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Influence of crustal mechanical layering on the seismic potential of active faults: insights from the southwestern Valencia Trough (W Mediterranean)

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Short summary

This study investigates the main active faults located within the southwestern Valencia Trough, an offshore region east of the Spanish coast. Utilizing subsurface data, we identify and characterize the 3D geometry of several of these faults for the first time. Given that active faults pose a significant natural hazard due to their potential to generate earthquakes, we also assess the seismic potential of the faults within the southwestern Valencia Trough.

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ABSTRACT

We present a structural and seismotectonic analysis of active faults in the southwestern Valencia Trough (western Mediterranean) on the basis of subsurface datasets. In our study, we identify and characterise three major active faults: the Cullera Fault, with a long-term slip rates that vary over time between 0.15 ± 0.1 mm/yr and 0.4 ± 0.1 mm/yr; the oblique Albufera Fault, with a long-term slip rate of 0.2 ± 0.1 mm/yr; and the normal Valencia Fault.

The seismogenic character of the southwestern Valencia Trough is controlled by a mechanically weak layer consisting of Triassic evaporites. This weak layer induces partial to complete decoupling between the suprasalt and subsalt successions, leading to two distinct mechanisms driving fault displacement: tectonic activity and salt withdrawal. A quantitative evolutionary analysis of the Cullera Fault reveals that these two mechanisms alternate over time.

The presence of a mechanically weak layer has implications for seismicity. Earthquakes can nucleate within both sub- and suprasalt successions, with total or partial decoupling influencing rupture propagation. We discuss how these two scenarios lead to different earthquakes and thus impact the seismic hazard of a region. Empirical source-scaling relationships, which are commonly used to estimate the seismogenic potential of active faults, generally assume a homogeneous seismogenic crust. To address this limitation, we propose a methodological approach based on the use of the aspect ratio. Our findings highlight the need to incorporate stratigraphic mechanical layering into seismic hazard assessments, particularly in salt-influenced tectonic settings.

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1. Introduction

Seismic-hazard analyses are often performed by scaling relationships. These relationships are regressions in which the seismogenic potential of active faults is derived from geometric parameters of the fault, such as the potential fault rupture length or area (Stirling et al., 2013). Pioneering works on scaling relationships began in the 1970s (Kanamori & Anderson, 1975; Geller, 1976). The regressions of Wells & Coppersmith (1994) represent a milestone in the application of scaling relationships, as they included a very large dataset of historical earthquakes. The equations proposed by Wells & Coppersmith became a standard for determining the seismogenic potential of active faults. Subsequently, other scaling relationships have been proposed, accounting for factors such as the tectonic environment, fault dip, or seismogenic thickness (Stirling et al., 2002 and 2013; Leonard 2010 and 2014; Huang et al., 2024, among many others).

Most scaling relationships employed to evaluate crustal earthquakes correlate the moment magnitude (Mw) with the fault dimensions (length, width, and/or area). Some of these scaling relationships consider the fault width vs. fault dip growth of ruptures for large earthquakes, as rupture width is limited by the maximum depth of the seismogenic crust (Leonard, 2010; Yen and Ma, 2011; Leonard, 2014; Cheng et al., 2019). However, these relationships do not consider the influence of potential heterogeneities within the seismogenic crust, which could control the propagation of ruptures and, therefore, the magnitude of earthquakes.

Here, we present an analysis of several subsurface datasets, including high-resolution seismic profiles, from the southwestern Valencia Trough. We identify and characterise the main active faults in this region, and we carry out a detailed geometric description. The results of this analysis also emphasize that this region is characterised by a mechanically weak layer within the seismogenic crust. After mapping the main faults, we apply conventional scaling relationships to evaluate the potential magnitudes of future earthquakes. We propose a methodological approach for integrating the effects of mechanically weak layers—such as Triassic evaporites—into routine seismic hazard assessments, highlighting the need to refine existing scaling relationships in tectonically complex settings.

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2. Tectonic setting

The Valencia Trough is an extensional basin located in the western Mediterranean region (Fig. 1). This basin is the result of polyphase tectonic evolution spanning from the Triassic to the present day, as it is located between the Betic-Balearic fold-and-thrust belt to the south, the Iberian Chain to the west, and the Catalan Coastal Ranges to the north (De Ruig, 1992; Guimerà & Álvaro, 1990; Maillard & Mauffret, 1999; Roca & Desegaulx, 1992; Roca et al., 2004; Vergés & Fernàndez, 2012). The tectonic evolution of the Valencia Trough is also partially influenced by extension related to the retreat of the Maghrebian–Ligurian Tethys subduction slab (Etheve et al., 2016; Faccenna et al., 2004; Jolivet & Faccenna, 2000; Maillard & Mauffret, 1999; Rehault et al., 1984; Roca et al., 1999; Séranne, 1999; van Hinsbergen et al., 2014).

The Valencia Trough (Fig. 1) underwent a Mesozoic rifting process related to the Iberian intraplate rift and the opening of the Western Tethys (Arche and López-Gómez, 1996; Nebot and Guimerà, 2018; Ramos et al., 2023; Salas et al., 2001). This process led to the formation of NW–SE and NE–SW high-angle faults offsetting the pre-Mesozoic basement and to the deposition of a 5–15-km-thick Upper Jurassic–Lower Cretaceous succession.

During the Late Cretaceous, the onset of convergence between Nubia and Eurasia caused the transition from a Mesozoic extensional tectonic regime to successive compressional and extensional stages (Roca, 2001; Salas et al., 2001; Vergés and Sàbat, 1999). From the late Eocene to the Oligocene, the Valencia Trough was dominated by shortening. Onshore, this episode led to the formation of the intraplate Iberian Chain and Catalan Coastal Ranges (Gaspar-Escribano et al., 2004; Geel, 1995; Guimerà and Álvaro, 1990).

From the late Oligocene to the middle Miocene, the western Mediterranean region was subsequently affected by an extensional regime, driven by the complex interplay between the European–Cenozoic rift system (e.g., Séranne, 1999) and the rollback of the Maghrebian–Ligurian Tethys slab (Faccenna et al., 2004; van Hinsbergen et al., 2014). This extensional phase led to the formation of the Liguro-Provençal and Algerian Basins, as well as the Valencia Trough. However, subsidence in the southwestern Valencia Trough during this period cannot be accounted for by

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rifting, due to the limited occurrence of Cenozoic basement extensional faults (Roca and Guimerà, 1992). Therefore, extension has been interpreted as due to the collapse of a back-arc transient uplift event (Fang et al., 2021).

The extension in the Valencia Trough occurred immediately before or synchronously with the formation of the compressional Betic Cordillera. This compressional deformation is well expressed by a thin-skinned fold-and-thrust system observed in the Eastern Betic Cordillera (De Ruig, 1995; Sàbat et al., 2011) and in the Balearic Promontory (Mallorca and Ibiza Islands). At the same time, significant magmatic activity took place in the area, and was divided into two phases: (1) late Oligocene to Serravallian calc-alkaline activity and (2) Tortonian to present alkaline volcanic activity (Martí et al., 1992).

From the Pliocene to the present, the tectonic setting in the Valencia Trough has been dominated by NE–SW extension, as indicated by focal mechanisms (Stich et al., 2010) and broad regional global navigation satellite system (GNSS) analyses (Stich et al., 2006). This extension has been related to thermal subsidence (Roca, 1992, 1996, and 2001; Roca and Guimerà, 1992; Roca et al., 1999a; Gaspar-Escribano et al., 2004) and has been interpreted as the final stage of an aborted rift event responsible for the ENE motion of the Balearic promontory (Palano et al., 2015). Several normal active faults have been defined in the southwestern Valencia Trough thus far (Fig. 1): the Western Cabo Cullera Fault, Central–Western Cabo Cullera Fault, Central–Eastern Cabo Cullera Fault, Eastern Cabo Cullera Fault and Southwest Columbretes Fault (Perea, 2006). Some of these faults were previously recognised from vintage seismic lines (Diaz del Rio et al., 1986; Roca, 1992, 1996; Perea, 2006; Maillard & Mauffret, 2013), but fault traces and geometry were defined only very approximately. Similarly, the slip rates derived from the displacement of Plio-Quaternary seismic reflectors observed in the vintage seismic lines present high uncertainties (0.02 ±0.01 mm/yr; Perea, 2006). In the Valencia Trough, seismicity is characterised by low- to moderate-magnitude events (Fig. 1). The few available focal mechanisms (Stich et al., 2010; IGN, 2025) indicate a normal–oblique or strike slip kinematics, although these focal mechanisms present high uncertainties, mainly because they occur at long distances from seismic stations

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and are registered with significant azimuthal gaps (González, 2017). According to the data published by the Spanish Earthquake Catalogue (IGN, 2025), this seismicity is very shallow, as most of the events are assigned depths of less than 10 km (Fig. 2). However, ~~once again~~, these data should be taken with caution, as the depths assigned to these earthquakes present high uncertainties (González, 2017).

In the onshore domain located west of the Valencia Trough, only one major active structure, namely, the Jumilla Fault, has been postulated (García-Mayordomo et al., 2012), together with other minor active faults (Alcoy, Mariola, and Benasau Faults). In this onshore area, several significant historical earthquakes have occurred, such as the 1396 Tavernes (I_{EMS98}=VIII-IX), 1620 Alcoy (I_{EMS98}=VIII-IX), 1644 Muro (I_{EMS98}=V) and 1748 Estubeny (I_{EMS98}=IX) earthquakes (Martínez Solares and Mezcua, 2002; IGN, 2025; Buforn et al., 2105; Buforn & Udías, 2022).

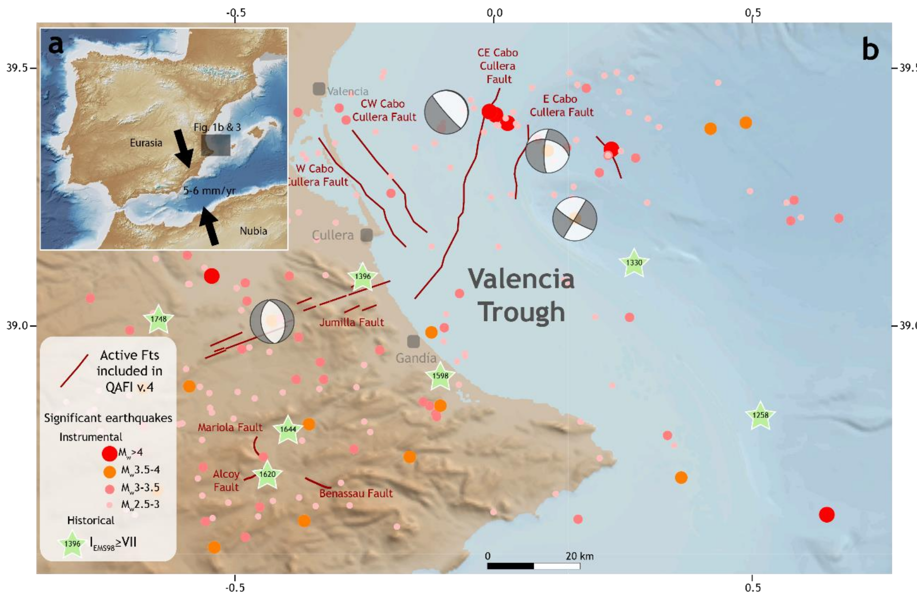

Fig. 1. a. Location of the Valencia Trough. Convergence vectors between Nubia and Eurasia are after DeMets et al., 1994; McClusky et al., 2003; Nocquet, 2012; Nocquet & Calais, 2003; Pérez-Peña et al., 2010; Serpelloni et al., 2007; Stich et al., 2006. b. Seismotectonic map of the southwestern Valencia Trough and surrounding areas. Fault traces from Quaternary-Active Faults of Iberia database (García-Mayordomo et al., 2012)

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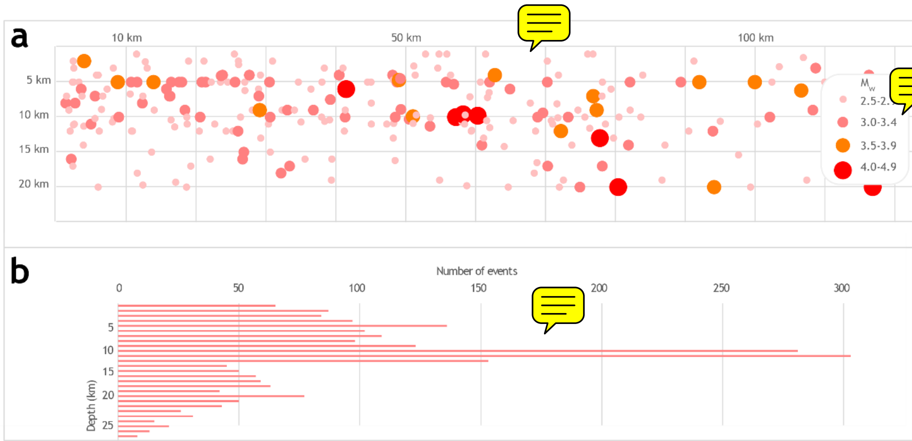

Fig 2. Seismicity of Mw>2.5 in the southwestern Valencia Trough shallower than 20 km since 1950 from the Instituto Geográfico Nacional database (IGN, 2025) a. Distribution of the depth of seismicity. Horizontal axis represents distance along the southwestern Valencia Torugh in a SW-NE direction. b. Depth histogram.

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3. Methods

The interpretation of the offshore area is based on mainly 2D multichannel seismic reflection data calibrated with well data (Fig. 3). The central part of the study area is covered by a high-quality seismic survey acquired by Fugro-Geoteam with the RV Geo Baltic, processed by Robertson Research International Ltd. in 2002. The survey consists of 30 seismic sections with an average length of 90 km (totalling approximately 2,800 km). They are oriented WNW–ESE and NNE–SSW, with maximum spacings of 13 km and 6 km, respectively. The details regarding the acquisition and processing parameters can be found in Cameselle & Urgeles (2017). Most of the area affected by Plio-Quaternary faulting nearer to the coast is covered only by vintage 2D seismic lines from the late 1970s, acquired by various operators, which are publicly available upon request in the Instituto Geológico y Minero de España (IGME-CSIC) (http://info.igme.es/sigeof/). More than 100 of these seismic lines, with a total line length of approximately 2,500 km, were selected for mapping; although the quality of these lines varies from moderate to poor, the high-density grid spacing (varying from 1 to 3.5 km) allows fault mapping with reasonable confidence. The seismic interpretation was performed in two-way travel time (TWT) by using Move software (by Petex). The seismic dataset was converted to depths using velocity data derived from Expanded Spread Profile ESP 7 (Pascal et al., 1992; Torné et al., 1992). A second-order polynomial trend was applied to establish time–depth relationships, ensuring strong correlation with the well data, similar to the methodologies of Fang et al. (2021).

The interpretation of seismic horizons is calibrated by 9 offshore petroleum exploration wells, all of which penetrate the entire Neogene section and whose bottoms are in Mesozoic rocks. Original well reports, log data (lithology, dipmeter, gamma–ray, sonic and resistivity data) and palaeontological data (from cuttings and sidewall cores) were retrieved from the IGME-CSIC archive (https://info.igme.es/hidrocarburos/). Well-to-seismic ties were established by integrating the sonic logs and using synthetic seismograms from end-of-well reports. Palaeontological analyses and range charts from the original well reports

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were reviewed and adapted to the Mediterranean biozonation of Lirer et al. (2019) to obtain approximate absolute ages for the seismic horizons.

No seismic data were available for the onshore area of southern Valencia and only two deep exploration wells were drilled (Jaraco-1 and Perenchiza-1). However, stratigraphic information is available from 95 hydrogeological wells in the Valencia coastal plain, as are vertical electric sounding (VES) profiles acquired for hydrogeological surveys. The data are publicly available in the online IGME-CSIC databases IRYDA, BD Puntos Agua 2.0 and Sistema de Información Documental (SID) (accessible through https://info.igme.es/catalogo/).

In areas with poor seismic coverage, structural mapping was aided by regional Bouguer gravity anomalies processed with a Butterworth High-pass filter with a 1-degree cut-off frequency to highlight short-wavelength features of the data (by Getech, 2015).

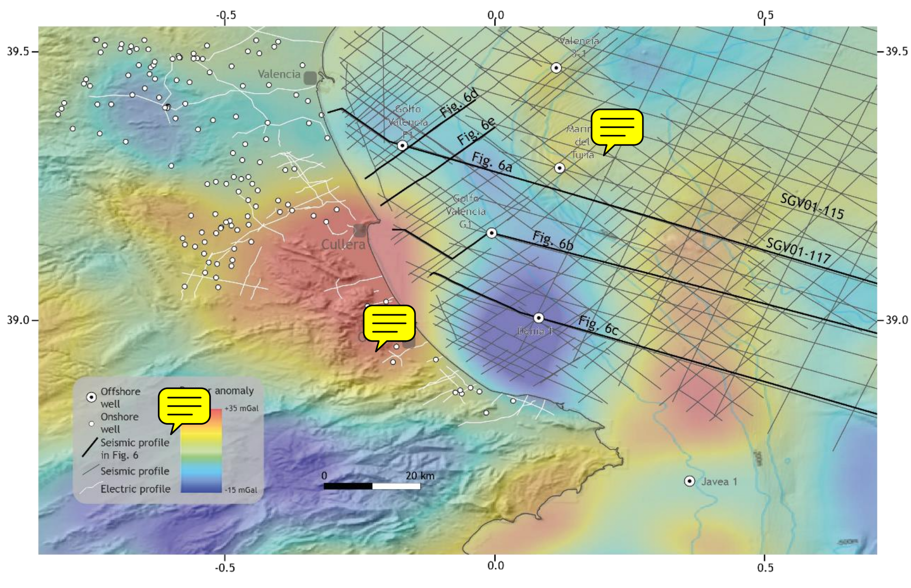

Fig. 3. Geophysical dataset used in this work. Filtered Bouguer anomaly data after Getech (2015). The location is shown in figure 1.

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4. Stratigraphy

The general stratigraphic arrangement of the southwestern Valencia Trough (Fig. 4) consists of a rigid Palaeozoic–Middle Triassic basement overlain by a 1.5–7-km Upper Triassic–Quaternary stratigraphic cover. Here we present a new detailed stratigraphic framework for the late Miocene–Quaternary of the southern Valencia Trough. The definition of the pre-Neogene stratigraphic units presented in this work is based on mainly previous literature and our analysis of well data, as well as outcrops in the mainland for the most recent sediments.

The Upper Triassic succession (Fig. 4) consists of evaporites, shales and dolomites (Keuper Facies) (Vargas et al., 2009). The Upper Triassic deposits are overlain by shallow-water dolomites and anhydrites deposited from the Early to Middle Jurassic (Salas et al., 2001). The Upper Jurassic and Lower Cretaceous successions are represented by platform carbonates that grade to marls basinwards and are overlain by middle–late Albian to Late Cretaceous carbonates. The top of the Mesozoic succession corresponds to an erosive, angular unconformity that is directly overlain by Neogene deposits. Cenozoic infilling has been broadly studied in recent decades (e.g., Arche et al., 2010; Clavell and Berástegui, 1991; Maillard et al., 1992; Ribó et al., 2016b, 2016a; Soler et al., 1983). The succession starts with a transition from continental clastic sediments to marine platform carbonates, ending with a deposit formed by progradational terrigenous shelf-talus sediments (Clavell and Berástegui, 1991; Etheve et al., 2018; Lanaja, 1987; Roca and Desegaulx, 1992; Soler et al., 1986).

The Neogene succession onshore of the southwestern Valencia Trough (Fig. 4) mostly consists of middle–late Miocene continental to marginal marine deposits. In the offshore part of the study area, the Miocene stratigraphic succession is entirely marine. The base of the Miocene sequence is composed of a basal conglomerate overlain by coralline algal limestones. The middle Miocene (late Langhian–Serravallian) deep marine calcareous claystones, marls and fine-grained sandstones overlie the algal limestones or rest directly on deeply eroded Mesozoic rocks. Within the southern and central parts of the study area, the early–middle Miocene sequence is no more than 200 m thick. Towards the north, the middle

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Miocene interval rapidly thickens, reaching almost 2000 m. Tortonian and Messinian deposits consist of mainly marls with thicknesses varying between 180 m and 425 m. The top of the Tortonian–Messinian series is an erosional unconformity (Messinian Erosion Surface (MES)) (Stampfli & Höcker, 1989; Lofi et al., 2011; Cameselle et al., 2014).

In the onshore and nearshore areas, upper Miocene deposits are overlain by thin cover (generally less than 50 m) of Pleistocene–recent alluvial fans, laterally grading to lagoonal and beach barrier deposits near the coast. No Pliocene sediments have been identified in the entire onshore coastal area, except for local karstic cave infills with mammal remains (Agustí et al., 2011). Below the southern parts of the city of Valencia, the thickness of Pleistocene–recent deposits abruptly increases. Vertical electric sounding profiles seem to indicate the presence of several large normal faults in this area, which have locally dropped the top Miocene surface down to more than 400 m below sea level. From Cullera southwards, shallow boreholes encounter Pleistocene to recent interbedded alluvial gravels, brackish lagoon, and beach barrier deposits. Vertical electric sounding profiles and well correlations indicate abrupt thickness changes, likely controlled by a complex system of normal faults in the Mesozoic–middle Miocene basement, ranging from less than 50 m in offset to more than 200 m towards the coast. Subsidence in the southern Valencian coastal area continues to the present day, as evidenced by well-documented submerged beach barriers of Tyrrhenian age (Eemian interglacial, 127–106ky), which are currently found between 10 and 40 m below sea level in shallow offshore areas (Zazo et al, 1979; Alcántara-Carrió et al, 2012).

In the offshore area, Pliocene–recent sediments form a large prograding shelf complex with prominent clinoforms visible in seismic data, which downlap onto the MES. Prominent undulations on slope foresets are visible on most seismic lines and are interpreted as sediment waves (Ribó et al., 2015). In the offshore wells, the stratigraphic succession consists of an overall shallowing-upward series of thick grey claystones with calcareous interbeds at the base, grading upwards into sandstones and shell beds at the top. No unconformities have been identified in the

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entire sequence, except for erosional gullies and canyons at the shelf edge. The Plio-Quaternary sequence reaches a maximum thickness of approximately 3000 m.

To determine the Plio-Quaternary depositional history and slip rate of major faults, six seismic horizons have been mapped and dated with palaeontological data from offshore wells, via the biostratigraphic scheme of Lirer et al. (2019). Starting from the Messinian unconformity at 5.3 Ma, seismic markers have been dated at 3.8 Ma (LO of *G. margaritae*), 3.3 Ma (FO *G. bononiensis*), 2.6 Ma (LCO *G. obliquus*) and 2.0 Ma (FO *G. truncatulinoides*). As no samples were collected from any of the offshore wells above the lower-middle Pleistocene interval, an additional marker (approximately 1.0 Ma) has been picked halfway through the 2.0 Ma marker and seabed (0 Ma), assuming a constant sedimentation rate.

Isopach maps (Fig. 5) were produced for the intervals of Pliocene (MES to 2.6 Ma marker) and Pleistocene–recent (2.6 Ma marker to the seabed), revealing a significant shift in the location of the depocenter. The Pliocene depocentre is located very close to the southern coast near Denia, attaining a maximum thickness of approximately 1500 m, whereas the Pleistocene depocentre has prograded ca. 20 km to the NNW, reaching a thickness of more than 1750 m. The western shoreward edge of both the Pliocene and Pleistocene depocentres is controlled by very large NNW–SSE-trending normal faults (see below).

The described stratigraphic architecture indicates significant mechanical layering in the southwestern Valencia Trough. A rigid basement is overlain by a mechanically weak layer represented by the Upper Triassic Keuper Facies. Above this interval, a rigid Mesozoic carbonate succession is present, followed by a semirigid layer composed of primarily detrital deposits.

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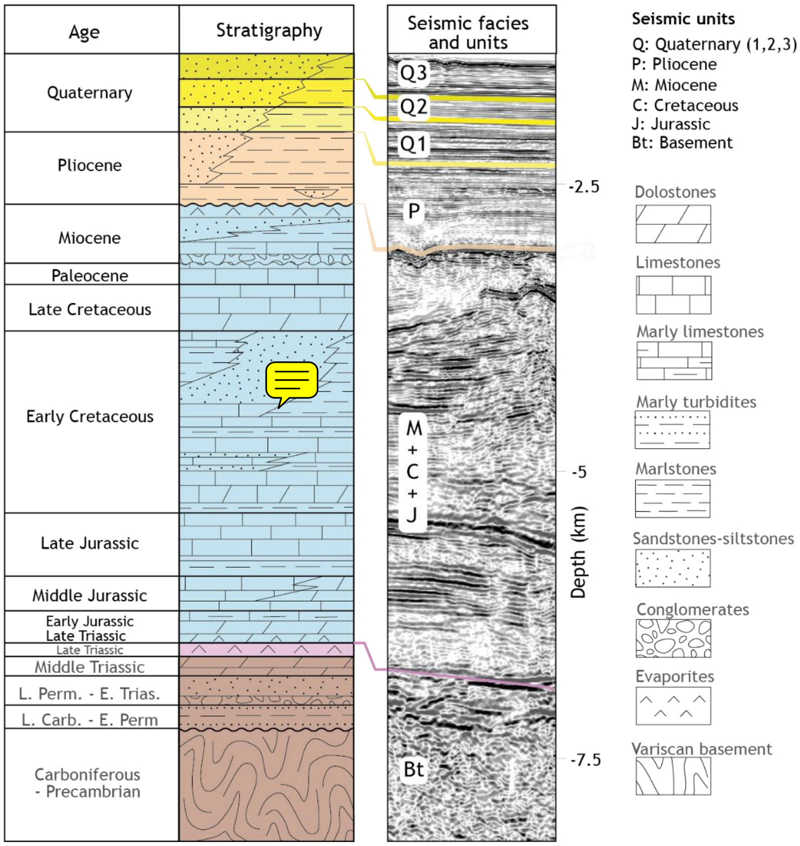

Figure 4: Chronostratigraphic diagram of the southwestern Valencia Trough. Note that the depth scale shows maximum thicknesses ofunits.

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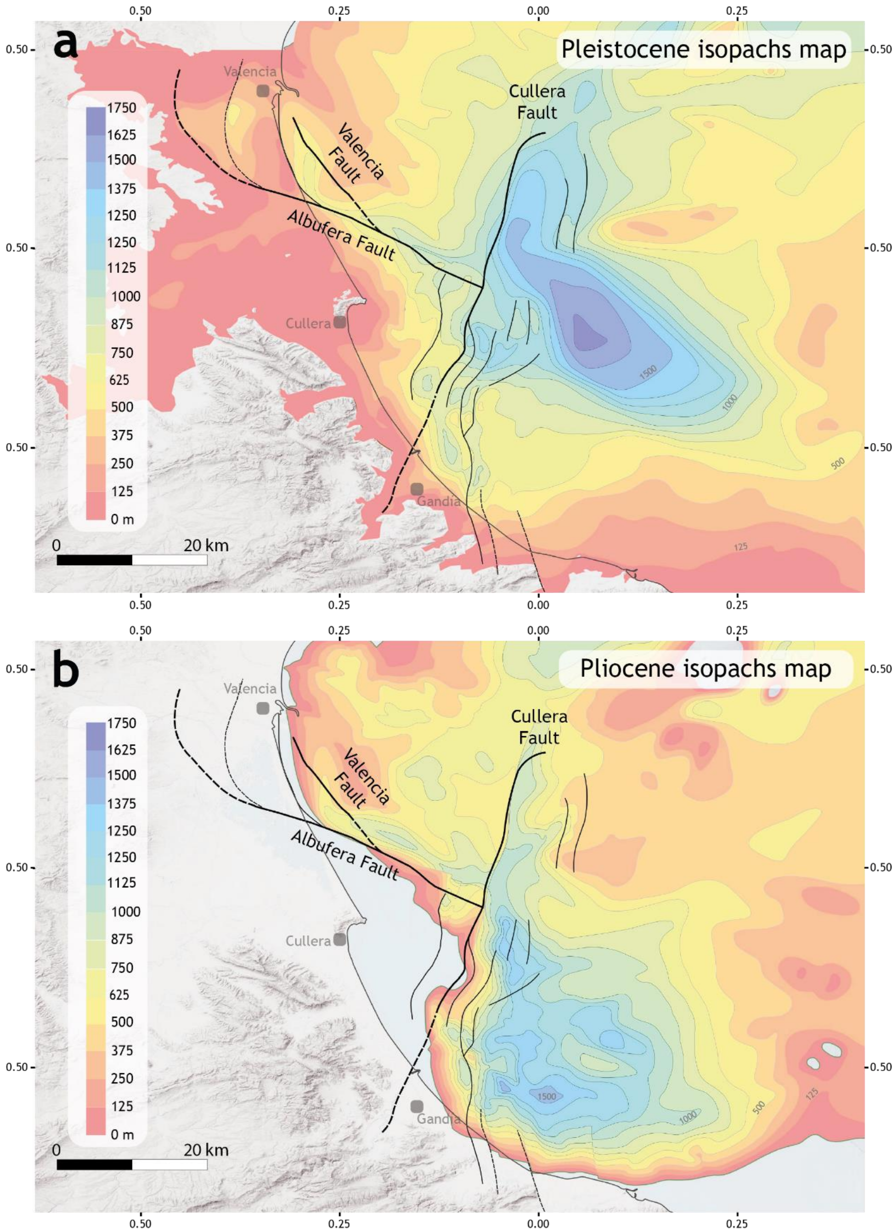

Figure 5. Isopach maps of the southwestern Valencia Trough for the Pleistocene (a) and Pliocene (b). The traces of the active faults are also depicted. Fault traces represent the horizontal projection of the direction line of the fault plane, located midway between the intersection line of the top-of-the-Pliocene horizon and the

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top-of-the-Quaternary horizon. Fault traces are derived primarily from their position on seismic profiles, supplemented by isopach maps and observed thickness variations in stratigraphic units, as indicated by the available wells. Dashed lines show interpreted traces. Modified from Ramos et al. (2025).

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5. Main active faults in the southwestern Valencia Trough

In this section, we describe the main structural features of the southwestern Valencia Trough after the analysis of gravity data and isopach maps obtained from the subsurface dataset (seismic lines, wells and VES) (Figs. 3 and 5).

The filtered Bouguer anomaly map (Fig. 3) reveals a positive anomaly in the central part of the study area, referred to as the Cullera anomaly. This positive anomaly is surrounded by a region exhibiting a negative anomaly, particularly in the offshore area located east of Cullera. We interpret this pattern of anomaly to be because of mass excess associated with a basement high (Cullera positive anomaly) surrounded by a region with greater sedimentary cover (negative anomaly). This interpretation is further supported by the isopach maps derived from interpretation of the subsurface data (Fig. 5). The negative gravity anomaly correlates with an abrupt increase in the thickness of both the Pliocene and Quaternary sedimentary successions. Furthermore, the transitions in both the gravity anomaly and sedimentary thickness correspond to the positions of the main faults observed in the seismic dataset (see below). On the basis of this evidence, we propose that the southwestern Valencia Trough is structurally characterised by the presence of three major faults offsetting the basement and significantly influencing the stratigraphic evolution of the area. These three major faults are: the Cullera Fault, the Valencia Fault and the Albufera Fault (Fig. 5).

The structural configuration of the southwestern Valencia Trough is also influenced by the presence of Upper Triassic evaporites and shales at the base of the Mesozoic sedimentary cover. This mechanically weak layer induces tectonic decoupling within the seismogenic crust of the southwestern Valencia Trough. As a result, the deformation style of the suprasalt succession (cover) differs significantly from that of the subsalt succession (basement) (Etheve et al., 2018; Fang et al., 2021; Ramos et al., 2023, 2025; Roma et al., 2018).

The analysis of the seismic reflection profiles (Fig. 6) reveals three distinct fault types: i) faults restricted to the subsalt basement; ii) faults restricted to the

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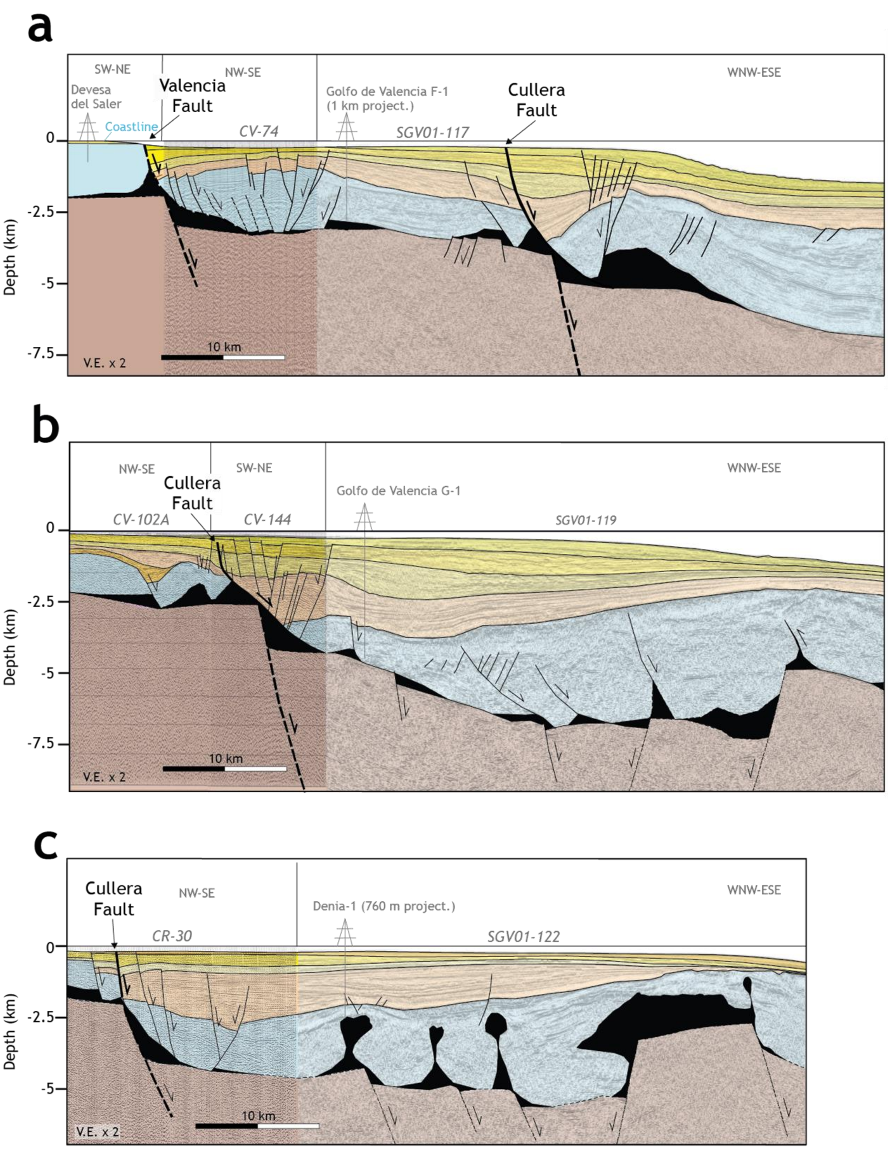
suprasalt cover; and iii) faults cutting through the sedimentary cover, basement and salt layer.



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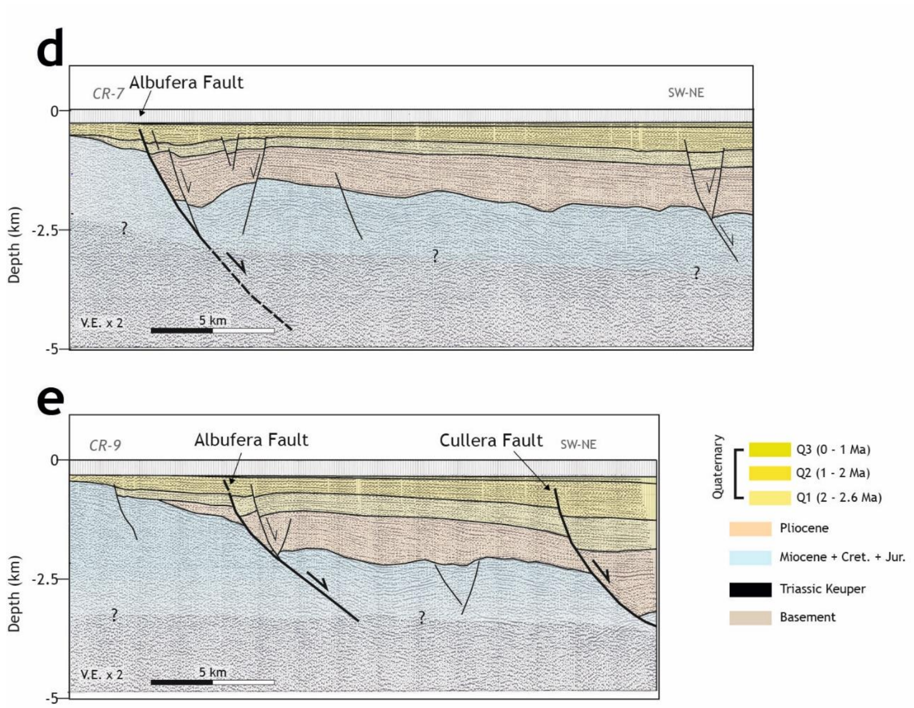

Fig. 6. Interpreted sections derived from onshore cross-sections (a) and the offshore 2D seismic profiles (a-e). See Fig. 3 for the location. a-c sections after Ramos et al., 2025.

5.1 Cullera Fault

The Cullera Fault is the longest along-strike fault in the region, spans approximately 59 km, and has the highest cumulative offset, with more than 1800 m of vertical displacement at the top of the Messinian horizon (Figs. 5 and 6).

The along-section geometry of the fault across the suprasalt succession is well imaged in the seismic reflection dataset (Fig. 6). The Cullera Fault is a normal, NNE–SSW-trending fault that dips highly towards the east. The fault offsets the entire suprasalt cover, including the 1 Ma horizon. Owing to the low resolution of the available bathymetric data, it is not possible to confirm whether the fault offsets the seafloor. The Cullera Fault displaces the top of the basement horizon, indicating that this fault involves both subsalt and suprasalt successions.

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Within the basement, the Cullera Fault is poorly imaged in seismic profiles. Nevertheless, the available data suggest that it is a planar fault (Fig. 6). This is also supported by the absence of significant tilting of the basement-top horizon.

In contrast, the geometry of the Cullera Fault in the sedimentary cover is heterogeneous. In the northern area (Fig. 6), the part of the Cullera Fault offsetting the cover exhibits a listric geometry, which is responsible for the development of a rollover structure in the hanging wall (Fig. 6). This listric geometry consists of a highly dipping (50–60º) upper part offsetting the Plio-Quaternary succession and a gently dipping (20–30º) lower part in the Mesozoic cover. Southwards, the listric geometry and related rollover fold becomes less pronounced (Fig. 6).

To better constrain the geometry of the Cullera Fault, we constructed a structural map of the fault by integrating fault traces identified in the seismic reflection dataset with isopach maps (Fig. 7). Additionally, a 3D model of the Cullera Fault, along with the two other major faults, was generated following a 2½D construction approach, integrating interpreted seismic profiles via interpolation. We employed the ordinary kriging algorithm implemented in MOVE software, a methodology consistent with previous approaches applied to analogous structures (Ramos et al., 2020), ensuring a geologically consistent representation of the fault geometry in the subsurface. This approach allows for the reconstruction of complex fault surfaces by integrating available geophysical data while minimising spatial uncertainties. Analysis of the reconstructed 3D fault indicates that the surface area of the Cullera Fault offsetting the sedimentary cover is approximately 360 km^2.

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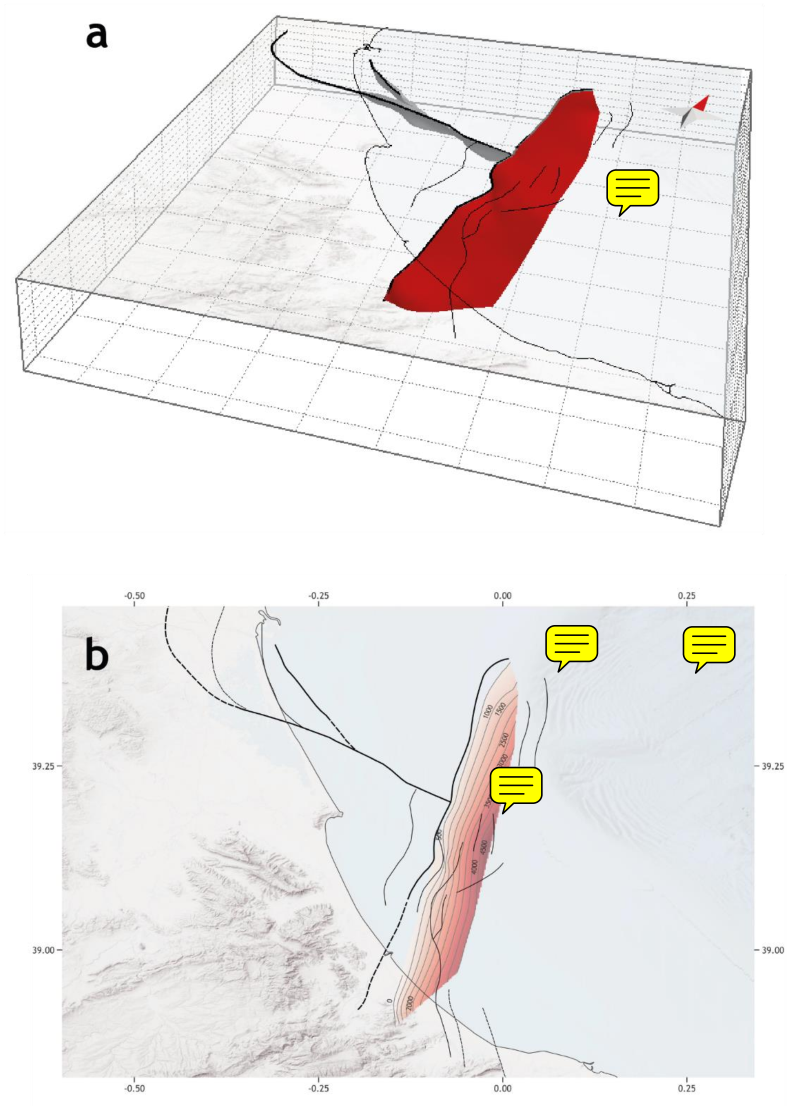

Figure 7. 3D model (a) and structural map (b) of the Cullera Fault (red surface). Squares in figure a represent 10 km x 10 km. Note the red arrow pointing to the North in figure a.

Several minor normal faults have developed in the hanging wall of the Cullera Fault (Figs. 5). These faults displace only the suprasalt succession without affecting the

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underlying subsalt units. In previous studies (e.g., Perea 2006; Roca 1992) distinct names were assigned to these faults, such as the Western Cabo Cullera Fault, Central Cabo Cullera Fault, and Eastern Cabo Cullera Fault. However, the improved resolution and quality of the new seismic dataset enable a more detailed characterisation of these tectonic structures, allowing for a reassessment of their nomenclature and role. On the basis of our analysis, we interpret these minor faults to be part of the damage zone associated with the main Cullera Fault. Fault damage zones typically consist of subsidiary structures that develop in response to the distribution of strain surrounding a major fault. In this context, these minor faults represent secondary features that contribute to the overall deformation but are structurally subordinate to the Cullera Fault. Consequently, we propose consolidating the nomenclature to avoid potential confusion. Instead of assigning separate names to these subsidiary faults, we retain the term Cullera Fault exclusively for the main structure.

The quality of the seismic dataset in profiles GV-102A and SGV-117 (Fig. 3) allows for an analysis of the slip rate of the Cullera Fault. This analysis is approximate, because of the resolution of the seismic profiles, the uncertainties in the recognition of the markers in the hanging wall and footwall, and the age of these markers. Net slip rates were obtained for the Top-Messinian, Top Pliocene, Top-Q1, and Top-Q2 horizons, with assigned ages of 5.3 Ma, 2.6 Ma, 2 Ma, and 1 Ma, respectively. Analogous values of the slip rate for each of these markers were obtained from the two analysed seismic profiles (Fig. 8). The slip rates for the Cullera Fault seem to have decreased over time, as the calculation yielded mean slip rates of 0.40 ± 0.1 mm/y for the Pliocene and 0.15± 0.1 mm/y for the Quaternary. However, we cannot dismiss that this apparent in-time evolution could be an artefact related to the epistemic uncertainties mentioned above.

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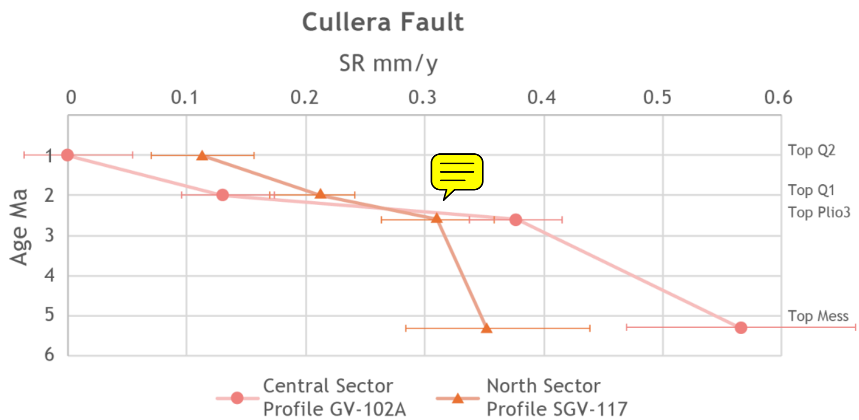

Figure 8. Long term slip rates (SR) for the Cullera Fault derived from the seismic profiles for the Top Messinian, Top Plio3, Top Q1, and Top Q2 horizons. Pink line and dots represent SR for the central sector of the fault. Orange line and triangles indicate SR for the north sector of the fault. Slip rates seem to decrease in time, from 0.40 ± 0.1 mm/y for the Pliocene to 0.15± 0.1 mm/y for the Quaternary. Error bars are estimated on the basis of uncertainties in the recognition of the markers and their ages.

5.2. Albufera Fault

The Albufera Fault (F3) (Figs. 5 and 6) is a newly defined active structure in the southwestern Valencia Trough. This NW–SE striking fault extends approximately 55 km and exhibits a maximum normal offset of 1000 m for the Top-Messinian horizon. This would imply a long-term slip rate of 0.2 ± 0.1 mm/y. The fault offsets both the supra- and subsalt successions (Figs. 5 and 6). The Albufera Fault is visible only in the vintage seismic reflection dataset, where it presents a low dip and a listric geometry.

The Albufera Fault appears to offset the entire suprasalt cover, including the 1 Ma horizon. As with other faults in the region, the low resolution of the available bathymetric data prevents us from determining whether this fault offsets the seabed. Nevertheless, high-resolution seismic profiles from the offshore shelf analysed by previous authors indicate seabed offsets caused by secondary normal

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faults likely associated with the Albufera Fault (Díaz de Río et al., 1986; Albarracín et al., 2013).

The available seismic dataset reveals a normal kinematic component for the Albufera Fault. However, mapping of small-scale fault traces in upper Pleistocene–recent sediments (interval between the seabed and the 1.8 Ma horizon) reveals that these faults are oblique to the main trend of the Albufera Fault, forming an en echelon pattern in map view, which suggests that the Plio-Quaternary reactivation of the main fault has a significant right-lateral strike-slip component. This dextral component along the NW–SE trending fault is consistent with the regional ENE–WSW direction of Plio-Quaternary extension in the southwestern Valencia Trough and kinematically consistent with NNW–SSE trending normal faults. The fault influences the Plio-Quaternary sedimentary infill of the southwestern Valencia Trough (Fig. 5). The computed isopach maps reveal that the Pliocene succession significantly increased in the hanging wall relative to the footwall. Similarly, the Quaternary succession is thicker in the hanging wall than in the footwall. The listric geometry of the Albufera Fault is responsible for the development of a rollover anticline in the hanging wall (Fig. 6). This anticline is likely accentuated by the palaeoshelf edge of the late Tortonian–early Messinian shelf, which is located in the central part of the rollover structure.

To further constrain the geometry of the Albufera Fault, a structural map of the fault was constructed (Fig. 9). Analysis of the reconstructed 3D fault surface indicates that the fault encompasses an area of approximately 560 km^2.

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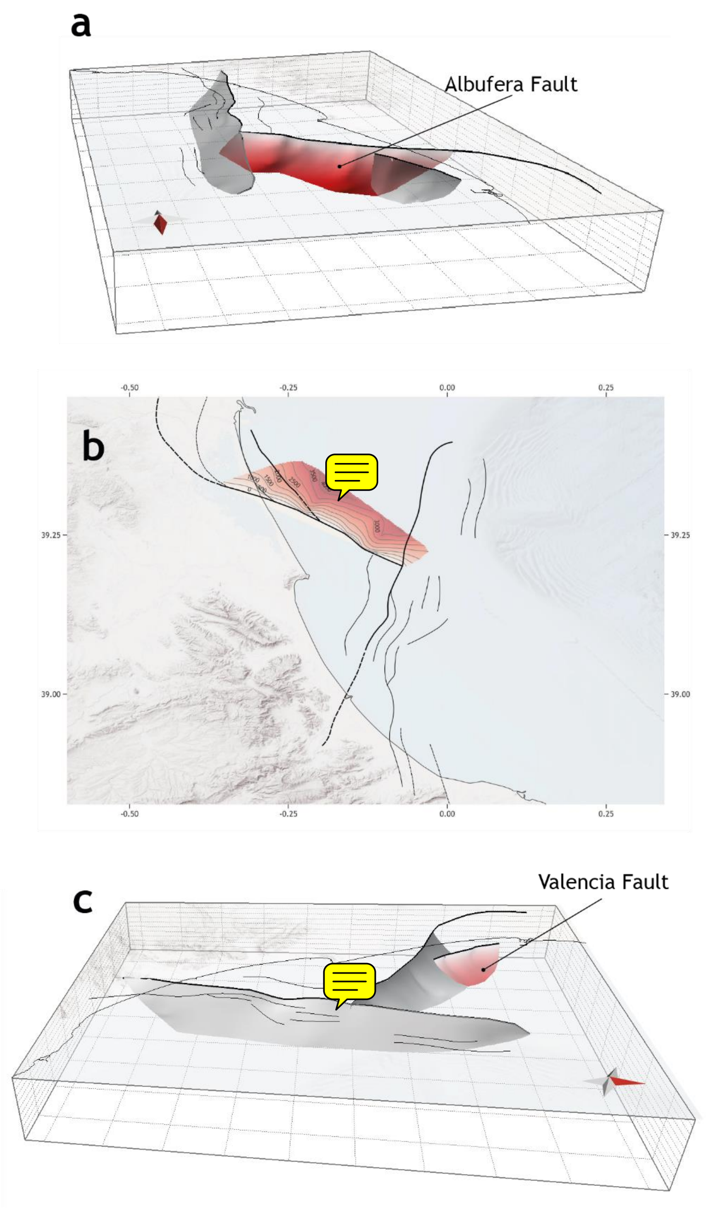

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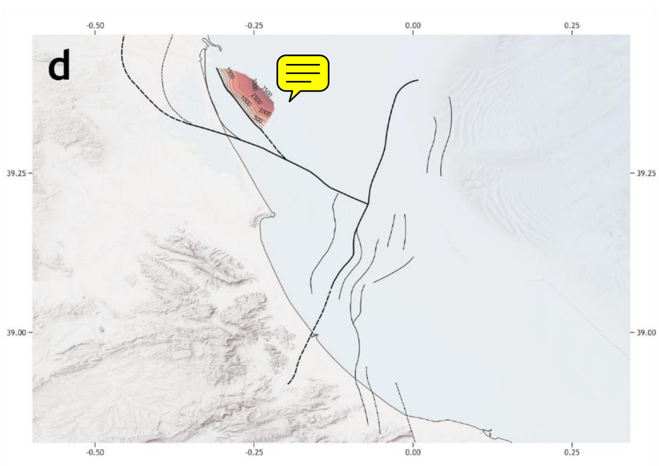

Figure 9. 3D model and structural map of the Albufera Fault (a and b) and the Valencia Fault (c and d). Squares in 3D models represent 10 km x 10 km. Note the red arrow pointing to the North in figures a and c.

5.3 Valencia Fault

In this section, we define ~~for the first time~~ the Valencia Fault (Figs. 5 and 6). This structure is considered one of the main active faults in the southwestern Valencia Trough because of its length of approximately 20 km and its significant impact on the distribution of Quaternary depocentres. The Valencia Fault displaces both the supra- and subsalt successions (see below) (Figs. 5 and 6).

This NNW–SSE trending, steeply dipping fault is imaged primarily in the vintage seismic reflection dataset, where it exhibits a listric geometry, at least in the portion offsetting the suprasalt succession (Fig. 6). The Valencia Fault offsets the entire suprasalt cover, including the 1 Ma horizon. However, owing to the low resolution of the available bathymetric data, it is not possible to determine whether this fault offsets the seabed. The Valencia Fault also displaces the top of the basement horizon, indicating that this structure involves both subsalt and suprasalt successions. Within the basement, the Valencia Fault is not well-imaged in the

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seismic profiles, but the absence of tilting in the basement-top horizon suggests that it is a planar fault (Fig. 6). The Valencia Fault and its secondary strands very likely continue onshore below the City of Valencia. The lack of onshore seismic data hampers the mapping of these fault strands, but their presence can be inferred from the abrupt Plio-Quaternary thickness changes observed in water wells and Vertical Electric Sounding profiles.

To further constrain the geometry of the Valencia Fault, a structural map of the fault was constructed (Fig. 9). Analysis of the reconstructed 3D fault surface indicates that the fault encompasses an area of approximately 208 km^2.

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6. Evolutionary growth of the Cullera Fault: interplay between tectonics and salt withdrawal.

This section aims to provide further insights into the evolution of the active faults in the southwestern Valencia Trough. The low resolution of the vintage seismic dataset limits the ability to perform a detailed analysis only for the Cullera Fault. To analyse recent along-dip variations in throw, we constructed throw-depth plots (T-z plots) for the post-Messinian markers (Fig. 10). These plots provide insights into the evolutionary growth of the fault (Mansfield and Cartwright, 1996; Hongxing and Anderson, 2007). The quality of the available seismic reflection dataset allows this analysis to be performed on two seismic profiles located in the northern part of the fault, where the listric geometry is well-developed (LINES SGV01-115 and SGV01-117; Fig. 6).

We computed T-z plots for six suprasalt horizons: Top-Messinian, Top Plio1, Top Plio2, Top Plio3, Top Q1, and Top Q2 (Fig. 10). The T-z plots for the Cullera Fault reveal a general increase in the throw and throw gradient with depth. However, the data indicate two distinct portions with differing throw gradients: (i) the lower portion, with higher throw gradients, includes horizons from the Top Messinian to the Top Pliocene; (ii) the upper portion, with lower throw gradients, comprises the Quaternary horizons. This distinction between these two portions is particularly pronounced in the southern seismic line (line SGV01-117, Fig. 6). Here, the throw gradient decreases, from 2.38-2.98 in the lower portion to 0.22-0.10 in the upper portion.

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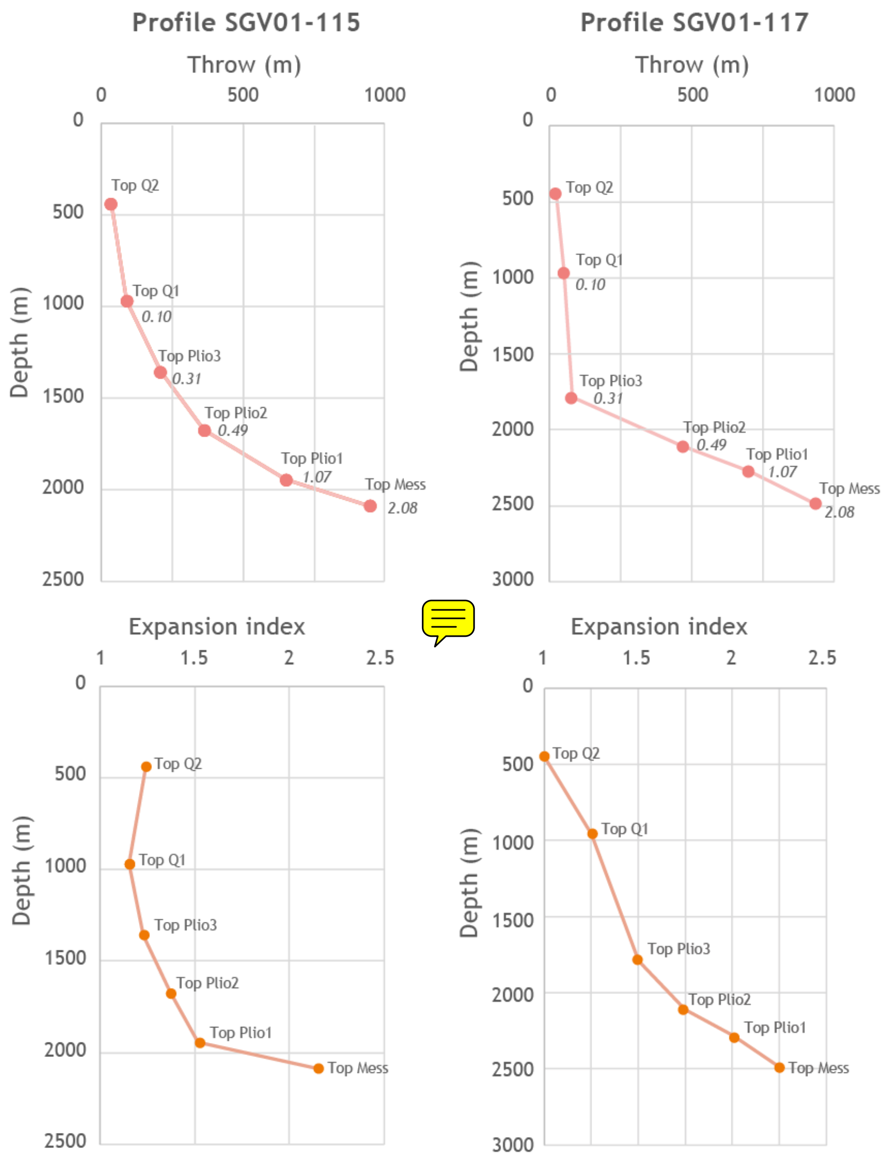

Figure 10. Throw depth (T-z) and expansion index plots for the Cullera Fault computed from profiles SGV01-115 and SGV01-117. The numbers within the T-z plots indicate the throw gradient for the corresponding interval. The T-z plots reveal an increase in the throw and throw gradient, with a higher throw gradient for the Top Messinian–Top Pliocene interval and a lower throw gradient for the Quaternary interval.

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The Cullera Fault significantly influences the Plio-Quaternary sedimentary infill of the southwestern Valencia Trough. Isopach maps indicate a marked increase in the thickness of both Pliocene and Quaternary successions in the hanging wall with respect to the footwall (Fig. 5). This thickness variation offers critical insights into the history of fault growth. To quantify this relationship, we computed the expansion index (Thorsen, 1963; Rouby et al., 2003; Jackson and Rotevatn, 2013) for the post-Messinian stratigraphic units (Fig. 10). The expansion index consistently exceeds 1 across all the analysed intervals, indicating a synkinematic deposition in these units. Notably, the Pliocene units exhibit a greater expansion index than the Quaternary units do, with the difference being particularly pronounced in the southern seismic line (Fig. 6 LINE SGV01-117).

Finally, to shed light on the mechanisms controlling the creation of accommodation space related to the Cullera Fault, we analyse the tectonic–stratigraphic arrangement of the hanging wall units. In the northern part of the Cullera Fault, where the rollover structure is well developed (Fig. 6), the position of the Plio-Quaternary depocenter in the hanging-wall varies along the dipdirection. The Pliocene depocentre remains in the immediate hanging wall of the fault. However, during the deposition of unit Q1, the depocentre migrated basinwards. The depocentre of unit Q2 is located adjacent to the fault, whereas the depocentre of unit Q3 is located further east, related to the progradational geometry of the sedimentary bodies. Nevertheless, when focusing strictly on the area affected by the fault, the local Q3 depocentre also remains adjacent to the fault.

Analogous stratigraphic geometries have been observed in the Danish North Sea, where they have been interpreted in terms of the evolution of a salt-influenced fault (Duffy et al., 2023 and references therein). In such a setting, two mechanisms create accommodation space: fault displacement and load-driven salt withdrawal in the hanging-wall. These two mechanisms can act separately or contemporaneously in time. When the accommodation space generated by the fault offset exceeds that created by salt withdrawal, the depocentre axis remains adjacent to the fault. In contrast, when salt-related accommodation space is dominant, the depocentre migrates away from the fault (Duffy et al., 2023).

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Accordingly, we interpret that, during the Pliocene, the accommodation space generated by the displacement of the Cullera Fault exceeded that produced by the accommodation space related to salt withdrawal, as evidenced by the depocentre's axis being located adjacent to the fault (Fig. 6). During the deposition of unit Q1, the depocentre migrated basinwards, suggesting that salt withdrawal-related accommodation space outpaced that related to fault displacement. Finally, during Q2 and Q3, the depocentre axis shifted towards the fault, indicating that fault displacement-related accommodation space regained dominance over salt mobility.

All the above-described features shed light on the evolution of the salt-influenced Cullera Fault. As previously discussed, the creation of accommodation space results from two mechanisms: tectonic offset along the fault and displacement related to salt withdrawal. Both mechanisms act cumulatively; that is, both mechanisms produce slip along the Cullera Fault and create accommodation space. The migration of successive depocentres suggests that, during the Pliocene, accommodation space related to tectonic offset was greater than that created by salt withdrawal. As, the throw gradient is high (≈ 2.4) during this period, we postulate that both mechanisms were active. During the deposition of Q1 (2.6–2 Ma), the position of the depocentre suggests that salt mobility became the dominant mechanism, likely due to a decrease in fault activity, an increase in salt withdrawal, or both. As the throw gradient decreases during this period, we postulate that a decrease in the fault displacement rate could be the reason for the change in the main mechanism. Finally, during the rest of the Quaternary (2 Ma to present), fault displacement-related accommodation space once again exceeded that created by salt withdrawal. The constant throw gradient observed during this period with respect to the previous time interval (2.6–2 Ma) suggests that the change in the main mechanism was due to a reduction in or cessation of salt withdrawal. This interpretation is further supported by the off-fault geometry of the Q2–Q3 sedimentary bodies, as no significant change in thickness is observed above the salt withdrawal-related anticlinal crest located east of the Cullera Fault (Fig. 6). Therefore, the evolution of the Cullera Fault during the Pliocene–Quaternary time

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span was controlled mainly by the tectonic offset, except for the time interval between 2.6 and 2 Ma, when offset was related mainly to salt withdrawal.

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7. Influence of mechanical layering on the seismic potential: the case of the southwestern Valencia Trough

The southwestern Valencia Trough has a distinct mechanical stratigraphy characterised by a subsalt basement and a suprasalt Mesozoic–Quaternary sedimentary succession. These two units are separated by a weak mechanical layer composed of Triassic evaporites. These lithologies are well documented for their ductile behaviour, which enables them to act as regional detachment layers (e.g., Morley et al., 2003; Jackson and Hudec, 2005) and inhibits the propagation of faults (e.g., Withjack et al., 1990; Pascoe et al., 1999; Maurin and Niviere, 2000; Withjack and Callaway, 2000; Richardson et al., 2005; Ford et al., 2007; Kane et al., 2010; Marsh et al., 2010). Moreover, mechanically weak layers have been shown to induce full or partial geometric and kinematic decoupling between sub- and supradetachment successions (e.g., Stewart et al., 1997; Withjack and Callaway, 2000; Ford et al., 2007; Tvedt et al. 2013). In this section, we focus on the implications of this mechanical arrangement in terms of the seismic potential of salt-influenced active faults.

In an active region, tectonics are generally the main driving mechanism of fault displacement. However, in the case of salt-influenced faults, displacement can also result from salt withdrawal. Our analysis of the evolution of the Cullera Fault presented in the previous section indicates that the fault offset is related to the interplay between two mechanisms: tectonic offset along the fault and displacement related to salt withdrawal. Our analysis also reveals how these two processes interact with each other. Consequently, in areas with salt-influenced faults, seismicity can potentially be produced from either mechanism or a combination of both.

In terms of seismic potential, there is a significant difference between a tectonic earthquake and a salt-withdrawal earthquake. This difference lies in the maximum potential thickness of the seismogenic layer involved in the rupture. A tectonically driven earthquake could theoretically rupture the entire seismogenic crust. In contrast, a salt withdrawal-related earthquake would imply offset restricted to the suprasalt succession. Therefore, in an earthquake restricted to the suprasalt

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succession, the thickness of the seismogenic layer is limited by the depth of the mechanically weak layer, reducing the maximum potential rupture area and, consequently, the seismic potential. A salt-withdrawal-related earthquake could induce a vertical stress drop related to salt displacement, potentially triggering displacement in the subsalt succession and leading to a complex rupture. However, in terms of seismic potential, such a hypothetical earthquake would not differ from a tectonically-driven event. Similarly, a tectonically driven earthquake may rupture only the suprasalt succession.

Despite the mechanism driving seismicity, the presence of a weak mechanical layer within the seismogenic crust significantly influences the seismogenic potential of active faults. We hypothesise that this weak layer could locally hinder the effective vertical propagation of a rupture, thereby resulting in faults being seismogenically bonded. Specifically, the total or partial decoupling induced by the weak evaporitic layer may limit the effective width of the seismogenic layer. This hypothesis is independent of the weak layer composition; therefore, our hypothesis can be extended to any region with a similar structural configuration.

A widely used approach to characterise the seismic potential of an active fault involves earthquake fault scaling relationships. These relationships estimate the seismic parameters of an active fault on the basis of its geometric and/or kinematic features (Kanamori and Anderson, 1975; Geller, 1976; Wells and Coppersmith; 1994; Stirling et al., 2002 and 2013; Leonard, 2010 and 2014; among many others). In the case of the southwestern Valencia Trough faults, the available data support characterisation on the basis of geometric features, such as fault area, length, or width. However, the mechanical layering observed in the southwestern Valencia Trough necessitates the cautious application of these scaling relationships. The influence of the weak mechanical layer introduces complexities that may not be fully accounted for by traditional scaling methods.

Therefore, we begin our analysis by comparing the southwestern Valencia Trough with the Zagros fold-and-thrust belt. While Zagros fold-and-thrust belt differs tectonically from the southwestern Valencia Trough, as it is dominated by shortening rather than extension, it structurally resembles the southwestern

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Valencia Trough because of its pronounced mechanical layering in the upper crust. The Zagros fold-and-thrust belt features a crystalline basement overlain by a 10-km-thick Precambrian–Quaternary sedimentary cover. These two successions are separated by the Hormuz salt layer (Casciello *et al.* ,2009; Sherkati *et al.;* 2005; Molinaro *et al.,* 2005). That is, similar to the southwestern Valencia Trough, the seismogenic crust is characterised by the presence of an intermediate mechanically weak layer. Seismicity in the Zagros fold-and-thrust belt is characterised by a general absence of coseismic surface ruptures. This seismicity nucleates both in the basement and in the cover (Nissen et al., 2011). Notably, the centroids of most of the larger events (magnitudes exceeding Mw 5), are located at depths between 4 and 14 km, indicating that seismic activity nucleates both within the suprasalt succession and in the basement (Nissen et al. 2007, 2010; Roustaei et al. 2010). Additionally, very large earthquakes have occurred in the Zagros fold-and-thrust belt; these earthquakes include the Ghir and Khurgu events (M_w=6.7), which are interpreted as ruptures involving both the basement and the cover, rupturing through the basement–cover interface (Nissen et al., 2011).

We propose that the southwestern Valencia Trough may exhibit a comparable pattern of seismicity to that of the Zagros fold-and-thrust belt. Specifically, we hypothesise that seismic events in the southwestern Valencia Trough could have nucleated within both the basement and the suprasalt succession. Furthermore, we postulate that larger earthquakes in the southwestern Valencia Trough could also rupture both mechanical layers. Available centroid data for the southwestern Valencia Trough suggest that most earthquakes nucleate at depths between 1 and 13 km (Fig. 2). Although these depth estimates carry significant uncertainties, we interpret this dataset as supporting evidence for our hypothesis that seismicity in the southwestern Valencia Trough nucleates both in the basement and in the cover.

As we mentioned previously, most empirical source-scaling relationships for crustal earthquakes correlate the moment magnitude (Mw) with the fault dimensions (length, width, and/or area; (Kanamori and Anderson, 1975; Geller, 1976; Wells and Coppersmith; 1994; Stirling et al., 2022; Leonard, 2010; among many others). We propose that when these scaling relationships are applied to regions with a weak

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mechanical layer, the role of this layer should be explicitly considered in the analysis. This is because the presence of a weak layer can potentially hinder the effective vertical propagation of a rupture, thereby limiting the effective width of the seismogenic layer. This consideration is particularly relevant for earthquakes that nucleate above the weak layer.

Several studies suggest that the downdip width of the seismogenic crust (the thickness of seismogenic crust measured along the fault plane) can constrain the maximum magnitudes of earthquakes (Hyndman, 2007; Ruff and Kanamori, 1983; Weng & Yang, 2017). For large-magnitude events involving the entire seismogenic crust, some scaling relationships account for the constraint on fault-width rupture growth relative to fault-length rupture growth by incorporating a change in slope in width-to-length scaling (Leonard, 2010; Yen and Ma, 2011; Leonard, 2014; Cheng et al., 2019; Huang et al., 2024). This change in slope reflects the width of the seismogenic crust, which imposes a limit on rupture propagation owing to variations in the mechanical behaviour of the crust. We propose a similar approach to evaluate the seismic potential of regions characterised by a weak mechanical layer within the upper crust, such as the southwestern Valencia Trough.

Our approach involves including the rupture aspect ratio when calculating the geometric parameters of an active fault. Specifically, we propose that, instead of using the total area or length of the fault as direct inputs to scaling relationships, a correction factor should be applied to these geometric parameters. This correction factor is based on the empirical aspect ratio of faults. For example, consider an earthquake nucleating above a weak mechanical layer. Two potential scenarios for the propagation of such an earthquake can be envisioned: i) that it propagates through the basement–cover interface or ii) that it remains restricted to the succession above the weak layer. In the first scenario, the potential maximum rupture area can be calculated by multiplying the fault length by the fault width. Any area-based or length-based scaling relationship can then be applied. This scenario represents the maximum seismic potential of the fault.

In the second scenario, where rupture propagation is restricted to succession above the weak layer, a simplistic calculation of the fault area would multiply the total fault

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length by the thickness of the ruptured succession (Fig 11). However, since the hypothesised rupture offsets only the succession above the mechanically weak layer, the width of the rupture is significantly limited. This would result in a highly elongated rupture with an unusually high aspect ratio, deviating from commonly observed values (Nicol et al., 1996; Stock & Smith, 2000). For this second scenario, we propose using the thickness of the ruptured succession as a limiting factor. Specifically, the rupture area should be calculated by multiplying the width of the fault offset (based on the thickness of the succession above the weak layer and corrected by the fault dip) by the total fault length weighted by the aspect ratio (Fig 11). This weighted area can then be used as input in any area-based scaling relationship. We consider that this calculation offers a more realistic estimation of the maximum seismogenic potential for events rupturing only the succession above the weak layer. Finally, we recommend avoiding length-based scaling relations for this second scenario, as such relations implicitly assume a rupture of the entire seismogenic crust.

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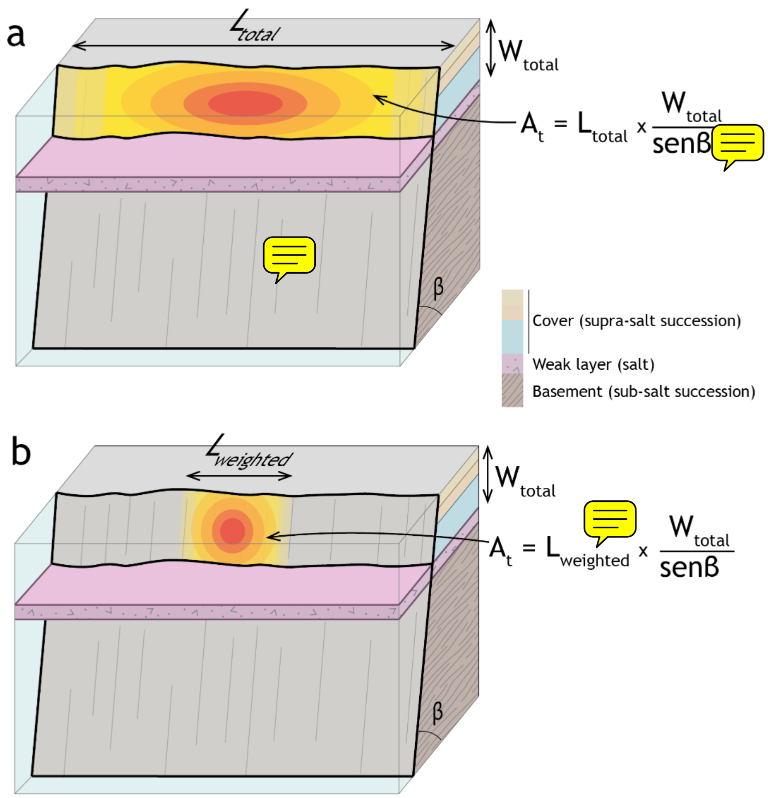

Figure 11. Conceptual model of the weighted rupture area of an earthquake nucleating above the weak mechanical layer. The area of the rupture is shown using a red–yellow gradient. An earthquake rupturing the total fault length (L) and the total thickness (W_{total}) above the weak layer would result in nonrealistic, highly elongated ruptures. In figure panel b, we propose a more realistic case: an earthquake offsetting the total thickness above the weak layer (W_{total}) and a rupture length weighted by the aspect ratio (L_w).

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8. Seismic characterisation of active faults in the southwestern Valencia Trough.

In this section, we compute the seismic potential of the active faults in the southwestern Valencia Trough by applying several scaling relationships. We perform two distinct calculations corresponding to the two scenarios described earlier. i) In the first scenario, we assume a rupture involving both the supra- and subsalt successions. That is, this first scenario accounts for an earthquake rupturing the entire seismogenic crust. This scenario provides the maximum seismic potential of the faults. ii) In the second scenario, we assume that a rupture is restricted to the suprasalt succession. For this calculation, we apply several area-based scaling relationships, and we use the area weighted by the aspect ratio as the input parameter. Since the rupture area involved in this second scenario is relatively small, a relatively low seismogenic potential is expected.

8.1. First scenario: Ruptures involving the entire seismogenic crust.

For both scenarios, we apply the scaling relationships of Wells & Coppersmith (1994) (values corresponding to normal faults) and Stirling et al. (2002). In the first scenario, i.e., ruptures involving the entire seismogenic crust, we assume that a complete fault ruptured from the subsalt basement through the suprasalt succession. Since the total thickness of the seismogenic crust is not precisely known, we used the fault length as the primary input parameter for these calculations (Table 1).

Table 1 Source parameters obtained from scaling relationships (Wells & Coppersmith, 1994 -WC94- and Stirling et al., 2002 -Stirling02-) assuming ruptures involving the entire seismogenic crust.

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	Input parameters	WC94			Stirling02	
	L km	M_W	AD m	MD m	M_W	AD m
Cullera Fault	59	7.2 ±0.34	1.61 ±0.37	4.94 ±0.41	7.3 ±0.30	2.39 ±0.24
Albufera Fault	20	6.58 ±0.34	0.42 ±0.37	0.97 ±0.41	6.92 ±0.30	1.97 ±0.24
Valencia Fault	40	6.97 ±0.34	0.99 ±0.37	2.75 ±0.41	7.16 ±0.30	2.23 ±0.24

8.2. Second scenario: Ruptures involving only the suprasalt succession

In this scenario, the presence of a mechanically weak layer within the seismogenic crust is considered to control the seismic potential of active faults. As discussed previously, we use the weighted rupture area as the input parameter for the scaling relationships. The weighting factor is based on the aspect ratio of normal faults. To provide context for this approach, we also present seismic parameters calculated from the total fault area offsetting the entire suprasalt succession. The aspect ratios of normal fault ruptures vary widely (0.4–18); however, most of the observed ruptures are within the range of 0.5 to 3.5 (Nicol et al., 1996; Stock & Smith, 2000), with a mode value of 1.8 (30%, Stock & Smith, 2000). Numerical simulations of strike-slip faults by Weng & Yang (2016) demonstrated that the width of the seismogenic layer significantly influences the rupture aspect ratios. According to their findings, a seismogenic layer thickness of approximately 10 km marks a critical boundary: for thicknesses less than this value, rupture aspect ratios remain low (ca. 2), whereas thicknesses greater than 10 km result in significantly higher aspect ratios (<8). Considering these findings and given that the suprasalt succession in the southwestern Valencia Trough has an average thickness of approximately 5 km, we adopt an aspect ratio of 1.8 for our calculations.

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In the southwestern Valencia Trough, the suprasalt succession thickness (~5 km) and an average fault dip of ~45° yield a maximum rupture width of approximately 7.1 km for events confined to the suprasalt succession. For events unrestricted by the aspect ratio (i.e., earthquakes rupturing the entire fault length and width of the suprasalt succession), we compute the rupture area as the product of length and width (L*W). However, when the seismic potential for ruptures weighted by the aspect ratio is calculated, the controlling factor is the fault width. As we assume a constant thickness for the suprasalt succession across southwestern Valencia Trough, the rupture area and corresponding seismic potential are consistent for all the faults in this study (Table 2).

Table 2 Moment magnitude obtained from scaling relationships (Wells & Coppersmith, 1994 -WC94- and Stirling et al., 2002 -Stirling02-). The first column (not weighted area) corresponds to the values obtained assuming ruptures involving the total suprasalt succession. The second column (weighted area) shows the values obtained using the area weighted by the aspect ratio as input parameter.

	Not weighted area			Weighted area		
	Input parameters A km^2	M_W WC94	M_W Stirling02	Input parameters A km^2	M_W WC94	M_W Stirling02
Cullera Fault	511.4	6.69 ±0.34	7.07 ±0.26	135.2	6.10 ±0.34	6.65 ±0.26
Albufera Fault	346.[illegible]	6.21 ±0[illegible]	6.72 ±0.26	135.2	6.10 ±0.34	6.65 ±0.26
Valencia Fault	173.4	6.52 ±0.34	6.94 ±0.26	135.2	6.10 ±0.34	6.65 ±0.26

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The comparison between the standard application of earthquake source scaling relations and the approach presented here for regions characterised by the presence of a weak mechanical layer within the seismogenic crust reveals significant differences (Fig. 12). The maximum expected magnitudes for characteristic events rupturing the entire seismogenic crust (i.e., propagating across the basement–cover interface) are estimated to be 7.2–7.3, 6.58–6.92, and 6.97–7.16 for the Cullera, Valencia, and Albufera Faults, respectively. In contrast, for hypothetical earthquakes restricted to the suprasalt succession and rupturing of the total length of the faults, the expected magnitudes are lower, ranging from 6.7–7.1, 6.2–6.7, and 6.5–6.9 for the Cullera, Valencia, and Albufera faults, respectively. However, in such cases, we argue that the seismic potential derived using area-weighted relations provides a more realistic estimate. Using this approach, our calculations yield maximum magnitudes of 6.1–6.7 for all faults. These values are 2–9 % lower than those obtained when accounting for the total suprasalt succession thickness.

When the area-weighted values are compared with the maximum expected magnitudes for ruptures involving the entire seismogenic crust, the results reveal a 4–15% reduction. This discrepancy highlights the importance of incorporating mechanical layering into seismic potential assessments in regions where weak layers influence fault dynamics and rupture propagation. Furthermore, these differences in seismic potential should be addressed in probabilistic seismic hazard assessments.

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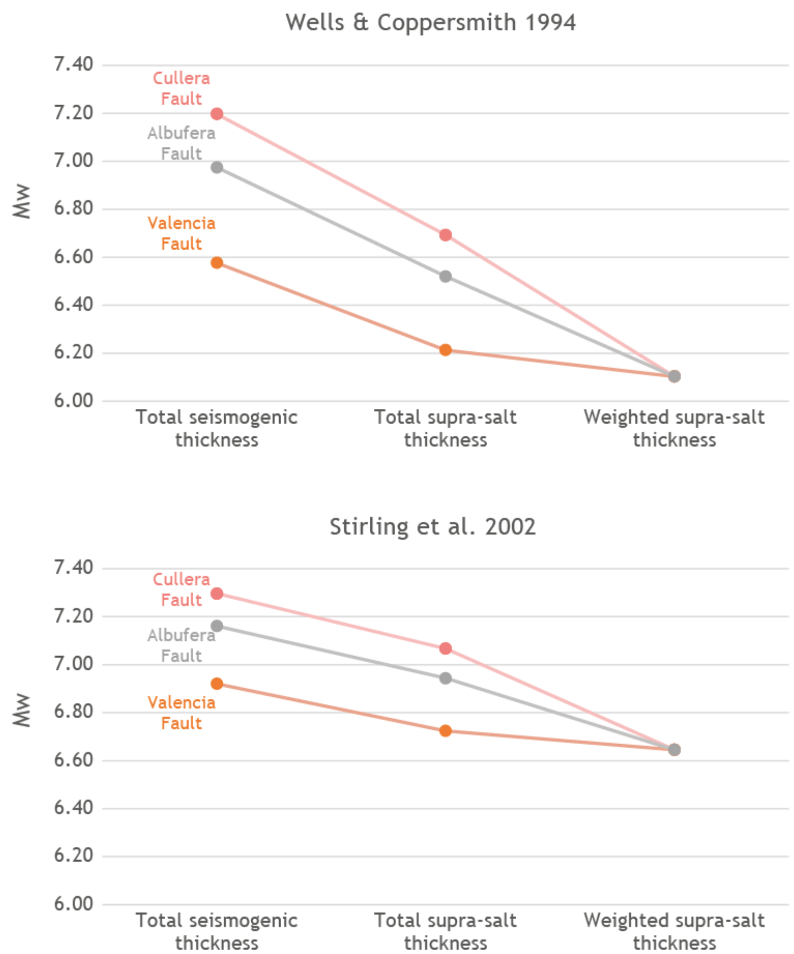

Figure 12. Plots of M_w values for the Cullera, Albufera and Valencia Faults obtained using the scaling relationships of Wells & Coppersmith (1994) and Stirling et al. (2002). The plots show the values computed assuming a rupture of the total seismogenic thickness, a rupture of the total suprasalt succession, and the values assuming a rupture of an area calculated using a suprasalt thickness weighted with the aspect ratio.

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9. Conclusions.

Analysis of a comprehensive subsurface dataset from the southwestern Valencia Trough enables the identification of three major active normal faults: the Cullera, Albufera and Valencia faults. Among these faults, the Cullera Fault is the main active structure in this region, with a cumulative offset of 1800 m at the top of the Messinian marker. The long-term slip rate varies over time between 0.15 ±0.1 mm/y and 0.4 ±0.1 mm/y. The Albufera Fault, which is 55 km in length, has a long-term slip rate of 0.2 ±0.1 mm/y, whereas the 20-km-long Valencia Fault significantly influences the spatial distribution of Quaternary depocentres.

Our results also reveal heterogeneous seismogenic crust in the study area, largely because of a mechanically weak layer, which is composed mainly of Triassic evaporites. Consequently, two competing mechanisms are responsible for the offset along the active faults: tectonics and salt withdrawal. A quantitative evolutionary analysis of the Cullera Fault indicates that tectonics was the dominant mechanism during the Pliocene, whereas salt withdrawal took precedence in the early Quaternary (2.6–2 Ma). After 2 Ma, tectonic activity once again became the primary driver of fault displacement.

The mechanically layered crust of the southwestern Valencia Trough influences seismicity: events may nucleate in either the basement or the suprasalt succession. Total or partial decoupling related to the mechanically weak layer implies that an earthquake that nucleated in the suprasalt succession would likely be restricted to this upper part of the seismogenic crust, yet larger events involving basement and cover units are also plausible. For reliable seismic hazard assessments, both scenarios must be accounted for. To compute the seismogenic potential of active faults under the assumption of rupture within the suprasalt succession, we propose the use of the rupture aspect ratio as a correction factor for the maximum rupture area. Specifically, the product of the suprasalt thickness (corrected by the fault dip) and the fault length—weighted by the aspect ratio—provides a more realistic approximation of the maximum rupture area. Using this method, the maximum magnitudes for suprasalt ruptures are 2–9% lower than those obtained by

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considering the full suprasalt thickness alone, and 4–15% lower than estimates involving the entire seismogenic crust.

Overall, these findings greatly enhance our understanding of the seismogenic potential of the southwestern Valencia Trough, an offshore area near densely populated areas. These findings provide a basis for improved seismic hazard assessments. Additionally, as we are addressing offshore faults exhibiting vertical displacement, our findings can be used to establish the tsunamigenic potential of this region. Furthermore, this approach for incorporating mechanical heterogeneities in the seismogenic crust can be applied to other regions and tectonic settings with analogous structural configurations.

10. Author contribution

Martin-Rojas, I.: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft preparation, review & editing

Ramos, A.; Data curation, Formal analysis, Funding acquisition, Investigation, Resources, Visualization, Writing – original draft preparation, review & editing

De Ruig, M.: Data curation, Formal analysis, Investigation, Resources, Visualization, Writing – original draft preparation, review & editing

Medina-Cascales, I.: Data curation, Formal analysis, Investigation, Visualization, Writing –review & editing

Santamaría-Pérez, E.: Data curation, Formal analysis, Investigation, Writing – review & editing

Alfaro, P.: Data curation, Formal analysis, Investigation, Supervision, Writing – review & editing

11. Competing interests

The authors declare that they have no conflict of interest.

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