FORENSIC RECONSTRUCTION OF THE 365AD EARTHQUAKE

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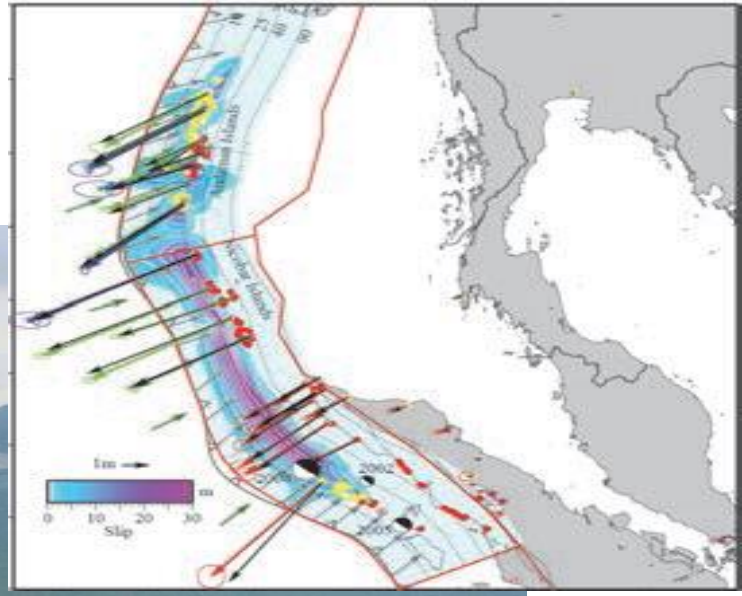
Chief Research Officer

9th Humboldt Conference
Istanbul

The question of the 365AD Earthquake

- In the 1980s evidence accumulated around the eastern Mediterranean of sudden sea level changes and archaeological evidence of cities destroyed in earthquakes between 300 and 600AD
- Pirazzoli (1986) termed this the ‘Early Byzantine Tectonic Paroxysm’
- The earthquake historian Emanuela Guidoboni strongly refuted the ‘paroxysm’ as a singular event and proposed there were multiple earthquakes affecting a wide region of the Eastern Mediterranean
- It was inconceivable at the time that an earthquake could cause damage all the way from Cyprus to Sicily (1200km apart)

2004 Earthquake (and Tsunami)

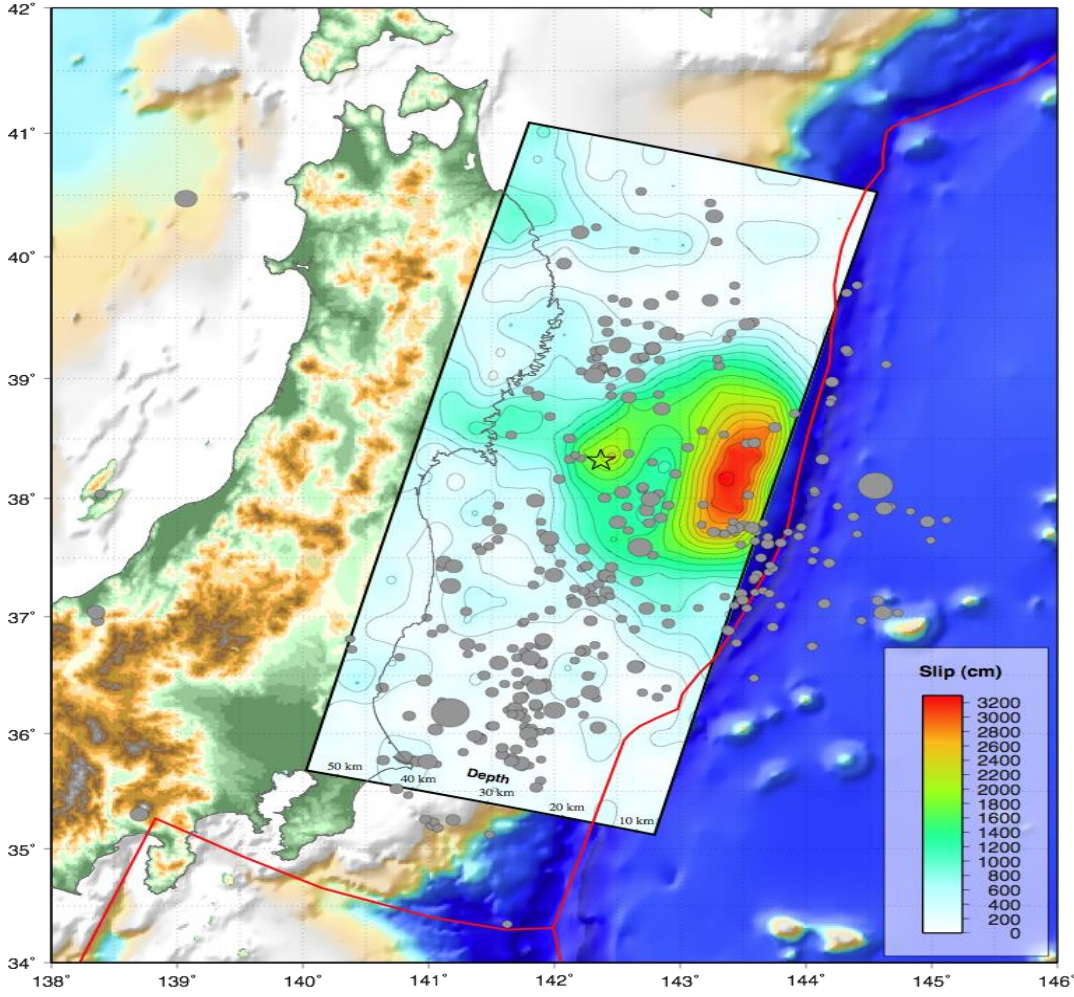


Mw 9.1 earthquake 1200km fault rupture

Displacement up to 20m

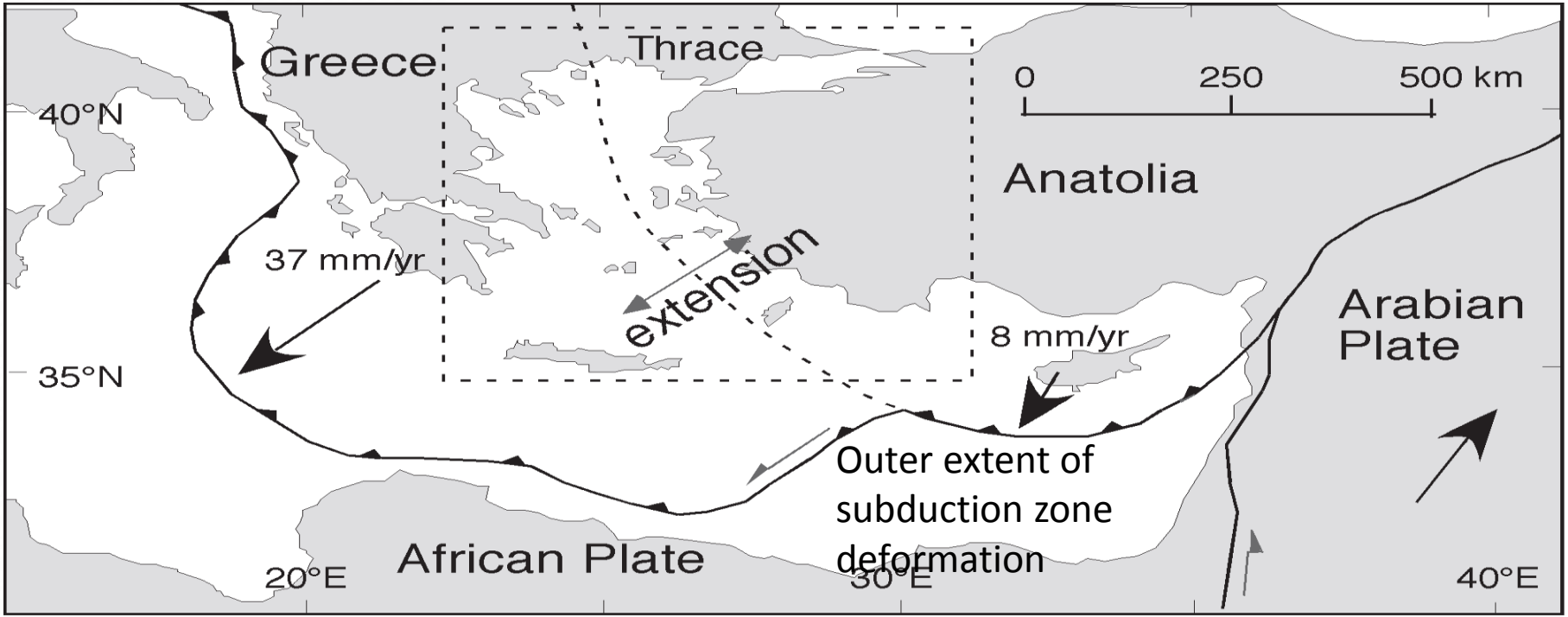
Sendai Airport March 11th 2011 Mw9 Earthquake & tsunami

Tohoku, Japan Earthquake: Fault Model USGS V2 - 2011/03/18

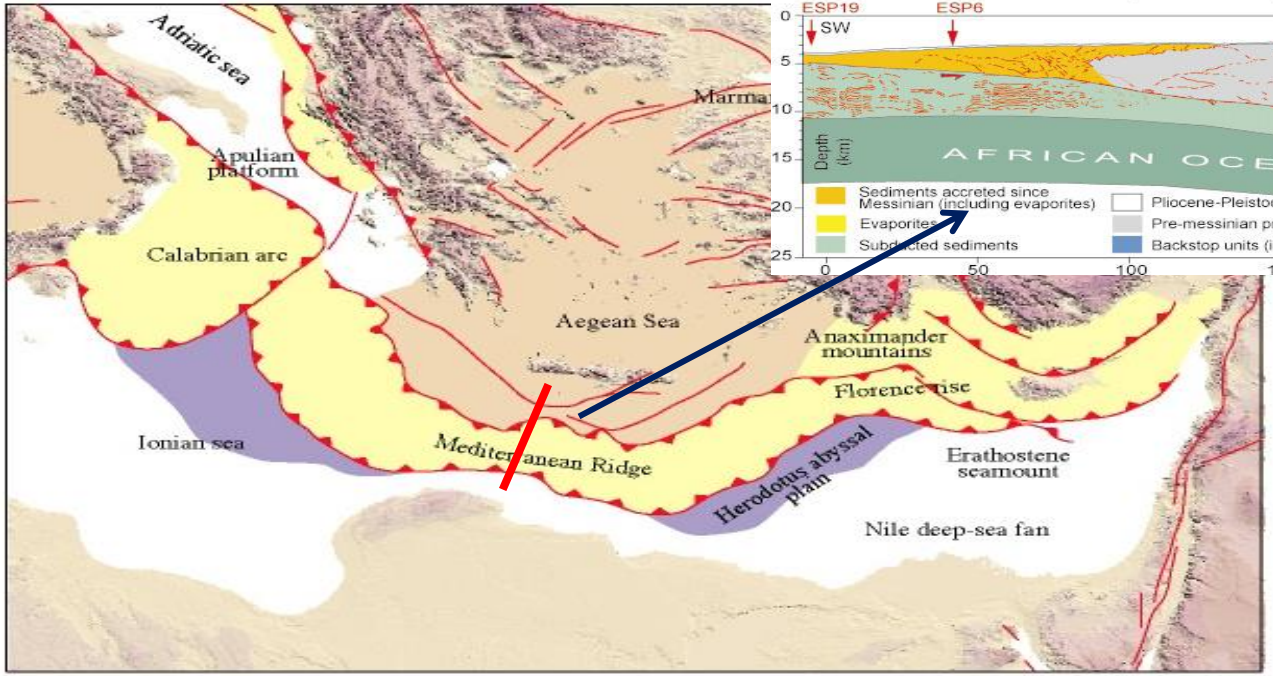


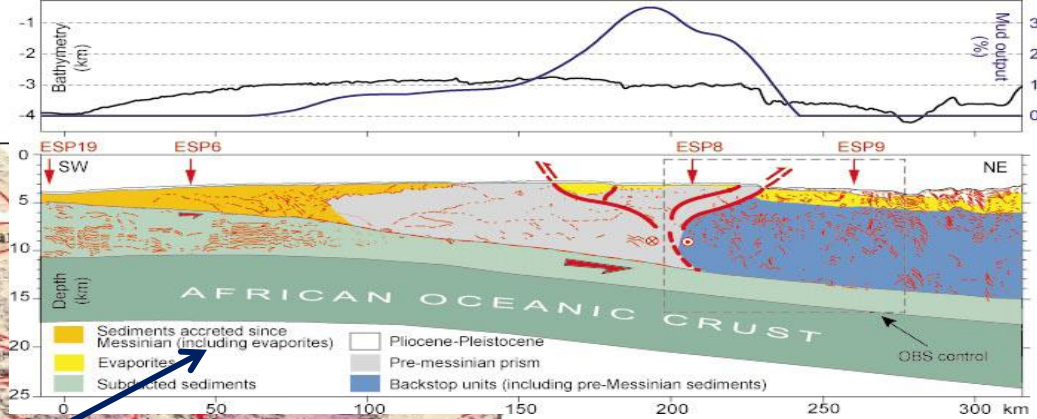
Subduction zone sites of Giant >Mw8.7 earthquakes

The Eastern Mediterranean plate boundary – the potential site of an Mw9 earthquake and mega-tsunami?



Hellenic Arc Subduction Zone





Post-orogenic basins
Neogene shortening
Neogene oceanic crust
Mesozoic oceanic crust
Thrust
Fault

Tectonic sketch of the Eastern Mediterranean
(adapted from Barrier, E., Chamot-Rooke, N. and Giordano, G., 2004,
Geodynamic Map of the Mediterranean, Commission for The Geological Map of the World, CCGM)

Ammanius Marcellinus, born325-330AD probably in Antioch, grew up speaking Greek, served as a soldier and around 380AD wrote a detailed history of Rome. Last great Roman historian.

At the end of one of his books detailing the Emperor's military campaigns Ammanius announces: ***'on the 21st of July (365AD) fearful dangers suddenly overspread the whole world, such as are related in no ancient fables or histories***'.

Ammanius's account of the July 21st 365AD catastrophe

Paulo enim post lucis exortum, densitate praeuia fulgurum acrius uibratorum, tremefacta concutitur omnis terreni stabilitas ponderis, mareque dispulsum retro fluctibus euolutis abscessit, ut retecta uoragine profundorum species natantium multiformes limo cernerentur haerentes, ualliumque uastitates et montium, tune, ut opinari dabatur, suspicerent radios solis, quos primigenia rerum sub immensis gurgitibus amendauit. Multis igitur nauibus uelut arida humo conexis, et licenter per exiguas undarum reliquias palantibus plurimis ut pisces manibus colligerent et similia, marini fremitus, uelut grauati repulsam, uersa uice consurgunt, perque uada feruentia insulis et continentis terrae porrectis spatiis uiolenter illisi, innumera quaedam in ciuitatibus et ubi reperta sunt aedificia complanarunt, proinde ut, elementorum furente discordia, inuoluta facies mundi miraculorum species ostendebat. Relapsa enim aequorum magnitudo, cum minime speraretur, milia multa necauit hominum et submersit, recurrentiumque aestuum incitata uertigine, quaedam naues, postquam umentis substantiae consenuit tumor, pessumdatae uisae sunt, exanimataque naufragiis corpora supina iacebant aut prona. Ingentes aliae naues extrusae rabidis flatibus culminibus insidere tectorum, ut Alexandriae contigit, et ad secundum lapidem fere procul a litore contortae sunt aliquae, ut Laconicam prope Mothonen oppidum nos transeundo conspeximus, diuturna carie fatiscentem.

‘*Slightly after daybreak, and heralded by a thick succession of fiercely shaken thunderbolts, the solidity of the whole earth was made to shake and shudder, and the sea was driven away, its waves were rolled back, and it disappeared, so that the abyss of the depths was uncovered and many-shaped varieties of sea-creatures were seen stuck in the slime; the great wastes of those valleys and mountains, which the very creation had dismissed beneath the vast whirlpools, at that moment, as it was given to be believed, looked up at the sun's rays. Many ships, then, were stranded as if on dry land, and people wandered at will about the paltry remains of the waters to collect fish and the like in their hands; then the roaring sea as if insulted by its repulse rises back in turn, and through the teeming shoals dashed itself violently on islands and extensive tracts of the mainland, and flattened innumerable buildings in towns or wherever they were found. Thus in the raging conflict of the elements, the face of the earth was changed to reveal wondrous sights. For the mass of waters returning when least expected killed many thousands by drowning, and with the tides whipped up to a height as they rushed back, some ships, after the anger of the watery element had grown old, were seen to have sunk, and the bodies of people killed in shipwrecks lay there, faces up or down. Other huge ships, thrust out by the mad blasts, perched on the roofs of houses, as happened at Alexandria, and others were hurled nearly two miles from the shore, like the Laconian vessel near the town of Methone which I saw when I passed by, yawning apart from long decay*.’

‘…people wandered at will about the paltry remains of the waters to collect fish and the like in their hands; then the roaring sea as if insulted by its repulse rises back in turn, and through the teeming shoals dashed itself violently on islands and extensive tracts of the mainland’…

‘….Other huge ships, thrust out by the mad blasts, perched on the roofs of houses, as happened at Alexandria,….’

Libanius oration for the Emperor Julian (died June 363AD)

- Libanius - born in Antioch, 10-15 years older than Ammanius, living in Constantinople
- '*At all this, what man that has sense would not cast himself prostrate on the ground...! Earth truly has been fully sensible of her loss, and has honoured the hero by an appropriate shearing off of her tresses, shaking off, as a horse doth his rider, so many and such great cities. In* ***Palestine*** *several; of the* ***Libyans all and every one***. ***Prostrate lie the largest towns of Sicily***, ***prostrate all of Greece save one***; *the fair* ***Nicaea lies in ruins***; *the city, pre-eminent in beauty, totters to her fall, and has no confidence for the time to come!* '
- The earthquake in Palestine is well documented and occurred on May 19th 363 AD
- The Italian earthquake historian Emanuela Guidoboni, argued, on the basis that this was written soon after the death of Julian in June 363AD, that it must report other, formerly unknown, earthquakes in Greece, Libya and Sicily.
- Yet these pre June 363AD catastrophic earthquakes are not documented by any other source.
- The oration mentions an earthquake at Nicaea (Iznik) which has now been identified to October 368AD.
- Therefore the oration was written after Nov 368AD
- And the earthquakes in Greece, Libya and Sicily likely all relate to July 21st 365AD.

Accounts of the 365AD earthquake

- ‘Crete was very much shaken, as was likewise the Peloponnese, and all Greece, many places being destroyed; indeed almost all were overturned, except Athens and the country of Attica.’ *(Chronicler Zosimus)*
- ‘100 towns in Crete were completely destroyed’.(*Chronicler Malalas*)
- ‘there was destruction in Crete, Achaea, Boeotia, Epirus and Sicily and many ships were thrown 100 stades on to mountainsides’. (*Chronicler George the Monk)*
- ‘ ‘the sea changed its familiar boundaries; for in some places the quaking was so severe that places where previously people walked they could now sail. In other places, the sea retreated so far that the bottom of the sea was found to be dry. (*5thC Socrates Scholasticus*)

Accounts of the 365AD Tsunami

- ‘In these times there occurred a great and very fearsome earthquake to the extent that at Alexandria the sea disappeared for a long time and boats were found lying as if on dry land. And a multitude of people ran to see the unexpected wonder, and when the water turned around and came back further than its accustomed place, 50,000 people were drowned and some of the ships moored there were covered by the waters, and others found in the River Nile were thrown inland up to 180 stades (18km)’. (Byzantine chronicler George the Monk)

Alexandria at the western end of the Nile delta was the second largest city in the Empire after Rome, with a population of more than 300,000.

Two centuries later Alexandrians were still organising a yearly festival 'the birthday of the earthquake’ – or ‘day of horror',

“There was an earthquake throughout the world, and the sea flowed over the shore, causing suffering to countless people in Sicily and many other islands”. Jerome

5 ROMAN EMPERORS FROM 360-365AD

Constantius II born Aug 7th 317
Emperor May 22, 337 AD – November 3, 361 AD

Julian II born 331 AD/332 AD, Emperor February 360 AD – June 26, 363 AD

Jovian born 331 AD,
Emperor June 26, 363 AD – February 17, 364 AD

Valentinian I born 321 AD, Co-emperor February 26, 364 AD – November 17, 375 AD

Valens born 328 AD,Co-Emperor March 28, 364 AD – August 9, 378 AD

Summary of mid 4th C earthquake destruction layers

- Crete
  - Kissamos (W Crete) shortly after 355-361 (destruction so great the dead were left unburied
  - Eleutherna W Crete shortly after 355-361
  - Gortyn I(Central Crete) 10-15 years before 383AD
- Libya
  - Leptis Magna, Tripolitis NW coast shortly after 364-367
  - Sabratha, Tripolitic NW coast shortly after 364-387 before 378
  - Balagrae (El Beida) Cyrenaica, NE Coast shortly after 364
  - Cyrene, Cyrenaica, NE Coast shortly after 364
  - Ptolemais, Cyrenaica, NE Coast shortly before 364-378
- Cyprus
  - Kourion between late 364 and Sept 365
- Sicily/Italy
  - Agrigento – shortly after 364-367
  - Selinunte Temple C after 330AD
  - Reggio Calabria before 374

There were 5 Roman emperors between 360-365AD
New emperor's head coin stamps were sent to each town
Coins in rubble constrain the date of collap

Locations of c365AD destruction

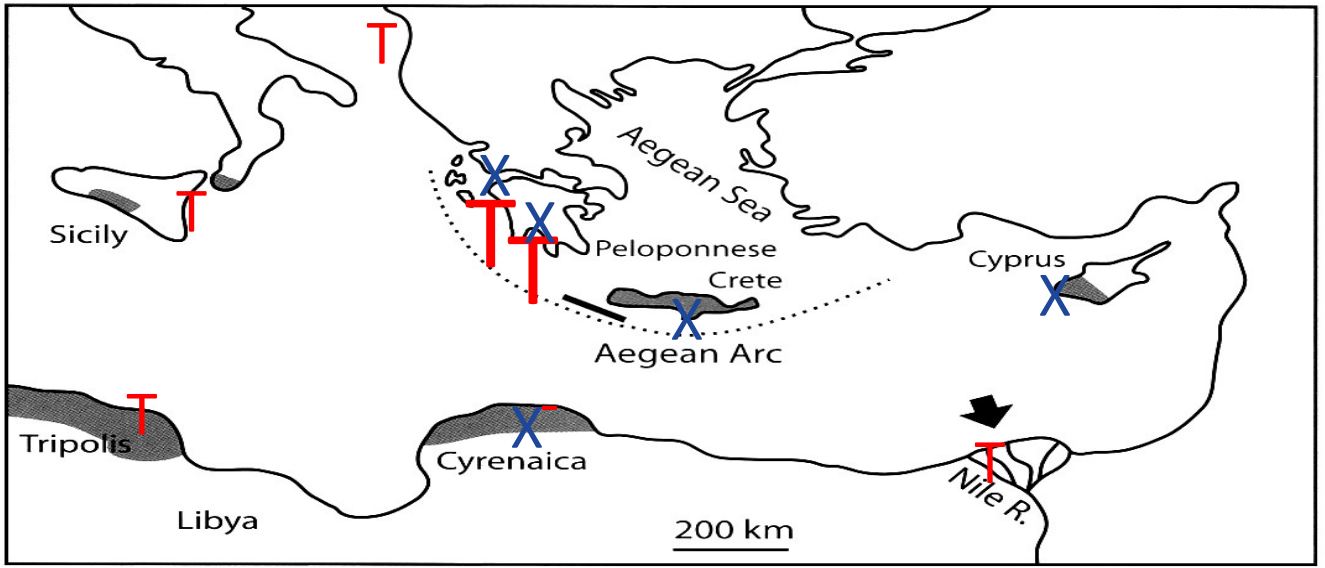
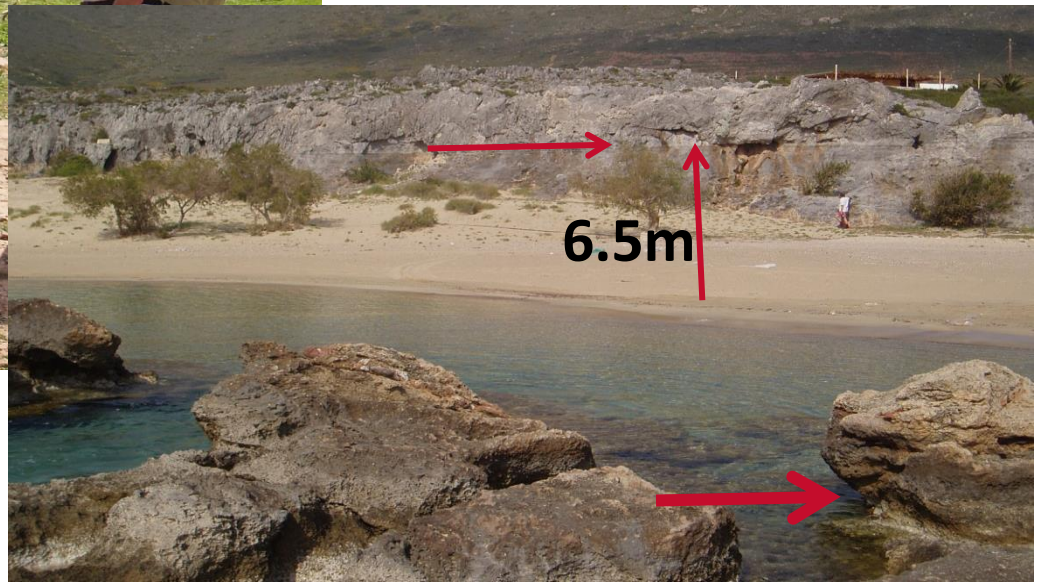


Fig. 1. Location and summary map. Areas for which there is clear archaeological and historical evidence for destruction caused by the AD 365 earthquake are dotted. An arrow points to the Nile Delta where inundation and much destruction by the tsunami following this earthquake are reported. A dotted line indicates the Hellenic (Aegean) Arc, and a solid line the approximate trace of the modeled causative thrust. Gavdos islet is marked by a dot at the eastern termination of this fault; another dot north of Crete indicates Antikithira.

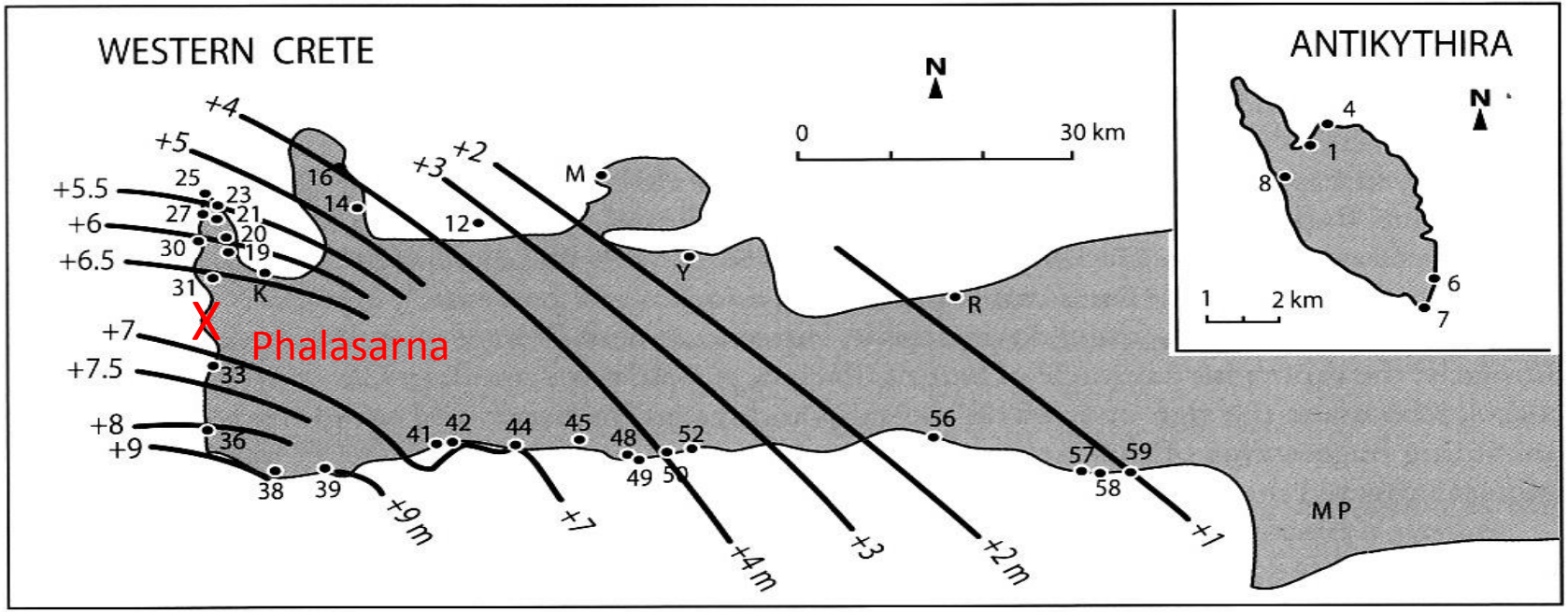
T Tsunami X Destruction

Phalasarna, W Crete (Phoenecian harbour)

'the sea changed its familiar boundaries; for in some places the quaking was so severe that places where previously people walked they could now sail. In other places, the sea retreated so far that the bottom of the sea was found to be dry'. (5thC Socrates Scholasticus)

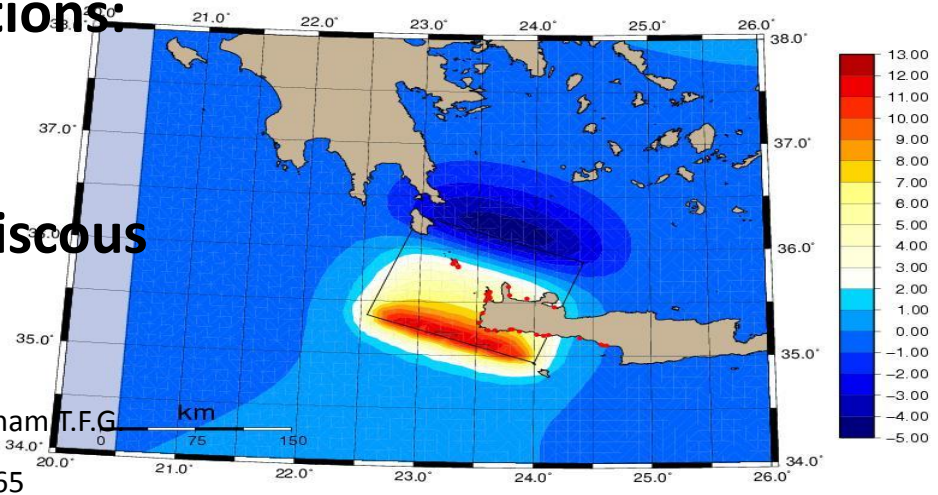


Uplift event of the pre-365AD solution notch sea level



Fault parameters required to generate West Crete uplift

- **Best fit with surface uplift observations:**
  - **315 degree strike**
  - **100km long fault**
  - **20m displacement (25m with viscous relaxation)**
  - **dip 30 degrees to 45km**

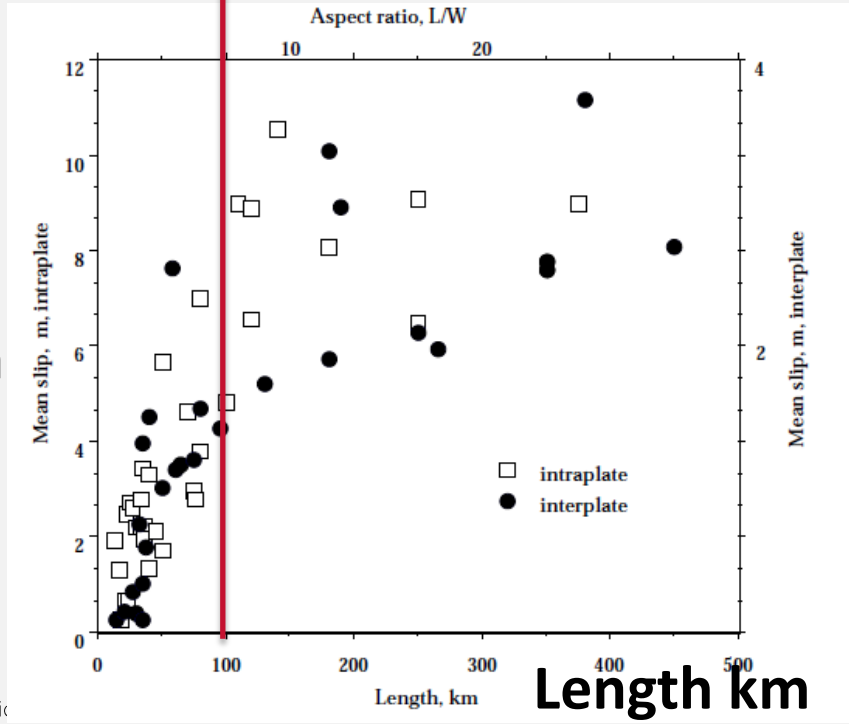


Shaw B., Ambraseys N.N., England P.C., Floyd M.A., Gorman G.J., Higham T.F.G Jackson J.A/. Nocquetz J-M., Pain C.C. & Piggott M.D. (2008) Eastern Mediterranean tectonics and tsunami hazard inferred from the AD 365 earthquake ***Nature Geoscience* 1, pp268-276**

- **Stiros et al., (2006) proposed:**
  - **16m slip**
  - **100km x 100km fault**
  - **dipping at 40 degrees down to 70km**

Stiros, S. C. & Drakos, (2006) A. A fault model for the tsunami-associated, magnitude 8.5 Eastern Mediterranean, AD 365 earthquake. ***Z. Geomorphol. 146, 125–137***

Figure 1. Compilation of mean slip vs length for large crustal earthquakes (modified after [Scholz, 1994b]). The aspect ratio is based on an assumed value of W = 15 km.



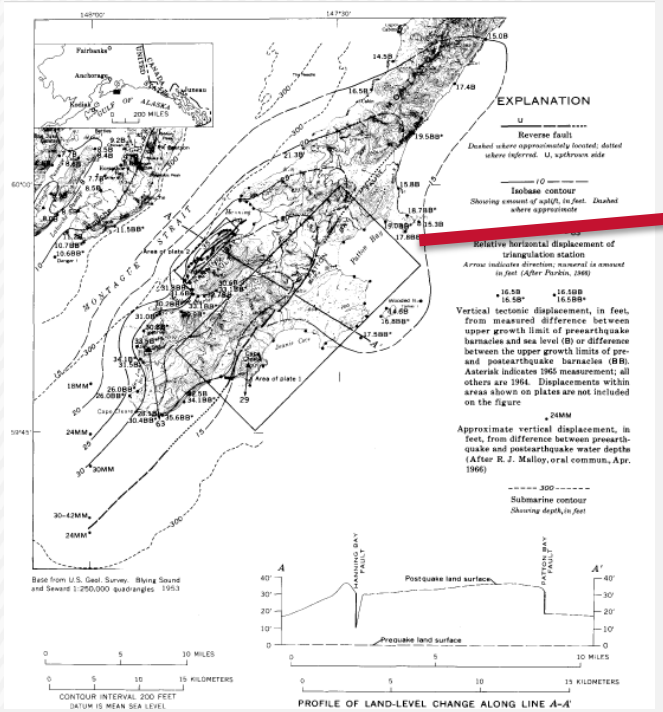
Mean slip m

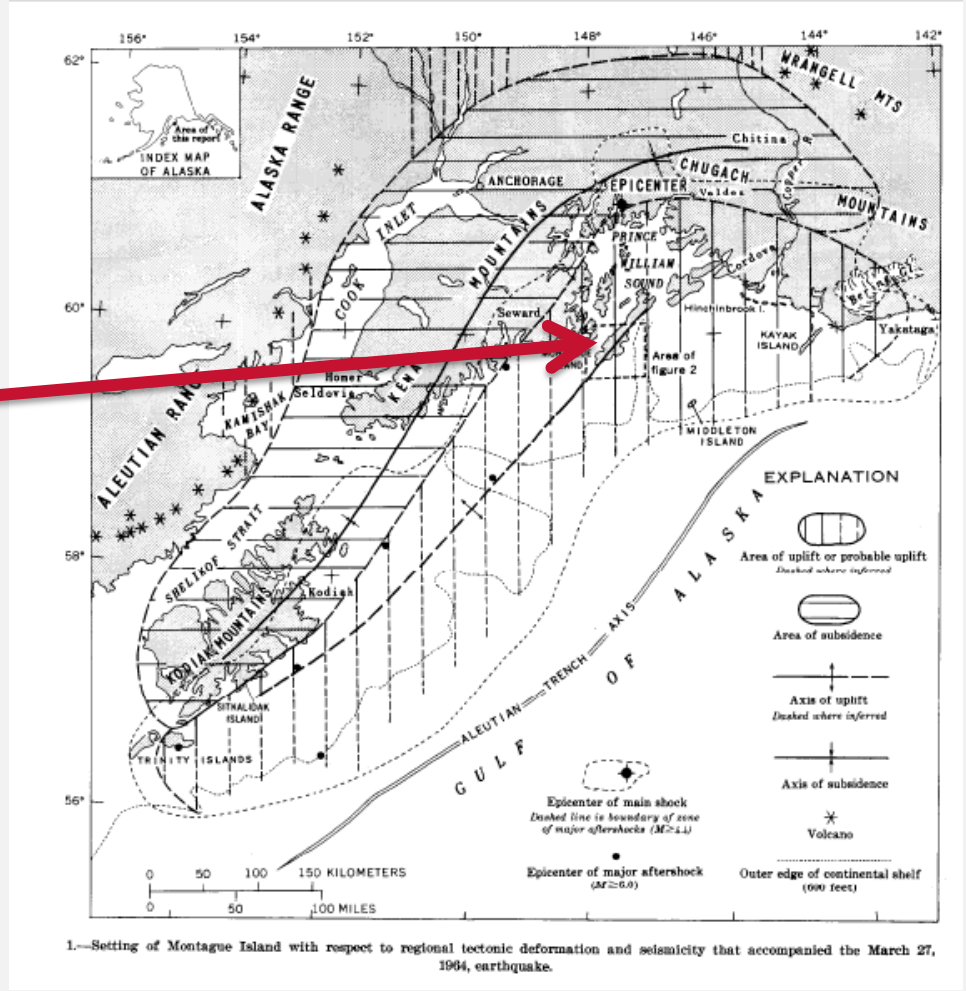
Length km

1964 Alaska Montague Island high angle thrust

60km long 10m uplift – 2 reverse faults one with 8m rupture

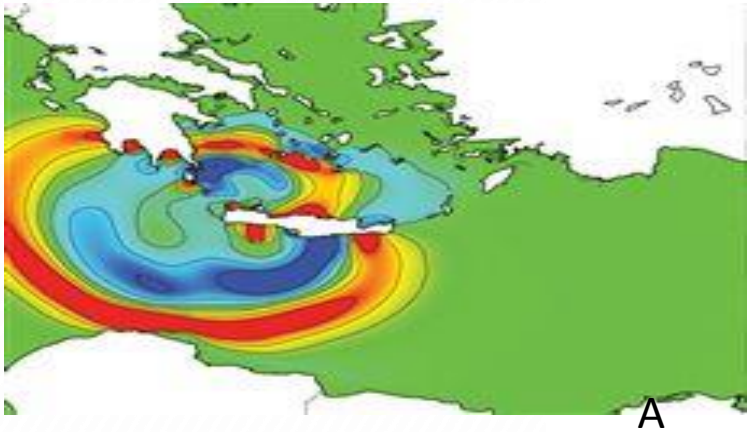
MONTAGUE ISLAND UPLIFT 1964



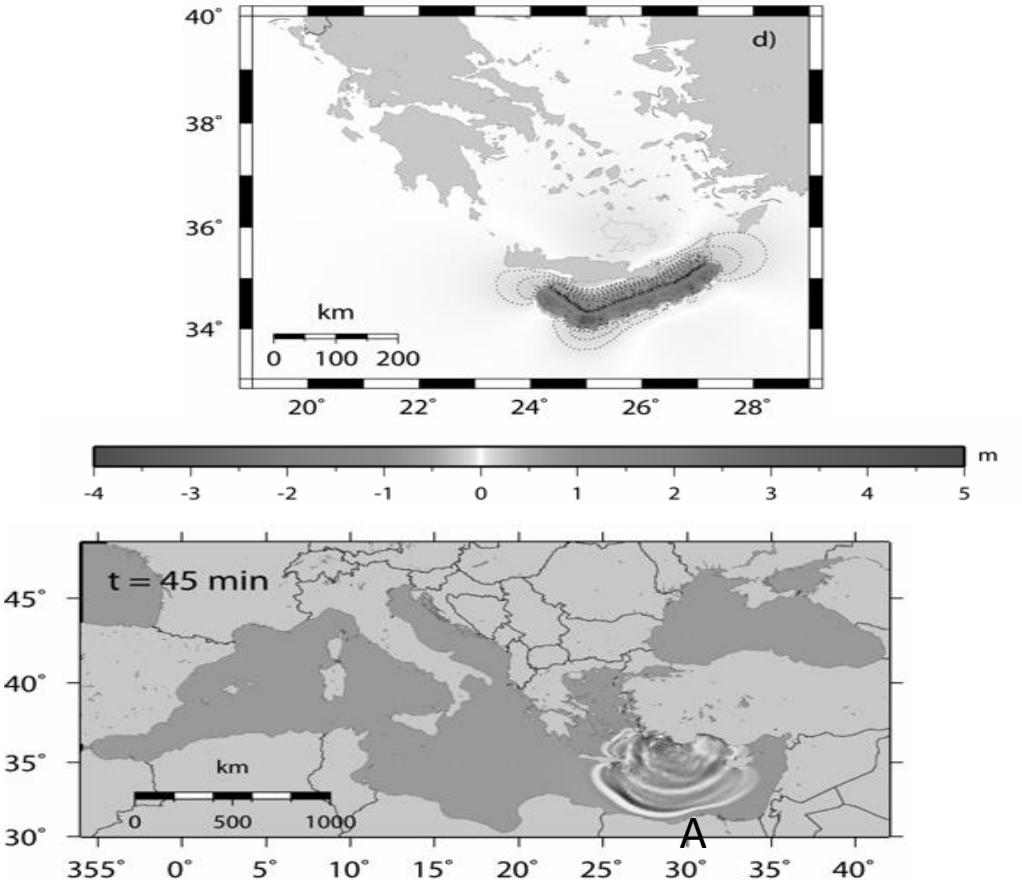


1.—Setting of Montague Island with respect to regional tectonic deformation and seismicity that accompanied the March 27, 1964, earthquake.

Tsunami Polarity & Height



West Crete thrust source
Shaw et al (2008)

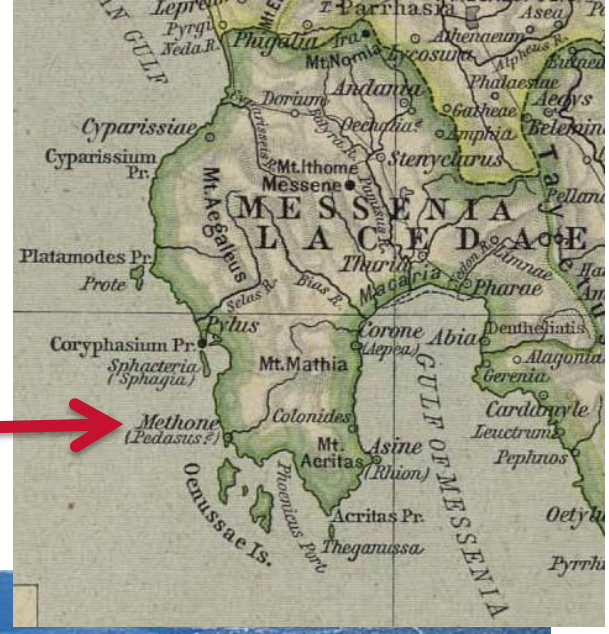


ISET Journal of Earthquake Technology, Paper No. 464, Vol. 42, No. 4, December 2005, pp. 171-188
SCENARIOS OF GIANT TSUNAMIS OF TECTONIC ORIGIN IN THE
MEDITERRANEAN Stefano Tinti, Alberto Armigliato, Gianluca Pagnoni and Filippo Zaniboni

What is inconsistent with the West Crete thrust fault explanation for the 365AD earthquake?

- 20m displacement on a 100km fault length inconsistent with modern earthquake fault ruptures
- Far field 1-2m uplift (100-150km to the east of culmination of uplift) unexplained
- Earthquake reported as strongly felt at Alexandria (800km distance)
- Actual tsunami much higher at Alexandria and first motion of the sea was a lengthy withdrawal
- Does not explain widespread destruction reported across Greece and Libya
- Or archaeological evidence of destruction in Cyprus
- (and therefore requires additional 'deus ex machina' earthquakes)
- Alternative explanation – as within M9.3 2004 Sumatra or 1964 Alaska deformation - that Western Crete was a localized imbricated steeper overthrust intersecting the larger subduction zone interface fault rupture at depth
  - 20-25m displacement likely to be the displacement on the underlying subduction zone interface fault

Other huge ships, thrust out by the mad blasts… were hurled nearly two miles from the shore, like the Laconian vessel near the town of Methone which I saw when I passed by, yawning apart from long decay.'



THE END OF THE OLYMPICS

 Confidential

ANCIENT OLYMPIA

Ancient Olympia
Ολυμπία

At the confluence of the rivers Alfeiós and Kládeos, the Sanctuary of Olympia enjoyed over 1,000 years of esteem as a religious and athletics centre. Though the sanctuary flourished in Mycenaean times *(see pp26–7)*, its historic importance dates to the coming of the Dorians and their worship of Zeus, after whose abode on Mount Olympos the site was named. More elaborate temples and secular buildings were erected as the sanctuary acquired a more Hellenic character, a process completed by 300 BC. By the end of the reign of Roman Emperor Hadrian (AD 117–38), the sanctuary had begun to have less religious and political significance.

Aerial view south over the Olympia site today

Decorative window
This window is part of Pheidias's workshop where a huge statue of Zeus (see p241) was made.

Stadium Entrance
Late in the 3rd century BC, the stadium entrance acquired a vaulted ceiling, part of which survives. The existing stadium was the third laid out at Olympia.

The Temple of Hera, begun in the 7th century BC, is one of the oldest temples in Greece.

The Philippeion, commissioned by Philip II, honours the dynasty of Macedonian kings.

The Treasuries, which stored votive offerings from their donor city-states, looked like miniature temples.

The Metroön was a Doric shrine to the pre-Olympian goddess Rhea.

Olympia Museum

Main entrance

South Hall

Altar of Oaths

The Bouleuterion, or council house, was the seat of the Olympic Senate.

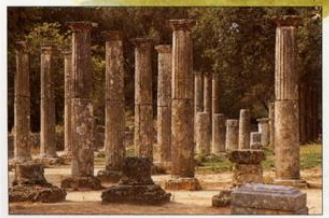
Sanctuary entrance

The Leonidaion, with its clover-shaped water-garden, accommodated distinguished guests.

The Heroön housed an altar dedicated to an unknown hero.

0 metres 50

0 yards 50



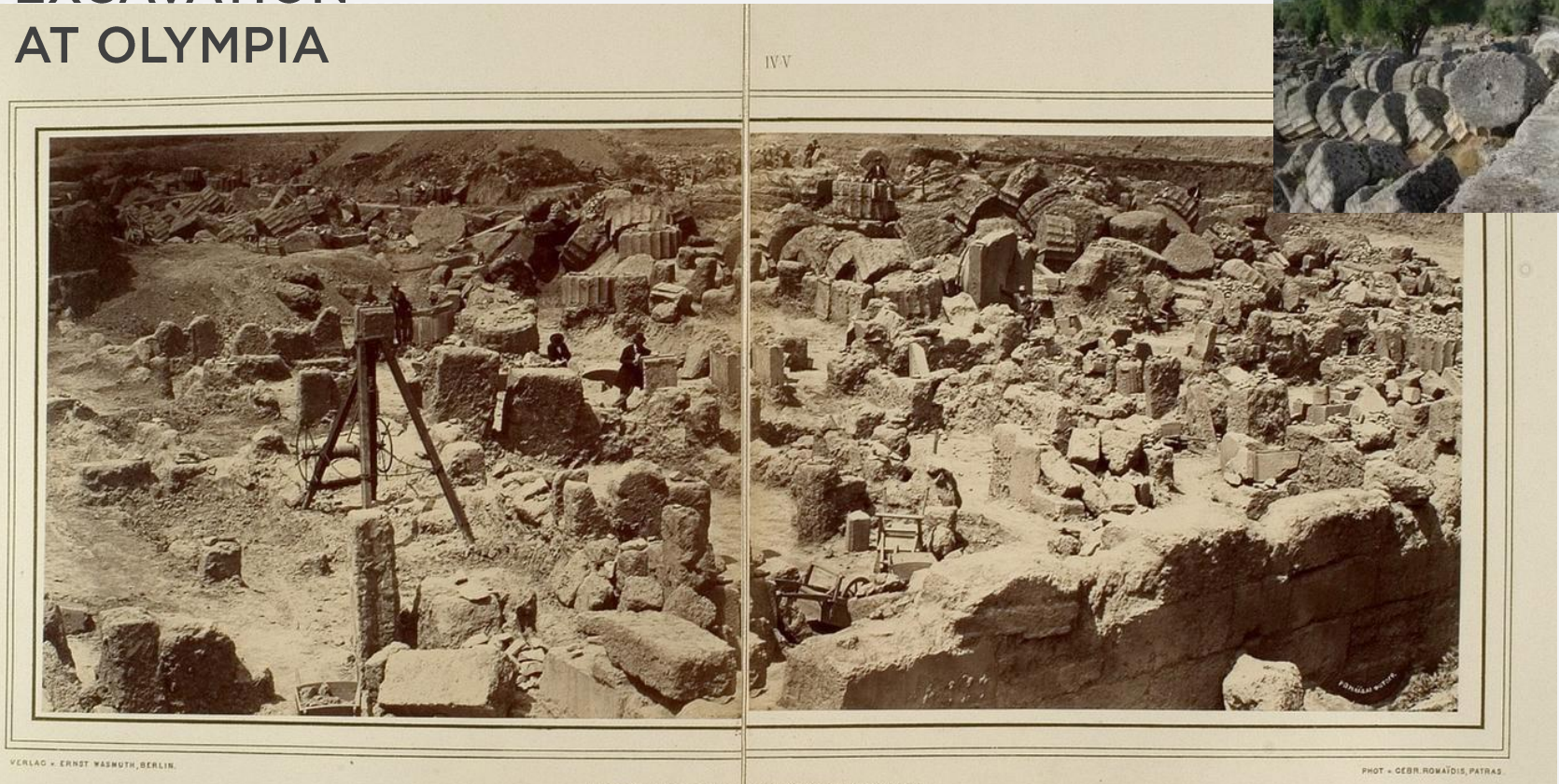
Palaestra
This was a training centre for wrestlers, boxers and long-jumpers. Much of the colonnade which surrounded the central court has been reconstructed.

RECONSTRUCTION OF OLYMPIA (AD 100)
This shows Olympia as it was under the Romans. At that time the worship of Zeus predominated; the games were dedicated to him, and his temple (containing a huge statue of the god) was at the heart of the Olympian enclosure.

Temple of Zeus
Though only column bases and tumbled sections remain, they clearly indicate the grandeur of this 5th-century BC Doric temple.

RMS™

EXCAVATION AT OLYMPIA



1875 http://www.mpiwg-berlin.mpg.de/en/research/projects/DeptII-StefanieKlamm_ImagesInArchaeology

SEDIMENTARY BURIAL OF ANCIENT OLYMPIA (PELOPONNESE, GREECE) BY HIGH-ENERGY FLOOD DEPOSITS – THE OLYMPIA TSUNAMI HYPOTHESIS

A. Vött et al., (2011) 2nd INQUA-IGCP-567 International Workshop on Active Tectonics, Earthquake Geology, Archaeology and Engineering, Corinth, Greece (2011)

•Detailed geo-scientific studies were carried out in the Kladeos and lower Alpheios River valleys in order to clarify the mystery of the rapid burial of Olympia under 4-6 m of sediments after the 6th cent. AD and subsequent erosion of the Kladeos River by 8-10 m down to the ancient flow level.

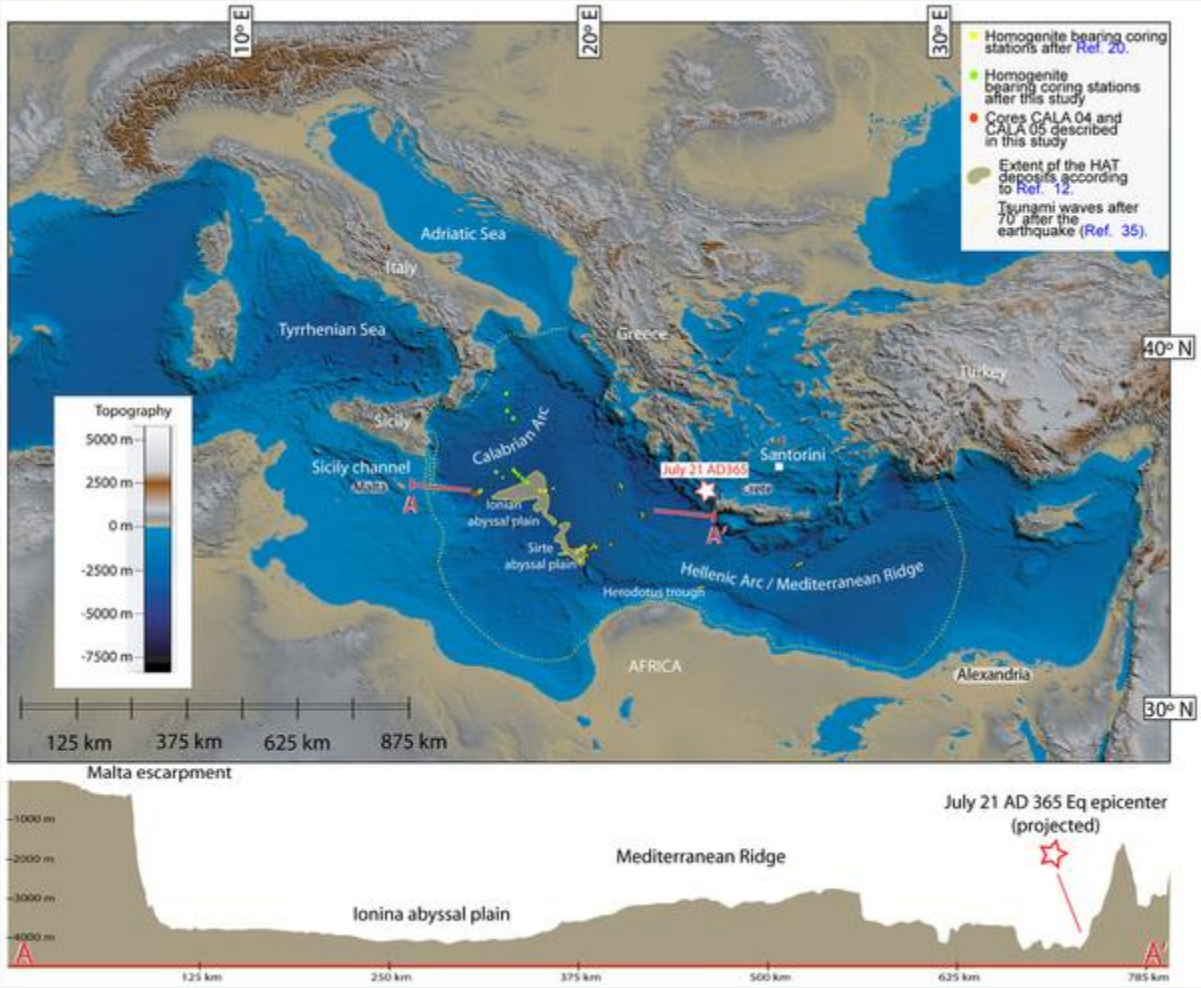
•Sedimentological, geophysical, geochemical and microfaunal analyses were conducted along the Olympia terrace

•Our results show that the Kladeos River valley and Olympia experienced at least four distinct phases of catastrophic high-energy flood events. Sedimentary, geochemical and faunal traces found in the adjacent Basin of Flokas-Pelopio clearly document multiple tsunami impact.

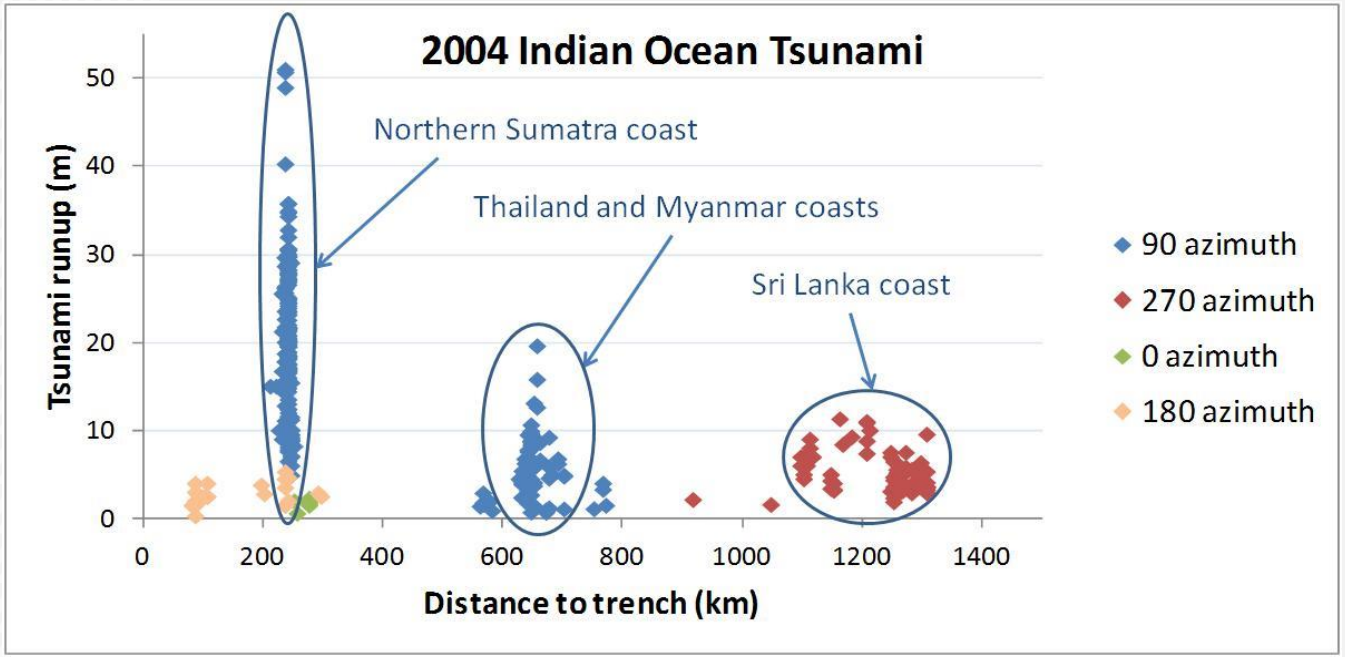
•Identical fingerprints and strong stratigraphical correlations were also detected along the Kladeos River beyond the Ridge of Flokas-Platanos.

•In the Olympia Tsunami Hypothesis shallow saddles of the ridge were repeatedly overflowed by tsunami waters and the cult site Olympia was rather destroyed by tsunami than by fluvial processes related to the Kladeos River.

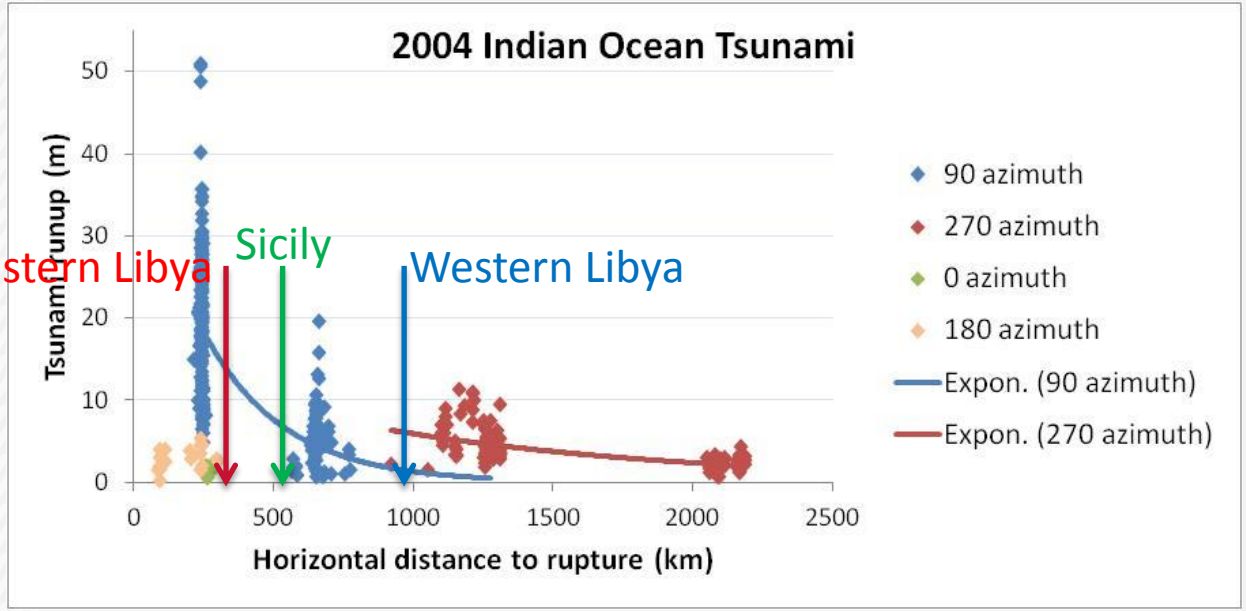
THE 365AD IONIAN SEA SEAFLOOR TURBIDITE (>20M THICK)



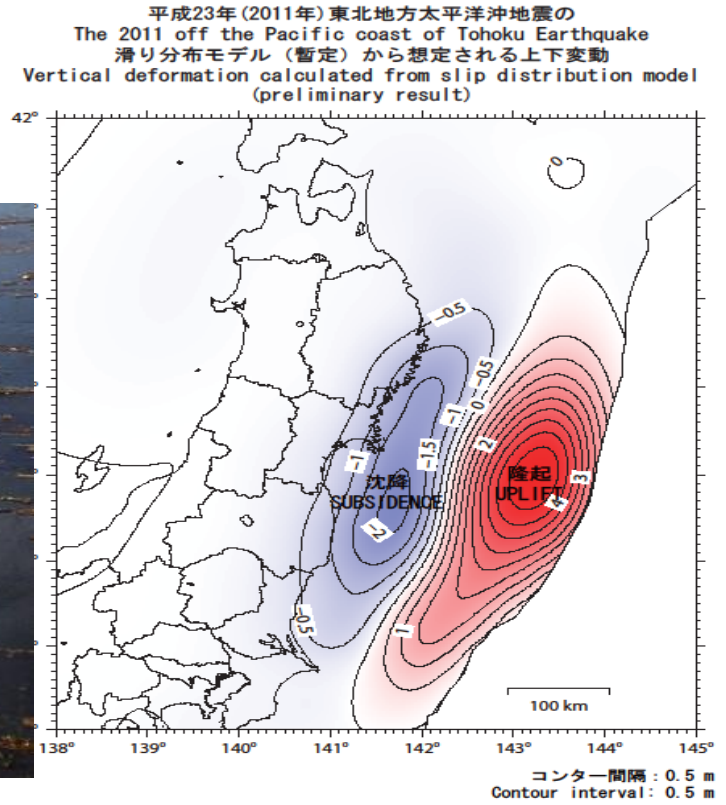
2004 TSUNAMI HEIGHTS



COMPARISON WITH CENTRAL MEDITERRANEAN



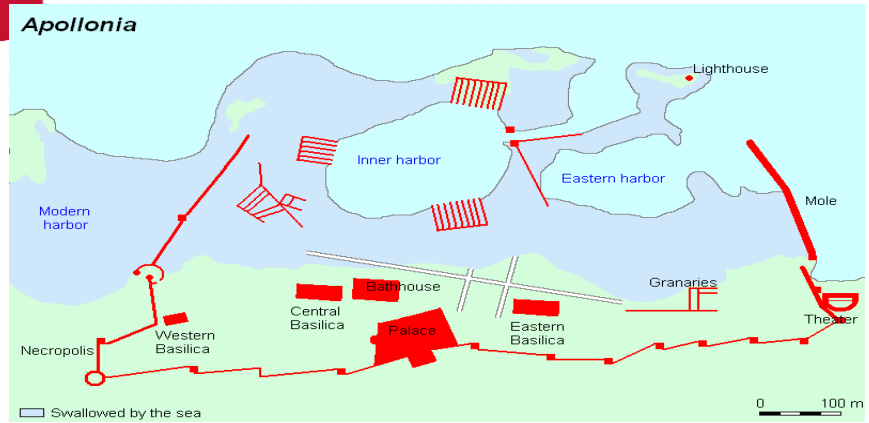
3/11/2011 Tohoku
M9 EQ Coastal Subsidence



※この上下変動図は、電子基準点（GPS連続観測点）データからプレート境界面上での滑り分布モデルを推定し、そのモデルから想定される上下変動の推定値を図示したものです。従って実際の変動量とは必ずしも一致するものではありません。

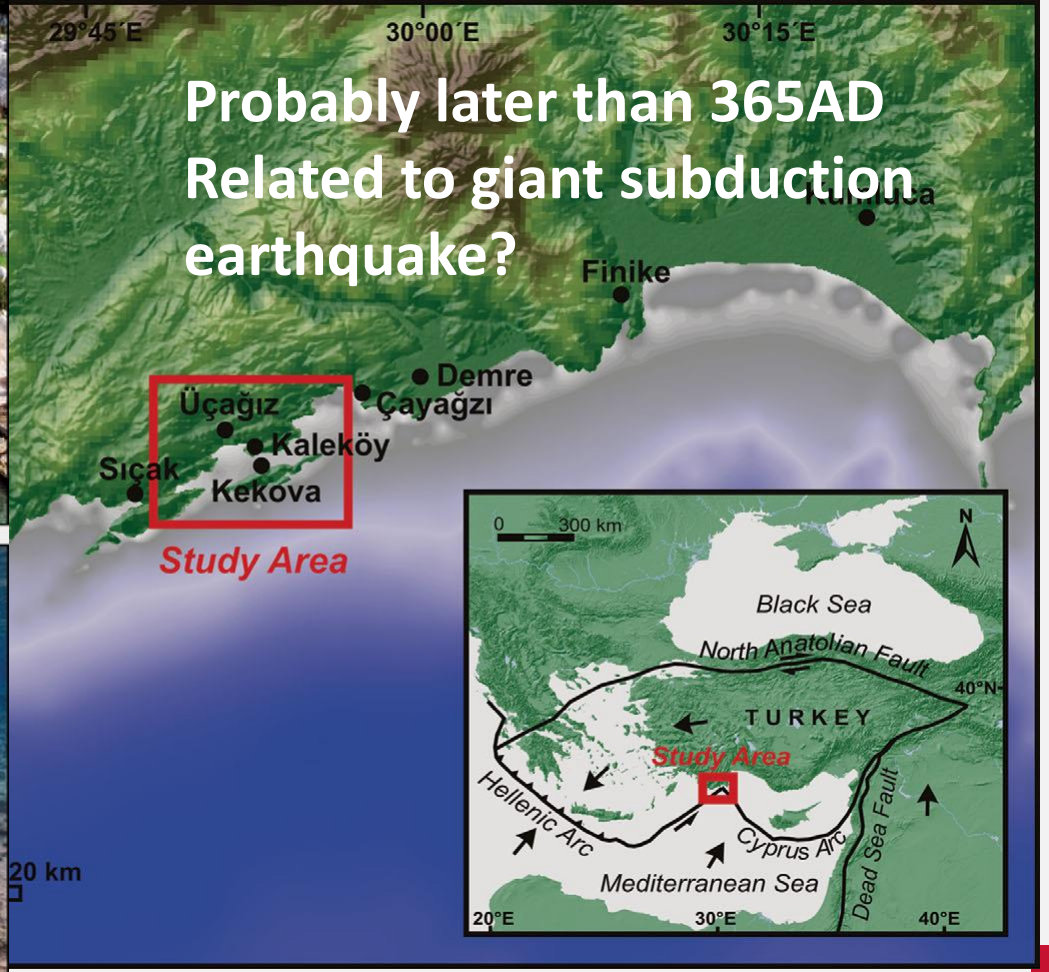
国土地理院
Geospatial Information Authority of Japan

Subsidence on northern coast of Libya Apollonia

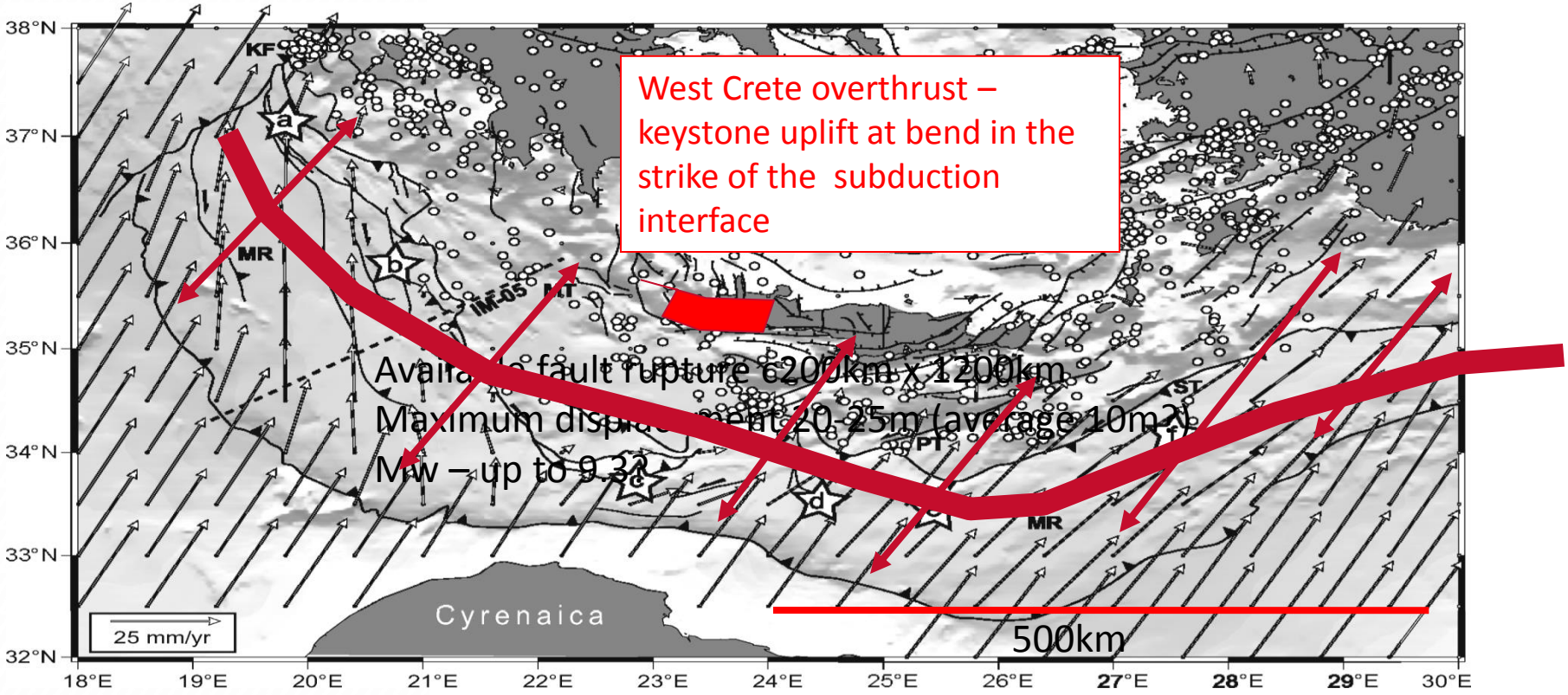



a

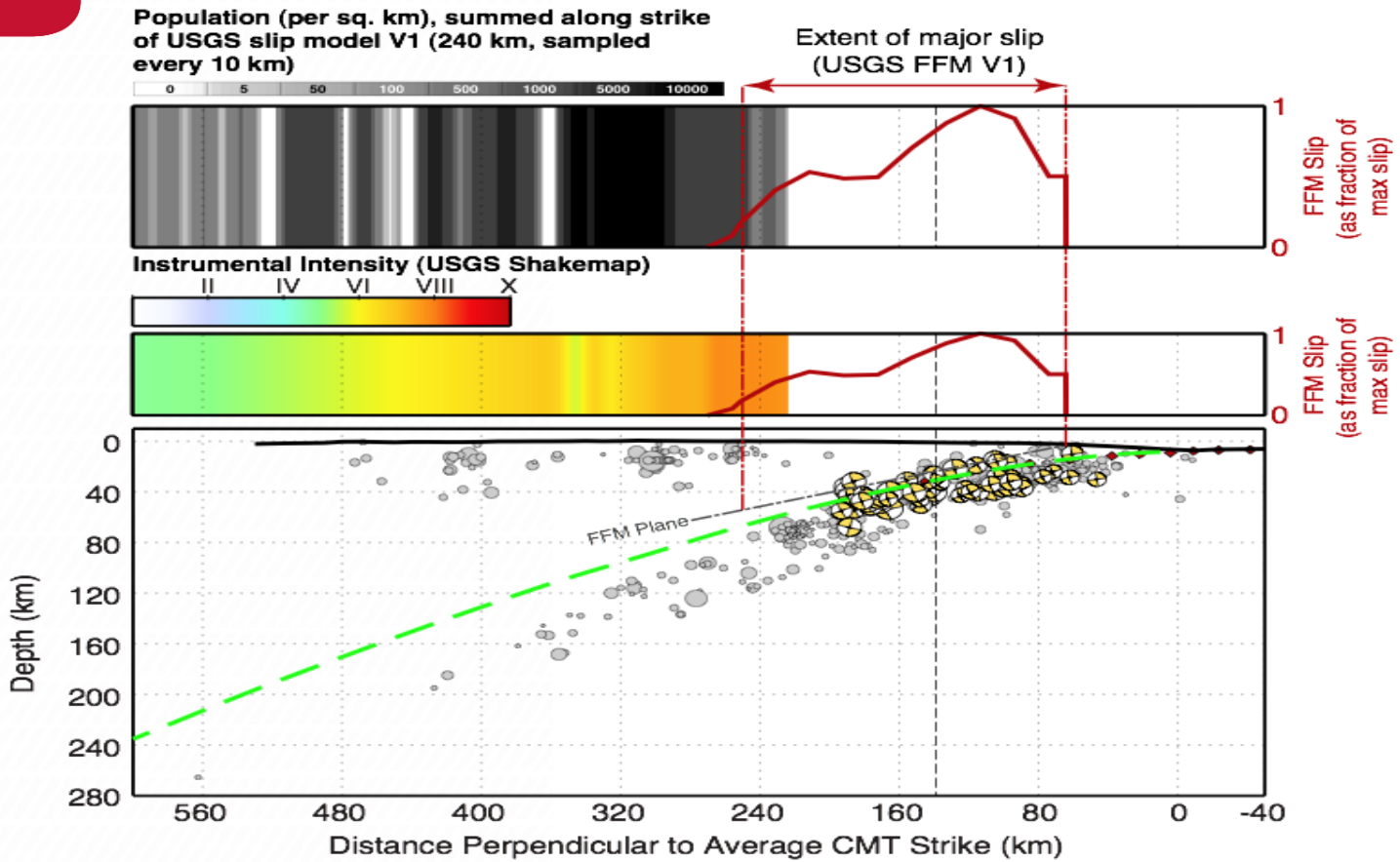

2.8m subsidence
b


29°45´E
30°00´E
30°15´E
Probably later than 365AD
Related to giant subduction earthquake?
Finike
Demre
Çayağzı
Üçağız
Kaleköy
Sıçak
Kekova
Study Area
20 km
0
300 km
N
Black Sea
North Anatolian Fault
40°N
TURKEY
Study Area
Hellenic Arc
Cyprus Arc
Mediterranean Sea
Dead Sea Fault
20°E
30°E
40°E

Potential extent of the 365AD earthquake source

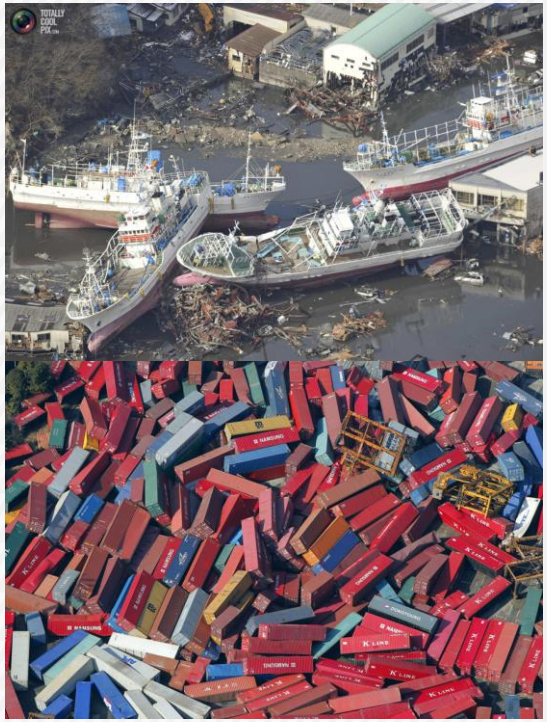


Tohoku, Japan Earthquake: Population Exposure & Shaking Intensities vs Slab Geometry & Slip Extent



Note that slip during the earthquake likely did not extend to the depths of the plate boundary directly under the Japan coastline as shown here, because GPS data indicate that the coastline moved down coseismically.

M9 EARTHQUAKES



Economic Impacts

- Potential to be the #1 regional loss
- Can affect multiple countries
- Shaking damage to coastal towns and inland high rise
- Extreme nearfield tsunami destruction (to 20m+ elevation)
- Damage for coastal properties at medium distances
- High marine losses - especially from cargo and ships in harbour

M9 EARTHQUAKES: HUMANITARIAN ISSUES

Planning for rapid evacuations

- Need for comprehensive signage in all potential coastal tsunami zones
- Identification of safe vertical evacuation destinations
- System for transmitting and distributing the warnings
- Evacuation drills

(Employ significant Japanese experience)