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RECOGNITION OF STRIKE-SLIP FAULTING ON THE SUPRA-DETACHMENT BASIN OF MESSARA (CENTRAL CRETE ISLAND) WITH REMOTE SENSING IMAGE INTERPRETATION TECHNIQUES

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ABSTRACT

The role of remote sensing in the identification of NNE-SSW trending strike slip fault zones and the implications on the development of the E-W trending Messara basin in Central Crete is examined in this paper. The examination of several tectonic and mophotectonic criteria along with high and medium resolution remote sensing image interpretation are leading to the conclusion that this quite recently formed basin on the top of the hanging wall of the Southern Crete extensional detachment fault is still evolving and the lateral slip of faults trending oblique to the Hellenic trench are very significant. The history of this supra-detachment basin starts during Middle Miocene only after the compressional phase of the alpine units' nappe pile stacking has been accomplished at the southern part of the Hellenic Arc system. The Iraklion basin, delimitated by two nearly N-S trending fault zones, which is located to the north of Messara and also including the area at the easternmost part of it, begins to get filled with lacustrine sediments, during Serravallian. The eastern marginal fault zone is almost vertical with some fault surfaces dipping to the west and has a strong left lateral component, which is active at least since Tortonian, as this has been proved by tectonic analysis of syn-sedimentary faults found on marine sediments, along the faulted area. During Messinian time, left-slip displacement was relocated to the fault system bounding the western margin of the Heraklion-Messara basin. These oblique fault activations are causing the segmentation of the south dipping Cretan detachment fault and the variation of the slip rates of each of the –at least– three segments that were identified. The westernmost segment of the detachment seems to have the highest slip rate as the largest structural omission related to the alpine units has been detected along its trace. The continuous subsidence of the hanging wall is boosting Messara to be formed as an individual basin trending E-W differentiated by the Iraklion basin, the area of which is reduced and finally remained on the footwall of the Southern Crete detachment fault. The new independent supra-detachment basin is stabilizing whilst internal deformation takes place and becoming homogenous during the Holocene as the modern topography shows. Remote sensing image interpretation based on spectral analysis led us to high detail and accuracy geological mapping of these major and in many cases blind structures and eventually build the evolution model of a very complicated area at the edge of the Hellenic trench.

INTRODUCTION

The broader area of central Crete (Figure 1) represents a particular neotectonic structure which comprises of two separate post nappe stacking basins with different orientations forming a uniform basin complex. In this paper we will refer to this as the Iraklion-Messara basin complex as Iraklion basin to the north has been developed

along the nearly N-S trend and at its southern border and adjacent to it, Messara basin develops at an E-W trending. The latter has a quite symmetrical arrangement at the southern part of central Crete Island and it could be misinterpreted as an extensional graben parallel and adjacent to the Hellenic subduction zone. In a closer look it is clear that there are quite a few deviations from the model of an ideal graben as there are no marginal continuous faults trending E-W along either the south or the north border. Additionally, more than half of the northern margin is ambiguous because of the existence of the adjoined Iraklion basin covered by the same formations with Miocene to Pliocene marine sediments. Finally, the same post-alpine formations cover the southwestern part of Messara basin outside the supposed neotectonic graben, a fact that leads to more questions about the real location of the southern margin, which should be further to the south under the Libyan Sea.

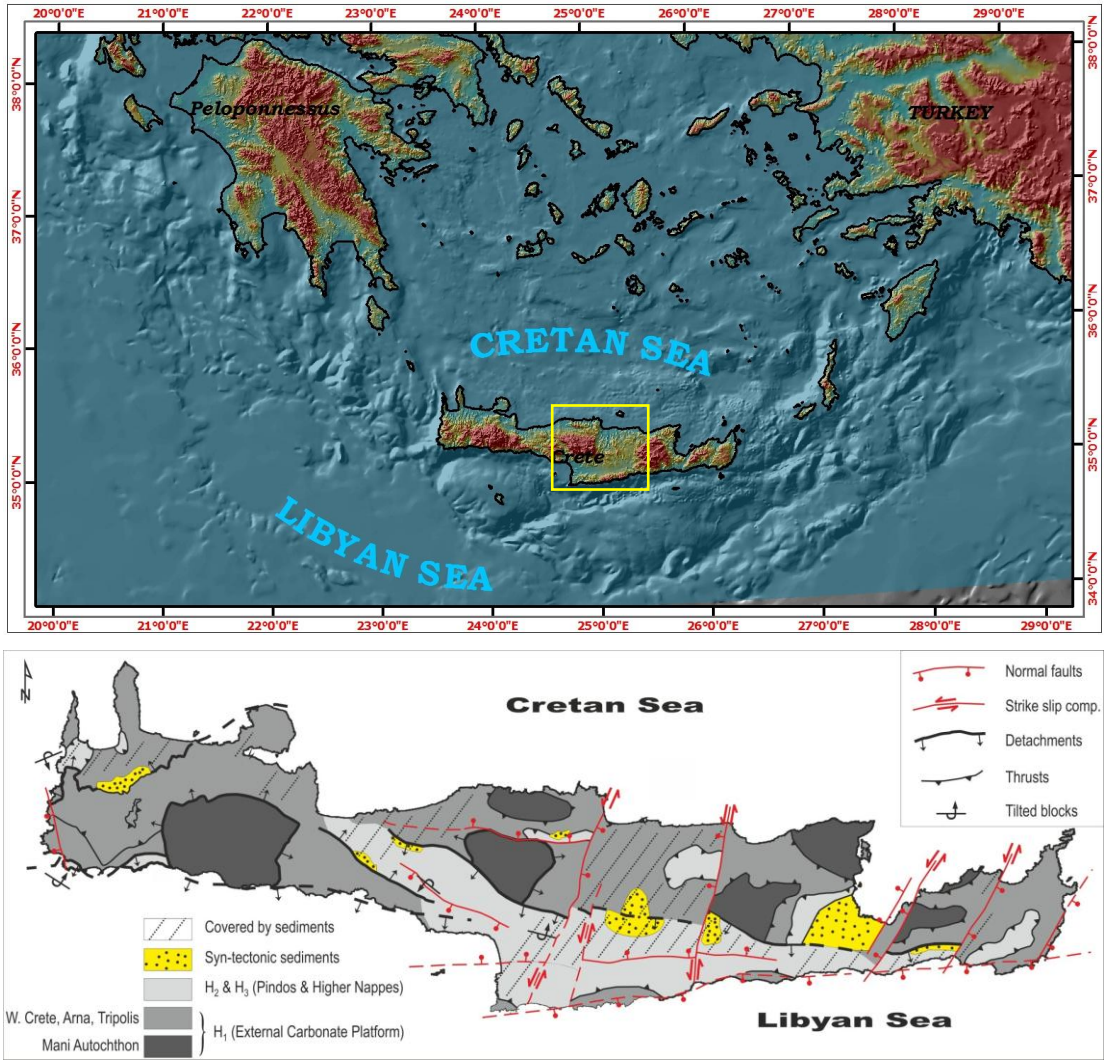

Figure 1: The onshore and offshore morphology of southern Aegean. Crete is located north of the Hellenic trench (upper figure) and the main geological structures (1,2) are shown at the bottom figure.

It is recently published that Messara basin is a supra-detachment basin which lies on top of the south Cretan extensional detachment (Figure 2) and therefore it has all the characteristics to be identified as an active half graben as it is located at the active margin of the rapidly moving southwestwards Aegean micro-plate (3,4,5). It is a similar structure but in a much smaller scale to the Cretan Sea half graben (6) which

lies on top of the north dipping Cretan low angle normal fault (7,8,9). This detachment's procedures have been completed before 15-17 Ma (10) and various tectonic movements have disrupted the fault surface much later. In many cases the contact has been covered and sealed by post-alpine sediments and therefore indirect dating of the age that the movement had stopped was made (11).

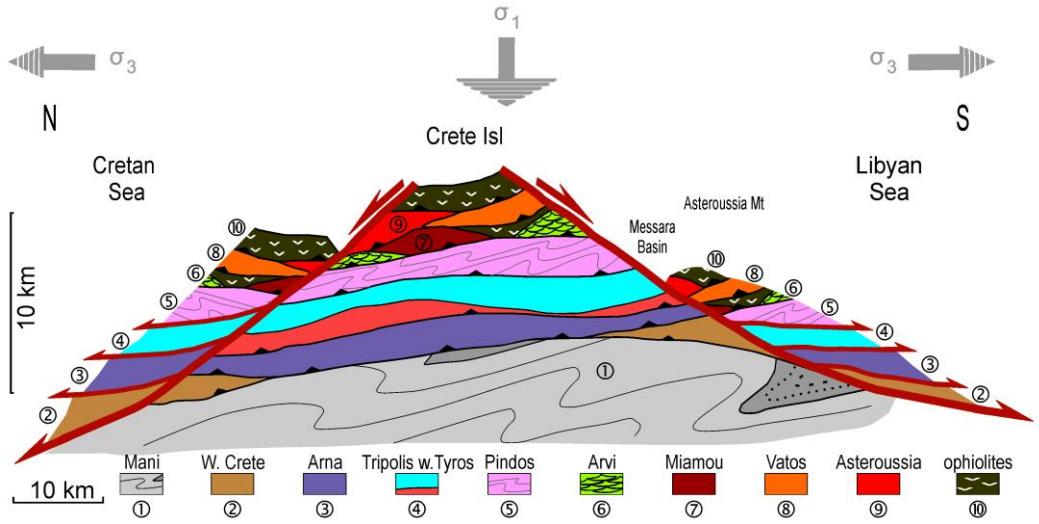

Figure 2: The alpine nappe pile has been affected by two low angle normal faults (2).

Even though the discussion about detachments in the Aegean and especially in Crete has begun for more than a decade, only few authors have published data and their opinions about the shear zones that intersect with extensional structures. In this paper, we present our observations at the field and after remote sensing data interpretation, which revealed the existence of several strike slip fault zones causing the segmentation of Crete Island, and hence the tectonic structures which were normal to them (Figure 1, bottom). We argue that the sinistral shear zones of the Hellenic forearc propagate across Crete to the Aegean Sea forming the eastern and western margins of Iraklion basin and consequently leave their imprints in the supra-detachment basin of Messara. The most prominent methodology seemed to be the evaluation and categorization of several kinds of field and lab data for reconstructing the broader onshore area, which was affected by these major structures.

REMOTE SENSING IMAGE INTERPRETATION

The data collection for tectonic analysis was based on extensive fieldwork and detailed geological mapping of the area of central Crete. The study of the major structures that seemed to control the Iraklion-Messara basin complex led to the definition of key areas, which were studied in higher detail and were mapped in a large scale. The area around Viannos village was selected because it is located at the easternmost post-alpine sediment outcrops where several major structures seem to intersect. Similar were the reasons for selecting the area around Ag. Varvara village, as this location the present morphological separation of Messara from the Iraklion contemporary basin exists. The third key area is located at the westernmost part of Asteroussia Mountain chain, around Matala village where relatively broad outcrops of Miocene sediments have been mapped even though they seem to be located out of the strict contemporary Messara basin. Within all the above mentioned areas the marks of recent tectonic disruptions are clear, since block tilting, unconformities and syn-sedimentary tectonism are observed in various scales. The tectonic and statistical analysis of the collected fault data has been performed with

software containing processing algorithms, which are based on published methodologies about structural tectonics. The large amount of the field data needed to be organized and categorized, thus a geo-database in a high end geographic information system had to be designed and constructed.

Remote sensing data proved to be very useful especially after digital interpretation in different levels. Several images were produced, especially by using spectral band combinations as well as spectral ratios aiming to a clear and precise outcrop imaging. The combination of various remote sensing data with different spectral and spatial resolution by merging them to a single fused dataset was very significant as this gave the opportunity to work in various scales. A high-resolution digital elevation model was generated and used for the three dimensional representation of the areas of interest giving different choices of observation, especially at places with problematic approach.

The remote sensing data used at the easternmost margin of Iraklion-Messara basin consisted of a SPOT-4 multispectral dataset (20m resolution) and a pan-sharpened Ikonos-2 (1m resolution). A large number of band ratios were applied at both datasets, as well as band combinations in order to understand if there is a visible strike slip component on the marginal fault zone of the supra-detachment basin. The main points of interest were at the broader areas of the sites, where field data revealed such tectonic movements. After the image interpretation, it became more than clear that oblique faults with significant sinistral component have been activated at this marginal area of the basin and this was also confirmed by fieldwork. Particular structures on the surface were observed being offset by linear features trending NNE-SSW (Figure 3). These structures are highly related to E-W trending faults antithetic to the major structure of south dipping detachment. The strike slip faulting has affected the late Miocene lacustrine and marine sediments that outcrop at this area and therefore the tectonic movement should be placed much later, possibly during or after Pliocene.

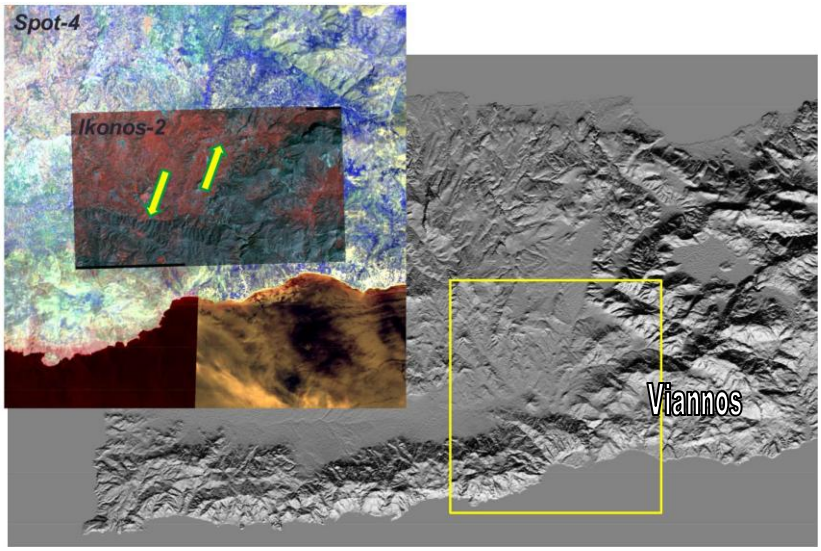

Figure 3: Image samples of various resolution from Viannos area, which were interpreted and led to the existence of a significant left lateral movement component along the easternmost marginal fault zone of central Crete.

Similar structures have been identified at the westernmost margin of the Iraklion basin, but at the footwall of the south dipping Cretan detachment. The remote sensing data used consisted of a SPOT-4 multispectral dataset (20m resolution). At this specific area the outcrops comprise mainly of alpine basement rocks (flysch, carbonates) and therefore the image interpretation was much easier. Band ratios

were also applied and several pseudo-chromatic images were produced. Additionally, a large number of lineations were identified trending either NNE-SSW or E-W. A sinistral sense of movement was clear in this area as well (Figure 4). The detachment fault zone seems to be affected as its trace has been offset with a significant left lateral component. It is a major structure that seems to begin at the northern coastal area of the island and it is very possible that it continues offshore. The southern wards prolongation of the fault zone affects the supra detachment basin of Messara, by dividing it in two subareas and several branches can be identified at the E-W trending mountain chain of Asteroussia, which bounds the basin to the south.

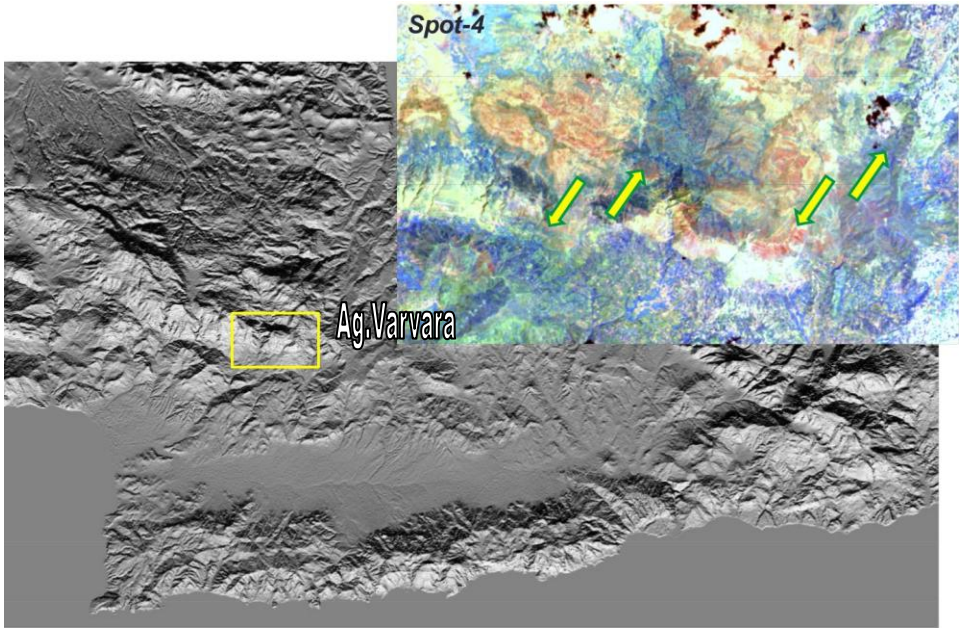

Figure 4: The key area of Ag. Varvara, where sinistral strike slip movements were identified by remote sensing data interpretation and verified after extensive fieldwork.

That is the exact location of the next area that is studied in this paper, just east of Matala village. The remote sensing data used at the westernmost margin of Iraklion-Messara basin consisted of a SPOT-4 multispectral dataset (20m resolution) and a pan-sharpened Ikonos-2 (1m resolution). The high spatial resolution of Ikonos-2 images enabled us to identify step like structures at the northern foot of Asteroussia mountain chain, which are compatible with left lateral strike slip movement (Figure 5). It is rather clear by the scalar outcrops of the basement rocks and the recent sediments of the basin but also by linear features that were identified on the images that a major sinistral structure has affected this part of the island, as well.

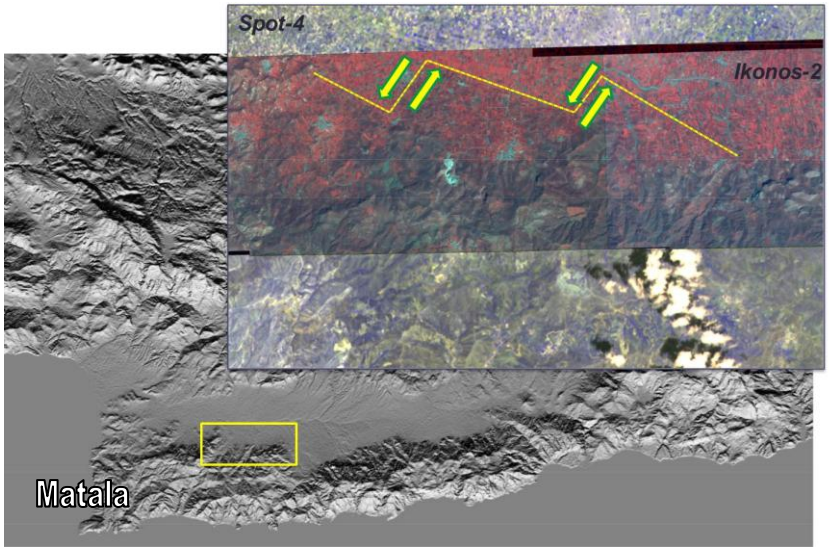

Figure 5: Step like structures compatible with left lateral strike slip movement.

DISCUSSION

The tectonic framework that has been described implies a continuously developing tectonic regime, taking place at the southern edge of the Hellenic island arc, which can be also identified in remote sensing images before proving it through fieldwork. Crete Island has a unique geo-tectonic position on this island arc and the complexity of the tectonic structures reveals an active environment throughout the entire post-nappe stacking period till present. Thus, in a clearly strong E-W trending structure (Messara), a lot of NE-SW and NW-SE trending structures seem to co-exist, which can be identified in remote sensing images and studied in a bigger scale, as they are segmented and buried under the recent sediments of the supra-detachment basin. The existence of these conjugant structures is associated to the geodynamic evolution of the bending island arc and could be mapped more or less throughout the Messara basin and is highly related to the post-alpine period. The overall bending of the Hellenic trench which has followed the southwestward movement of the Aegean micro-plate during late Miocene was the main reason for the development of a dominating trans-tension stress field at this segment of the island arc. Both of the conjugant structures were active but on central Crete a strong left lateral component is observed even though the main stress field remains extensional. The stress field changes, which were derived by extensive fieldwork and various interpretations, refer to the dominating component during every time period and not to an entire alteration of the stress axis. The nearly N-S trending extension is imprinted on the fault blocks and between their boundaries which are delineated by the large shear zones that also disrupt the margins of the overriding plate.

It is clear that the contemporary Messara basin is operating in its present shape since Pleistocene and is not a typical symmetrical E-W trending neotectonic graben with parallel marginal fault zones bounding the post-alpine formations. On the contrary it can be separated by a transversal NNE-SSW trending shear zone which among others it causes tectonic block rearrangement and disturbs the river network by dividing the pre-existing single watershed into two independent catchments flowing to the east (Anapodaris) and flowing to the west (Geropotamos) (12). The westernmost has an active north margin dipping to the south, which is the western segment of south dipping Cretan low angle normal fault (Figure 6). The easternmost has an active south margin dipping north which is a segmented fault zone, antithetic

to the eastern segment of the detachment, with en-echelon arrangement of the fault traces, probably because of the implications of the left lateral strike slip transversal structure. At the eastern area the most active structures are the north dipping normal fault zones that are causing the uplift of the east Asteroussia Mountain chain. This continuous and rapid uplift of its morphology contributes to intense incision and generation of several gorges normal to the Libyan Sea coastline.

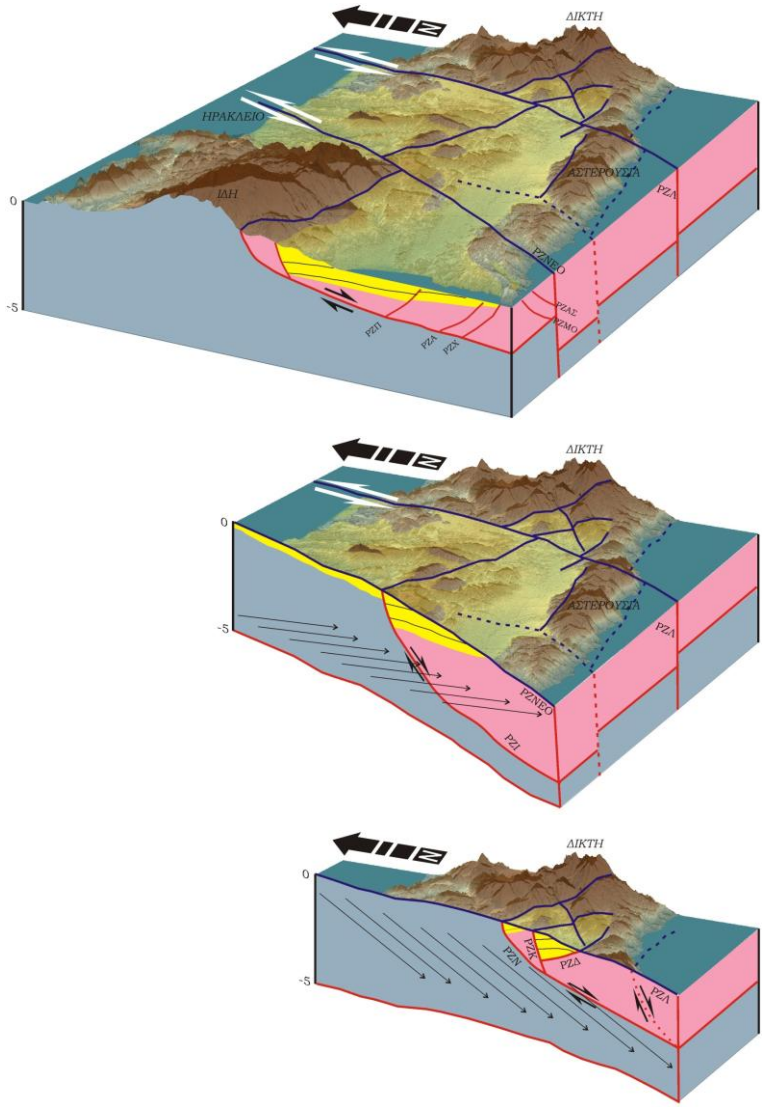

Figure 5: Block diagram of central Crete showing the main fault blocks, which have been created by the generation of the south dipping Cretan detachment and its segmentation by the NNE-SSW trending left lateral strike slip zones.

The most active area along Messara basin seems to be the one that lies on the western fault block of the strike slip shear zone. The dominating structure is the Cretan detachment's westernmost segment and the hanging wall seem to tilt towards north as its northern area subsides with relatively high rates, sliding on the low angle fault surface. The eastern margin of this fault block is located at the projection of the western margin of Iraklion basin in Messara and crosscuts Asteroussia at its western part, along the previously described shear zone. The left slip along this zone seems to be rather active as it still hosts micro-earthquakes with significant strike slip component, which is proved by the interpretation of micro-seismicity data collected at the mid 1990's (13).

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