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New Insights on the Role of the Strike-Slip Tectonics in the Late Miocene-Quaternary Evolution of Sicily

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Abstract

Understanding the influence of the Late Miocene-Quaternary opening of the Tyrrhenian Basin on the evolution of the external sectors of the Africa paleo-margin in Sicily, actually, represents a hard challenge, even though several, and contrasting, models have been proposed in the last decades. One open problem refers to localizing the main regional scale tectonic lineaments of Sicily that accommodated the hundreds of kilometers of lateral displacement, due to the Tyrrhenian Basin opening. In the present work, we present the results rising from a detailed field mapping carried out in relevant vast areas of central Sicily. These data enabled to reconstruct a Neogene-Quarternary kinematic evolutionary model of the collision belt of Sicily. We analyzed the northern tectonic margin of the Caltanissetta Through, which represents a structural depression hosting a thick allochthonous tectonic wedge, on which lay different unconformable thrust-top basin deposits. In more details, our study aims to reconstruct the tectono-sedimentary Late Tortonian-to-Quaternary evolution of this tectonic wedge, revealing that regional E-W-trending dextral shear zones deform and cut the NE-oriented, SE-verging, thrust-and-fold belt. The strike-slip tectonics thus controlled the deposition of different sedimentary cycles on the thrust-top basins and governed the tectonic inversion of the external sectors of the Africa paleo-margin.

Keywords

Thrust and Fold Belt, Accretionary Wedge, Africa Paleomargin, Numidian Flysch, Caltanissetta through

1. Introduction

The Sicily collision belt represents the eastern termination of the east-west striking collision belt, which overthrust the Africa continental margin of the western Mediterranean [1] [2] (see inset in **Figure 1**). This orogenic segment has been classically described as a SE-verging thrust and fold edifice, resulting from a complete orogenic cycle that involved the Europe and the Africa continental margins and the intermediate Neo-Tethyan accretionary wedge terrains, sandwiched between them [2]-[8]. Recent studies on the Neogene tectonic evolution of Sicily [9] [10] evidenced the primary role of the Neogene-Quaternary E-W trending dextral shear zones (e.g. the Sicanian-Etna Line of [10]) that border the main tectonic domains of the region. The E-W-oriented Mt. Kumeta-Alcantara Line [9] [11] separates the Madonie-Nebrodi Axial Zone from the Pedemountain Zone (**Figure 1**). The Sicanian-Etna Line (**SEL**; [10]) is the northern tectonic border of the Caltanissetta Through (**Figure 1**), hosting a huge allochthonous tectonic wedge (Caltanissetta Thrust Wedge; **CTW**), responsible for the impressive negative gravimetric anomaly of central Sicily (**Figure 1**).

In this paper, we describe and discuss the results of 1:10,000 scale geological and structural field mapping of relevant vast areas of the Caltanissetta Through

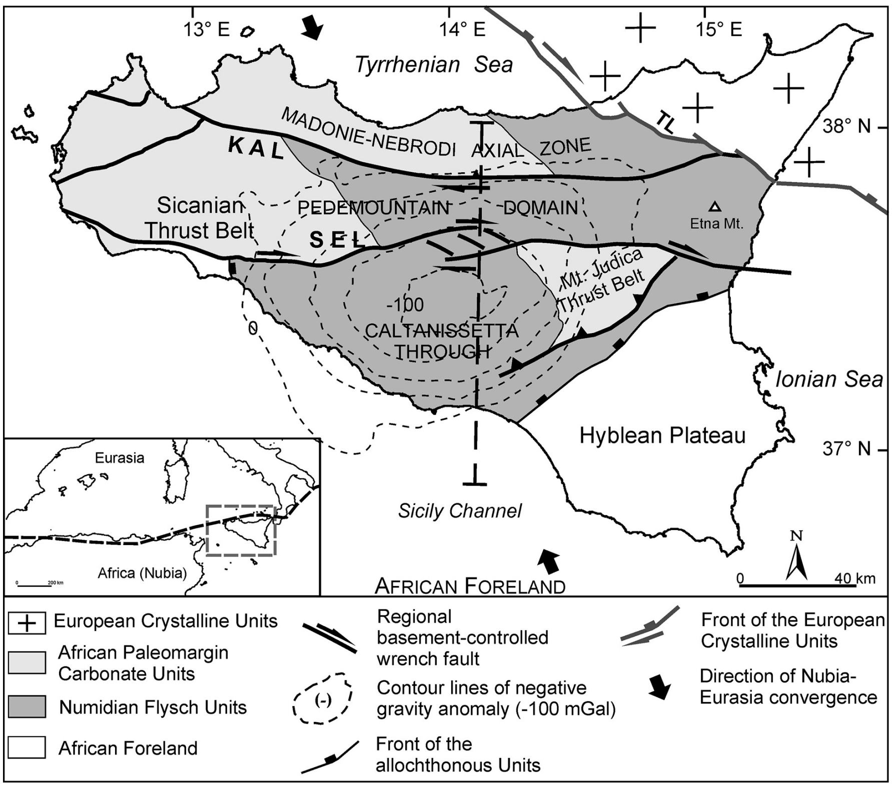

Figure 1. Tectonic sketch map of the Sicily showing the main tectonic lineaments of the Sicily Collision Belt and the main tectonic domains. Contour lines of negative gravity anomaly (from 0 - 100 mGal) of the Caltanissetta Through are modified from [36]. **SEL:** Sicanian-Etna Line; **KAL:** Mt. Kumeta-Alcantera Line; **TL:** Taormina Line. The inset shows the E-W-trending collision belt along the Nubia-Eurasia plate boundary [37].

(see **Figure 2** for location), also using several available seismic lines and boreholes [8] [12] [13] [14] [15] (**Figure 2**) that show the subsurface regional scale tectonic structures across the orogenic belt. The new collected geological and structural field data completes the dataset of available previous geological maps and stratigraphic surface data [16] [17] [18] [19].

In the following sections, after the description of the tectonic setting of Sicily, we will describe the architecture of the Caltanissetta Thrust Wedge, desumed from literature surface and sub-surface geological data. In the second part of the paper we will argue on the Neogene-Quaternary deformation of the Caltanissetta Thrust Wedge, based on original geological field mapping of two key areas (Butera and Centuripe areas), discussing about the relationships between the main tectonic features of central Sicily. Finally, our study provides new insights to better understand the relation between the thrust propagation within the **CTW** and the concurrent displacement along the main dextral **SEL** and their relation with the Tortonian-Quaternary tectono-sedimentary evolution of the region.

2. Tectonic Setting

The Sicily mountain belt consists of an allochthonous edifice that derived from the tectonic imbrication of the Meso-Cenozoic successions of the African paleo-margin (e.g. Panormide and Imerese units of [2]), which are involved, together with the overlying Neo-Tethian derived units (e.g. Sicilide units of [2]) along the E-W striking Africa-Europe collision zone [5] [6] [12] [20] (**Figure 1**). The thrust motion, driven by the NW-SE Nubia-Eurasia convergence [21], was markedly oblique to the strike of the collision belt, giving rise to impressive E-W trending dextral thrust ramps, the Mt. Kumeta-Alcantara Line (**KAL** in **Figure 1**; [9] [22] [23]) and the Sicani-Etna Line (**SEL** in **Figure 1**; [10]) that duplicate the entire Africa Crust, breaching the overlying allochthonous edifice, in the northern and the central sectors of Sicily, respectively. At the northeastern corner of the island, the collision zone is interrupted by the southern edge (Taormina Line; **TL** in **Figure 1**) of the Calabrian arc [24]-[31], which represents a portion of the crystalline European margin that migrated at the hangingwall of the Neogene-Quaternary Ionian subduction zone [32] [33].

At the hangingwall of the **KAL**, a wide ramp-anticline of the carbonate Africa-margin units, capped by the Late Oligocene-Middle Miocene Numidian Flysch successions and the overlying allochthonous Neo-Tethyan units [6] [34] [35], form the E-W trending axial zone of the Sicily collision belt.

In the Pedemountain Zone (**Figure 1**), at the footwall of the axial zone, the Numidian Flysch successions are mostly detached from their primary substratum and form a several thousands of meters thick imbricated stack, tectonically emplaced on the flexured portions of the Africa foreland [6] [12]. The Numidian Flysch units reach their maximum thickness to the south of the **SEL**, where they form the backbone of the Late Tortonian-Quaternary accretionary wedge (**CTW**) infilling the Caltanissetta Through (**Figure 1**) [2]. The **SEL** is marked at

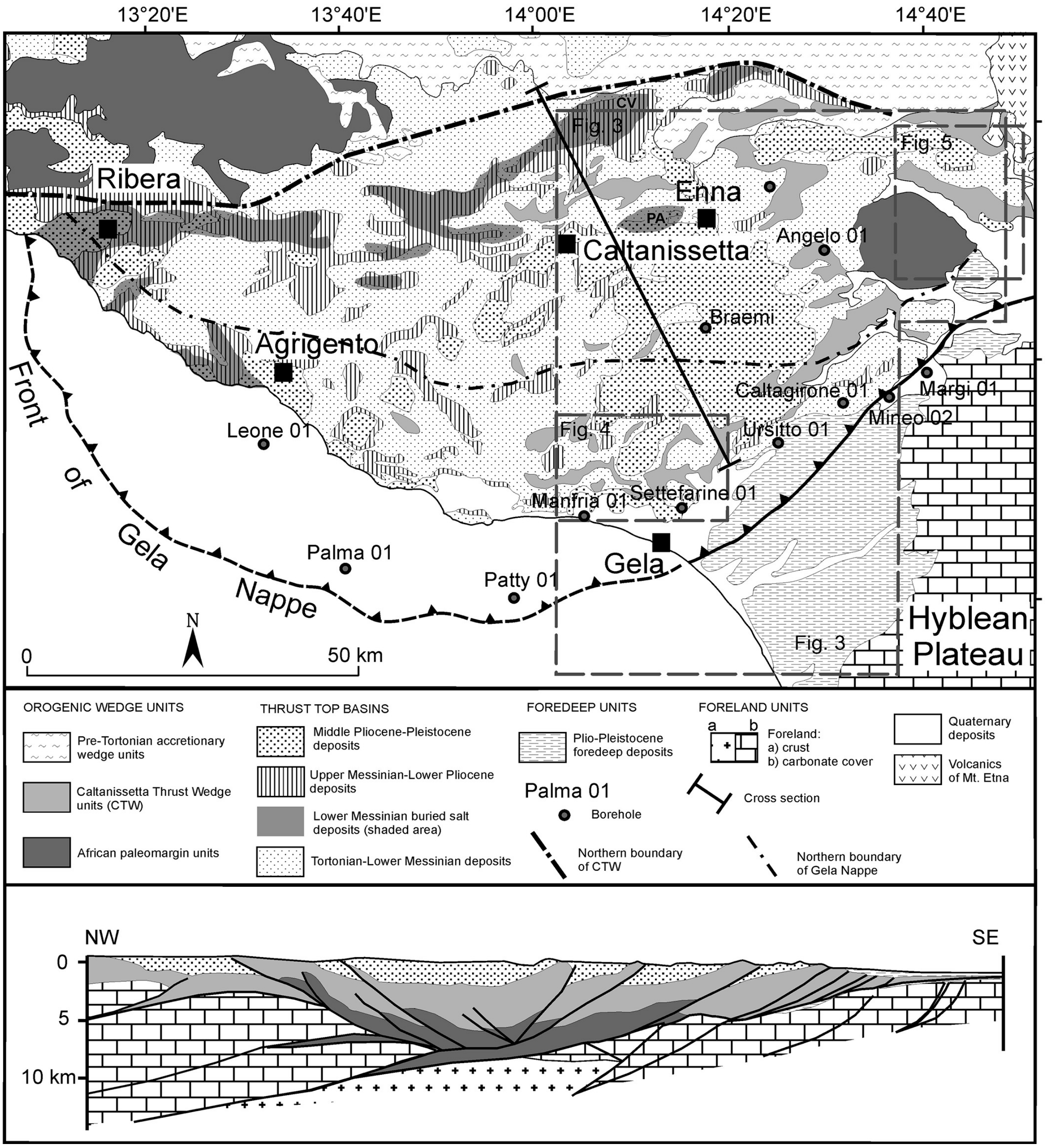

Figure 2. Geological map of the Caltanissetta Through (modified from [10]). Dashed boxes refer to the study areas (see reference to the corresponding figures). In the map the buried salt deposits (from [40]), the inner edge of Gela Nappe (from [39]), the depocenters of the Pasquasia (**PA**), Corvillo-Mandre (**CV**) and Centuripe (**CE**) basins, and borehole (from [15]) are also reported. The schematic geological profile are modified from [12].

depth by to a wide tectonic stack of the African foreland succession [8] (see profile in **Figure 2**). This deep-seated imbrication caused a re-organization of the physiography of the thrust-top basins perched on the Numidian Flysch, mainly due to the huge tectonic subsidence of the Caltanissetta Through area. In the thrust-top basin resting on the hangingwall of the imbricated stack, the Tortonian-Messinian deposition setting remained almost stable, with depth from 0 to 200 m b.s.l.. Conversely, in the adjacent subsiding footwall, the thrust-top basins sedimentary setting evolved from continental-shallow water to deep (-1000 m) marine conditions during the Early Messinian [10] [38]. Nevertheless, most of the accommodation space (about 7 km) due to the foreland down-bending was balanced the by imbrication of the Numidian Flysch units at the front of the **CTW**. The syn-tectonic deposition at the hangingwall of the **SEL** ended with the deposition of the the Lower Pliocene Trubi Fm., whereas it persisted during the Plio-Pleistocene on the subsided areas of the **CTW** (**Figure 2**) [2] [7] [17].

To the east, the **CTW** is bordered by a culmination of the Africa paleo-margin sequences, exposed in the Mt. Judica area (**Figure 1**). To the south, the arc-shaped frontal portion of the **CTW**, described as the Gela Nappe [39], is now emplaced on Early Pleistocene deposits on top of the African foreland of the Hyblean Plateau region (southeastern Sicily) [6] [7] (**Figure 2**).

3. Architecture of the Caltanissetta Thrust Wedge

The seismic lines across the Caltanissetta Through [8] [12] evidence that the **CTW** form a thin-skinned regional scale pop-up structure, due to the impressive tectonic extrusion of the allochthonous Numidian Flysch units and the underlying Africa paleo-margin units, infilling the Caltanissetta Through. The impressive back-verging tectonic slices at the northern border of the **CTW** [10] ramped on the previous tectonic stack of the Africa-margin units along the **SEL**. The frontal S-verging tectonic slices of the **CTW** (Gela Nappe; **Figure 2**) are widely emplaced on the Early Pliocene horizons (Trubi Fm.) on top of the down-bended African foreland carbonate sequences (see boreholes Manfria 01, Settefarine 01, Ursitto 01, Caltagirone 01; Leone 01; Palma 02, Patti 01 in [15]), ramping even on the Late Pliocene-Early Pleistocene horizons of the present foredeep [39] (see boreholes Margi 01 and Mineo 02 in [15]).

The Numidian Flysch units of the **CTW** consist of Cretaceous up to Tortonian successions. They include basal chaotic varicolored clays [41] that show characters of a tectonic mélange with a typical block-in-matrix fabric. This unit locally preserves coherent layered intervals of red-to-greenish claystone with associated fine-grained siliciclastic and calcareous turbidites and wrapping blocks of various size, nature and origin (e.g. red-to-green radiolarites, Scaglia-type sediments, marly limestomes and calcareous turbidites, exotics of aphiric basalts and pillow lavas; [3] [42] [43]). Upward, the basal chaotic varicolored clays pass to the Upper Oligocene-Early Miocene Numidian Flysch turbidites, which are represented by almost regular arenaceous-pelitic alternations, otherwise by a broken formation [44] [45]. This latter shows extensive stratal disruption with locally preserved layered intervals represented by sequences of grey-to-green marls and quartzarenitic sandstones. The sequence ends upward with the overlying marly clay sequence of the Licata Formation [3] [43].

The **CTW** is unconformably covered by Late Tortonian to the Early Quaternary syn-tectonic deposits [17] [46], which filled thrust top basins perched on the allochthonous units (**Figure 2**). The Late Tortonian to the Messinian syn-tectonic deposits widely cover the entire thrust wedge. Along the inner portion of the Caltanissetta Through, the Late Tortonian horizons unconformably cover the internal successions of the Numidian Flysch Nappe and consist of alluvial sandstones, clays, and patch reef sediments of the Terravecchia Formation [47]. In the more external domains of the Caltanissetta tectonic wedge, the Late Tortonian horizons indeed represent the top of the continuous Early Langhian to Late Tortonian hemipelagic clays sequence of the Licata Formation. The Messinian horizons on the **CTW** recorded a severe tectonic subsidence of the area associated with an impressive contractional deformation. They form two distinct sequences, separated by a regional unconformity [38] [40] [48] (**Figure 2**). The lower sequence is made of evaporitic limestones, gypsum and salts, while the upper one mainly consists of gypsum horizons interleaved within prevalent detrital evaporites and coarse-grained clastic deposits. Huge volumes of salts, capping the lower sequence, are preserved at the core of the main footwall synclines of the **CTW** [16], concealed by the unconformable clastic deposits of the second Messinian cycle. The analysis of available deep well logs provided to identify distinct deepest basin-depocenters that, from SE to NW, are represented by the Braemi (see borehole location on **Figure 2**), Pasquasia (**PA** in **Figure 2**) and Corvillo-Mandre (**CV** in **Figure 2**) footwall synclines.

The Early Pliocene sediments consist of the marls and the marly limestones of the Trubi Formation, spread all over the **CTW** and deposited during the Zanclean flooding, successive to the Messinian Salinity Crisis [48]. On the allochthonous units, Late Zanclean to Middle Pleistocene thrust-top basin successions are represented by distinct cycles of terraced regressive deltaic depositional sequences [46]. Each sequence consists of a proximal clastic and bioclastic wedge, onlapping onto the pro-delta deposits of the previous cycle and prograding onto the coeval distal pro-delta marls [16] [17] [18]. The basal unconformities of the proximal clastic wedges laterally correlate with conformities within the pro-delta succession, which is represented as undifferentiated pro-delta deposits in **Figure 3**, that are thus progressively younger towards the front of the orogen. These Plio-Pleistocene depositional cycles are confined, to the northeast, by a large NW-SE oriented antiform of the pre-Pliocene substratum (Angelo Antiform in **Figure 3**), drilled by the borehole Angelo 01 (see location in **Figure 3**).

The relics of the delta deposits of the I cycle (Enna cycle) are now preserved in the area of Enna, at an elevation of about 1000 m a.s.l. (**Figure 3**). They represent the Late Zanclean-Early Piacenzian regressive half-cycle following the Trubi transgression and consist of calcarenites and sands [17] system tracts prograding on pro-delta marls.

The Piacenzian proximal wedge of the II cycle is widely distributed in the M. Capodarso-Pergusa area at elevations of about 800-850 m a.s.l. (**Figure 3**). It consists of sands beds with intercalated SW-ward prograding clinoform strata of biocalcarenites. These deposits onlap onto the forelimb of a roughly E-W to ENE-WSW trending anticline, affecting the pro-delta deposits of the I cycle and progressively pass to marls with sand levels and lenses of sandstone and, more to the southwest, to hemipelagic marls.

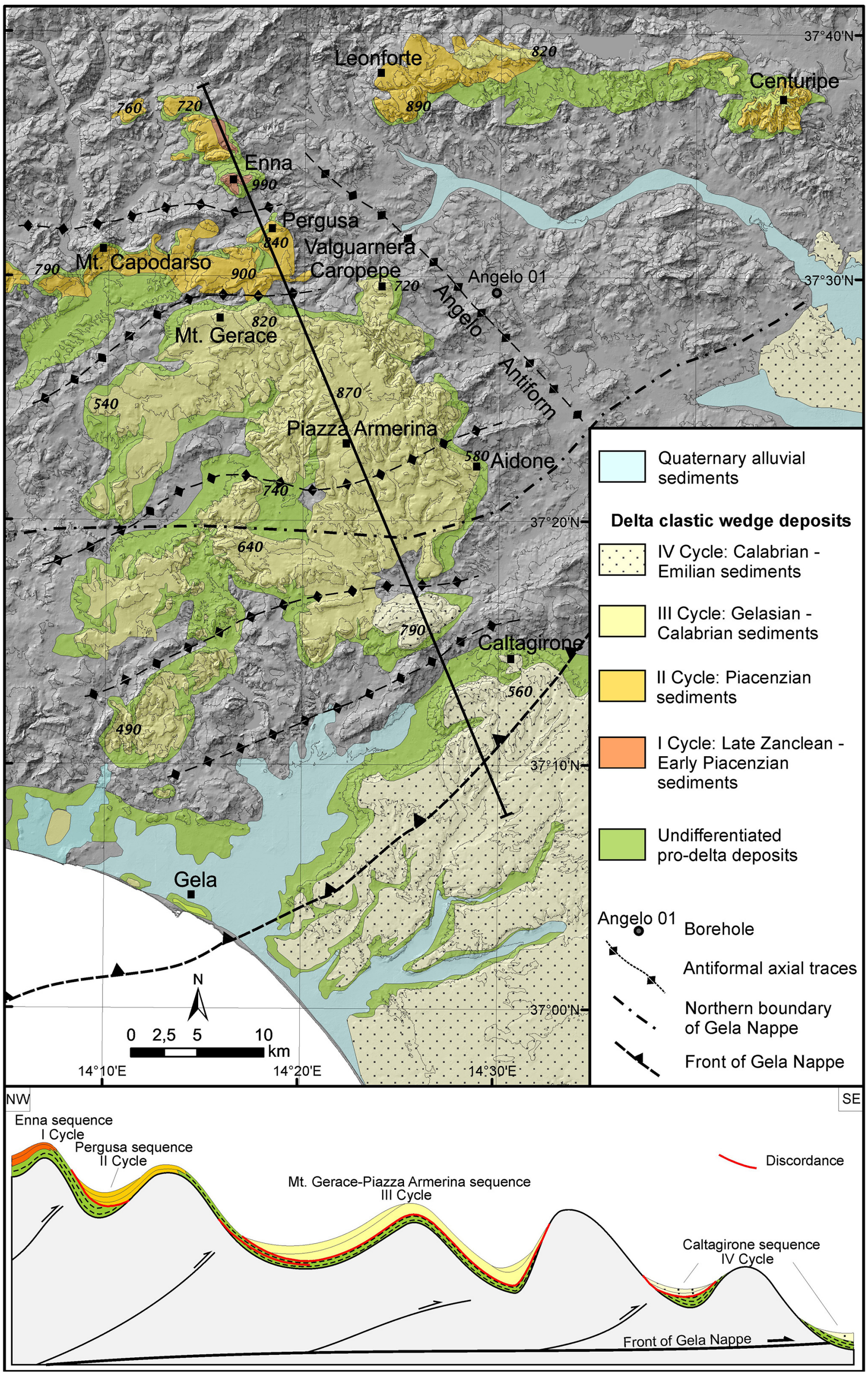

Figure 3. Geological schematic map (see location in **Figure 2**) of the Plio-Pleistocenic delta clastic wedge deposits of the thrust-top basins developed on Caltanissetta Thrust Wedge (revised combining data from [17] and original geological and structural data).

The III cycle, Gelasian-Calabrian in age, crops out more to the south and consists of a series of parasequences composed of sand and sandstones, in the area of Mt. Gerace, and sand and calcarenites in the area of Piazza Armerina. The proximal wedge of this cycle is now preserved in the area of Mt. Gerace-Valguarnera Caropepe, to the south of the forelimb of an anticline that, with an arc-shaped axial trace changing from NE-SW to E-W, deforms the deposits of the second cycle. The III cycle proximal deposits, also onlapping onto the inner limb of the NW-SE oriented Angelo Antiform (**Figure 3**), prograded south-westward onto the correlative prodelta marls facies.

The Calabrian-Emilian deposits of the IV cycle unconformably rest on the units of the Gela Nappe. The Emilian horizons also extend on top of the fore-deep succession, concealing the front of the Gela Nappe (**Figure 3**). The proximal clastic wedge of this final cycle covers the Late Zanclean-Calabrian hemi-pelagic marls draping the antiformal stack at the front of the allochthonous edifice and, at places, directly overly the pre-Pliocene substratum exposed along the thrust front.

The overall thrust-top basin successions, resting on the **CTW**, are intruded by several levels of chaotic rock-bodies, essentially consisting of mud breccias (Argille Brecciate of [49]) and including blocks from both the underlying Cretaceous-Middle Miocene mélange and broken formations and the overlying Tortonian-Lower Pliocene successions. In the external sectors of the Sicily orogeny, mud-diapirism processes are still active as mud volcanoes (Maccalube di Aragona, Santa Barbara di Caltanissetta, Salinelle di Paternò) erupting mud, saline waters and methan-rich fluids.

4. Neogene-Quaternary Polyphase Deformation in Central Sicily

In this section we present the main results of extensive field mapping carried out in a key area of the frontal sectors of the **CTW** (Butera area; **Figure 4**, see **Figure 2** for location) and along the **SEL** (Centuripe area; **Figure 5**, see **Figure 2** for location). The two investigated sectors are both characterized by the occurrence of distinct unconformable cycles of syn-tectonic deposits that provides the opportunity to recognize the superimposed structural assemblages related to the different stages of the Late Tortonian-Quaternary polyphase deformation of the two regions and to define the relation between the deformation and the evolution of the syn-tectonic basins.

4.1. The Butera Area

The geological map of the area of Butera (**Figure 4**; see **Figure 2** for location) illustrates the geometry of the **CTW** and of the overriding Late Miocene-Quaternary thrust top basin deposits, at the front of the orogenic edifice (Gela Nappe, **Figure 2**). The map details on the impressive bend of the thrust front, from the NE-SW to the roughly E-W orientation that occurs immediately to the southeast of Butera. In this area, the units of the **CTW** are widely exposed at the hangingwall of the main thrust front. They consist of the Cretaceous-Lower Oligocene varicolored clays of the basal mélange, the Late Oligocene-Middle Miocene Numidian Flysch and the Early Langhian to Tortonian marls of the Licata Formation. The allochthonous nappes are covered by a very

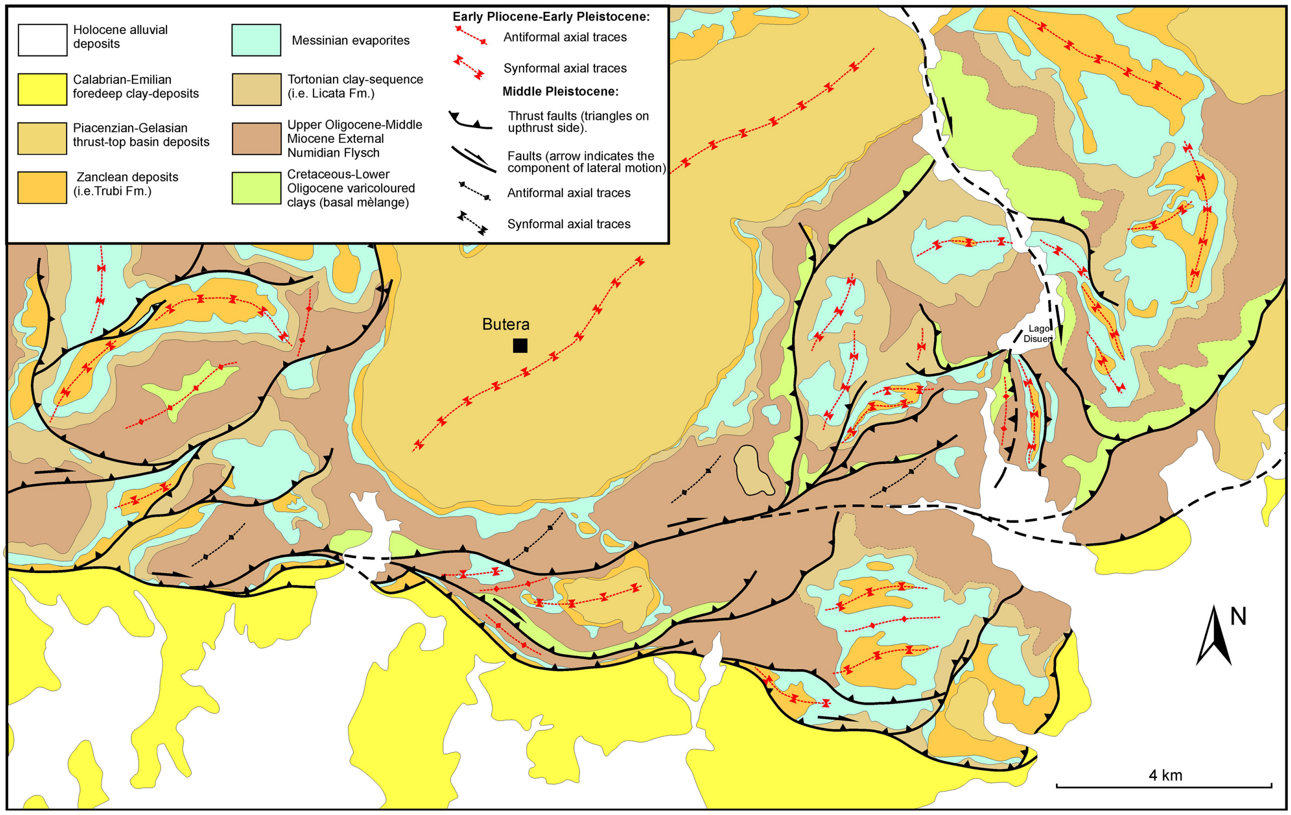

Figure 4. Geological and structural map of the Butera Area (see location in **Figure 2**).

thin thrust-top basin sequence, ranging in age from the Messinian to the Middle Pleistocene, that is now preserved at the core of open synclines. The Messinian horizons consists of few tens of meters of evaporitic limestones and gypsum. They unconformably cover a previous thrust and fold system, resting on the Licata Formation, preserved at the core of the Tortonian syncline, or directly on the Numidian Flysch, culminating on the ancient thrust ridges. The Messinian succession and the overlying marls and marly limestones of the Trubi Formation are deformed by short wavelength NW-SE trending folds. This fold system is concealed by the Plio-Pleistocene deposits, which include a thin sequence of Late Zanclean-Piacenzian basal marls and the Gelasian-Calabrian calcarenites and sands [17]. The Plio-Pleistocene deposits are preserved at the core of a large NE-trending open syncline, centered in the area of Butera, depicting a complex interference pattern due to the superposition of NE-SW oriented structures on the NW-SE trending ones.

The frontal allochthonous nappes of the Caltanissetta Thrust Wedge, with their unconformable covers, are emplaced on Early Pleistocene deposits of the Gela Foredeep [39]. In southeastern Sicily, the thrust front (**Figure 2**) is inserted between the Early and the Middle Pleistocene deposits of the foredeep [50] [51]. Nevertheless, in the region of Butera a series of NE-SW to N-S oriented thrust ramps involve the allochthonous units and the Middle Pleistocene foredeep deposits (**Figure 4**). These younger structures are associated with a new generation of folds that superimposed on the previous Early Quaternary set of NE-SW oriented fold axis, giving thus rise to a new local interference pattern. The Middle Pleistocene structures splay from the termination of a roughly E-W oriented transpressive (dextral) front that juxtaposes the allochthonous nappes of the **CTW** and the Middle Pleistocene foredeep deposits, to the south of Butera. The oblique dextral shear zone truncates and drags the previous fold and thrust lineaments of the **CTW** that are progressively clockwise rotated to parallel the E-W trend of the main oblique thrust, approaching this structure.

4.2. The Centuripe Basin

The Centuripe Basin is an E-W elongated depocenter, perched on the Numidian

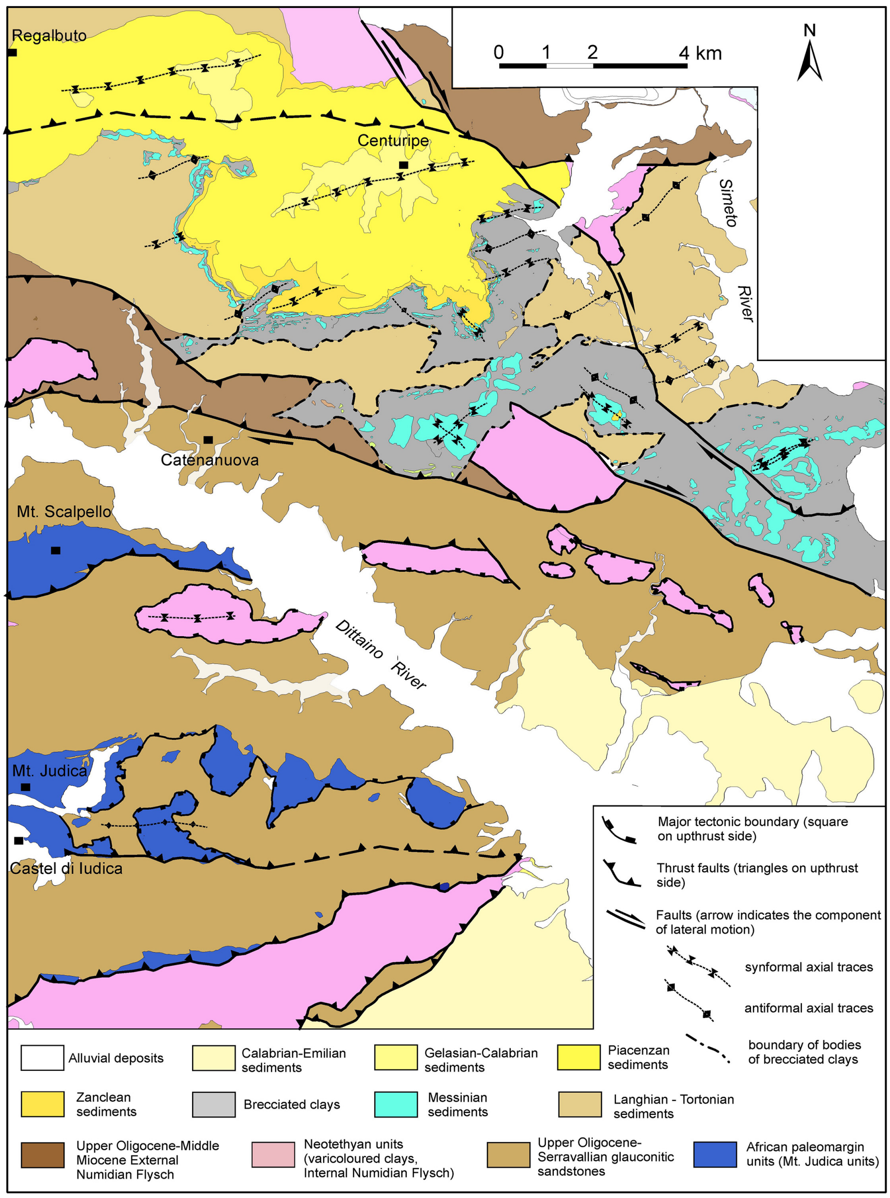

Figure 5. Geological and structural map of the Centuripe Basin area (see location in Figure 2).

Flysch Nappe, which developed along the **SEL**, to the northeast of the Caltanissetta Through (**Figure 5**; see **Figure 2** for location). The geological map of the area of Centuripe details on the easternmost edge of the basin, where the E-W oriented lineaments of the **SEL** [10], control, the depocenter of the basin. The syn-tectonic deposits of the Centuripe Basin, in fact, cumulated on the footwall of a main E-W oriented oblique (dextral) thrust-ramp, duplicating the Numidian Flysch allochthonous units [10], and onlap, towards the north, onto the thrust ridge of the hangingwall. The depocenter of the basin is floored by the External Units of the Numidian Flysch that represent a portion of the **CTW** which was entrapped between distinct dextral segments of the **SEL**. Impressive volumes of mud breccias (Brecciated Clays in **Figure 5**) intrude the External Units of the Numidian Flysch and different horizons of the overlying Messinian to Piacenzian syn-tectonic succession of the Centuripe thrust-top basin. The External Units of the Numidian Flysch, with the associated Brecciated clays and the Cebturipe Basin deposits, are in fact bordered by a sharp N100 oriented dextral tectonic boundary that juxtaposes them onto the Africa paleomargin units of the Mt. Judica Thrust Belt (**Figure 1** and **Figure 5**). According to the available seismic lines interpretation [6], this impressive tectonic boundary would correspond at depth to an abrupt change of the thickness and the magnetic susceptivity of the crust, associated with the huge vertical dislocation of the Africa Paleomargin units. These are widely cropping out to the south of this main tectonic boundary, in the Mt. Judica Thrust Belt, whereas they are buried beneath several thousands of meters of Numidian Flysch succession, to the north, in the Centuripe Basin area. At surface, the N100 oriented tectonic boundary consists of a push up structures along which the Numidian Flysch succession culminates. On this structural high, shallow-water marginal facies of the Messinian evaporites, consisting of ortochemical limestones with sulfur-bearing calcareous breccias, developed. The marginal facies are also widely distributed on diapirs located to the southeast of Centuripe. Laminated gypsum characterise the facies of depocenter. The Zanclean pelagic marls and marly limestones (Trubi Fm.), related to the post-evaporites transgression, are confined at the top of the depocentral succession, while they are totally absent in the marginal areas. The Trubi evolve upward to Zanclean-Early Piacenzian marls [52]. The entire succession from the Messinian to the Piacenzian is confined at the footwall of the main thrust-ramp bordering to the north the Centuripe Basin and is deformed by a short-wavelenght (1 km) dome and basin fold pattern due to superposition of roughly N80-60 oriented folds on previous N140 oriented ones (**Figure 5**). A progressive unconformity of the Messinian-Lower Pliocene deposits indicates their syn-tectonic deposition during the folding. It is remarkable that the Zanclean levels are affected by both the two generations of fold, as well as the Messinian horizons. A main angular unconformity characterizes the base of the Piacenzian cycle [52], here represented by marls containing intercalations of N-ward prograding quartz-rich sandstones that are progressively prevalent towards the top. The Piacenzian deposits conceal the N140 trending folds and are exclusively affected by the second generation of folds, along which they form an inclination angle of about 35˚ with the underlying Early Piacenzian marls. The N80 folds form an en-echelon arrangement evidenced by the location of the synclines in the area of the villages of Centuripe and Regalbuto (**Figure 5**). At the core of these two folds, the Gelasian-Calabrian deposits (third cycle, **Figure 3**) are preserved. They consist of quartz-rich sandstones that form a southward prograding fan, unconformably covering the previous deposits.

The succession of the Centuripe Basin is confined to the E by a prominent NW-SE oriented dextral shear zone, here designed Salso-Etna Fault Zone [20] [53].

In the Mt. Judica Thrust Belt, the Africa paleomargin units consist of the basinal Meso-Cenozoic successions, capped by Late Oligocene-Middle Miocene glauconitic turbidites, which form S-verging tectonic slices (**Figure 5**). These are bounded by high-angle E-W trending thrust ramps that displace a previous low-angle thrust, carrying the Meso-Cenozoic sequence on the Oligo-Miocene turbiditic sequence. In the thrust belt, a very thin horizon of allochthonous terrains is also involved. It is now preserved as small, elongated klippen, at the core of the main E-W oriented footwall syncline of the Mt. Judica thrust belt (**Figure 5**). The imbricated stack of Mt. Judica, controlled by the E-W oriented ramps, overthrust the northeastern edge of the Gela Nappe, controlled by a NE-SW oriented thrust front. This frontal nappe includes the allochthonous Neo-Tethyan and Numidian Flysch units with the overlying Tortonian to Early Pleistocene terrigenous covers. As well as in the Butera area, the Gela Nappe is widely emplaced on Early Pliocene horizons at the top of the down-bended Hyblean Foreland succession [6], whereas the thrust front ramps on Calabrian-Emilian deposits [54] of the foredeep.

5. Discussion

A review of the tectono-sedimentary evolution of central Sicily is here proposed by the combination of the new collected field data with previous geological information. Our considerations start from some main evidence, deriving from previous study:

- The available seismic lines indicate that the central Sicily gravimetric anomaly of the Caltanissetta Trough, marking the flexure of the foreland lithosphere beneath the orogenic belt, is mostly due to tectonic imbrication of a thrust wedge, here designed Caltanissetta Thrust Wedge (**CTW**), rather than to sediments accumulation on surface;
- The geological field data constrain that the allochthonous wedge infilling the Caltanissetta Trough was already emplaced at the Messinian Time, as demonstrated by the main unconformity at the base of the evaporites in the frontal areas of the tectonic wedge (**Figure 5**).

However, the **CTW** exhibits a complex structural pattern made of distinct and superimposed groups of thrust-faults and associated folds that affected the

Plio-Pleistocene horizons, deposited on the **CTW**. These later structure are related to the final emplacement of the entire thrust wedge on the Pliocene foredeep and to the coincident impressive breaching of the **CTW**, giving rise to the regional pop-up geometry imaged by the seismic lines.

The earlier and oldest structures of the thrust wedge (**Figure 6(a)**) are evidenced by the location of the main depocenters of the Lower Messinian sediments (e.g. Corvillo and Pasquasia basins in **Figure 2**) [10]. The two depocenters rest on the opposite sides of a major pop-up structure, which developed during the breaching of the internal sectors of the **CTW**. The thrust ridge played a major role on the Messinian-Early Zanclean syn-tectonic deposition of the region, as it dammed the clastic deposits of the Messinian second cycle fed from the Madonie-Nebrodi axial zone [10] [13] and represented the physiographic boundary of the Late Zanclean transgression (I cycle in **Figure 3**; Enna cycle). At this stage, a depocenter of the Messinian-Early Zanclean deposits, controlled by NW-SE oriented tectonic alignments developed in the Centuripe area.

The new collected field data provided precious information to complete the dataset on the Late Zanclean to Quaternary tectono-stratigraphic features of the **CTW**, useful to constrain the overall tectonic evolution of the **CTW** and its relation with the kinematics along the tectonic boundaries of the structural depression. Two different stages can be identified:

5.1. Late Zanclean-Calabrian Stage

This stage is characterized by the progressive emergence of the **CTW** that is evidenced by the distribution of the proximal delta deposits of the subsequent Plio-Pleistocene depositional cycles (**Figure 3**). The emersion started after the emplacement of the tectonic wedge onto the marls and marly limestones of the Trubi Formation that deposited on the margin of the Hyblean Foreland [6].

Figure 6(b) illustrates the approximate position of the coastal deposits of the four deltaic cycles that deposited in the Caltanissetta Through. Each of them developed at the forelimb of an anticline deforming the deposits of the previous sequence (**Figure 3**). Four main anticlines, showing wavelength of about 10 km, deform the Plio-Pleistocene deposits in the external areas of the **CTW**. Combining the field evidence with seismic data the anticlines can be interpreted fault-propagation folds (see profile in **Figure 3**) related to blind ramps that propagated to the SE through the **CTW**. This imbricated fan was responsible for the huge thickening of the allochthonous wedge, emplaced on the regional monocline of the African Foreland. The ages of the different cycles, coherent with the foreward-younging of the ramp anticlines, is indicative of the propagation of the thrust system for about 60 km during this time interval.

In the Butera area (**Figure 4**), at the frontal sector of the **CTW**, a new generation of NE-SW oriented folds, affecting the Piacenzian-Gelasian thrust-top basin deposits, developed at the toe of the tectonic wedge, whose front can be considered as almost fixed. The superposition of NE-SW to N-S oriented fold axes on previous NW-SE trending folds determines a clear interference pattern.

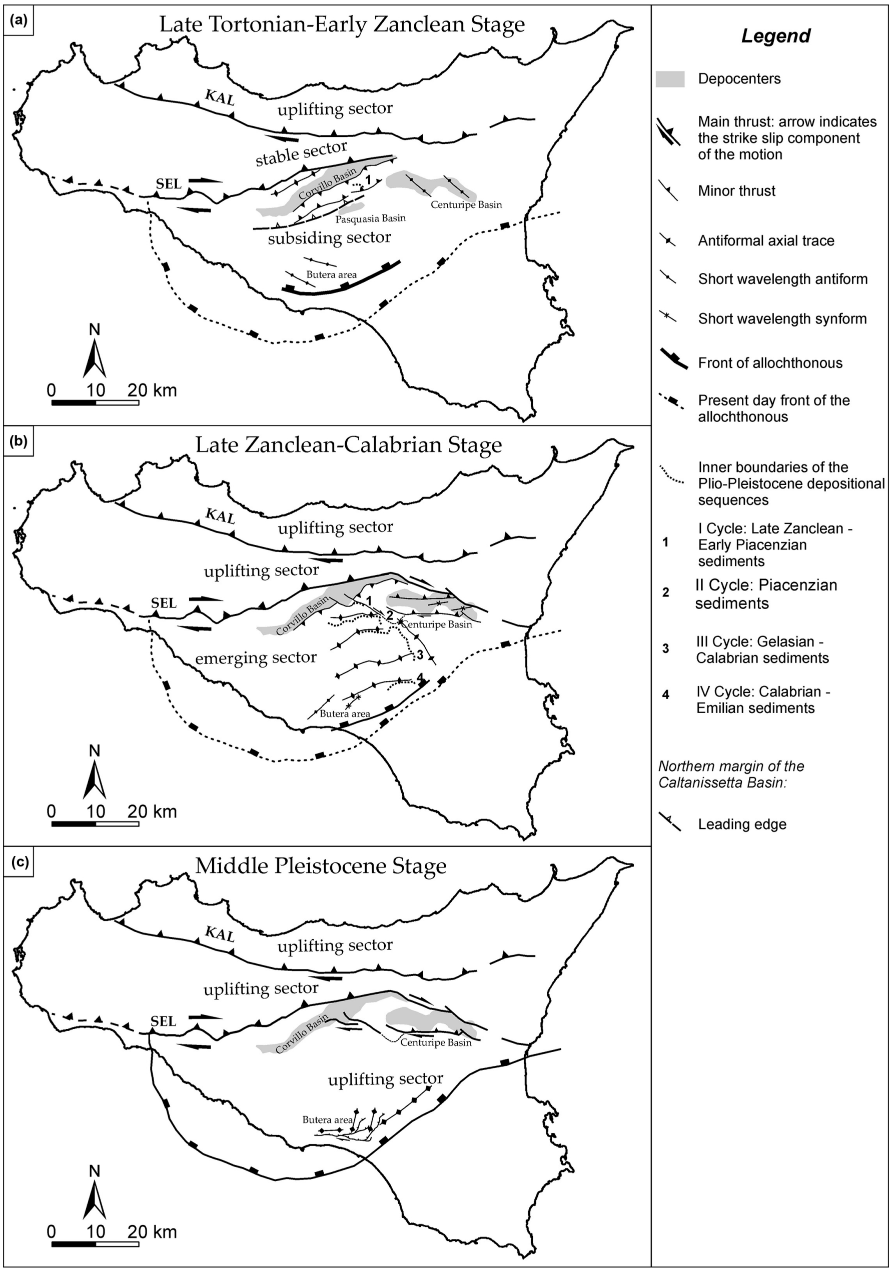

Figure 6. Schematic Messinian-Middle Pleistocene tectonic evolution of the Caltanissetta Thrust Wedge.

At the end of the Piacenzian, a NW-SE oriented antiformal culmination (Angelo Antiform) developed at the transition to the Mt. Judica Thrust Belt, separating the deposits of Enna-Capodarso area, to the west, from those of the Centuripe Basin to the east.

In the Centuripe area (Figure 5), E-W trending dextral thrust ramps of the **SEL** with the associated NW-SE oriented dextral faults propagated from the Africa basement to the surface, through the Numidian Flysch units, after their emplacement [10]. These structures controlled the geometry of the basin, whose depocenter remained almost fixed during the entire considered time-interval.

However, motions along the boundary faults caused a severe deformation of the entire Piacenzian succession, mainly consisting of an impressive NE-SW trending fold system. This stage of folding, as well as the previous NW-SE-oriented one, was associated with mud-diapirism that produced sill-like intrusions in the entire sequence of the Centuripe Basin. This set of right-stepping en-echelon N80 oriented synclines, as well as the related mud-breccias belt, are confined to the south by a dextral oblique up-thrust that produced the sharp juxtaposition of the Numidian Flysch Nappe against the culmination of the deformed Africa paleomargin (Mt. Judica Thrust Belt) (**Figure 5**). According to the interpretation of the available seismic lines [6] and field data this dextral oblique main structure would represent the field evidence of Sicanian-Etna Line [10], representing a crustal wrench fault located just beneath the Centuripe Basin.

5.2. Middle Pleistocene Stage

This stage coincides with the final emplacement of the Gela Nappe on the Calabrian horizons of the foredeep and the deposition of the Emilian horizons on the front of the allochthonous (**Figure 6(c)**). The field data collected in the Butera area (**Figure 4**) provided useful information on the kinematics along the main bend of the frontal nappes that connect the NE-SW oriented segment, adjacent to the Hyblean Plateau, to the E-W trending one, parallel to the southern coast of the island. In this period, the enucleation of the thrust front was associated to the growth of a wide ramp-anticline that deformed the Calabrian-Emilian deposits. Also in this area, the final emplacement of the allochthonous units was followed by the migration of E-W striking strike-slip faults through the **CTW**. These structures control the main bend of the front, where the NE-SW oriented features are interrupted by an impressive E-W oriented dextral fault zone, along which a clear clockwise rotation of the previous fold axes occur (**Figure 4**). The main splays of dextral shear zone terminate with a complex pattern of N-S to NNE-SSW trending thrust ramps, according to a contractional horse tail arrangement, thus accommodating the strike-slip motions (**Figure 4**). The strike-slip tectonics and the related structures fully involve the Emilian succession of the foredeep and strongly deformed the frontal nappes at the hangingwall of the Early Pleistocene thrust front.

6. Conclusions

The new field data, collected in the analyzed key areas of the Caltanissetta Through, allowed us to provide a new interpretation of the origin and significance of the Plio-Pleistocene basins of central Sicily. The new geological constrains suggest that the Nubia-Eurasia convergence was likely accommodated by both the SE-ward propagation of thrust and fold system and by strike-slip displacements along crustal E-W high angle wrench fault. Until the migration of the allochthonous edifice was active, the foreward motion of nappes inhibited the propagation of the strike-slip features to the surface. So, the effects of the strike-slip motion become effective since the final emplacement of nappes, when the lateral motion along the wrench faults remain the only mode to accommodate the regional shortenings.

In conclusion, the new field data point out several evidence of dextral shearing along E-W oriented belts that overprint the thrust and belt features of the Caltanissetta Thrust Wedge. The reconstructed shear zone seems to have played a major role in the tectonic picture of central Sicily, causing the dextral lateral shifting of the major tectonic domains of the region. In this new kinematic picture, the tectonic stacking of the Caltanissetta Thrust Wedge is the result of the tectonic inversion of the Africa paleomargin, trapped between the dextral shear zone, to the north, and the converging Hyblean plateau crustal buttress, to the southeast.

Finally, this paper represents a further tile for understanding the main role of the strike-slip tectonics in Sicily and could constitutes a relevant tectonic feature for the identification of the on-shore prolongation of the major strike-slip fault systems recognized in the Ionian offshore.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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