RAPID COASTAL CHANGES AND TSUNAMI IMPACTS AT THE PATARA HARBOUR (TURKEY)

Conference Paper · November 2012

4 authors:

Selma Ünlü
Istanbul University

Bedri Alpar
Istanbul University

Yıldız Altınok
Istanbul University

Naside Ozer
İstanbul University-Cerrahpaşa

RAPID COASTAL CHANGES AND TSUNAMI IMPACTS AT THE PATARA HARBOUR (TURKEY)

Selma UNLU[1], Bedri ALPAR[1], Yildiz ALTINOK[2], Naside OZER[2]

[1] *Istanbul University, Institute of Marine Sciences and Management, Muskile Sokak 1, Vefa-Istanbul, Turkey*
E-mail: su@istanbul.edu.tr
[2] *Istanbul University, Engineering Faculty-Avcilar - Istanbul, Turkey*

SUMMARY

The ancient city of Patara (Fethiye, Turkey) is one of the places which may possibly have been hit by historical tsunamis. The marsh-filled depositional sedimentary basins behind the sand dunes and low-lying coastal areas along the Patara beach may hide the fingerprints of historical tsunami impacts. An engine core was recovered from the marsh area in the margin of a lagoon to provide biogeochemical evidences for the possible paleotsunami deposits in the study area. The core has been described lithologically and then scanned by multi-sensor core logger. Fatty acid biomarkers can be used to assess the degree of marine-terrestrial mixture and their distributions indicate if most of the organic matters in the samples are marine-sourced. For discrimination of marine and freshwater sub-environments; we have determined mono- and polyunsaturated fatty acids and high-branched isoprenoids using standard chromatographic techniques (GC/MS-SIM). On the basis of knowledge on sedimentary and paleo-environment conditions, and on the micropaleontological and biochemical data obtained from our analyses, the results indicate some influxes of marine water in a freshwater environment. Whether they can represent possible tsunami deposits or not, however, is not easy to answer.

Keywords: Fatty acids, marine-sourced biomarkers, coastal changes, tsunami impacts, tsunami deposits, Patara Harbour

1. INTRODUCTION

Rapid coastal changes, wave erosion, vertical movements and silting up processes along the SW Mediterranean coasts of Turkey developed various types of rugged coastal shapes and beaches. Patara is the most popular and longest (15 km) delta beach in this region and has been regarded as "Specially Protected Area" since the end of the 1980s (Figure 1). The white-sand delta beach is built up by a combination of physical processes, the fluvial and terrigenous input of the Esen and Özlen Rivers and the alongshore wave and current regimes of the Mediterranean [1]. The sediment carried by the Esen River is relatively finer-grained due to a narrow pass behind it which prevents coarser-grained sediments to be transported into the Patara plain. The sediment transportation by the Özlen River, at the NW border of the Patara beach, is not much important. The Patara beach has a swash zone and backshore sub-environments. Backshore areas, between shoreline and sand dunes, are uncovered by vegetation and range mostly between 50 and 100 meters but locally scale up to 600 meters also occur.

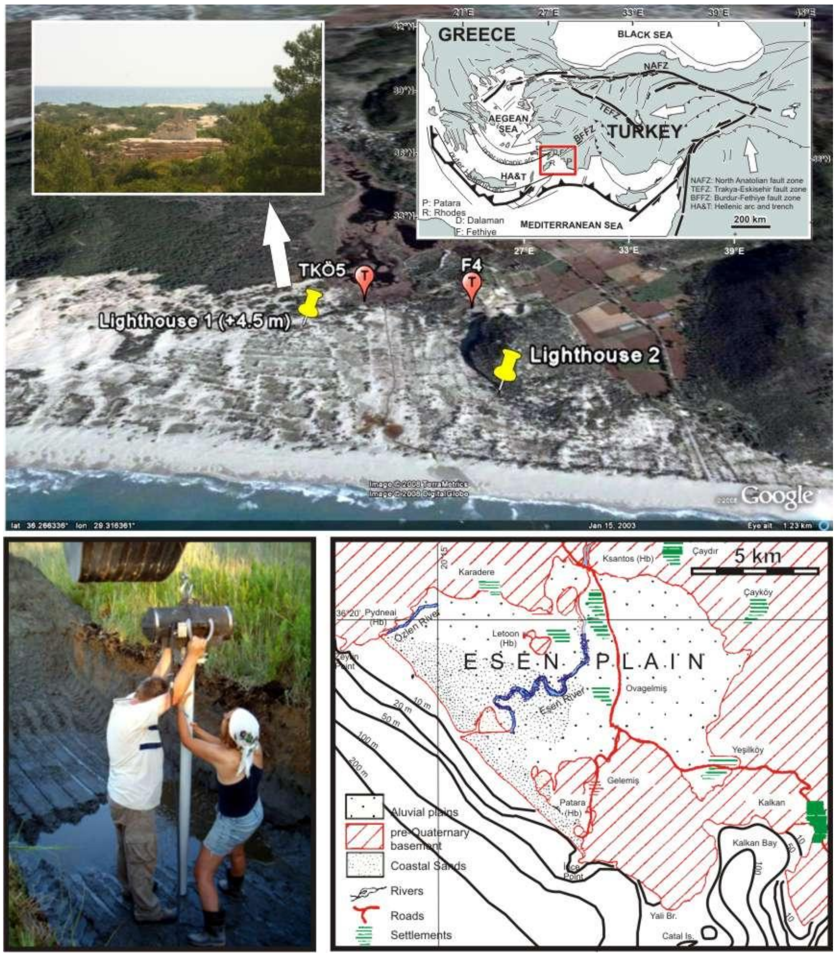

Figure 1: The Patara lagoon and the core location (TKÖ5) behind the ancient harbour lighthouse unearthed recently under the coastal sand dunes.

The first settlements started around an ancient estuary in Patara (Fethiye, Turkey) about 3000 years ago. Its harbour played a critical role in the Lycian civilization [2]. The use and significance of the Patara port ended practically at the end of the XIVth century due to its failure to recover following the sack of 1362, in addition to the known gradual silting up of the port [3] mostly due to the flooding of Esen deltaic plain [4]. The ancient harbour is now under the sand dunes and a marsh area, intermittently covered with water, having aquatic and grass like vegetation behind the natural sand dunes. The long accreting beach at present is a result of the discharges from the Esen River and the prevailing environmental conditions. The location of paleo-shoreline is not precisely known, but the position of the recently discovered ancient Patara lighthouse at the port entrance of the ancient Patara city may give a clue about its position. The remains of the 12 meter-high lighthouse, the oldest in history, were discovered by chance under a sand dune 600 m away from the present shoreline (Figure 1). It was built by Emperor Nero between A.D. 64 and 65, as it is carved on the stones with 30 cm-high bronze inscriptions. Another lighthouse is believed to be lying under the thick sand dunes at the eastern side of this ancient port. Considering the distribution of the stone blocks of the collapsed lighthouse and the position of its keeper's skeleton, the archaeologists claim that this lighthouse might have been destroyed not by the earthquake itself but by an accompanying tsunami. In fact, the region was hit by some co-seismic historical tsunamis occurring along the South Aegean trench. The most important events occurred on 21.07.365 (East Mediterranean, Crete, Greece, Adriatic coasts, Alexandria and West Anatolia), 08.08.1303 (Eastern Mediterranean, Rhodes, Crete, Peloponnesus and Dodecanese), 03.05.1481 (Rhodes, south-western coasts of Anatolia and Crete) and 31.01.1741 (Rhodes). Their effects are not precisely known, but the numerical simulations indicated that amplification of tsunami waves near coast exceeded the amplitude of the initial wave causing excess inundation [5].

If these sights are true, then the fingerprints of the historical tsunami impacts can be obtained in the marsh-filled depositional sedimentary basins behind the sand dunes. It is well-known that tsunami deposits occur typically in low-energy depositional environments such as coastal wetlands, lagoons and places protected from the sea by onshore natural barriers. In fact, such places protect the deposit from post-depositional erosion.

On the other hand, the region is also prone to the possible impacts of coastal changes and storms. Tides are not important depending on the tidal data recorded in Antalya from 1961 to 1977 [6]. The sea-level variations are mainly governed by the energy inputs in the low frequency band and low-amplitude semi-diurnal variations, 56 and 39%, respectively [7]. Seasonal variations have a major minimum and maximum in March and August, respectively. The subtidal oscillations with dominant periods of 14.2 and 28 days can be related with the mesoscale meteorological phenomena. When the cyclones affect the region, the coastal sea level is directly related with NS wind stress in low-frequency band. Southerly winds set up a surface slope as well. The wave heights may be as high as 8 m with directions SW, WSW and W [8]. Suspended finer sediments of riverine inputs are transported by the prevailing currents and waves. Only about one third of the riverine input remains along shore to form the beach. Even the fluvial input cause the delta plain to extend offshore; the erosional effect of wind forces are important on shoreline and lower backshore sediments causing retrogradation at the beach and occasionally exposing former beach rocks which are normally overlaid by backshore and dune areas [1].

The scope of this study is to find possible tsunami deposits in a semi-dry lagoon in Patara and provide data for processes associated with tsunami sediment transport, their deposition and nature. The interpretation of sedimentary features, accurate paleo-environmental assessments might be possible by distinctive biogeochemical researches on marine-sourced organic matters, geochemical properties, quantitative amounts of marine-sourced biomarkers and deterministic ratios.

2. DATA COLLECTION AND ANALYSES

An engine core has been recovered from a marsh (a semi-dried lagoon) near the ancient city of Patara. The core is somewhere behind the old harbour which was still active as a small estuary till the end of XVth century. That is why the core is 720-730 m far from the present shoreline. It is close, however, to the ruins of an ancient lighthouse which were recently unearthed at the ancient Roman port of Patara under the sand piles.

This core is made up of two different parts. The upper part (100 cm) was taken from the open wall 1-m deep trench and the lower part (70 cm) was recovered by the engine core (Figure 1). In coring, 110 mm diameter PVC liners have been used. The split cores were described lithologically and stored at 11°C in a cold storage room. The lower part of the core was logged in GEOTEK MSCL 7.6 (Multi Sensor Core Logger) every 0.5 cm using the sensors of gamma density, resistivity, P-Wave and magnetic susceptibility. In addition, foraminifera and ostrocodes in the core samples were identified according to the criteria given by Loeblich and Tappan [9].

The samples have been analyzed using HP6890 gas chromatograph with mass detector equipped with a split/splitless injector for the presence of marine-sourced biomarkers ($\sum C_{16}/\sum C_{18}$, 16:1/16:0 ratio, (20:5ω3), (22:6ω3), (22:6ω3/20:5ω3) ratio, (20:1), (22:1), (24:1), (18:2ω6), (18:3ω3), alkanes, alkenes, high-branched isoprenoids and deterministic ratios (e.g. abundance of S-containing compounds vs. pristane:phytane ratio). The fatty acid methyl esters (FAMEs) were identified by comparison of retention times with a standard (Supelco-37 components FAME mix). The absolute concentrations of mono- and polyunsaturated fatty acids (PUFAs) were calculated using the mean fatty acid molecular weight in each sample based on the method given by Alpar et al. [10]. Recoveries of FAMEs in the analytical procedure were between 75% and 105%.

3. RESULTS & DISCUSSION

The length of the core is 160 cm. The core consists of three main layers. From bottom to top, they are: a) 8 cm-thick soil, b) 55 cm-thick silt sand (brown), c) 20 cm-thick grey sand d) 15 cm-thick grey silt sand (brown), and e) 62 cm-thick grey sand. The deepest sands contain a 2 cm-thick anomalous layer ranging between 139 and 141 cm below the ground surface. Deposition of thin sand sheets, which can be normal, massive, inversely graded, chaotic or bimodal, may be one of the most important sedimentary characteristics of tsunami deposits.

The thickness of the lower part of the core is between 7.18 and 7.28 cm (Figure 2). The P-wave velocity and acoustical impedance show a sudden increment in this unit at 123 cm. In addition a thin anomalous layer was observed between the depths of 139 and 141 cm. The magnetic susceptibility increases below this layer (Figure 2).

The fossil content is an important characteristic of tsunami deposits. We did not observe any foraminifera or ostrocodes in the core samples, except a few *Globigerina sp*. (class Rhizopoda, order Foraminiferida) in the levels of 93 cm and 104 cm. It is a protozoan genus whose members are commonly pelagic, unlike most foraminiferas which are benthic.

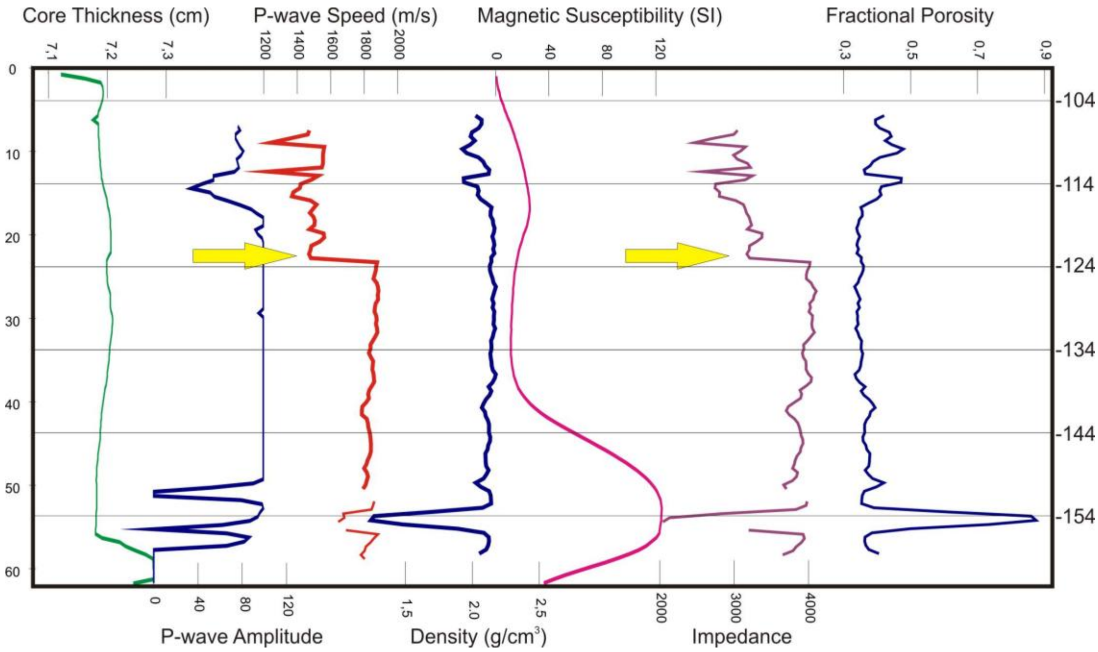

Figure 2: Physical parameters of the lower part of the core.

Biomarker is defined as "a molecule whose carbon skeleton can ambiguously be linked to that of a known biological precursor compound". They are complex organic compounds, which are originated from formerly living organisms. Biomarkers are characteristic of an organism / plant which can be used to indicate the presence of the organism / plant in the environment and to estimate its biomass. Paleo-environmental conditions are often readily inferred from the presence and distribution patterns of biomarkers. Tsunami sediment layers show increments in abundance of marine and brackish water diatom species, planktonic diatoms and foraminifera, implying an introduction of marine and brackish assemblages into otherwise non-marine (terrestrial) sediment sequences. Then, some quantitative estimation of marine biomarkers, compounds or groups of compounds that can be used as signatures of individual organisms or groups of organisms or of certain environmental processes, and specific deterministic ratios were tested to differentiate their depositional environments. Table 1 shows normal and branched alkanes, fatty acid biomarkers and other diagnostic indicators which are used to assess the degree of marine, lacustrine or terrestrial inputs or their mixtures.

C15, C17, C19 n-alkanes are predominant in algae while C23-33 n-alkanes are dominant in land plants and spores. These are also present in zooplankton and fish. Pristane, phytadienes, C20 mono- and diolefins are present in zooplankton, fish and sharks. C21 mone-to-hexaolefins are present in algae [11]. Pristane (2,6,10,14-tetramethylpentadecane) is a biomarker of zooplankton particularly of calanoid copepods, which produce it from the phytol in chlorophyll-a from their diet. It has been detected in bacteria, algae, and higher plants. The marine sources of pristane include zooplankton, lobster, fish, sharks and sperm whale [12]. Phytane (2,6,10,14-tetramethylhexadecane) has been identified by GC/MS as a phytadiene (MW 278) which may be derived from phytol in the diet of zooplankton living in the overlying waters [13] or may also be derived from the sediment itself by biological activity [14].

Phytane and corresponding saturated C15, C16, C17 and C18 regular isoprenoid alkanes were dominant in the samples taken from 24, 45, 78, 104, 124 and 144 cm (Figure 3). Important indicators for the marine input to the organic matter came from the presence of n-C17, C19 – isoprenoid and C20 highly branched isoprenoid alkane (found in 24, 45, 78, 93, 104, 114, 124, 134 and 144 cm). They might have been derived from the phytol in the sea water which was transported into the core location by some means.

Freshwater and marine environments can be obtained from the relative abundance of S-containing compounds. Organo-sulphur compounds, on the other hand, are less abundant in sediments deposited in fresh-water [15]. A plot of pristane/phytane ratio against S-containing parameter (dibenzothiophene / phenanthrene) is particularly useful in discrimination of basic marine and freshwater sub-environments [16]. This diagnostic ratio changes between 0.08 and 0.13 in the samples of 24, 65, 78 and 93 cm. This implies that the depositional environment of these soil samples is sulphate-poor lacustrine environment. In addition, no fossil fuel oil contamination have been observed throughout the core, as no distinguishable unresolved complex mixture hump (UCM) can be seen in the chromatograms, except for the sample of 24 cm which may be a result of a recent fire in the reed bed surrounding the lagoon (Figure 3).

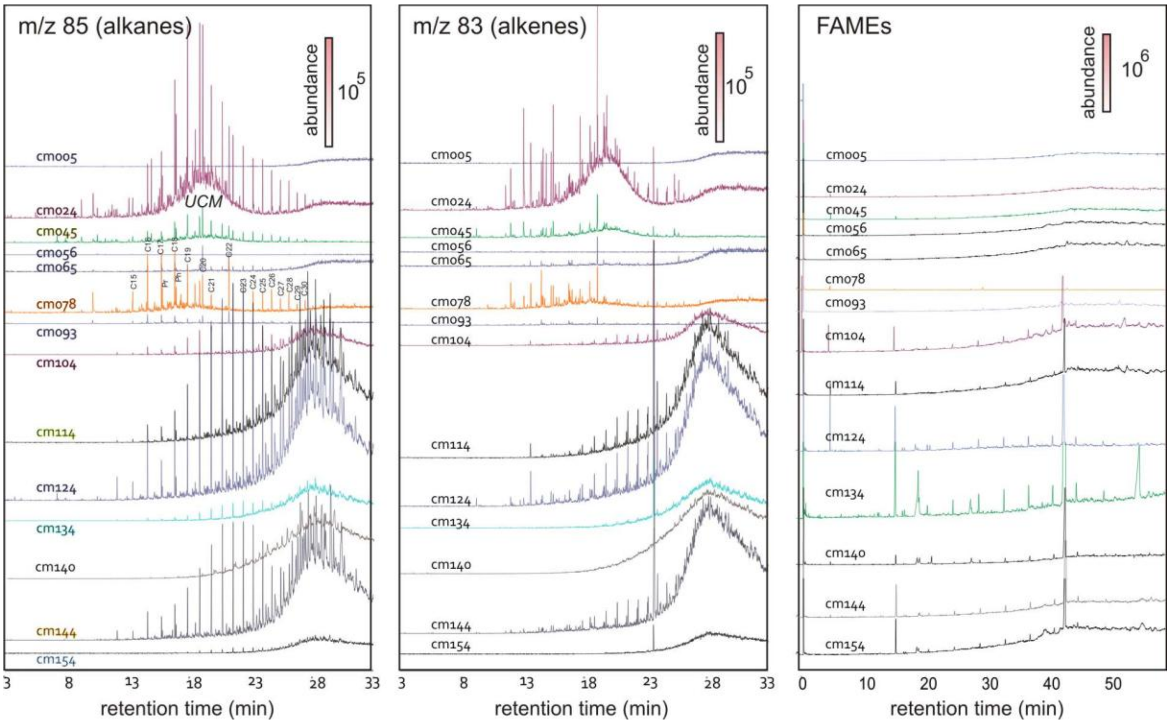

Figure 3: GC/MS chromatograms of n-alkanes, alkenes and FAMEs of the core samples from the Patara lagoon.

The important fatty acids, which can be used as specific biomarkers for source characterisation of organic matter in aquatic environment, are encapsulated in Table 1. The ratios of 16:1/16:0 and the sum of all fatty acids having 16 carbon atoms to the sum of all fatty acids having 18 carbon atoms ($\sum C_{16}/\sum C_{18}$) is considered to be an indicator of benthic phytoplankton [17]. In the present study, these markers also comprised approximately 31% of total fatty acids at the level of 24 cm (Figure 4), which supports the significant contribution of diatom organic matter. In addition to elevated amounts of 16 carbon fatty acids, diatoms produce large proportions of 20:5ω3.

Dinoflagellates generally contain higher proportions of 22:6ω3. The combination of those two fatty acids in a ratio, 22:6ω3/20:5ω3, produces a marker which reflects the predominance of dinoflagellates versus diatoms. Dinoflagellates and diatoms in the core samples are major producers of 22:6ω3 and 20:5ω3, respectively. The evidence of diatoms also produce larger proportions of 20:5ω3 above 120 cm, and dinoflagellates at the levels of 5, 65, 93, 124, 144 and 154 cm may imply marine influence (Figure 4).

Zooplankton biomarkers (20:1, 22:1 ve 20:1+22:1) can also be employed to determine the importance of marine zooplankton sources [18]. Zooplankton grazing is an important link between lower and higher trophic levels in marine systems. Generally, herbivorous and omnivorous zooplankton feeding predominantly on phytoplankton contains elevated amounts of long-chain monounsaturated fatty acids within the wax ester lipid fraction [18, 19]. Therefore the sum of 20:1 and 22:1 fatty acids may be used as a zooplankton marker. In the present study, the highest ratio of zooplankton markers was observed between 5 and 124 cm, which covered 14 to 66% of the total fatty acids (Figure 4). For the samples between 134 and 154 cm this ratio was calculated 5 to 10%. The lack of riverine zooplankton marker (18:0) in the core samples implied that there was no effect of riverine inputs (Table 1).

Terrestrial plant contributions and long chain (>24 carbons) fatty acids are often used as terrestrial plant indicators in marine environments [20, 21]. Monounsaturated fatty acid 24:1 is dominant for the upper part of the core (Figure 4) representing the marsh area, intermittently covered with water. For the lower part of the core, on the other hand, the fatty acids of 18:2ω6 and 18:3ω3 are dominant. They can be used as green algae markers [22], and comprise up to 80% of total fatty acids in the lower part of the core (104-154 cm).

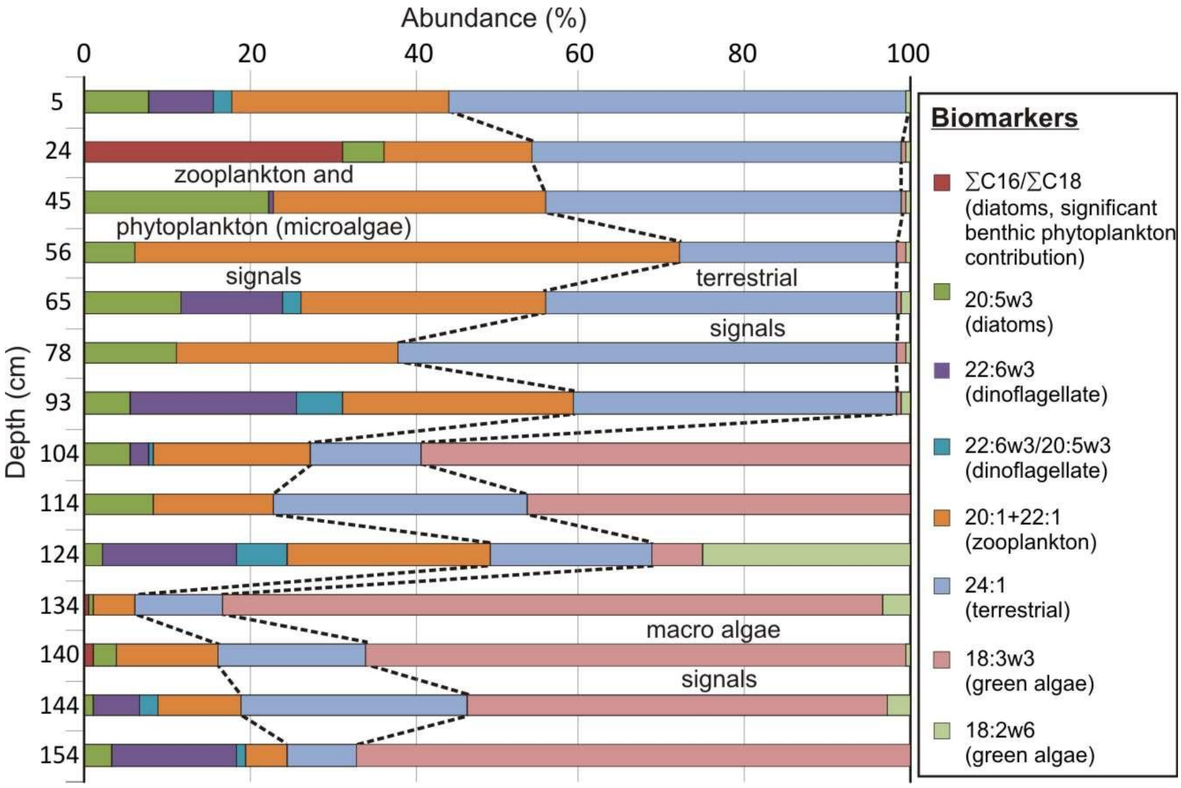

Figure 4: The relative abundance of the biomarkers in the core samples from the Patara lagoon. The dashed lines separate different paleo-environmental signals.

Table 1: Specific biomarkers for source characterization of organic matters in the core samples.

Normal and Branched Alkane Biomarkers		
C_{15}, C_{17}, C_{19},n-alkanes	Algae	24, 45, 78, 104, 124, 144 cm
C_{23-33}, n-alkanes	Land plants and spores; zooplankton and fish	24, 45, 65, 78, 124, 144 cm
Pristane	Zooplankton, fish and sharks	24, 45, 78, 93, 104, 114, 124, 134, 144 cm
Phytane	Derive from phytol in the diet of zooplankton living in the overlying waters [13] or the sediments themselves [14].	24, 45, 78, 93, 104, 114, 124, 134, 144 cm
Fatty acid biomarkers		
16:1/16:0, ($\sum C_{16}/\sum C_{18}$)	Diatom marker, if >1 significant benthic phytoplankton contribution [17]	24 cm
20:5ω3	Diatoms	2-to- 13 ppm through the core
22:6ω3	Dinoflagellates	0.3-to- 48.1 ppm through the core
22:6ω3/20:5ω3	Dinoflagellates	High at 5, 65, 93, 124, 144, 154 cm
18:0	Riverine zooplankton [23]	Not observed
Sum of 20:1 and 22:1	Zooplankton marker [18]	4-to-37 ppm through the core
18:2ω6	Green algae [22]	lower part of core (120-to-150 cm)
18:3ω3	Green algae [22]	lower part of core (below 100 cm)

4. CONCLUSIONS

Deposits generated by tsunamis occur typically in low-energy depositional environments such as coastal wetlands, lagoons and places protected from the sea by sandy barriers. In order to find possible tsunami deposits we recovered an engine core in a semi-dry lagoon in Patara, which may preserve possible records of tsunami-deposited sediments from post-depositional erosion. The results on paleo-environmental condition of the region are based on the sedimentary setting of the core, biogeochemical analyses on marine-sourced organic matters, geochemical properties, quantitative amounts of marine-sourced biomarkers and deterministic ratios.

The upper part of the core (0-100 cm) represents a sulphate-poor lacustrine environment with variable conditions far from the shoreline. Marine biomarkers, especially macro green algae, are dominant in the lower part of the core (below 104 cm), which are made up of coarse-grained sands. A few pelagic foraminifera which have only been observed throughout the core are located between these upper and lower parts of the core, namely 93 and 104 cm. This level should be corresponding to the rapid silting up of the ancient Patara port. Even though the evidence of diatoms and dinoflagellates at upper part of the core may show some minor marine effects, there are no distinct levels to represent any catastrophic marine invasion. Therefore, it is not easy to answer the question if they can represent possible tsunami deposits. On the other hand, it should not be disregarded that tsunami deposits may be discontinuous near the limit of inundation. Multidisciplinary studies are needed with deeper cores around the alluvial plains of Patara which is prone to the moderate-scale tsunamis posing risks to coastal communities. At present, 51% of the Turkey's population live and work within coastal communities and related hinterland that encompass less than 30% of the Turkish land area. Storm surges will also accelerate this vulnerability.

Acknowledgements
The field studies were supported under the Project TRANSFER (Tsunami Risk and Strategies for the European Region) by the Commission of European Communities, contract n. 037058, 6th Framework Programme, FP6-2005-Global-4, reduction of tsunami risks.

5. REFERENCES

[1] Ergin, M-Karakaş,Z-Sözeri,K-Özdoğan,S: "Grain size distribution and related depositional conditions on the modern Patara beach (SW Turkey)", In: Özhan, E. (Ed.), Proceedings of the Eight International Conference on the Mediterranean Coastal Environment, MEDCOAST07, 13-17 November 2007, Alexandria, Egypt, 2, 1355-1362, 2007.

[2] Işık,F: "Caput Gentis Lyciae" Patara Capital of the Lycian League" Scala Matbaacılık Ltd. Şti., ISBN No: 9786056229619, İstanbul, 2011.

[3] Duggan,TMP: "The Lycian Port of Patara and its environs during the 13th and 14th centuries", Gephyra, Journal for the Ancient History and Cultures of the Eastern Mediterranean, 7, 47-72, 2010.

[4] Öner,E.: "Zur geomorphologie der Esen – Deltaebene und des antiken Hafens von Patara in der Südwesttürkei", Adayla III, Suna & Inan Kirac Research Institute on Mediterranean Civilizations, 1998.

[5] Yalçıner,AC-Zaytsev,A-Chernov,A-Özer,C-Dilmen,DI: "Database development by modeling for tsunami mitigation strategies for Fethiye town, Turkey", Geophysical Research Abstracts, Vol. 10, SRef-ID: 1607-7962/gra/EGU2008-A-06811, EGU General Assembly, 2008.

[6] General Command of Mapping: "A brief Information about the tide gauge stations operated between years 1935-1983 in Turkey and monthly mean sea-level data of Antalya, Karşıyaka/Izmir, Samsun Tide Gauge Stations", Published by the General Command of Mapping, Ankara, Turkey, (6), 60p, 1991.

[7] Alpar,B-Altınok,Y-Yalçıner,AC-Ünlü,S: "Vulnerability of the Marmaris-Fethiye coasts, SW Turkey", In: Proceedings of the Tenth International Conference on the Mediterranean Coastal Environment, MEDCOAST 11, E. Özhan (ed.), 25–29 October 2011, Rhodes, Greece, Vol. 2, 627–638, 2011.

[8] Özhan,E-Abdalla,S: "Wind and deep water wave atlas for the Turkish Coast", MEDCOAST Publications, Ankara, 445 p, 2002.

[9] Loeblich,Jr.AR-Tappan,H: "Foraminiferal Genera and Their Classification", Van Nostrand Reinhold Company, New York, 970 p. (842 pls), 1988.

[10] Alpar,B-Ünlü,S-Altınok,Y-Özer,N-Aksu-A: "New approaches in assessment of tsunami deposits in Dalaman (SW Turkey)", Natural Hazards, 60, 27–41, 2012.

[11] Blumer,M-Robertson,JC-Gordon,JE-Sass,J: "Phytol-derived C19 di-and triolefinic hydrocarbon in marine zooplankton and fishes", Biochemistry 8, 4067-4074, 1969.

[12] Tissot,BP-Welte,DH: "Petroleum Formation and Occurrence", New York, Springer-Verlag, Berlin, Heldelhert, New York, 538p, 1984.

[13] Blumer,M-Thomas,DW: "Phytadienes in zooplankton", Science, 147(3662), 1148–1149, 1965.

[14] Ikan,R-Baedecker,MJ-Kaplan,IR: "Thermal alteration experiments on organic matter in recent marine sediment. II. Isoprenoids", Geochimica et Cosmochimica Acta, 39, 187–194, 1975.

[15] Brocks,JJ-Summons,RE: "Sedimentary hydrocarbons, biomarkers for early life", In: H.D. Holland and K.K. Turekian (eds.), Treatise on Geochemistry Vol. 8, W.H. Schlesinger (volume editor), Biogeochemistry. Elsevier Pergamon. pp. 63-115, 2004.

[16] Hughes,WB-Holba,AG-Dzou,LIP: "The ratios of dibenzothiophene to phenanthrene and pristane to phytane as indicators of depositional environment and lithology of petroleum source rocks", Geochim. Cosmochim. Acta. 59, 3581-3598, 1995.

[17] Parrish,CC-Abrajano,T- Budge,SM-Helleur,RJ-Hudson,ED-Pulchan,K-Ramos,C: "Lipid and phenolic biomarkers in marine ecosystems: analysis and applications", In: Wangersky,P (ed.) The Handbook of Environmental Chemistry, Part D, Marine Chemistry, Springer, Berlin, pp. 193-233, 2000.

[18] Albers,CS-Kattner,G-Hagen,W: "The compositions of wax esters, triacylglycerols and phospholipids in Arctic and Antarctic copepods: evidence of energetic adaptations", Mar. Chem., 55, 347–358, 1996.

[19] Hazel,JR-Williams,EE-Livermore,R-Mozingo,N: "Thermal adaptation in biological membranes: functional significance of changes in phospholipid molecular species composition", Lipids, 26, 277-82, 1991.

[20] Santos,V-Billett,DSM-Rice,AL-Wolff,GA: "The fate of organic matter in deep sea sediments from the Porcupine Abyssal Plain. I. Lipids", Deep Sea Research, 41, 787-819, 1994.

[21] Colombo,JC-Silverberg,N-Gearing,JN: "Lipid biogeochemistry in the Laurentian Trough—II: Changes incomposition of fatty acids, sterols and aliphatic hydrocarbons during early diagenesis", Organic Geochemistry, 26, 257–274, 1997.

[22] Meziane,T-Tsuchiya,M: "Fatty acids as tracers of organic matter in the sediment and food web of a mangrove/intertidal flat ecosystem, Okinawa, Japan", Marine Ecology Progress Series, 200, 49-57, 2000.

[23] Jeffries,HP-Lambert,RM: In: Estuarine Comparisons, Kennedy,VS (ed). 91-101, Academic Press Inc., New York, 1982.