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The Mw 6.6, July 21, 2017 Kos Earthquake Scientific Report (Version 2.0)

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About

Non-periodic publication of the Post-graduate Studies Program "Environmental Disasters & Crises Management Strategies" of the National & Kapodistrian University of Athens, issued after significant events for the immediate information of the scientific community and the general public. The publication includes also scientific data from various research teams from universities, organizations and research institutes.

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Scientific Mission

Of the National and Kapodistrian University of Athens, Faculty of Geology and Geoenvironment, Department of Dynamic Tectonic Applied Geology

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EARTHQUAKE INFORMATION, EARTHQUAKE ENVIRONMENTAL EFFECTS AND BUILDING DAMAGE

General information

On July 21, 2017 (01:32 GMT), an Mw 6.6 earthquake occurred with focal depth of about 10 km and epicenter located offshore northeastern Kos.

It was generated by an E-W striking and south dipping (38°) fault located east of Kos and constitutes the westward prolongation of the Akyaka-Gökova fault of the Muğla province in Asia Minor. This fault is 16 km long and coincides with the spatial distribution of the aftershock sequence.

The earthquake claimed the life of 2 tourists and caused 10 injured, which were immediately transferred to the Heraklion (Crete) and Elefsina (Attica) general hospitals for treatment.

Earthquake environmental effects

The earthquake caused secondary earthquake environmental effects comprising slope failures and tsunami. The tsunami was of small scale and was probably generated by submarine landslides close to the earthquake epicenter. Moreover, the onshore slope movements included landslides and rockfalls resulting in damage to the road network and to coastal touristic facilities.

Building damage

Building damage induced by the 2017 Kos earthquake was limited to the city of Kos. Old buildings with masonry load-bearing walls, more specifically monumental structures and archaeological sites, such as the historic castle of Kos, the Ottoman mosque and the Metropolitan Church of Agios Nikolaos. Slight damage was observed to recent structures with reinforced-concrete frame and infill walls.

Many buildings were characterized as uninhabitable. However, taking into account the earthquake magnitude and its small focal depth, it is concluded that the earthquake vulnerability of recent structures is very low.

Kos port and related facilities underwent failures including longitudinal cracks of the jetties parallel to the seashore, detachments and displacements of the quay seawalls as well as significant subsidence.

Disaster management

Agencies, authorities and organizations competent in civil protection and disaster management were mobilized in central, regional and local level in order to assess the extent of damage induced by the 2017 Kos earthquake and to implement actions for the short-term emergency assistance and relief of the affected population. More specifically, within two hours after the generation of the earthquake, the Ministry of Citizen Protection, the General Secretariat for Civil Protection, the Earthquake Planning and Protection Organization, the Hellenic Fire Service and the Hellenic Police Force were mobilized, while a Disaster Management Special Unit (EMAK) was on site in order to launch search and rescue operations. All joint actions during the first hours of the disaster response phase were successfully coordinated, while self-protective measures against earthquakes to be applied at home during the post-earthquake period were provided to the local population and tourists for the effective management of the disaster and the mitigation of its undesirable effects on humans, on natural environment and the building stock of the affected area.

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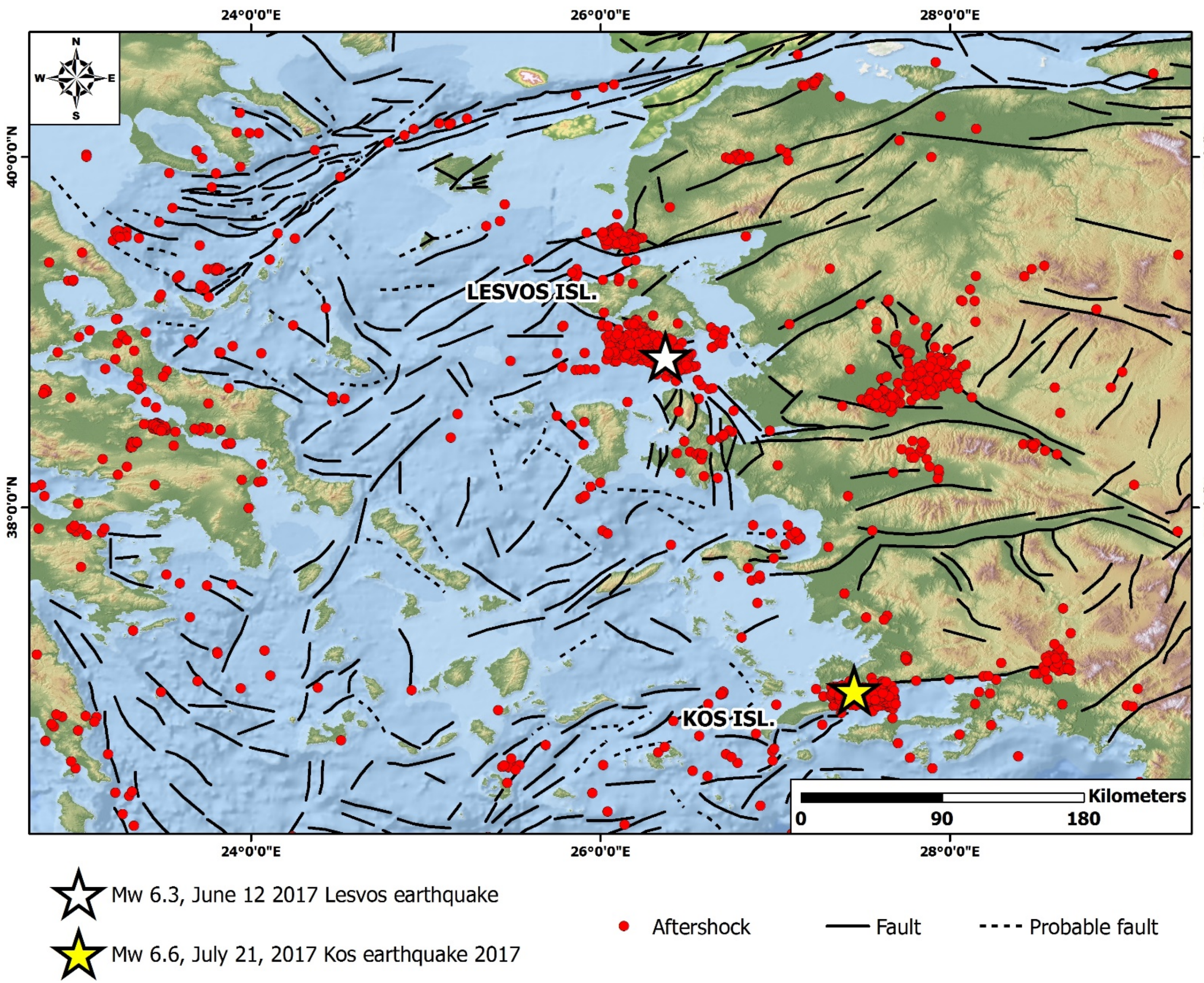
EARTHQUAKES DURING 2017 JUNE-JULY IN THE WIDER STUDY AREA



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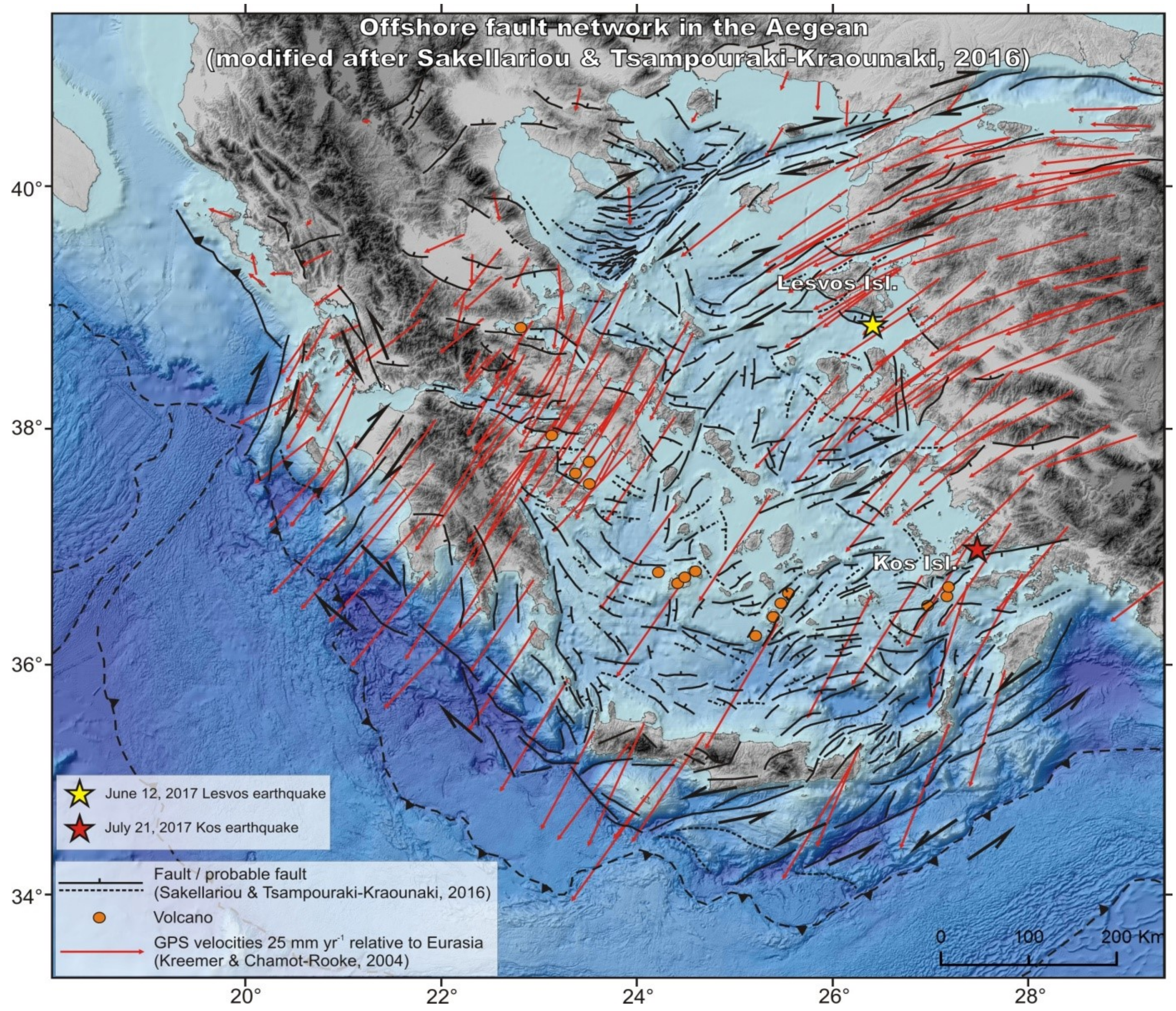
OFFSHORE FAULT NETWORK AND GPS VELOCITIES IN THE BROADER AEGEAN REGION

YELLOW AND RED STARS SHOW THE EPICENTERS OF THE RECENT LESVOS AND KOS-BODRUM EARTHQUAKES



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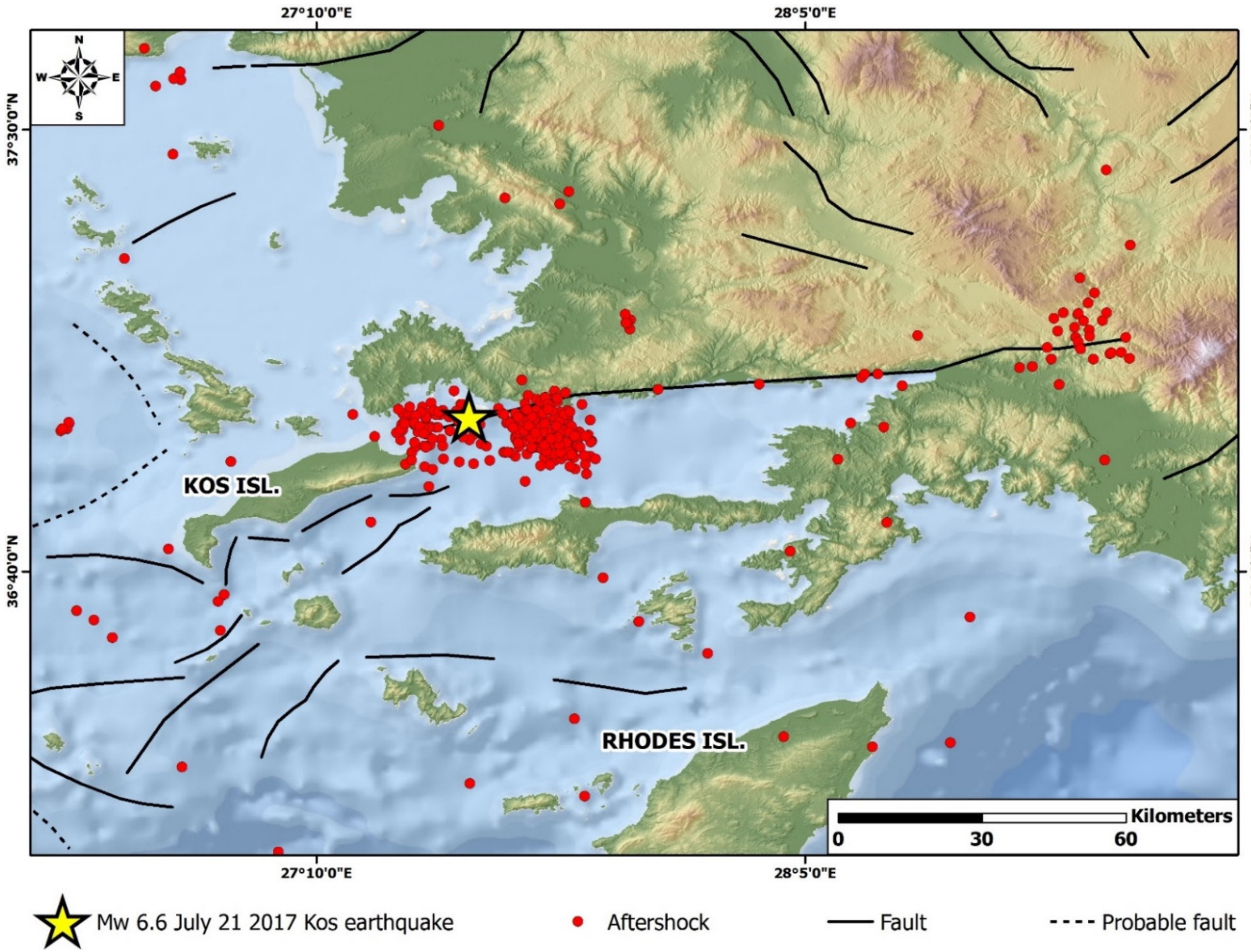
KOS EARTHQUAKE AND AFTERSHOCK SEQUENCE

(EARTHQUAKE CATALOGUES FROM SEISMOLOGICAL LABORATORY, NATIONAL AND KAPODISTRIAN UNIVERSITY OF ATHENS AND PERMANENT REGIONAL SEISMOLOGICAL NETWORK, ARISTOTLE UNIVERSITY OF THESSALONIKI)



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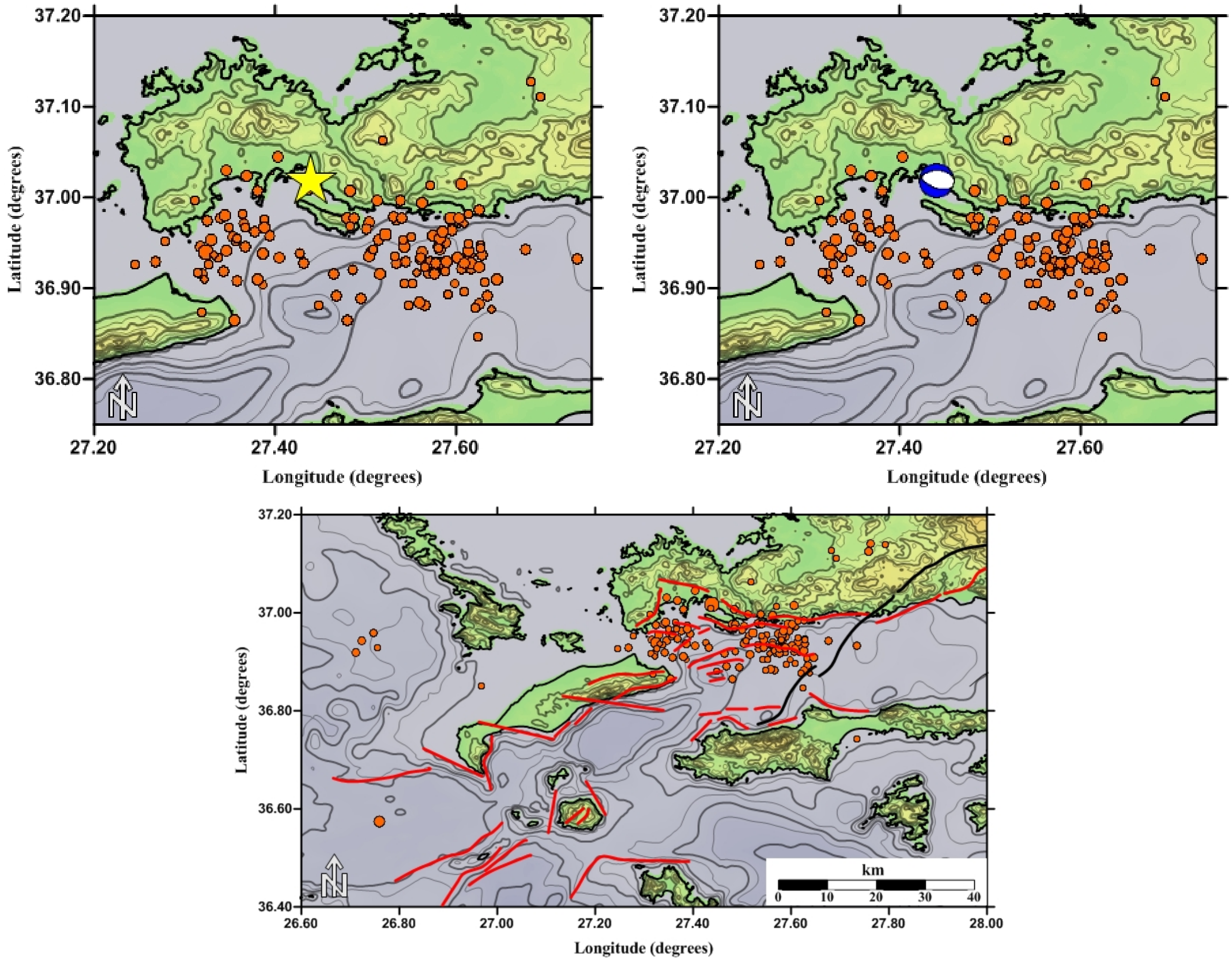
KOS EARTHQUAKE, FOCAL MECHANISM AND AFTERSHOCK SEQUENCE FROM JULY 20 TO 25, 2017

(EARTHQUAKE CATALOGUES FROM SEISMOLOGICAL LABORATORY, NATIONAL AND KAPODISTRIAN UNIVERSITY OF ATHENS AND PERMANENT REGIONAL SEISMOLOGICAL NETWORK, ARISTOTLE UNIVERSITY OF THESSALONIKI)



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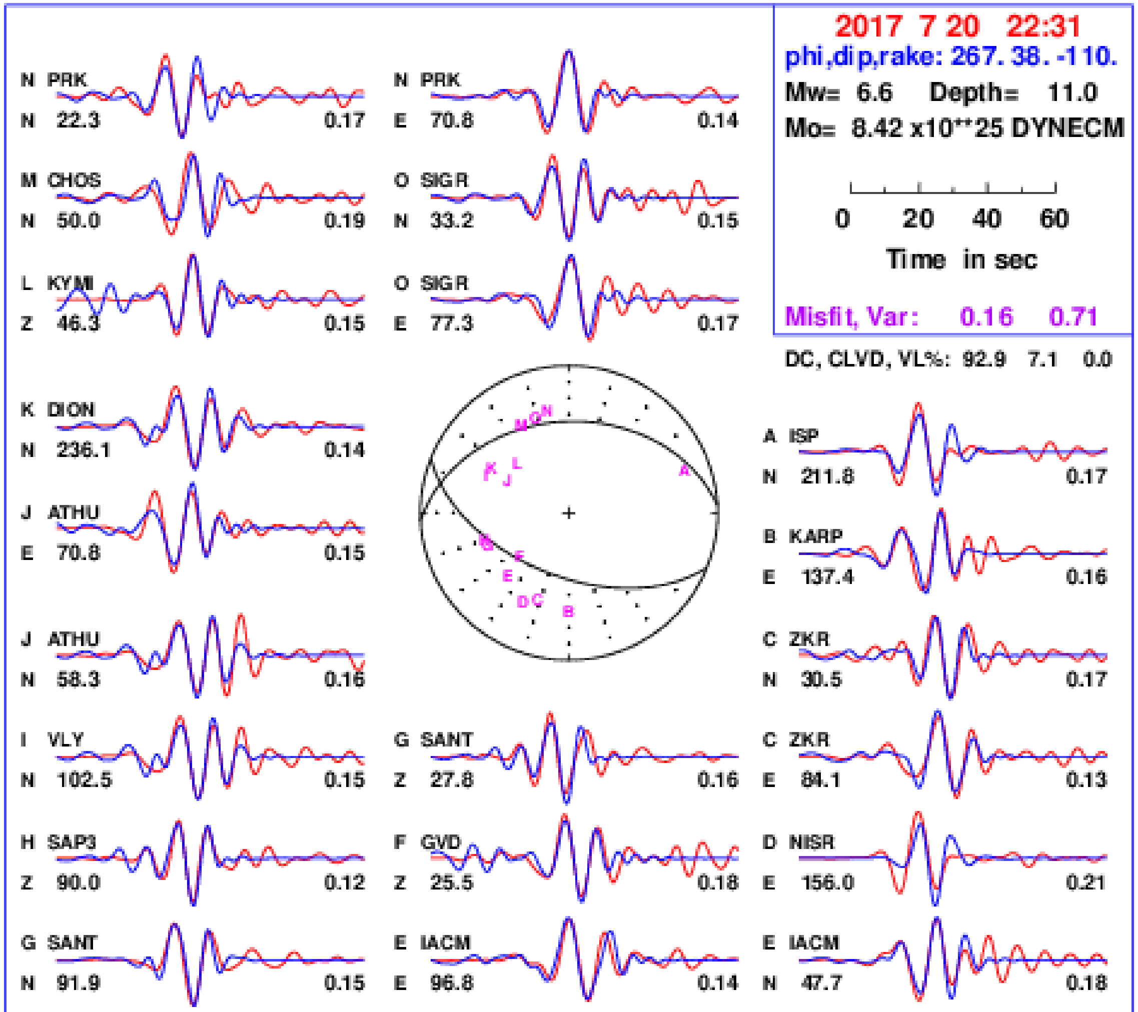
SOURCE PARAMETER DETERMINATION FOR THE MW 6.6, JULY 20, 2017 EARTHQUAKE USING MOMENT TENSOR INVERSION AND RECORDINGS IN REGIONAL DISTANCES

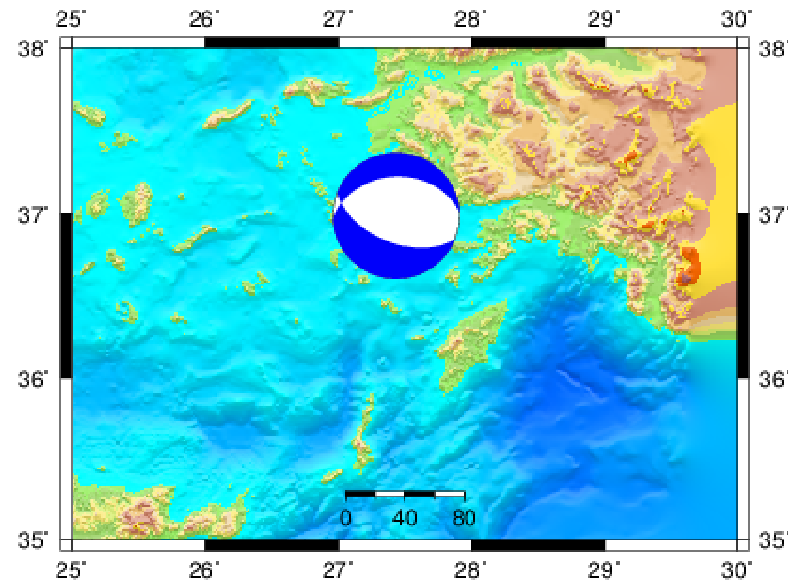
RED AND BLUE COLOR LINES REPRESENT THE OBSERVED AND SYNTHETIC WAVEFORMS, RESPECTIVELY

(source: SEISMOLOGICAL LABORATORY, NATIONAL AND KAPODISTRIAN UNIVERSITY OF ATHENS, http://www.geophysics.geol.uoa.gr)

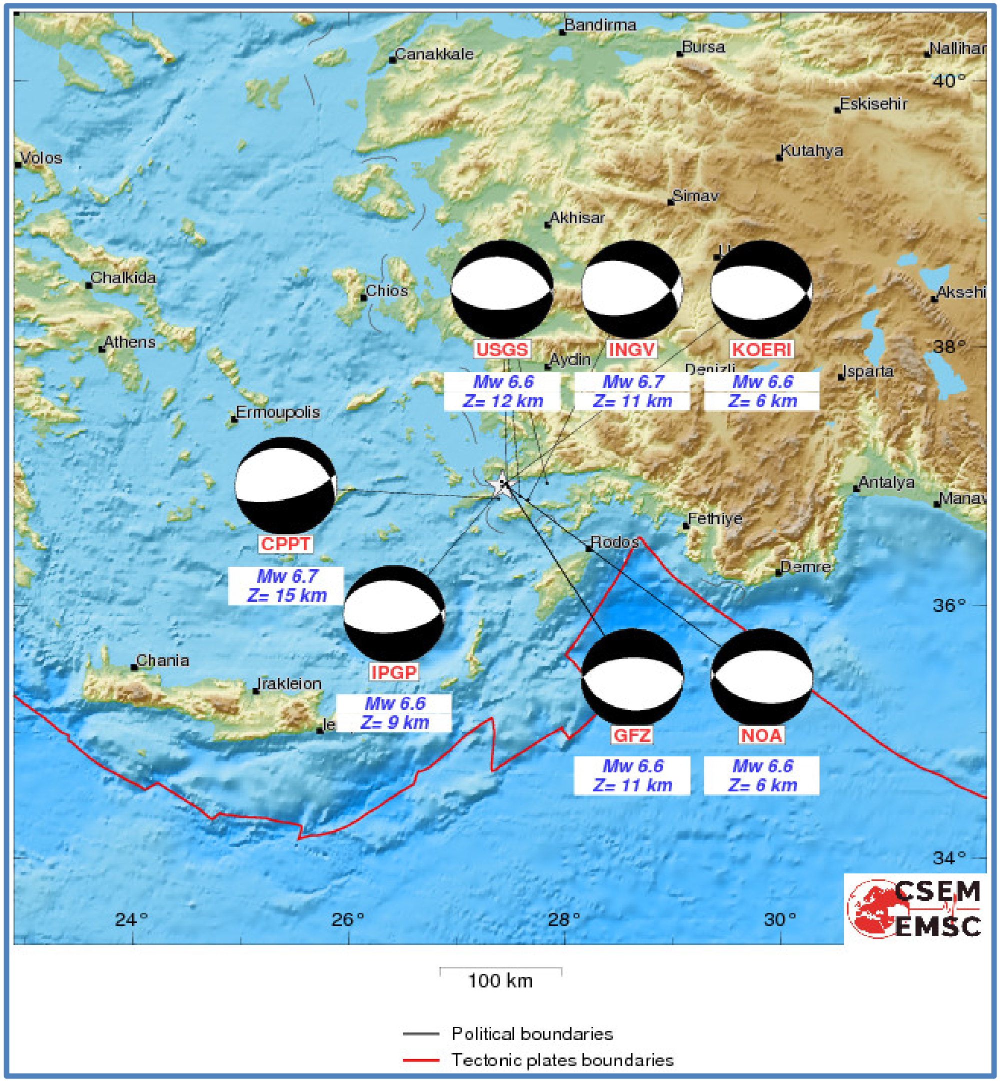


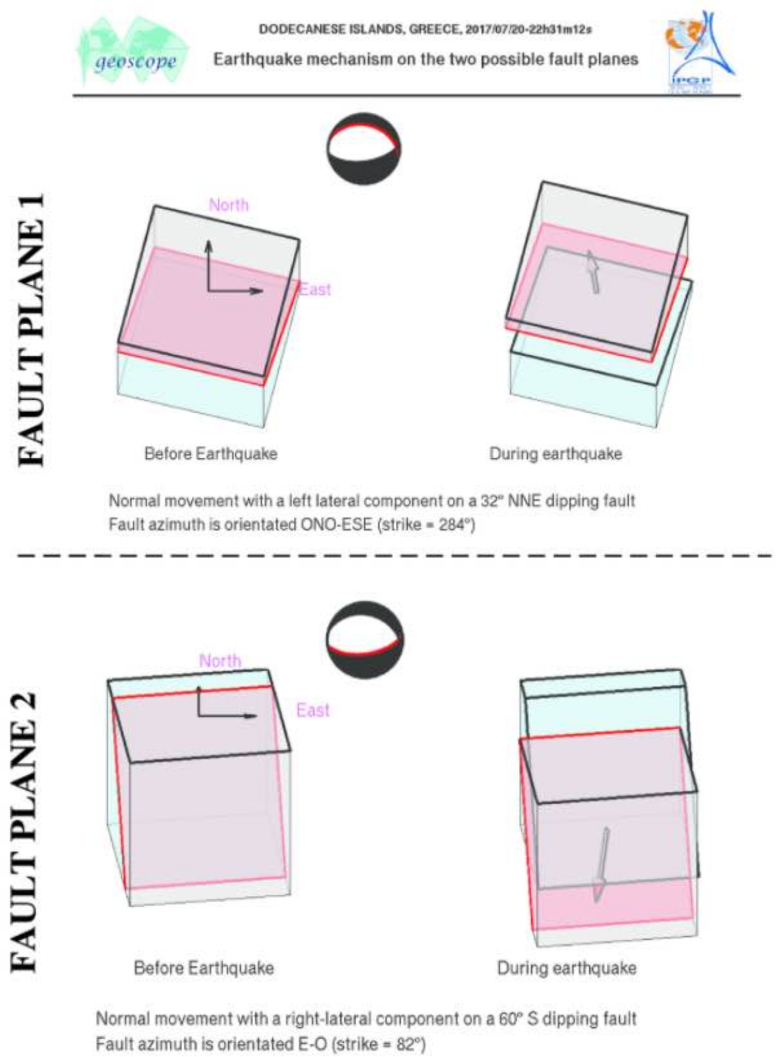
Map presenting the focal mechanism determined for the Mw 6.6, July 21, 2017 Kos earthquake

(Source: SL, NKUA, http://www.geophysics.geol.uoa.gr)



EARTHQUAKE FOCAL MECHANISM





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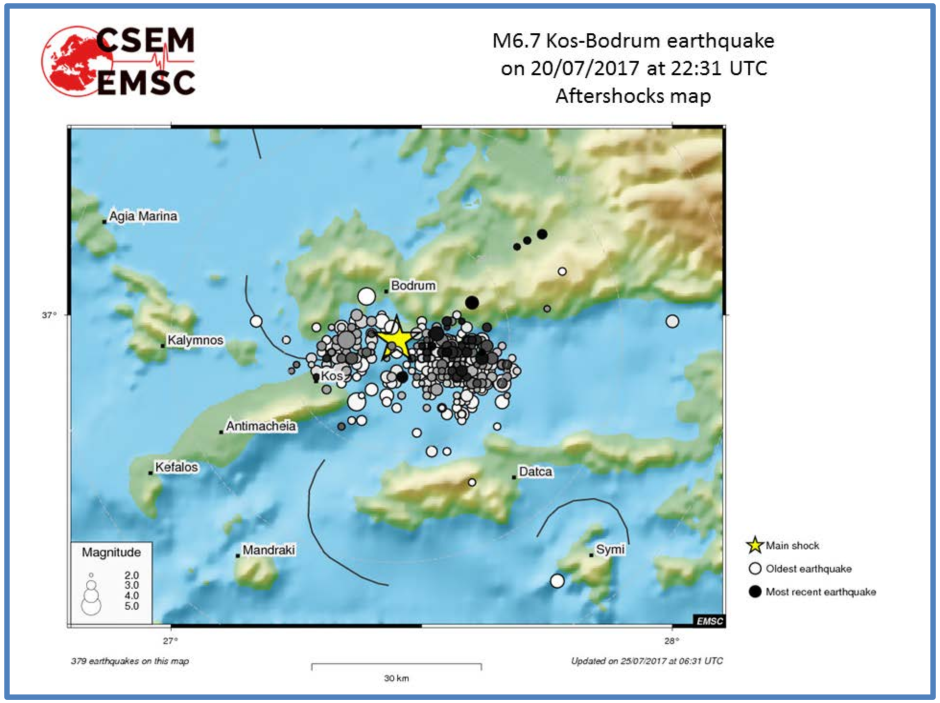
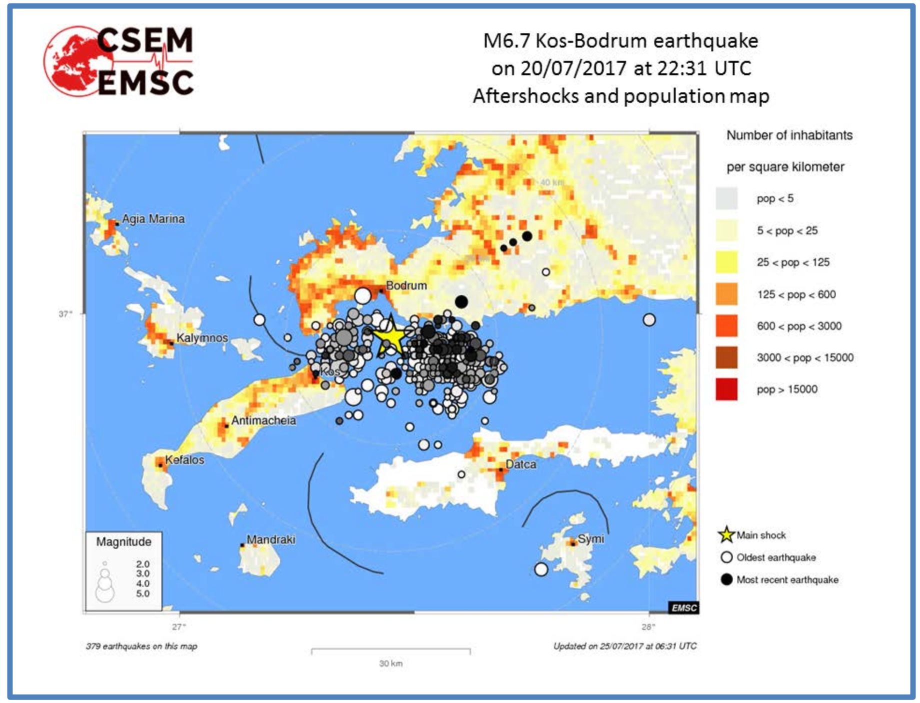
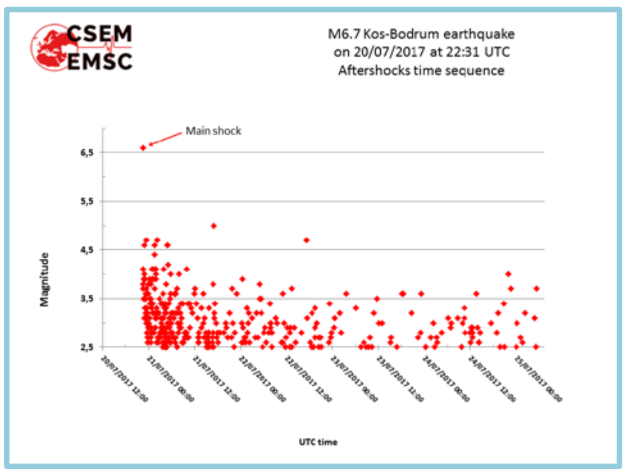
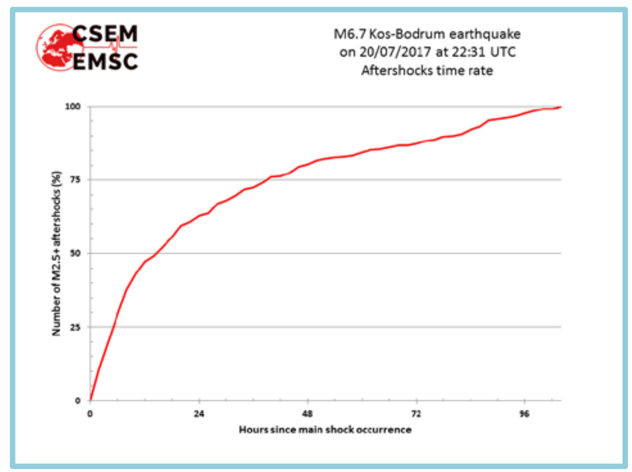
EPICENTER AND AFTESHOCK SEQUENCE









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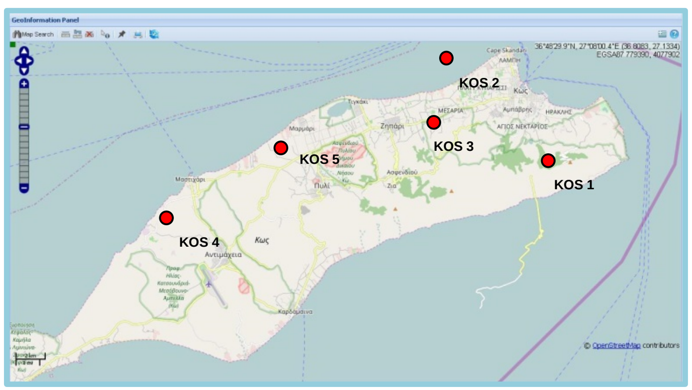
MONITORING OF THE EARTHQUAKE SEQUENCE BY THE EARTHQUAKE PLANNING AND PROTECTION ORGANIZATION

Staff of the Earthquake Planning and Protection Organization arrived in Kos a day after the generation of the July 21, 2017 Kos earthquake and installed a network of mobile digital 3-component seismographs comprising 5 stations TELEDYNE GEOTECH DL 24-A equipped with seismometers MARK PRODUCTS L-4-3D of 1 sec. Recorded data are incorporated in the Greek National Seismological Network in order to contribute to the better monitoring of the evolution of the aftershock sequence and the overall activity of the earthquake activity. The geometry of the installed network was adjusted to the spatial and temporal evolution of the seismic sequence. Thus, the “Antimachia” station (KOS 4) was transferred to Kalolimnos Island (KOS 41) on July 26, while the “Linopoti” station (KOS 5) was transferred to Pserimos Island (KOS 51). This network is planned to be in full operation until the end of August 2017.



Stations of the network installed by the Earthquake Planning and Protection Organization

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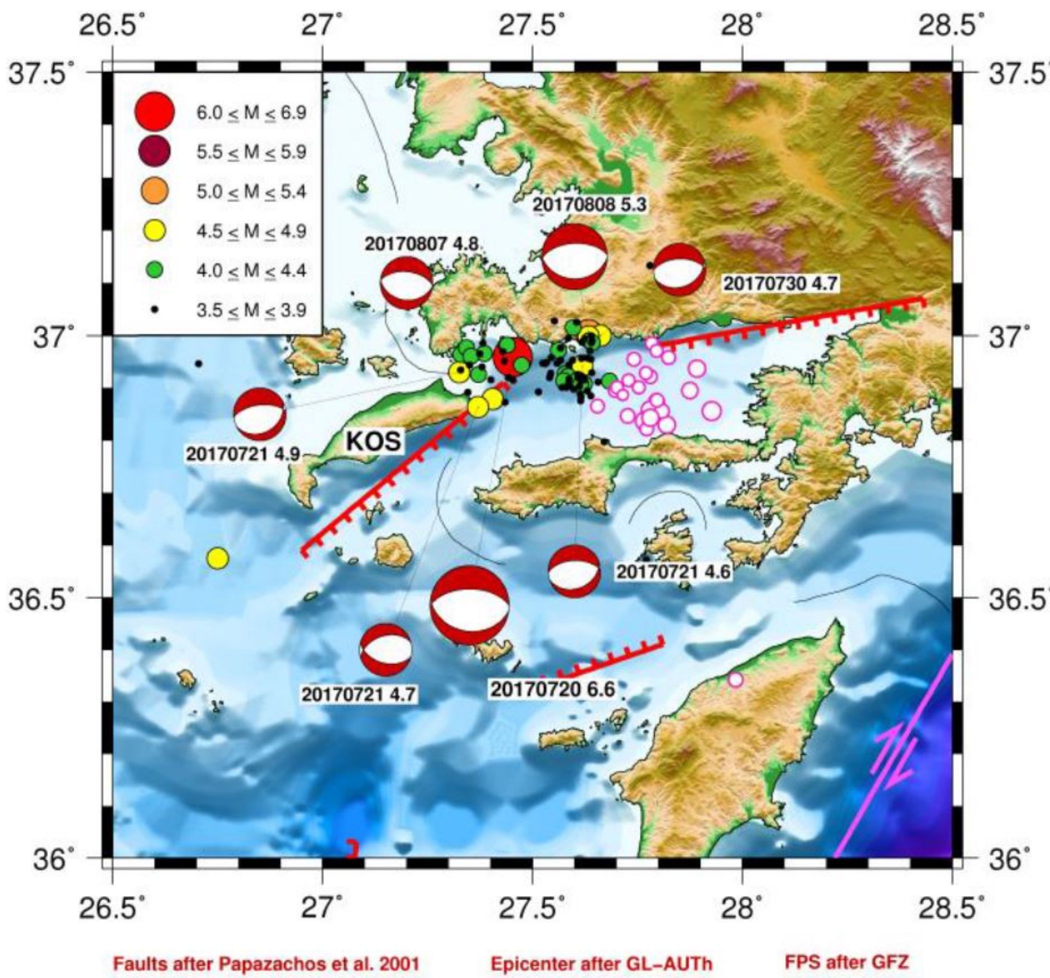
MONITORING OF THE EARTHQUAKE SEQUENCE BY THE INSTITUTE OF ENGINEERING SEISMOLOGY AND EARTHQUAKE ENGINEERING



Spatial distribution of epicenters of the largest aftershocks and the focal mechanisms of aftershocks with magnitude M ≥ 4.4. White circles in the central part of th Gökova Gulf represent epicenters of the 2004-2005 earthquake sequence. The faults of the earthquake affected area are from Papazachos et al. (2001).

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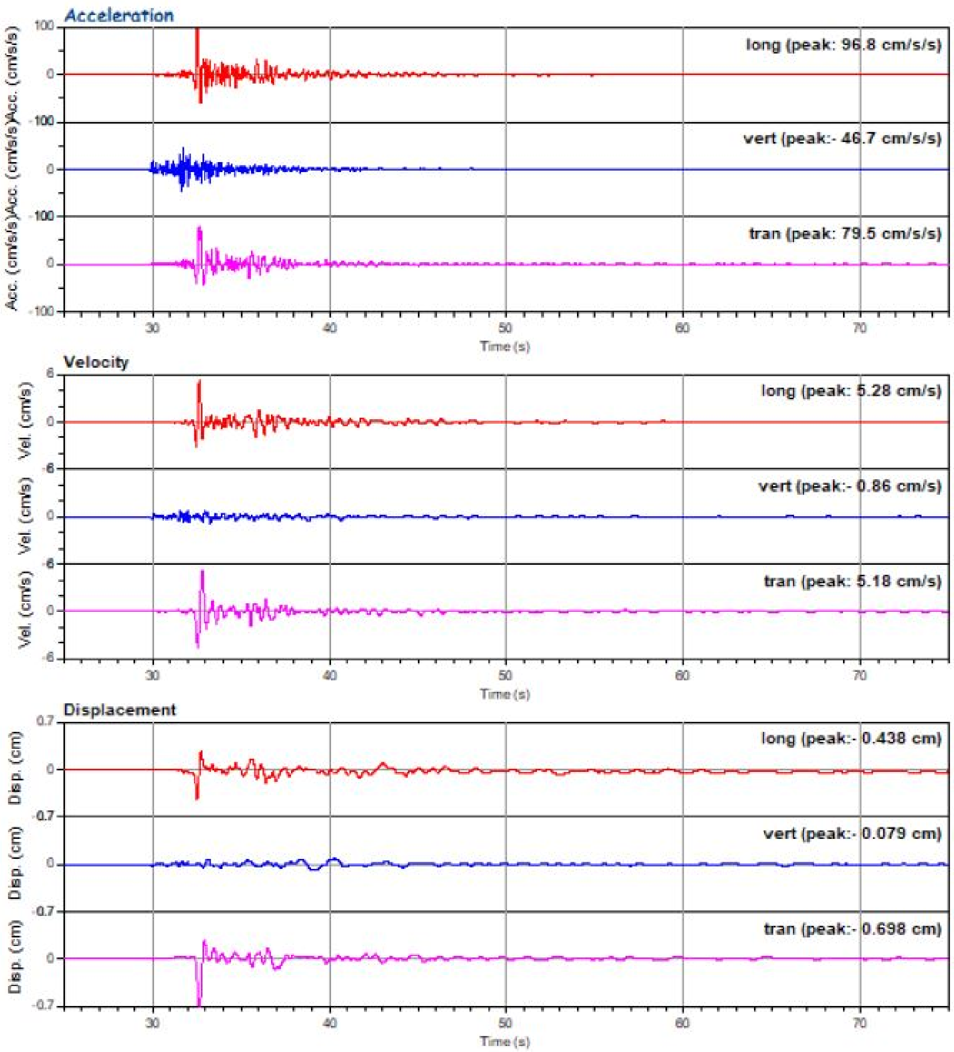
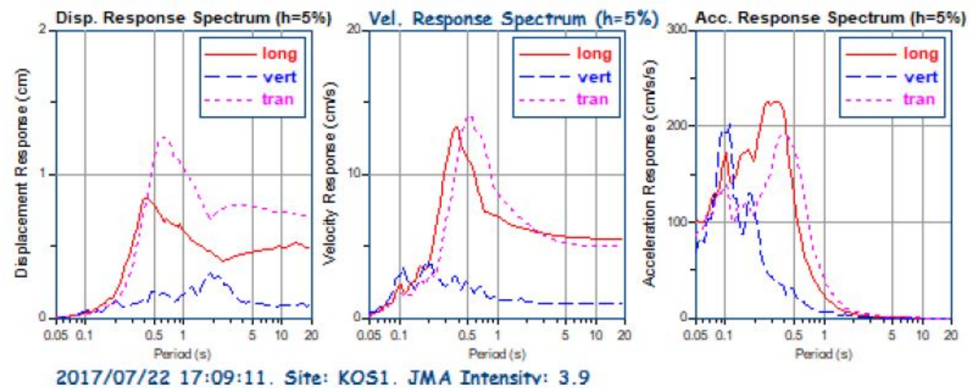
STRONG GROUND MOTION ANALYSIS
FOR THE M 4.4 LARGEST AFTERSHOCK GENERATED ON JULY 22, 2017





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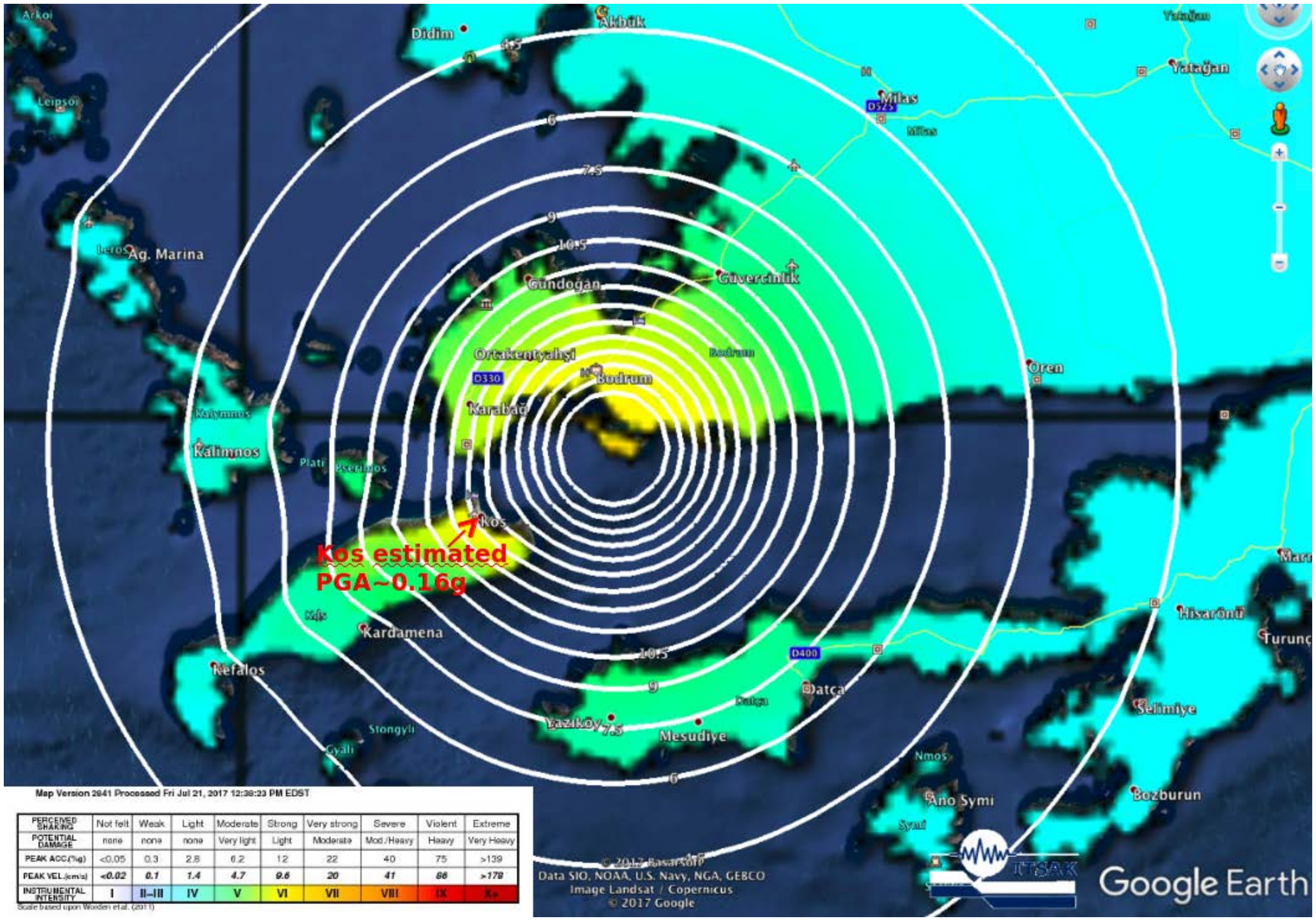
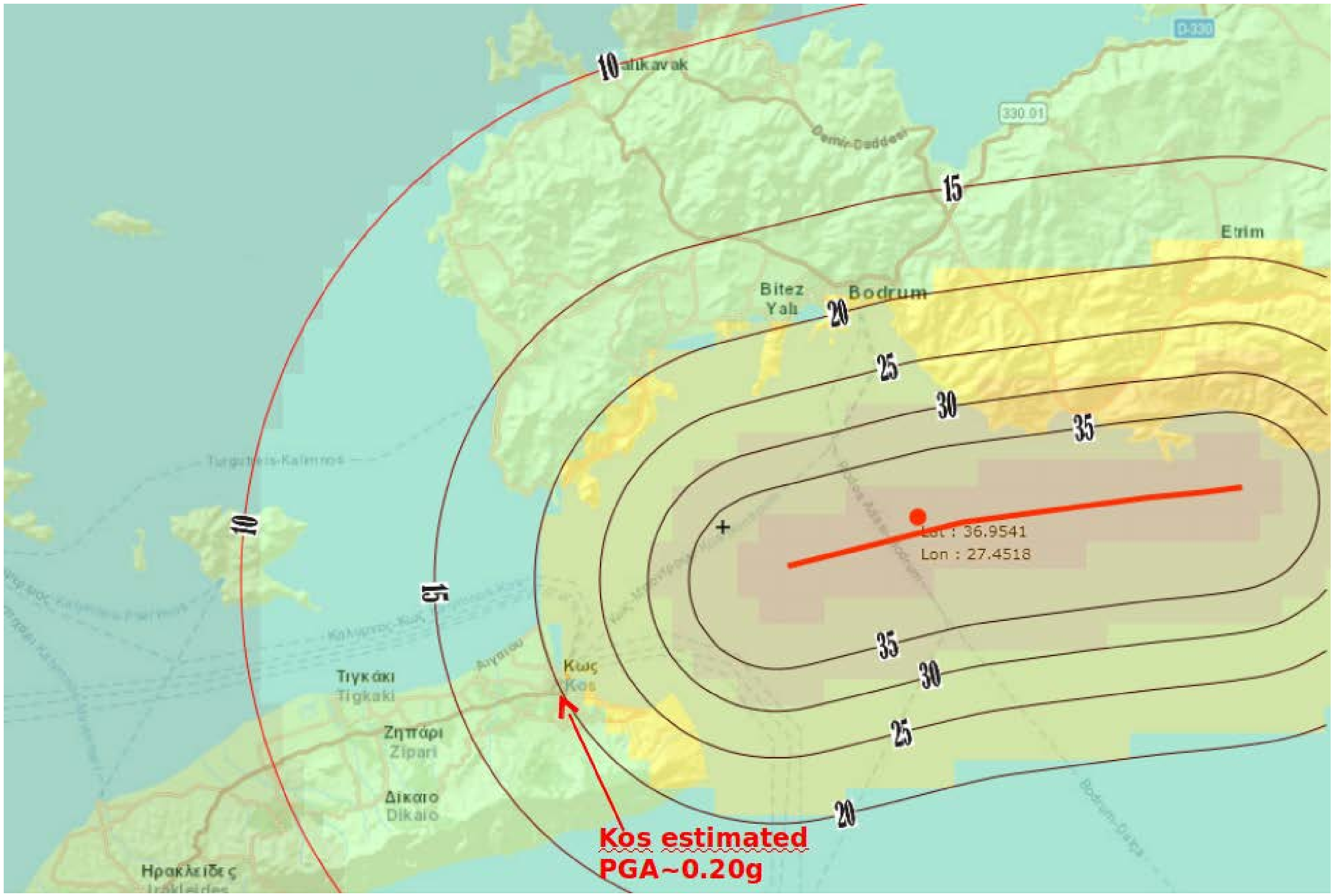
PRELIMINARY SHAKEMAP AUTOMATICALLY PRODUCED FROM REAL-TIME DATA DELIVERED BY IESEE



Within 10 minutes the corresponding preliminary shakemap was automatically produced from real-time data delivered by the ITSAK Strong Motion Network. The estimated Peak Ground Acceleration (iso curves) and intensity (see color legend) distribution are presented in the following image. These maps are produced using the USGS ShakeMap® software adapted for the Greek region.

PRELIMINARY SHAKEMAP AUTOMATICALLY PRODUCED FROM REAL-TIME DATA DELIVERED BY IESEE



Based on the most probable causative fault of the Kos earthquake, a preliminary seismic scenario is produced in terms of peak ground acceleration (PGA). The estimated PGA in the town of Kos is ~0.20g. This map is based on the web based software ELER ©).

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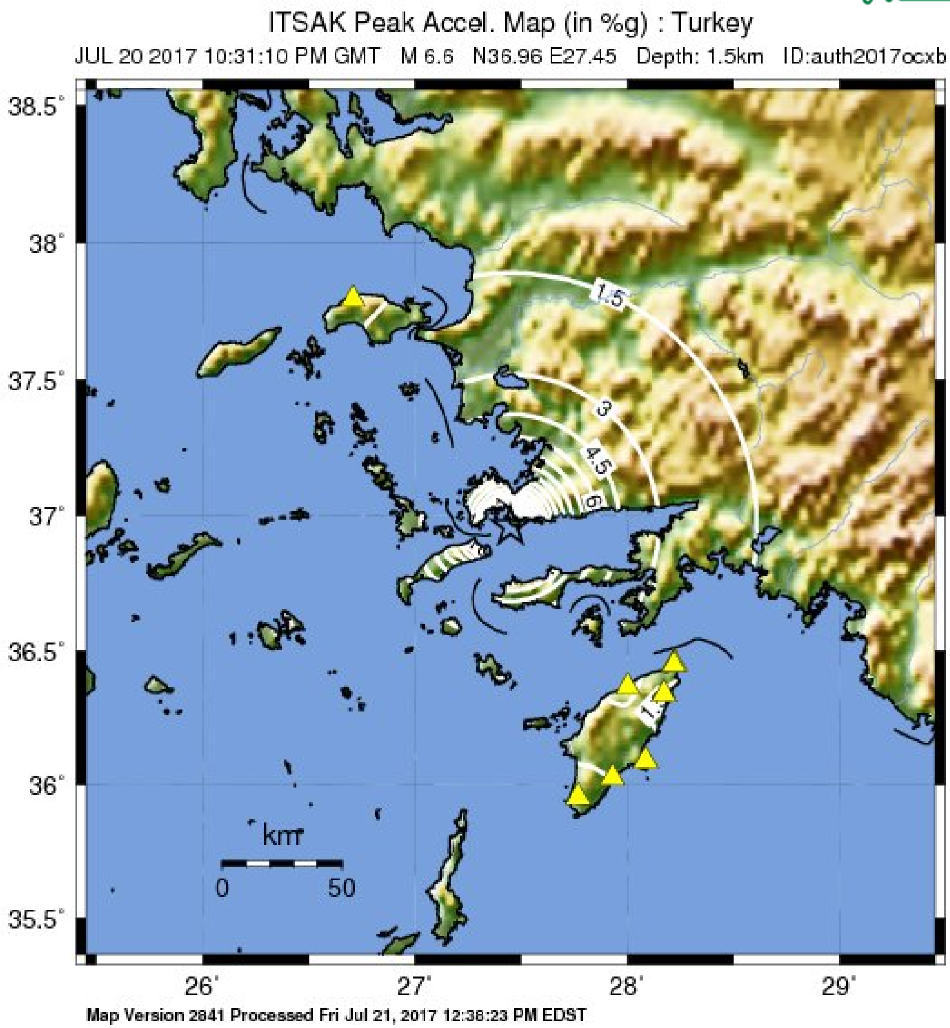
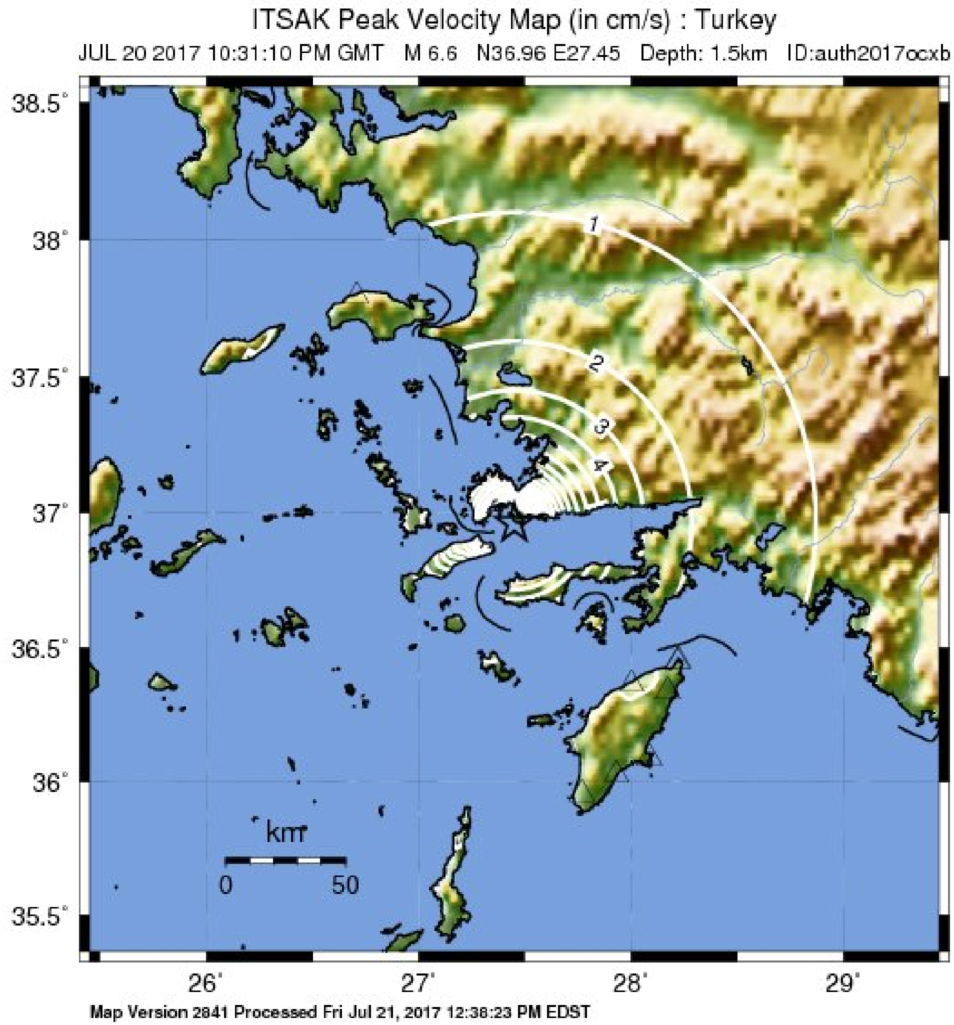
PEAK ACCELERATION (IN %G) AND PEAK VELOCITY (IN CM/S) MAPS





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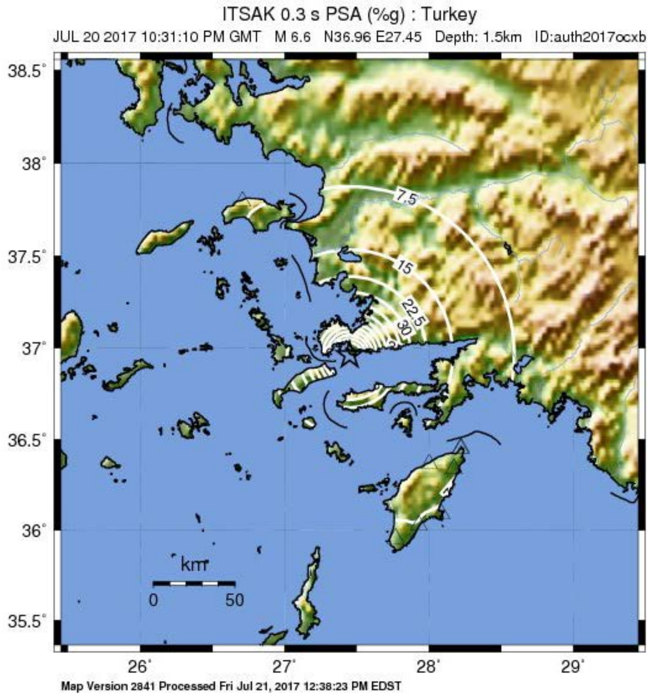
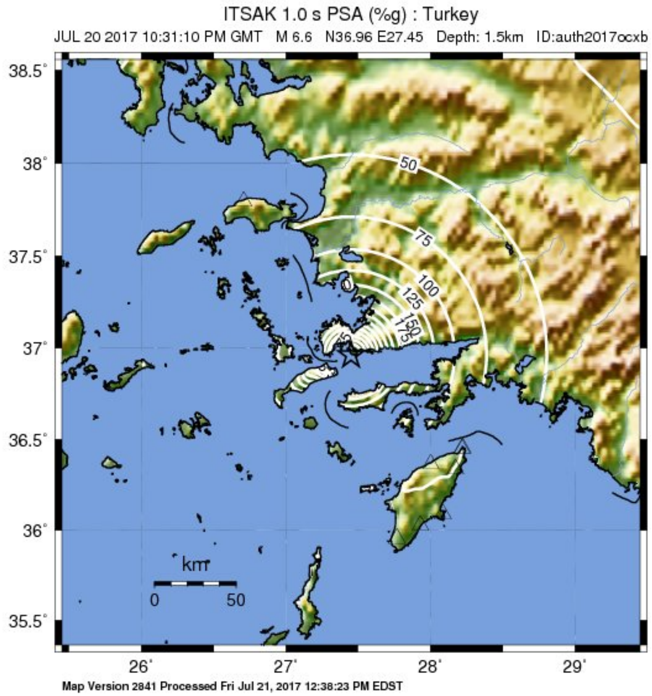
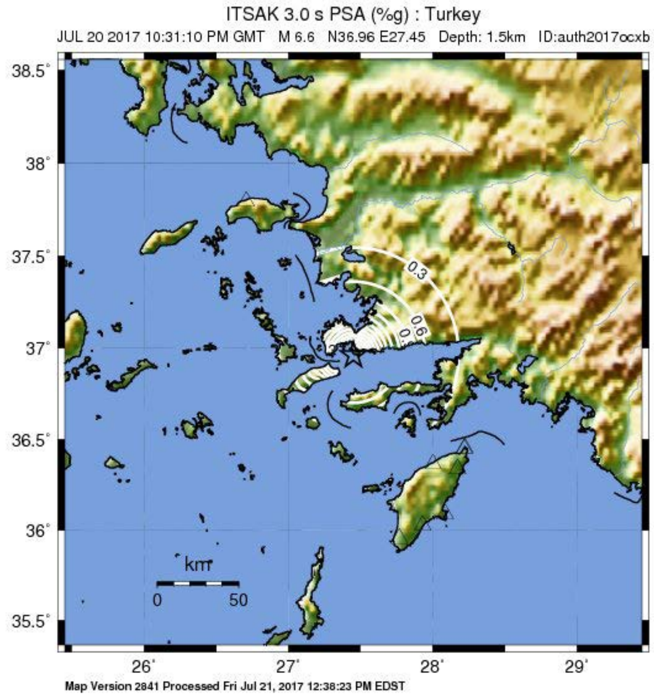
SPECTRAL RESPONSE (0.3, 1.0, 3.0 SEC)







Ο.Α.Σ.Π. ΙΤΣΑΚ

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SEISMIC SEQUENCE

(source : B.U. KOERI REGIONAL EARTHQUAKE – TSUNAMI MONITORING CENTER)

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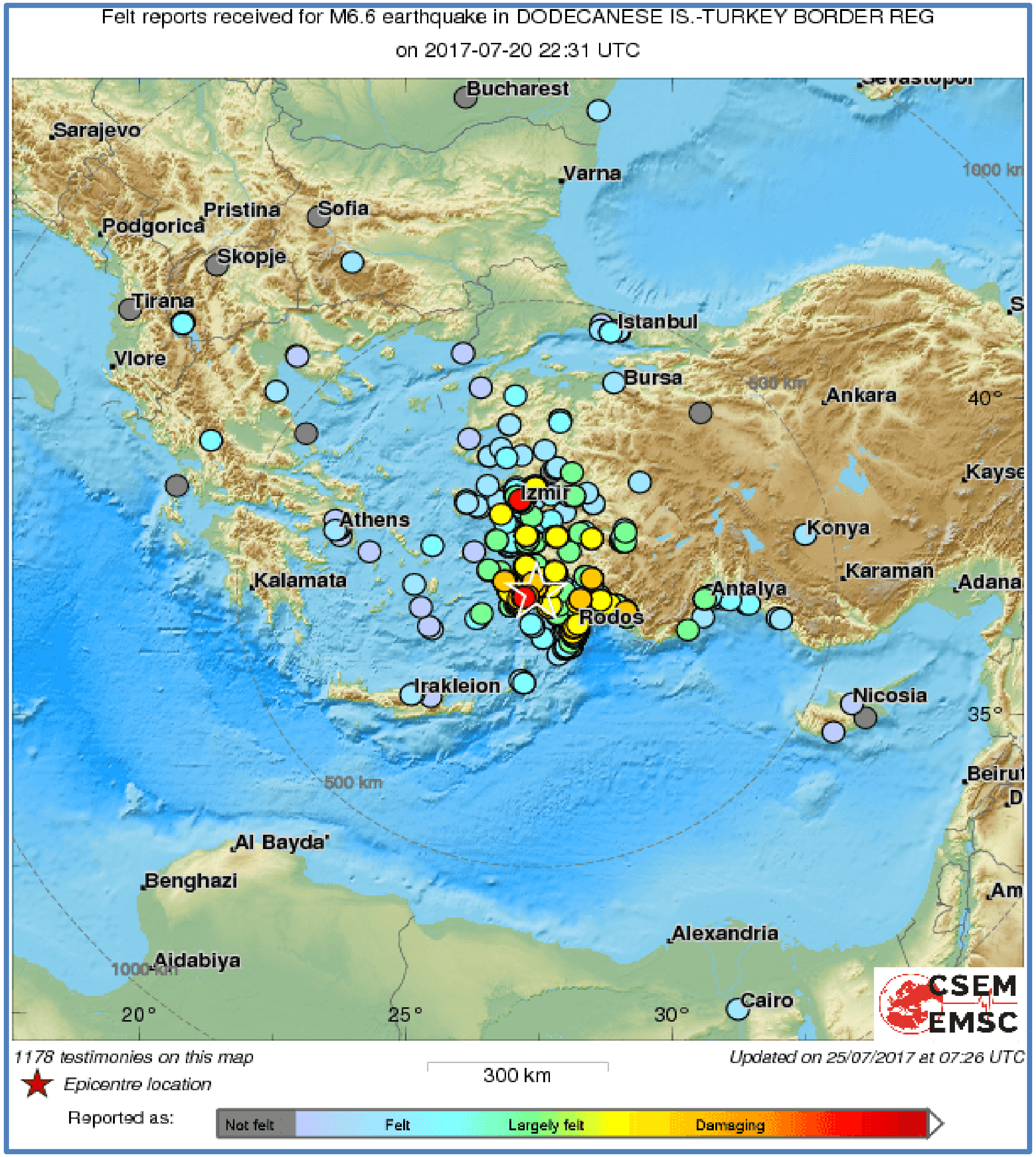
SHAKEMAP



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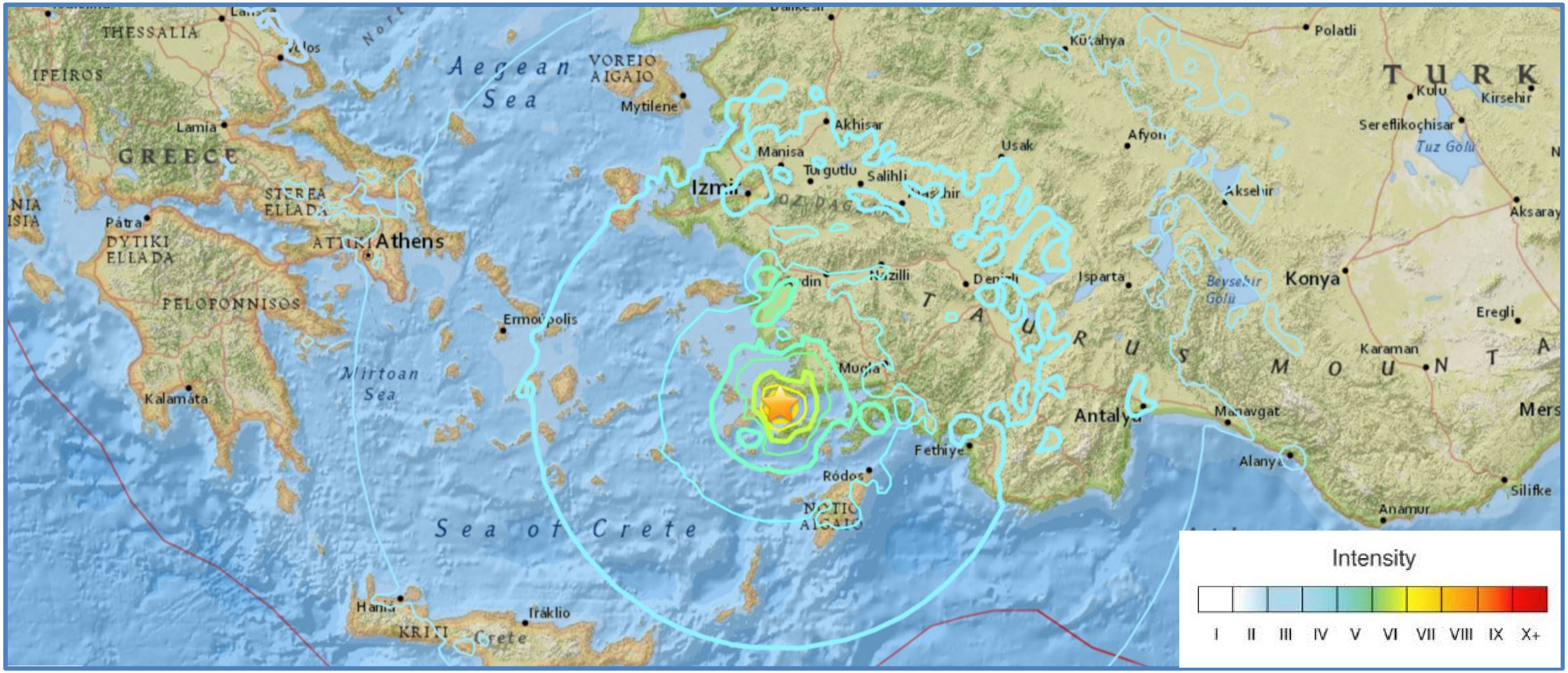
SHAKEMAP



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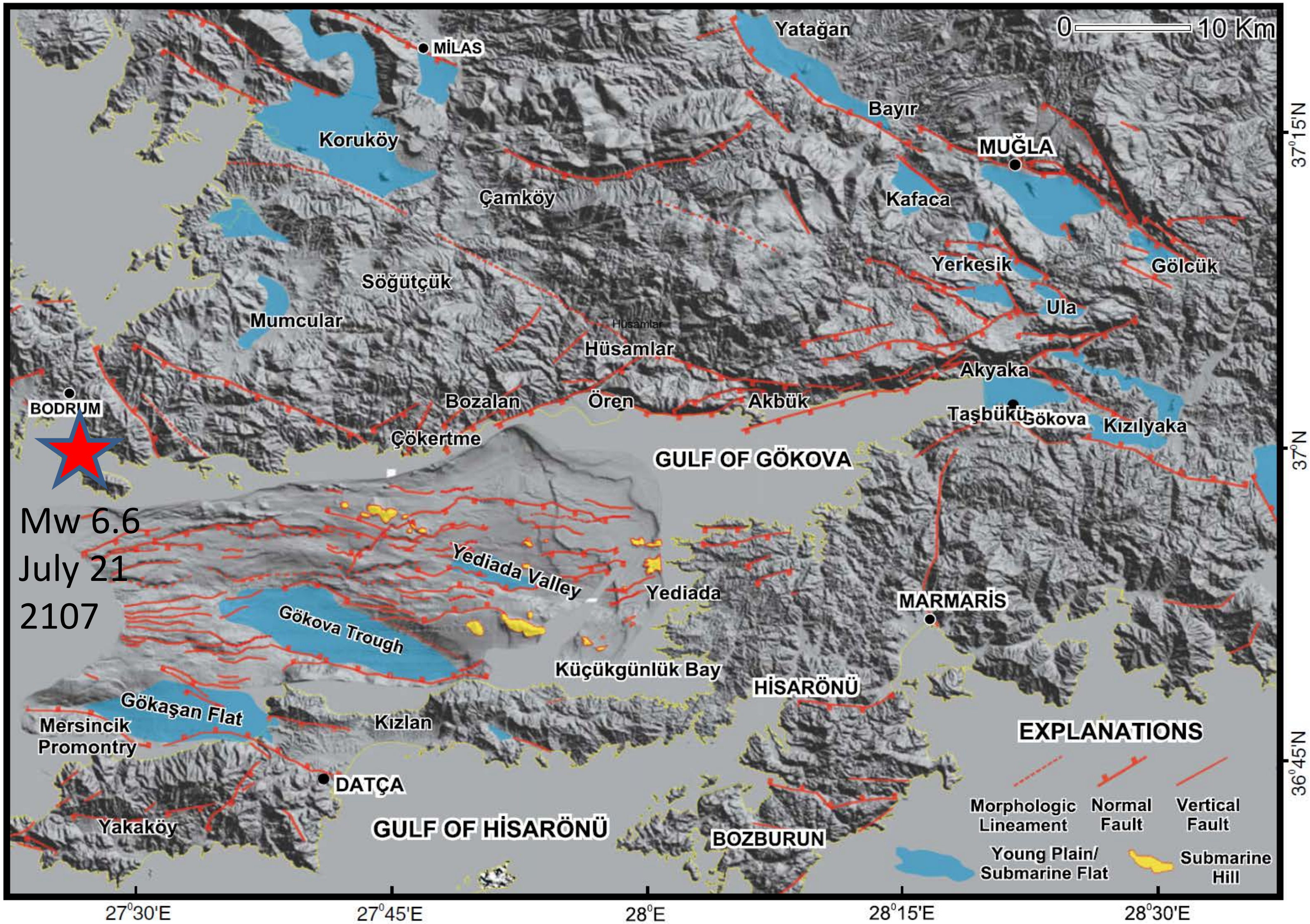
MORPHOTECTONIC MAP OF THE GULF OF GÖKOVA AND ENVIRONS PLOTTED OVER THE DIGITAL ELEVATION MODEL (LAND) AND MULTIBEAM BATHYMETRY (MARINE AREAS) MAP

(source: Tur et al., 2015)



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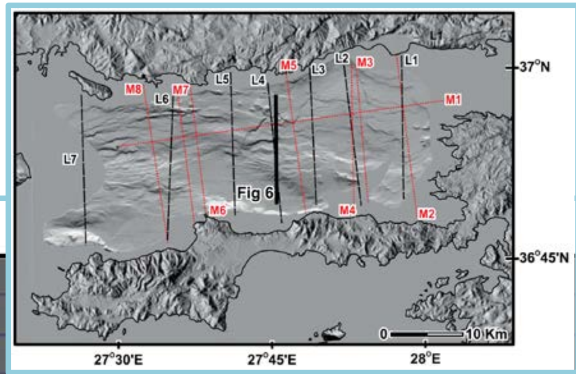
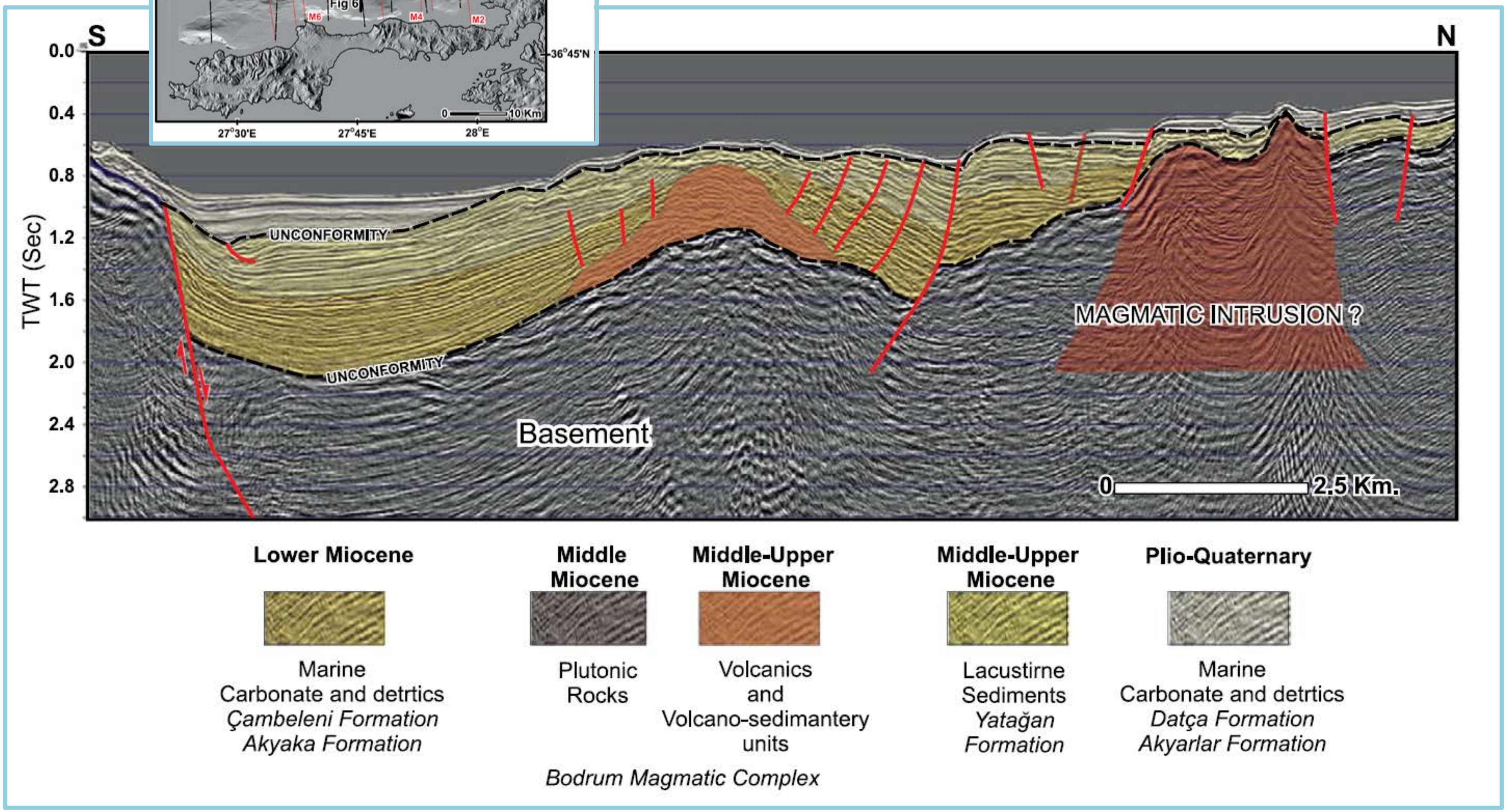


RE-INTERPRETED DEEP SEISMIC LINE LOCATION MAP SHOWS LINE POSITION

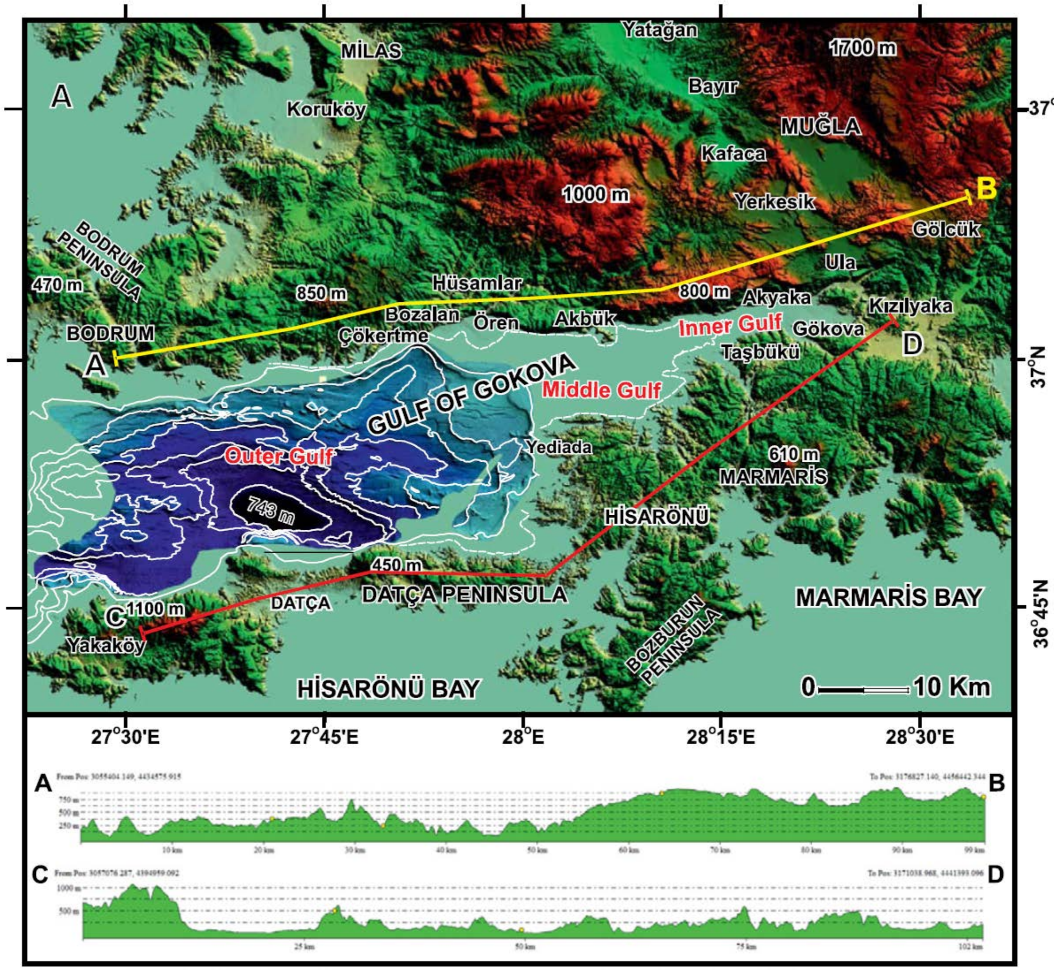
(source: Kurt et al., 1999; Tur et al., 2015)



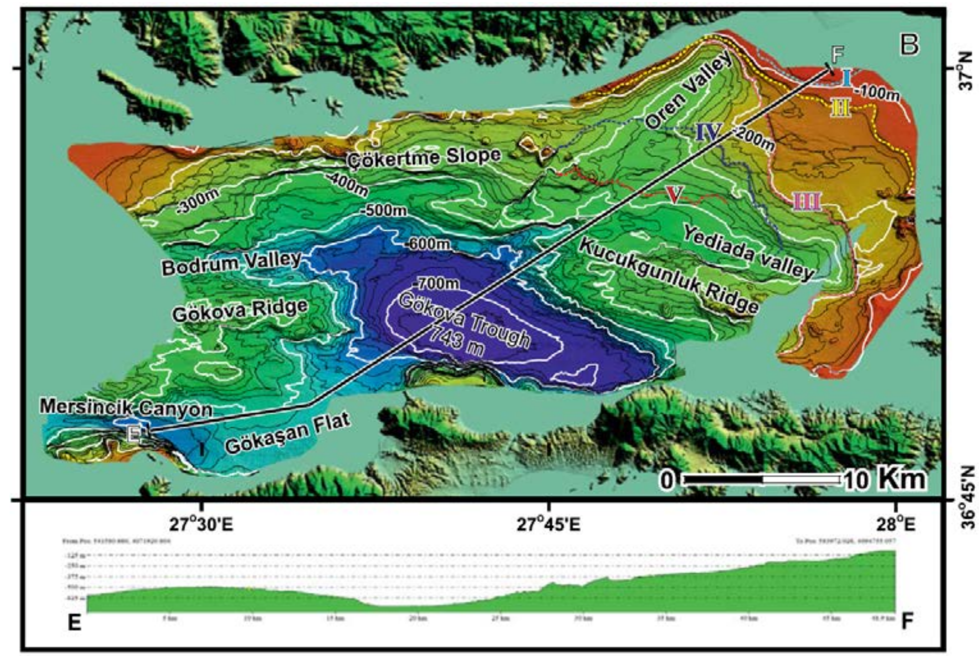
DIGITAL ELEVATION MODEL AND MULTIBEAM BATHYMETRIC MAP OF STUDY AREA

(source: Tur et al., 2015)

Datça, Bodrumand Muğla region with Gulf of Gökova



Detailed bathymetric map of outer Gulf of Gökova



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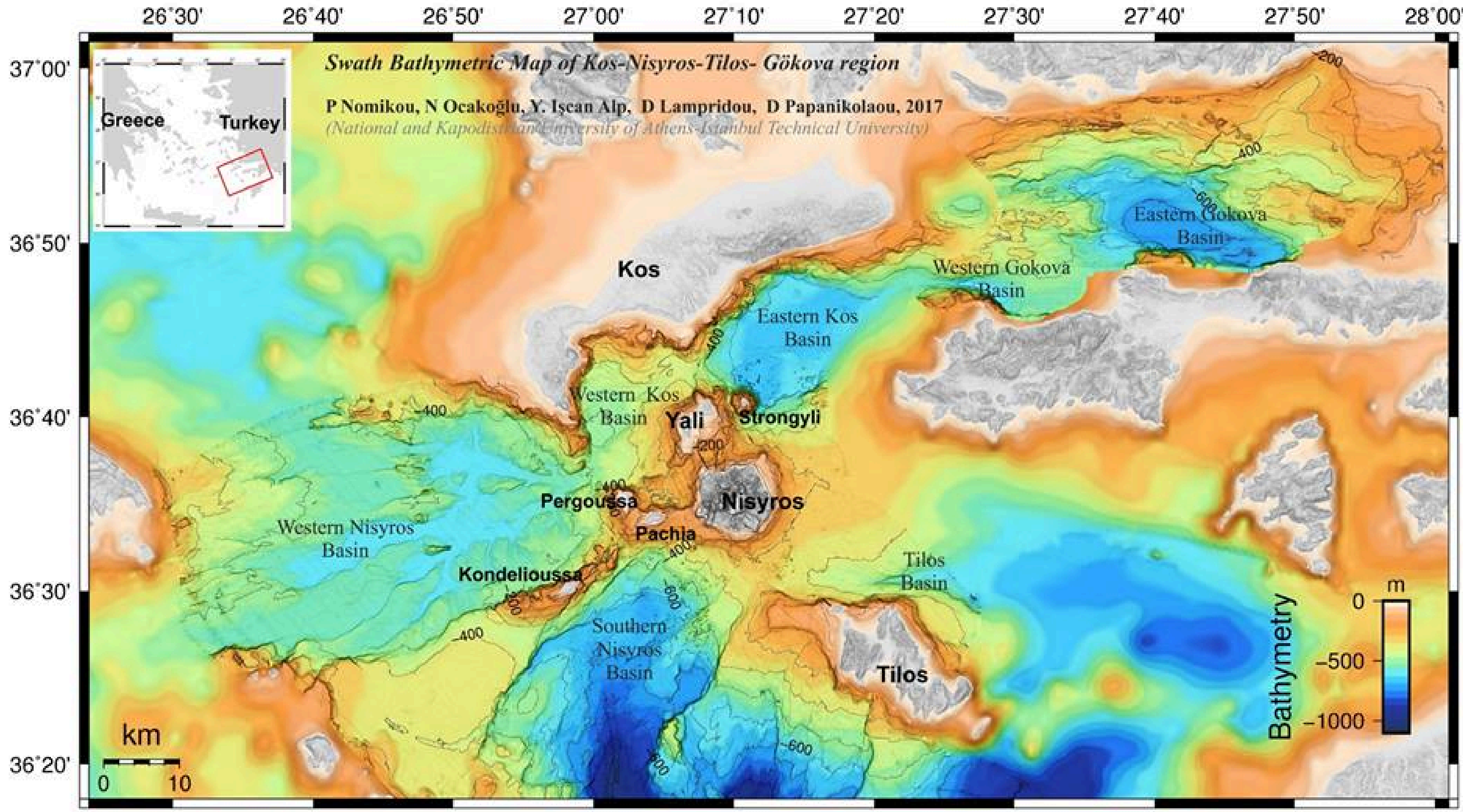
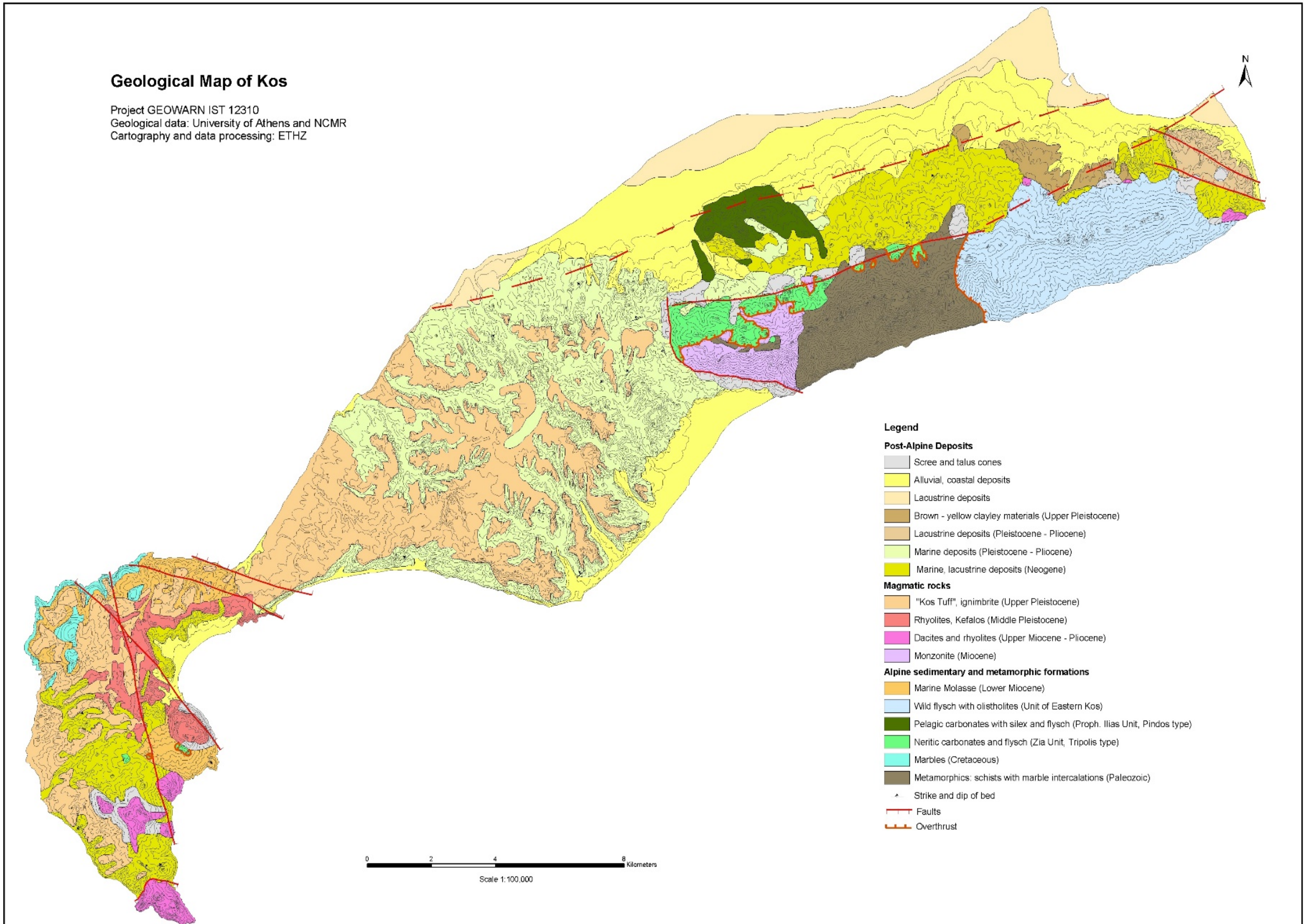
SWATH BATHYMETRY MAP OF KOS – NISYROS – TILOS – REGION

(source: Nomikou et al. 2017)



GEOLOGICAL MAP OF KOS ISLAND



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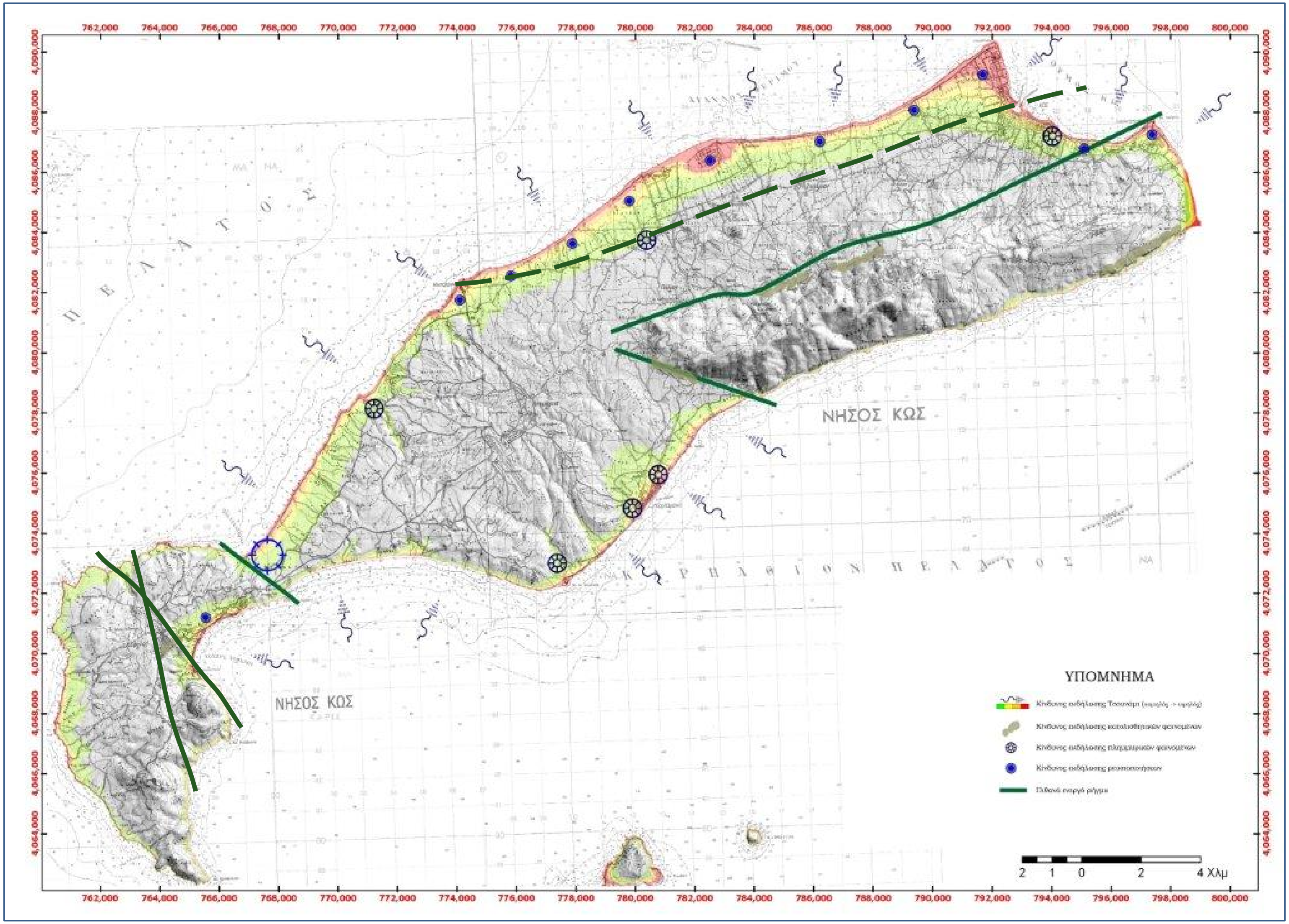
SITES SUSCEPTIBLE TO THE GENERATION OF SECONDARY EARTHQUAKE ENVIRONMENTAL EFFECTS

(FROM LEKKAS ET AL. 2008: OPERATIONS ORGANIZATION FOR MANAGEMENT OF NATURAL AND TECHNOLOGICAL DISASTERS IN KOS MUNICIPALITY. DEPARTMENT OF DYNAMIC TECTONIC APPLIED GEOLOGY, FACULTY OF GEOLOGY AND GEOENVIRONMENT, APPLIED RESEARCH PROGRAM, ATHENS)



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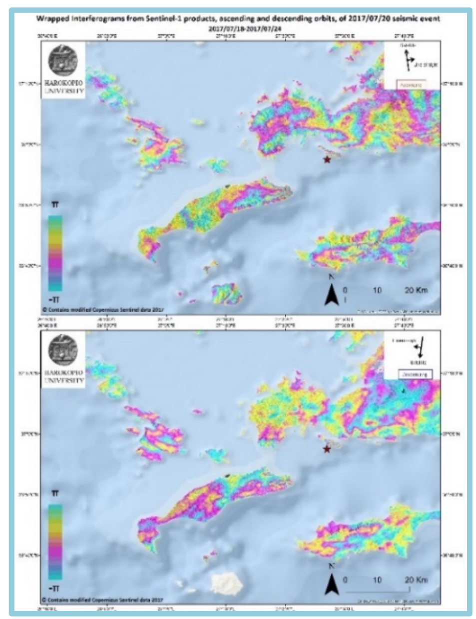
Geodetic data, obtained by ground or spaced-based techniques, can be used to infer the distribution of slip on a fault that has ruptured in an earthquake. Satellite images can capture co-seismic displacements without advance knowledge of the earthquake's location. Synthetic aperture radar (SAR) interferometry can be used to detect changes in the ground surface, by removing the signal from the topography. Here we use **Differential SAR Interferometry to capture the movements produced by the 2017/07/21 earthquake in the broader area of Kos Island, Aegean Sea**. The remote sensing team at the Department of Geography/Harokopio University of Athens construct interferograms by combining topographic information with SAR images by the Sentinel-1 satellite before and after the earthquake. During the stage of processing, the SAR images which were used, are on the dates 2017/07/18 and 2017/07/24. The seismic event took place at 2017/07/20, so we had the opportunity to include this date into the intermediate time period between the two images. Then, in the processing, we have made a mosaic of the images, in order to achieve a better temporal separation between the interferometric pair and to cover all the affected area. It is noticeable that the second image 2017/07/24 was taken three days after the seismic event. As a consequence, those results include the displacement pattern of the post-seismic sequence. Some parameters, during the processing, was the perpendicular baseline which was 11,2719m for descending orbit.

The map of wrapped interferograms (Figure 1) shows the fringe pattern associated with the event, where each color cycle demonstrates phase difference of [-π π], interpreted as ground deformation equal to 2.8 cm in the LOS (Line Of Sight) direction to the satellite. On the map are depicted clearly six or seven fringes which cover fully the surface of a smaller island located at the NE of KOS. The unwrapping image of the differential interferogram revealed a deformation pattern of several centimeters over this island with a relative motion between the northerm part and the southern part of it (Figure 2). The motion concerns the difference rate of motion between north and south.

It is important to mention that in the case of the Kos island (Figure 3) in the wrapped interferograms (ascending and descending geometry of acquisition) it is clear the presence of one fringe located in the city of Kos (descending) as well as two fringes along the northeast coast (Kefalos cape, ascending).

In conclusion, the precision of the measurements obtained by generating a differential interferogram and especially the phase unwrapping procedure needs prior information and if it is possible in situ observations.



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Department of Geography

Figure 1

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Figure 2

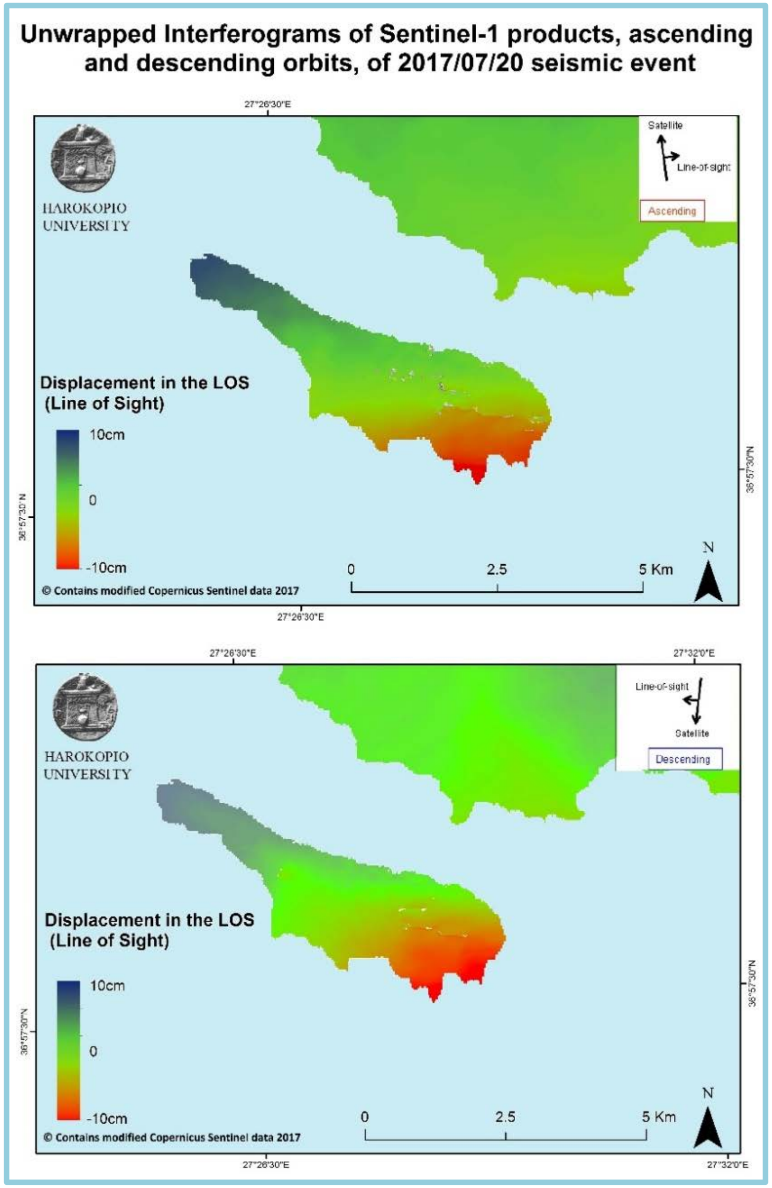
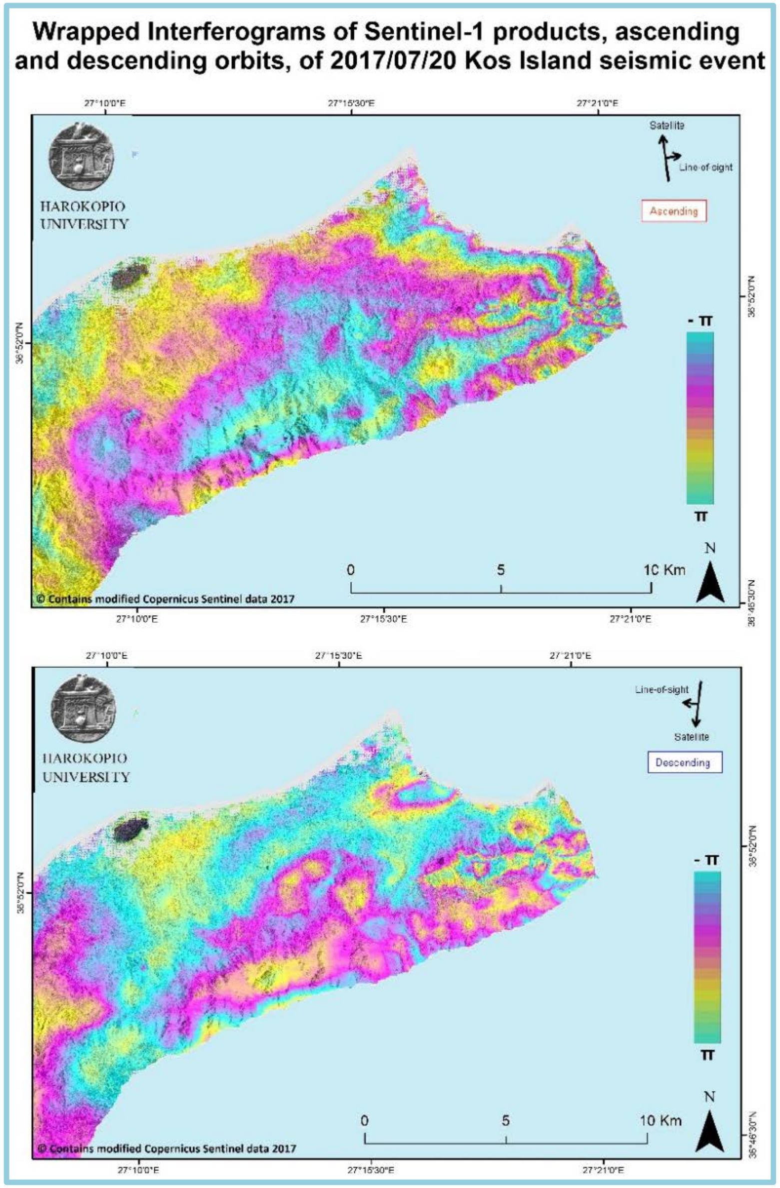


Figure 3



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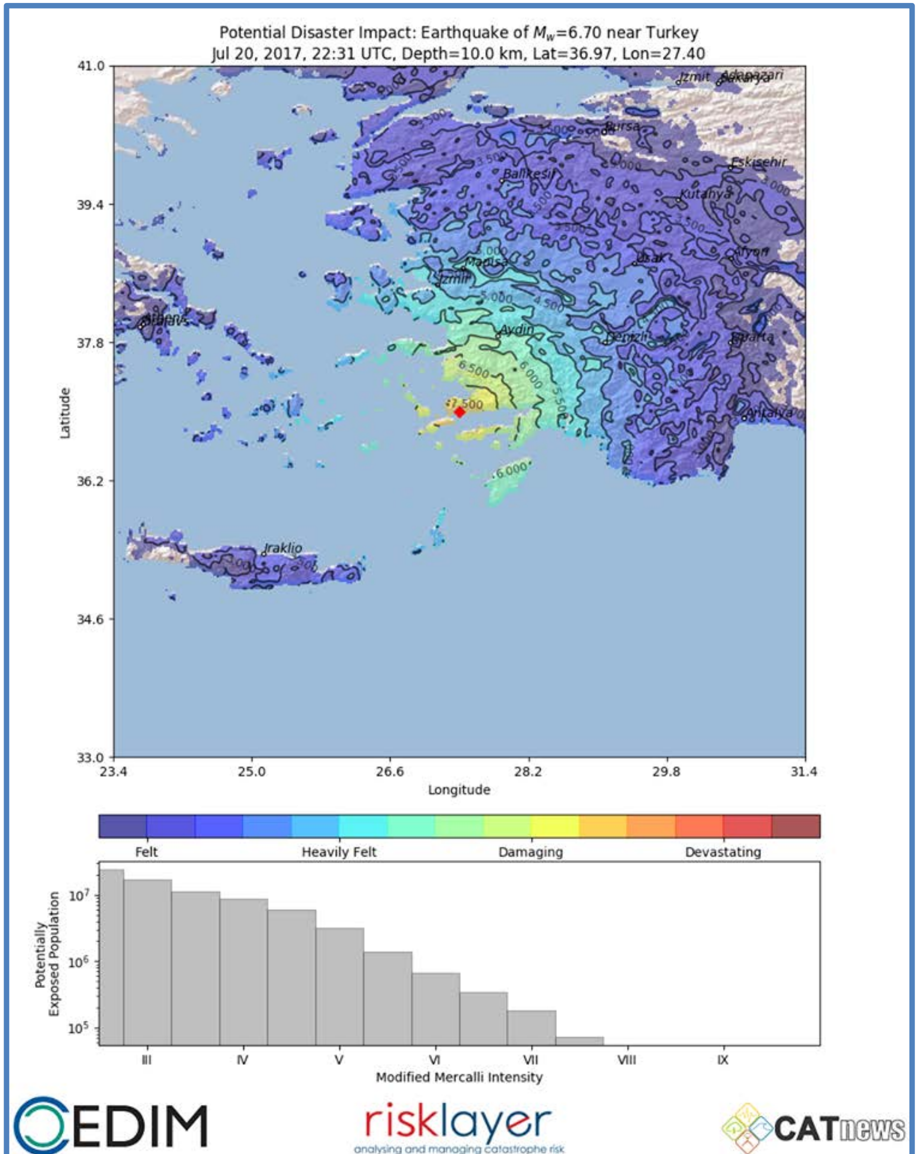
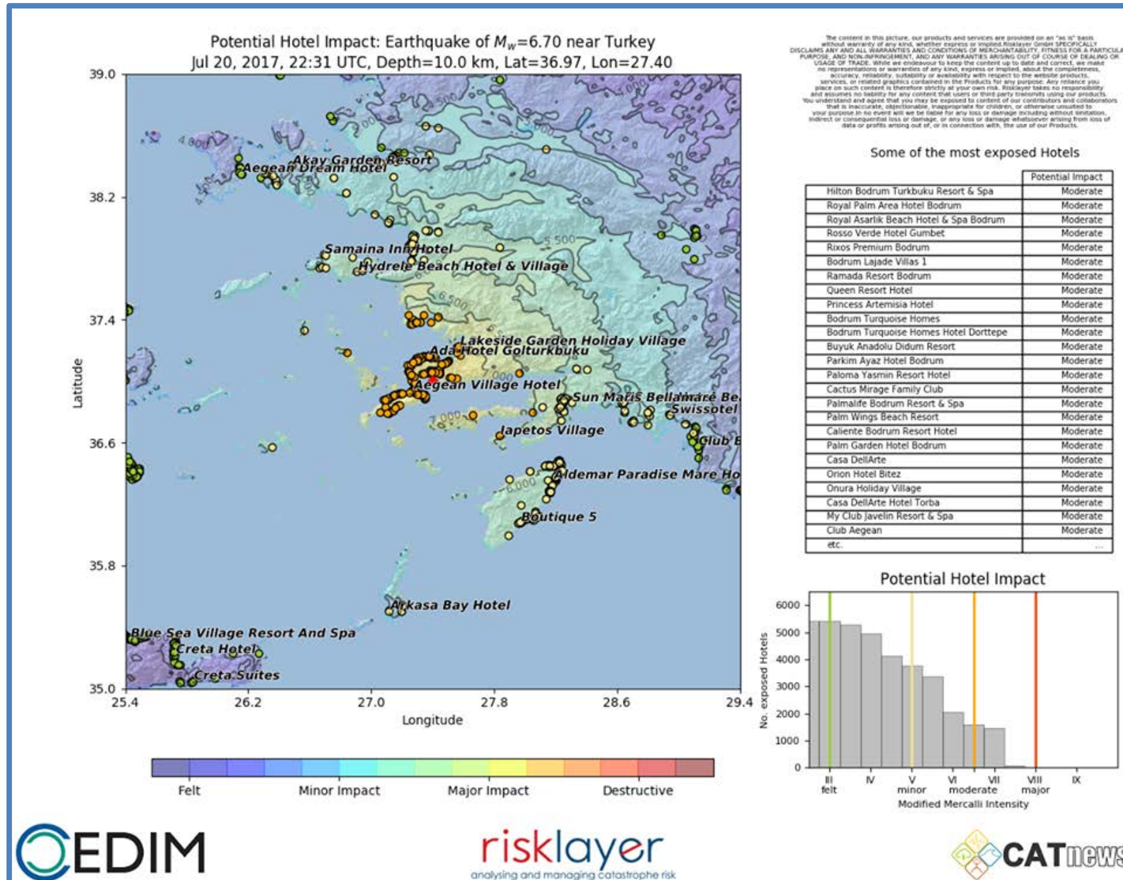
MAPS OF POTENTIAL DISASTER IMPACT AND POTENTIAL HOTEL IMPACT





	Potential Impact
Hilton Bodrum Turkbuku Resort & Spa	Moderate
Royal Palm Area Hotel Bodrum	Moderate
Royal Asarlik Beach Hotel & Spa Bodrum	Moderate
Rosso Verde Hotel Gumbet	Moderate
Rixos Premium Bodrum	Moderate
Bodrum Lajade Villas 1	Moderate
Ramada Resort Bodrum	Moderate
Queen Resort Hotel	Moderate
Princess Artemisia Hotel	Moderate
Bodrum Turquoise Homes	Moderate
Bodrum Turquoise Homes Hotel Dorttepe	Moderate
Buyuk Anadolu Didum Resort	Moderate
Parkim Ayaz Hotel Bodrum	Moderate
Paloma Yasmin Resort Hotel	Moderate
Cactus Mirage Family Club	Moderate
Palmalife Bodrum Resort & Spa	Moderate
Palm Wings Beach Resort	Moderate
Caliente Bodrum Resort Hotel	Moderate
Palm Garden Hotel Bodrum	Moderate
Casa DellArte	Moderate
Orion Hotel Bitez	Moderate
Onura Holiday Village	Moderate
Casa DellArte Hotel Torba	Moderate
My Club Javelin Resort & Spa	Moderate
Club Aegean	Moderate
etc.	...

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BUILDING DAMAGE IN THE EARTHQUAKE AFFECTED AREA OF KOS ISLAND BASED ON THE FIRST RAPID BUILDING INSPECTION CONDUCTED BY THE NATURAL DISASTER REHABILITATION DIRECTORATE (2017)

ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
ΥΠΟ.ΜΕ.ΔΙ.
Δ.Α.Ε.Φ.Κ.

	From July 21 to August 6 2017											
		Residential buildings		Professional premises		Monumental and public use buildings		Commercial buildin gs and buildings with various uses		Total		
Nr	Localities	INHABITABLE	UNINHABITABLE	INHABITABLE	UNINHABITABLE	INHABITABLE	UNINHABITABLE	INHABITABLE	UNINHABITABLE	INHABITABLE	UNINHABITABLE	
1	Kos	489	160	171	37	26	15	18	17	704	229	933
2	Kefalos	1	0	0	0	0	0	0	0	1	0	1
3	Pyli	5	1	0	0	2	3	0	0	7	4	11
4	Asfendiou	2	4	5	0	1	0	0	2	8	6	14
5	Kardamaina	0	0	5	0	0	0	0	0	5	0	5
6	Antimachia									0	0	0
	Total	497	165	181	37	29	18	18	19	725	239	964
		662		218		47		37		964		

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DAMAGE TO KOS PORT

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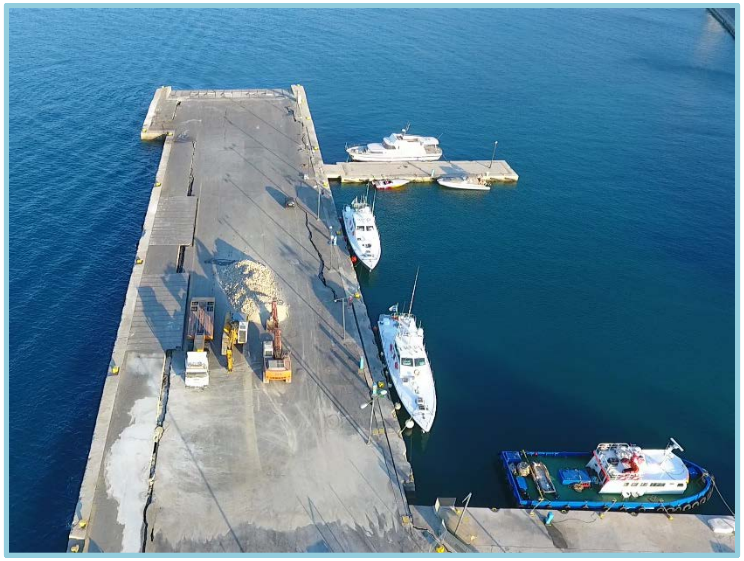
DAMAGE TO KOS PORT



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DAMAGE TO KOS PORT

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DAMAGE TO PORT FACILITIES AND RELATED BUILDINGS

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DAMAGE TO PORT FACILITIES AND RELATED BUILDINGS

▲ No horizontal deformation along the plane and perpendicular to the surface of the retaining wall was observed. A vertical subsidence attributed to the dynamic consolidation along with liquefaction of the fill material may be observed.

◀ The quay seawall is not disturbed at both horizontal and vertical planes and along its length. This indicates that there is not any major structural damage of the quay seawall.

▶ The direction towards which debris of rigid bodies collapse shows the location of the epicenter. The debris of two walls collapsed and present the same orientation. They fell parallel towards the same direction.

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HEAVY STRUCTURAL DAMAGE (FAILURE OF GROUND FLOOR) TO RECENT REINFORCED-CONCRETE BUILDINGS

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HEAVY STRUCTURAL DAMAGE (FAILURE OF GROUND FLOOR) TO RECENT REINFORCED-CONCRETE BUILDINGS

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HEAVY STRUCTURAL DAMAGE (FAILURE OF GROUND FLOOR) TO RECENT REINFORCED-CONCRETE BUILDINGS

Two stories were added at a later stage on an existing weak ground floor. The ground floor totally collapsed being squeezed, while the two upper stories suffered relatively no damage.

Spalling of the concrete cover attributed to concentration of many steel bars without retaining the appropriate distance among them. Steel corrosion and the resulting bloating of bars is also observed.

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DAMAGE TO MASONRY LOAD-BEARING WALLS






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DAMAGE TO ARCHAEOLOGICAL SITES AND MONUMENTAL STRUCTURES

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DAMAGE TO MASONRY STRUCTURES

(RESIDENTIAL BUILDINGS, MONUMENTAL STRUCTURES AND ARCHAEOLOGICAL SITES)

The down-town areas, where the historic centers of cities are located, offering a romantic atmosphere, old houses are handly transformed into restaurants and bars where people crowd. The earthquake threat in the most of the cases is ignored. The reason of a partial or total collapse of the structure, which in the most of the cases, result in fatalities and injuries, is common: lack of maintenance and non-proper human interventions.

The symmetrical damage of the wall of the chancel arch indicates the prevalence of the vertical component of the earthquake ground motion.

The fountain of Hippocrates. Very strong and heavy cup over slender and weak columns, without adequate column to cup and column to ground connections. Moreover, the connections between consecutive architectural elements (vertebrae) is realized mainly by simple friction.

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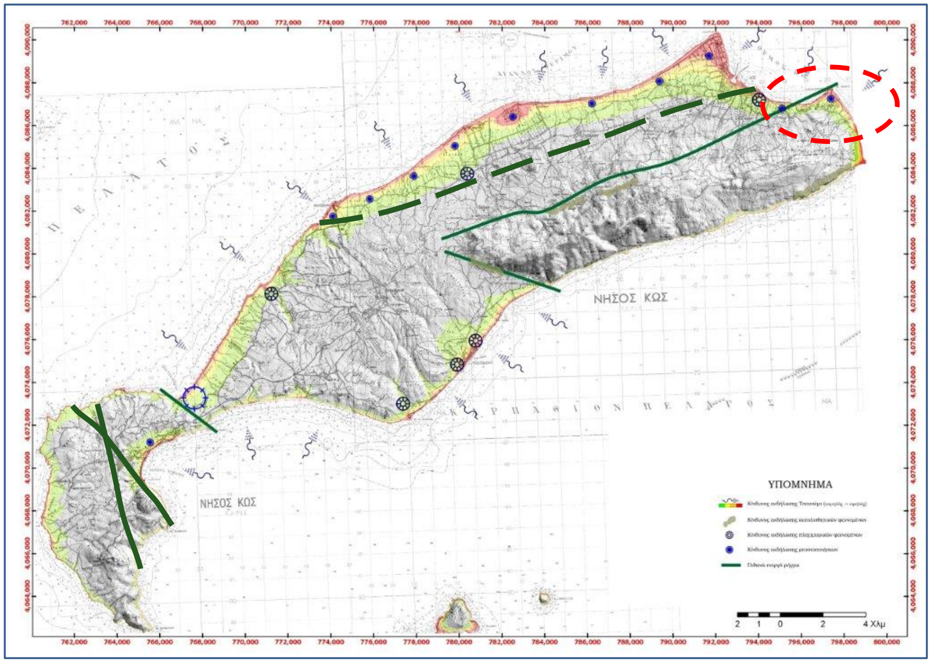
DAMAGE TO MASONRY STRUCTURES

(RESIDENTIAL BUILDINGS, MONUMENTAL STRUCTURES AND ARCHAEOLOGICAL SITES)

▲ The orientation of the collapse of the minaret indicates the location of the epicenter. The collapse is not attributed to the initial strong pulse, but later on, after some oscillations, to its higher flexibility. If the minaret was not fixed to the rigid structure, the collapse might be avoided.

▼ The displacement of the stiff structure is oriented towards the location of the epicenter due to the first strong pulse of the seismic motion.

LIQUEFACTION PHENOMENA



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LIQUEFACTION PHENOMENA

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COASTAL SUBSIDENCE

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COASTAL SUBSIDENCE

Ο.Α.Σ.Π.

Staff of the EPPO conducted a macroseismic survey in order to detect the earthquake impact in the meizoseismal area. More specifically, in the eastern coastal part of Kos, liquefaction phenomena were generated in the form of mud volcanoes and coastal subsidence varying from 30 to 40 cm was also detected resulting in inundation of the coast.

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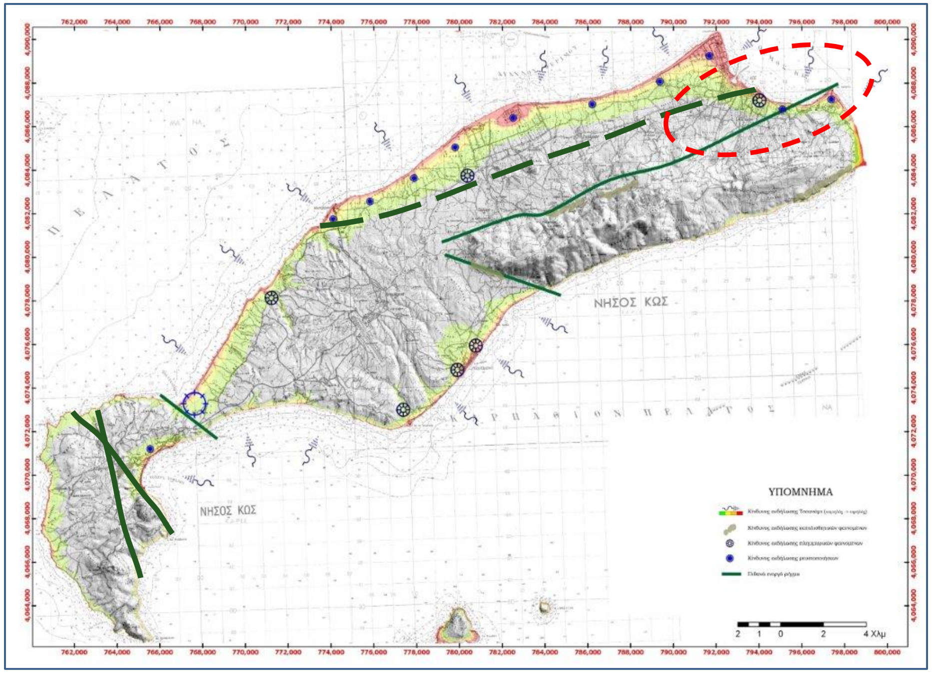
E-W STRIKING SEISMIC RUPTURES



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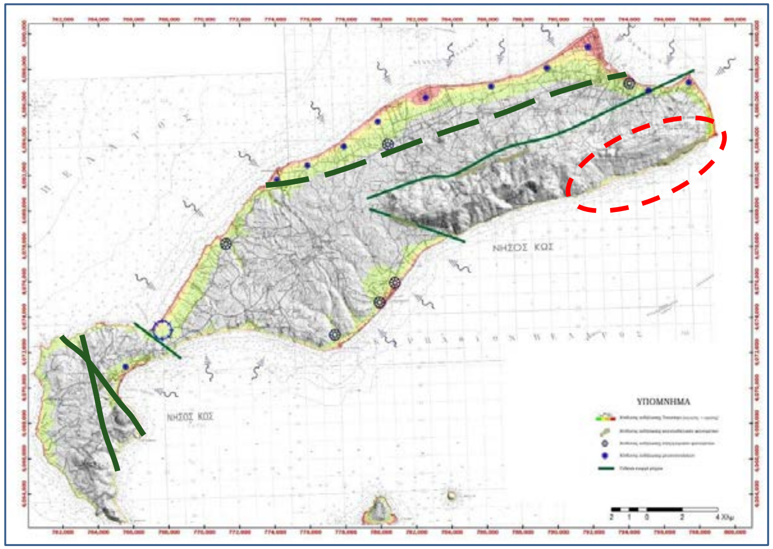
SLOPE MOVEMENTS



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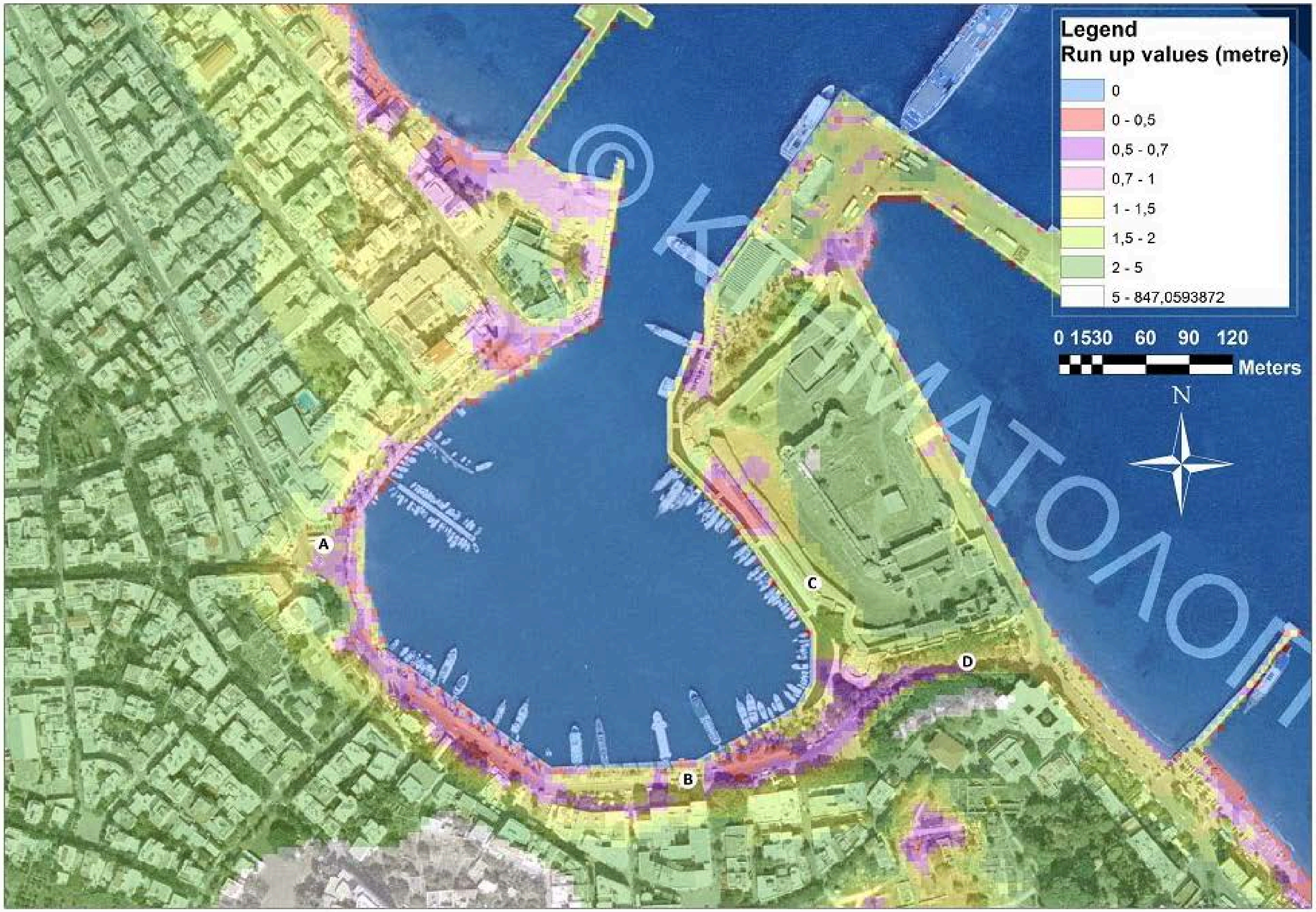
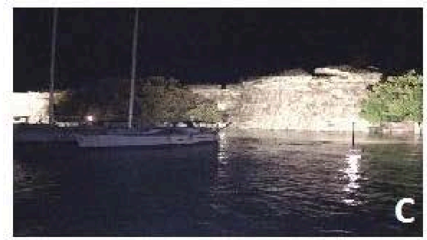
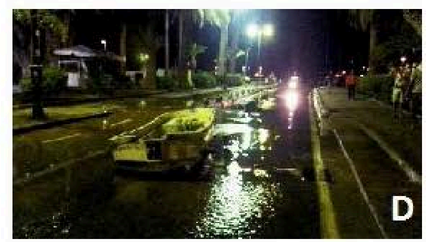
TSUNAMI IN KOS PORT

TSUNAMI RUN UP VALUES IN KOS PORT ITIS 2012







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TSUNAMI-INDUCED DAMAGE DISTRIBUTION IN KOS PORT BASED ON VERBAL AND PHOTOGRAPHIC TESTIMONIES

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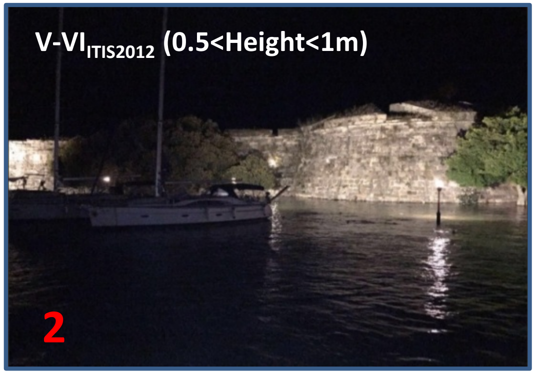
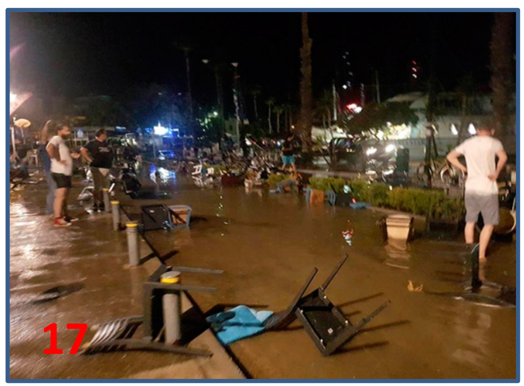
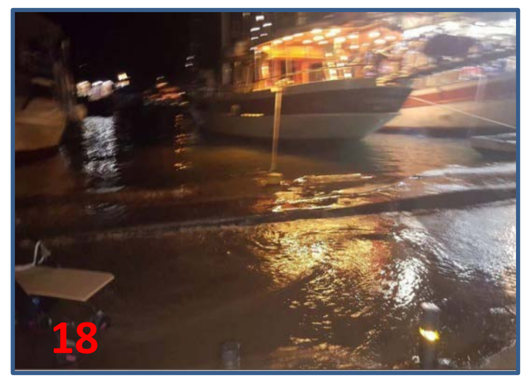
TSUNAMI EFFECTS IN THE COASTAL ZONE CLOSE TO KOS PORT



TSUNAMI EFFECTS IN THE COASTAL ZONE CLOSE TO KOS PORT





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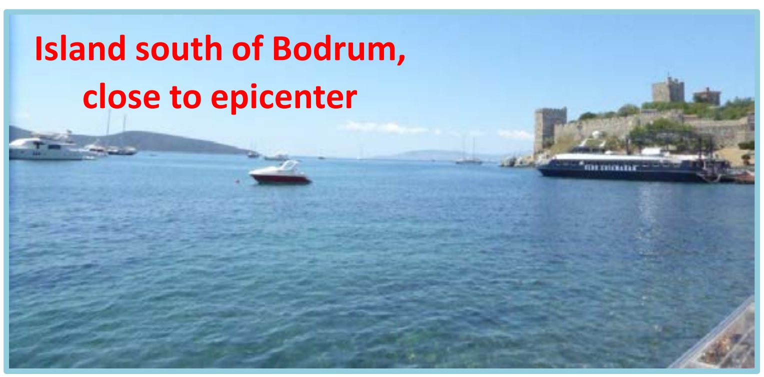
TSUNAMI EFFECTS IN THE COASTAL ZONE OF BODRUM (TURKEY)



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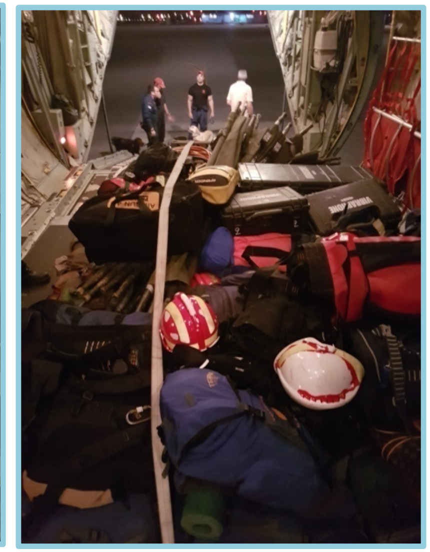
DISASTER MANAGEMENT





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