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Article

A New Fault Branch Revealed by Geology and Archaeology Under the Seismic Lorca Town (Southeast Spain)

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Abstract: Lorca town (southeast Spain) is on the trace of the southwest-northeast Alhama de Murcia fault. This fault splits into several branches in Lorca, which are hidden under the urban area. Most of the branches were identified in excavation sites and deformed houses at the surface. The formerly hypothesized Alburquerque branch is here confirmed, with the discovery of two closely spaced faults in the 6 Selgas street excavation site. This branch, coated with fibrous gypsum, cut and verticalized middle Miocene lutites during the Plio-Quaternary, creating a breccia and fracture cleavage. It also produced surface rupture, disturbing both Late Antiquity burials and a XIII century red gravel unit, most probably accompanied by earthquakes in the town between the 5th century and the house construction date (1775 AD). The preserved southwest Aguado alley facade of that house appears nowadays bent, with the vertical edge of the dihedral angle located directly above the Alburquerque fault. This implied both 2.5° of rotation and 0.2 m of horizontal displacement in the southeast corner of the facade, along the last 250 years. Series disruption, breccia, fracture cleavage, surface rupture, and recent rotation, all features together suggest left-lateral oblique-slip action of the Alburquerque fault.

Keywords: Alhama de Murcia Fault; Alburquerque Fault Branch; Surface Rupture; Bent Facade; Miocene-Present; Sinistral Oblique-Slip

1. Introduction

Lorca, a town in southeastern Spain, is situated in a tectonically active area with a history of frequent recent earthquakes. More precisely, the town rests on the fault trace of the southwest-northeast Alhama de Murcia Fault (AMF). This is a major tectonic feature in the eastern Betics, which lies predominantly in Murcia province between Puerto Lumbreras and Murcia (**Figure 1**) [1]. This fault is a part of the larger-scale Eastern Betic Shear Zone and shows left-lateral strike-slip kinematics [2,3]. Many authors reported movements in the fault from late Miocene to the present day [4–16]. Moreover, in the AMF segment to southwest of Lorca, 5 km from the town center, the fault splits towards the northeast into several branches that affect the Betic basement, Miocene formations, and even Quaternary deposits [1,3,17–24].

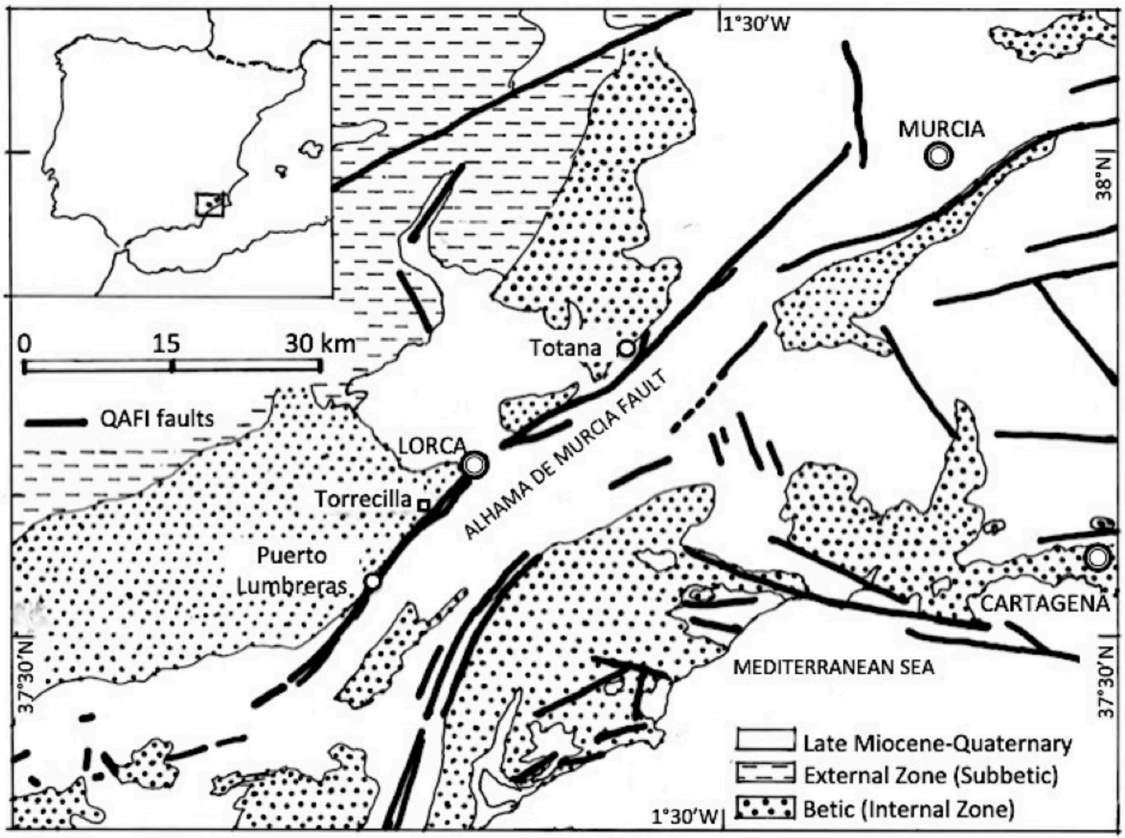

Figure 1. Location of Lorca on the trace of the Alhama de Murcia fault. Map of the faults with evidence of Quaternary activity.

Source: Quaternary Active Faults Database of Iberia [1].

Repeated movements in the Puerto Lumbreras-Lorca and Lorca-Totana segments of the AMF (**Figure 1**) produced numerous earthquakes affecting this town [9]. At least four relatively major events have been recorded over the last 500 years, dated 1579, 1674 (a double quake), 1818, and 2011, the latter with a magnitude of 5.1 [25]. All of them were quite destructive, especially the last one, despite its moderate intensity [26]. On the occasion of this shock, many studies described its surface effects [8,21,27,28].

Two recent studies in places close to Lorca are mentioned here. The first one was realized in Totana, 20 km to the northeast of Lorca. It was an archaeosismological study of the Tira del Lienzo site (Argaric, 2200–1550 cal BC), located on the trace of the Alhama de Murcia fault. It revealed an Earthquake Archaeological Effect (EAE) (c.18 cm left-lateral offset), suggesting the probable occurrence of at least one strong seismic event (6.3–6.5 Mw) around 1550 cal. BC [29]. The other one was based in La Torrecilla, 5 km to the southwest of the Lorca old town. Archaeological remains from the Andalusian Period (VIII–XII centuries) appeared affected by a 55 ± 20 cm offset in the AMF fault. The event was attributed to an intensity VIII and was attributed to the 1674 catastrophic earthquake that occurred in Lorca [13].

In a previous publication, a contribution to the post-2011 earthquake was made by characterizing old buildings with the southeast parts of their northwest-southeast facades rotated to the NE. These structures were compatible with the left-lateral movements attributed to the AMF in Lorca [23]. Other studies had already characterized those left-lateral movements [2,3,6,8,9]. Multiple archaeological excavations conducted in Lorca town during the last decades substantiated that information, as they discovered several fault branches in different points of the urban area. Considering the orientations of these faults and the orientations of traces of significantly deformed old houses, a hypothetical fault network for the Lorca urban area was proposed [23].

Only one of the named fault branches of that network lacked validation by a fault plane or structure in the subsurface: the Alburquerque fault branch, described on a map in the last section. It was proposed based on the existence of a trace of deformed houses. In 2011, a house located in that particular area was destroyed due to the last earthquake that struck the town [30]. The inner part of the house was then demolished, and in 2020, the site was archaeologically excavated. This house is in 6 Selgas Street in the old part of the town (1°41´57´´west longitude and 37°40´38´´north latitude).

The geological and archaeological exploration of the site of that house revealed the presence of a fault that had remained hidden in the urban area for hundreds of years. It is the Alburquerque fault previously hypothesized [23] and the main objective of this work. Getting inspiration from the purposes of the program "Seismic Cities" of the British Geological Survey ("Our focus is to explore the potential impact to cities from earthquakes on lesser-known local faults that are often overlooked in hazard assessments" [31]), in this work, the Alburquerque fault and its effects were characterized, contributing to understanding their past history. This history spans from the middle Miocene early Langhian (≈16 million years ago) to the present day, as the geological and archaeological remains testify.

Several cities and settlements in various parts of the world have been affected by active faults and earthquakes throughout their histories. Examples worth citing here are the 10th–11th century Church in the Central Apennines (Italy), whose remains were affected by the 1209 earthquake, collapsed during the 1706 earthquake, and were damaged again during the 1933 earthquake [32]. Another case is in the harbour city of Corcyra (Corfu, Greece), where remains of a massive quay wall, dating from the 4th to 3rd century BC, were affected by an earthquake and associated tsunami during Classical and Hellenistic times [33]. In relation to this, an intimate relationship has been established between seismic faults and past human settlements in Aegean antiquity [34]. The Helike city of ancient Achaea (Gulf of Corinth, Greece) was founded in Mycenaean times and destroyed by an earthquake and tsunami in 373 BC. Architectural remains in the area brought to light spanned the Early Bronze Age, Mycenaean, Geometric, Classical, Hellenistic, Roman, and Late Byzantine periods. In the Roman period, another earthquake hit the area in the 5th century AD, and destroyed Roman Helike. This city has suffered from strong earthquakes throughout its long history [35]. The ancient inhabitants of the area "consistently choose to resettle there, adjusting their way of living to the prevailing geomorphology and natural hazards each time" [36]. A classic example worth mentioning here is the modern city of San Francisco in California. It constitutes a large urban area on the San Andreas fault, repeatedly struck by earthquakes, with a persistent population always trying to cope with their adversities [37].

2. Materials and Methods

In the geological study traditional field work was practised, with compass and laser devices used to obtain numerical data and photographs to draw the figures. Rock types, stratification, sedimentary textures and structures, and tectonic minor and major structures were recognized directly in the excavation site. This was accompanied by office work, with elaboration of the graphic part of the study and the writing. The archaeological field work also relied on traditional data collection methods, identifying units of Late Antiquity (V-VII centuries AD) and Medieval (XII-XIII transition centuries AD) by their specific materials, including bones and man-made artifacts. It was complemented by laboratory analyses of the ceramics and human bones recovered from the excavation, as well as the office work of writing the specific part of the text.

3. Results

3.1. Geology at 6 Selgas Street Excavation

The plot of land examined for its geology was a rectangle 7 × 8 m, located in the southern corner of the excavation site. The base level of the exposed area was from 1.0 m (W) to 1.5 m (E) below the ground floor base of the demolished house. In the southern part of the excavation (southeast part of the Aguado alley facade), a vertical geological section 0.3 to 1.0 m high displayed fresh outcrops of rocks, with detailed stratigraphy and structure (**Figure 2**).

It contained strata, mostly compacted gray lutites, with intercalated thin (up to 15 cm thick) isolated beds of very thin-grained sandstones and siltstones, completely decalcified and dipping 340/62 (**Figure 3**).

Figure 2. Southwestern part of the excavation site showing middle Miocene compacted lutites directly below the foundations of the Aguado alley wall. The bar (1 m) gives the scale. View from the southeast.

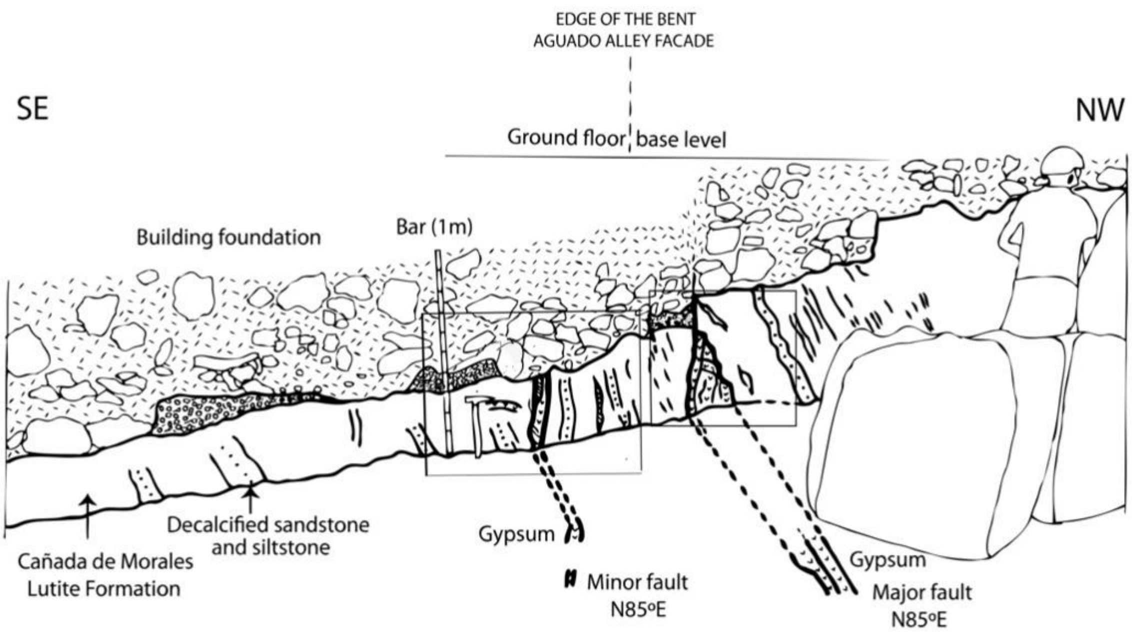

Figure 3. Drawing made from the photograph in **Figure 2**. Middle Miocene lutites (N70°E62°N) with isolated sandstones and siltstones in **Figure 2** are cut by two vertical faults, Major and Minor (N85°E), coated with fibrous gypsum. The Major fault shows a step approximately 15 cm high, partially filled with red gravel, located below the house foundations. The bar (1m) gives the scale. The left box shows the area of the Minor fault that appears in detail in **Figure 4**. The right box shows the area of the Major fault represented in detail in **Figure 5**.

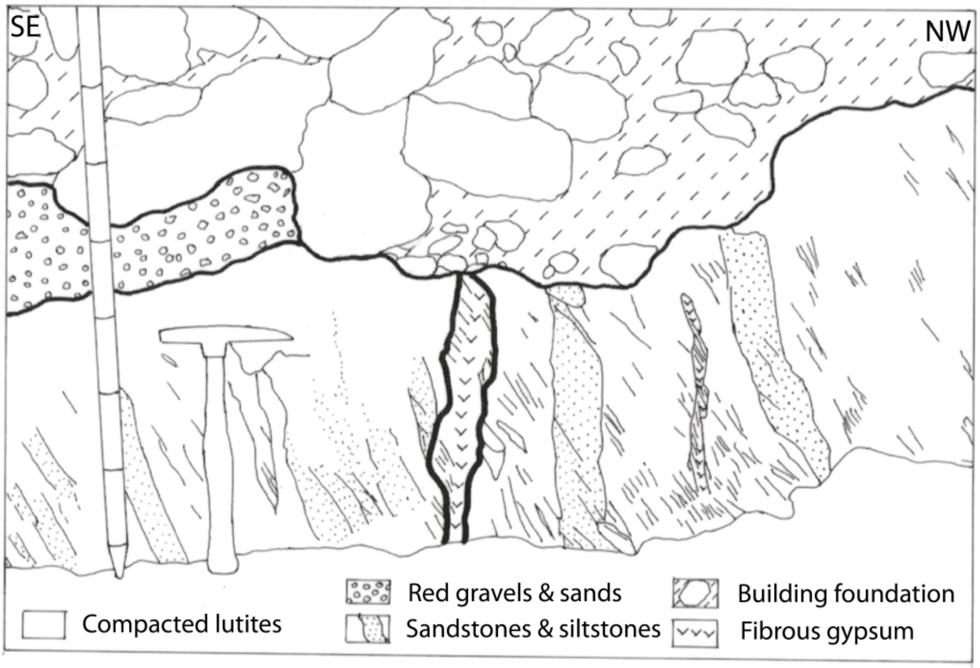

Figure 4. Close-up view of the area affected by the Minor fault, taken from a picture. Strata adjacent to the fault to the northwest are vertical, as the fault plane. Lutite, sandstone, and gypsum lithologies exhibit similarly oriented fracture cleavage, dipping towards the northwest and concentrated northwest of the fault. A residue of red gravel rests below the building foundations in the left part of the drawing. The geological hammer (0.33 m) gives the scale.

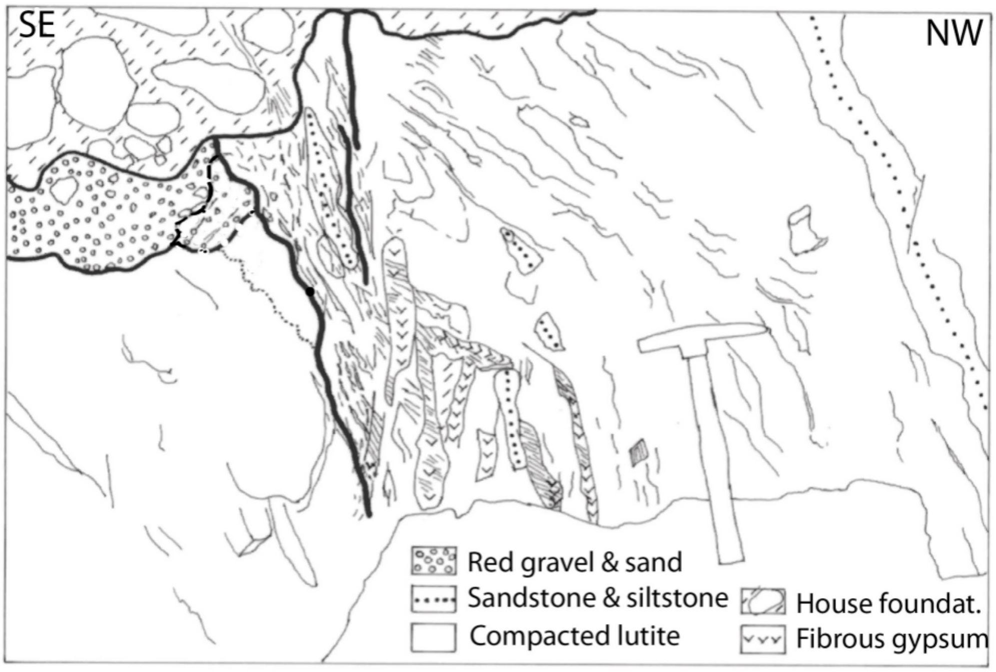

Figure 5. Close-up view of the vertical section affected by the Major fault. This structure shows a step depressing the southeastern block, previous to the emplacement of house foundations, with a residue of red gravel trapped by the fault plane at least 4 cm. A fault breccia up to 30 cm thick, made up of lutite, gypsum, and sandstone angular clasts, characterizes the fault zone. Fracture cleavage affects all lithologies in the northwest block, with sub-vertical orientation close to the fault plane, and decreasing dip towards the northwest . The geological hammer (0.33 m) gives the scale. Drawing made from a photograph, different from the one shown in **Figure 2**.

At a distance of 4 m from the SE end of the Aguado alley facade, a fault oriented N85°E90° appeared between two sandstone-siltstone beds. The fault plane had associated a white gypsum vein 5 to 6 cm thick, with oblique fibers (**Figure 4**).

Just northwest of this fault, the stratification showed up verticalized. In an interval up to 0.7 m wide equally to the northwest of the fault, these vertical strata presented a set of regular, closely spaced, parallel fractures, spaced from 0.5 to 2.0 centimeters, along which the rock easily split. These fractures, abundant in the compacted lutites, were also present in the gypsum intercalations. In this later lithology, they appeared as oblique fibers both in the fault-bound vein and in another, discontinuous vein 2–3 cm thick, located 0.3 m to the northwest of the fault. On the contrary, fractures were rare in the intercalated vertical sandstones, and they did not appear in the red gravel and building foundation rocks located above the lutites. They showed a 61° dip in the N320°E direction in both lutite strata and gypsum veins, so they were parallel irrespective of their supporting lithology (**Figure 4**).

In the same vertical section, 1 m to the northwest from the described fault, another fault oriented N85°E74°N was present (**Figures 3** and **5**).

The plane of this later fault bounded a polymictic breccia, 15 to 30 cm thick, made up of gypsum vein fragments up to 36 cm long, and sandstone bed fragments up to 23 cm long, supported by gray lutites. Most of the breccia clasts appeared oriented subvertically, but a few of them -one of gypsum lithology- were also oriented subhorizontally (**Figure 5**). In a small sharp bend of the section, a preserved little area of the fault plain revealed faint, subhorizontal stretch marks in lutites, slightly dipping to the East. This little exposure showed stuck sand and siliceous rounded clasts provenient from an adjacent red gravel and sand unit. This precise unit, interrupted by the fault, covered unconformably the lutites (**Figure 5**).

The 15 cm thick interval of lutites in the uppermost part of the breccia was bounded by the main fault plane, oriented N85°E74°N, and by a discontinuous vertical fracture in the northwest. This interval showed multiple small, discontinuous, closely spaced, and subparallel fractures, separated from each other by a few millimeters to 2 centimeters. They dipped 74° to the northwest, and were present in all lithologies: lutites, sandstones, and gypsum. In the lowermost part of the breccia, similar small fractures were also present in lutites and gypsum clasts, but in this case their dip to the northwest was smaller: 34° on average. It was also observed in this outcrop that closely spaced fractures, originating from the fault breccia, disappeared towards the northwest, up to a sub-rectilinear sandstone bed, which provided the orientation of the strata: N70°E62°N (**Figure 5**). Therefore, the total width affected by these fractures was approximately 0.7 m, extending from the fault plane to the northwest. According to its relevance in the excavation site, this second fault is named "Major fault", and the first one is described as "Minor fault."

The Major fault formed a small vertical step about 15 cm high in the upper surface of the vertical section. A residue of red gravel, corresponding to the unit that covered the gray lutites unconformably, was present before the house was built, showing a 4 cm thick interval vertically trapped in that step (**Figure 5**). During the excavation time, the Major fault was leaking water at the base of the parcel, spreading about 1 m onto the eroded lutites. Finally, another body of residual red gravel 1 m long and 0.2 m maximum thick, located in the southeast part of the section, separated gray lutites from the building foundation above (**Figure 3**).

The traces of the described faults stretched out horizontally towards the East in the excavation site (**Figure 3**). Each fault was identified by a gypsum vein close to the vertical section (**Figures 6** and **7**).

Another view of the Major fault trace, looking towards the opposite (eastern) part of the site, is shown in **Figures 8** and **9**. Remarkable in this plan view are: a fibrous gypsum vein in the foreground; gray lutites in the left (northern) part; Late Antiquity burials in the background; and the base of the red gravel unit scattered in the depressed, southern part of the drawing (right side of **Figure 9**).

The gray lutites showed multiple, closely spaced parallel fractures, similar to those described in the vertical section. They were abundant on the north side of the fault, where they affected an interval up to 67 cm wide, and a few of them were also present on the southern side of it. They appeared oriented N120°E83°N. A few small fractures, parallel to the fault and oriented N85°E90°, were visible within the oblique fractures. Finally, the fibers of the gypsum vein, in the foreground, were also oblique and parallel to the more abundant fractures described in the lutites (**Figure 9**).

Figure 6. Central southwestern part of the excavation site, with Late Antiquity burials in the foreground and the Aguado alley wall in the background (western interior facade). View from the East.

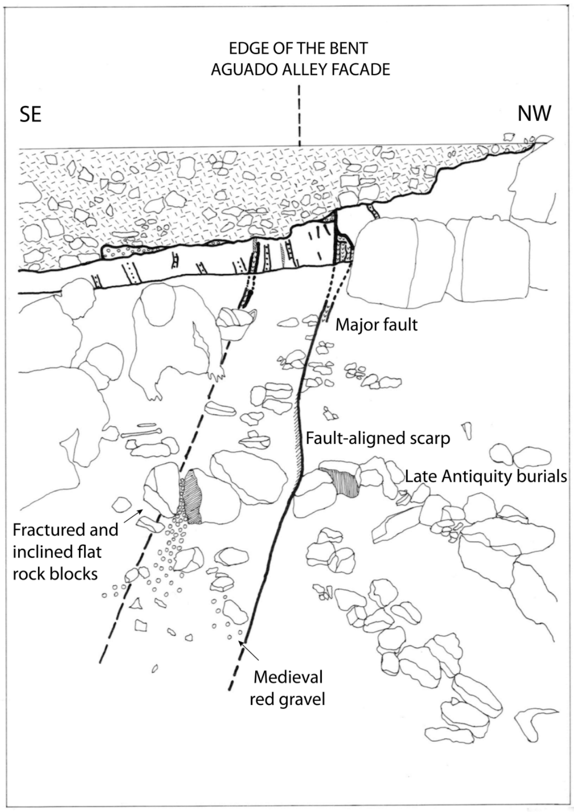

Figure 7. Drawing made from the photograph in **Figure 6**. A fault-aligned vertical scarp (10 cm high) and inclined flat rocks from Late Antiquity burials (V–VII centuries) are located along the trace of the Major fault. Scattered remains of the base of the red gravel unit are present in the depressed southeast area of the site. The faults are separated by 55 cm at the height of the man with his hand on the ground, and the major, unbroken flat rock between the two faults is 40 cm long.

Figure 8. Southeastern corner of the excavation site. Grey lutites intersected by the Major fault are present in the foreground; Late Antiquity burials appear in the photograph centre; and the unit of red gravel is seen in the background corner below the house foundations. A gypsum vein along the fault trace is also seen in the foreground. The box in this figure marks the area represented in **Figure 9**.

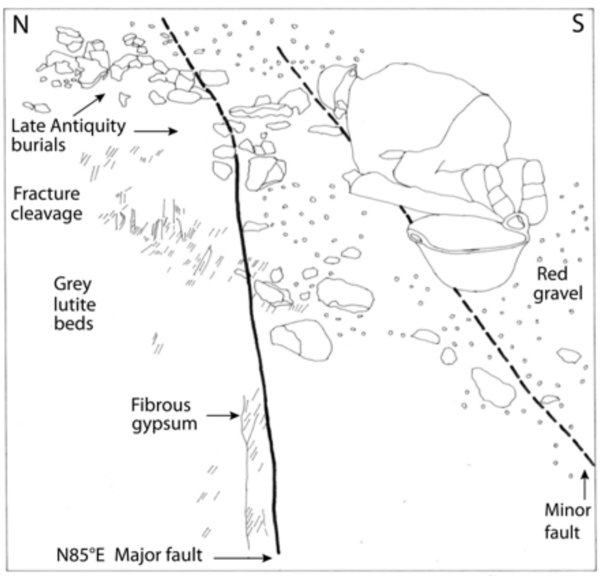

Figure 9. Drawing made from the foreground part of the photograph in **Figure 8.** The trace of the Major fault shows a discontinuous vein of fibrous gypsum in the lower part of the illustration. A well-developed fracture cleavage is present, both in the gypsum and the lutites of the northern block of the same fault. The southern depressed block contains residues of the base of the red gravel unit. The rubber basket (0.40 m diameter in the upper ring) gives the scale. View from the West.

The red gravel layer was up to 0.9 meters thick in the easternmost corner of the site (**Figure 8**), and both its base and top showed irregular erosive surfaces. It was at the base of the building foundations, mostly disorganized, and presented a framework of rounded siliceous clasts with ø = 3–5 cm in average size. It contained ceramic fragments among the major clasts. In its easternmost outcrop, in the very corner of the parcel aligned with the fault trace, the incipiently indurated red gravel displayed vertical slices 10–20 centimetres wide, separated by short, discontinuous rupture planes. The interval was 0.65 m wide and up to 0.4 m high (**Figures 8** and **10**).

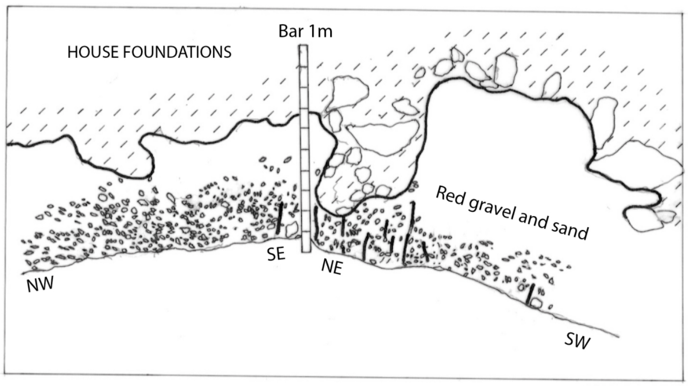

Figure 10. Southern corner of the studied site, with the sub-horizontal red gravel unit separating Miocene lutites from building foundations. The gravel exhibits a few discontinuous vertical fractures, and the long axes of its rounded clasts are perceptibly oriented vertically in the corner, where both the Major and Minor faults intersect the walls. The bar (1m) gives the scale.

The gravel structure, in the same corner, showed its rounded, elongated clasts more steeply inclined than the surrounding clasts (**Figure 10**).

3.2. Aguado Facade Deformation

Deformation in the northwest-southeast oriented Aguado facade of the 6 Selgas house consists of the displacement of the southeast part of the wall towards the northeast. Not only this wall but also the adjacent Aguado staircase alley, and the Aguado facade of the Alburquerque palace, appear similarly deformed (**Figure 11**).

Figure 11. View towards the NW of the 6 Selgas Street building with the bent Aguado alley facade. The Alburquerque palace on the left part of the photograph also shows a bent Aguado alley facade, and the Aguado staircase is deformed between the two facades (modified from García-Mondéjar et al. [23]).

In plan view, deformation is shown in **Figure 12**. **Figure 12A** represents a horizontal section at the base level in the present-day reconstructed house. It consists of two rectilinear segments with the SE one deflected to the East. These new parameters of deformation were measured with a laser point, and they were slightly bigger than those taken before reconstruction and illustrated in García-Mondéjar et al. [23]. Thus, the southeast segment of the facade is now deflected 3.38° towards the northeast, versus 1.8° measured in 2017, and the lateral displacement of the southeast point of the facade is nowadays 0.29 m, versus 0.2 m measured in 2017. Concerning this subject, a new set of deformation measurements taken from the house prior to its reconstruction is shown in **Figure 12B**. It represents the Aguado alley facade in the location map made by the archaeologists [34] (**Figure 1**). The parameters graphically represented in that picture are 2.5° of deflection and 0.2 m of lateral displacement of the southeast point.

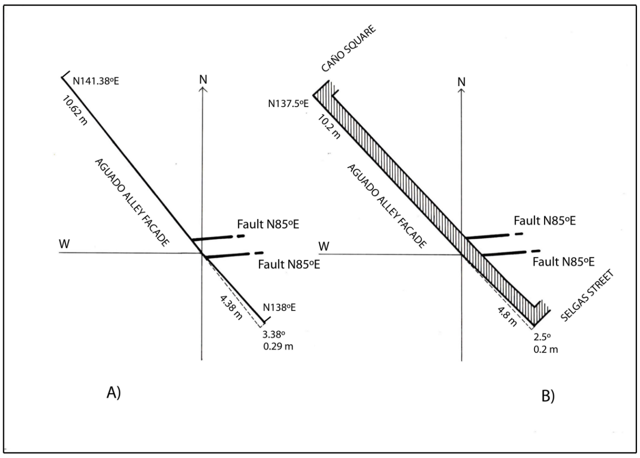

Figure 12. The Aguado alley facade of the 6 Selgas Street house, shown in plant view with its southern part bent to the northeast. (**A**) Present-day horizontal section at ground level, after reconstruction of the house; and (**B**) Horizontal section at ground level presented by the archaeologists in 2021, prior to reconstruction of the house. In both pictures, the vertical projection of the edge of the bent facade lies between the two faults revealed in the excavation.

3.3. Archaeology Data and Interpretation

The excavation in 6 Selgas Street took place in spring 2020. The archaeology data were published one year later [38]. They revealed the presence of several units above the geological series. The older one consisted of 13 funeral units of Late Antiquity (V–VII centuries), related to a major necropolis already known in the surrounding areas. It was covered by a mixed natural and anthropogenic red gravel unit, which contained Andalusian ceramics characteristic of the late XII to early XIII centuries. It is possible that at least part of the red gravel was deposited by stream waters onto the funeral units, before the Andalusian ceramic rests were mixed with it. The upper part of the excavation consisted of foundations of houses from the XVIII century to the Present.

Lorca is one of the few sites in Spain whose population has persisted in the place since the Neolithic to the present day. The following cultures have been documented with remains below the urban area, over the last two centuries. They are reported with their approximate ages: Final Neolithic (6000–5500 BP), Calcolithic (5500–4200 BP), Argaric (4200–3500 BP), Late Bronze (3500–3200 BP), Final Bronze (3200–2600 BP), Old Iron (2600–2500 BP), Iberian (2500–2200 BP), Republican Roman (2209–2027 BP), Imperial Roman (2027 BP–290 AD), Late Roman (290–400 AD), Late Antiquity (400–713 AD), Andalusian Period (713–1244 AD), Late Medieval (1244–1492 AD), and Modern and Contemporaneous (1492 AD-Present day). The archaeologists who described this huge amount of information, in multiple publications over the years, built a "composite archaeological stratigraphy" piece by piece, consisting of about 15 archaeological units. As it occurs in physical stratigraphy, not all units appear to succeed each other vertically at any particular point. Negative stratigraphy can also be present. As an example, only three units (Late Antiquity, Andalusian, and Contemporaneous) appeared vertically superposed in the Selgas 6 site described in this paper. In summary, the knowledge of the local archaeology of Lorca is so great that it permits to date most remains with traditional methods very accurately. These dates combine narrowly with 14C dates in selected points, which represent a sort of "guide fossils" in that stratigraphy.

The summary that follows is taken from the original work [38], translated into English and presented in quotation marks. In the published report, the authors firstly set up the real age of the house and placed its construction in the second half of the XVIII century, modifying the less precise pre-XX century age shown in official urban plans. According to that change, it is assumed that the most probable date for the house building was 1775, as the place was already inhabited one year later. Hence, calculations of deformation rates of the building are here refined, correcting those presented in García-Mondéjar et al. [23].

"The oldest historical remains described in 6 Selgas street are attributed to a necropolis. They consisted of thirteen funeral units partially devastated, with accumulation of disjointed human bones, destroyed funeral containers, cut graves, and other remains. The disorganized red gravel unit sealing the necropolis contained Andalusian ceramic material that was very much fragmented. Specifically, it was made up of little sgraffito jar fragments, epigraphic decorations, stamped clay jars, and some other pieces.

Data with chronological relevance result from a series of guidelines followed in the funeral rituals: all funerary units showed a rock structure and a stone and slab facing, diversely preserved. The bodies were deposited in rectangular graves dug in lutites. They were placed in various orientations, perhaps owing to the slope relief characteristic of the area. Although the human remains were apparently compact, they suffered microfractures during the exhumation work, when both the temperature and humidity of their environment changed. The dead bodies were buried lying face up, with the legs extended, both in single and multiple inhumations. They appeared with their arms extended along their bodies or on their pelves. Wood remains and numerous nails found within the graves pointed to wooden coffins, although they could also indicate boards or stretchers to put corpses.

In the cemetery, the skeletonization shown by most of the bodies was thought to proceed from their wrapping in shrouds, although in some cases it suggested that tissues did not hold tight, but simply wrapped the bodies up. There were no household elements, clothing, or adornment remains preserved, except for one bronze pin in one tomb and two hoop earrings in another one, all of them useless for an accurate dating. Therefore, the direct age attribution relied on some ceramic or glass fragments, as well as on the nails mentioned above.

A reliable indirect chronology was provided by the Granero Street necropolis [39], located approximately 100 meters southeast of the Selgas 6 excavation site. The Granero excavation site presented an Andalusian potter´s workshop, featuring a segment of gypsum plaster, the corner of a clay settling pond composed of masonry and filled with reddish earth, and a rubbish dump also filled with earth that contained ceramic fragments with sgraffito decoration. These remains were integrated into the already known Islamic Lorca pottery district, dated in the first half of the XIII century [39]. The underlying necropolis had the burial pits dug into a red gravel sediment, and they were oriented east-west. They contained very few elements of a funerary trousseau, among them a gold ring with the PROCLINA legend. Fourteen graves and sixteen corpses were exhumated, corresponding to the following pit typologies: 1) directly excavated in the ground; 2) with a stone slab cover; 3) lined with lime mortar and a stone and slab cover; and 4) lined with stones or sandstone slabs and a cover made of large slate or sandstone slabs. After a comparison of these typologies with others from necropolises in the Murcia Region, and with others from necropolises in diverse regions of Spain, with similar stratigraphic contexts and with Visigotic cemeteries, it was possible to define their chronological date between the 5th and 7th centuries AD [39]". No absolute dating was performed in the 2020 archaeological study.

All these data suggested that both necropolises described, 6 Selgas Street and Granero Street, most probably belonged to the same archaeological area and had the same chronology: Late Antiquity. In relation to the red gravel unit covering the cemetery, it was archaeologically interpreted as a rubbish dump. The Andalusian ceramics found in it were considered characteristic of the late XII to early XIII centuries.

4. Discussion

4.1. Geological Interpretation

In stratigraphic terms, the excavation site studied consisted of two units separated by an angular unconformity: a compacted gray lutite layer below and an incipiently hardened red gravel layer above. The main characteristic of the lower unit is silt and clay dominance, with isolated sandstone and siltstone beds. This association was found to be very much extended in many neighbouring excavations, making up a big lithostratigraphic subcrop at least 300 m long and 100 m wide. Observations in other studied urban sites provided supplementary features of this unit, which can be sedimentologically interpreted according to García-Mondéjar et al. [10]. They are graded bedding in sandstones with erosional bases (overbank deposits); channel-fill sandstone structures about 0.5 m deep and 5 m wide (distal fan distributary channel deposits); plane-parallel sandstone intervals with bed thicknesses up to 0.9 m (distal lobe deposits); scattered gypsum veins in lutites and claystones; and pervasive reddish, salmon or gray colours in fine-grained materials (playa-lake type deposits). Taking into account, on the one hand, the stratigraphic position of this unit, underlying the Lorca red conglomerates in the northern face of the Castle hill, and, on the other hand, its reported characteristics, a lateral extension of the Cañada de Morales Lutite Formation is considered, which makes up the big subcrop south of San Patricio ex-collegiate. This continental formation was defined in the northeast part of Lorca, characterized by lutites, claystones, sandstones, polymictic conglomerates, and fine gypsum beds within the finer-grained sediments, and was attributed to an alluvial fan of the middle Miocene, early Langhian (≈16 million years) [10]. The gypsum lithology found in 6 Selgas Street site is not considered sedimentary but diagenetic, related to the joints and faults that affected the lutites.

The upper unit, a polymictic red gravel mostly disorganized with ceramic fragments, is considered a mixed natural and human deposit. Its siliceous rounded clasts and red clay originated directly from close outcrops upslope in the town, particularly from the Lorca Red Conglomerates unit, also of middle Miocene Langhian-Serravallian age [10]. On the other hand, the ceramic fragments point to a rubbish dump established in the area in Andalusian Medieval times (XII–XIII centuries transition).

The studied materials were quite affected by tectonic movements, as the very compacted lutites with dips close to vertical testify. The two approximately vertical faults oriented N85°E, with gypsum-covered planes, cut the N70°E62°N oriented sedimentary succession. Moreover, the interval bounded by the two faults was characterized by verticalized beds as well, with the same orientation as the faults. This interval held a gypsum slice within it, pointing to another small joint or fault (**Figure 4**). The original joints and faults channelized fluids, depositing gypsum on their planes. This gypsum came most probably from sedimentary beds of the same type, dissolved in other parts of the unit.

4.2. Cleavage

Movements along the faults produced other structures in the study area. Representative of these structures are the closely spaced parallel fractures, seen in the vicinity of both the Minor and the Major faults. In the Minor fault, fractures were located preferentially in its northwest block, and affected to the lutites, sandstones, and gypsum veins (**Figure 4**). In the Major fault, fractures also located in its NW block affected the same three lithologies; they also appeared, in vertical section, parallel to the fault plane in its vicinity and oblique to it further away (**Figure 5**); in horizontal section, fractures were all oblique to the Major fault plane, except a few of them, which were parallel to it (**Figure 9**). All these structures in both faults can be described as cleavage: "a set of closely spaced secondary, planar, fabric elements that impart mechanical anisotropy to a rock without apparent loss of cohesion. It would be named spaced cleavage if it is recognizable in outcrop" [40]. On the other hand, "disjunctive cleavage domains" cut across pre-existing (sedimentary) layering in the rock without reorienting the layers [41]. "Fracture cleavage" refers to "closely-spaced planes separated by uncleaved slices occurring in homogeneous rocks" [42]. In the same way, fracture cleavage "is commonly developed at high structural levels, in lithologies when ductile deformation is precluded. It is normally confined to unmetamorphosed rocks, or with only a low grade of metamorphism (...) Although fracture cleavage is commonly associated with the folding of layers, it can also develop in the vicinity of fault or thrust zones" [43].

Hence, fracture cleavage is a good denomination for the structures associated with Selgas 6 faults [42], as well as spaced cleavage [40]. These structures were developed in the vicinity of the two Minor and Major faults. In a synthesis on "Primary Cleavage," it was reported that most studies about the subject considered an observation fact that the cleavage plains are perpendicular to the direction of maximum finite shortening [44]. This assertion, valid for all types of primary cleavage, had also been verified in experimental models [45]. Based on these characteristics, and taking into account that the cleavage plains associated with the Major fault are oriented N120°E83°N, it is deduced, for that structure, a compression vector with N30°E trend and 7° plunge to N210°E. Now it is considered that the northern block of this Major fault contains most of the cleavage development, i.e., most of the interpreted deformation. This deformation is very pronounced next to the fault plane (**Figure 5**), but fades away when a displacement is made from this plane towards both the northwest and the north (**Figures 5** and **9**, respectively). In consequence, the polarity of this compressional stress was from the southern block to the northern one, along a N30°E direction and 7° of ascending component. This stress and the structures that formed were compatible with a sinistral, slightly oblique slip regime of the Major fault.

Cleavage associated with the Major fault in horizontal view (**Figure 9**), showed inclinations of the individual rock slices that separated from the fault plane towards the northwest (downwards in the figure). This organization is comparable with examples taken from nature and produced experimentally, so it is also compatible with sinistral slip along the fault [46] (as in Brandon et al. [47]). The latter authors proposed component surfaces of slip in brittle-shear zones, at the base of Cretaceous nappes, among which are surfaces inclined in the opposite direction of the moving block; they labeled these surfaces P (shear fractures or penetrative foliations). A similar scheme, but with strong lineations and foliations, which separate in the opposite direction of the moving block of a reverse fault, was modelized in Sibson [48]. Cleavage surfaces in the present work, represented in **Figure 10**, can be considered of that P-shear fracture type. On the other hand, cleavage surfaces oriented parallel and attached to the Major fault, in the vertical section (**Figure 5**), can be considered parts of the primary slip surface of the fault. In the same way, cleavage surfaces in vertical sections (**Figures 4** and **5**) showed downward separations respectively from each verticalized trace of the Minor and Major faults. These orientations suggest that the moving block, in each case, was its respective southeastern one, and that both moving blocks had an upward component, besides the horizontal component deduced in the horizontal section (**Figure 9**).

With respect to the fibrous gypsum affected by cleavage, it was reported that "the dominant deformation mechanism of fibrous gypsum veins is brittle, at least at shallow crustal depths (< 1 km), and probably under fluid overpressure conditions. Veins tend to reopen and undergo disruption at different grades in accommodating shear" [49]. The cleavage plains of gypsum analyzed here, with orientations similar to those of the adjacent lutites and sandstones (**Figures 4**, **5**, and **9**), point first to a common lithified state in all lithologies, and second to a common deformation mechanism.

4.3. Fault Scarps

The extension of the Major fault horizontally towards the East, showed an aligned scarp approximately 1.5 meters long and 10 cm high, with its southern side depressed relative to the northern one (**Figures 6** and **7**).

This feature raises the issue of ground surface evolution, specifically whether it was modified before the house construction and how could affect the scarp that crosses the burial. The actual data and arguments are as follows. The scarp is aligned with the Major fault and shows the depressed southern block with remains of the base of the red gravel unit (**Figure 6**). Although the height of the scarp is about 10 cm, an adjacent smoothed scarp in the elevated block (right middle part of **Figure 6**), presumably could add at least another 10 cm to that elevation, as long as the base of the red gravel is considered a reference level in such a short distance. This elevated block contains a well-developed cleavage zone extending up to the scarp, which is aligned with the fault (**Figure 9**). Overall, the features of the escarpment relevant to its interpretation are: fault aligned scarp; southern downthrown block equally found in the described vertical section (**Figure 5**); notable cleavage development in the respective northern blocks of both horizontal and vertical sections; and finally, disturbed burial rocks and large flat rock blocs tilted and broken at the foot of the escarpment, one of them with a gravel-filled fissure. All these features point to the action of the Major fault, probably more than once since the V–VII centuries, with provocation of earthquakes. It is also reasonable to speculate if some degree of erosion might have taken place in the area, perhaps creating the scarps, before the red gravel was deposited on top of it. However, it is difficult to explain natural east-west erosion (highly oblique to the local slope), which would have resulted in a rectilinear escarpment, removing a layer of rock at least 20 cm thick. In addition, such erosion, either natural or anthropogenic, would have eliminated the graves of the then non-depressed block of the escarpment, whose respective vertical dimensions were about the same as the supposedly eliminated layer of rock. A final speculation is to consider the existence of the scarp prior to the burial episode. If it was made by men before, but related to the burials, it does not explain the cut and disturbance shown by these burials along the scarp nowadays. Another possibility is an action of the fault before the V century, but equally it would not explain the disturbed, inclined, and fractured flat rocks of the depressed area, and the trapped lutite and gravel units shown in the downthrown block of the vertical section.

In the same fault trace but in the vertical SE-NW section (background of **Figures 5** and **7**), the Major fault formed a small step about 15 cm high. The appearance of a residue of the red gravel unit that covered unconformably the gray lutites, below the house foundations in the sunken step block, demonstrated that the step already existed in the lutites before the house was built. It also demonstrated that the step had been reactivated vertically, at least 4 cm (the recognized thickness of gravel directly in contact with the fault), after the year 1200 AD (**Figure 5**). Slightly marked stretch marks in a small area of fault exposed, with scattered siliceous rounded clasts, plunging about 5° eastwards, indicate subhorizontal movements that affected the gravel (**Figure 5**). These movements could have created local transtension owing to a small bend in the fault trace (**Figure 8**). However, the recent strike-slip value of the Major fault cannot be deduced from the studied outcrops. In summary, recent activity of the Major fault, also with oblique-slip movements, caused surface rupture after the Late Antiquity (after the 5th century), and between the years 1200 and 1775 AD.

The former assertion is something never reported in Lorca, where the main deformations described in relation to faults were rotated facades during the last 500 years. Moreover, during the formation of these rotated facades, five relatively big earthquakes took place in the city with large destruction effects and many casualties. We suppose that previous earthquakes with surface ruptures could have been of larger magnitude than the five earthquakes mentioned by historical sources. As an indicative example, talking about the 10–15 cm of vertical offset in Lorca, the EAE reported in Totana (c. 18 cm of lateral offset), suggested an earthquake of 6.3–6.5 Mw [29].

The red gravel unit also suggests action of both Major and Minor faults in the eastern corner of the excavation site since the Middle Ages. At that point, located exactly in the hypothetical continuation of the faults, there is a 0.7 m wide zone with a few, discontinuous fractures, individualizing vertical intervals in the barely indurated red gravel (**Figures 8** and **10**). The rounded clasts in that corner, with their longest diameters more steeply inclined than those of the surrounding areas, suggest a reorientation of their long axes tending to parallel the vertical fractures. This effect is attributed to shear strain affecting the area subsequently to gravel deposition. There are comparable examples of rotated pebbles by fault action, like the one described in the Alhambra (Granada) [50].

4.4. Bent Facade and Faults Underneath

The old house in 6 Selgas Street was significantly deformed in its Aguado alley facade [23] (**Figure 3**). As it was exposed in that article and is maintained here, such deformation cannot be related to soil-gravity slip or normal ruin processes. In the monumental part of Lorca town, it is compulsory to preserve intact the facades in reconstruction processes. Therefore, deformation in the Aguado facade appears today similar to it was before the reconstruction of the house (**Figure 11**).

The new deformation figures taken by the archaeologists before the house reconstruction, 2.5° of deflection and 0.2 m of lateral displacement of the southeast point, are very close to those of the first measurements made in 2017. Therefore, the excess deformation shown by the house in the present day after reconstruction (3.38° of deflection and 0.29 m of lateral displacement of the southeast point) can be attributed to its rehabilitation process. During this action, the bricklayer of the bent facade, looking for a straight vertical edge, applied wall plastering to repair irregularities and smooth its segments. This procedure slightly enhanced the parameters of deformation that had been measured before, both independently in 2017 and 2020. Hence, in order to calculate deformation rates, the more recent measurements made in 2020 (2.5° and 0.2 m) are taken here, changing only the construction date of the house.

The straight vertical edge of the bent Aguado alley facade (**Figure 11**) projects downwards between the two faults shown in the excavation site (**Figure 12**). These two faults can be considered a unique fault branch at depth (Alburquerque), as they are similar and stand very close together on the surface. These faults are made responsible for the bending of the facade and, by extension, responsible for the rotation of the following items, from east to west (**Figure 11**): 1) the southeast part of the 6 Selgas Street house, 2) the Aguado alley, and 3) the adjacent Alburquerque palace.

An interesting revelation about the Alburquerque fault branch at the 6 Selgas site (western part) is that the building foundations of the house rested directly on sub-horizontally cut faulted lutites, that is, on strongly compacted Miocene materials (**Figure 7**). In other words, there was neither soft intermediate material (recent Quaternary) at the base of those foundations, nor a significant slope to provoke gravity slip in them. In contrast with this, there was a soft red gravel separating foundations from the compacted lutites in the eastern part of the site, but it was only a thin, residual carpet (**Figure 10**). All this revealed a scarcity of what could be named stress-damping, made by a thick mattress of soft material. On the other hand, and very important, the displacement shown in **Figures 11** and **12** was not in favour of the topographic slope of the area, represented by the Aguado alley, but perpendicularly to it, i.e., horizontally towards the northeast (Selgas Street). It is known that a type of deformation caused by a very big earthquake can be horizontal torsion of an individual building, owing to the stiffening effect of its welded walls [30]. However, in this case, there are two houses and an alley in between, all of them deformed in the same way: left-lateral rotation of their respective southeast parts. It is not the case of two complete buildings turning around themselves. Similarly, this precise effect perfectly agrees with the left lateral oblique-slip characteristics of the fault underneath. Furthermore, there are other houses, also deformed in the same way, aligned with the presumed continuation of the fault. Therefore, we rule out soil-gravity slip and stand up for a direct fault influence on the foundations of the house.

5. Fault History at 6 Selgas Street House

5.1. Steps in Fault History

Considering both the lithology and age of the described units at the 6 Selgas site, as well as the tectonic structures associated with the Alburquerque fault branch, this section establishes a local history of this fault from Miocene to the present day, based on the Aguado alley vertical geological section (**Figure 13**).

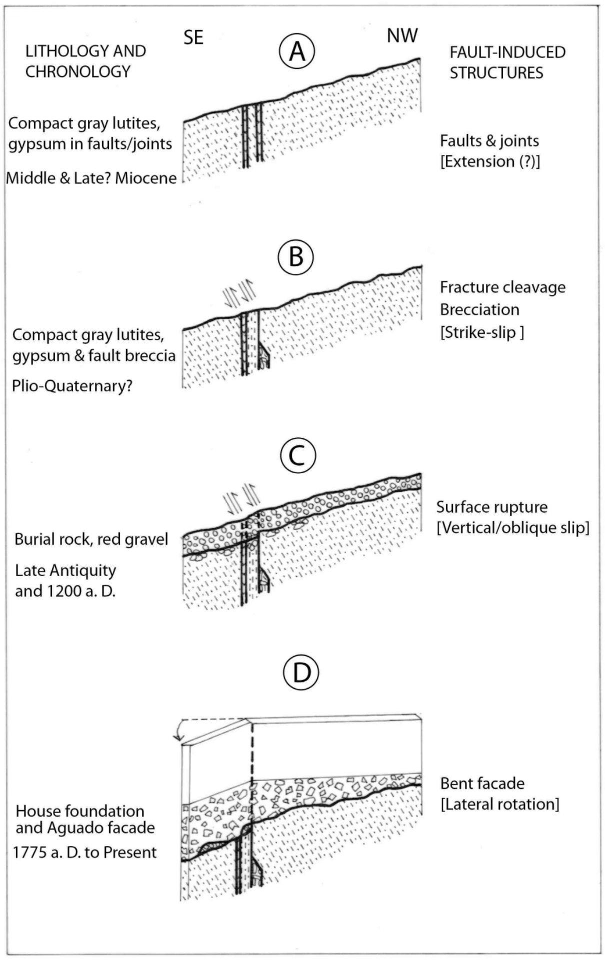

Figure 13. Schematic illustration showing a history of the studied faults. Lithology and chronology of the excavation site are on the left, and the structures created by the Alburquerque fault over time are on the right. These structures are: (**A**) Faults and joints (Middle and Late Miocene); (**B**) Fracture cleavage and brecciation (Plio-Quaternary); (**C**) Surface ruptures (Late Antiquity-1550 AD); and (**D**) Bent facade (1775 AD to present day). Unscaled drawing, referred to the Aguado alley geological section and facade.

Figure 13A shows middle Miocene lutites cut by two structures, joints or faults, filled with gypsum veins. According to Rustichelli et al. [49], "gypsum vein development seems to be enhanced by fluid overpressure in layered and moderately jointed rocks; veins do not form in pervasively and densely fractured rocks". Reviewing the geological history of Lorca, it is known that after deposition of the continental Cañada de Morales lutites (lower Langhian), and the equally continental Lorca red conglomerates (Langhian-Serravallian), the shallow marine Castillo limestones (early Tortonian) and the deep marine Llano de la Serrata marls, calcarenites and cherts (middle and late Tortonian) were formed [10]. This stratigraphic succession suggests progressive drowning conditions in the area, responsible for its deepening upwards characteristics. On the other hand, the Llano de la Serrata marls included millimetric fragments of volcanic rocks in a calcarenitic interval. These fragments were related to volcanic domes and breccias, reported 10 km to the east of Lorca [10], which had been previously described and dated in the base of the latest Tortonian [51]. Combining outcrop information with subsurface data [7], these authors proposed that there was a "geographic superposition of a late Miocene age, first-order, extensional fault, with a hundred kilometers trace, and the younger strike-slip fault of the Alhama de Murcia line". According to the same authors, a late Miocene extensional system was followed by a late Pliocene-Quaternary inversion characterized by a North-South to North-northwest-South-southeast regional compression. When recounting drainage network evolution with a changing tectonic scenario, from late Miocene extension to transpression since the middle Pleistocene [52], these authors also described the same tectonic inversion, with the main role played by the Alhama de Murcia sinistral-reverse fault.

Taking into account all these arguments with their attributed chronologies, the formation of gypsum veins of this work can be related to the late Miocene extensional phase described. This extension produced deepening marine conditions, volcanism, and hydrothermal mineralizations in many areas of the Murcia region [53].

Figure 13B shows the two vertical faults of 6 Selgas house, Minor and Major, coinciding with the previously reported faults or joints filled with gypsum. They are accompanied by a well-developed fracture cleavage that affects lutite, sandstone, and gypsum lithologies. They also appear to be compressing the strata until they are vertical and, in the case of the Major fault, it is accompanied by a polymictic brecciation with large angular lutite, sandstone, and gypsum clasts. The breccia shows previously lithified clasts affected by the same fracture cleavage mentioned above. Cleavage orientation analysis suggests sinistral strike/oblique slip in the history of both faults, which is compatible with the strike/oblique slip character of the Alhama de Murcia fault. In this precise Selgas site, it is concluded that relevant transpression efforts took place during this stage. Taking into account the two major tectonic phases of the Alhama de Murcia fault, as reported in del Olmo et al. [7] and Pérez-Peña et al. [52], both Selgas faults are attributed to the middle Pleistocene tectonic inversion, which was produced by regional North-South to North-northwest-South-southeast compression.

From the middle Pleistocene to the end of the Pleistocene (≈129–12 ka), the area was subjected to a strong phase of strike/oblique slip faulting. By the early Holocene, the Alhama de Murcia fault (AMF) had notable activity in the Lorca-Totana segment, testified, among other effects, by the formation of an angular unconformity between two units of fan deposits. The overlying of these units was dated in the interval 6000–8000 years BP (14C) [54]. That activity was later related to proposed early Holocene transtensional efforts developed just East of Lorca, in the Guadalentín Valley [55]. Two surface ruptures near Lorca were finally attributed to a couple of earthquakes towards the end of the Holocene [13,29]. Therefore, the Holocene activity of the Alhama de Murcia fault connects with the interpreted activity of the Albuquerque fault in this article, and this includes the formation of the scarp described in the Selgas 6 site.

In **Figure 13C**, there are represented materials dated in the interval 5th–7th centuries, and 1200 AD. The former ones (Late Antiquity) are burial rocks and their associated skeletons, which are on both sides of the Major fault scarp. This structure shows its southern block downthrown a minimum amount of 10 cm with respect to the northern one (**Figure 7**). The Medieval materials are red gravels affected by the same Major fault, which appear in vestiges below the house foundations of the Aguado alley facade (**Figures 5** and **7**). As reported above, one of these remains is trapped in a step with the southern block lowered at least 4 cm with respect to the northern one, although it could have been downthrown by up to 11 cm (**Figure 5**). Furthermore, the presence of sub-horizontal striae slightly dipping east in a small portion of the fault plane adjacent to the gravel suggests oblique slip in the fault. This slip created, on the one hand, an indeterminate strike throw and, on the other hand, a dip throw amounting the reported minimum 4 cm. Unlike what happened in the previous Plio-Quaternary stage, tectonic movements taking place in the Selgas site during this recent stage, depressed the formerly upraised southern area, perhaps owing to the appearance of a bend in the fault trace. This change of efforts at a precise point of a strike-slip fault is not uncommon in long-lived systems with irregular fault traces [56,57]. The maximum time elapsed during this stage, assigned by archaeological work, comprises the period from the 5th century to the year 1775 AD, i.e., 1275 years, from the earliest Late Antiquity to the age of house construction.

Since the area is seismically very active, these fault-related structures are attributed to one or more of the relatively major earthquakes that shook Lorca in the time interval considered. From the historical series (four major earthquakes -one of them double- in the last 446 years [25]), only the two older ones (1579 and 1674) can be chronologically considered. The 1579 earthquake probably had its epicenter southwest of Lorca, related to the Alhama de Murcia fault [58]. On the other hand, the 1674 event is considered the most destructive one of the historical series in Lorca [25]. According to the effects it produced in terms of casualties and collapsed houses [13], the authors assigned it a magnitude of $M_w > 6.0$. These authors described a surface rupture of a Medieval Andalusian ditch in the La Torrecilla area, 6 km southwest of Lorca, that they linked to this earthquake. Taking into account the big magnitude of the event and the destruction it caused in Lorca, the 1674 earthquake seemed at first sight a good candidate to explain the surface rupture in the 6 Selgas Street Major fault, with its vertical jump of at least 10 cm in the lutites.

However, the vertical deformations reported in the burial rocks and red gravels of 6 Selgas Street, all of which developed before 1775 AD. (**Figure 13C**), were not extensive to the adjacent Alburquerque palace, built in 1550 (**Figure 11**). In this building, only horizontal rotational deformation, in its Aguado facade, has been mentioned to this day [23]. Hence, the surface rupture structures of 6 Selgas Street are attributed to the time interval comprised between the 5th century and the year 1550 AD, i.e., about one thousand years. If a unique surface rupture affecting simultaneously both units (gray lutites and red gravels) is considered, the time interval for the rupture occurrence would have been within the interval 1200–1550 years AD, i.e., 350 years. On the contrary, if two surface ruptures are considered, based on the red gravel that filled the fractured and inclined flat rocks of a burial, then the first rupture would have been produced between the 5th century and the year 1200 AD (a lapse of 700 years), and the second rupture would have occurred between the years 1200 and 1550 AD (a lapse of 350 years). During any of those time intervals, several major earthquakes most probably affected the area of the house, as the subsequent historical series of earthquakes, mentioned above, suggests.

Figure 13D shows the bent Aguado alley facade of the 6 Selgas Street house. This wall has its southeast part rotated 2.5° and displaced 20 cm (southeast point) to the northeast. Deformation took place during the last 250 years. These recent movements can be related to the long-lived ones responsible for the sinistral oblique-slip Alburquerque fault. Four arguments support this connection. First, the exact position of the edge of the bent Aguado facade, just above the two branches Minor and Major of the Alburquerque fault (**Figure 12**). Second, left-lateral movements are deduced from the rotated southeast part of the facade. Third, there have been a succession of two relatively major destructive earthquakes, as well as numerous minor ones, affecting Lorca town over the past 250 years. And fourth, the rotating movements were developed horizontally, at right angles to the local slope.

With all these arguments, it can be said that the Aguado bent facade reveals horizontal stresses in the ground during the last 250 years, or even 473 years if we include the adjacent Alburquerque palace alley facade, built in 1550, with similar horizontal deformation. These stresses rotated the southern parts of both Selgas houses, but did not yet produce lateral offsets in them. The associated deformation parameters of both Aguado alley facades, permit the establishment of rates of horizontal movements in the houses during the last centuries. In 6 Selgas Street house, values from measurements in 2020, nearly identical to those taken in 2017, are considered reliable and conservative. They are 0.01°/yr for the rotation rate (vertical axis) and 0.8 mm/yr for the lateral displacement rate (SE point) over 250 years. In the Alburquerque palace, values of 0.01°/yr and 1.29 mm/yr (SE point) were calculated for 475 years [23]. These values suggest tectonic movements in the area with constant angular deformation, but without surface ruptures produced yet, at least during the recent 475 years.

As a summary, in large intervals of time (millions of years) the Alburquerque fault created relevant disruption structures in the enclosing rocks, although it cannot be determined with the available data the offset produced. In short time intervals (about one millennium), the fault created small, centimetric surface ruptures associated most probably with relatively large earthquakes. Finally, in even smaller lapses of time (a few hundred years), the fault created modest deformations in houses (lateral rotations) related to stress accumulations between earthquakes and associated with them. Combining all types of deformation created, the prevalent movements in the Alburquerque fault can be categorized as left-lateral oblique slip.

5.2. The Alburquerque Fault Branch

The two subvertical faults described in this paper, oriented N85°E, are correlated with the Alburquerque fault branch hypothesized in García-Mondéjar et al. [23] (**Figure 14**).

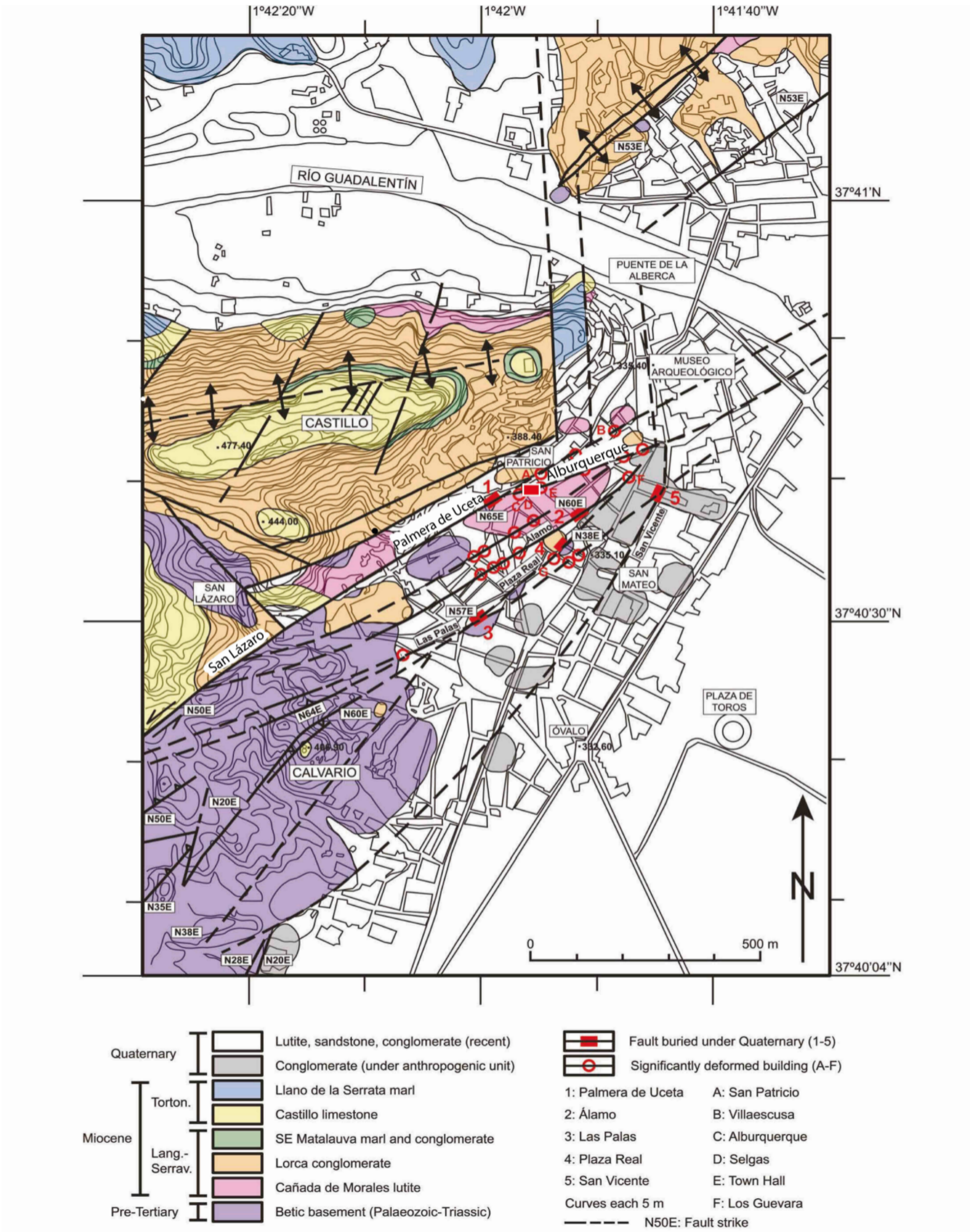

Figure 14. Geological map of Lorca made from outcrops and subcrops in the urban area, the later obtained through archaeological excavations. Circles refer to deformed buildings, and rectangles represent faults seen at excavations. A new solid red rectangle with white borders, corresponding to the Alburquerque fault branch described in this paper, is included (6 Selgas Street house). In the same way, the fonts of Palmera de Uceta and San Lázaro faults are highlighted. Thick lines in the urban area hypothetically link faults from subcrops with deformed buildings, and they are correlated with outcropping faults in the Calvario (Calvary) area. Unit names proceed from García-Mondéjar et al. [10] and de Galdeano et al. [22]. Modified from García-Mondéjar et al. [23].

The measured orientation of this fault in 6 Selgas Street, N85°E, differs by 20° from the N65°E orientation of an adjacent, northwesterly located Palmera de Uceta Fault, from which the Alburquerque one diverges towards the East. On the other hand, Palmera de Uceta is the continuation, rotated 15° towards the East, of the N50°E-oriented San Lázaro fault. This latter fault was first named in Estrella and Jiménez [5], and can be considered a genuine representation of the master Alhama de Murcia fault in Lorca [23] (**Figure 14**).

The western end of the Alburquerque fault branch, in 6 Selgas Street, was hypothetically drawn in the last quoted article with N80°E direction, in other words, practically identical to the N85°E here reported with direct measurements on the ground. This coincidence supports firstly that there is a direct relationship between significantly deformed houses and faults, and secondly that there is an arching of fault branches, both towards the East (faults reported above), and towards the North in the case of faults deduced from aligned deformed houses and tests in excavations. In this second case of northwards change, the Alburquerque fault branch would hypothetically turn from N85°E to N70°E, in as much as about 300 meters, as suggested by deformed houses significantly aligned to the northeast.

A final comment is dedicated to the turned facade on 6 Selgas Street, and the similar facades reported in Lorca. As previously advanced in an article [23] and subscribed here, their generating movements in the ground can be aseismic or associated with low-seismic earthquakes. This topic has become relevant today because recent investigations on earthquakes have proposed that in natural faults, slow, aseismic rupture should always precede rapid seismic rupture [59]. Following this reasoning, a disturbing question arises: can the last five hundred years, a period in which several fault branches under Lorca hypothetically deformed buildings with lateral rotations, represent together a phase of slow, aseismic, and "relatively low" seismic rupture? And if this was the case, will that phase precede another one of rapid seismic rupture, similar to the ones hypothesized here for the intervals 500–1200 and 1200–1550 years AD?

Lorca suffered a strong earthquake with casualties in 2011. Many studies about it reported deformations in buildings and streets, related to the propagation of waves coming from the source, located north of the city [29]. However, the rotating deformations in buildings and a street here described, valid for at least the last 475 years, would hypothetically result from repeated tiny horizontal movements of a fault block displaced to the northeast under the city. This double source of origin of deformations gives Lorca a distinctive character that is worth further investigation, since the city is at risk of further earthquakes. New investigations on the Lorca faults will allow to take the necessary prevention measures and will facilitate the Lorca inhabitants to face possible future adversities.

6. Conclusions

In Lorca town, ephemeral outcrops of the underlying geological series are occasionally revealed by mandatory archaeological excavations in the old town center. The excavation in 6 Selgas Street discovered a fault previously hypothesized (Alburquerque). In the process of characterization of this fault, its deduced movements allowed to relate the deformed geological series with disturbed archaeological remains, and with the bent facade of an overlying ruined house.

1. Data from an excavation in 6 Selgas Street of Lorca town revealed the presence of N70°E62°N oriented, middle Miocene compacted grey lutites. They were unconformably covered by a residual, sub-horizontal red gravel (≈1200 AD). Two closely spaced faults (Major and Minor, interpreted as a single fault at depth, Alburquerque) were covered by fibrous gypsum and oriented N85°E. They cut vertically the lutites and showed fracture cleavage, oriented N120°E83°N, in their respective northern blocks. These structures are compatible with sinistral strike/oblique slip movements in both faults.
2. Late Antiquity burials (5th to 7th centuries), described in a previous report, were associated with a small scarp, 10 cm minimum high, along the Major fault trace. On the other hand, a red gravel vestige (≈1200 AD), also described in the same report, was preserved at the foot of a vertical step of the same Major fault, below the house foundations. Both structures showed their respective southern blocks depressed, and are attributed to a couple of surface ruptures created by at least two earthquakes, between the years 500 and 1550 AD.
3. The Aguado alley foundations of the 6 Selgas house were anchored into compact grey lutites, and they did not show deformation related to soil-gravity slip or normal ruin processes. The facade above these foundations presented its southeast part rotated 2.5° to the northeast, with respect to a vertical axis, and its extreme southeast point laterally displaced 0.2 m. The vertical edge of the bent Aguado alley facade, projected into

the ground, appeared between the two faults located beneath the foundations. Deformation of this facade is attributed to movements of left-lateral oblique-slip related to the Alburquerque fault. These movements had values of 0.01°/yr for the rotation rate and 0.8 mm/yr for the lateral displacement rate (southeast point) over the last 250 years.

4. A history of the Alburquerque fault in 6 Selgas house is summarized in four stages: a) extensional faults and joints with gypsum deposition, developed in gray lutites probably during the Late Miocene; b) sinistral strike/oblique-slip movements creating a shear zone with breccia and fracture cleavage formation, since the middle Pleistocene inversion tectonics developed in the Alhama de Murcia fault; c) vertical/oblique slip movements creating at least two surface ruptures, respectively from 500 to 1200 and 1200 to 1550 years AD; and d) sinistral strike-slip movements creating the Aguado bent facade, from 1775 to the present day, through aseismic and low seismic lateral rotation.
5. The Alburquerque fault belongs to a set of branches derived from the master Alhama de Murcia fault in the Lorca urban area. These branches are interpreted as curved in plant view, tending to get northeast orientations, as suggested by fault tests in excavations and concordant trends of significantly deformed houses.

Author Contributions

Conceptualization, J.G.-M.; investigation, J.G.-M., T.F.A., A.M.R., and J.P.G.; writing—original draft preparation, J.G.-M.; writing—review and editing, J.G.-M., T.F.A., A.M.R., and J.P.G.; supervision, A.M.R. and J.P.G.; funding acquisition, T.F.A. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare that there is no conflict of interest.

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