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EVIDENCE OF HOLOCENE TECTONIC ACTIVITY AFFECTING ALLUVIAL FILL EVOLUTION IN THE VEGA MEDIA OF THE SEGURA RIVER, SOUTHEASTERN SPAIN (WESTERN MEDITERRANEAN REGION)

Abstract: Rodríguez-Estrella T., Conesa-García C., Navarro-Hervás F., Pérez-Cutillas P. & García Mariana F., Evidence of *Holocene tectonic activity affecting alluvial fill evolution in the Vega Media of the Segura River, southeastern Spain (Western Mediterranean region).* (IT ISSN 0391-9838, 2018).

A compressive stress pattern, associated with active faults, controlling Holocene alluvial deposits was analyzed here by adopting an integrated approach focused on direct and indirect research methods, and taking the Vega Media of the Segura River (VMSR) (SE Spain) as a case study. In particular, geological reconnaissance to determine the morphology of valley edges was carried out, and geophysical methods, boreholes, hydrochemical analysis, piezometry, seismic records, and ^{14}C dating with the AMS technique were also used. This neotectonic activity responds to a compressive regime, maximum in a N-S orientation, which is manifested by dextral strike-slip faults (N125º-140ºE direction), with horizontal displacements of up to 5 km, and normal faults, trending N50º-70ºE with throws in the upper silt unit of up to 8 m in less than 200 m. Within the meander-belt zone of the VMSR, the age of clayey silts, at 14-15 m depth, was estimated to be between 2,754 and 7,561 cal yr BP, representing slip rates for these faults of between 0.26 and 0.53 mm/yr since the middle Holocene. Considering the whole Holocene alluvial fill in this area, the complete set of possible net slip rates comprises values from 0.12 to 0.57 mm/yr. In addition, age differences of up to 4,350 cal yr BP were found at 9 m depth in boreholes spaced less than 100 m apart. Such Holocene tectonic activity has determined the displacement of the Segura River towards the southern valley margin and the formation of sharp meander bends.

Key words: Neotectonics, Alluvial fill, Holocene, Silts, Vega Media of the Segura River, Spain.

INTRODUCTION

Rivers and alluvial plains are extremely sensitive to tectonic tilting and faulting, resulting in morphological and sedimentary adjustments (Mackey & Bridge, 1995; Hofmann & *alii*, 2011). Such variations arise because rivers change position by gradual channel-belt migration or by abrupt avulsion in response to the deformation of the land surface (Alexander & *alii*, 1994; Schumm, Dumont & Holbrook, 2000; Mack & *alii*, 2011; Hajek & Wolinsky, 2012). Such channel-belt movements have the potential to increase the proportion and connectedness of channel-belt deposits within a basin fill (e.g., Besley & Collinson, 1991; Hajek & *alii*, 2010). However, few studies on alluvial fill evolution and channel planform changes in areas tectonically active during the Holocene are available to test these observations (Holbrook & Schumm, 1999). At best, the most recent case studies are focused on the tectonic factors controlling drainage networks and channel patterns (e.g. Sagri & *alii*, 2008). More typically, in areas subjected to active normal faulting or compressional folding (e.g. the northeastern Mediterranean area and the Betics), active structures produce local or regional anticlines or uplifted blocks, separated by depressions – cut across by rivers – that alternate between incision of uplifted structures and aggradation in the subsiding areas (Macklin & *alii*, 1995). Previous studies have highlighted the influence of recent compressive tectonics on the alluvial fills in western Mediterranean valleys, associated with large NE-SW left-lateral,

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strike-slip fault systems (Serpelloni & *alii*, 2007; Nocquet, 2012; Papadopoulos & *alii*, 2014). Such tectonic movements continue in the Holocene, through associated dextral strike-slip faults, since normal faults have reactivated as reverse faults. This tectonic pattern, controlling Holocene alluvial sedimentation, is very common in the southeastern Iberian Peninsula, but it is not sufficiently well understood.

The main objective of this paper is to analyze how a Holocene compressional tectonic regime has conditioned the evolution of recent alluvial filling in a tectonically-active valley; specifically, the Vega Media del Segura (VMSR; the middle reach of the Segura River valley) in southeastern Spain. In particular, the Upper Silt Unit (USL), the main representation of the Holocene alluvial fill in this area, is analyzed in relation to the peculiar tectonic activity affecting the Lower Segura Valley. The difference in activity between the edge faults and the set of reverse and strike-slip faults in the VMSR during this period has increased the asymmetry of the valley, already defined in the Middle Pleistocene, accentuating the shift of the river towards the southern margin and increasing the angularity of the meanders within the area of higher subsidence of the floodplain (Conesa-García & *alii*, 2016).

In this work we present a review of the structure, stratigraphic features, neotectonic activity, and morphological and sedimentary implications of the VMSR. For this, previous data based on traditional methods (interpretation of hydrogeological and geotechnical borehole logs, vertical electrical soundings -VES-, trenching, and hydrochemical analyses) and current information derived from mechanical surveys and ^{14}C dating (DYCAM-SEG project) are spatially integrated using a GIS. First, we show the relationships between changes in the river planform and the strike direction of active faults on both edges of the valley. Then, the upper section of silts (USL), which represents the Holocene alluvial fill well in this area, is described from isodepths and the total salinity of the groundwater. By combining the results with GIS, a lithological and tectonic map related to the USL base at 16 m depth is produced. We interpret these findings as being clearly consistent with the results provided by conventional procedures. A special section is dedicated to the absolute dating of Holocene deposits and faults. Finally, new neotectonic and paleogeographic evidence found in the VMSR is discussed in comparison with other Holocene tectonic patterns in Mediterranean alluvial valleys.

GEOLOGICAL SETTING

The VMSR constitutes a rift valley, which extends to the northeast, crossing the Valle del Guadalentín and forming one of the most important interior postorogenic depressions of the Betic Cordillera. The VMSR (200 km^2 approx.) is located at the eastern end of the Betic Cordillera, in the Lower Segura valley (southeastern Spain). This area lies over the contact between the Internal and External Zones (Montenat, 1977; fig. 1) and, as a result, shares most of the geological and structural features of both domains. Consequently, the materials on the southern border of the VMSR (Internal Zone) consist of Permian-Triassic rocks, Neogene sediments, and Pleistocene colluvial deposits, which are arranged in sliding nappes with predominant northern vergence. In contrast, the northern border (External Zone) is mainly made up of sedimentary rocks (marls, sandstones, and conglomerates) belonging to the Late Miocene-Pliocene, and is essentially characterized by the existence of normal faults and strike-slip faults. These structures were active from the pre-Tortonian up to the Quaternary in the Internal Zone, while the External Zone was dominated by a Neogene compressive deformation (ENADIMSA, 1974).

In this context, the VMSR makes up part of an extensive valley running in an ENE-WSW direction and controlled by active faults – particularly the Alhama de Murcia Fault (AMF) to the north (Martínez-Díaz & *alii*, 2012) and the Carrascoy Fault Zone (CFZ) to the south (Martín-Banda & *alii*, 2014) – which are responsible for the current seismic activity (Martínez-Díaz & *alii,* 2012). The mountain fronts that border the valley were elevated by the reactivation of both faults in the Late Miocene, up to the present day (Alfaro, 1995; Rodríguez-Estrella & *alii*, 1999). Since the Pliocene, several generations of alluvial fans have developed at the base of these fronts (Goy & *alii,* 1989). The most recent fans (Late Pleistocene–Holocene in age) show features typical of active tectonics (e.g. progressive discordances, counterslope tilting, overlapping alluvial fans, and linear meander-belt zones) (Rodríguez-Estrella, 1979, 1983; Silva & *alii*, 1992; Martínez-Banda & *alii*, 2014).

As a result of sea-level fluctuations as well as neotectonic activity (Soria & *alii*, 2001), increasing the erosive processes due to Betic foothills uplift, the Quaternary alluvial filling has reached a maximum thickness of 100 m at the valley bottom (fig. 7), being comprised of sediments mainly provided by the Segura and Guadalentín Rivers during flood events.

Geomorphological and sedimentological studies on the Pleistocene neotectonics in the study area are abundant. Montenat & *alii* (1987) placed the Elche-Lower Segura Basin Depression at the northern end of the "left strike-slip corridor", limited by pre-coastal mountain ranges within the Betic Cordillera. Goy & *alii* (1990) related the current configuration of the coastal sector of the Segura River valley to neotectonic activity of the final part of that "corridor". According to these authors, the final stretch of the "strike-slip corridor" underwent a major reactivation during the Early-Middle Pleistocene. It was produced as a result of the combined action of the Palomares-Alhama and Vélez Rubio faults and the interplay of the N120°-130°E faults, causing paleogeographic changes throughout the area, such as: i) higher elevation of the surrounding Betic range; ii) strong subsidence of the interior sectors, in which sediment arising from the erosion of nearby mountain ranges accumulated; iii) delta formation with a dominance of conglomeratic facies (Goy & *alii*, 1989); iv) a general retreat of the coastline to occupy a position similar to the present one; v) formation of alluvial fans with distal fronts overlapping the "Moncayo-EI Molar Unit of Transition" (Somoza, 1989; Goy & *alii*, 1989), a unit consisting of mixed facies of barrier-lagoon islands; and vi) in the area of Rojales and La Zeneta, development of prograding beaches to the north

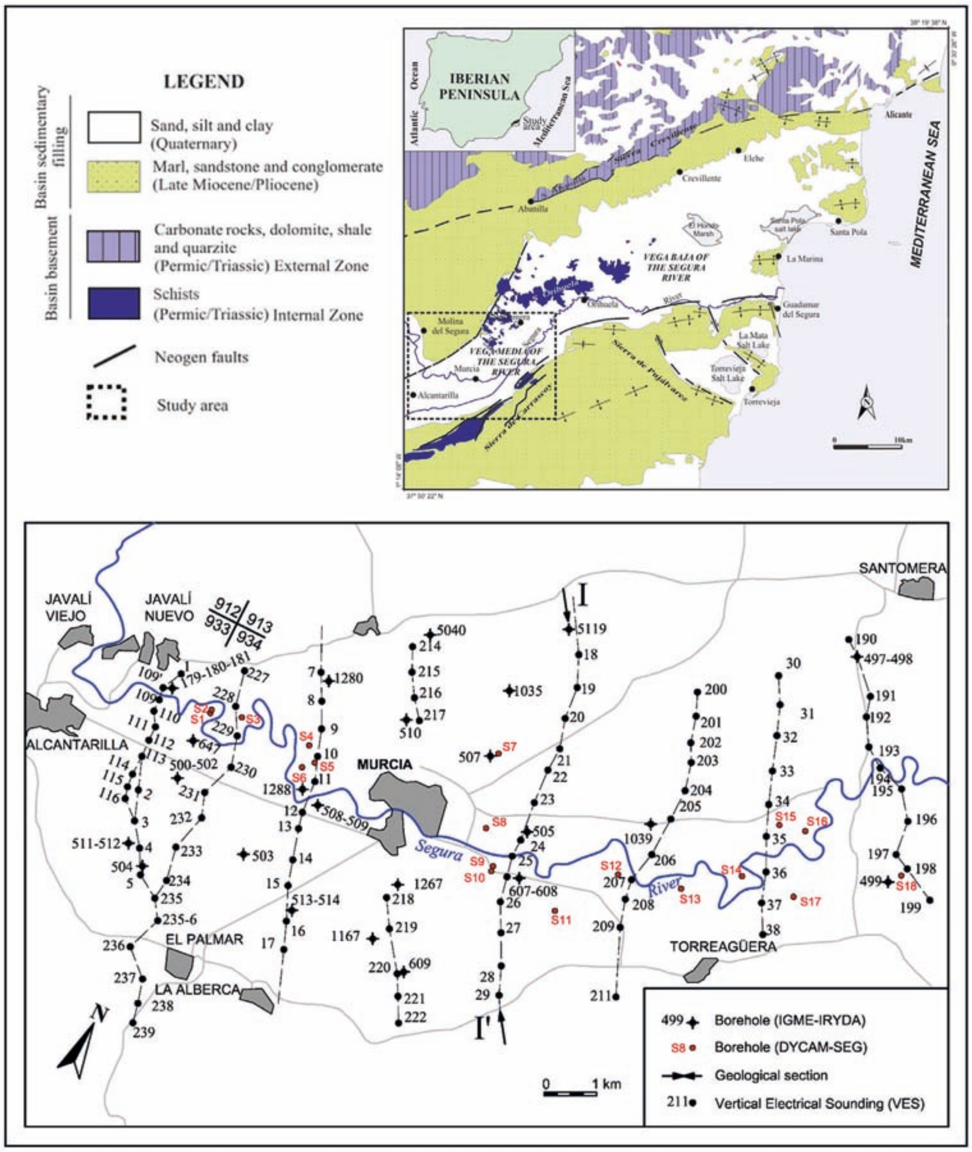

FIG. 1 - Geological setting of the Vega Baja and Media of the Segura River Basin (based on Montenat, 1977) (upper part); location of the mechanical surveys and geophysical VES carried out by the IGME-IRYDA in 1975 (Rodríguez-Estrella & *alii*, 1999), and of the boreholes installed in the project DYCAM-SEG (2010-2015) (lower part).

and east, traversed by channel segments having a predominantly west-east direction.

Moreover, the Holocene tectonic history described above is consistent with neotectonic studies conducted on the Lower Segura Valley (Echalier & *alii*, 1978; Rodríguez-Estrella, 1979, 1983; Rodríguez-Estrella & *alii*, 1999; Martínez-Díaz & *alii*, 2000; Teixido & *alii*, 2000). From a series of electrical soundings performed in the Vega Baja and Campo de Elche, Echalier & *alii* (1978) showed the existence of faults in the recent Quaternary, affecting an alluvial fill having a maximum age of 4700 years. The influence of recent normal faults on the current channel geometry and form of the Lower Segura was shown by geochemical methods (Rodríguez-Estrella, 1979), stressing their continuity to the south of the area studied by Echalier & *alii* (1978). Several lateral displacements of the river have been attributed to the movement of N120º-140ºE-oriented dextral strike-slip faults (Rodríguez-Estrella, 1983); successively, the existence of recent neotectonics in the Plio-Quaternary depression of the Segura (Murcia-Orihuela) was demonstrated, associated with the reactivation of hidden faults oriented N140°E and N60°E (Rodríguez-Estrella & *alii*, 1999). The analysis of the recent deformation of the basement of the Lower Segura basin evidenced differential subsidence (Martín-Rojas & *alii*, 2007; Tomás & *alii*, 2014).

MATERIAL AND METHODS

Previous data

The stratigraphic analyses in this study were based on a combination of data from several sources and methods, collected during field trips and geological surveys at the edges of the depression. Borehole stratigraphic logs and data are often used to detect subsidence processes and faults in plains and urban areas (Cinti & *alii*, 2008; Dang & *alii*, 2014). To study the interior of the VMSR, the results of different types of survey have been analyzed: i) 70 vertical electrical soundings (VES) (up to 500 m deep) over the lengths of nine profiles, performed by the IGME (Geological Survey of Spain) and the IRYDA (National Institute for the Reform of Agricultural Development) in 1975 during a geophysical expedition (fig. 1); ii) hydrogeological boreholes (up to 250 m deep) installed by the IGME/IRYDA and individuals in recent decades; and iii) 40 geotechnical boreholes (up to 35 m deep) installed by the IGME in 1984 (fig. 1).

Furthermore, borehole logs compiled by the Hydrographic Confederation of the Segura (CHS, Ministry of Environment), the Municipal Water and Sanitation Company of Murcia (EMUASA), and various specialized geotechnical companies were also consulted. The work of the companies mentioned above often included test drilling *in situ*, specifically dynamic standard penetration and the cone penetrometer test. Geotechnical reports and studies were provided by the Official College of Architects of Murcia, the Directorate General of Heritage (Autonomous Community of the Region of Murcia), and different testing laboratories. The data regarding 70 hydrochemical analyses and 70 piezometric measurements related to shallow aquifer water, performed by the IGME-IRYDA in 1975, were accessed in order to detect active faults. Specifically, we focused on significant changes in the data values among neighboring boreholes.

Current data

The information collected was georeferenced and included in our own database using ArcGIS v.10.1, a tool that allowed us to analyze the spatial locations of the lithostratigraphic columns in the VMSR. This part of the work was useful to locate the sites of new surveys, necessary to supplement the previously acquired data. In this way, 18 mechanical rotation probings with core recovery (16 with an average depth of 20 m and 2 of 50 m) were performed in our research project DYCAM-SEG (2010-2015) (fig. 1). In addition, fieldwork was performed to determine the sedimentary sequences, using holes and trenches excavated in previous civil works and still visible.

Sediment samples were collected at different depths in 15 of the 18 boreholes, to obtain radiocarbon data. A total of 25 ^{14}C datings were made for total organic carbon (TOC) in the Poznan Radiocarbon Laboratory. The content of ^{14}C in each sample of carbon was measured using the "Compact Carbon AMS" spectrometer described by Goslar & *alii* (2004). The measurements were performed by comparing the intensities of the ionic beams of ^{14}C, ^{13}C, and ^{12}C measured for each sample and for standard samples (modern standard: "Oxalic Acid II" and standard of ^{14}C-free carbon: "background"). The conventional ^{14}C age was calculated using a correction for isotopic fractionation (according to Stuiver & Polach, 1977).

Finally, we calibrated the ^{14}C age with OxCal ver. 4.2. 2014, the basis of which is described by Bronk Ramsey (2001), while more recent versions can be consulted in Bronk Ramsey (2009) and Bronk Ramsey & Lee (2013). This calibration was performed against the newest version of the ^{14}C calibration curve, INTCAL13 (Reimer & *alii*, 2013). For discussion has been taken into consideration, the median probability within the calibration ranges was 2σ (95.4% confidence interval).

Methodology

To analyze the Holocene compressional tectonic regime in the VMSR, several methods have been used. The most important ones applied in the detection of the neotectonic events are described below.

– Isobath of the USL base. The map of the isobaths of the silts was elaborated using geophysical and soundings data (IGME-IRYDA, 1975). These data were integrated into the GIS to produce an isobath model of the USL. Using a 'topo to raster' tool (ArcMap v.10.1), a base topography was interpolated from the depth isolines of the USL. The algorithm generates a generalized morphology of the surface based on the curvature of the contours, and then implements the contours as a source of digital topographic model (DTM) information at this depth level. The DTM elaborated was useful to determine the adjustment of the USL data and the location of the current urban pattern surface, through visual analysis using ArcScene v.10.1 (3D Analyst extension).

– Total salinity of the groundwater associated with the upper silts unit (hydrochemical analyses). Hydrochemistry contributes decisively to the resolution of tectonic and neotectonic problems when a large number of analyses of many samples are available, as in our case.

Salinity is directly proportional to conductivity, which is inversely proportional to resistivity. This latter value is used for the geophysical method of Vertical Electrical Probes (VEP); in this way, a physical method is obtained from a hydrochemical method. In our case, we are analyzing gravels that have higher resistivity and lower salinity than silts.

To produce an isosalinity location, a map representing the values of total salinity of the groundwater in relation to the silts units was constructed; from this the faults affecting the Holocene alluvial filling were deduced.

– Spatial depth distribution of lithological material. To analyze the spatial distribution of the lithological material at different depths, stratigraphic data from 384 boreholes (previous and current data) located throughout the VMSR were used. The lithological data were processed using the 'Kriging' tool in ArcMap v.10.1, an interpolation technique which uses a geostatistical point estimation method (Krige, 1951), based on the premise that the lithological spatial variation follows homogeneous patterns (Rosenbaum & *alii*, 1997). This solution does not provide the best results, but to a substantial degree allows the determination of the approximate location of the materials obtained at each meter of depth.

RESULTS

Stratigraphic features of the VMSR

From a stratigraphic point of view, there is good agreement between the data provided by geophysical methods and those obtained from lithological columns of nearby boreholes. This similarity allowed the correlation of the two different sets of data, after the establishment of the correspondences between the resistivities, lithologies, and ages. Moreover, stratigraphic and/or mechanical discontinuities were found at all the analyzed levels. According to the lithological characteristics of the different stratigraphic sections, we reconstructed a general stratigraphic sequence; from top to bottom, this includes:

– Anthropogenic level: recent formation, consisting of arable land and/or debris.

– Upper level (8-10 Ω/m): Holocene sandy silts and clayey silts of varying thickness, which rarely exceed 30 m (hereafter referred to as "Upper Silt Unit" - USL).

– A level of more or less cemented Late Pleistocene conglomerates, outcropping in foothill areas.

– Intermediate level (25-50 Ω/m): pebbles, gravels, and sands of the Middle-Late Pleistocene. They have a maximum thickness of 50 m, south of Los Garres, near the Sierra "Cresta del Gallo" (fig. 2).

– Lower level (12-16 Ω/m), attributable to the Early Pliocene-Pleistocene. In this low-resistivity geoelectric profile, the white Pliocene marls, claystone, red siltstones, and Plio-Quaternary crusts (the "*Sucina formation*" of Montenat, 1973) are combined to form gray clays with Quaternary gravels. The maximum thickness of this lower level (around 100 m), detected by geophysical methods and corroborated by boreholes data, is much greater than that of the levels described above (between 10 and 50 m). The lower level is thicker towards the southern part of the valley (fig. 2), due to higher activity along the southern VMSR fault compared to the northern fault. This is evidenced by the greater development of the alluvial fans in the south, as a consequence of compressive activity during the lower Pleistocene, as well as by greater uplift and greater active erosion. Another thing to consider is that all the foothills start from the same line, associated with the fault.

Under the lower unit of the Plio-Quaternary, continental reddish deposits (30-60 Ω/m), with lenticular intercalations of clays and gypsum, appear, with a thickness greater than 200 m; Montenat (1973) referred to them as the Messinian. At the very bottom, the Betic substrate (150-300 Ω/m) is made up of schists and/or Permo-Triassic dolomites. It was detected only by geophysical methods and confirmed by the data from some deep boreholes in areas near the mountainous borders of the depression (Rodríguez-Estrella & *alli*, 1999). Therefore, in these zones of transition from valley to hillside, stratigraphic and/or mechanical discontinuities have been found, showing the existence of neotectonic activity.

The stratigraphy of the USL, in accordance with the detailed descriptions given in the geotechnical surveys and IGME project (fig. 1), is as follows, from top to bottom:

– Filling of anthropogenic debris and arable land. It can reach a thickness of 4 m, as in the western area of the city of Murcia (fig. 1). Nevertheless, in one borehole (S5), fragments of ceramic pots and lime mortar were found at 11.5 m depth, below the level of the clays containing gastropods.

– Brown clay level (5-8 m thick).

– Gray and reddish clayey silts with remains of gastropods and bivalves and black nodules of organic matter. According to the dating of the sample Poz-73915, collected at 9.2 m depth in the S10 borehole (tab. 1), and considered representative of this layer, we can assign an age of 5,595 - 5,733 cal. yr BP to the clayey silts. The significant presence of organic remains and gastropods in this level suggests the existence of freshwater in the valley for a certain time, in ponds of varying extension, probably associated with warm and humid conditions.

– Sandy silts (brown and gray) with black nodules (organic matter) or ocher color (3-5 m thick).

– Level composed of fine sands and gray and brown clays (up to 80 cm thick), with flaser bedding.

– Reddish silt level (1-4 m thick).

Tectonic features of the VMSR

Also in this work, we have described a series of neotectonic processes, based on the sequence of the stratigraphic data. Several active fault sets with different strike directions have been located on the southern edge of the Segura depression (fig. 2):

– Direction of strike N-S to N20°E. This system includes normal faults, with left strike-slip kinematics, which affect the deposits of the alluvial fans flanking the southern edge of the VMSR.

– Direction of strike N35°-50°E. This system, with northern vergence, predominantly includes left lateral strike-slip faults with a reverse component, exposed to N-S stress. By the direct observation of several outcrops and by mapping the studied structures, it is apparent that these faults occur after those with direction N60°-70°E. The combination of both fault sets is the main tectonic feature along some portions of the southern edge of the Segura depression. The direction of the contact between the Plio-Quaternary deposits and the bedrock is predominantly N70°E, being oblique to the direction of the faults trending N35°-50°E. This could explain why the fault set with direction N35°-50°E reaches inside the Segura depression.

– Direction of strike N60°-70°E. This system, with the same vergence as the previous fault set, concerns inverse-left faults (Silva & *alli*, 1992; Silva & *alii,* 1993; Martín-Banda & *alii*, 2014) with dips ranging from 40 to 60° towards the southeast. They form a tectonic corridor that stretches along the Sierra de Carrascoy (CFZ) (fig. 2) with a length of 35 km and a visible width of 1 km.

– Direction of strike N90°-100°E. The faults of this system are less frequent than those of the previously described ones and do not appear to be related to the edges of the depression, although they may define segments of the previously described tectonic corridors, both on the northern edge and in the southern part of the depression, as in the case of the fault close to the town of Zeneta.

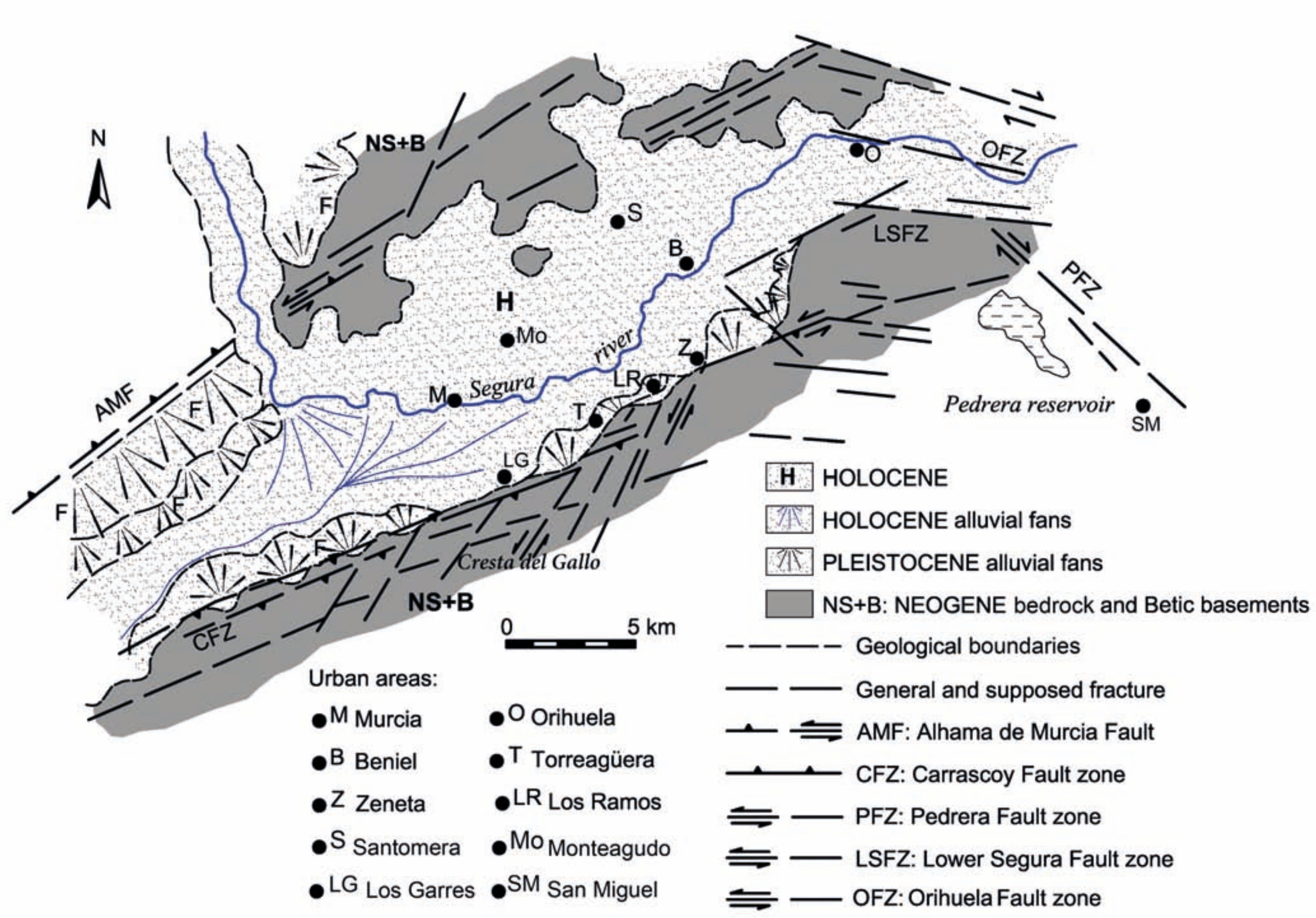

FIG. 2 - Faults at the edge of the Vega Media of the Segura River (based on Rodríguez-Estrella & *alii*, 1999).

– DIRECTION OF STRIKE N100°-110°E. Right lateral strike-slip faults, with important displacements on the horizontal, are located in the east of the study area; of these, the Orihuela fault (OFZ) is the most important (fig. 2). These faults affect those of N60°-70°E, and their recent effects have caused the displacement of the river course by about 7 km.

– DIRECTION OF STRIKE N140°-150°E. This fault system is not frequent along the edges of the VMSR, but has a significant longitudinal extension. It is composed of several right lateral strike-slip faults, of which the Pedrera Fault (PFZ) stands out, with a length of 10 km.

Geological detail of the upper section of silts (USL)

ISODEPTHS OF THE GROUNDWATER ASSOCIATED WITH THE UPPER SECTION OF SILTS. The depth of the groundwater level in an alluvial aquifer is conditioned almost exclusively by topography, since it increases towards the adjacent reliefs and decreases towards the fluvial course. Accordingly, the map of the alluvial aquifers of the middle and lower reaches of the Segura River (Rodríguez-Estrella, 1983) (fig. 3) shows that water occurs in almost all the valley, at a depth of less than 2 m, while at the edges the depths are greater (2-5 m). However, the Segura River has generated natural levees that make the piezometric level in the areas near the river deeper than in areas distant from it. The higher area is associated with the river in the stretch from Murcia to Orihuela and appears again in Benejúzar, as a result of a dextral strike-slip fault (OFZ) which determines the course of the river and passes along the route Benejúzar-Orihuela (fig. 2). The fact that no levees appear indicates the recent emergence of this fault. This is demonstrated by the existence of the dextral fault plane (as shown in fig. 3 - Isodepths of the groundwater) located at a higher relative elevation (with respect to nearby areas further away from the river) and showing continuous movement that maintains the levees deposited on either side of the fault; consequently, here, the levees do not reach the same height as in other parts of the course of the river. Such tectonic behavior could explain why some of the meanders located here currently maintain a certain angularity, scarce extent of waves, and stretches that are relatively rectilinear, despite the mobility of the riverbed and the intense, historical geomorphological activity in the floodplain (frequent neck cutoff phenomena, chutes, breakage of natural levees, and crevasse splays) (Conesa-García & *alii*, 2016).

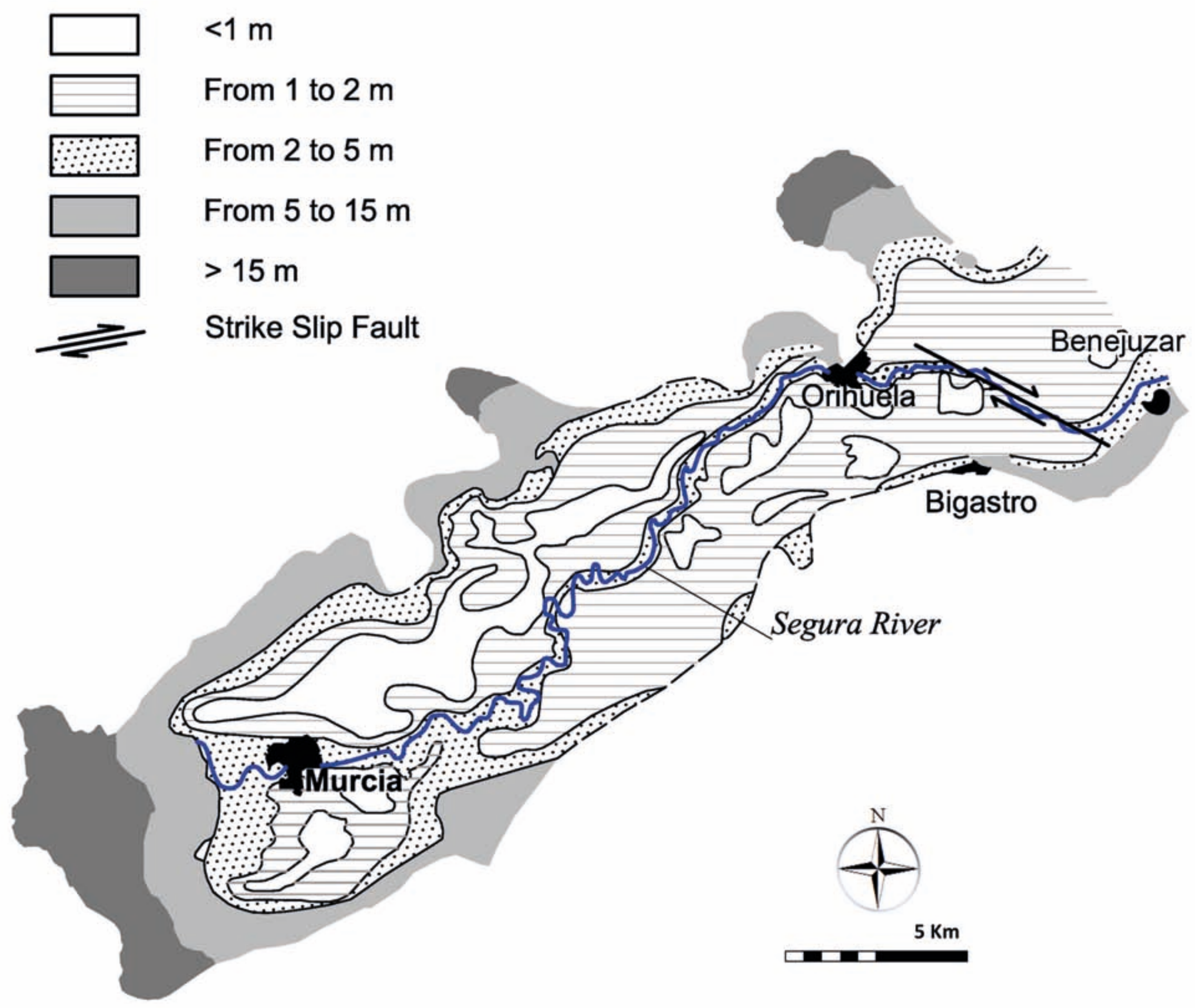

FIG. 3 - Isodepths map of groundwater associated with silts, according to data collected in 1972-73 (Rodríguez-Estrella, 1983).

TOTAL SALINITY OF THE GROUNDWATER ASSOCIATED WITH THE UPPER SECTION OF SILTS. Among the observations arising from the cartography of the total salinity of the groundwater associated with silts (fig. 4), it is worth highlighting the following:

– The salinity values are lower in the city of Murcia and its surrounding areas than in the east of the study area (towards Orihuela). This is because there is a predominance of gravels in the western sector (and these are closer to the surface, since they are in a tectonically elevated zone), whereas to the east layers of clays alternate with gypsum, and the gravels are deeper (in S-18, for example, the gravels occur at a depth of 39 m).

– There is a predominance of faults of direction N50º-70ºE, the same as for the Segura River in this area, which is in line with the results obtained using stratigraphic correlation from borehole logs; it is probable that they are normal faults, but this cannot be confirmed by this method.

– The faults described above are displaced by dextral strike-slip faults having a N125º-140ºE direction, some with a throw exceeding 5 km - such as those between Orihuela and Bigastro, whose trace is partially followed by the river in the southeast of the valley.

– Less frequent are left strike-slip faults having an almost N-S direction and being posterior to those of a N50º-70ºE direction.

– Many of these faults that determine the channel geometry and planform of the Lower Segura River valley coincide with those already mentioned, derived by other methods.

Using GIS techniques, a lithological map at 16 m depth was produced (fig. 5), the interpretation of which gives findings that are clearly consistent with the results described above: i) well defined zones of gravels and sands, delimited by reverse-reactivated normal faults and active strike-slip faults; ii) the tectonic horst zone in the northern half of the city of Murcia is still observed; iii) these faults coincide with those derived by other methods.

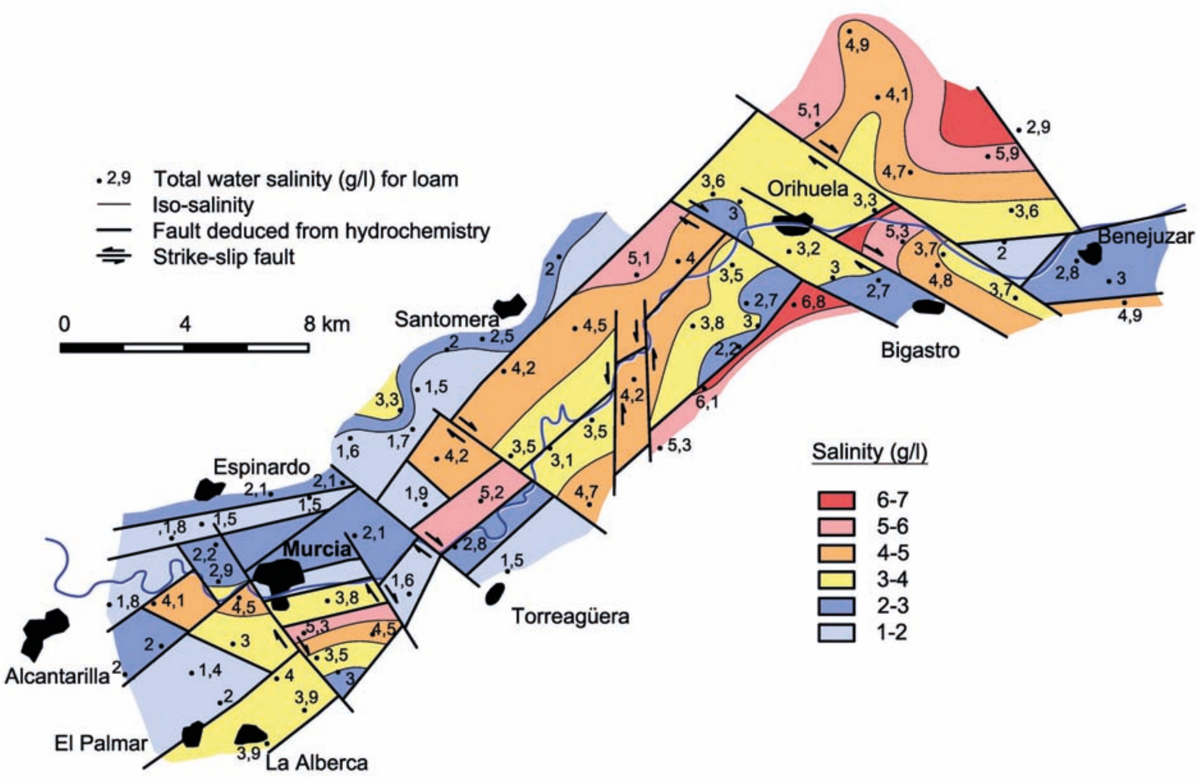

FIG. 4 - Faults deduced from the values of total salinity of the groundwater associated with silts.

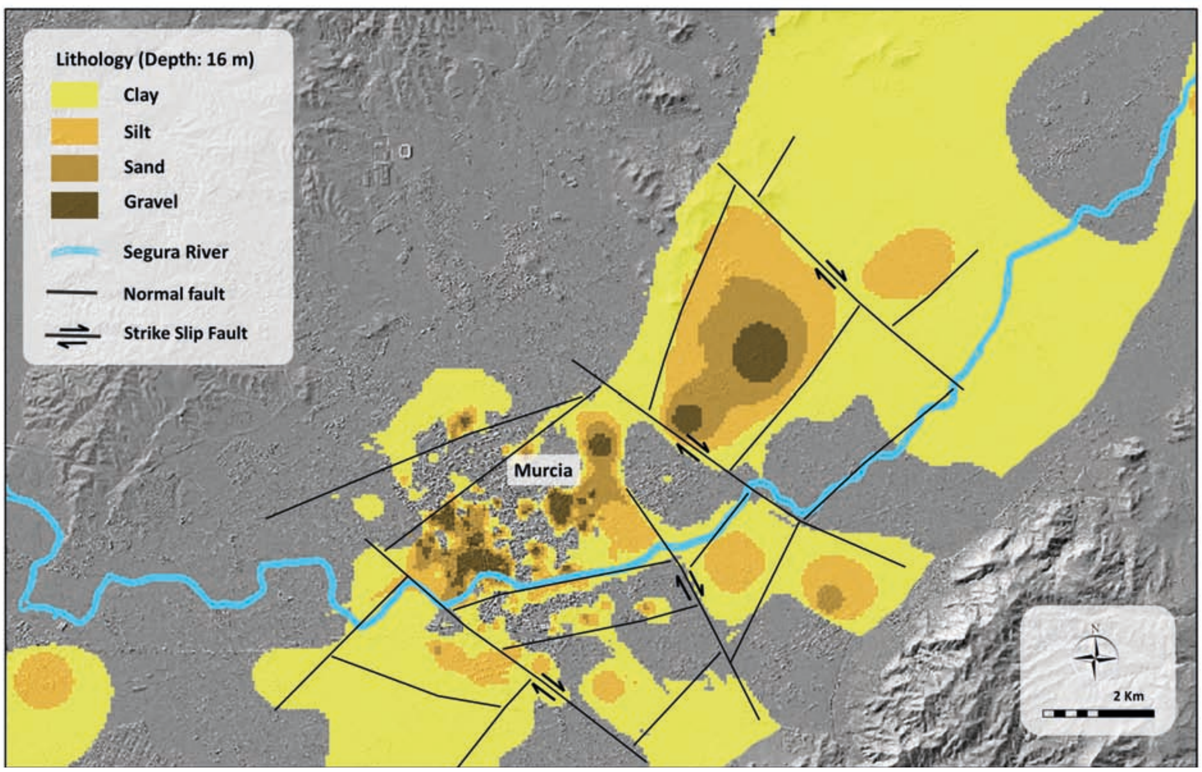

FIG. 5 - Spatial distribution of the materials found at 16 m depth.

Absolute age of Holocene deposits and faults

Six geological sections (fig. 6), with direction WNW-ESE, cutting across the city center of Murcia and surrounding areas (see location in fig. 6), were compiled according to the data collected from boreholes. According to our interpretation of the sections, the alluvial deposits are displaced by neotectonic faults (fig. 6) that coincide with those found by the methods described above. The analysis of the geological sections, integrated with ^{14}C radiocarbon datings, obtained for a total of 25 samples taken at different depths of the Holocene alluvial filling (tab. 1) allowed the following considerations.

In some areas we identified two sub-units of silts, usually separated by a layer of sand: a) the lower sub-unit of silt, yellowish-brown in color, has an absolute age between 3,334 (S4) and 13,939 (S10) cal yr BP, with a dominance of datings between 4,700 and 6,000 cal yr BP; b) the base of the upper sub-unit of silt, greyish-beige in color, has an age ranging between 435 (S1) and 735 (S8) cal yr BP.

The stratigraphic boundary between the upper silts is erosional. For example, in borehole S13 (see location in fig. 1), the gravels appear at a depth of 20 m and the age of the upper silt changes from 495 cal yr BP at the base to 2,754 (S13) cal yr BP towards the top of the gravels. As confirmed by radiometric datings, there are possible recent faults affecting the alluvial infill of the VMSR, which have conditioned the morphological evolution of the Lower Segura River and its floodplain during the Holocene. This was revealed previously by Rodríguez-Estrella (1986), using geophysical, geochemical, and boreholes data. Our results are coincident with these findings.

The investigations carried out in this project revealed a new fault lying between boreholes S9 and S10, which are separated by a distance of 97 m (fig. 6). At 9 m depth in S9, a sandy level with organic matter was dated between 597 and 633 cal yr BP, while in S10, at the same depth, there is a much older deposit composed of clayey silt and gastropod shells (5,603-5,663 cal yr BP) (tab. 1); in this latter borehole, at 19.50 m below ground level (only 20.30 m were drilled), the same formation of clayey silt continues, with an age between 13,728 and 13,939 cal yr BP (Late Pleistocene). This contrasts with the lower age of similar materials located at a depth of 18.1 m in S8, 1.2 km away (fig. 6 and tab. 1), giving a net slip rate close to 0.56 mm/yr.

The area in which boreholes S4, S5, and S6 are located (west of Murcia city; fig. 1) should be a more elevated block, since the lower sub-unit of silts, whose age ranges from 3,334 to 5,745 cal yr BP, is at a depth of 5 m. Similarly, in the area of the S11 and S12 boreholes (east of Murcia city; fig. 1) the lower silt sub-unit is at a depth of 4.7 m and is more than 4,800 cal yr BP old.

Most of the normal faults, trending N50°-70°E, have displaced the USL base of 2-9 m, resulting in net slip rates of between 0.12 and 0.57 mm/year. Figure 6, in section 6, shows a clear example, where a vertical throw of 8 m is identified between two very close boreholes (S7 and S8). In addition, age differences of up to 4,350 cal yr BP were found at 9 m depth in boreholes less than 100 m apart. Within the meander-belt zone of the VMSR the age of the silts at 14-15 m depth is estimated to be between 2,754 (S13) and 7,561 (S11) cal yr BP, giving slip rates for these faults of between 0.26 and 0.53 mm/yr since the middle Holocene.

DISCUSSION

Comparison with other Holocene tectonic patterns in Mediterranean alluvial plains

The tectonic pattern described for the VMSR shows some similarity with certain models of tecto-sedimentary evolution described for other fluvial valleys of the Mediter-

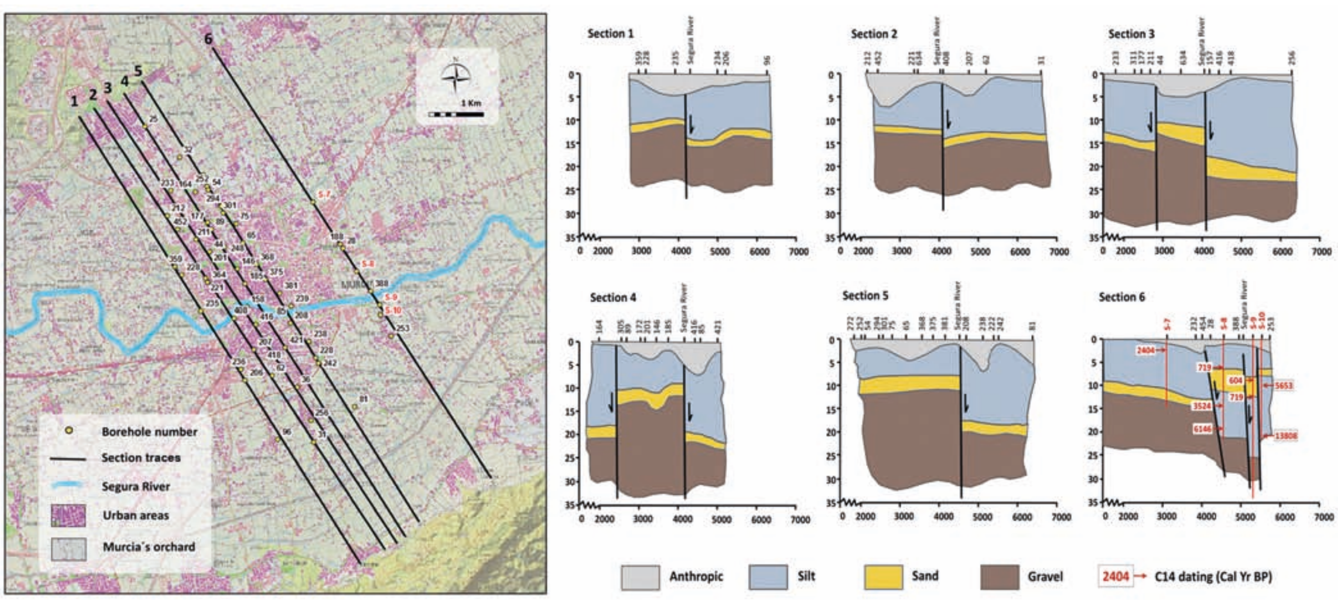

FIG. 6 - Locations of the geological sections and boreholes used to collect samples for dating. Geological sections 1, 2, 3, 4, 5, and 6.

ranean basin. Numerous case studies have shown the influence of recent compressive tectonics on the alluvial fills in western Mediterranean valleys, associated with the NW–SE convergence between the Nubian and Eurasian plates (De Mets & *alii*, 1990; McClusky & *alii*, 2003; Serpelloni & *alii*, 2007; Rodríguez-Estrella & *alii*, 2011; Nocquet, 2012; Papadopoulos & *alii*, 2014). As a result, Quaternary fault activity, dominated by a large NE-SW left-lateral, strike-slip fault system, has affected many of these alluvial valleys. Such tectonic movements continue in the Holocene, through associated fault systems of the dextral strike-slip fault type as well as normal faults reactivated as reverse faults (Rodríguez-Estrella & *alii*, 1999; Martínez-Díaz & Hernández-Enrile, 2004; Gràcia & *alii*, 2012; Pedrera & *alii*, 2012; Martínez-García & *alii*, 2011; Martínez-García & *alii*, 2013). Around these faults, earthquakes of moderate magnitude have been recorded (Gràcia & *alii*, 2006; Zitellini & *alii*, 2009).

This tectonic pattern, affecting Holocene alluvial deposits, is shared by the VMSR and other valleys located in the southeastern Iberian Peninsula. For example, Holocene deposits in the Campo de Dalias (Almería, Spain) area are strongly affected by three active faults: two NW–SE striking normal faults (the Balanegra and Punta Entinas faults) and the Loma del Viento fault, which has a certain degree of right kinematics (Gracia & *alii*, 2012). In the case of the VMSR, the faults of both edges of the valley, particularly the southern edge (Lower Segura Fault -LSF-), have become reverse kinematics, after operating as normal faults, with a strike and a style of deformation similar to those of the Los Tollos Fault (LTF), located southwest of the CFZ in the Eastern Betic Cordillera (fig. 2). The LTF was previously mapped as a normal fault dipping to the northwest (Silva, 1994; Leyva Cabello & *alii*, 2010) and was interpreted more recently (Insua-Arévalo & *alii,* 2015) as a left-lateral reverse fault, dipping to the southeast and affecting Holocene deposits. These faults, which form part of a set of NE-SW-trending left-lateral strike-slip faults, include the Alhama de Murcia, Albox, Palomares, and Carboneras faults, which belong to a very active tectonic zone, the Eastern Betic Shear Zone (EBSZ). Extensive geomorphic evidence of recent tectonic activity in this zone is provided by deflected thalwegs and abrupt lateral changes of sedimentary facies (Bell & *alii*, 1997; Reicherter & Reiss, 2001; Silva & *alii*, 2003; Masana & *alii*, 2005). Also, in the External Prebetic of Albacete, NW-SE (N150ºE) dextral strike-slip faults and E-W normal faults remained active during the Late Quaternary-Holocene, controlling the thickness of young alluvial units (Martín-Velázquez & *alii*, 1998). Further inland in the Iberian Peninsula, the Holocene deposits of some rivers - such as the Manzanares and Jarama - continue to show the effects of a compressive tectonic regime, this time related to families of normal faults in domino arrangements and reverse faults, around which appear rectilinear sand dykes, water leak structures, slumps, etc. (Giner, 1996; Silva & *alii*, 1997; Uribelarrea, 2008). In the SW of Spain, the Guadiamar River runs through an asymmetric valley, as is the case in the VMSR, but - unlike the VMSR - such asymmetry is caused by recent regional tectonic tilting towards the SSE, which has led to greater thickness of sediments in the western margin (Salvany, 2004).

A large number of modified fluvial features have been found also in alluvial valleys affected by recent compressive tectonics in the eastern Mediterranean region. Specifically, the most recent compressive forces produced by the collision of the Arabian microplate and the Eurasian plate, during the Late Pleistocene and Holocene, significantly revived major strike-slip faults, which affect the alluvial fillings in various valleys like the Pasinler Valley, in eastern Turkey, or the Manisa Valley, in western Anatolia. In the former case, the difference in river channel elevations, which decrease from south to north in the area west of Pasinler, suggests localized subsidence at the base of the northern mountain front (Collins & *alii*, 2005). As in the VMSR, this subsidence has provided the space to accommodate a considerable body of alluvial sediments, leading to an asymmetrical fill within the valley. In the southeastern part of the MFZ (Manisa Fault Zone), the presence of Holocene normal faulting, which cuts through the young deposits, affects the Nif River pattern (Allen, 1974). These Holocene deformations have been linked to fault reactivation from an early phase of left strike-slip, later as right strike-slip, and subsequent normal-slip movement (Bozkurt & Sözbilir, 2006; Özkaymak & Sözbilir, 2008; Özkaymak & *alii*, 2013).

Neotectonics and paleogeographic evidence in the VMSR

The VMSR is located on a graben, with a NE-SW direction (fig. 7), belonging to the postorogenic intramontane depressions of the Betic Cordillera and, continuing eastward, of the Guadalentín Valley. At the edges of the Segura depression, several fault systems denote clear neotectonic activity affecting sediments dating from the Late Miocene to the Quaternary (Rodríguez-Estrella & *alii*, 1999). Specifically, ENE-WSW trending reverse blind faults and secondary NW-SE dextral faults, continued by the Lower Segura Fault Zone (LSFZ) (Alfaro & *alii*, 2012), have recently controlled the fluvial sedimentary architecture and are responsible for the current topography of the valley, with uplifted areas at the borders and subsiding areas inside. These fault systems differ from one edge of the tectonic depression to the other. On the northern edge, from Alcantarilla to Orihuela, the continuity towards the northeast of the AMF is hidden by recent sediments and does not produce significant geomorphological features (fig. 2). Indeed, between Monteagudo, Santomera, and the outskirts of Orihuela there is no evidence of the activity of the AMF, and the area of the Late Pleistocene fans merges with the alluvial deposits of the Depression of the Lower Segura. Simultaneously, geological deposits composed of Paleozoic schists and Triassic dolomites are found on the Betic basement, and have a slope of 10° in a NW-SE direction towards the valley bottom. Despite these uncertainties, the activity of the AMF is clear since, in the Alcantarilla-Monteagudo area, it deforms the Plio-Quaternary deposits - leaving them as progressive unconformities, with dips towards the SE, ranging from 15° to 40º.

To the north of the Vega Media and the city of Murcia, the Segura River changes direction to NW-SE, due to the adaptation of a larger scale fault, denominated the Alto Seg-

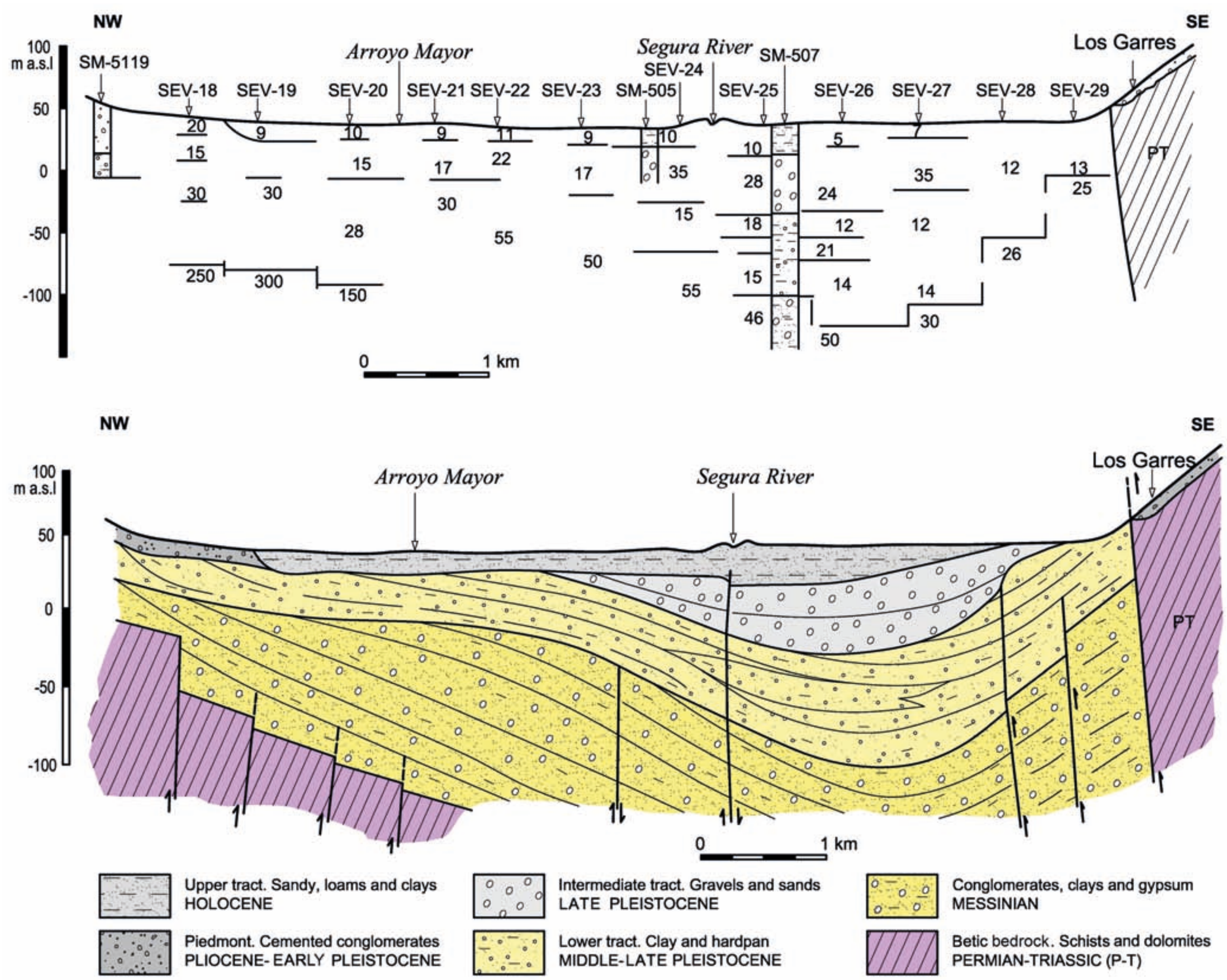

FIG. 7 - Geological and tectonic cross-section I-I´ (see location in Fig. 1) of the Vega Media of the Segura River (Rodríguez-Estrella & *alii*, 1999). Source: geophysical and mechanical boreholes data.

ura High (USF) fault (Rodríguez-Estrella, 1979), confirmed by later work (Sanz de Galdeano, 1983; Silva, 1994). However, on the southern edge of the Segura depression, several active fault sets, with strike directions varying within the range N0ºE to N150ºE, are present. The widespread recent deformation of the southern edge of the Segura depression is manifested through the structures affecting the Plio-Quaternary deposits, represented mainly by alluvial fans. Supported by the observation of some of these structures (e.g. those affecting the alluvial fans located between Torreagüera and Los Ramos), it can be deduced that there is continuous activity of the N60º-70ºE faults, evidenced by the presence of progressive, angular discordances (fig. 2) in the fan deposits (Rodríguez-Estrella & *alii*, 1999). Evidence of similar deformation was found by Martín-Banda & *alii* (2014) in the northeastern segment of the CFZ, and by Silva & *alii* (1992) in the northwestern sector of the Sierra de Carrascoy, within the tectonic depression of the Guadalentín River. Therefore, this southern edge is defined not by a single structure but by a fault system. In the eastern sector of the study area there is movement to the north of the Plio-Quaternary deposits and the underlying materials, as a consequence of a strike-slip fault. Figure 8 shows examples of this type of fault in the field, specifically between Torreagüera and Los Ramos.

At the northeastern end of the southern edge of the depression (to the south of Orihuela), this system is noteworthy, with a length and width measured in kilometers, giving rise to a NW-SE morphostructure - as seen in the Sierra de Pujálbarez and mountains located east of the Pedrera reservoir (Figs. 1, 3). Its northeastern tip is delimited by the PFZ, close to San Miguel de Salinas (fig. 2). This system even displaces the N140°-150°E structures, which correspond to a system of dextral strike-slip faults reported from 1973 (Montenat, 1973) onwards. On the southern edge of the depression, these kinematics have been observed in the Nº140ºE fault planes affecting Late Miocene marls, metrically and decametrically, in a longitudinal extension.

FIG. 8 - Progressive discordance in the western foothills of the Los Ramos area.

Inside the depression, the intensely modified floodplain does not show tectonic features on its surface. This necessitated the combination of direct techniques and methods (e.g. boreholes, DTM representing the topography of the USL base, and recognition and interpretive analysis of fluvial units from field work and aerial photographs) with indirect methodologies (e.g. geophysical and hydrogeological). The integrated analysis of tectonic data allowed the establishment of the following considerations:

– The VMSR has an asymmetric shape (being deeper to the south), resulting from the difference in behavior of the faults bounding the depression. Those on the southern border (in the Carrascoy-Cresta del Gallo tectonic corridor) exhibit a different slip rate. In particular, the maximum uplift rate of the Carrascoy range is estimated to have been 0.2 mm/yr since the Late Tortonian (Sanz de Galdeano & *alii*, 1998), with a net slip rate of 0.54 mm/yr for the CFZ, considering a rake of 20º (García-Mayordomo & Álvarez-Gómez, 2006). The Segura depression shows an evident asymmetry in terms of the spatial distribution of facies, the thickness of the deposits, and the size of the detritic sediments. This asymmetry between the northern and southern edges of the VMSR, derived from the differential movement of the different morphological units, has led to progressive unconformities among the Plio-Quaternary formations within the Segura depression.

– Examples of unevenness are present in the base rock (fig. 7); these are attributable to the existence of hidden buried faults (detected by geophysical methods and in deep boreholes installed by the IGME), which have conditioned the overlying deposits. Such faults have been repeatedly active over time, but differently because the throws between formations are different. In general, the deformations are smaller in the most recent materials, which shows that the tectonic intensity was more important in the Tertiary than in the Quaternary.

– The Carrascoy fault (CFZ) has been reactivated at different times. However, it did not always move in the same way; in the Upper Pleistocene it proceeded as a normal fault, providing an extensional character, whereas during the Holocene (up to the present day) it has changed to a compressive loading.

The progressive uplift of the part of the valley closest to the hills, due to the activity of reverse faults, explains

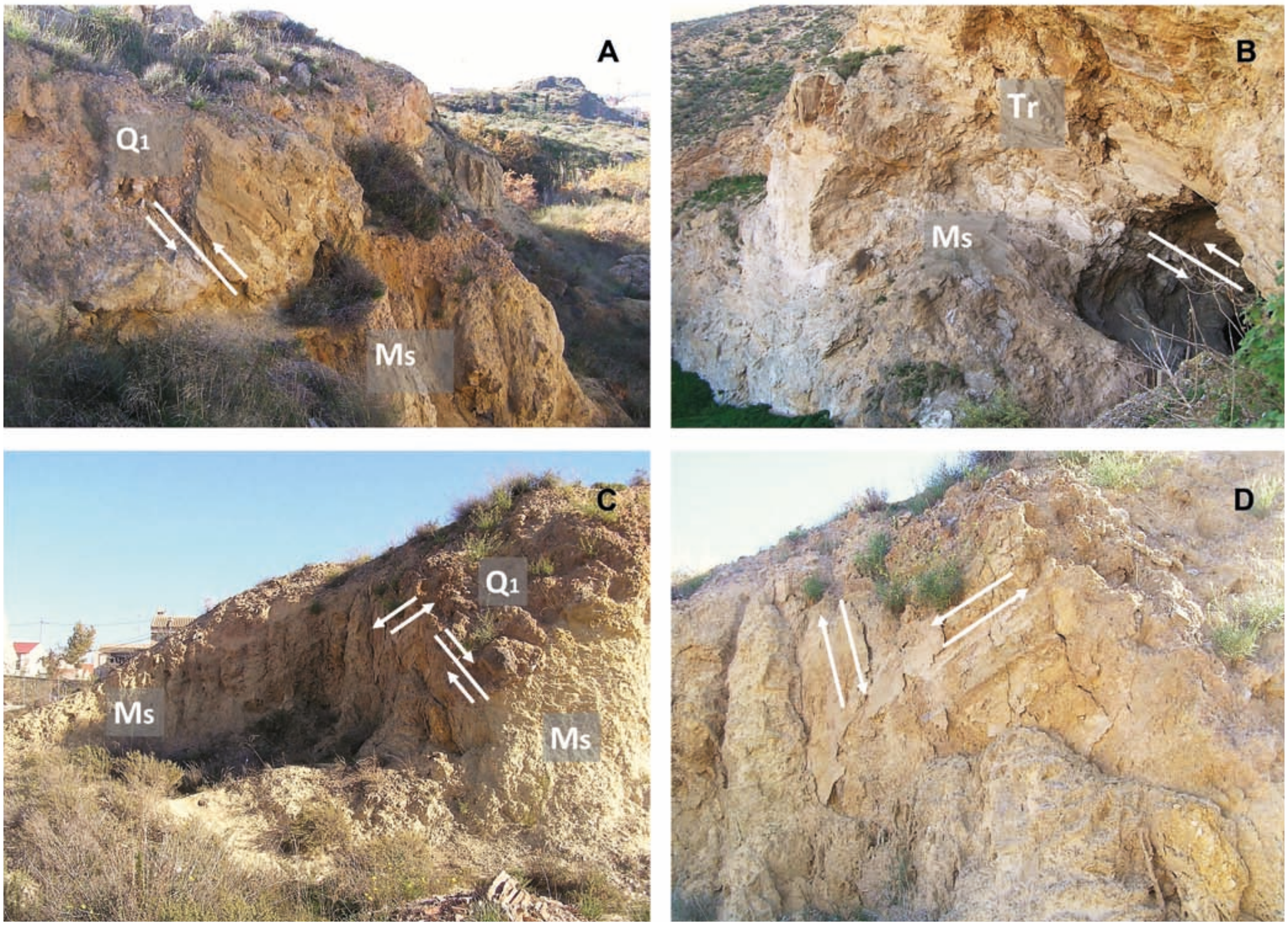

FIG. 9 - A) West of Los Ramos. Reverse-left fault at the margin of the basin (see striations); Q1: Inclined foothill conglomerates, of the Late Pleistocene; Ms: Gypsums with verticalized marls, of the Late Miocene. B) East of Los Ramos. Reverse-left fault at the margin of the basin (see sub-horizontal striations); Tr: Triassic dolomites; Ms: Gypsums of the Late Miocene, which are exposed in the cave. C) Los Ramos. Strike-slip fault, with horizontal striations, and normal fault, with vertical striations. D) Details of the horizontal and vertical striations of the previous photo.

the phenomenon that appears immediately north of Los Garres (fig. 2), where the foothill conglomerates have disappeared and only marls of the Pliocene and Quaternary are visible.

To complete the discussion of neotectonics, some aspects related to seismicity should be mentioned. The Carrascoy Fault has been the subject of regional studies (Silva, 1994; Sanz de Galdeano & *alii*, 1998; García-Mayordomo & Álvarez-Gómez, 2006; Martín-Banda & *alii*, 2014) due to its seismogenetic potential in an area of densely populated urban centers.

Beyond the southern range front, in the center of the valley, there is an instrumental seismic epicenter of magnitude 3 to 4 (fig. 9) (IGN, 2105), which coincides with the intersection of two faults, one of direction N140ºE and another of direction N50ºE. At a distance of 1300 m from this epicenter, to the east, there is a historical epicenter of macroseismic intensity V (Ibargüen & Rodríguez-Estrella, 1996), located along the path of a normal fault, with a direction almost W-E and about 4 km in length (fig. 9A). This suggests that this epicenter corresponds to the above mentioned NW-SE dextral strike-slip faults. Such a consideration is clearly supported by the Ramonete earthquake of 09/22/1996, of magnitude 4.5 and intensity VI (Ibargüen & Rodríguez-Estrella, 1998).

Finally, from the data obtained from lithological columns of mechanical boreholes, ^{14}C radiocarbon dating, and isobath maps of the USL base, in and around sharp meanders (shown in fig. 10), we can reconstruct the paleogeography and the neotectonic activity in the area around the city of Murcia as follows:

The greatest depths of the bottom of the USL are next to the current course of the Segura River. In the present setting, the banks are 1 to 3 m higher than the surrounding alluvial plain, due to the accumulation of loams after floods, specifically in the area of abandoned meanders. Similarly to this, in the center of the city of Murcia, along the NE-SW alignment of San Antolín-Romea Theater, there must have been an old course of the Segura River, on whose banks the city would have been founded (fig. 10B).

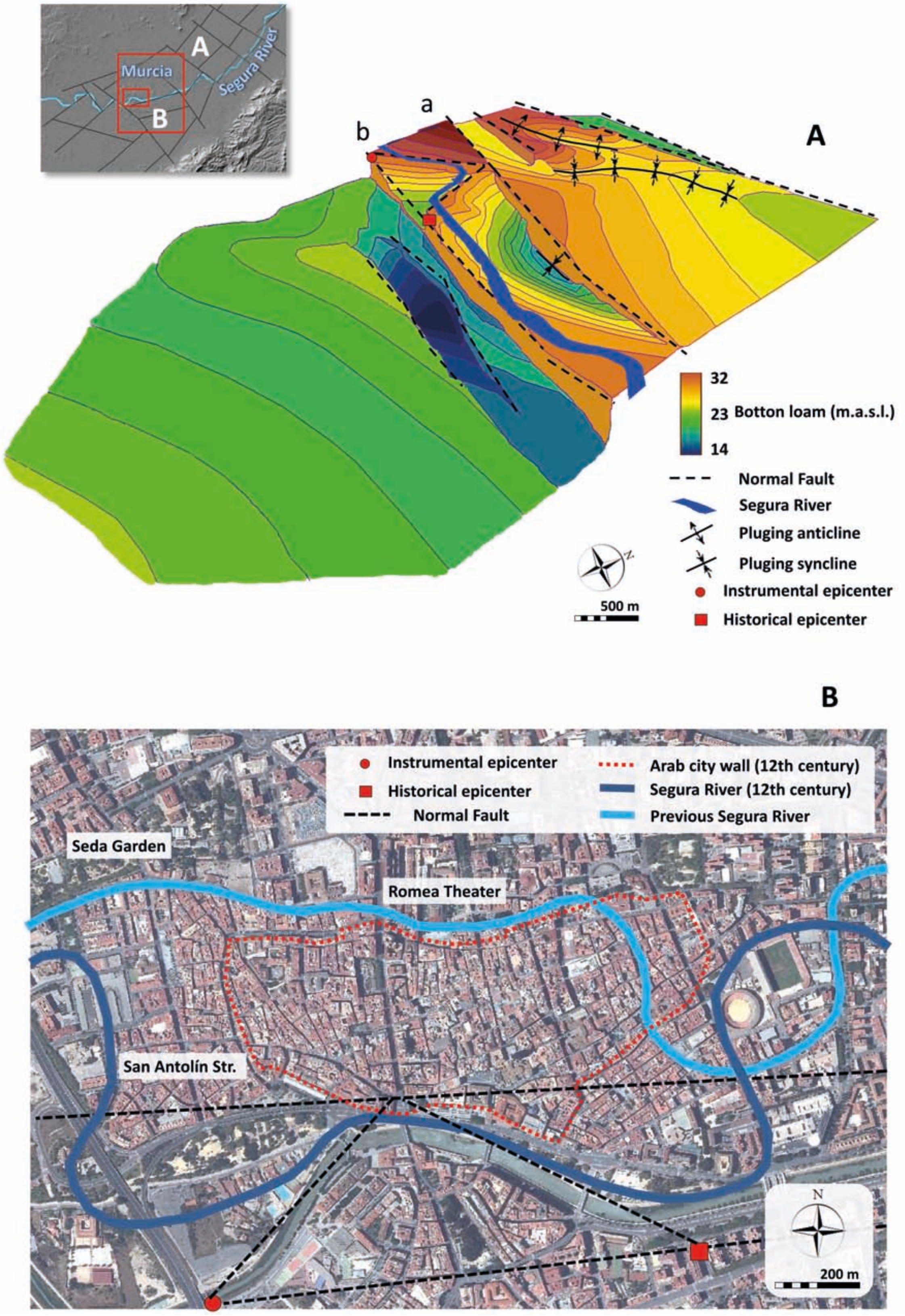

FIG. 10 - A) MDT produced from the height contours of the USL base, in the area of Murcia, indicating the main neotectonic features, a: Rincón de los Mancheños; b: Carrilero. B) Elevated sector in the center of the city of Murcia, indicating the perimeter of the Arab wall (Twelfth century; red dashed line). The old courses of the Segura River, which flanked this sector in past ages, are displayed.

This may be the reason why the greatest thicknesses of rubble were found along this alignment and why, in the Romea Theater Square, the remains of an Arab wall are buried at a depth of more than 4 m. Along the wall, a paleochannel filled by 14 m of silts and clays is located (Tomás & *alii*, 2014). The perimeter of the wall, built in the twelfth century (Frey-Sánchez, 2001), marked the boundary of the elevated area where the city settlement was at that time. It is striking to see how the Segura River bordered this zone, both in the period of Muslim rule and in previous ages, being conditioned by the two normal faults that bounded it (fig. 10A).

In Rincón de los Mancheños (designated with the letter a), the river undergoes a strong change in the flow direction of the meander, rotating from a N50ºE direction to N140ºE (fig. 10A). These two alignments have been conditioned by fault lines, which were deduced using hydrochemical methods (Rodríguez-Estrella, 1986); the second could be considered to be of the dextral fault type, since the course of the river, following a N50ºE direction upstream of the strike-slip fault, has been moved 750 m southwards, subsequently retaking a direction similar to that before the supposed directional fault. This phenomenon is explained by the geometry of ancient abandoned meanders further to the north (García Lorenzo & *alii*, 2017) that indicate the existence, at an earlier stage, of a less sinuous channel planform in accordance with the W-E fault direction (fig. 10B).

In the area located east of Carrilero (fig. 10A, designated with the letter b), the river seems to adapt to another fault, of direction N70ºE (because it has a rectilinear course), and, judging by the throw represented on the 3D map of fig. 10A, it is a normal fault with a south downthrown block. The boreholes installed in the present study show a displacement in a direction perpendicular to the river, which affects a silt thickness of 8 m over a distance of less than 200 m, in a direction perpendicular to the river. This fault was located by geophysical and hydrochemical methods, being evidenced by equivalent values of the resistivity and conductivity of the groundwater, in addition to the rectilinear geomorphology of the channel. Both to the north and south of this latter fault, there are other normal faults with the same strike (N70ºE) but a different direction of the dip; two of these generate a small tectonic depression (fig. 10A) highlighted in the area around borehole S-9, where the contact between silts and gravels is located at a depth of 28 m (fig. 6). Based on the throws in thickness of the silts, other possible extensional faults with a strike of N50ºE have been deduced north of Murcia city center, but in this case with a northern downthrown block (fig. 10A). The city of Murcia would originally have been settled north of the Segura River in a tectonically (and topographically) horst zone. This makes sense since its first settlers would have needed protection from the frequent floods of the Segura River and so would have settled in a relatively higher area.

The DTM generated by a GIS, from the USL base, has proved to be very similar to the isobaths of this surface (fig. 10A), and may be considered more reliable to identify possible faults because it does not take into account the topographic effect. In this isobaths surface appear all the fault lines that had already been deduced, some of them being extended laterally, while new N70ºE normal faults have been added. The isobaths surface also shows that the northern part of the city of Murcia is located in an elevated area, conditioned by a tectonic horst structure.

The isometric perspective (fig. 10A) shows the notable representation of the edges in relation to the central flat areas. The well-defined NE-SW lineation of the southern edge is confirmed, and contrasts with the irregular geometry of the northern border. Within the depression the major tectonic alignments of direction N140º-150ºE and N60º-70ºE can be seen. Rodríguez-Estrella & *alii* (1999) considered that these alignments correspond to minor unevenness in the ground caused by the coupling of Holocene material to a geometry of active faults, which would form a paleorelief before sedimentation. Many of these alignments match faults deduced by other methods.

The above-mentioned NW-SE dextral strike-slip fault systems are conditioned by NE-SW normal faults of greater length originating in a previous age of distension; these affect the entire valley bottom and control the meander-belt width, including the width of ancient channel-belts and the overall meander-belt amplitude. During tectonically stable phases and frequent large floods, dominated by meanders with high migration rates, the changes in the ground due to local faults are quickly destroyed. Neck cutoffs, chutes, and crevasse splays are very frequent in these stages, resulting in a floodplain of complex sedimentary architecture. The most common channel filling series show an upper stretch of well-developed vertical silt-clay accretion, on top of another stretch that is less thick with respect to silts, sands, or gravels and corresponds to the abandonment phase. In addition, the former abandoned meanders show less sharp curves and loops with an enhanced bend radius, as a result of greater bending freedom (García Lorenzo & *alii*, 2015). However, the form of these abandoned meander loops within an asymmetric meander belt suggests that they were produced by gradual southeast migration of the active channels, probably associated with tectonic tilting caused by valley southern edge faults and higher subsidence rates. In fact, this meander belt migrated several kilometers southwards to the current position. A study by Conesa-García & *alii* (2016), using A-DInSAR for the periods 1995-2005 and 2004-2008 in the VMSR, revealed that subsidence was more intense in the active floodplain of the Segura River - especially to the south of Murcia city, where values of cumulative subsidence around 2 mm yr^{-1} and 5 mm yr^{-1}, respectively, were recorded. In particular, in this current meander belt, certain straight channel reaches and sharps bends - a result of syngeneic faults with effects which are still being felt today - can be identified.

CONCLUSIONS

The Vega Media of the Segura River is a tectonic depression, elongated in a NE-SW direction, which belongs to the postorogenic interior depressions of the Betic Cordillera and is a continuation, eastward, of that of the Guadalentín Valley. The initial origin of this basin was associated with

TABLE 1 - ^{14}C datings of different materials sampled in the boreholes drilled.

Borehole	Material dated	Sample depth (m)	Laboratory	codeBP date	Cal yr BP date [a]		
					Conf. interval σ,ρ = 0.954	Median	2σ most probable range
S1	SOM	8.75	Poz-73880	375±30	435 - 497	442	424 - 504
S1	SGS	9.50	Poz-74007	4285±35	4835 - 4864	4852	4822 - 4893
S2	SOM	6.50	Poz-73881	535±30	521 - 552	543	598 - 632
S3	SOM	6.70	Poz-73910	415±30	468 - 510	487	432 - 521
S4	SOM	5.60	Poz-73911	3130±35	3334 - 3392	3353	3316 - 3411
S5	STC	4.50	Poz-73912	4680±40	5345 - 5416	5400	5316 - 5475
S6	CSPR	4.40	Poz-74012	4980±40	5652 - 5745	5705	5606 - 5758
S6	SDPR	7.60	Poz-73882	905±30	854 - 905	837	744 - 913
S7	SOM	1.70	Poz-74062	2380±30	2349 - 2432	2404	2342 - 2490
S8	SOM	5.8 to 6.2	Poz-73883	810±30	690 - 735	719	681 - 770
S8	CSOM	14.75	Poz-74064	3300±30	3481 - 3537	3524	3453 - 3592
S8	CSOM	18.10	Poz-73913	5360±40	6175 - 6214	6146	6096 - 6222
S9	SDOM	8.7 to 9	Poz-73884	580±30	597 - 633	604	582 - 649
S9	SDOM	11.95	Poz-73914	810±30	690 - 735	719	681 - 770
S10	CSGS	9.20	Poz-73915	4930±40	5603 - 5663	5653	5595 - 5733
S10	CSOM	19.3 to 19.5	Poz-73916	11,960±70	13,728 - 13,939	13,808	13,586 - 14,008
S11	SOM	4.70	Poz-73789	4265±35	4829 - 4857	4843	4810 - 4878
S11	SPR	6.80	Poz-73791	5170±40	5904 - 5947	5930	5885 - 5998
S11	SPR	8.70	Poz-73792	5970±40	6744 - 6807	6805	6711 - 6900
S11	SDOM	14.90	Poz-73776	6720±70	7561 - 7655	7586	7464 - 7683
S12	CSOM	7.65	Poz-74207	4835±35	5580 - 5606	5585	5576 - 5645
S13	SPR	8.75	Poz-73955	445±30	495 - 520	507	465 - 534
S13	SPR	14.80	Poz-73793	2685±35	2754 - 2796	2789	2750 - 2851
S14	SOM	15.70	Poz-73794	5190±50	5910 - 5991	5952	5884 - 6027
S16	SOM	14.00	Poz-73794	4150±35	4616 - 4727	4694	4572 - 4826

SOM = Silt with organic matter; CSOM = Clayey silt and organic matter; SPR = Silt and plant remains; SGS = Silt with gastropod shells; CSGS = Clayey silt and gastropod shells; SDOM = Sand with organic matter; SPR = Silt with plant remains; SDPR = Sand with plant remains; CSPR = Clayey silt with plant remains; STC = Silt and traces of coal. ^{14}C calibration program, OxCal 4.2.2014 (Reimer et al., 2013). Poznań Radiocarbon Laboratory.

an extensional regime; specifically, during the late Pleistocene. However, during the Holocene, it has suffered the effects of a compressive N-S-oriented stress, such that the faults of the two edges of the Segura depression, that were normal initially, have been reversed (the northern fault to a south vergence and the meridional fault to a north vergence). It is an asymmetrical basin with more subsidence in the south, due to differential tectonic activity.

The neotectonic effects in this floodplain have been proven through the study of the upper stratigraphic section of the Vega Media of the Segura River, specifically of the silts belonging to the Holocene. This was achieved by applying various interdisciplinary methods, both direct and indirect (field surveys along the edges, near-surface geophysics, mechanical boreholes, hydrochemical analysis, piezometric measurements, elaboration of surfaces by GIS, analysis of seismicity, and radiometric dating).

This neotectonic activity, which continues even today (as seismic activity with superficial hypocenters, some of them less than 2 km deep), has conditioned the geomorphology of the Segura River (angular meanders) and manifests itself through N125º-140ºE dextral strike-slip faults and N50º-70ºE normal faults, with vertical throws of 2 to 9 m and net slip rates estimated to be between 0.12 and 0.57 mm/yr. Many of these faults, which were also active during the Early Quaternary, are the result of the reactivation of faults hidden in the Betic substrate.

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