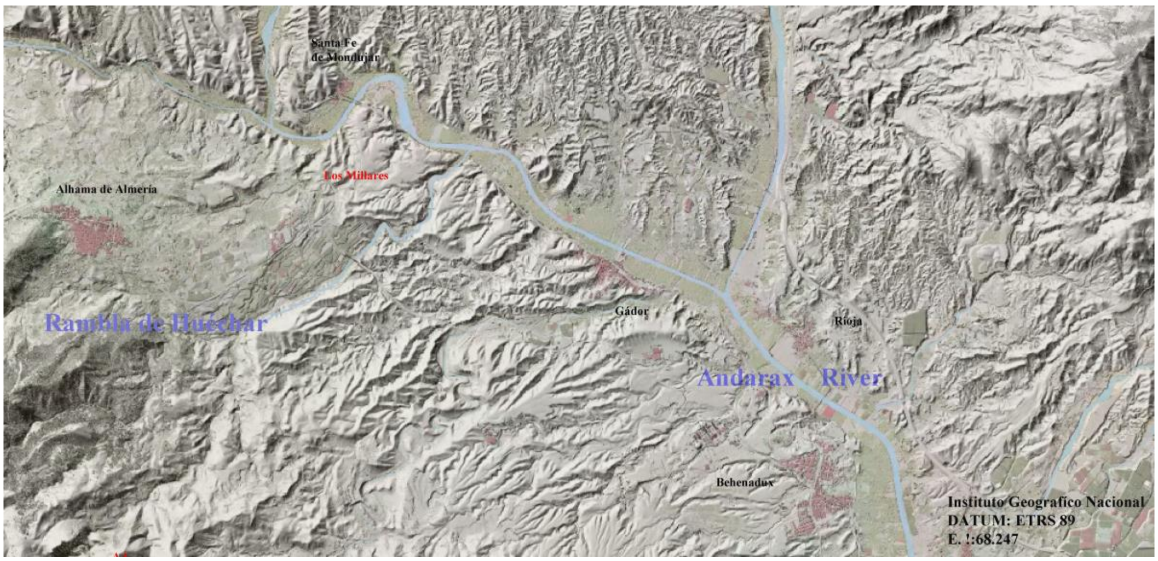

Santa Fe
de Mondújar
Los Millares
Alhama de Almería
Rambla de Huéchar
Gádor
Rioja
Andarax River
Benahadux
Instituto Geografico Nacional
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Fig. 3—Photo of the indurated conglomerates forming bluffs on which the site and its plateau rest, taken from Rambla Huachar

Fig. 4.—Cross-section of the Andarax River valley at the Los Millares site, oriented N45E. At the site, three concentric half-walls shown (each terminating at river bluff), outermost to the left adjacent to necropolis. Horizontal scale, 100 m for each grade mark shown, i.e. vertical exaggeration is 1.6. Geologic units are H Holocene gravels, P cemented Pleistocene conglomerate, T undifferentiated Tertiary deposits. Base of Holocene is based on data in figs. 4, 5, and 6, and hypothetical inner arroyo is not shown. Note however that any such arroyo would be cut in unit T. Mean sea level (MSL) shown to illustrate the improbability of unit H reaching sea level, i.e. Los Millares being an estuarine site.

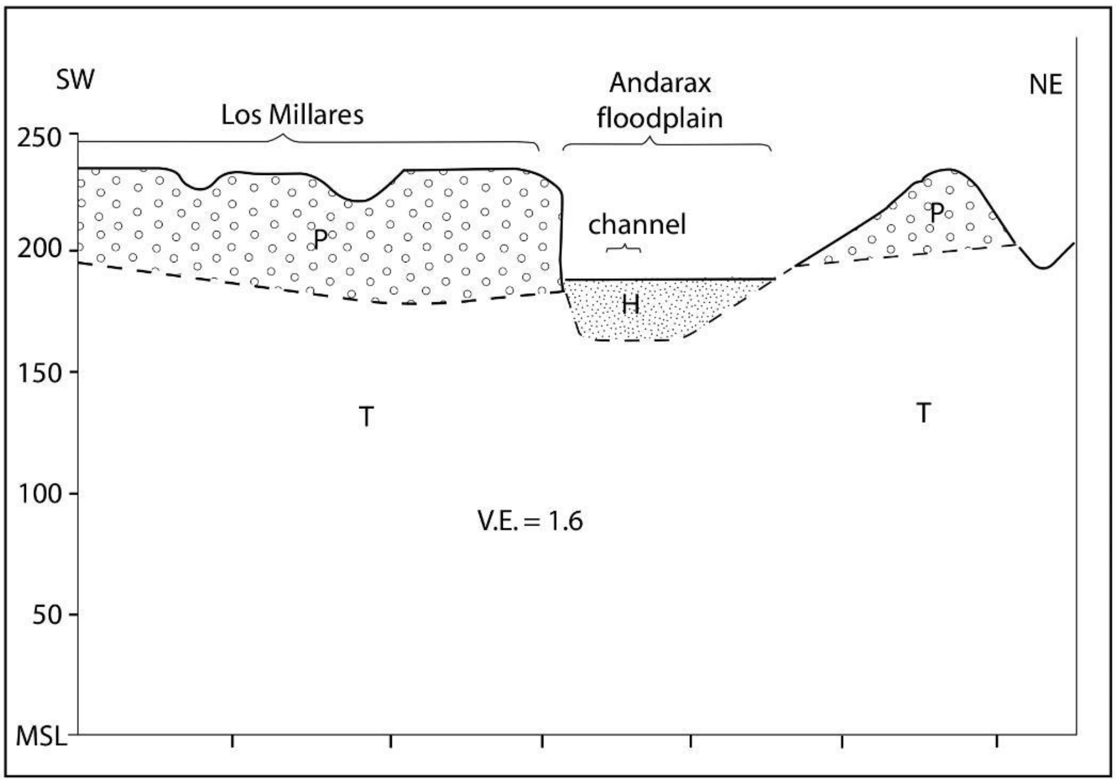
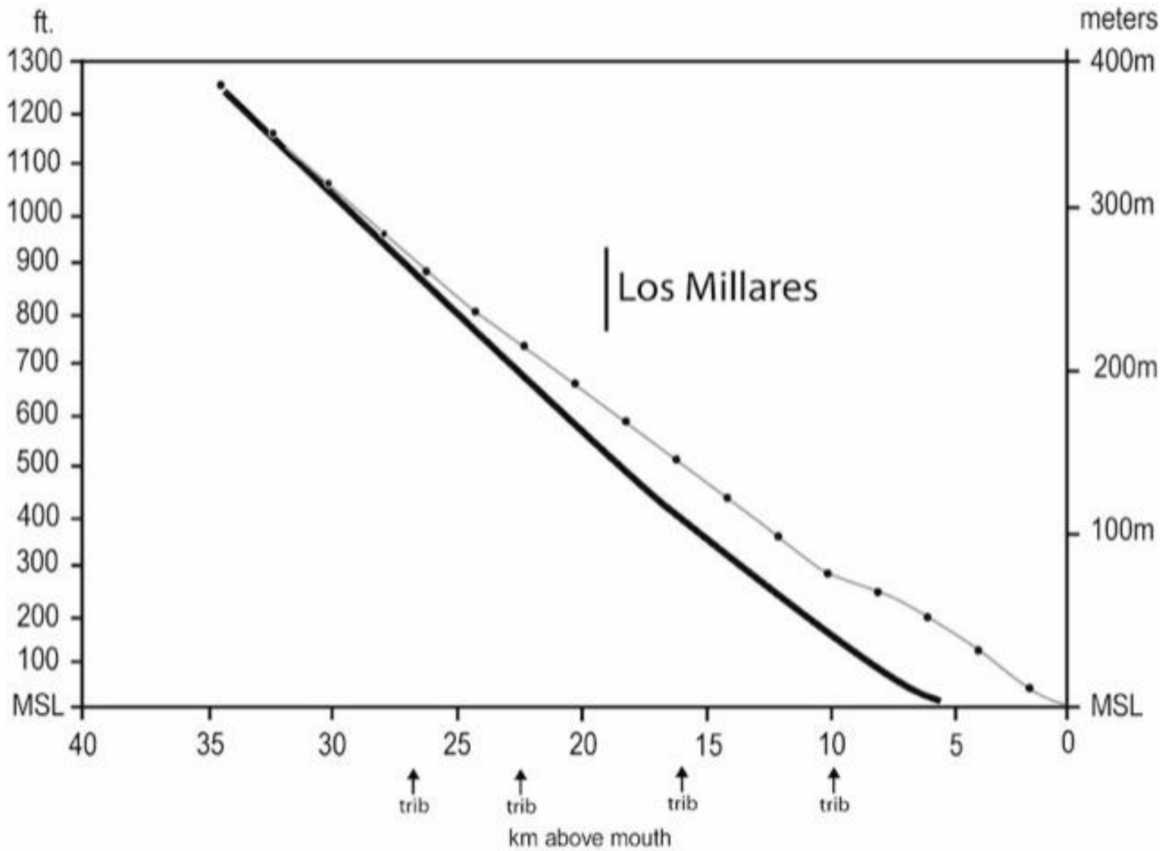


Fig. 5—Gradient diagram of the modern Andarax River from its present-day mouth through the length of its braided aggrading course (lighter line with control points). Note that no knick point is currently present between the sierras Gador and Almahilla. Superposed (heavier line) is a hypothetical gradient prior to delta growth at constant sea level for the medieval and Copper-Age periods (using a 6 km estuary position for both; see text). Note the implied situation for Los Millares relative to former fluvial surfaces.

➢ 

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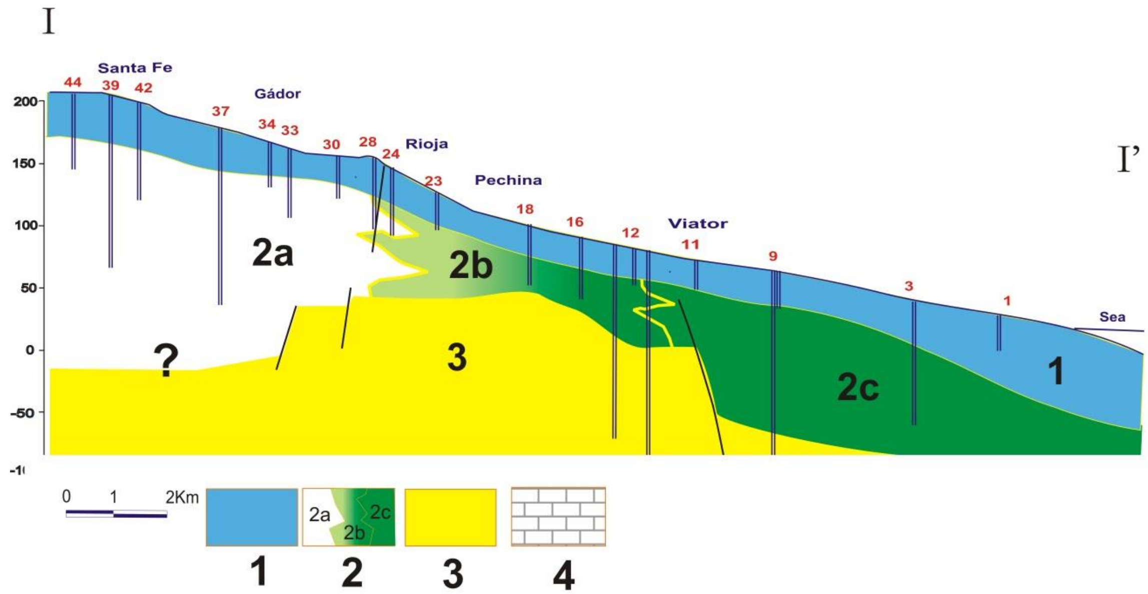
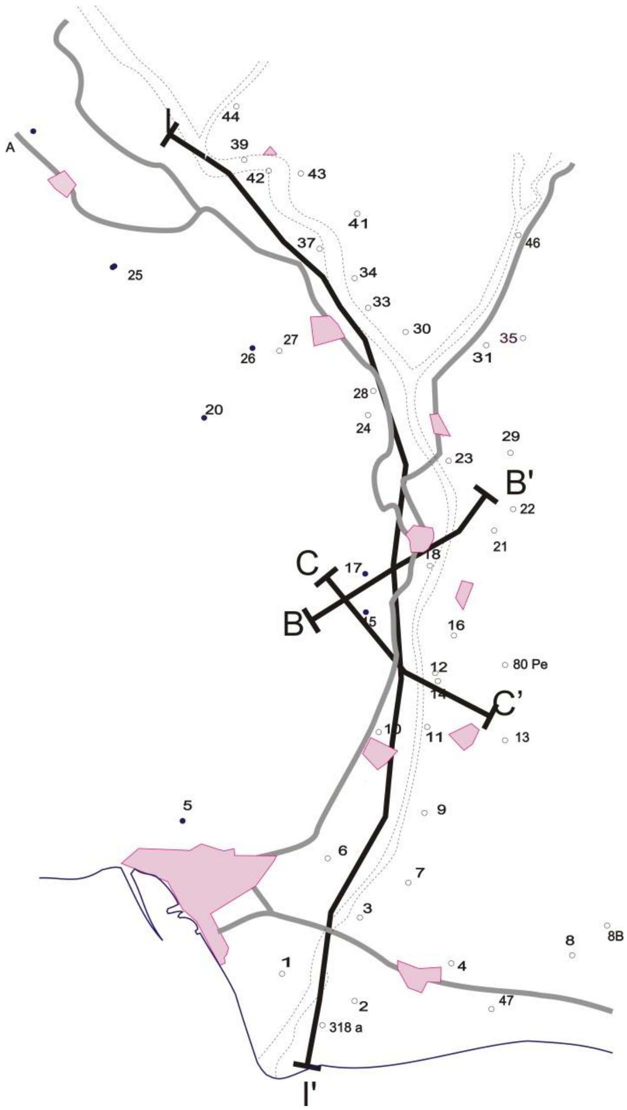
km above mouth

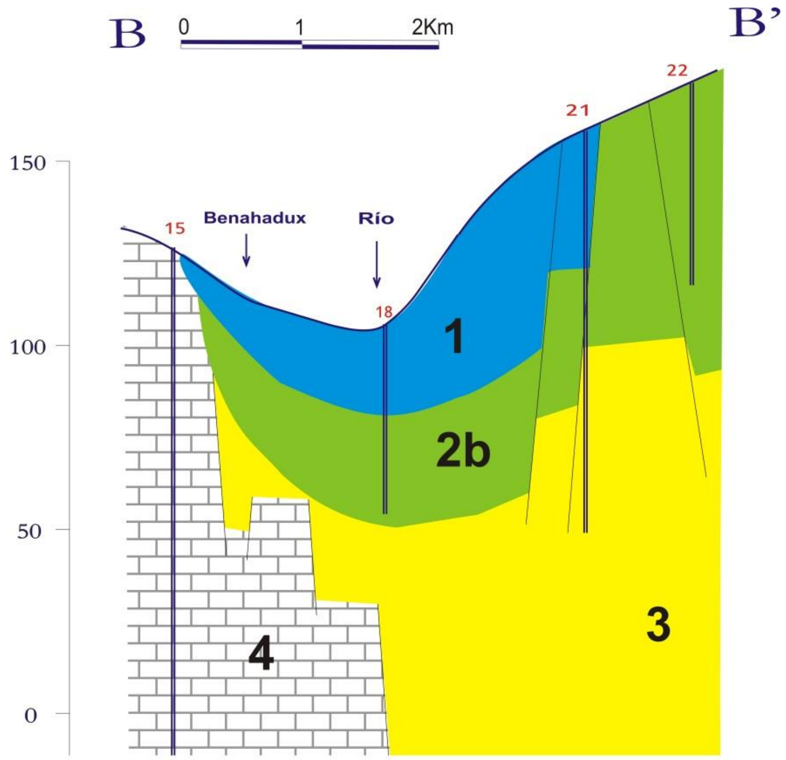
Fig. 6.—Longitudinal section of the Andarax valley (location map shows section and numbered control borings, roads in gray, and settlements (largest being Almeria), in pink) from Sanchez-Martos (1997). Units are: 1: Recent alluvial deposits of the Andarax River; 2. Pliocene deposits, 2A mostly conglomerate, 2B mostly sandy, 2C mostly marls; 3. Miocene marls; 4. Carbonate rocks;

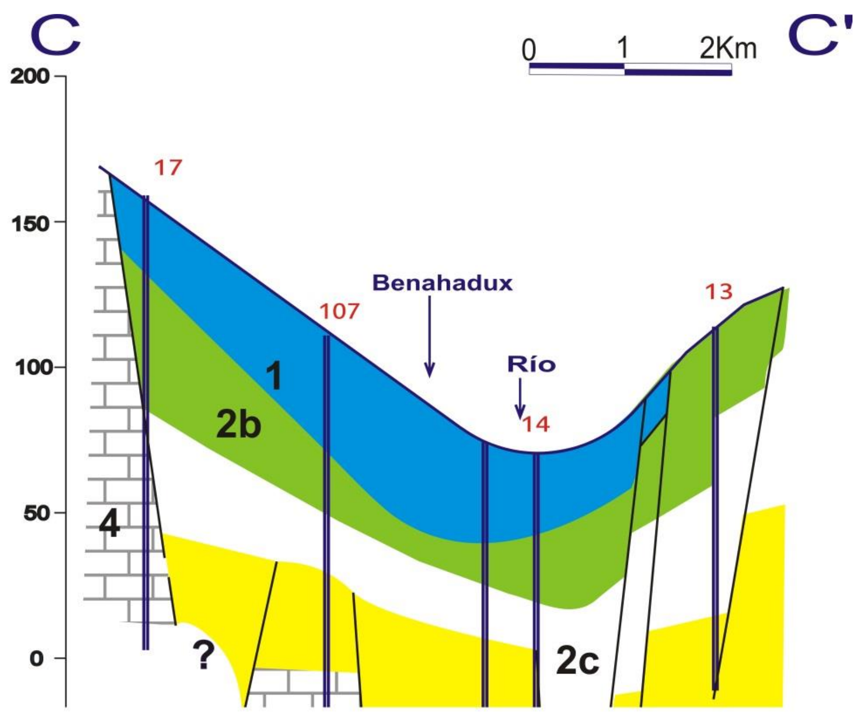




A
I
44
39
42
43
41
37
46
25
34
33
27
30
35
26
31
20
28
24
29
23
B'
22
21
C
17
18
B
15
16
12
80 Pe
14
C'
10
11
13
5
9
6
7
3
8
8B
1
4
2
47
318 a
I'

Fig. 7.—Cross-section(s) of the Andarax valley (fig. 6 inset shows location) from Sanchez-Martos (1997)





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FOOTNOTES

[i] Slightly younger than the Chalcolithic of Mesopotamia

[ii] Indeed the epicenter for the most damaging, that of 1522, is shown quite near Los Millares (Pedrera et al. 2012))

[iii] I.e. with ground accelerations 20% that of gravity

[iv] Thereby minimizing possible glacial-era erosional modification.

[v] So the fan-delta is a continuation of the grade as observed for many kilometers upstream. The lower Andarax is thus only slightly graded in the sense of decreasing downstream gradient. No gradient disruption due to constriction between Sierras Gador and Almahilla is apparent.

The term medieval is insufficient for some of these calculations; it covers 500 years of different situations, as we will see.

[vi] Here we address the broader context of Quaternary units included in the cross-sections: Quaternary valley-margin deposits shown in figure 7 suggest the presence of pre-Holocene terraces, indeed the maps of IGME (1983) suggest the Los Millares site sits on one. Garcia et al. (2004) describe Pleistocene terrace deposits of the Andarax valley, suggesting that deposits of previous Quaternary cycles are part of these valley-wall accumulations. The area is being uplifted tectonically (Braga et al. 2003); for example, the youngest previous (Sangamonian/Eemian) highstand shorelines are 10 to 15 m above modern sea level in this area (Zazo 1999). Some authors (e.g. Harvey and Mather 2015) posit glacial-era valley filling; we need not comment except that glacial valleys of some Pleistocene times apparently existed.

[vii] Conversely put, why did any estuary persist into the medieval period?

[viii] Contrast Gilman and Thornes (1985). Irrigable fields useful to inhabitants of Los Millares and some related settlements would likely be 10 or more meters below the current land surface.