Geologic, Geomorphic and Geodetic Constraints on Vertical Motion Trends of Itea-Amfissa Basin (Northern Corinth Rift, Central Greece)

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INTRODUCTION

In the Itea – Amfissa basin there is a general contrast in the morphology with co-existence of low-relief remnant surfaces with slow erosion rates with dissected river valleys (Sweeting 1963, Mpelos 2000, Gouliotis 2014). **Thus the basin is in a transient geomorphological stage**, where part of its landscape has adjusted, or is adjusting to new conditions and part has not. This adjustment is the result of an increase in elevation and/or rock uplift rate. However, along the coastal zone of the Gulf of Itea there is evidence for Holocene subsidence from tidal-notch profiles and archaeological remains.

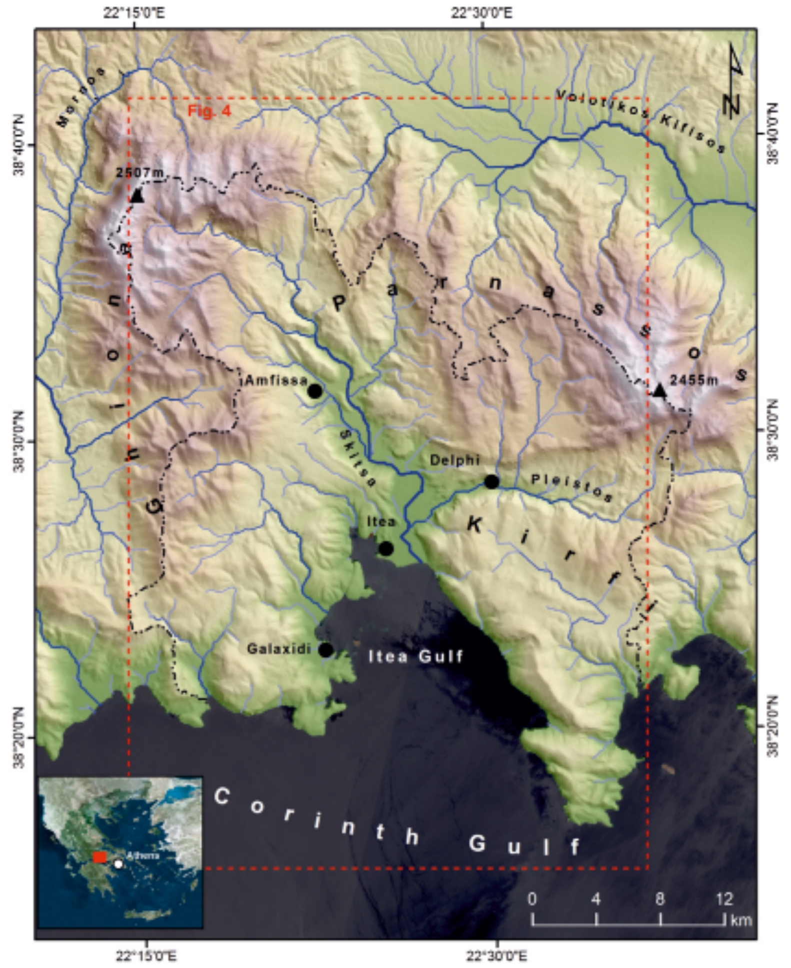


Figure 1. Topographic map of Ghiona, Parnassos, Kirfi and the Itea – Amfissa basin; a narrow morphological depression that is drained by the Skitsa River to the Gulf of Itea. The topography is derived from available 20m resolution Digital Elevation Model (Geographical Survey of the Greek Army). Inset dotted box refers to Figure 4.

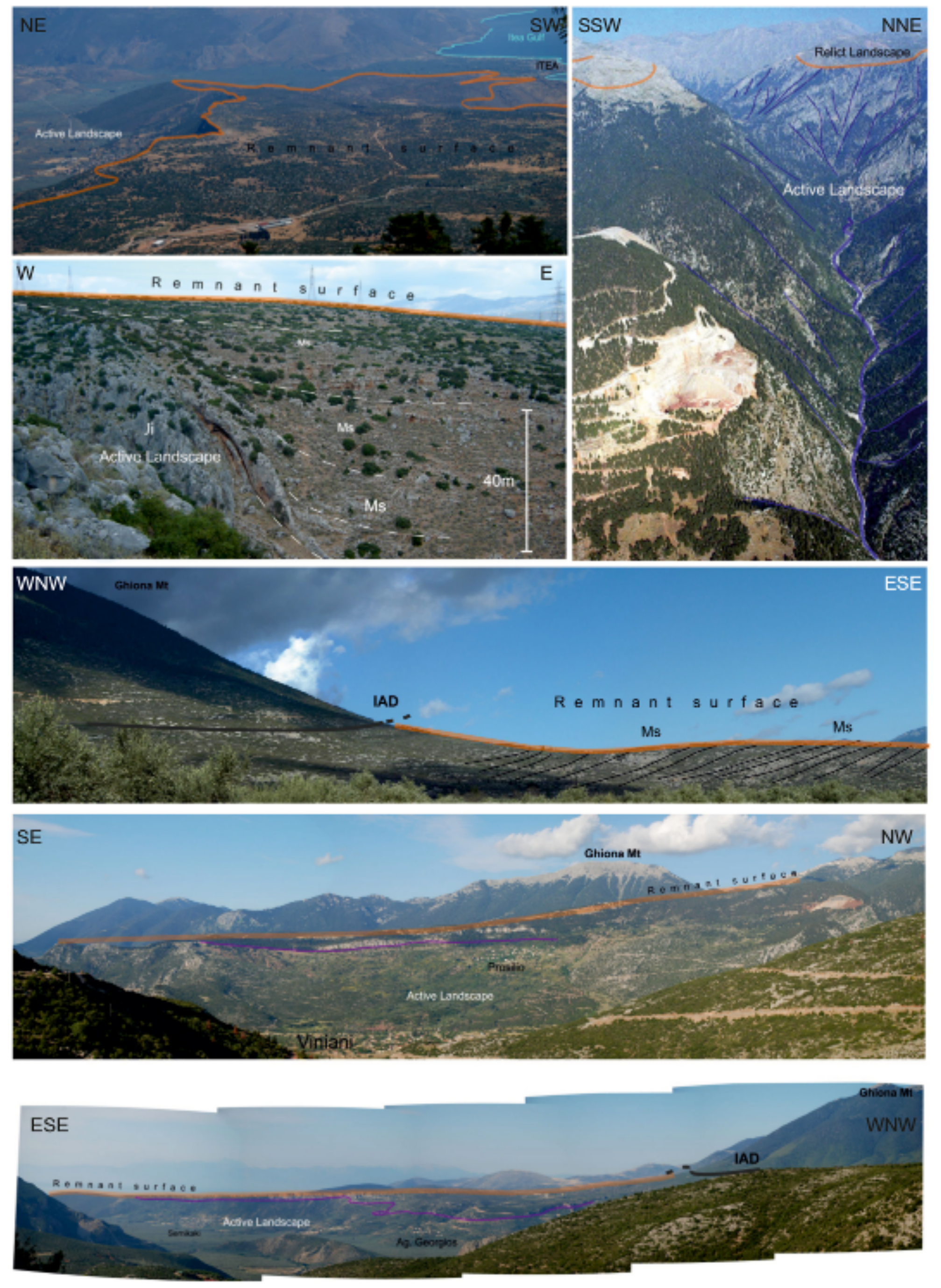


Figure 2. Field examples of the co-existence of the remnant surfaces (orange) with the deep river gorges and the major valleys in the morphology of the Itea – Amfissa basin. Close to the Itea - Amfissa detachment (IAD) remnant surfaces cut on top Late Miocene terrestrial deposits (Ms), its synsedimentary faults with the alpine basement and the unconformity (purple) with the Early – Middle Miocene marine sediments below. a) View to the SE b) View to the WNW c) View to the N d) View to the NNE e) View to the SW f) View to the SSW

SAR INTERFEROMETRY (InSAR)

We measured ground displacements over the last 18 years (1992-2010) using SAR interferometry (InSAR). The entire SAR archive of the ERS and ENVISAT missions in both ascending and descending orbits were utilized for the purposes of the study. A DEM aided co-registration approach, as per geometry, was implemented using precise orbit state vectors and a 20m resolution DEM, interpolated from 1:5000 scale topographic maps.

The conventional Differential InSAR technique followed by Interferometric Stacking was applied to extract deformation signals. The InSAR results correspond to average ground displacement rates in the line-of-sight (LOS) of the satellite for the examined period. By referring the InSAR measurements to a geologic frame, instead of minimizing the motion of an arbitrary selected region, we enable meaningful interpretation of deformation trends to what expected by the local geodynamic regime.

Among the main observations are, (i) the overall subsidence along the coastal areas, (ii) the relative stability of the majority of regions within the Itea-Amfissa basin, and (iii) the complexity of motion trends in surrounding mountain ranges.

Figure 8. To facilitate comparison between geodetic-derived displacement estimates and geologic-geomorphological observations, a reference area located at a karstic doline was selected. The knownen vertical motion of the doline, estimated over approximately the last 6,000 years by means of geological dating (Evelpidou et al. 2011), was projected to the corresponding LOS geometries and added to the individual InSAR solution.

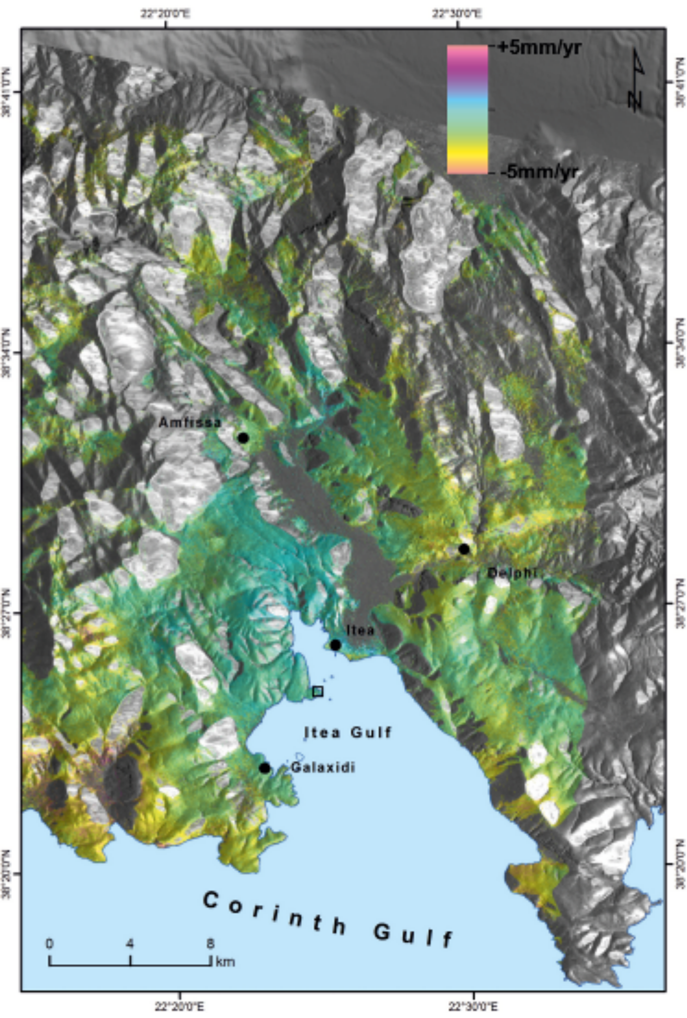


Figure 9. Average vertical displacement rates for the period 1992-2010, as derived by combining ascending and descending SAR interferometric measurements.

ABSTRACT

Combining geological and geomorphological data together with geodetic SAR interferometry (InSAR) measurements an attempt has been made to investigate the vertical deformation of the Itea-Amfissa basin at the northern part of the Corinth rift. The north–south trending basin has been developed normally to the east – west trending Corinth Rift and on the hanging wall of the Itea-Amfissa detachment. In the stratigraphy of the Itea–Amfissa supra-detachment basin, two sequences can be distinguished; the lower marine polymict conglomerate of Early–Middle Miocene age and the upper terrestrial monomict carbonate breccia of Late Miocene age. The unconformity between them has been uplifted to the north of the basin up to the elevation of 1100m and subsided below sea level at its southern part. Remnants of low-relief surfaces are retained on top of the upper terrestrial sequence, that permit to reconstruct the paleo-landscape of the basin and to measure the spatial distribution of its vertical deformation after compensating the erosional isostatic adjustment. The exact delineation of the paleo-landscape, involved detailed mapping as well as quantitative analysis of geomorphological features caused by river incision, based on measurements of several tectonic geomorphology indices. Geodetic InSAR estimates of vertical ground displacements, combining almost 18 years of ascending and descending ENVISAT data, were also utilized both for refinement of delineated surfaces as well as for validation of geology-based deformation trends. Interferometric results were constrained to the geologic time frame, considering the well-defined long-term deformation trend of a doline, proven to be sinking over the last 6000 years. It is shown that over the last 18 years the largest uplift rates are observed within the Itea-Amfissa basin, while the coastline regions follow a more complex spatial deformation pattern of successive submergences and uplifts. The synthesis of geological and geomorphological data indicates that the Itea-Amfissa extensional basin from its development in the Middle-Late Miocene and throughout Plio-Quaternary, has been tilted towards south, while contemporary geodetic measurements from InSAR confirm that the basin is still uplifting with regard to its surrounding mountains and coastal areas.

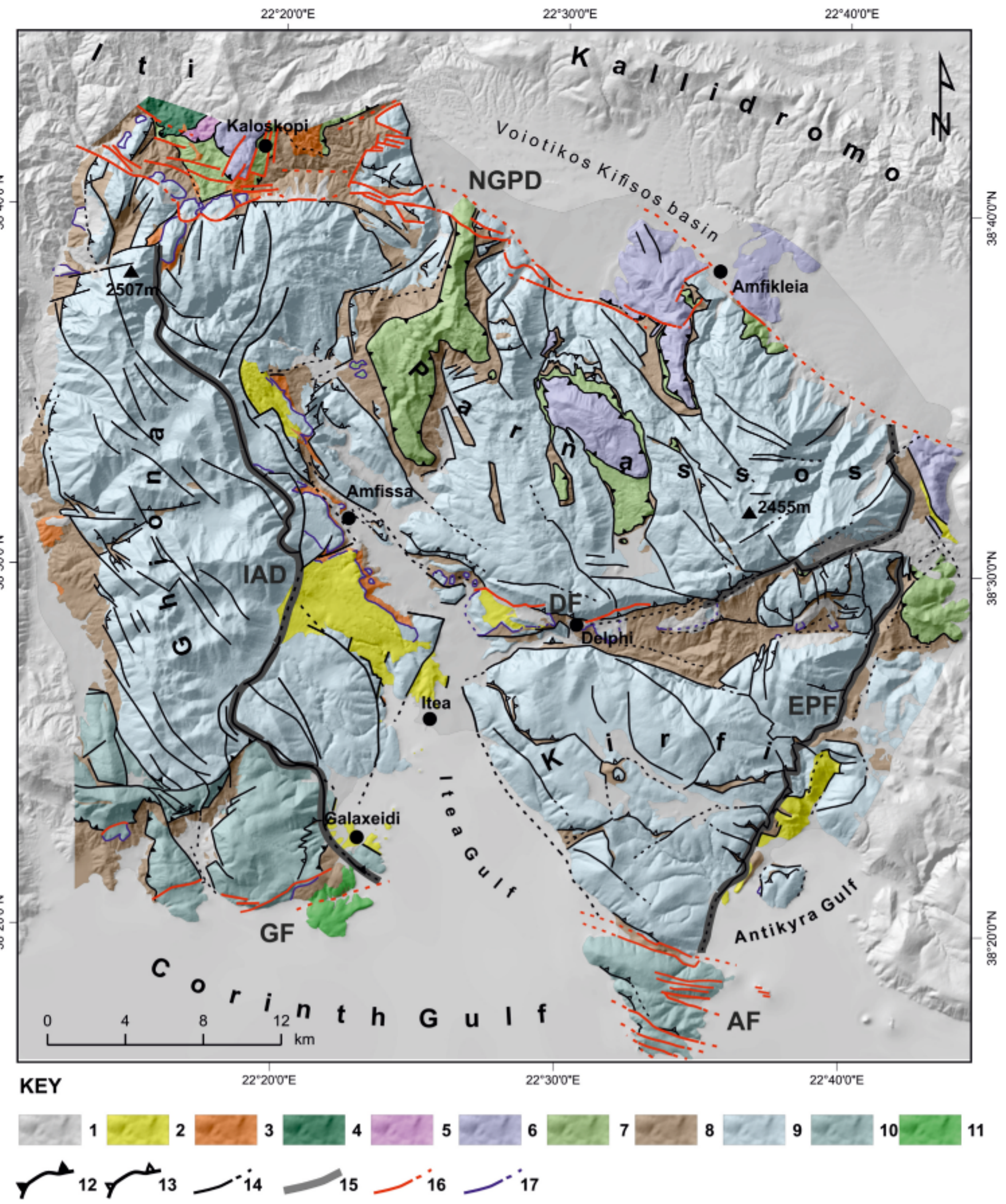


Figure 3. Geologic map of Ghiona Mt, Parnassos Mt and Kirfi Mt. modified after Papastamatiou (1960), Célet (1962), Schwan (1976), Wigniolle (1977), Combés (1983), Hofbauer (1985), Richter et al. (1996), Papanikolaou et al. (2009) and Gouliotis (2014).
1. Alluvial deposits and scree (Pleistocene) 2. Monomict terrestrial carbonate breccia (Late Miocene) 3. Polymict marine conglomerate (Early - Middle Miocene) 4. Ophiolithic mélange 5. Maliac unit 6. Sub-Pelagonian unit 7. Beotian unit 8. Flysch (Paleocene – Eocene) 9. Mesozoic carbonate platform of Parnassos – Ghiona unit 10. Mesozoic slope and pelagic facies of the Vardousia, Penteoria and Skotomeni units 11. Cretaceous pelagic facies of the Pindos unit 12. Overthrust 13. Thrust 14. (?Late Oligocene) Miocene faults 15. Trace of the major Middle - Late Miocene extensional systems 16. Plio-Quaternary faults 17. Gravity slides. Abbreviations refer to major faults as follows: IAD. Itea – Amfissa detachment; EPF. East Parnassos Fault; NGPD. North Ghiona – Parnassos detachment; DF. Delphi faults; GF. Galaxeidi faults; AF. Antikyra faults.

GEOLOGIC BACKROUND

The formation of the Itea-Amfissa basin is related to the NNW-SSE Itea-Amfissa extensional detachment (IAD) located along the eastern slopes of Ghiona Mt (Papanikolaou et al. 2009). To the south, a series of ~E-W (?)active neotectonic faults cross-cut the IAD a) the onshore ENE-WSW normal faults observed west of Galaxidi (GF), b) the WNW – SSE faults of Antikira (AF) and c) the offshore active faults of the Northern Corinth rift (Taylor et al. 2011). To the north is flanked by the North Ghiona – Parnassos detachment (NGPD) (Kranis & Papanikolaou 2001, Gouliotis 2014).The only E-W fault occurring in the broader area of the Itea-Amfissa basin is the Delphi fault (DF)(Piccardi 2000), which runs parallel to the Delphi Valley. This fault shows some recent activity by affecting consolidated scree and slope debris of the South Parnassos slopes, but it also exhibits similar geometry to the older extensional faults on the hanging wall of the Itea-Amfissa detachment.

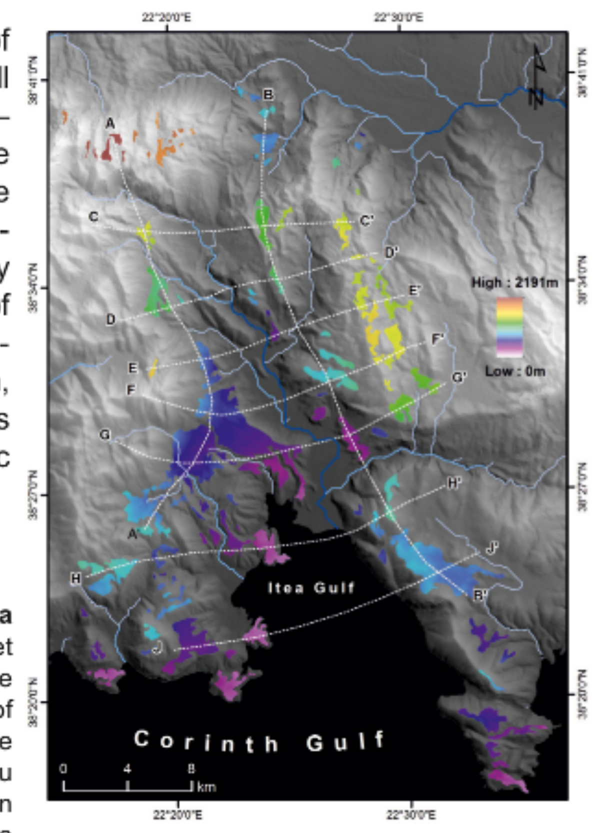


Figure 4. Detailed elevation map of remnant surfaces over digital topography. Dashed lines show location of cross sections in Figure 5.

RELICT LANDSCAPE

In order to measure the vertical deformation throughout Plio-Pleistocene we reconstructed its "relict landscape" (Clark et al. 2006). For the mapping of the remnant surfaces we used criteria such as: local elevation, local slope, local relief, river steepness index, categorization by age of the major tectonic structures, quantification of the erosional processes and field work. From the regional continuity of remnant surfaces we reconstructed the relict landscape **by fitting an interpolated surface using a spline interpolation with tension**. We plotted the spline surface and topography along down-slope and cross-slope sections to show that the spline provides an acceptable fit to the individual remnant surfaces. We subtracted the initial elevation of the spline from the original DEM topography and **we calculated the geophysical relief**, which is the spatially averaged depth of erosion from the reconstructed surface. **This helped us to estimate the effect of isostatic adjustment** using a three dimensional rebound model incorporating the effect of flexural rigidity of the crust into predictions of the isostatic rock uplift in response to the negative load associated with valley development. The resulting map (for flexural strength of the crust T=10km) showed that the maximum contribution to the modern topography from isostatic adjustment due to surface erosion, is generally less than 14 m across much of the Itea – Amfissa basin and might be as much as 74 m in regions that are more extensively dissected. This value is small and suggests that almost **all of modern elevation of the reconstructed paleolandscape is due to tectonic processes**.

AGE OF RELICT LANDSCAPE

Most of the remnant surfaces especially on the western part of the hanging wall of the Itea – Amfissa detachment, cuts on top the Late Miocene terrestrial sediments (Papanikolaou et al. 2009). The younger rocks that locally mantle the remnant surfaces and located mainly along the "active" landscape that dissects the Miocene supradetachment Itea – Amfissa basin are of Pleistocene age (Papastamatiou 1960, Célet 1962). Assuming that the onset of river incision in the basin postdates its planation, then **the age of the relict landscape of the Itea – Amfissa supra-detachment basin is Late Miocene – Pliocene**.

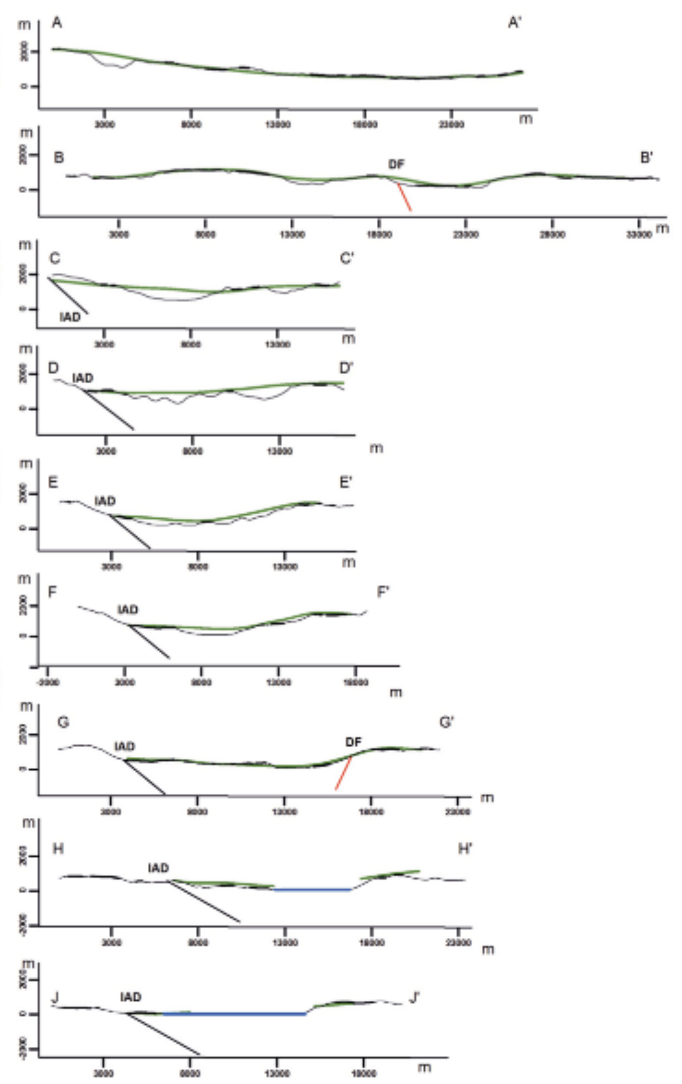


Figure 5. Topographic profiles located parallel and perpendicular to the regional topographic gradient of the Itea – Amfissa basin (for location in the map see Figure 4). Actual topography along the profile is shown by the thin line. Thick line represents areas where remnant surfaces are preserved. Thick green shading highlights the profile of the interpolated surface (paleolandscape), where the width of this line represents the average local relief (<100m) on the remnant surfaces.

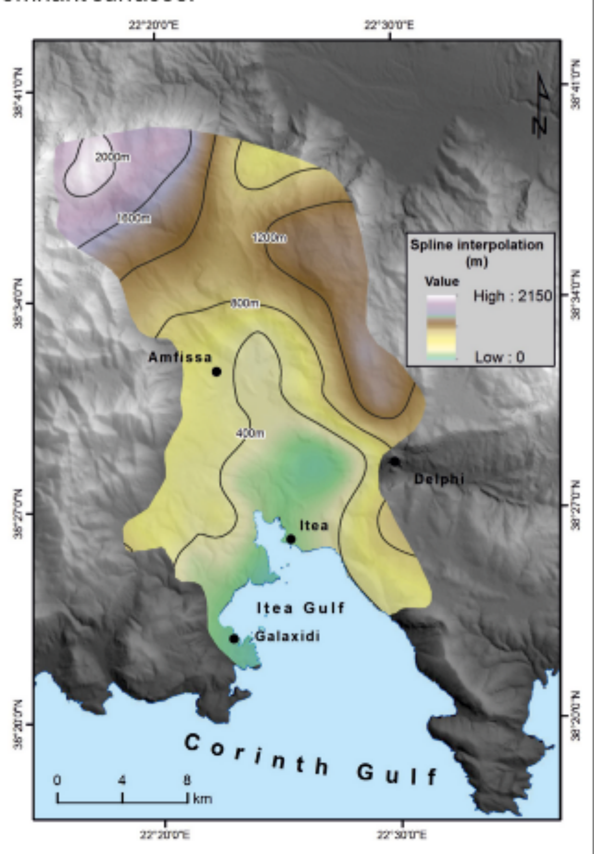


Figure 6. Interpolated fit (spline with tension) to remnant surfaces colored by elevation with 400m elevation contours. This interpolated surface represents the reconstructed relict landscape of the Itea - Amfissa supra-detachment basin.

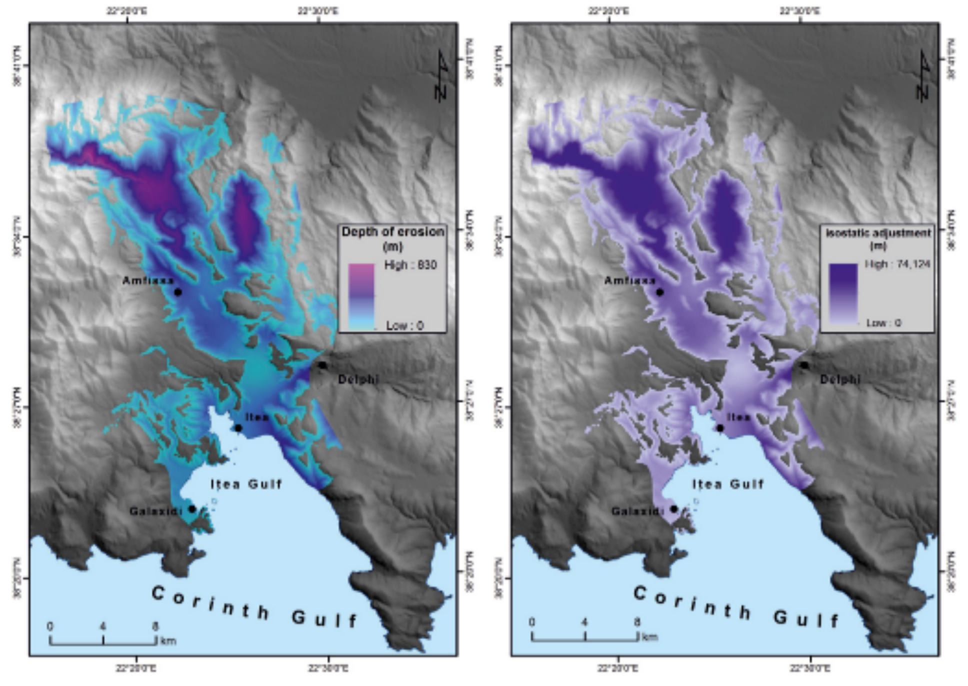
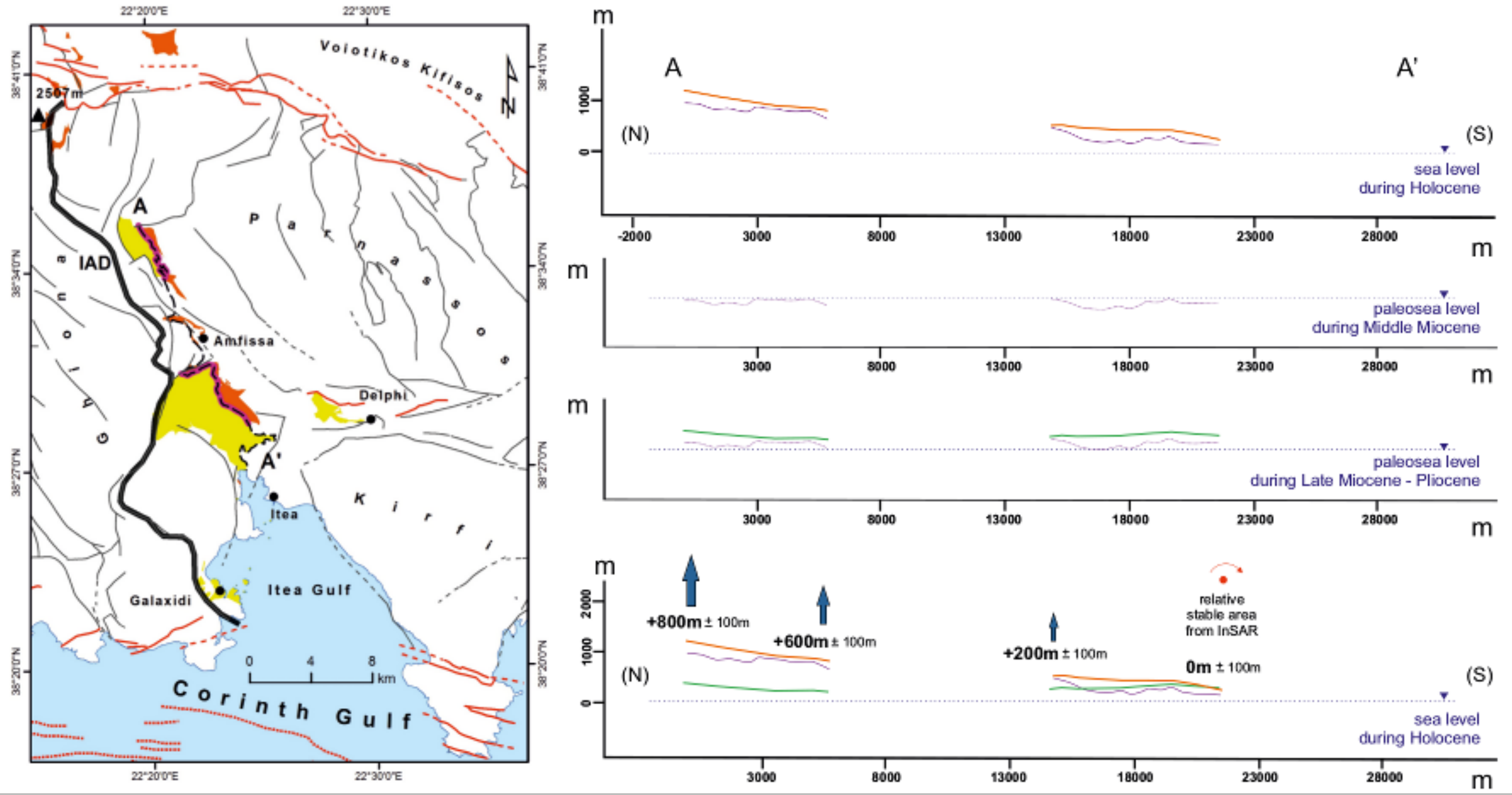


Figure 7. (Left) Depth of erosion map. Deviations of actual elevation from interpolated spline surface. Regions of high values (incision into the relict landscape) correspond to deep, narrow gorges of the major rivers. (Right) Calculated isostatic adjustment due to erosion.



VERTICAL MOTION TRENDS OF ITEA-AMFISSA BASIN - CONCLUSIONS

The slow erosion rates of the remnant surfaces of the basin allow us to use the modern elevation of the relict landscape as a measure of long-term vertical deformation. In order to achieve that, we calculated the vertical displacement of the paleolandscape along two topographic profiles parallel to the unconformity (purple) between the marine and the terrestrial sequence of the Miocene basin. This allowed us to calculate the vertical deformation in two stages. The first stage corresponds to the vertical deformation during Middle – Late Miocene (as part of the IAD hanging wall - green line along A-A' section) and the second stage during Pliocene – present (as part of the NGPD footwall and also related to the Corinth rift active faults - orange line along A-A' section). The absence of Plio-Pliostocene faults that could account for a differential uplift between these two areas, could be explained as the result of horizontal axis rotation along an E-W axis.

- **A combined geological, geomorphological and geodetic study can reveal significant information about vertical motion trends in an area.**
- **The Miocene Itea-Amfissa basin shows evidence for rotation along an horizontal E-W axis, as a result of the combined activity along the NPGD faults to the north and the Corinth Rift faults to the south. This rotation can account for the uplift of the basin to the north and the subsidence at the coastal zone of the Gulf of Itea.**
- **The location of the horizontal axis based on the relative stable areas from InSAR has been tentatively estimated to be at equal distance (20km) from the active offshore faults of the Corinth Rift to the south and the NGPD to the north . The continuation of the axis to the east coincides with the Delphi Fault.**
- **Although the Itea - Amfissa basin is a part of a 1st order Plio-Quaternary tectonic horst within the extensional province of Central Greece, its inherited tectonic grain accounts for its aseismic deformation.**