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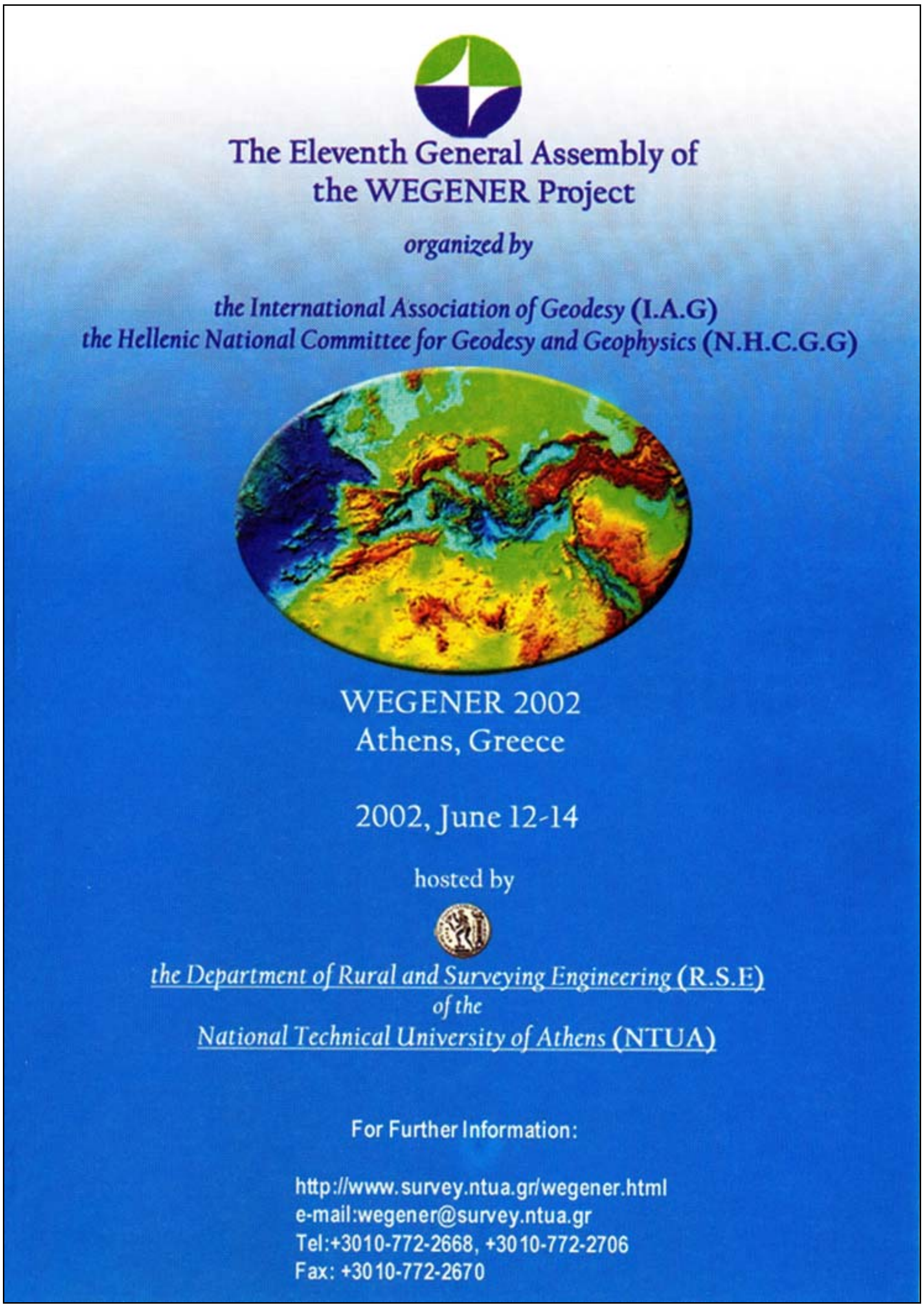

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RECENT MOVEMENTS OF THE UPPER CRUST DUE TO CREEP DEFORMATION BASED ON GPS MEASUREMENTS IN W. MACEDONIA (NW GREECE)

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Abstract

An attempt is made to understand the present deformation type in the Grevena area (W. Macedonia, Greece). GPS network was established after the 13 May 1995 earthquake and measurements were taken on May 1995, May 1996, May 1998, and September 2000. The study of the these measurements combining with the geological data, gave us the opportunity to calculate the mean horizontal velocities of the distinguished blocks as well as to try to estimate the vertical displacement in some sites comparing the measurements of 1995 and 2000. It is worth mentioned that in the time period 1998 – 2000 a very important horizontal displacement was measured without having any important seismic activity in the same time.

Introduction

The Kozani – Grevena area was, until recently, considered as one of the most tectonically and seismically inactive regions in Greece (PAPAZACHOS, 1990) did not seem to be of any particular interest (**Fig. 1)**.

The earthquake of 13 May 1995 came to contradict the notion of seismic inactivity; great damage was caused to relatively small triangular-shaped region, bounded by the Paleohori - Sarakina fault zone at the south (which may be a prolongation of the prominent Servia fault), the Chromio - Varis fault zone at the north and Aliakmon river at the west (**Fig. 2**).

In the broader study area the following fault zones occur: the Aliakmon (AFZ), the Pramoritsa (PFZ), the Dafnero (DFZ), Paleohori – Sarakina (PSFZ), Chromio – Varis (CVFZ) and the Servia fault (**Fig. 2**).

After the earthquake of May 13 1995, between the years 1995 and 2000, a number of GPS measurements took place by the National Technical University of Athens, and the University of Oxford, at a network of observation pillars, most of them belonging to the Hellenic Triangulation Network.

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In this paper it is an attempt to investigate thoroughly the degree of tectonic activity of the area and to integrate Geodetic and Geological data.

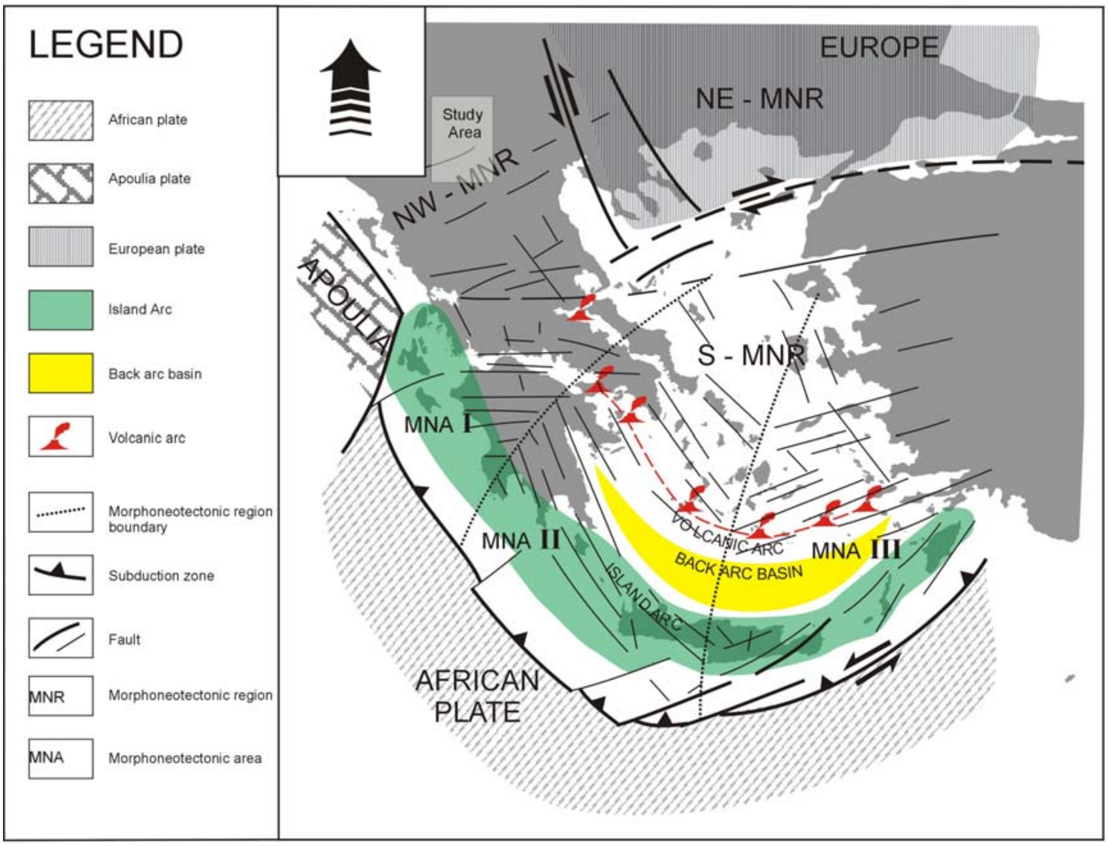

Fig. 1 The present geodynamic regime and location map of the study area.

Regional Geology – Neotectonics

The area affected by the earthquake activity of May 1995 is an E-W trending zone, from the northeastern margin of the Meso-Hellenic Trough. Three tectonic macrostructures can be distinguished: (i) the NW-SE trending margin of the Meso-Hellenic trough, at the east of Grevena; the main outcrops are the Miocene Pentalofos and Tsotyli marine formations, overlain by Early Pliocene marine deposits and Pliocene –Quaternary mainly fluvial – lacustrine conglomerates, sands and marls (FOUNTOULIS *et al.,* 2001); (ii) the ophiolites mass of Mt. Vourinos in the middle and (iii) the lacustrine basin of Kozani – Servia at the east (Pliocene – M. Pleistocene, BRUNN, 1956, KOUFOS & KOSTOPOULOS*,* 1993), faulted against Mt. Vourinos by a NW-SE fault zone (MAVRIDIS & KELEPERTZIS, 1994); its southern border is also tectonic, with the prominent NE-SSW Servia fault juxtaposing it against the Mesozoic rocks of Mts. Kamvounia and Titaros. The SW prolongation of Servia fault running through Paleohori, Sarakina, and Kendro (villages that suffered great damage), may constitute a separate segment, recognizable by the morphologic escarpment created in the molassic deposits (FOUNTOULIS *et al.,* 2000) .

Within the structures of Grevena and Vourinos, few faults are recognizable, the majority of which have E-W or NW-SE trends. Some NW-SE and ENE-WSW trending lineaments that, based on aeromagnetic anomalies, could be interpreted as faults have also been detected in the mountainous mass of Vourinos (MAVRIDIS & KELEPERTZIS, 1994). One of them is the

Chromio – Varis – Knidi lineament, which can represent a fault reactivated during the 15 May 1995 earthquake, as all villages lying along its strike were razed (Knidi, Varis) or suffered extensive damage (Chromio).

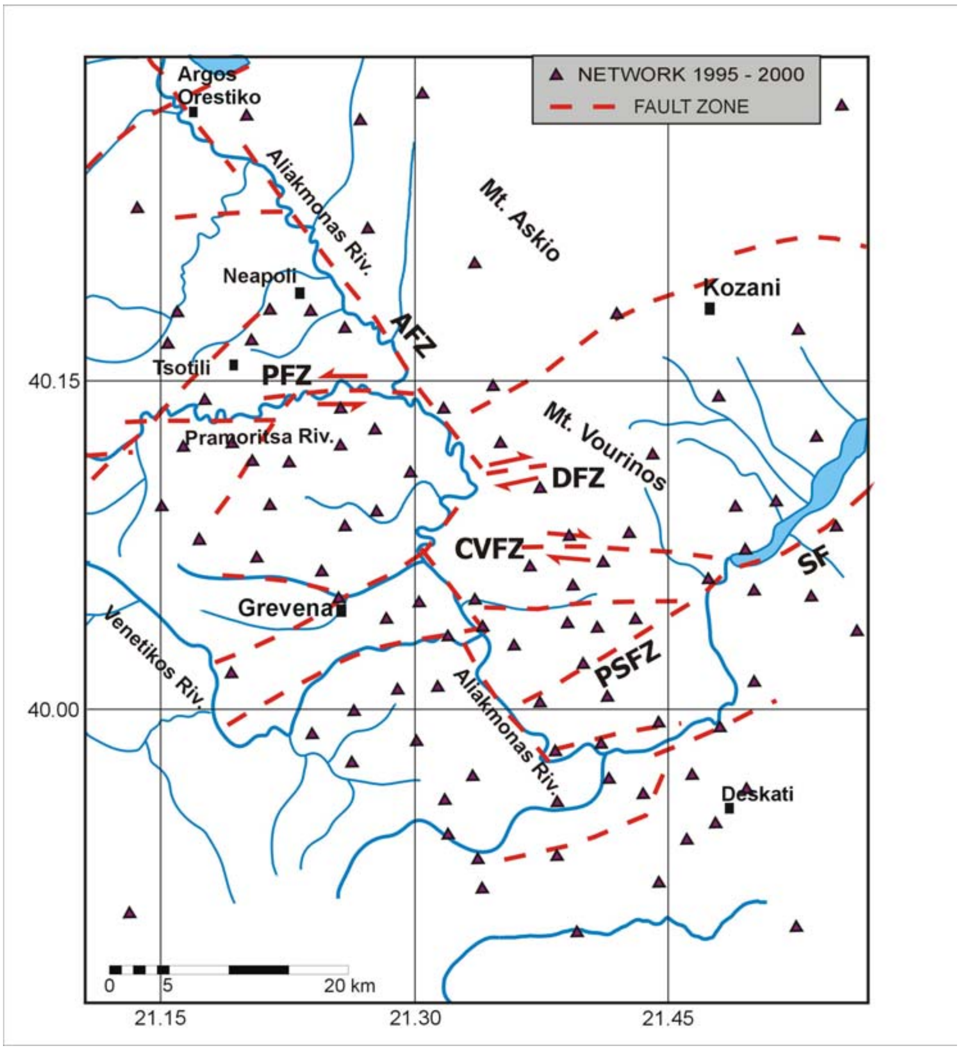

Fig. 2 The Geodetic Network as well as the main fault zones of the study area. AFZ: Aliakmonas fault zone, PFZ:Pramoritsa fault zone, DFZ:Dafnero fault zone, CVFZ:Chromio – Varis fault zone, PSFZ:Paleohori – Sarakina fault zone, SF:Servia fault

The Grevena – Kozani GPS Network

The National Technical University of Athens realizes GPS geodetic measurements in many Greek regions in order to calculate the displacements of several areas and thus to study the tectonic activity.

As already mentioned, between the years 1995 and 2000, a number of measurements took place at a network of observation pillars, most of them belonging to the Hellenic Triangulation Network. The coordinates have been determined by terrestrial geodetic methods. The use of these pillars permits us to compare the results of satellite geodesy methods to their known coordinates on the Hellenic Geodetic Reference System 1987 (HGRS 87). The epoch of the HGRS 87 coordinates is assumed to be in the early 80's, since the 1st order measurements were done in the period 1975 – 1979 and the 2nd order measurements in the period 1982 – 1985.

In May 1995, a week after the main shock, 91 pillars were measured. Most of these pillars belong to the Hellenic Triangulation Network. These triangulation pillars were occupied without prior knowledge of the location of the earthquake epicenter and the measurements have been taken every two hours.

Further measurements took place in September 1995, May 1996, May 1998 and September 2000, where 37, 39, 56 and 59 sites were measured respectively, in order to check the aftershock behavior of the affected area.

More specifically, on September 1995 measurements took place on 37 from the initially 91 pillars of the Network. On May 1996, 39 pillars were measured, and on May 1998, 56 pillars were measured.

On September 2002 (1/9/2000 to 10/9/2000) 59 pillars were measured, from which, the 53 belong to the Hellenic Triangulation Network. Two of the pillars locating at Siatista as were used as basic stations of the network and were measuring during the whole period of the measurements. Two more stations were used, one at the Dionysos Satellite Center belonging to NTUA, and the other at the rooftop of the Labatharios building in the Polytechnioupoli, Zografou. These two last stations were used for the connection of the Network with the geocentric system ITRF (International Terrestrial Reference Frame) (stable Europe), while the other two stations were markers. In every pillar a GPS receiver was put at least one time during the 9 days of the measurements and at least for 4 hours. In order to succeed the best localization of the pillars, many of them were measured twice up to five times for more than 4 hours in different days. For this reason most of the pillars were measured for more times than twice, since the 18 of the 55 pillars were measured only in one day.

The whole network consists of 120 sites observed within these 5 years (**Fig. 2**). This high number of sites permits us to draw some conclusions concerning the movements that took place due to the seismic activity, as well as the movements that took place in the period 1998 – 2000 without any serious seismic activity.

The accuracy of the GPS results is estimated to be better than 1 cm for the horizontal components and of the order of 2 cm for the vertical component.

Comparison of Different Epoch Measurements

For the time period 1980 – May 1995, that is a week after the main earthquake, there were 91 common sites and the mean displacement was calculated to be at the order of 11 cm and the mean velocity 0.73 cm/y (**Fig. 3**).

For the time period May 1995 – May 1996 there were 19 common sites and the mean displacement was calculated to be 1.5cm. This value is very high (double) in comparison with the previous ones (**Fig. 4**).

For the time period May 1996 – May 1998 there were 29 common sites and the mean displacement was calculated to be 0.6 cm and the mean velocity 0.3 cm/y (**Fig. 5**).

For the time period May 1998 – September 2000 there were 31 common sites and the mean displacement was calculated to be 0.8 cm and the mean velocity 0.6 cm/y. That is the mean velocity is hypo double than these of the 1995 – 1980 and 1980 – 2000 periods (**Fig. 6**).

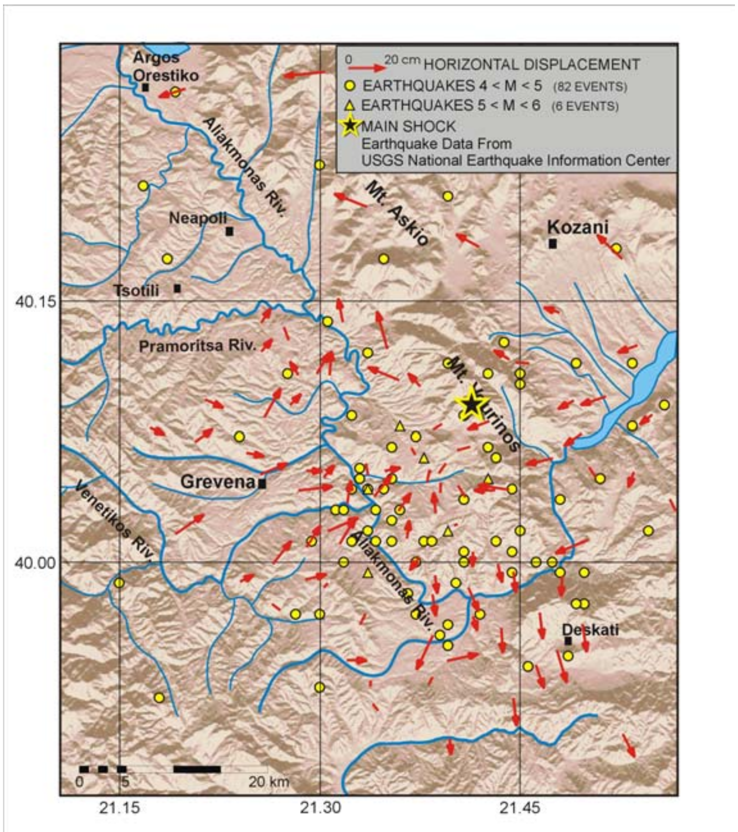

Fig. 3 Horizontal displacement and earthquake epicenters for the time period 1980 – May 1995.

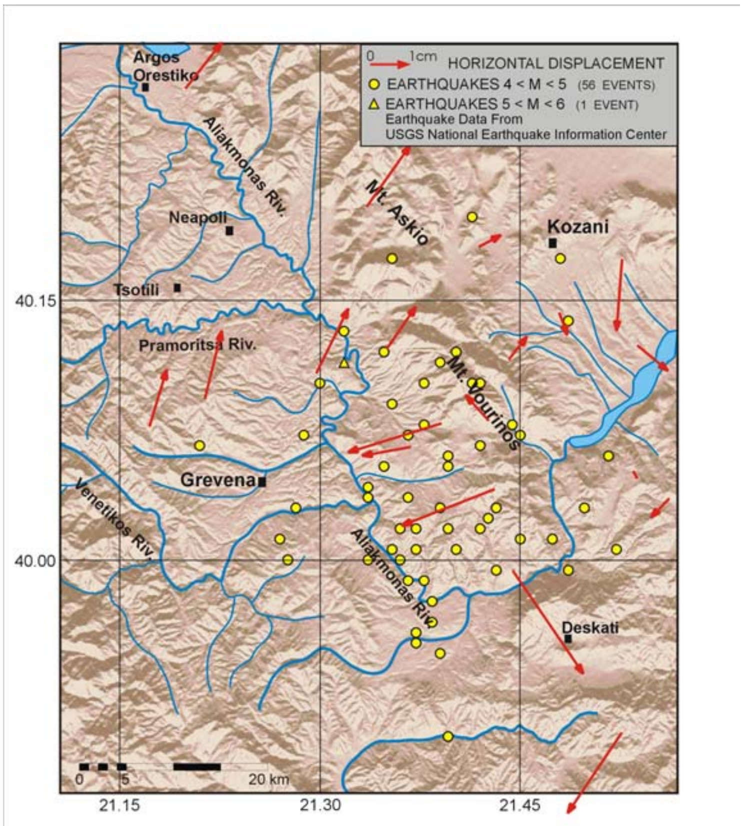

Fig. 4 Horizontal displacement and earthquake epicenters for the time period May 1995 – May 1996.

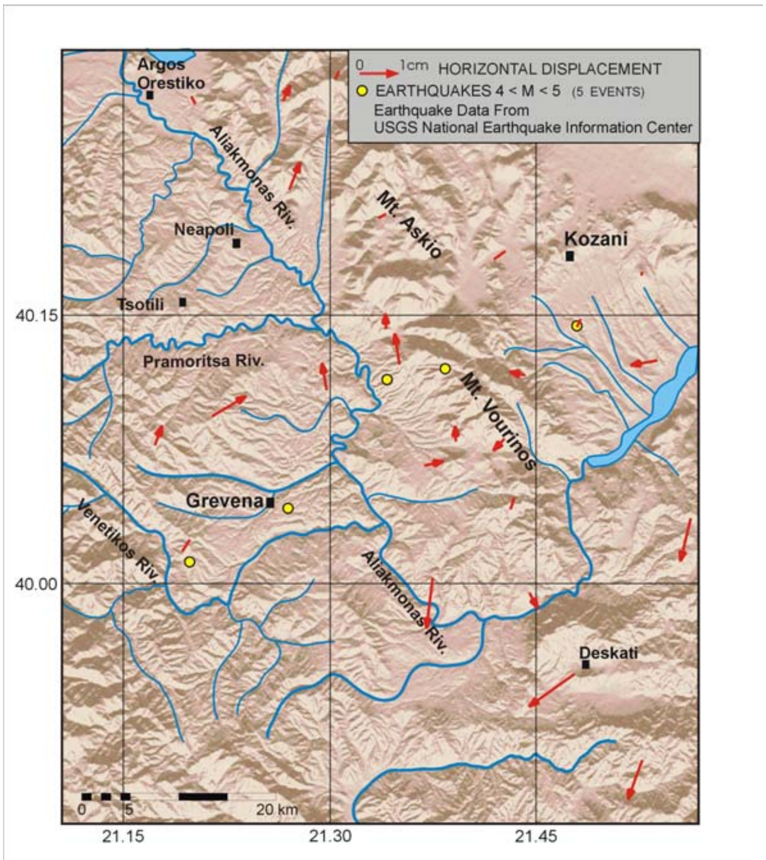

Fig. 5 Horizontal displacement and earthquake epicenters for the time period May 1996 – May 1998.

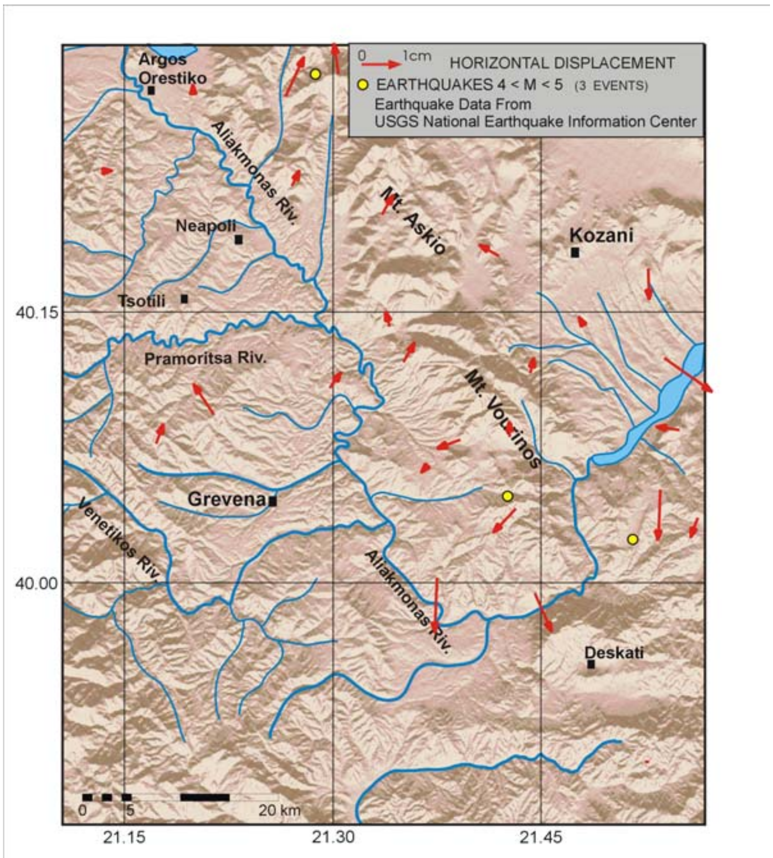

Fig. 6 Horizontal displacement and earthquake epicenters for the time period May 1998 – September 2000.

Seismic Activity

In order to understand better the relationship between the crust deformation processes we have to correlate the seismic activity and the crust movements in every period of measurements. We used the earthquake data from USGS National Earthquake Information Center.

The time period 1980 – May 1995 includes 9 earthquakes before the main shock, the main shock and 79 aftershocks. All shocks have M>4.0 R (**Fig. 3**).

The time period May 1995 – May 1996 includes 57 aftershocks. 56 of these shocks have magnitude between 4 and 5 Richter, while only one shock has magnitude between 5 and 6 (**Fig. 4**).

The time period May 1996 – May 1998 includes only 5 aftershocks. All these shocks have magnitude between 4 and 5 Richter (**Fig. 5**).

The time period May 1998 – September 2000 includes only 3 aftershocks with magnitude between 4 and 5 Richter (**Fig. 6**). Two of these aftershocks are located out of the meizoseismal area and only one within the affected area.

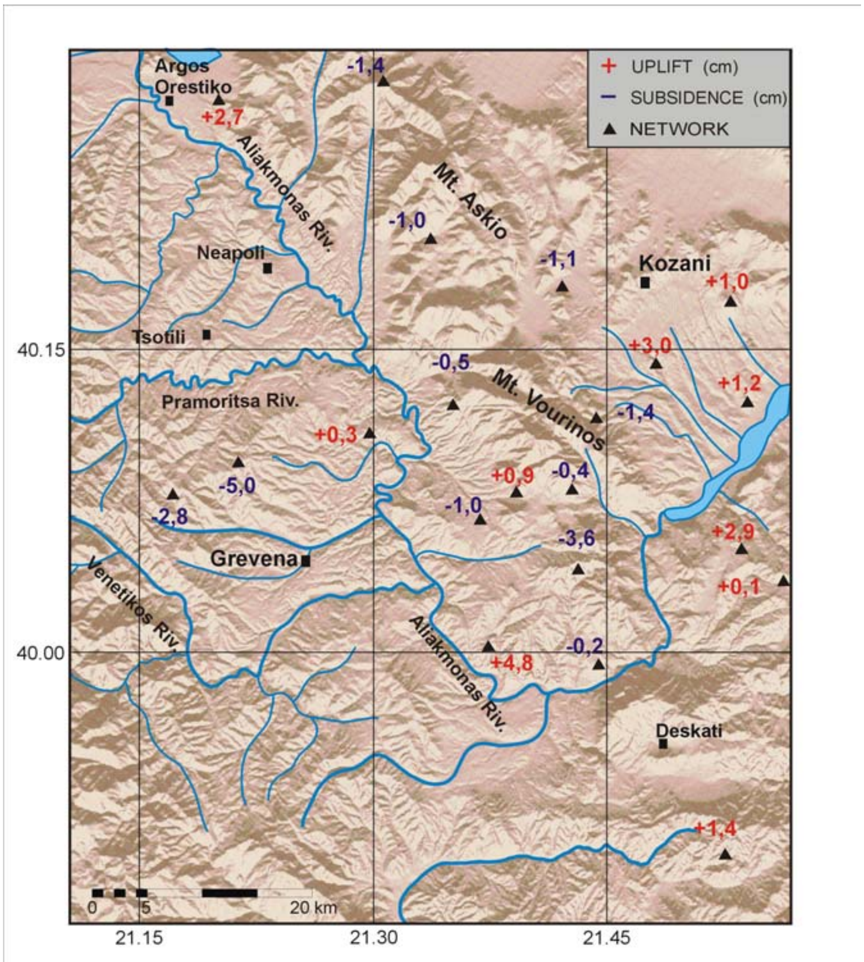

Fig. 7 Vertical displacement for the time period May 1995 – September 2000.

Heights Comparison May 1995 – September 2000

It is known that a comparison of heights can be done between GPS coordinates only, since the heights in HGRS 87 are orthometric and heights derived from GPS measurements are geometrical. So we present a comparison of heights between May 1995 and September 2000. The value of subsidence was calculated 5cm and the mean subsidence velocity 1cm/y, whereas the highest value of uplift was calculated 4.8cm and the mean uplift velocity 0.96 cm/y (**Fig. 7**).

Discussion - Conclusions

The study area is characterized by low relief with extended sub-horizontal planation surfaces develop mainly on the Plio-Quaternary deposits with the exception of the Askion and Vourinos mts. The morphological discontinuities occur mainly where incision has taken place, as the observed faults or fault zones do no cause any conspicuous morphological discontinuity, with only exception the Servia fault which is a typical normal fault (FOUNTOULIS, *et al.,* 2000).

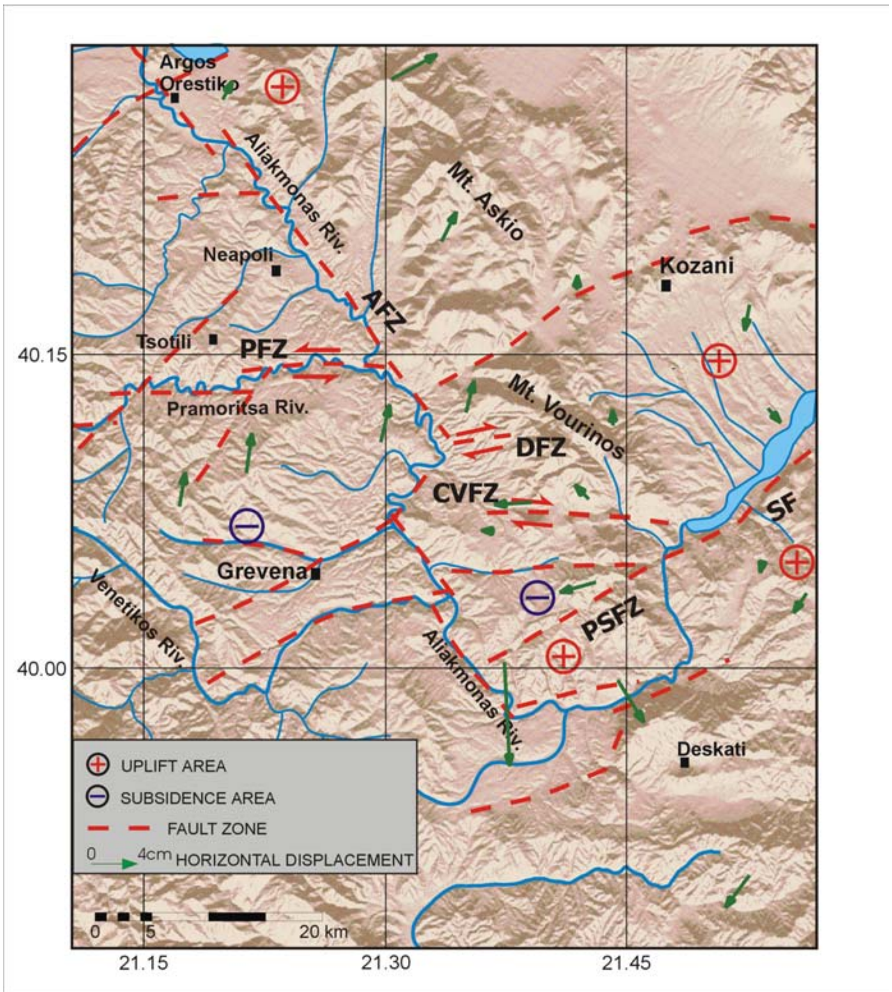

Fig. 8 Block and fault kinematics resulting from the geological and geodetic data.

Taking into account all the above mentioned it is clear that there is a terminator line along the Aliakmonas River distinguishing the area to the east which presents to have a clear component of movement towards west, while the area located west of it presents a clear component of movement toward east. Furthermore, combining the geological and geodetic data, we can distinguish a number of tectonic blocks with the following general characteristics:

(i) the blocks are bounded by fault zones which are mainly of strike slip character (FOUNTOULIS, I., & BAKOPOULOU, A., 1999, FOUNTOULIS, I., *et al*., 2000).

(ii) the kinematics of the blocks resulting from the GPS measurements are in good relation with kinematics of the fault zones

FOUNTOULIS, I., *et al*., 2000 mentioned that in none of the fault zones could be found kinematic indicators, so as to verify a normal character of motion. Almost all of them PFZ, DFZ, and CVFZ are strike-slip, with some vertical (reverse or normal) component. Besides no kinematic indicator could be verified for PSFZ, which can be also strike-slip, with some vertical component of displacement. At this point we have to mention that the horizontal component of slip is present in all the earthquake fractures.

Furthermore, the blocks that are under a subsidence regime according to GPS measurements coincide with the areas that have been filled in with Plio-Quaternary sediments. The only exception is the area located NW of Grevena, which has suffered a complicated brittle-ductile deformation.

So for the 1996-1998 as much us for the 1998-2000 periods there is a significant horizontal displacement of the sites, without any important seismic activity. The mean velocity for the time period 1998-2000 is double (0.6 cm/y) comparing with the mean velocity (0.3 cm/y) for the 1996-1998.This means that in the study area the deformation processes in the present time is not only due to seismic activity but even aseismic (Creep).

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