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A 3D geological model of Campo de Cartagena, SE Spain: Hydrogeological implications

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ABSTRACT

Knowledge and understanding of geologic basins for hydrogeologic purposes require an accurate 3D geological architecture representation. For model building, surface and subsurface data integration with the interpretation of geophysical survey and lithologic logs is needed. A methodology to reconstruct the geometric architecture of the sedimentary basin and relationships among stratigraphic formations, as well as to define hydrostratigraphic units, has been applied to the Campo de Cartagena Neogene formations. Data analysis included seismic reflection profiles and gravimetric data from oil exploration, electric resistivity surveys and 491 lithologic logs. The 3D model obtained from a close integration of stratigraphic and geophysical data was generated through a computer-based tool. It presents a common framework and a good starting point for hydrogeologic applications.

KEYWORDS **Stratigraphy. Hydrostratigraphy. 3D visualization. Campo de Cartagena.**

INTRODUCTION

In arid and semi-arid regions, water requirements for human and ecosystem needs are usually covered by existing aquifer resources. This fact implies an adequate management of the groundwater system, which first of all relies on a geologic formation and requires an accurate knowledge (Frind et al., 2002). A thorough understanding of the geological structure is essential for groundwater flow system characterisation and to draw up appropriate strategies to expand the scope of water protection, and to achieve a good ecological and chemical status (Directives 2000/60/EC and 2006/118/EC). Geological conceptual model assumptions greatly condition groundwater flow models and as a result may lead to incorrect outcomes (Robins et al., 2005). Also, the presence of heterogeneities in geological records, usually associated with facies changes, conditions groundwater hydrodynamics (Cabello et al., 2007). Therefore, an accurate knowledge of the geological formations, geometrical aspects, spatial relationships among them, and of the presence of tectonic features that deform them is essential (Gámez, 2007). Although the analysis and representation of the geological architecture for hydrogeologic numerical models are often made on a 2D basis, a 3D analysis is necessary to gain a better understanding of complex geological systems.

Subsurface geophysical survey techniques constitute a powerful tool to determine the geometry of lithological formations, reducing the geologic uncertainty among wells and improving the 3D subsurface knowledge (Martelet et al., 2004). A close integration of stratigraphic and geophysical data helps to determine the presence of confining layers as well as of subsurface aquifers and aquitards. However, this is not an easy task, due to the heterogeneity of the data, and applications still represent a significant challenge to be overcome (Ross et al., 2005).

The aim of this research is to establish the 3D subsurface geometry and hydraulic relationship of the different aquifer units that form the Campo de Cartagena, by combining information provided by stratigraphic logs, geophysical data and surface geology. The Campo de Cartagena plain (SE of Spain), located in a semi-arid region where the primary land use is intensive irrigated agriculture (Comunidad Autónoma de la Región de Murcia, 2008), is characterised by an intensive groundwater exploitation and man-made pollution. The established 3D geological model will provide a common initial framework for hydrogeologic applications.

CAMPO DE CARTAGENA

Study area

The Campo de Cartagena basin is a 1440km^2 plain with elevations ranging between sea level and 1065m.a.s.l. located in the South-eastern part of Mediterranean Spain (Fig. 1). To the South and East the area is limited by the Mediterranean Sea, and by low mountain ranges to the North and West. The region is characterised by a semi-arid Mediterranean climate, with an average temperature of 18ºC and 300mm of annual rainfall which is unevenly distributed into a few intense events that are highly variable in space and time. Rainfall is mainly produced during spring and autumn. Agriculture is the primary land use, with drip irrigation widely used in the region due to a scarcity of water resources and the need for water conservation. No permanent watercourse exists and the area is drained by several ephemeral streams. The population's water supply mainly relies on groundwater resources and the Tajo-Segura water transfer, which transfer water from the Tajo basin (central Spain) to the study region and was initiated in 1980. Water resources from private (owned by farmers) desalination plants of brackish groundwater have greatly increased since 2005.

Geological setting

The area constitutes a Neogene and Quaternary sedimentary basin located in the Eastern part of the Betic Cordillera. The detrital sedimentary rocks are unconformably laid over three metamorphic complexes that conform the Internal Zones of the cordillera. The metamorphic complexes are from bottom to top: Nevado-Filábride, Alpujárride and Maláguide (Fig. 1). The Nevado-Filábride Complex is mainly composed by marbles and mica-schists of Palaeozoic, Permian and Triassic age; it outcrops in the Cartagena-La Unión and Los Victorias mountain ranges to the South and West of the study area respectively (Ovejero et al., 1976; Manteca and Ovejero, 1992; Manteca et al., 2004). The Alpujárride Complex, outcropping in the Cartagena-La Unión and Carrascoy mountain ranges (North), is composed by schists, marbles, phyllites and quartzites of Permian and Triassic age (López-Garrido et al., 1997; Sanz de Galdeano et al., 1997; García-Tortosa et al., 2000a, b). Finally, the Maláguide Complex is formed by Permian and Triassic sandstones, quartzites, silts, conglomerates and limestones and outcrops in the northern part of the area (García-Tortosa et al., 2000c).

NE-SW to E-W normal faults rupture the bedrock, developing several horst and graben structures, as the Cabezo Gordo and Riquelme horsts or Torre Pacheco and San Javier grabens (Rodríguez Estrella, 1986; Rodríguez Estrella and Lillo, 1992). The block structure (horst and graben) is also observed in the Cartagena-La Unión mountain range (Robles-Arenas et al., 2006). During the Tortonian, dacites and basalts flows, result of the volcanic eruption favoured by fractures as a consequence of the tectonic activity, were deposited in the Southern part of the basin (Duggen et al., 2005).

The Neogene sedimentary rocks, with a thickness of 2000m, are lightly folded by the settlement. Overlying the Neogene sedimentary rocks, the Quaternary sediments cover great part of the surface of Campo de Cartagena, which are affected by the recent tectonic activity at local sites (Giménez, 1997). The sedimentary infill was divided into stratigraphic units by several authors, based on studies made by oil companies, and summarized in Instituto Geológico y Minero de España (1994). To establish hydrostratigraphic units in the present work, the new stratigraphic units redefined by Instituto Geológico y Minero de España (2005) according to litostratigraphic and paleontologic criteria have been used (Table 1). The observed stratigraphic variability and structural complexity of the area has important implications for the conceptual hydrogeological model establishment.

Hydrogeological framework

The sedimentary infill of the basin is mainly composed of detrital, low-permeability sediments (marls) with interlayered high-permeability material (limestones, sands and conglomerates) deposited during the Tortonian through to

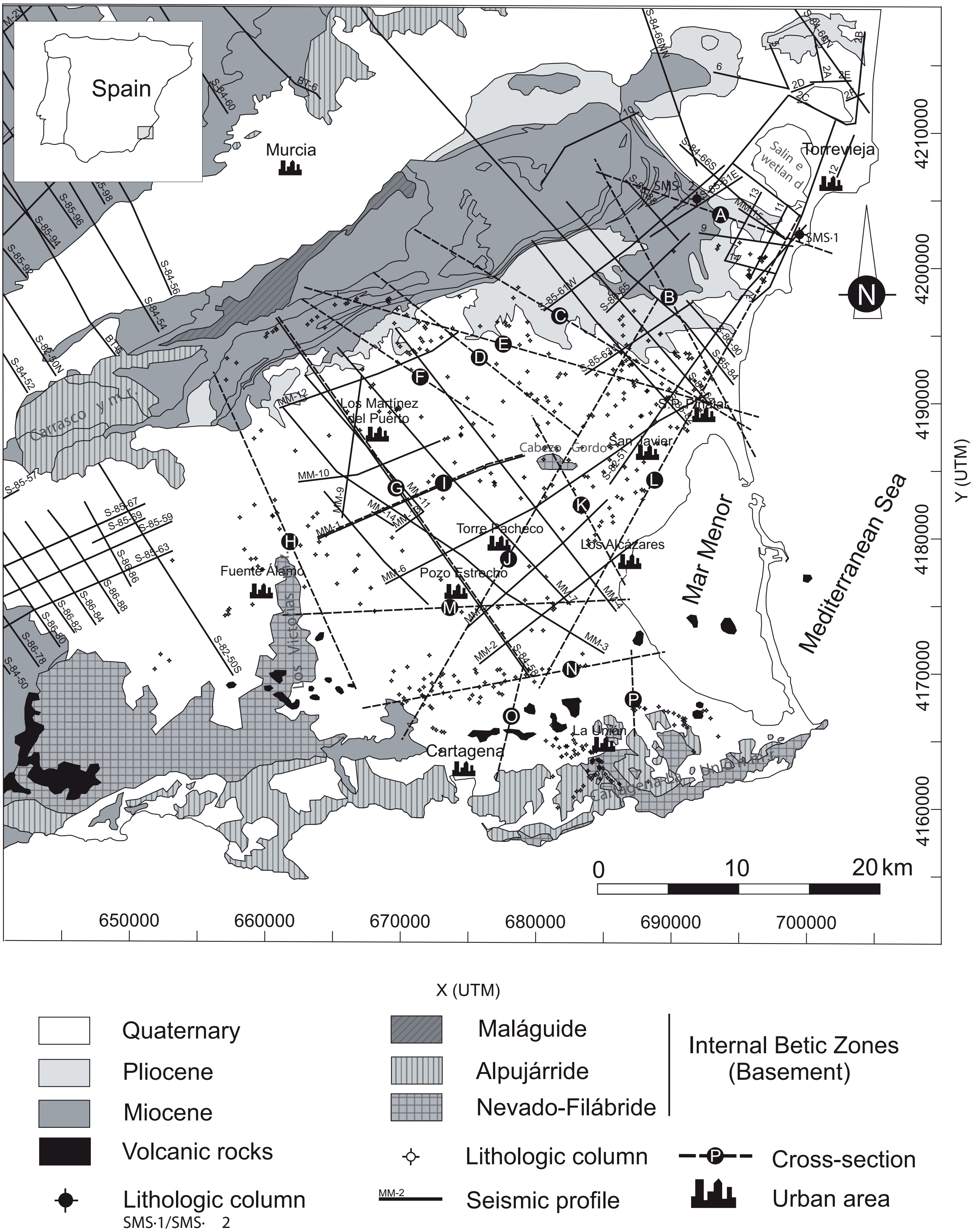

FIGURE 1 | Study area and geological sketch. Map location of seismic profiles, lithologic columns and cross-section locations. m.r.: mountain range. (Modified from IGME, 2005).

TABLE 1 | Campo de Cartagena geologic basin. Summary of stratigraphic and hydrostratigraphic units, formations, lithology and hydraulic properties of the Neogene and Quaternary sedimentary package. Modified from López-Bermúdez and Conesa-García (1990) and IGME (2005)

Chronology			Stratigraphic units	Formations	Lithology	Observations	Hydraulic properties	Hydrostratigraphic units
Quaternary			Q		Sand, silt, clay, conglomerate, caliche and sandstone		Aquifer	Qt
Pliocene			VI		Marl and evaporite		Aquitard	U_{LT}
				"Loma Tercia"	Sandstone	Intra-Messinian erosive surface, unconformity with the unit V	Aquifer	LT
				"El Espartal"	Clay and sand		Aquitard	EE
Miocene	Late	Messinian	V	"Venta La Virgen"	Sandstone		Aquifer	VLV
					Evaporite and marl		Aquitard	L_{VLV}
		Tortonian	IV		Oolitic limestone	Very local (thickness 40m)	Aquifer	U_{TLC}
				"Torremendo-Los Carceles"	Marl and clay with intercalations of limestone and sand	Variable thickness	Aquitard	TLC
			III	"Columbares"	Sandstone	Abundant fragments of echinoderms, oysters, etc.	Aquifer	Co
				"La Guardia Civil"	Marl and clay with intercalations of sand		Aquitard	LGC
				"Puerto Cadena"	Sandy limestone and conglomerate		Aquifer	PC
	Middle	Serravallian	II	"Atalaya"	Marl with intercalations of sand	Influence of differential subsidence	Aquitard	At
				"Cresta del Gallo"	Conglomerate		Aquifer	CG
		Langian	I	"El Relojero"	Conglomerate and sandstone with thin intercalations of marl	Internal structures of cross stratification	Aquifer	ER
	Early	Aquitanian-Burdigalian						
Basement								

the Quaternary period. Sands and conglomerates of Tortonian age, organic limestones of Messinian and sandstones deposited during the Pliocene constitute the potential aquifer materials. The Quaternary sediments are also detrital and form the upper unconfined aquifer (Instituto Geológico y Minero de España, 1994). Therefore, the hydrogeologic system is constituted by deep confined aquifers (Tortonian, Messinian and Pliocene age) and a Quaternary unconfined shallow aquifer (Instituto Tecnológico y GeoMinero de España, 1991; Rodríguez Estrella, 1995). The deep aquifers are an important source of water, which is processed by private desalination plants mainly in the case of one of them (Pliocene), while the unconfined aquifer is barely exploited due to contamination by agrochemicals from irrigation return flows. High pumping rates from desalination plants, pollution by agrochemicals, along with aquifers connected through poorly constructed wells (Jiménez-Martínez et al., 2011), constitute the main hydrogeological problems in the area.

METHODOLOGY AND DATA GATHERING

The initial step was to carry out an intensive search of available literature, current investigations taking place in the area and other sources of information. Many surveys conducted by public agencies and oil exploration companies were not research-oriented. Useful information include a great number of published and unpublished reports, which are confidential to a greater or lesser extent, covering geologic mapping, geophysical data and geologic logs.

To build the 3D subsurface geological and hydrogeological model, a wide range of geophysical records based on measurement variations of the electrical properties of sub-soil materials Vertical Electrical Soundings (VES), Electrical Tomography Resistivity (ETR) and density, and lithological columns from well logs were compiled. The geologic information was standardised according to the stratigraphic units and criteria (lithology, fossil content, etc) defined by Instituto Geológico y Minero de España (2005) and López-Bermúdez and Conesa-García (1990) (Table 1) to facilitate correlation between geologic boreholes and geophysical data. The applied stratigraphic criteria and descriptions agree with those of other similar basins on the Mediterranean coast (Friend and Dabrio, 1996).

Geologic boreholes and stratigraphic logs

A total of 491 geologic borehole logs were collected for further stratigraphic examination and sedimentary

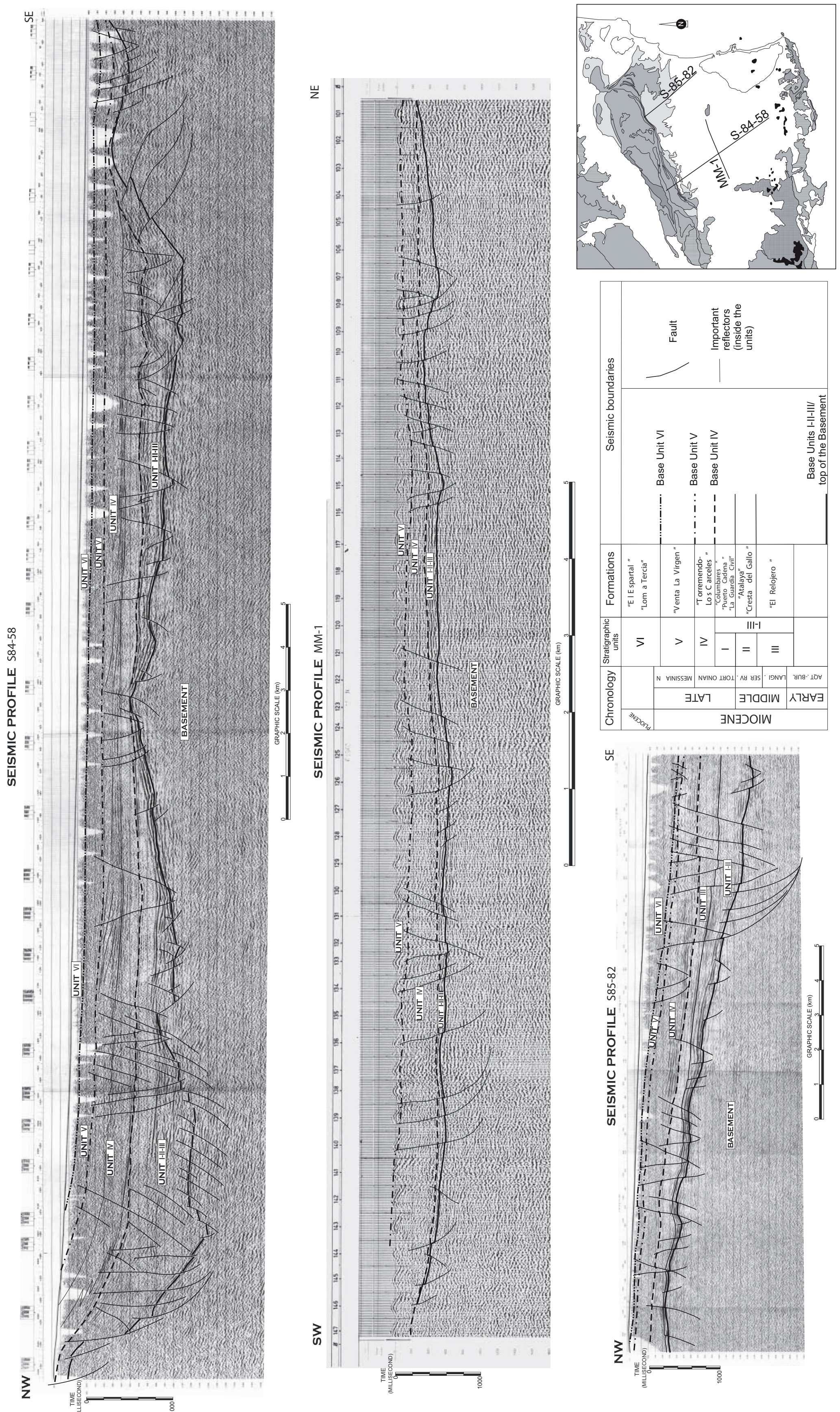

FIGURE 2 | Seismic reflection profiles: S-84-58 (Chevron, 1984); MM-1 (Sepesa, 1968); S-85-82 (Chevron, 1985) and geographic location. Modified from IGME (2005). (AQT.-BUR.: Aquitanian-Burdigalian. LANG: Langhian, SERRV: Serravalian).

basin reconstruction. Boreholes were mainly carried out for groundwater exploration purposes under rotary, percussion and percussion-rotary drilling where continuous stratigraphic logs were rarely recorded. Borehole density increases from inland towards the coast as well as in agricultural areas. The drilled depth for groundwater exploration varies between a few meters up to 750m. Two wells for oil exploration reaching more than 1000m of depth (Ini-Coparex, 1967, 1970) through which loggings were developed (self potential, resistivity, sonic log, gamma ray and neutron log), helped to improve the lithology characterisation and hydraulic properties. Moreover, an additional borehole (982m deep) for deep brine injection (Ramos and Sánchez, 2003) was also analysed.

Geophysical data

The following geophysical surveys were obtained and further analysed in order to understand the deep structure of the Campo de Cartagena basin: Seismic reflection profiles, VES, ETR (Loke and Barker, 1996; Loke, 2004), residual and Bouguer gravimetric maps, and Thermal Remote Tomography (TRT) (Rolandi et al., 2008).

Seismic reflection profiles

Sepesa (1968) and Chevron (1982, 1984, 1985, 1986) carried out a large number of seismic reflection studies in the area. Only three of them (S-84-58; MM-1 and S-85-82) are shown in Fig. 2. Lengths of profiles are generally greater than 10km and no spatial surface pattern is observed. The maximum exploration was of 3000m, where the MM survey (Sepesa, 1968) is less accurate than the S survey (Chevron, 1982, 1984, 1985 and 1986).

The processing and interpretation of reflection profiles based on the analysis of the seismic signal against travel time, considering models of velocity [double time (milliseconds) vs. depth] obtained from deep oil exploration boreholes, provides estimates of the thickness, layering, depth and facies changes of geologic materials besides basin boundary delineation.

For the identification of the different deeply buried geophysical units and basin structural and stratigraphic information, data analysis followed the classical seismic procedure (i.e. reflection endings, erosional truncation, onlap, downlap and configurations).

Electrical resistivity profiles

The Instituto Geológico y Minero de España (1983) electrical resistivity measurements here analysed, a continuation of a previous one developed in 1976 by Instituto Geológico y Minero de España, consists of 150 VES grouped into 5 profiles in a linear transect. Besides, in November 2007, an ETR survey to assess the lateral extent of geologic formations at the Southern limit of the basin was carried out (Jiménez-Martínez et al., 2008). A total of 6 profiles of apparent resistivity with a maximum length of 470m and a maximum exploration depth of 96m were obtained.

Gravimetric data

The Bouguer anomaly reveals the presence of masses with densities differing from earth average by large and local variations. A regional anomaly is due only to large-scale changes such as crustal thickening or thinning, while a residual anomaly expresses the presence of local rock bodies without the influence of changes in the crustal properties. The residual gravimetric anomalies constitute

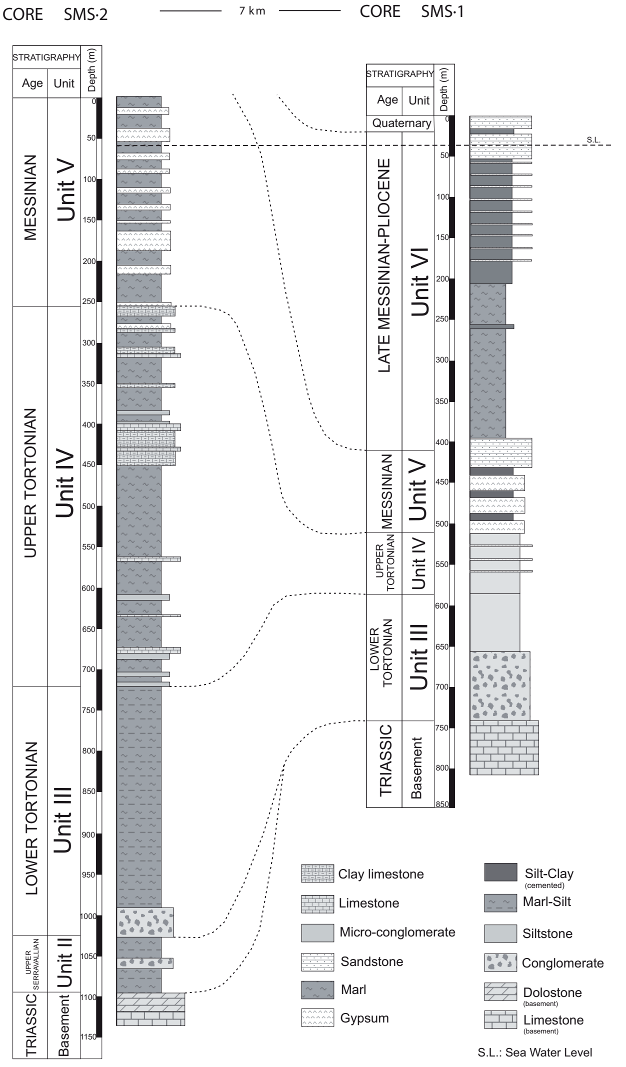

FIGURE 3 | Stratigraphic correlation between SMS-1 (Ini-Coparex, 1967) and SMS-2 (Ini-Coparex, 1970) lithological columns. See location in Figure 1.

a useful tool to determine the geometry of geological formations (Duque et al., 2008). Residual and Bouguer anomaly maps were developed by Chevron Oil Company Spain during 1984-1986. Density variations between sediments and basement allowed the measurements interpretation in terms of shape, size and position of subsurface structures (Instituto Tecnológico y GeoMinero de España, 1989).

APPROACH

The three-dimensional architecture of the basin was generated through a graphical interface (AutoCad®). The first step was the identification and definition of hydrostratigraphic units and the establishment of geologic correlations among them, based on the Neogene stratigraphic units previously defined by Instituto Geológico y Minero de España (2005) and the Quaternary (López-Bermúdez and Conesa-García, 1990) (Table 1). Recorded information from the existing borehole data base was not very useful due to the low quality (or absence) of geologic descriptions. This fact also made the establishment of correlation between them a complex task (Fig. 3).

Subsurface lithological changes and sediment thickness estimation was further performed by a joint analysis of gravimetric and seismic profiles and lithological logs from well characterised boreholes (Fig. 2). Results from VES and ETR also allowed a decrease in the subsurface uncertainties (geometry and lithology) between wells, by providing geophysical records to assess stratigraphic correlation. It needs to be mentioned that in some VES, the high salinity of water-bearing sediments, the presence of paleo-groundwater, and man-made pollution, all contributed to compromising the final interpretation. The presence of saline water overpowers the signal given by a lithology.

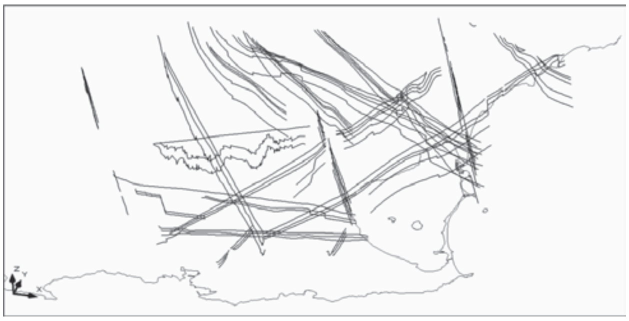

FIGURE 4 | Imported cross-sections are set as lines. The lines represent the lower boundary of the stratigraphic units defined in Table 1 (white colour). The shoreline is shown in grey.

Finally, 16 geo-referenced geological cross-sections integrating all reliable data, surface and subsurface information (geological boreholes, seismic profiles, gravimetric data, VES and ETR), were used to build a 3D model. Figure 4 shows the constructed diagram; only lower boundaries of the stratigraphic units are presented.

GEOLOGICAL MODEL AND HYDROGEOLOGICAL IMPLICATIONS

Geological model

The unconsolidated Quaternary sediments cover the greater part of the Campo de Cartagena surface. Neogene rocks crop out in the Northern part of the study area and are slightly dipping under the Quaternary. They are unconformably deposited over the basement materials and present several open folds as a result of bedrock settlement (Fig. 5). Neogene materials are also highly deformed by faults and joints, in some cases also affecting the Quaternary.

The geologic structure of the area is rather complex. Two principal grabens, Torre-Pacheco and San Javier, and horsts, Cabezo Gordo (that crops out) and Riquelme, are the most important structural features of the bedrock. The Torre-Pacheco sub-basin is characterised by the presence of two depocentres reaching a thickness of 2000m, located to the NW of Los Martínez village and a third depocentre with a thickness of 2300m located to the SW of Los Alcazares. The San Javier sub-basin has only one depocentre of 2000m thick located 5km to the NW of San Javier (Fig. 6).

The relationship between sedimentary infill of Quaternary and Neogene age at the basin boundaries is mainly controlled by faults and basal unconformities. The "Cartagena-La Unión fault" (Manteca and García, 2001) and other existing structural features, together with the metamorphic rocks of the Cartagena-La Unión mountain range (Jiménez-Martínez et al., 2008), characterise the sedimentary basin's Southern limit. A similar structural relationship with Los Victorias mountain range can be identified in the Western part (see section M Fig. 5). Presence of faults in the surroundings of Mar Menor (a hyposaline coastal lagoon) has been indicated by published works (Rodríguez Estrella, 1983, 1986, 2004; Rodríguez Estrella and Lillo, 1992, Rolandi et al., 2008), whilst further North at the basin contact with the Mediterranean Sea, they have not been observed. Regrettably, the presence of faults cannot be confirmed for the present model due to the lack of seashore geological and geophysical information.

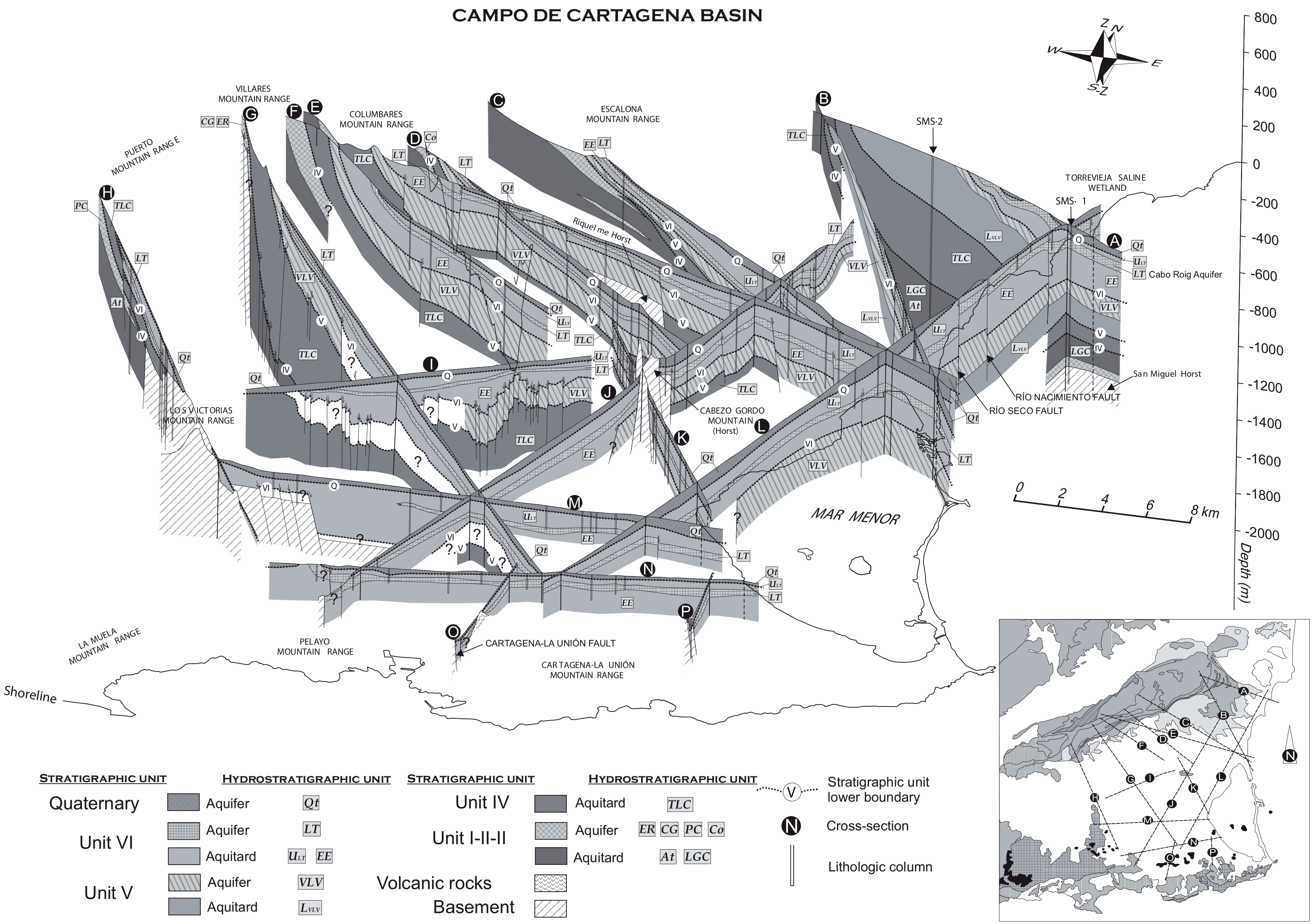

FIGURE 5 | Fence diagram of the stratigraphic and hydrostratigraphic units of the Campo de Cartagena basin. (see Table1).

FIGURE 5 | **Fence diagram of the stratigraphic and hydrostratigraphic units of the Campo de Cartagena basin. (see Table1).**

Hydrostratigraphic units

From the data set analysis of the Neogene and Quaternary sedimentary package and stratigraphic units, eight hydrostratigraphic aquifer units (Qt; LT; VLV; U_{TCL}; Co; PC, CG and ER) and six aquitard units (U_{LT}; EE; L_{VLV}; TLC; LGC and At) were defined. The hydrostratigraphic units, mainly of detrital origin, range from the Middle Miocene to the Quaternary. A summary of the associated stratigraphic formation; lithology and hydraulic characteristics are presented in Table 1. Aquifer unit areal extensions have been plotted in Figure 7; Table 2 presents the principal geometric characteristics derived from this work and hydraulic properties obtained from

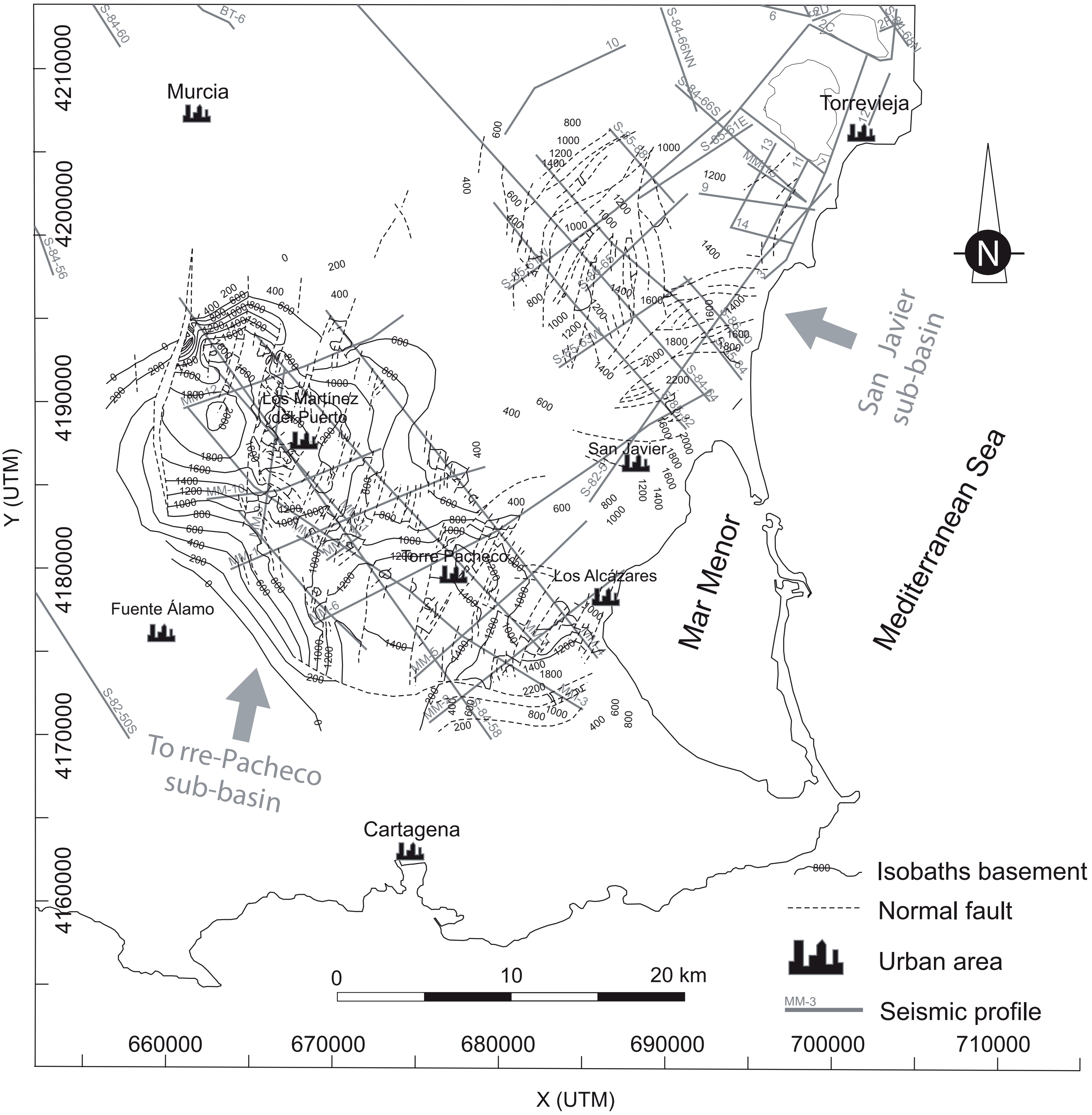

FIGURE 6 | Campo de Cartagena basin, isobaths of the Mesozoic basement. The two sub-basins (Torre-Pacheco and San Javier) with the existing depocentres are clearly observed (Modified from IGME, 2005).

FIGURE 5 | **Fence diagram of the stratigraphic and hydrostratigraphic units of the Campo de Cartagena basin. (See Table1).**

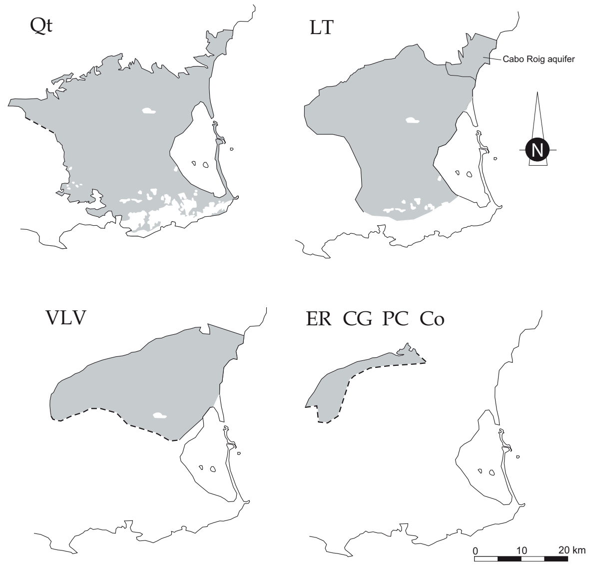

FIGURE 7 | Surface spatial extension for the Qt, LT, VLV and jointly ER, CG, PC and Co aquifer units have been mapped. The dashed line represents either an unknown unit border or a lateral facies change, in the Qt aquifer unit it constitutes the groundwater boundary.

previous works (Instituto Geológico y Minero de España, 1994) and pumping test analyses (Rodríguez-Estrella et al. 2004; unpublished data) for each defined unit. It needs to be mentioned that due to the remarkable spatial variability of the geologic media, those values must be considered in many cases as punctual estimates.

In the I-III stratigraphic unit, four aquifer units are distinguished from bottom to top: ER, conglomerate and sandstone; CG, conglomerate; PC, sandy limestone and conglomerate; Co, sandstone. The areal extent of the ER, CG, PC and Co aquifer units below the Campo de Cartagena coastal plain is not known accurately as they also show lateral facies changes among them. Their presence appears to be limited to some lithological columns and small reflections detected in the seismic profiles (Fig. 7). For the aquifer units PC and Co, respectively, lateral facies changes are observed to the centre of the basin, as illustrated in the H and C cross-sections (Fig. 5). All aquifer units pinch out towards the SE of the area.

Within stratigraphic unit IV, a local aquifer unit of approximately 40m thickness, U_{TLC}, composed of oolitic limestone, has also been identified.

The stratigraphic unit V presents a single aquifer unit, VLV, constituted by sandstone which is only present in the mid-North of Campo de Cartagena. The VLV unit presents two different lower aquitards depending of the sub-basin: the L_{VLV} unit in the San Javier sub-basin, and the TLC unit in the Torre-Pacheco sub-basin. The Cabezo Gordo horst crops out in the Southern part of the VLV aquifer unit surface extension, formed by marbles and limestone of the basement. The hydraulic connection between the aquifers and the basement materials is unknown. To the East, the unit is dipping under the Mediterranean Sea, but neither geologic, structural nor stratigraphic information exists. The VLV aquifer unit has not been observed in the mid-South of the study area (Fig. 7). This fact supports the structural control by a fault hypothesis stated in previous works (Instituto Tecnológico y GeoMinero de España, 1989, 1991, Instituto Geológico y Minero de España, 1994); the movement along the fault would move down the VLV aquifer unit to the mid-South of Campo de Cartagena. As the fault has not been detected neither in the S-84-

TABLE 2 | Information required for numerical modelling of the Campo de Cartagena hydrostratigraphic units. S_s: Storage coefficient/formation thickness (IGME, 1994; Rodríguez Estrella et al., 2004; Jiménez-Martínez, personal communication)

Stratigraphic Unit	Hydrostratigraphic Unit	Type	Out cropping surface	Total surface	Depth*	Thickness	Hydraulic conductivity	Specific storage	Specific yield	Effective porosity	Total porosity	Observations
			(km^2)	(km^2)	(m)	b (m)	K $(m\ d^{-1})$	S_s (m^{-1})	S_y	m_e	Ø	
				known (optimistic scenario)	Top/ Bottom	Average [max.]	Av. [max./ min.]	[max./ min.]	Av. [min./ max.]	Av. [min./ max.]	Av. [min./ max.]	
Q	Qt	aquifer	1135	1135	0/50	55 [150]	0.5 $[10^{+3}/10^{-6}]$	-	0.2 [0.1/0.4]	0.23 [0.1/0.4]	0.4 [0.15/0.6]	
VI	U_{LT}	aquitard	-	-	50/85	60 [110]	-	-	-	-	-	
	LT	aquifer	22	817	85/130	30 [110]	8 $[10^{+1}/10^{-4}]$	$[10^{-4}/10^{-6}]$	-	0.25 [0.1/0.4]	0.3 [0.035/0.38]	Fractured
	EE	aquitard	-	-	130/195	90 [180]	-	-	-	-	-	
V	VLV	aquifer	28	570	195/315	125 [240]	6.5 $[10^{+1}/10^{-5}]$	$[10^{-4}/10^{-6}]$	-	0.19 [0.01/0.4]	0.3 [0.05/0.5]	Fractured
	L_{VLV}	aquitard	-	-	-	-	-	-	-	-	-	
IV	U_{TLC}	aquifer	-	-	-	-[40]	-	-	-	-	-	Very local
	TLC	aquitard	-	-	315/-	-[800]	-	-	-	-	-	
I-II-III	Co	aquifer	25**	43 (230)**	-	90 [200]**	-	-	-	0.24 [0.1/0.4]**	-	Lateral facies changes between aquifer units
	LGC	aquitard										
	PC	aquifer										
	At	aquitard				70						
	CG	aquifer										
	ER	aquifer										

*Central part of the basin.

**Average value for all aquifer hydrostratigraphic units.

58 seismic profile (Chevron, 1984) (Fig.3) nor in cross-section G (Fig. 5), and given the lack of information supporting the tectonic feature, the authors consider a lateral facies change to be the best explanation.

Stratigraphic unit VI presents a single aquifer unit, LT, constituted by sandstone. The LT aquifer unit practically covers the entire area of Campo de Cartagena (Fig. 7), except in the surroundings of Los Victorias mountain range (Western area, see cross-section M in Fig. 5), where sandstone changes to silt, clay and conglomerate (Mora Cuenca et al., 1988). The hydraulic relation with Cabezo Gordo horst and Los Victorias mountain range (partially formed by marbles and limestone) is unknown. At the North-eastern part, the LT aquifer unit is hydraulically disconnected from the rest of the unit and it is named Cabo Roig aquifer (Fig. 7). The Mar Menor boundary is conformed by faults which may act as hydraulic barriers avoiding seawater intrusion in the aquifer (Rodríguez Estrella, 1983, 1986, 2004; Rodríguez Estrella and Lillo, 1992; Rolandi et al., 2008). Further to the North, in contact with the Mediterranean Sea, the presence of faults has not been detected.

Finally, stratigraphic unit Q, Qt aquifer unit, crops out over almost the entire Campo de Cartagena area. It constitutes the upper unconfined aquifer (Fig. 7), receiving natural recharge from precipitation and by irrigation return flow. To the Southern border, geometric relationships between the Qt aquifer unit and the Cartagena-La Unión mountain range (derelicted mining area) present structural features similar to Neogene materials (faults and basal unconformities). However, the hydraulic connection still remains unknown, a potential risk of pollution by heavy metals and sulphurs may exist (García, 2004; Robles-Arenas and Candela, 2010).

CONCLUSIONS

Representation and analysis of geological architecture for specific applied research, such as groundwater modelling, are often simplistic approximations of real aquifer geometry. Generally, numerical model restrictions condense or simplify details. However, a detailed 3D basin study analysis integrating more interrelated concepts from different disciplines is necessary to gain a better understanding of geological systems. To build the stratigraphic architecture of the basins, to identify the potential aquifer formations and to discuss the relationship between aquifer formations and the bedrock, both geophysical and geological information and well-log data are the basic tools. Integration of applied geophysical techniques with stratigraphic data allows a more accurate prediction of changes in subsurface geology.

For the Campo de Cartagena basin, the integration of a large dataset of geophysical surveys and lithological logs has allowed a detailed geometric definition of aquifer and aquitard units. Data analysis has provided new insights for reducing the uncertainty associated with basin geometry characterisation and geologic heterogeneities, previously defined in other studies as tectonic features and more recently in this work many of them as lateral facies changes. The implications are obvious. For a more precise geologic interpretation and, in consequence, a more accurate hydrogeological model, lateral facies changes are the basis for the understanding of the system. Results also allowed establishing the principal differences between the San Javier and Torre-Pacheco sub-basins.

In the Campo de Cartagena basin there are multiple aspects that still require a more detailed study. Offshore data, for the VLV and LT aquifer units continental and marine data correlation, are needed for assessing aquifer-sea connection and vulnerability to seawater intrusion due to natural or pumping conditions along the entire shoreline. As observations are incomplete, a deeper investigation of the Cartagena-La Unión Southern boundary mechanisms, that may increase the aquifer potential risk to heavy metals and sulphurs contamination from the abandoned mining area, is necessary. Finally, relationships between the Neogene sedimentary package aquifer units and the basement, and the areal extension of aquifer units beneath the Campo de Cartagena plain, require a thorough investigation.

The obtained results on aquifer geometry and hydraulic parameters constitute a good starting point to all kind of future hydrogeologic studies raised in the Campo de Cartagena basin: to redesign the groundwater level and quality monitoring network; numerical flow and agrochemical contaminants transport model. The applied approach and the sedimentological aspects shown in this paper may be transferred to similar Neogene basins existing in the circum-Mediterranean area.

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